



MFN - 110 ADVANCED NUTRITION

उत्तर प्रदेश राजर्षि टण्डन मुक्त
विश्वविद्यालय, प्रयागराज

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PROF. SATYAKAM

VICE CHANCELLOR

COURSE DESIGN COMMITTEE

Prof. Meera Pal School of Health Sciences, UPRTOU, Prayagraj. UP.	Director In charge
Prof. Neelam Yadav IPS, Centre of Food Technology, University of Allahabad, UP	Member
Dr. Pinki Saini, Associate Professor Centre of Food Technology, University of Allahabad, UP	Member
Dr. Alka Gupta, Associate Professor, Department of Food and Nutrition, SHUATS, Naini, Prayagraj. UP	Member
Dr. Zoomi Singh, Assistant Professor, (C) Food and Nutrition, UPRTOU, Prayagraj. UP	Member

COURSE PREPARATION COMMITTEE

Dr. Neha Mishra Assistant Professor (Food and Nutrition) College of Home Science SHUATS, Naini (UP).	Units: 1-12	Writer
Dr. Ena Gupta Assistant Professor Food and Nutrition, Deptt. of Home Science University of Allahabad, UP.	Units :1-12	Editor
Prof. Meera Pal Director , Department of Food, Nutrition and Dietetics, UPRTOU, Prayagraj. UP	Course Coordinator	

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COURSE INTRODUCTION: ADVANCED NUTRITION

The "Advanced Nutrition" course is a comprehensive and detailed exploration of the science of nutrition, specifically tailored for M.Sc. students seeking to deepen their understanding of the role of nutrients in human health and disease prevention. Structured into four blocks, this course integrates the fundamental principles of energy metabolism, nutrient biochemistry, and dietary interventions with advanced topics in therapeutic and applied nutrition.

The first block covers **energy metabolism, carbohydrates, and proteins**, providing insights into energy content in foods, methods of measuring energy expenditure, and the physiological processes governing digestion, absorption, and metabolism. The units delve into the roles of dietary carbohydrates and fibers, their physiological effects, glycemic responses, and the importance of protein quality, amino acid metabolism, and therapeutic applications of specific amino acids in health management.

The second block focuses on **lipids, water, and minerals**, exploring the digestion, absorption, and transport of lipids, including essential fatty acids and their role in health and disease. It addresses the regulation of water balance and osmolality in the body, along with a detailed study of macro and micro minerals, their bioavailability, functions, recommended dietary allowances (RDA), and potential toxicities.

In the third block, the course transitions to **vitamins, non-nutritive components, and nutrition in specialized conditions**. It discusses the biochemical functions of fat- and water-soluble vitamins, their therapeutic and physiological effects, and deficiencies. This block also introduces non-nutritive bioactive compounds like polyphenols, phytoestrogens, and saponins, emphasizing their potential health benefits and role in gene regulation. Additionally, the course addresses unique nutrition management strategies for extreme conditions such as space travel, high altitudes, low temperatures, and submarine environments.

The final block provides foundational knowledge of food and nutrition by introducing students to the basic concepts of food functions, food groups, and dietary patterns like the food pyramid. It also

highlights the functions of nutrients, their dietary sources, deficiency signs, and adaptations of normal diets to meet specific qualitative and quantitative requirements, including various modes of feeding.

By the end of this course, students will gain an advanced understanding of the metabolic, physiological, and therapeutic aspects of nutrition, equipping them with the skills to critically analyze research, design evidence-based dietary interventions, and address complex nutritional challenges in clinical and public health settings. This course prepares students for leadership roles in academia, healthcare, research, and policy-making in the nutrition and dietetics field.

BLOCK I

INTRODUCTION

Block I is designed to provide a comprehensive understanding of the fundamental nutrients—energy, carbohydrates, and proteins—that are essential for human health and well-being. This block explores the intricate processes by which these nutrients are metabolized, their physiological significance, and their roles in maintaining energy balance and supporting growth and repair. It seeks to enable learners to appreciate the significance of these macronutrients in maintaining health, supporting growth, and preventing disease. Each unit delves into specific aspects of these nutrients, offering a blend of foundational knowledge and applied concepts.

UNIT-I: ENERGY

This unit focuses on the energy content of foods and their physiological fuel values. It reviews the methods of measuring energy expenditure, including basal metabolic rate (BMR), the thermic effect of feeding, and physical activity. The unit explains techniques for estimating the energy requirements of individuals and groups. It also explores the regulation of energy metabolism, encompassing food intake, digestion, absorption, and the balance required for maintaining body weight.

UNIT-II: CARBOHYDRATES

This unit discusses the types and classifications of carbohydrates, along with their digestion, transport, and physiological roles. It provides insights into dietary fiber, oligosaccharides, and resistant starch, emphasizing their chemical compositions and health effects. The concept of the glycemic index of foods is explored in detail, along with a comparison of nutritive and non-nutritive sweeteners.

UNIT-III: PROTEINS

This unit examines the classification, digestion, absorption, and metabolism of proteins. It highlights the roles of muscles, the liver, and the gastrointestinal tract in protein metabolism. The unit explains protein quality and various methods to evaluate it, as well as protein and amino acid requirements for optimal health. It also discusses therapeutic applications of specific amino acids, such as branched-chain amino acids, glutamine, arginine, homocysteine, cystine, and taurine.

Together, these units provide an integrated understanding of the macronutrients that form the cornerstone of nutrition science, equipping learners with the knowledge to assess their roles in health and disease management.

STRUCTURE

- 1.1 Introduction
- 1.2 Concept of Food and Energy
- 1.3 Food Energy Value and Physiological Fuel Value
- 1.4 Methods for Determining the Energy Value of Food
 - 1.4.1 Bomb Calorimetry
 - 1.4.2 Benedict's Oxy Calorimeter
- 1.5 Components of Energy Expenditure
 - 1.5.1 Basal Metabolic Rate (BMR)
 - 1.5.2 Thermic Effect of Food (TEF)
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- 1.7 Methods of Estimation of Energy Expenditure
 - 1.6.1 Direct Calorimetry
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 - 1.6.3 Doubly Labeled Water Method:
- 1.7 Respiratory Quotient (RQ)
- 1.8 Regulation of Energy Metabolism
- 1.9 Let Us Sum Up
- 1.10 Glossary
- 1.11 Answer To Check Your Progress

1.1 INTRODUCTION

As we know, energy is the driving force behind our daily activities and nutrients are the fuels for the body's machinery and physical activity, in turn, optimizes energy utilization and promotes vitality. The careful balance between nutrition and physical activity is crucial for sustaining overall health and well-being. In quantifying this essential force, the energy content of foods, commonly referred to as calories, is a measure of the amount of energy that can be obtained from consuming a particular food. Calories are essential for our bodies to function properly and carry out various activities. This energy, derived from macronutrients like carbohydrates, proteins, and fats, serves as the lifeblood of our physiological processes, providing the fuel for cellular activities, organ functions, and physical movements. Understanding the energy content of foods and their physiological fuel value is essential for comprehending how our bodies utilize and manage energy. This knowledge is foundational for various fields, including nutrition, health, and disease prevention, and has practical implications for everyday dietary choices and public health policies. The energy content of foods, measured in kilocalories or kilojoules, reflects the potential energy derived from macronutrients—carbohydrates, proteins, and fats. Carbohydrates and proteins supply approximately 4 kcal per gram, while fats deliver around 9 kcal per gram. However, the physiological fuel value of a food item can differ from its caloric content due to differences in digestion and metabolism efficiency. For instance, not all energy from dietary fiber is absorbed, resulting in a lower physiological fuel value compared to digestible carbohydrates.

Understanding the energy content of foods is crucial, but equally important is knowing your individual energy requirements. These requirements are composed of three primary components: basal metabolic rate (BMR), the thermic effect of feeding (TEF), and physical activity. BMR represents the energy required to maintain essential physiological functions at rest and varies based on factors such as age, sex, and body composition, while TEF indicates the increase in metabolic rate following food consumption, with different macronutrients affecting this rate differently. Physical activity significantly increases the total daily energy expenditure (TDEE) and calculating TDEE and adjusting for activity levels, is essential for tailoring dietary recommendations. Factors influencing energy expenditure include age, gender, body composition, and activity level, as well as climate, stress, and hormonal factors. Each person's energy needs vary depending on these factors. Understanding these mechanisms helps in managing energy balance, preventing obesity, and promoting overall health. The importance of these

concepts lies in their ability to guide effective dietary strategies, support healthy weight management, and improve nutritional outcomes, making them crucial for both individual health and broader public health initiatives.

In this article, we will explore the component of energy expenditure, energy content of different foods, including macronutrients and their caloric values, factors affecting energy expenditure, and how we could measure energy expenditure.

Expected Outcomes:

This unit will help to:

- Gain an understanding of food energy value of food and their physiological fuel value.
- Explain the components of energy expenditure and methods for estimating these components.
- Understand the regulation of energy metabolism.

1.2 CONCEPT OF FOOD AND ENERGY

Food is any substance that is consumed by living organisms to provide essential nutrients, energy, and support for growth, maintenance, and repair of the body. It is a basic necessity for life and plays a vital role in maintaining overall health and well-being. It is the source of different nutrients, including carbohydrates, proteins, and fats, which serve as the primary energy sources required for cellular activities and micronutrients such as vitamins and minerals, which primarily protect the body. Carbohydrates are the main energy source for the body and are rich in cereals and legumes. Carbohydrates are categorized as simple or complex based on their chemical structure. Simple carbohydrates, such as those in refined sugar, honey, fruits and milk products are rapidly converted into glucose, while complex carbohydrates, like those in whole grains and starchy vegetables, are digested more gradually. Each gram of carbohydrates provides 4 calories of energy.

Protein is a macronutrient essential for the growth, repair, and maintenance of body tissues. It is a fundamental component of cells and is involved in nearly all biological processes. Proteins are composed of building blocks called **amino acids**, which are linked together in specific sequences to form various protein structures. Proteins also provide 4 calories per gram. However, our bodies require protein for various metabolic processes, and not all protein is solely used for energy production. **Fat** is a macronutrient essential for energy storage, cell structure, and hormone production. It provides 9

calories per gram, making it the most energy-dense nutrient and primarily store energy in adipose tissue. The energy released during the breakdown of these macronutrients is captured in the form of ATP, which acts as a cellular energy currency. ATP is then utilized by cells for various functions, including muscle contraction, synthesis of biomolecules, and maintenance of cellular processes. The significance of energy content in foods reveals its pivotal role in sustaining metabolic processes, fueling physical activity, managing weight, and ensuring overall health and well-being. Understanding the importance of energy within our bodies is important as it is the vital force that sustains life and drives the intricate machinery of our existence. Understanding the energy content of foods is essential for maintaining a balanced and nutritious diet.

1.3 FOOD, ENERGY VALUE AND PHYSIOLOGICAL FUEL VALUE

Next, we shall introduce the concept of energy value of food and their physiological fuel value.

Energy is commonly measured in calories or joules. A kilocalorie (kcal), the standard unit for food energy, is the amount needed to raise the temperature of one kilogram of water by one degree Celsius, under standard atmospheric conditions. The joule (J), an SI unit named after physicist James Prescott Joule, represents the energy needed to move a 1 kg mass by one meter with a force of 1 newton. While the calorie is widely used in nutrition, the kilojoule (kJ) is often preferred in scientific and international contexts for expressing food energy values.

Interconversion factor:

- 1 kcal = 4.184 kJ
- 1 kJ = 0.239 kcal
- 1 kJ = 0.001 MJ
- 1 MJ = 239 kcal
- 1 MJ = 1,000 kJ

Understanding these measurements is essential for accurately assessing the nutritional and energy contributions of different foods to our diet. Later, a question comes in mind that Is the energy content of food is same inside or outside the body? No. Here, comes the concept of physiological fuel value. What is physiological fuel value?

Lets learn about it.

Physiological fuel value refers to the energy content within foods that the human body can extract and utilize for various physiological functions.

Physiological fuel value represents the amount of energy that can be obtained from specific nutrients within foods during digestion and metabolic processes. This value is typically measured in calories or joules and is attributed to macronutrients like carbohydrates, proteins, and fats, each offering a distinct amount of energy per gram:

- Carbohydrates and proteins provide approximately 4 calories per gram.
- Fats offer a higher energy yield, providing about 9 calories per gram.
- Alcohol also contributes calories at approximately 7 calories per gram.

Understanding the physiological fuel value of different nutrients is crucial for maintaining energy balance, managing weight, and ensuring that the body receives adequate energy for its metabolic demands. It forms the basis for assessing the caloric content of diets and helps individuals make informed choices about their nutritional intake to meet their energy needs for daily activities and bodily functions.

1.4 METHODS FOR DETERMINING THE ENERGY VALUE OF FOOD

After studying basic concept of energy content in food. Now, it is important to know how could we determine the energy value of food. Determining the energy value of food and quantifying the amount of energy derived from consuming a particular food item is a crucial for understanding its nutritional impact and guiding dietary recommendations. Several methods are employed to determine the energy value of food, taking into account the macronutrient composition and digestibility. Common methods providing comprehensive understanding of a food's energy content and its metabolic effects are as follows:

1.4.1 Bomb Calorimetry

Bomb calorimetry is one of the most precise and widely used method for quantifying energy. It measures the heat released during the combustion of a food sample.

In a bomb calorimeter, carbohydrates, fats, and proteins undergo complete oxidation, the environment condition is controlled and complete combustion occurs. In the following section we discuss the principles, apparatus, procedures, and applications of bomb calorimetry

Principle:

Bomb calorimetry is based on the principle of direct calorimetry. The method based on the fact that combustion of a substance in the presence of excess oxygen is an exothermic reaction, meaning it releases heat. The heat released during combustion is measured, and this value is directly related to the energy content of the food. The apparatus, commonly known as a bomb calorimeter, is designed to contain the sample, promote complete combustion, involves burning a known quantity of a food sample in a bomb calorimeter.

Apparatus:

Figure 1.1 shows the apparatus used in bomb calorimetry is designed to measure the heat released during the combustion of a substance. These components work together to create a controlled environment for the combustion of a sample, measure the resulting heat change, and calculate the heat of combustion. The key components of a bomb calorimeter apparatus include:

1. **Bomb:** The bomb is a strong, sealed container typically made of stainless steel, with platinum or gold plated copper lining. It houses the sample to be burned along with excess oxygen. The bomb is crucial for creating a controlled environment for combustion.
2. **Ignition System:** The ignition system initiates the combustion reaction within the bomb. It can include an electrical filament or fuse that ignites the sample. The precision of the ignition system is essential for accurate measurements.
3. **Water Jacket:** The bomb is submerged in a water jacket surrounding it. The water absorbs the heat released during combustion, and its temperature change is monitored. This temperature change is directly related to the heat evolved during the reaction.
4. **Thermometric System:** The thermometric system consists of a thermometer or other temperature-sensing device used to measure the temperature change in the water jacket. This change in temperature is a key parameter for calculating the heat released during combustion.

5. **Calorimeter Vessel:** The calorimeter vessel contains the water jacket, bomb, and other components. It provides an isolated environment for the combustion reaction and ensures that heat exchange with the surroundings is minimized.
6. **Stirrer:** A stirrer is often included to ensure uniform mixing of water within the calorimeter vessel. This promotes even heat distribution during the experiment.
7. **Oxygen Filling System:** An oxygen filling system is used to fill the bomb with excess oxygen before sealing it. This ensures that the combustion reaction can occur completely.

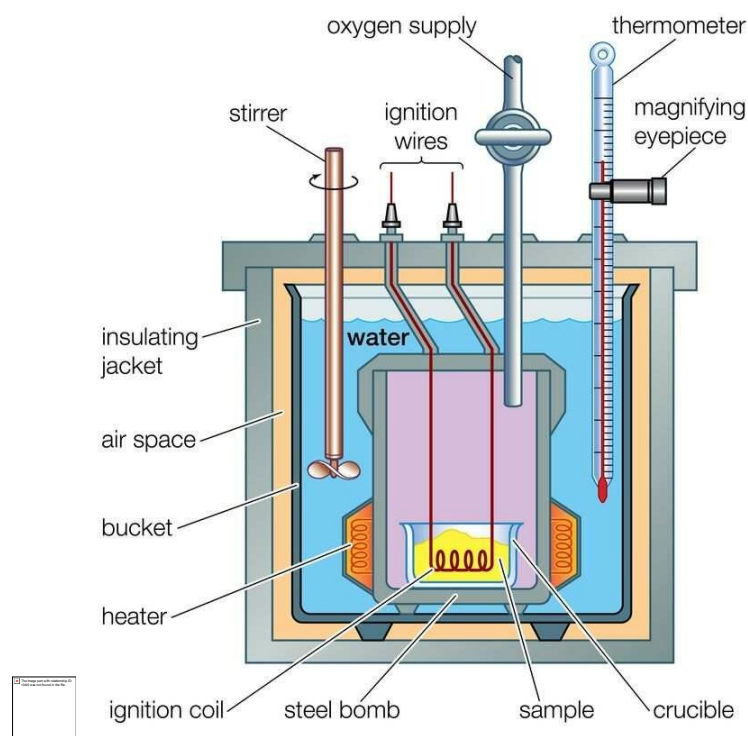


Figure 1.1: Bomb Calorimeter

(Source: [Bello and V Ndirika, 2023](#))

Procedure:

The sample, typically in the form of a finely ground powder, must be homogeneous to ensure consistent combustion. Once the sample is prepared, it is carefully weighed to determine the exact quantity to be used in the calorimeter.

1. **Sample Preparation**-The first step in bomb calorimetry is meticulous sample preparation. The food sample must be carefully prepared to ensure homogeneity and reproducibility. It is

typically ground into a fine powder to facilitate complete combustion. The precision of this step is essential as incomplete combustion can lead to inaccurate results.

2. **Sample Ignition-** The weighted amount of prepared sample is placed within the bomb, and the bomb is sealed except for the oxygen valve. Excess oxygen is added to the bomb to facilitate complete combustion during the subsequent reaction. The ignition system is activated, initiating the combustion reaction within the bomb. The bomb is then sealed tightly to create a controlled environment, ensuring that the combustion occurs in the presence of excess oxygen and that no heat is exchanged with the surroundings.
3. **Measurement of released heat-** The sample combusts completely, releasing heat as an exothermic reaction. The bomb is submerged in a water jacket, and the heat generated is absorbed by the surrounding water. The temperature change in the water is monitored using a thermometric system, typically a thermometer. This change in temperature is directly proportional to the heat released during combustion. The water temperature is recorded before and after the combustion reaction, providing the necessary data for calculating the heat evolved. The specific heat capacity of the water is a crucial parameter in this calculation, as it influences how much the temperature changes for a given amount of heat absorbed.
4. The calorimeter vessel, which houses the bomb, water jacket, and other components, is equipped with a stirrer. The stirrer ensures uniform mixing of the water within the calorimeter vessel, promoting even heat distribution during the experiment. This uniformity is essential for accurate measurements, as variations in water temperature could introduce errors into the calculations.
5. **Data Analysis:** The heat evolved, the mass of the sample, and the temperature change are used to calculate the heat of combustion of the sample. This information is then used to determine the energy content of the food.

Once the temperature change is recorded, the data analysis phase commences. The heat evolved during combustion is calculated using the formula $Q = mc\Delta T$, where Q is the heat, m is the mass of the water, c is the specific heat capacity of the water, and ΔT is the temperature change. This calculation provides the heat released during the combustion of the sample. To determine the energy content of the sample, the heat of combustion is related to the quantity of the substance burned. The energy value is often expressed in kilocalories per gram (kcal/g) or kilojoules per gram (kJ/g), providing a standardized measure of the calorific value of the substance.

1.3.2 Benedict's Oxy Calorimeter

The principle behind Benedict's Oxy Calorimeter is based on the combustion of food samples within a sealed chamber, where the released energy is measured through the increase in temperature of the surrounding water bath. As shown in figure 1.2, the device consists of a combustion chamber, typically made of stainless steel, where the food sample is placed along with a known quantity of oxygen. This chamber is immersed in a water bath, allowing for efficient heat transfer and temperature measurement.

To conduct a calorimetric analysis using Benedict's Oxy Calorimeter, a small portion of the food sample is weighed and placed in the combustion chamber. The chamber is then sealed, and oxygen is introduced to facilitate the combustion process. As the food sample burns, it releases heat energy, which is absorbed by the surrounding water bath. The rise in temperature of the water is recorded using a thermometer, and from this, the energy content of the food sample can be calculated.

One of the key advantages of Benedict's Oxy Calorimeter is its accuracy in measuring the energy content of foods. By directly measuring the heat released during combustion, this calorimeter provides precise data on the caloric value of different food items.

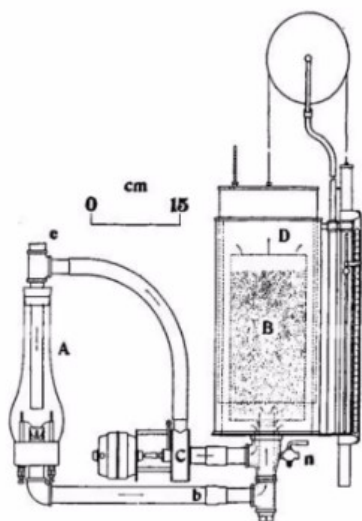


Figure 1.2: Benedict's Oxy Calorimeter

(Source: Sherman Henry 1945, Chemistry of Food and Nutrition)

A shows Combustion Chamber, B shows Soda lime Container, C shows circulating gas mixture and D is spirometer

Before moving to another section, first check your progress

CHECK YOUR PROGRESS EXERCISE 1

Q1. What do you understand by physiological fuel value?

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Q2. What is the principle behind bomb calorimetry in measuring food energy?

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Q3. How does Benedict's Oxy Calorimeter differ from bomb calorimetry in measuring energy value?

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1.5 COMPONENT OF ENERGY EXPENDITURE

Energy expenditure refers to the amount of energy a person uses to maintain bodily functions and perform physical activities. This includes everything from basic metabolic processes, like breathing and maintaining body temperature, to more complex activities, such as walking, running, or engaging in sports.

Energy expenditure is typically divided into three main components: basal metabolic rate (BMR), thermic effect of food (TEF), and activity energy expenditure (AEE).. Understanding energy

expenditure is important for maintaining a healthy weight, managing nutrition, and designing effective fitness or weight loss programs.

There are three main components of energy expenditure:

- A. Basal Metabolic Rate (BMR)
- B. Thermic effect of food
- C. Physical Activity

Let's study each component of energy expenditure in separate section in this unit .

1.5.1 Basal Metabolic Rate (BMR)

The amount of energy require to carry out involuntary work when body is at rest to maintain basic physiological functions is called basal metabolic rate. It includes the functional activities of various organ especially heart, liver, kidney and brain, secretory activities of gland, peristaltic movement of gastro-intestinal tract, body temperature regulation, and cell production. BMR constitutes the majority of total energy expenditure, usually ranging from 60% to 75%.

When measuring Basal Metabolic Rate (BMR), certain conditions need to be met to obtain accurate and reliable results. Here are the key conditions for measuring BMR:

- i. Performed when person awake but at complete rest, without any physical activity or mental stimulation. Physical activity or mental stress can increase energy expenditure and affect BMR measurements.
- ii. BMR measurements are performed at post absorptive stage after an overnight fast of 12 to 16 hours.
- iii. BMR measurements should be conducted in a relax, calm and comfortable room temperature of about 21 °C-24 °C

Factor affecting basal metabolic rate: There are several factors affecting basal metabolic rate. Let's discuss the key factors:

- i. **Body Composition:** The basal energy requirement per unit body weight is higher when muscle tissues is in higher proportion in the total weight. **Muscle, brain, and various glandar**

more active and consume more oxygen and produce more heat than less active tissue includes adipose tissue. Hence, individuals with a higher percentage of adipose tissue tend to have a lower BMR.

- ii. **Gender:** Men generally have a higher muscle mass than women therefore; have basal energy requirement. Young adult men contains 14 percent of fat and young adult women contains 23-32 percent of fat. Higher percentage of muscle mass is men, which is more metabolically active than fat tissue. The BMR of women is 10-12 percent lower than those of men of the same age, height and weight. Hormonal differences can also play a role in gender-based variations in BMR.
- iii. **Age:** Basal metabolic rate (BMR) typically declines with age, largely due to a reduction in muscle mass and a slowdown in metabolic processes. During the first two years, the BMR is at its highest peak. It declines gradually throughout childhood and accelerates slightly in adolescence. Thereafter, declines continuously throughout life. Older individuals may experience a slower metabolism and lower BMR compared to younger individuals.
- iv. **Body Size:** BMR is directly proportional to surface area. Basal metabolism is closely related to the body surface area and less directly related to either weight or height of an individual. Taller individuals generally have a higher BMR than shorter individuals. This is because larger bodies have a larger surface area and greater mass, which requires more energy for basic physiological functions.
- v. **Thyroid Function:** The thyroid gland is crucial in regulating metabolism, with its hormones, thyroxine (T₄) and triiodothyronine (T₃), directly affecting basal metabolic rate (BMR). In hypothyroidism, where the thyroid is underactive, BMR can decrease by up to 30%. Conversely, in hyperthyroidism, characterized by an overactive thyroid, BMR can rise significantly, often by 50-70%.
- vi. **Growth hormone:** The growth hormone that stimulates new tissue formation is responsible for enhanced metabolism that is observed in children, infants and teenagers. An increased secretion of epinephrine during excitement or fear temporarily raises the metabolic rate.
- vii. **Hormonal Factors:** Hormones play a critical role in regulating Basal Metabolic Rate (BMR), which is the energy expenditure required to maintain essential physiological functions at rest. These hormones influence metabolic processes, energy production, and the rate at which the body uses energy. Hormones such as cortisol, insulin, and sex hormones involved in controlling BMR. Hormonal imbalances, such as those seen in certain medical conditions or during pregnancy, can affect metabolic rate and BMR.

- viii. **Climate:** The lowest metabolic rate is observed at an environmental temperature of 26 °C or 78 °F. Higher metabolic rate is observed both above or below this temperature. In cold environments, the body requires more energy to maintain core body temperature, resulting in an increased BMR. Conversely, in hot environments, the body may have a slightly higher BMR due to the energy expended in regulating body temperature.
- ix. **Stress and Emotional State:** Chronic stress and certain emotional states can impact BMR. Increased stress levels can lead to hormonal imbalances that affect metabolism and energy expenditure.
- x. **Medications:** Certain medications, such as those used to treat thyroid disorders or metabolic conditions, can influence BMR.
- xi. **State of Nutrition:** Prolonged fasting or severe caloric restriction can lower BMR about 20-30 percent below normal. This reflects the body's survival mechanism to cope with reduced energy availability.

But we commonly measure Resting metabolic rate (RMR) instead of basal metabolic rate (BMR) to evaluate metabolic rate of individual. What is Resting metabolic rate (RMR)?

Resting metabolic rate (RMR) is comparable to basal metabolic rate (BMR) but is evaluated under less rigid conditions. It represents the amount of energy the body uses at rest to support essential physiological functions like circulation, breathing, , regulating temperature and other cellular processes. Instead of representing just the bare minimum of energy needed to maintain vital body processes, resting energy expenditure includes sufficient energy for secretory activities and the energy needed for the digestion of food. REE is usually considered to be 10 per cent above basal energy needs.

1.5.2 Thermic Effect of Food (TEF)

It also referred to as the thermogenic effect of food or diet-induced thermogenesis. It represents the amount of energy loss during digestion, absorption, and metabolism of food. Eating a meal can slightly increase your metabolic rate due to the thermic effect of food. This effect varies based on the composition of the meal. Consuming food prompts the body to expend energy to process nutrients, temporarily elevating the metabolic rate. TEF typically accounts for approximately **5-10%** of total

energy expenditure, varying based on factors such as the macronutrient composition of the meal, meal size, and individual differences.

Factor affecting: There are several factors affecting it, Let's discuss as follow:

- i. **Macronutrient Composition:** Since different macronutrients (carbohydrates, proteins, and fats) require different amounts of energy to be metabolized by the body. The composition of nutrient in diet plays a crucial role determining the thermic effect. Food rich in protein (20-30%) has the highest thermic effect, followed by carbohydrates (5-10%), while fats (0-3%) have the lowest. This shows requiring the most energy to digest, absorb, and metabolize and indicate the inefficiency of processing proteins and carbohydrates compared to fats. For example, fat is stored with minimal energy loss (approximately 4%), whereas converting carbohydrates into stored fat results in about 25% energy wastage. Other factors influencing TEF include meal frequency, meal size, and individual characteristics such as age, body composition, and metabolic health.
- ii. **Spicy meals:** Spicy meals, particularly those containing hot peppers, chilly, mustard and other spicy ingredients, may have a greater thermic effect compared to milder foods. Additionally, spicy foods may increase satiety and reduce overall food intake, which can also contribute to a higher thermic effect. Spicy meals may lead to a feeling of fullness and satisfaction, potentially resulting in a decrease in calorie consumption during subsequent meals.
- iii. **Other Factors:** Some research indicates that eating several smaller meals throughout the day might enhance the overall thermic effect of food compared to consuming fewer large meals. However, the influence of meal frequency on TEF remains a topic of debate and may differ from person to person.

It is also to consider that individual factors, such as age, sex, body composition, and metabolic rate, also play a role in determining the thermic effect of food. For instance, individuals with greater muscle mass typically experience a higher thermic effect due to the increased energy demands of muscle tissue.

1.5.3 Physical activity

It is the most variable factor and can significantly impact total daily energy expenditure (TDEE). Among these, physical activity holds the most potential for intentional modification, making it a focal point for health and fitness strategies. Physical activity energy expenditure is influenced by the type, intensity, and duration of the activity. Activities are often classified into categories such as light, moderate, or vigorous based on their energy demands.

Light activities include tasks like casual walking or stretching, which require minimal energy expenditure. Moderate activities, such as brisk walking or gardening, elevate the heart rate and metabolic rate noticeably. Vigorous activities, including running, cycling, or high-intensity interval training (HIIT), result in substantial increases in energy expenditure due to the higher intensity and demand on the body's systems. The more intense the activity, the greater the energy expended per unit of time, but even low-intensity activities contribute significantly when performed consistently.

The measurement of energy expenditure during physical activity is critical for understanding its impact. Techniques range from simple estimations using heart rate monitors or pedometers to sophisticated methods such as indirect calorimetry and doubly labeled water. Indirect calorimetry measures oxygen consumption and carbon dioxide production to estimate energy expenditure, while doubly labeled water provides an accurate assessment of TDEE over a longer period. Advances in wearable technology now allow for more accessible and reasonably accurate monitoring of energy expenditure, offering valuable insights for individuals aiming to manage their health and fitness goals.

Energy expenditure through physical activity is also influenced by factors such as age, sex, and fitness level. For example, younger individuals tend to have higher energy expenditure than older adults due to greater muscle mass and higher metabolic rates. Men typically expend more energy than women during the same activity, primarily due to differences in body composition. Additionally, highly fit individuals often demonstrate greater efficiency in their movements, potentially reducing the energy cost of certain activities. However, their ability to sustain higher intensities for longer durations often results in higher overall energy expenditure.

The role of physical activity in managing body weight is significant, as it directly affects the energy balance equation: calories consumed versus calories expended. Regular physical activity increases energy expenditure, making it easier to maintain or achieve a caloric deficit for weight loss. Moreover, the type of activity can influence fat loss and muscle retention. Resistance training, for instance, helps preserve muscle mass while promoting fat loss, whereas aerobic exercises primarily burn calories and

improve cardiovascular health. Combining different forms of physical activity ensures a more balanced approach to energy expenditure and overall fitness.

CHECK YOUR PROGRESS EXERCISE 2

Q1. What is basal metabolic rate and list the factors affecting it.

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Q2. What is the Thermic Effect of Food (TEF), and Why is TEF higher after consuming protein-rich foods compared to fats or carbohydrates?

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Q3. What factors determine the energy expenditure during physical activity?

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1.6 METHODS OF ESTIMATION OF ENERGY EXPENDITURE

The measurement of energy expenditure involves quantifying the amount of energy that an individual or organism expends during various activities, metabolic processes, and bodily functions. Several methods are employed to measure energy expenditure, each offering unique insights into different aspects of energy utilization

1.6.1 Direct Calorimetry: Direct Calorimetric method measures energy expenditure by directly assessing heat production. It is important to note that the human body's digestion process is not always 100% efficient, which means that the body does not eventually use all of the nutrients that are consumed.

Since, not all ingested nutrients are fully available for cellular use, the efficiency with which nutrient is digested is importance to taken into consideration. A nutrient's percentage that eventually becomes accessible to body cells is expressed by its coefficient of digestibility.

This method quantifies the heat generated by an individual or a metabolic process. However, direct calorimetry is less commonly used due to the complexity and cost of the equipment. Most common equipment used to determine energy expenditure during BMR or activity is At water and Roth respiration calorimeter. As shown in figure, it consists of airtight and thermally insulated chamber that can accommodate an individual comfortably. As shown in figure 1.3, the chamber is typically constructed using materials with low thermal conductivity to minimize heat transfer between the individual and the surrounding environment. The walls, ceiling, and floor of the chamber are often made of multiple layers of insulation material to ensure optimal thermal isolation. These whole-body calorimeters are specialized chambers used to measure energy expenditure by capturing the heat produced by an individual's body. The heat generated through metabolic processes. The heat generated by the individual is taken by water, pumped through a series of finned pipes which pass through the calorimeter. Heat output can be calculated by multiplying the temperature difference between the incoming and outgoing water by the volume of water flow.

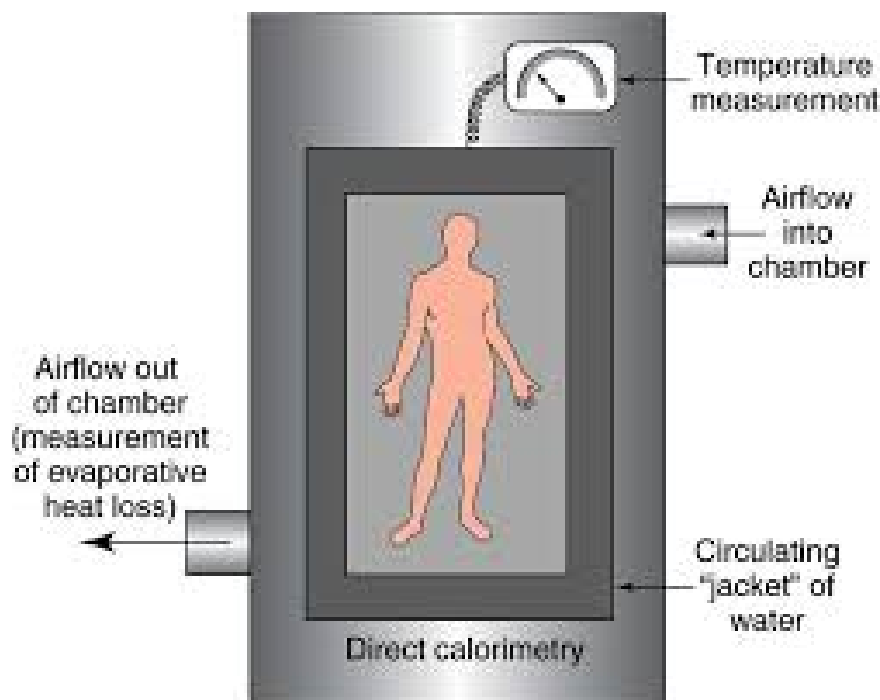


Figure 1.3 : Direct Calorimeter

(Source: Gordon Fisher, 2013)

1.6.2 Indirect Calorimetry

Indirect calorimetry is a technique used to estimate metabolic rate by measuring the amount of oxygen consumption and carbon dioxide production. The Benedict-Roth respiration apparatus is commonly used to determine an individual's energy expenditure and substrate utilization using the principles of indirect calorimetry. The Benedict-Roth Respirometer, named after its developers, Stanley Benedict and A. Arthur Roth, is a device used to measure energy expenditure is directly related to oxygen consumption and carbon dioxide production during metabolism. The Benedict-Roth Respirometer operates on the principle of gas exchange during respiration. As figure 1.4 depict, it consists of a sealed chamber where the subject breathes into, connected to a series of sensors and analyzers that measure the concentrations of oxygen and carbon dioxide in the inhaled and exhaled air. By monitoring the changes in gas concentrations over time, the rate of oxygen consumption and carbon dioxide production can be determined, providing valuable insights into the metabolic activity of the individual.

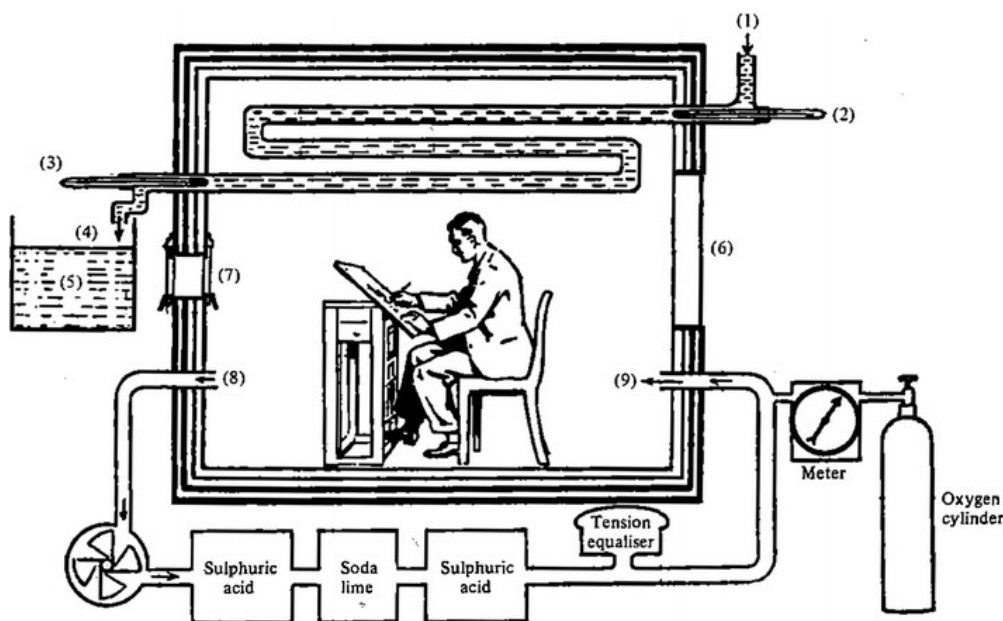


Figure 1.4: Benedict's Oxy Calorimeter

(Source : Bell et al. 1965).

There are two types of indirect calorimetry-

a.Closed Circuit Indirect Calorimetry: It is a sophisticated technique used in metabolic studies to assess energy expenditure and substrate utilization in humans and animals. In closed circuit indirect

calorimetry, the subject breathes into a sealed chamber or mask connected to a closed-loop system. The air exhaled by the subject is collected and analyzed for its oxygen and carbon dioxide content using gas analyzers. By measuring the changes in oxygen and carbon dioxide concentrations between the inhaled and exhaled air, the rates of oxygen consumption (VO_2) and carbon dioxide production (VCO_2) can be determined. These values are then used to calculate energy expenditure through the principles of indirect calorimetry.

Closed circuit indirect calorimetry offers several advantages over other methods of energy expenditure measurement. It provides real-time, continuous data on metabolic rates and substrate utilization, allowing for dynamic assessment of metabolic responses to various stimuli such as exercise, diet, or environmental conditions. Additionally, it enables the measurement of respiratory quotient (RQ), which indicates the relative contributions of carbohydrates, fats, and proteins to energy metabolism.

b.Open Circuit Indirect Calorimetry: It is a method used to estimate energy expenditure and metabolic rates by analyzing the respiratory gases exchanged during breathing. Unlike closed circuit indirect calorimetry, which involves capturing and analyzing all exhaled gases within a closed system, open circuit indirect calorimetry measures the gases inhaled and exhaled by the subject in an open environment. Figure 1.5 depicts the open circuit indirect calorimetry, in which subject breathes through a mouthpiece or mask connected to a flow meter and gas analyzers, which continuously measure the concentrations of oxygen and carbon dioxide in the inhaled and exhaled air.

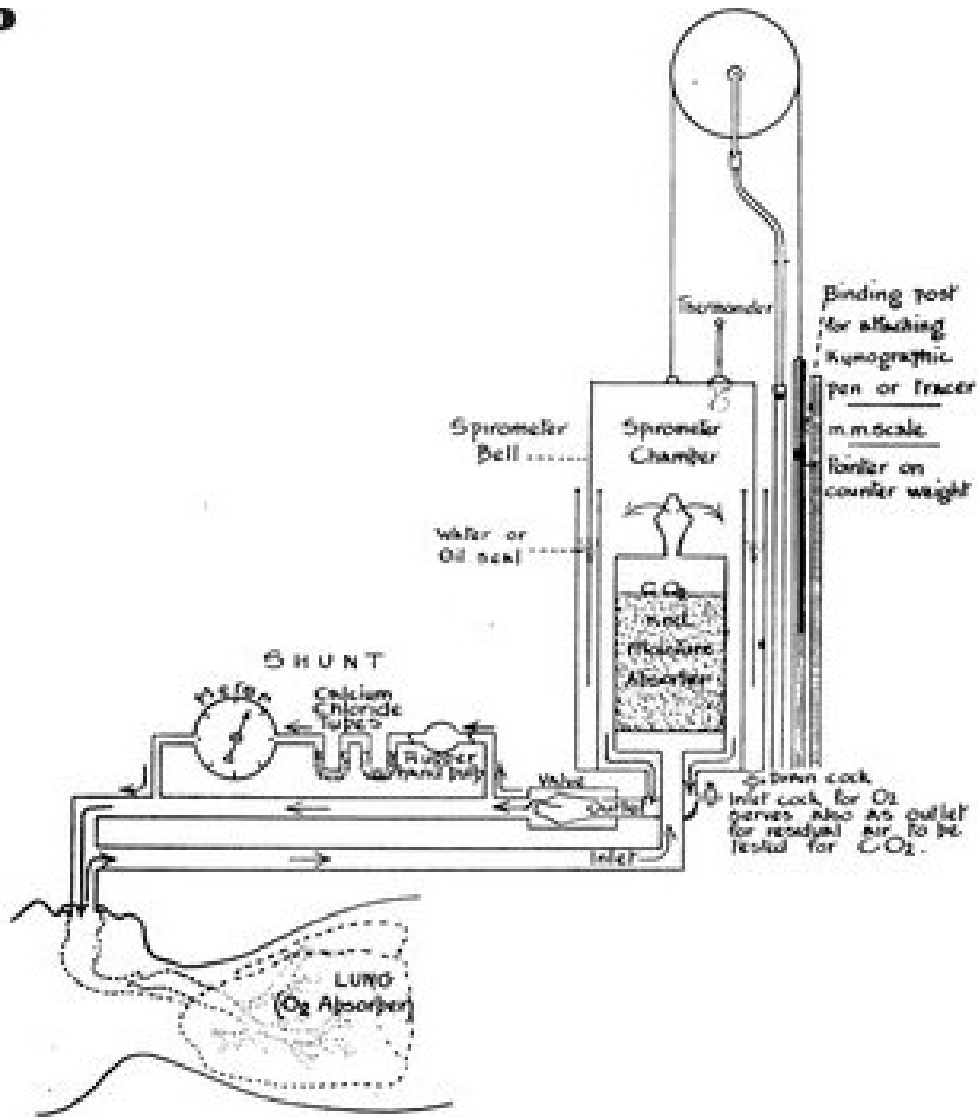


Figure 1.5: Open Circuit Indirect Calorimetry

(Source: Bhatta et al 2014)

The primary advantage of open circuit indirect calorimetry is its simple, non-invasive and allow real-time measurement of metabolic rates during rest, exercise, and various activities.

1.6.3 Doubly Labeled Water Method

The Doubly Labeled Water (DLW) method is a highly accurate and reliable technique used to measure total daily energy expenditure (TDEE) in individuals over a period of days or weeks. In this method, individual drink a known amount of water containing isotopes of hydrogen and oxygen (deuterium and oxygen-18). Once consumed, the isotopes integrate into the body water and are eliminated at different rate through sweat, urine, and respiration. By measuring the rate at which these isotopes are eliminated,

scientists can calculate the production of carbon dioxide (CO₂), which directly reflects energy expenditure, refer figure 1.6 . The key assumption is that CO₂ production correlates with the energy burned, as most of the body's energy comes from metabolic processes that produce CO₂.

This method is valuable in studying metabolism, energy expenditure, and body composition over an extended period, as it provides a more accurate measurement than traditional methods like diet logs or indirect calorimetry. It is particularly useful in field studies where direct measurements of energy expenditure are challenging. Researchers and healthcare professionals use the DLW method to assess energy balance, physical activity levels, and metabolic rates in various populations, helping to understand factors influencing weight management, nutrition, and overall health.

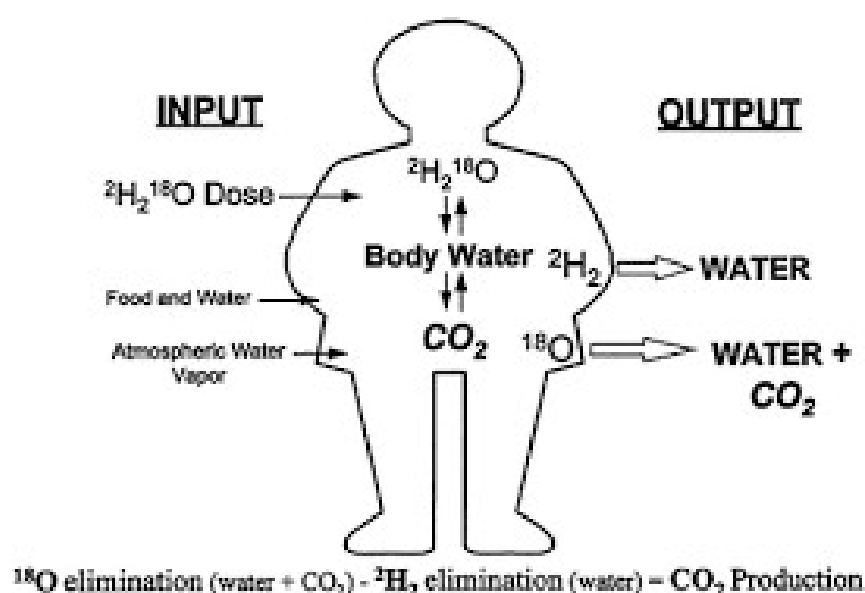


Figure 1.6: Doubly Labeled Water Method

(Source: Retrived fromMetabolic Solutions, Inc. 2014)

It provides an estimate of total energy expenditure over an extended period, often used in free-living conditions.

Steps in the DLW Method

1. **Isotope Administration:** The individual drinks a known dose of water containing deuterium and oxygen-18 isotopes.

2. **Initial Sample Collection:** Baseline samples of body fluids (e.g., urine, saliva, or blood) are taken to measure the initial concentrations of the isotopes in the body.
3. **Sample Collection Over Time:** Additional samples are collected periodically over the study period (usually 7–14 days) to track the decline in isotope concentrations.
4. **Analysis:** The isotopic concentrations are measured using techniques like mass spectrometry. The rate of CO₂ production is determined by the difference in the elimination rates of the two isotopes, and using recognized formulas, it is subsequently converted to energy expenditure.

Advantages of the DLW Method

- **Accuracy:** It gives precise measurements of energy expenditure in real-world conditions.
- **Non-Invasive:** It is a non-invasive method as participants only need to drink the labeled water.
- **Applicability:** It can be used on diverse populations, including infants, elderly individuals, and athletes.
- **Long-Term Measurement:** The method assesses energy expenditure over an extended period, offering a comprehensive view of daily energy use.

Limitations

- **Cost:** The isotopes and analytical procedures are expensive, limiting widespread use.
- **No Information on Activity Type:** While it measures total energy expenditure, it does not differentiate between types of activities (e.g., exercise vs. resting energy expenditure).
- **Complex Analysis:** Requires specialized equipment and expertise for isotopic analysis.
- **Assumptions:** The method assumes a constant respiratory quotient which might not always hold true for individuals with highly variable diets.

1.7 RESPIRATORY QUOTIENT (RQ)

The respiratory quotient (RQ) is a physiological measure that indicates the ratio of carbon dioxide (CO₂) produced to oxygen (O₂) consumed during metabolism. It provides valuable information about the body's utilization of carbohydrates, fats, and proteins as energy sources.

The formula for calculating the respiratory quotient is:

$RQ = \text{Volume of carbon dioxide} / \text{Volume of oxygen consumed}$.

The respiratory quotient can range from 0.7 to 1.0, with different values indicating the predominant substrate being metabolized:

- $RQ = 1.0$: Indicates pure carbohydrate metabolism, where only carbohydrates (glucose) are oxidized completely to CO_2 and H_2O .
- $RQ < 0.7$: Indicates lipid metabolism, where when only fat (fatty acids) are oxidized for energy.
- $RQ = 0.82$: Represents protein metabolism, where only protein metabolised although RQ values for protein oxidation can vary depending on the amino acid composition of the protein source.
- Immediately after meal almost all the food metabolised is carbohydrates so that respiratory quotient at that time approaches to 1.
- At post absorptive stage :RQ is about 0.82-0.7 depending on hours after the meal and into the type of fuel being metabolized.
In diabetes mellitus very little carbohydrate can be utilized by the body cells. The RQ is lowered to about 0.7 in diabetes mellitus as the body oxidises large amount of fat.
- $RQ > 1.0$: Rarely observed in physiological conditions, but can occur under certain circumstances such as during the metabolism of lipids with incomplete carbohydrate metabolism (e.g., diabetic ketoacidosis).

The respiratory quotient is commonly measured using techniques such as indirect calorimetry.

1.8 REGULATION OF ENERGY METABOLISM

Through metabolism body converts nutrients into usable energy, is regulated by a complex interplay of various factors and physiological mechanisms. These regulatory processes ensure that energy production and expenditure are balanced to meet the body needs. Here are some key factors involved in the regulation of energy metabolism:

1.8.1 Hormonal Regulation:

Insulin: **Insulin** is a hormone secreted by the pancreas that plays a key role in regulating energy metabolism, particularly by facilitating the uptake and storage of glucose, fats, and amino acids in the body. It facilitates glucose enter into cells, promote conversion of excess glucose into glycogen, fatty acids for storage. In addition, stimulates protein synthesis and reduce proteolysis.

Glucagon: Glucagon's actions are crucial for maintaining energy balance and preventing hypoglycemia. It also produced by pancreas like insulin, but works in opposition to insulin, which lowers blood sugar levels during fasting or low-energy states.

Leptin: Leptin interacts with the hypothalamus to reduce hunger when energy stores are sufficient. It promotes calorie burning by stimulating metabolic activity. It is commonly produced by adipose tissue and helps to maintain stable body weight. In addition, it also influence reproductive health and immune function.

1.8.2. Neural Regulation:

Sympathetic Nervous System: It also plays a role in maintaining homeostasis during normal activities or in stress or danger. Key role includes:

1. **Stress:** Psychological and physical stressors can activate the sympathetic nervous system, leading to increased heart rate, blood pressure, and the release of stress hormones like adrenaline.
2. **Exercise:** Physical activity stimulates the sympathetic nervous system to increase blood flow and oxygen to muscles, enabling the body to meet the demands of exercise.
3. **Temperature:** Changes in temperature, especially cold temperatures, can trigger the sympathetic nervous system to maintain body temperature through processes like shivering and vasoconstriction.
4. **Pain:** Pain signals can activate the sympathetic nervous system, causing the release of neurotransmitters that amplify pain perception and trigger a fight or flight response.
5. **Blood sugar levels:** Low blood sugar levels (hypoglycemia) can stimulate the sympathetic nervous system to release stress hormones to increase blood glucose levels.
6. **Blood pressure:** Low blood pressure can activate the sympathetic nervous system to constrict blood vessels and increase heart rate to maintain adequate blood flow to vital organs.

7. **Emotions:** Strong emotions such as fear, anxiety, or excitement can stimulate the sympathetic nervous system, leading to changes in heart rate, breathing, and other physiological responses.

Understanding these factors can help in managing stress, staying active, maintaining a healthy lifestyle, and recognizing situations that may trigger sympathetic nervous system responses.

CHECK YOUR PROGRESS EXERCISE 3

What is direct calorimetry, and how is it used to estimate energy expenditure?

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Q 2. What is the role of oxygen consumption and carbon dioxide production in indirect calorimetry?

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Q3. What is the respiratory quotient (RQ), and how is it used to assess the type of fuel the body is using?

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1.9 LET US SUM UP

In this unit, we gain the understanding the concept of food energy and its measurement. Energy from food is expressed as the Physiological Fuel Value, which represents the usable energy from carbohydrates, fats, and proteins. Methods like bomb calorimetry and Benedict's oxy calorimeter are used to determine the energy value of foods. Then, explores the components of energy expenditure, including Basal Metabolic Rate (BMR), the Thermic Effect of Food (TEF), and energy expended during physical activity. BMR represents the energy required for basic physiological functions, TEF accounts for digestion and absorption, and physical activity varies based on intensity and duration.

Different methods for estimating energy expenditure are discussed, such as direct calorimetry, indirect calorimetry, and the doubly labeled water method. The Respiratory Quotient (RQ) is highlighted for its role in assessing fuel utilization, such as carbohydrates or fats. The chapter concludes with the regulation of energy metabolism, emphasizing the role of hormones and metabolic pathways in maintaining energy balance. This understanding is critical for managing health, preventing obesity, and addressing metabolic disorders.

1.10 GLOSSARY

- **Basal Metabolic Rate (BMR):** Energy used at rest to maintain vital functions like breathing and circulation.
- **Benedict's Oxy Calorimeter:** Device measuring oxygen use and carbon dioxide output to estimate energy expenditure.
- **Bomb Calorimetry:** Measures food energy by combusting it in a sealed container and tracking heat release.
- **Direct Calorimetry:** Calculates energy expenditure by measuring the body's heat production.
- **Doubly Labeled Water Method:** Tracks labeled hydrogen and oxygen to measure energy expenditure in daily life.
- **Indirect Calorimetry:** Estimates energy use by assessing oxygen consumption and carbon dioxide production.
- **Energy:** The capacity to do work; measured in calories or joules, essential for bodily functions.
- **Physiological Fuel Value:** Energy from food after digestion, absorption, and metabolism.
- **Respiratory Quotient (RQ):** Ratio of carbon dioxide produced to oxygen used, indicating the fuel type metabolized.
- **Thermic Effect of Food (TEF):** Energy used for digesting and metabolizing food, part of total energy expenditure.

1.11 ANSWER TO CHECK YOUR PROGRESS

EXERCISE 1

A.1 Physiological fuel value refers to the amount of usable energy the body can obtain from a specific amount of food after digestion, absorption, and metabolism. It represents the energy available to the body for physiological functions such as growth, repair, and maintenance. The physiological fuel value differs from the total energy (gross energy) determined by bomb calorimetry because it accounts for the energy actually utilized by the body after the food is processed.

A 2. The principle behind bomb calorimetry is that it measures the heat released when a food sample is completely burned in a sealed, oxygen-rich container. The food sample is ignited, and the heat produced during combustion is absorbed by the surrounding water. The temperature rise in the water is measured, and from this, the total energy released by the food (in calories or joules) is calculated. This process determines the gross energy value of the food.

A 3. Benedict's Oxy Calorimeter and bomb calorimetry are both used to measure the energy value of food, but they differ in their methods and the type of energy they measure.

1. **Method of Measurement:** Bomb Calorimetry directly measures the heat released during the complete combustion of a food sample in a sealed container (the "bomb"). The heat generated is absorbed by the surrounding water, and the temperature change is used to calculate the energy value of the food. On the other hand, Benedict's Oxy Calorimeter measures energy by calculating the amount of oxygen consumed by the body during the metabolism of a food sample. The oxygen consumption is proportional to the energy expended, as oxygen is used in the process of oxidation of food for energy.

2. **Type of Energy Measured:** Bomb Calorimetry measures the total potential energy (gross energy) of the food, which includes all forms of energy, even those that are not utilized by the human body, such as heat released during combustion. On the other hand, Benedict's Oxy Calorimeter measures the metabolic energy, or the energy that can be utilized by the body. It focuses on how much oxygen is used to oxidize food during metabolism, providing a more accurate representation of the energy available for biological processes.

EXERCISE 2

A 1. It represents the minimum energy required for the body to perform these vital functions such as breathing, circulation, and cell production, typically measured after a person has fasted for 12 hours and is at rest in a comfortable environment.

Factors Affecting BMR:

1. **Age:** It typically declines with age, largely due to a reduction in muscle mass and a slowdown in metabolic processes
2. **Sex:** Men generally have a higher muscle mass than women therefore; have basal energy requirement.
3. **Body Composition:** BMR is directly proportional to muscle mass, while individual with higher body fat percentage have lower BMR
4. **Genetics:** Genetic factors can influence metabolic rate, with some individuals having a naturally higher or lower BMR.
5. **Hormones:** Thyroid hormones (such as thyroxine) significantly impact BMR. Hypothyroidism lowers BMR, while hyperthyroidism raises it.

A 2. It also referred to as the thermogenic effect of food or diet-induced thermogenesis. It represents the amount of energy loss during digestion, absorption, and metabolism of food. **Thermic Effect of Food (TEF)** is higher after consuming protein-rich foods because protein digestion and metabolism are more energy-intensive than those of fats and carbohydrates. Protein requires more energy to break down into amino acids, and the body spends additional energy on synthesizing proteins and converting amino acids for various functions. This results in a higher TEF for protein (20-30% of its calories) compared to carbohydrates (5-10%) and fats (0-3%).

A 3. Energy expenditure during physical activity is determined by factors such as **intensity** (how hard the activity is), **duration** (how long the activity lasts), **body weight** (heavier individuals expend more energy), **muscle mass** (more muscle mass increases energy expenditure), **fitness level** (fitter individuals may expend less energy for the same activity), and **type of activity** (aerobic vs. anaerobic exercises). Environmental factors like **temperature** and **altitude** can also influence energy expenditure.

EXERCISE 3

A 1. Direct Calorimetric method measures energy expenditure by directly assessing heat production by the body during metabolism. The individual is placed in an insulated chamber, where heat generated by the body is absorbed by surrounding water or air. The temperature change is measured, and the amount of heat produced is used to estimate total energy expenditure. This method provides a precise measurement of energy expenditure but is complex, costly, and not commonly used in everyday settings.

A 2. Indirect calorimetry is a technique used to estimate metabolic rate by measuring the amount of oxygen consumption and carbon dioxide production. These two variables are measured to calculate how much energy the body is using.

A 3. The **Respiratory Quotient (RQ)** is the ratio of carbon dioxide (CO₂) produced to oxygen (O₂) consumed during metabolism. It is used to assess the type of fuel (carbohydrates, fats, or proteins) the body is using for energy. By analyzing RQ, it's possible to determine whether the body is burning carbohydrates, fats, or proteins for energy. An RQ of **1.0** indicates the body is primarily using **carbohydrates** for energy, as the amount of CO₂ produced is equal to the O₂ consumed. An RQ of **0.7** suggests the body is predominantly utilizing **fats** for fuel, as fat metabolism requires more oxygen relative to CO₂ produced. An RQ of around **0.8** reflects the use of **proteins** for energy, though this is less common.

UNIT 2: CARBOHYDRATES

STRUCTURE

2.1 Introduction

2.2 Types of Carbohydrates

2.2.1 Monosaccharides\

2.2.2 Disaccharides

2.2.3 Polysaccharides

2.3 Functions of Carbohydrates

2.4 Dietary Fiber

2.4.1 Soluble Fiber

2.4.2 Insoluble Fiber

2.5 Resistant Starch

2.6 Oligosaccharides

2.7 Digestion

2.8 Absorption of Carbohydrates

2.9 Transport in the Bloodstream

2.10 Hormonal Regulation of Blood Sugar Levels

2.11 Glycemic index (GI)

2.12 Sweeteners

2.13 Glossary

2.14 Let Us Sum Up

2.15 Answer To Check Your Progress

2.1 INTRODUCTION

Carbon, hydrogen, and oxygen atoms combine to form carbohydrates, commonly referred to as saccharides. They are among the three macronutrients—along with proteins and fats—that are necessary for human nutrition. Carbohydrates is useas main source of energy and for number of

physiological functions. Carbohydrates are a vital nutrient for the human body. They provide energy for physical activity, fuel the brain and nervous system, spare protein for other functions, and play a role in metabolism and cellular communication. However, the energy management and overall health is significantly affected by type of carbohydrates consumed. Complex carbohydrates provide sustainable energy for longer time due to slow rate of digestion. They commonly found in whole grains and legumes. In contrast, low-quality carbohydrates, like refined sugars and processed foods, can lead to rapid blood sugar fluctuations, increased hunger, and long-term risks of metabolic diseases. Choosing the right type of carbohydrate is essential for maintaining a balanced diet, promoting better digestion, and lowering the chance of developing long-term illnesses. In this unit, we will study the different types of carbohydrate, its type, function. Further, we explore the process of digestion, absorption and metabolism of carbohydrate and factors affecting and regulating it.

Expected Outcomes:

After studying this unit, student will capable to:

- Identify and distinguish between different types of carbohydrates
- Understand the concept of fiber, resistant starch, and able to describe its health benefits.
- Describe the process of carbohydrate digestion, absorption and transport.
- Describe glycemic index (GI) and sweeteners and its role in reducing blood sugar
- Explain how hormones regulate carbohydrate metabolism

2.2 TYPES OF CARBOHYDRATES

Carbohydrates can be classified into several types based on their chemical structure and properties. Here are the main types of carbohydrates were illustrated in figure 2.1

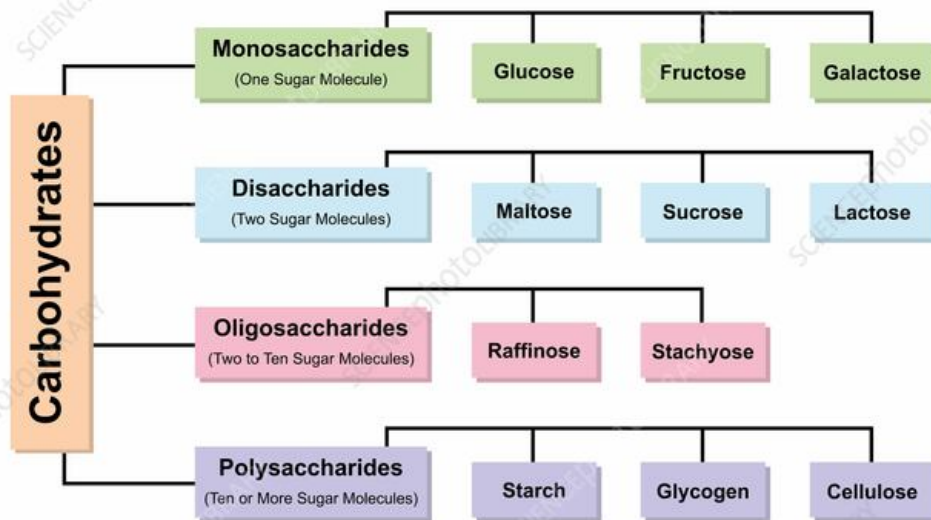


Figure 2.1 : Types of carbohydrate

(Source: ALI DAMOUH/SCIENCE)

Let's move to study in detail:

2.2.1 Monosaccharides

Monosaccharides are single sugar molecules. The general formula for them is $(CH_2O)_n$, where "n" is the number of carbon atoms. The most prevalent types of monosaccharides are trioses (3 carbon atoms), tetroses (4 carbon atoms), pentoses (5 carbon atoms), and hexoses (6 carbon atoms), which are categorized according to the number of carbon atoms they contain.

Figure 2.2 presented the three common types of monosaccharides-Glucose, galactose, and fructose that play essential roles in human metabolism and nutrition.

Monosaccharides

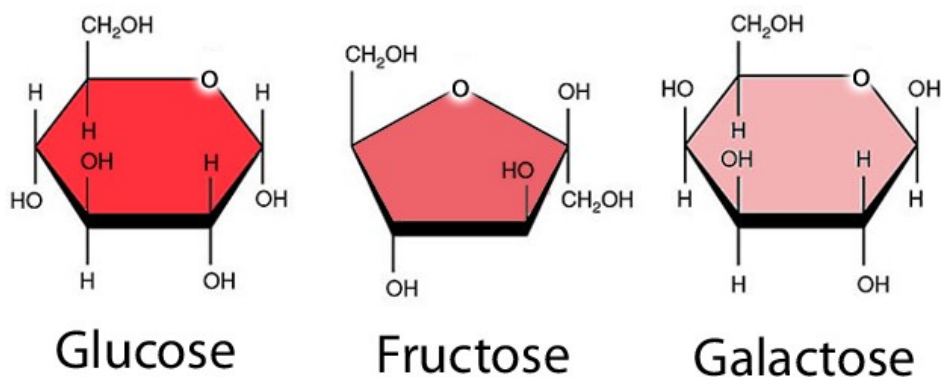


Figure 2.2: Structure of Common Monosaccharides

(Source: Retrieved from nutrireview.com)

Here we discuss as follow:

- i. **Glucose:** The body's cells use glucose, sometimes referred to as blood sugar, as their main energy source. It is produced when carbs are broken down and then taken up by the bloodstream to be distributed to all of the body's cells. They are generally found in certain fruits(eg. Oranges, banana), vegetables(eg. Sweet potato,carrots) and grains (eg rice,wheat).Studying glucose is crucial because it is the body's primary energy source, essential for cellular metabolism, and its regulation impacts critical processes like brain function and overall metabolic health.Glucoseplay cricual role in body's primary and important physiological processes.

Next, we will discuss the important functions of glucose for overall metabolic health.

- Glucose is the main substrate for cellular processes,acting as a critical energy source for most cells in the body..
- Glucose is only energy source to certain tissuse such as brain and red blood cells(RBC). Also, glucose is the main fuel for muscles during physical activity for providing energy.
- It can be stored in the liver and muscles as glycogen and can broken down into glucose when needed.
- When the body consumes more glucose than it immediately needs for energy or glycogen storage, the excess is converted into fat for long-term energy storage.

- Beyond energy production, glucose serves as a building block for biosynthesis, contributing to the formation of nucleotides, glycoproteins, and lipids.

ii. Galactose: Galactose is less commonly found in nature compared to glucose and fructose. It is primarily obtained from the digestion of lactose, a disaccharide found in dairy products. Galactose undergoes a sequence of biochemical processes in the liver to transform it into glucose after being absorbed into the bloodstream. Galactose contributes to the production of complex carbohydrates that are essential for cell structure and function, such as glycolipids and glycoproteins.

iii. Fructose: Fruits, honey, and some vegetables naturally contain fructose, commonly referred to as fruit sugar. Additionally, it is a part of sucrose, popularly known as table sugar, which is composed of one fructose molecule and one glucose molecule. Fructose is almost entirely digested in the liver, in contrast to glucose, which is mostly processed there. Through a sequence of enzymatic processes, it is transformed into lactate, glucose, glycogen, and other metabolites.

2.2.2 Disaccharides

Disaccharides are type of carbohydrate made up of two monosaccharide molecules bind together through glycosidic linkage. They play a vital role in energy storage and metabolism in humans and other organisms. The most notable disaccharides are presented in figure 2.3 and discussed below:

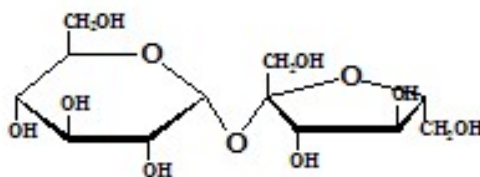
- Sucrose:** It is made up of two monosaccharide- glucose and fructose via an α -1,2-glycosidic bond. It is commonly known as table sugar because it is the most common form of sugar used in households for sweetening food and beverages. Sucrose is naturally present in fruits, primarily in sugarcane, sugar beet, and maple syrups. Sucrose, like other carbohydrates, provides energy as in human body. Like other carbs, sucrose gives the body energy. The enzyme sucrase breaks down sucrose in the small intestine into its monosaccharides, fructose and glucose. The bloodstream subsequently absorbs the glucose, giving the body a rapid energy boost. Although, it is found excessive consumption of sucrose can contribute to various health issues, includes weight gain, tooth cavity and **diabetes**. It is important to balance sucrose intake with other nutrients and maintain a healthy diet.
- Lactose:** The main carbohydrate in human milk and dairy products, as well as other mammalian milk, is lactose. It is made up of one glucose molecule and one galactose molecule connected by a β -1,4-glycosidic bond. The small intestine contains the enzyme lactase, which breaks down lactose into

its component monosaccharides. Lactose intolerance can result from a lactase deficiency in certain people.

iii. Maltose: It also known as malt sugar, is formed during the digestion of starch and is found in germinating grains and malted foods. It is composed of two molecules of glucose linked together by an α -1,4-glycosidic bond. Maltose is less sweet than sucrose and is often used in brewing beer and fermentation processes.

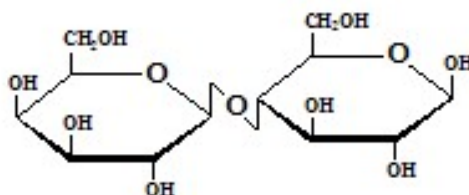
Sucrose

(Glucose-fructose)



Lactose

(Galactose-glucose)



Maltose

(Glucose-glucose)

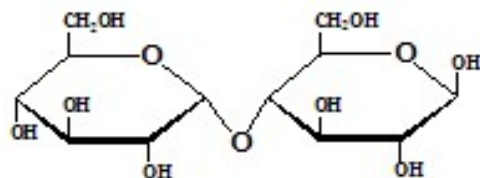


Figure 2.3: Structure of Disaccharides

2.2.3 Polysaccharides

Long chains of monosaccharide units combine by glycosidic linkages to form complex carbohydrates known as polysaccharides. In living things, these molecules function as structural elements or energy storage unit. They can be categorized into two types based on their structure and functions:

- Storage Polysaccharides:** Complex carbohydrates called storage polysaccharides are used by living things as energy stores. Repeating units of monosaccharides, usually glucose molecules, joined by glycosidic linkages make up these polysaccharides.

Let's move to learn about two primary storage polysaccharides found in living organisms that are glycogen and starch.

- **Starch:** Plants use starch as their main energy store and storage carbohydrate. Two different kinds of polysaccharides: amylopectin, and amylose joined via glycosidic linkages to form starch. Amylose is a linear chain of glucose molecules connected by α -1,4-glycosidic linkages while, amylopectin is a branching polymer at α -1,6-glycosidic links. It serves as a major source of dietary carbohydrates for humans and animals.
 - **Glycogen:** Animals, including humans, store glucose as glycogen, which is mostly kept in the muscles and liver. In periods of fasting or physical activity, Glycogen is broken down into glucose and acts as an easily accessible energy store that may be swiftly released to meet the body's energy requirements. It is similar to starch, made up of glucose molecules connected by α -1,4-glycosidic bonds, but more highly branched. frequently has α -1,6-glycosidic branch points.
- ii. **Structural Polysaccharides:** These are complex carbohydrates that gives cells, tissues, and organisms strength, support and structural integrity. Two prominent examples of structural polysaccharides are cellulose and chitin.
- **Cellulose:** The main component of plant cell walls is cellulose. It is a repeated unit of linear chain of repeated units of glucose, linked together by β -glycosidic bonds. Cell wall made up of cellulose are rigid and strong, allowing plants to maintain their shape and withstand mechanical stress. Cellulose indigestible in many animal because of its beta bond structure, which makes it extremely resistant to being broken down. It is important to note that humans lacks the enzymes, making it indigestible as dietary fiber. However, it serves as dietary fiber, promoting healthy digestion and providing bulk to the diet.
 - **Chitin:** Fungal cell walls and arthropod exoskeletons, such as those of insects and crustaceans, contain chitin, a structural polysaccharide. It is made up of linear chains of β -1,4-glycosidic linkages connecting N-acetylglucosamine (GlcNAc) units. For species with chitinous cell walls and exoskeletons, chitin offers protection and structural support.

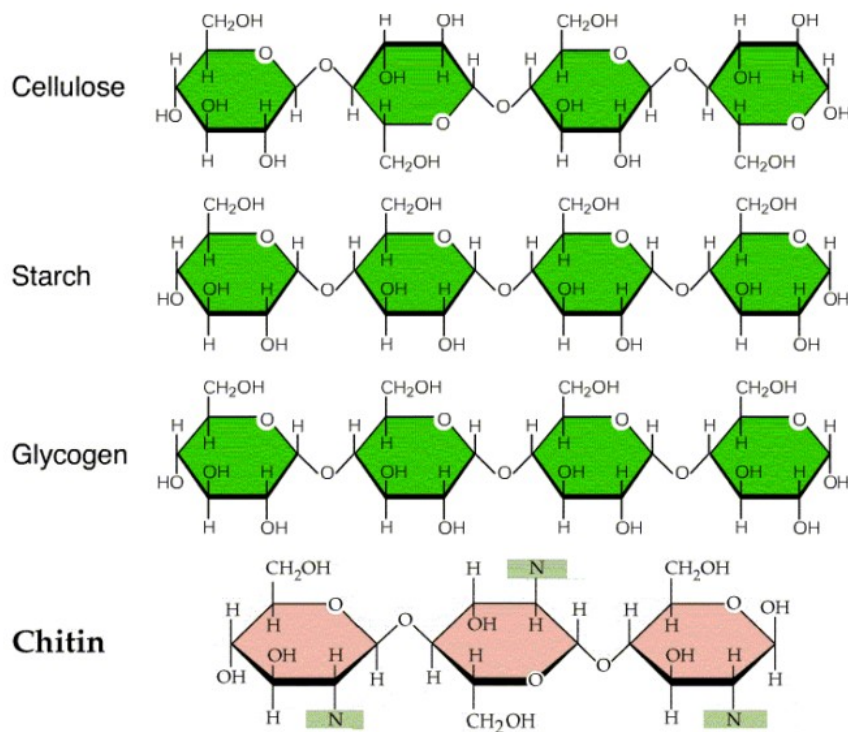


Figure 2.4: Types of Polysaccharides

(Source: Biochem Den, 2019)

2.3 FUNCTIONS OF CARBOHYDRATES

1. **Energy Source:** During cellular respiration, glucose, the most basic type of carbohydrate, is broken down to create ATP (adenosine triphosphate), the cell's energy currency. Muscle contraction, neuron transmission, and cellular metabolism are just a few of the functions that cells do using ATP. The body has adequate energy to support daily tasks and physical activity when it consumes enough carbohydrates.
2. **Protein-sparing action-** The protein-sparing action of carbohydrates refers to the ability of carbohydrates to conserve or "spare" protein for its essential functions in the body, rather than being used as an energy source. When carbohydrates are available in sufficient quantities in the diet, they can be used as the primary source of energy, thereby reducing the need for proteins to be metabolized for energy production. This allows proteins to be preserved for their essential functions, such as tissue repair, enzyme synthesis, hormone production, and immune function.

3. **Oxidation of fats:** In the oxidation of lipids, oxaloacetic acid from the metabolism of carbohydrates and amino acids combines with acetyl CoA from the oxidation of fatty acids to generate citric acid, which is then oxidized via the TCA cycle back to oxaloacetic acid through a sequence of events. Acetyl CoA is produced in large quantities from the oxidation of fatty acids if there is insufficient oxaloacetic acid available. A portion of this CoA is transformed into ketone groups (acetone, acetoacetic acid, beta hydroxy butyric acid), which build up in tissues and blood and cause ketosis.
4. **Main source in Nervous tissue-** Glucose is the main source of energy for nervous tissue, including the brain and spinal cord. The brain is highly dependent on glucose as its primary fuel source due to its efficient metabolism and high availability bloodstream and limited ability of brain to store energy reserves. However, during fasting or prolonged exercise, may also utilize ketone bodies derived from fatty acids as an alternative fuel source.
5. **Role in liver-** Carbohydrates are essential for maintaining normal liver function and metabolic homeostasis. The liver's ability to store, synthesize, and release glucose is crucial for providing energy to the body and ensuring proper regulation of blood glucose levels.
6. **Role in muscle-**carbohydrates are crucial for maintaining metabolism and muscle function. During exercise, carbohydrates serve as the primary fuel source for muscle contraction, providing the energy needed to sustain physical activity. Additionally, Carbohydrates also aid in the storage of muscle glycogen, which acts as an easily accessible energy source that may be used to fulfill the higher energy requirements of exercise. Consuming enough carbohydrates prior to, during, and following exercise is essential for maximizing performance, postponing exhaustion, and promoting muscle growth and repair.
7. **Synthesis of ribose-**The synthesis of ribose, a pentose sugar necessary for the synthesis of nucleotides, such as ribonucleic acid (RNA) and deoxyribonucleic acid (DNA), depends heavily on carbohydrates. The pentose phosphate route (PPP), sometimes referred to as the hexose monophosphate shunt, is how ribose is made.

After study the types of carbohydrates and their functions, let's move to learn about dietary fiber, which is also a type of complex carbohydrate. It was found that dietary fiber aids in maintaining a healthy gut microbiome, which is essential for overall health. Understanding fiber's impact on nutrition can guide dietary choices and improve long-term well-being.

Next, move to discuss dietary fiber

2.4 Dietary Fiber

The indigestible component of plant-based diets is known as dietary fiber. Fiber travels through the digestive system largely undamaged, in contrast to other carbohydrates, because it cannot be broken down by human digestive enzymes. It plays a crucial role in maintaining digestive health and supporting overall well-being. Adults are advised to consume around 25-30 grams of fiber per day. Dietary fiber comes in two primary forms, soluble and insoluble, each with unique uses and health advantages.

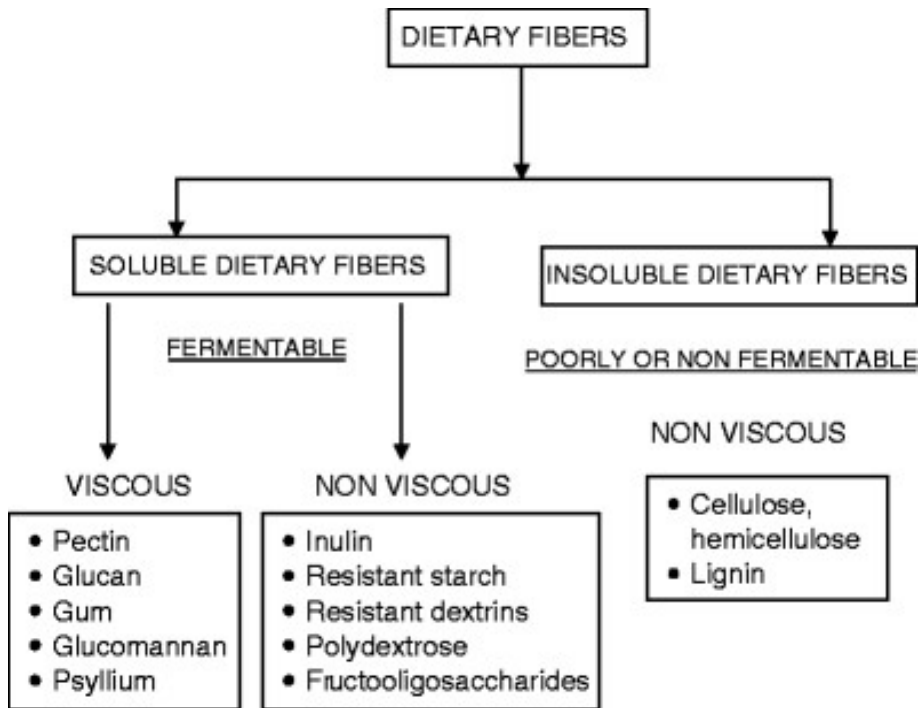
2.4.1 Soluble Fiber: Fiber that dissolves or swells in water to create a gel-like substance in the digestive tract is referred to as soluble fiber. Fruits, vegetables, grains, legumes, and other plant-based foods all contain it. Soluble fiber contributes to health in a number of significant ways:

- i. ***Regulating Blood Sugar Levels:*** Soluble fiber inhibits the release of carbohydrates into the bloodstream and delays the stomach's emptying when it solidifies into a gel-like material in the digestive tract. This lessens the likelihood of sharp increases in blood sugar levels following meals. Because soluble fiber can help with glycemic control, it is especially advantageous for people with diabetes or insulin resistance.
- ii. ***Lowering Cholesterol Levels:*** Soluble fiber has been shown to have cholesterol-lowering effects. It works by binding to cholesterol and bile acids in the digestive tract, ;thereby increase excretion of cholesterol from the body. By reducing LDL (low-density lipoprotein) cholesterol levels, soluble fiber helps to improve heart health and lower the risk of cardiovascular diseases.
- iii. ***Promoting Feelings of Fullness and Weight Management:*** Soluble fiber adds bulk to the contents of the digestive tract by absorbing water. This can promote feelings of fullness and satiety, leading to a reduced appetite and decreased calorie intake. Including foods high in soluble fiber in meals can help with weight management and prevent overeating.
- iv. ***Supporting Gut Health:*** The beneficial bacteria in the gut use soluble fiber as a food source because it functions as a prebiotic. By fermenting the soluble fiber, these bacteria create short-chain fatty acids (SCFAs), including butyrate, propionate, and acetate. SCFAs support a healthy gut environment by giving the colon's lining cells energy and by reducing inflammation. Improved immune system performance, better digestion, and a lower chance of developing some diseases are all linked to a healthy gut flora.

- v. ***Increasing Mineral Absorption:*** Some types of soluble fiber, such as pectin, have the ability to bind to minerals like calcium and magnesium, increasing their absorption in the digestive tract. This can contribute to better bone health and overall mineral balance in the body.

2.4.2 Insoluble Fiber: It is kind of fiber which does not dissolve in water and bulk to stool. It is primarily found in the outer skins of fruits and vegetables, whole grains, nuts, and seeds. Insoluble fiber offers various benefits to digestive health and overall well-being:

- i. ***Promoting Regular Bowel Movements:*** Insoluble fiber helps in relieving constipation by encouraging regular bowel motions. It adds bulk to stool by absorbing water, making it larger and easier to pass through the intestines and facilitating in acting as a natural laxative; which further lowers the incidence of digestive problems like diverticulosis, hemorrhoids, and irritable bowel syndrome (IBS).
- ii. ***Supporting Colon Health:*** By encouraging frequent bowel movements and avoiding the accumulation of waste in the intestines, insoluble fiber contributes to the maintenance of a healthy colon. It gives the stool more volume, which helps the body get rid of waste and toxins. By reducing the transit time of food through the colon, insoluble fiber may also have a protective effect against colon cancer.
- iii. ***Providing a Sense of Satiety and Weight Management:*** Similar to soluble fiber, insoluble fiber contributes to feelings of fullness and satiety. It adds volume to the diet, helping to create a sense of satisfaction after meals and reducing the likelihood of overeating. Including foods rich in insoluble fiber in the diet can support weight management goals.
- iv. ***Supporting Gut Health:*** Although insoluble fiber is not fermented by the gut bacteria to the same extent as soluble fiber, although, it promote the growth of healthy microbial community in the gut.
- v. Examples of foods high in insoluble fiber include whole wheat products, , whole grain cereals, bran, nuts, seeds, and the skins of fruits and vegetables.



Figures 2.5: Types of Dietary Fibers

Next, let us study about the starch of carbohydrates.

2.5 Types of Starch

The chemical composition of resistant starch is similar to that of regular starch, but it has structural characteristics that render it resistant to digestion. The chemical composition of resistant starch includes the following components:

1. **Amylose:** The linear chain of glucose molecules that makes up amylose is joined by alpha-1,4-glycosidic linkages.. It makes up approximately 20-30% of the starch content in most plant-based foods. Resistant starch can contain varying amounts of amylose, depending on the specific food source. Amylose helps to create resistant starch structures and is less soluble in water than amylopectin.
2. **Amylopectin:** It is branched molecule of glucose units joined in linear chains by alpha-1,4-glycosidic bonds and branched at points with alpha-1,6-glycosidic linkages. It accounts about 70-80% of the starch content in most plant-based foods.

3. **Retrograded Starch:** It is the process where gelatinized starch molecules, particularly amylose and amylopectin, reorganize and recrystallize upon cooling, leading to the firming or hardening of starch-based foods like bread or rice. This phenomenon affects texture, shelf life, and digestibility. Retrogradation involves the rearrangement of starch molecules, and forms insoluble and crystalline structures. These retrograded starch structures are more resistant to digestion and are considered a type of resistant starch.
4. **Starch Granules:** Starch exists in the form of granules in plant-based foods, and the size and shape of these granules can vary depending on the source. Resistant starch can be present within the granules, protected by the surrounding starch matrix and other components of the food.

2.5 RESISTANT STARCH

Starch that withstands digestion in the small intestine and makes it to the large intestine intact is known as resistant starch. It acts as a substrate for the gut bacteria's fermentation in the large intestine; resulting in increase in growth of bacteria and production of short-chain fatty acids (SCFAs). These action contribute to gut health; in addition it offer a number of other health advantages such as improved immune function, metabolism, and reduce risk against metabolic disorders.

Foods that contain resistant starch include cooked and cooled potatoes, green bananas, legumes (such as lentils, chickpeas), and certain whole grains. The chemical composition of resistant starch is influenced by factors such as the source of starch (e.g., legumes, unripe bananas, cooked and cooled potatoes), processing methods, and food preparation techniques. Different food sources and processing techniques can result in variations in the structure and composition of resistant starch, leading to differences in their physiological effects and health benefits.

2.5.1 Resistant starch offers several benefits:

1. *Promoting Colon Health:* The large intestine ferments resistant starch, generating short-chain fatty acids (SCFAs) that power the colon's lining cells and have anti-inflammatory properties. Additionally, resistant starch may lower the incidence of colon cancer.

2. *Blood Sugar Control:* Resistant starch has been found to have a lower glycemic index compared to digestible carbohydrates. This means that it has a smaller impact on blood sugar levels after a meal. Including foods high in resistant starch can contribute to better blood sugar control, particularly in individuals with diabetes or insulin resistance.

3. *Enhanced Mineral Absorption*: Similar to soluble fiber, resistant starch has the ability to bind to minerals like calcium and increase their absorption in the digestive tract. This can support optimal mineral balance and bone health.

2.5.2 Types of Resistant Starch

Resistant starch is categorized into several subtypes include RS1, RS2, RS3, RS4, and RS5. Each subtype has unique characteristics and can be found in different types of foods. The specific chemical composition and properties of resistant starch may vary depending on the specific source, processing, and cooking methods. Different food sources and preparation techniques can result in variations in the composition and distribution of resistant starch subtypes.

Consuming a variety of foods that contain different subtypes of resistant starch can contribute to a diverse and beneficial gut microbiome and provide associated health benefits Here is an overview of each subtype:

RS1 (Physically Inaccessible Starch): RS1 refers to starch that is physically enclosed within the food matrix and is resistant to digestion. Whole grains, seeds, and legumes are common sources of this kind of resistant starch, which is encased in fibrous cell walls or complex structures that make it inaccessible to digestive enzymes.

RS2 (Resistant Granular Starch): RS2 refers to starch that has a resistant granular structure, meaning it maintains its granular form even after cooking. Raw or partially cooked foods such as green bananas, high-amylose corn, and raw potatoes have this kind of resistant starch. The starch granules' structure prevents them from being broken down by the small intestine's enzymes.

RS3 (Retrograded Starch): RS3 refers to starch that forms after cooked starch-containing foods are cooled. During the cooling process, the starch molecules reassociate and form insoluble, crystalline structures. Due to its resistance to digestion in the small intestine, this retrograded starch reaches to the large intestine undigested, where gut bacteria can ferment it. Examples of foods high in RS3 include cooked and cooled potatoes, bread, and some types of cooked rice.

RS4 (Chemically Modified Starch): RS4 refers to starch that has been chemically modified to resist digestion. This type of resistant starch is often used as an additive in food products to improve texture, stability, or other properties. Examples of chemically modified resistant starch include cross-linked starches, esterified starches, and starches modified with enzymes.

RS5 (Starch Complexed with Other Molecules): RS5 refers to starch that is complexed or bound with other molecules, such as lipids or proteins. This complexation makes the starch resistant to digestion. Resistant starch of this type can be found in foods like high-amylose starch-lipid complexes, where the lipid component helps protect the starch from digestion.

2.6 OLIGOSACCHARIDES

The type of carbohydrate that consists of a small number of sugar molecules (typically 3 to 10) linked together via glycosidic bonds is called oligosaccharides. They are classified as complex carbohydrates and are commonly found in certain foods and as components of dietary fiber. Oligosaccharides are not easily digested by human enzymes in the small intestine, but undergo fermentation by intestinal bacteria. Consuming foods or supplements rich in oligosaccharides can contribute to a healthy gut microbiome, support digestion, and potentially provide other health benefits. However, individual responses to oligosaccharides may vary, and some individuals may experience digestive symptoms such as bloating, gas, or discomfort when consuming larger amounts of oligosaccharides. Oligosaccharides, particularly fructo-oligosaccharides and galacto-oligosaccharides, are often used as food additives in various processed foods, including dairy products, baked goods, and dietary supplements. They are added for their prebiotic properties and potential health benefits.

2.6.1 Types of oligosaccharides

There are several types of oligosaccharides, including:

Fructo-oligosaccharides (FOS): They are short-chain carbohydrates made up of short chain of fructose molecules and frequently terminate in a glucose molecule. FOS is a naturally occurring prebiotic that is fermented by good gut bacteria in the colon rather than being broken down by human enzymes. It can be found in foods including onions, bananas, chicory root, garlic, and asparagus. This fermentation enhances the equilibrium of the gut microbiota by promoting the growth of beneficial bacteria like *Lactobacilli* and *Bifidobacteria*. By reducing constipation, improving bowel regularity, and preserving the integrity of the gut barrier, FOS promotes digestive health. Furthermore, they may aid in controlling blood sugar and cholesterol levels and indirectly enhance immunological function.

Galacto-oligosaccharides (GOS): Galacto-oligosaccharides consist of galactose units linked together. They are found naturally in some legumes, such as lentils, chickpeas, and soybeans. Additionally, GOS promotes the furnishing of good bacteria in the stomach and functions as a prebiotic. It has been

demonstrated that it encourage the development of bifidobacteria, which are thought to be advantageous for gut health. GOS is often added to infant formulas as it can mimic the oligosaccharides naturally present in breast milk and promote the growth of healthy gut bacteria in infants.

Mannan-oligosaccharides (MOS): Mannan-oligosaccharides are composed of mannose units linked together. They are made up of the cell walls of yeast and are often used as a feed additive in animal nutrition. As a prebiotic, MOS can preferentially promote the growth of good bacteria in the gut while preventing the formation of bad bacteria. It has been demonstrated to enhance intestinal health, enhance immune function, and support overall animal health and performance.

- 1. **Xylo-oligosaccharides (XOS):** Xylo-oligosaccharides consist of xylose units linked together. They are derived from the hemicellulose fraction of plant fibers and are commonly found in bamboo shoots, oat bran, and certain fruits and vegetables. XOS also acts as a prebiotic and associated with improved gut health, enhanced mineral absorption, and potential immune system benefits.

Oligosaccharides, particularly fructo-oligosaccharides and galacto-oligosaccharides, are often used as food additives in various processed foods, including dairy products, baked goods, and dietary supplements. They are added for their prebiotic properties and potential health benefits.

CHECK YOUR PROGRESS EXERCISE 1

- 1. What are carbohydrates and Enlist different types of carbohydrate with suitable example?

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- 2. What is resistant starch, and how does it benefit digestive health?

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3. What is dietary fibre? Give the source and requirement of fiber.

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4. What are oligosaccharides. Give some examples.

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5. Write difference between amylose and amylopectin.

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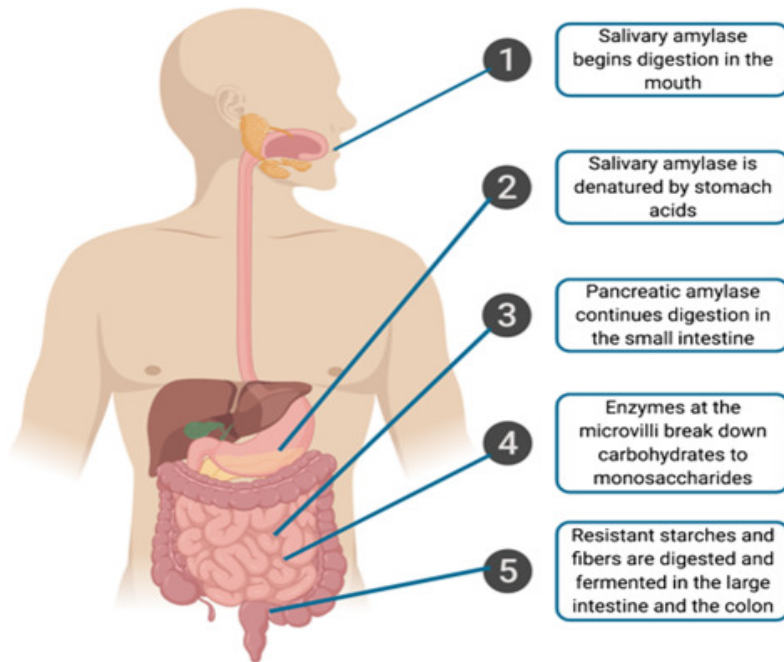
2.7 DIGESTION

Carbohydrate digestion is a complex process breaking down polysaccharides, disaccharides, and other carbohydrate forms into monosaccharides, which the body can absorb and use for energy. The digestion of carbohydrate can be divided in different stages as follow and presented in figure 2.6.

Mouth: Carbohydrates are first broken down in the mouth broken down into smaller pieces during the chewing process. It also increases the food's surface area for improved enzymatic action. Saliva, which contains the enzyme salivary amylase or ptyalin, is also released by the salivary glands. Complex carbohydrates like starch are broken down into smaller polysaccharides and disaccharides by the action of salivary amylase. However, carbohydrates are only briefly exposed to salivary amylase.as digestion continues in the stomach.

Digestion in the Stomach: The stomach's acidic environment inhibits salivary amylase's activity, which momentarily stops the breakdown of carbs. Here, the stomach's main function is to break down food through mechanical churning and the release of gastric juices, which primarily aid in protein digestion.

Digestion in the Small Intestine: The small intestine is where most of the digestion of carbohydrates takes place. Hormones such as secretin and cholecystokinin (CCK) are released as food passes from the stomach into the small intestine. These hormones cause the pancreas to secrete pancreatic juice. Pancreatic juice contains various enzymes, including pancreatic amylase, which is the key enzyme responsible for carbohydrate digestion. Pancreatic amylase acts on the remaining polysaccharides, breaking them down into smaller fragments, such as maltose, maltotriose, and alpha-limit dextrins. The brush border enzymes, also known as disaccharidases, are located on the surface of the microvilli. They include sucrase, lactase, maltase, and isomaltase. Each enzyme specifically acts on a particular disaccharide, breaking it down into its respective monosaccharides. Hence, brush border enzymes complete the digestion of disaccharides, resulting in the formation of monosaccharides.



Figures 2.6: Digestion of Carbohydrates

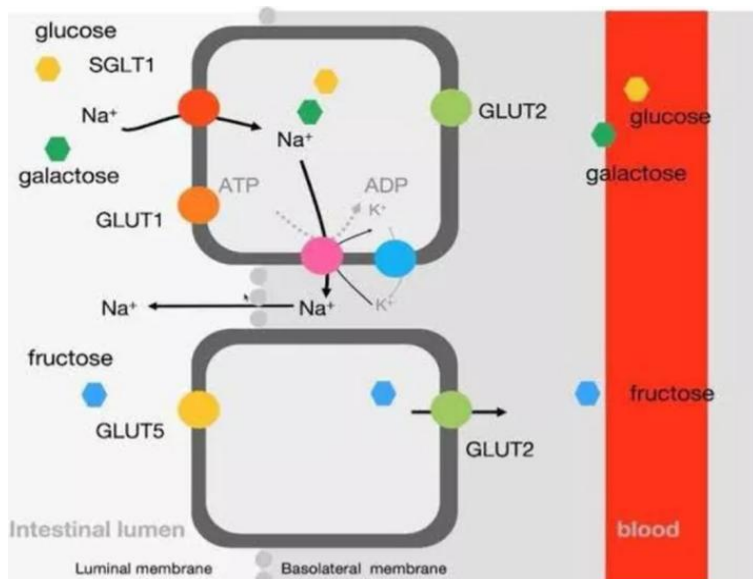
(Source: MS *et al.*,2020)

After understanding the process of breakdown of complex carbohydrates into simpler molecules. Next we will study how simple nutrients enter into the bloodstreams through intestinal lining. This process is called adsorption.

2.8 ABSORPTION OF CARBOHYDRATES

The epithelial cells lining the absorptive surface of the small intestine are equipped with specialized transporters for glucose, fructose, and galactose. These monosaccharides are transported across the intestinal walls and into the bloodstream through these specific carriers.

Glucose and galactose are absorbed via active transport through the sodium-glucose co-transporter (SGLT-1), which relies on the sodium gradient maintained by the sodium-potassium pump. Fructose, on the other hand, is absorbed by facilitated diffusion through the GLUT-5 transporter. Once inside the epithelial cells, all three monosaccharides are transported into the bloodstream via the GLUT-2 transporter, where they are distributed to cells for energy production or storage.



Figures 2.7:Absorption of Carbohydrates

(Source: Retrived from Mysportsscience.com)

2.9 TRANSPORT IN THE BLOODSTREAM

After absorption, the monosaccharides are taken to the liver, which plays central role in glucose metabolism to ensures a stable and continuous source of energy for bodily functions through the process of glycogenesis (convert and store glucose as glycogen), or glycogenolysis (breakdown of glycogen to glucose) or gluconeogenesis (glucose is produced from non-carbohydrate sources). Particularly during fasting or times of higher demand, this regulation guarantees a steady and balanced supply of glucose for energy.

2.10 HORMONAL REGULATION OF BLOOD SUGAR LEVELS

One essential mechanism that keeps blood glucose levels steady is the hormonal control of blood sugar levels. The pancreas secretes the two main hormones involved in this regulation, glucagon and insulin, in response to variations in blood glucose levels.

1. **Insulin:** In reaction to increased blood glucose levels, usually following a meal, the beta cells of the pancreatic islets of Langerhans generate and release insulin.

Insulin's primary roles include

- **Facilitating Glucose Uptake:** Insulin encourages the body's cells, especially those in muscle and fat tissue, to enter glucose into cells.
- **Glycogen Synthesis (Glycogenesis):** Insulin promotes the liver and muscles to turn extra glucose into glycogen. When needed, the glucose stored in glycogen can be released by subsequent breakdown.
- **Inhibiting Gluconeogenesis:** Insulin prevents glucose from being produced from non-carbohydrate sources (such as glycerol or amino acids) by inhibiting the gluconeogenic process.
- **Lipogenesis:** Insulin encourages the conversion of glucose into fatty acids, which results in the accumulation of lipids in adipose tissue.

2. **Glucagon:** The pancreatic islets of Langerhans' alpha cells respond to low blood glucose levels by producing and secreting glucagon. Glucagon's main function is to raise blood sugar levels by raising glucose levels. Let's explore in detail:

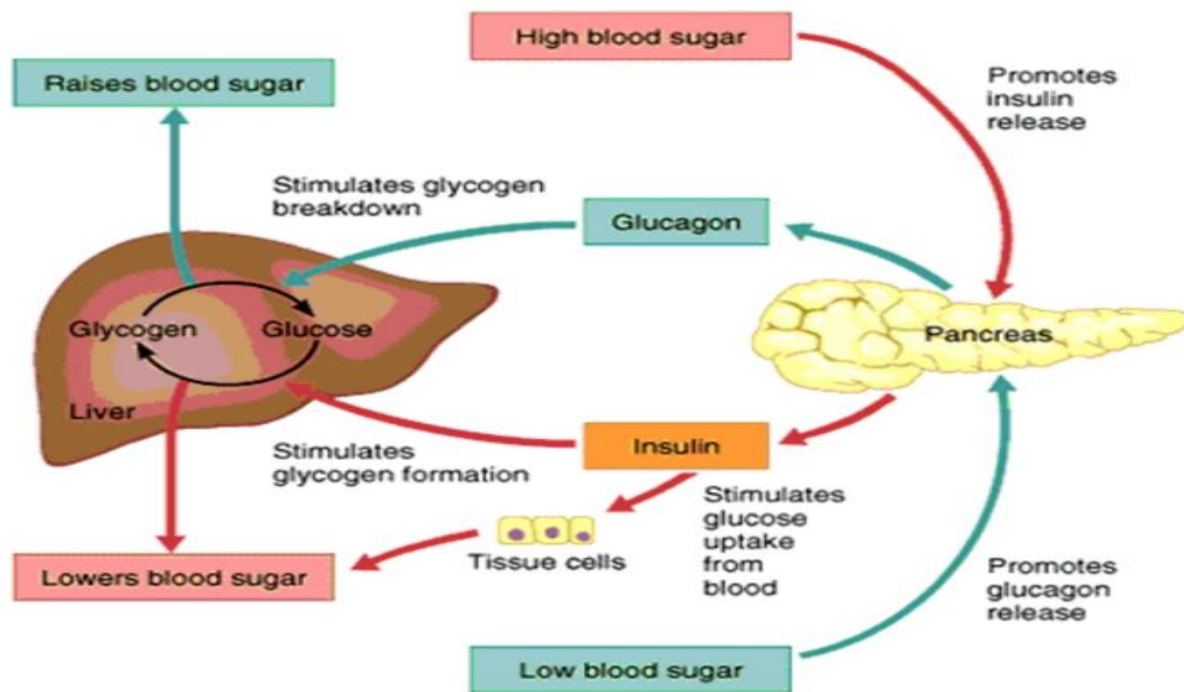
- **Glycogenolysis:** Glycogenolysis is the mechanism by which glucagon promotes the breakdown of glycogen into glucose. The liver is where this mostly happens. Blood sugar levels rise as a result of the released glucose being subsequently released into the circulation.
- **Gluconeogenesis:** It is a process by which non-carbohydrate sources such as glycerol and amino acids are converted into glucose and it is stimulated by glucagon. The liver is where this process mostly takes place.
- **Lipolysis:** Glucagon promotes lipolysis, which releases fatty acids into the bloodstream by breaking down triglycerides, or stored fat, in adipose tissue. When glucose supply is restricted, these fatty acids can be used as a substitute energy source.

By stimulating the production and release of glucose, glucagon helps raise blood sugar levels to ensure an adequate supply of energy to the body.

Glucose homeostasis, which refers to the stable blood sugar levels maintained by the combined effect of both hormones—insulin and glucagon. Insulin is released to aid in the absorption and utilization of glucose, lowering blood sugar levels when blood glucose levels rise after a meal. However, when blood glucose levels fall, as they may during a fast or in between meals, glucagon is released to promote glycogenolysis and gluconeogenesis, which causes glucose to be released into the

bloodstream and raise blood sugar levels.

This careful equilibrium between glucagon and insulin ensures that glucose is efficiently utilized or stored. Disruptions in the hormonal regulation of blood sugar levels can lead to conditions like diabetes mellitus, characterized by impaired insulin function or insulin production, resulting in elevated blood glucose levels.



Figures 2.8: Hormonal Regulation of Blood Sugar Levels

(Source: Ankur Choudhary, 16 Apr 20204 from Pharmaguideline.com)

2.11 GLYCEMIC INDEX (GI)

The rate and degree to which a carbohydrate-containing item rises blood glucose levels after intake in comparison to a reference food—typically white bread or pure glucose—is measured by the glycemic index, or GI. The GI is a numerical scale that goes from 0 to 100; higher numbers mean that blood glucose levels will rise more quickly.

The glycemic index (GI) of different foods can vary widely. Here is a list of common foods and their approximate glycemic index values:

Low-GI Foods (GI value of 55 or less):

- Legumes (e.g., lentils, chickpeas, kidney beans): GI ranges from 10 to 35.
- Non-starchy vegetables (e.g., broccoli, spinach, peppers): GI ranges from 0 to 15.
- Whole grains (e.g., oats, quinoa, brown rice): GI ranges from 40 to 55.
- Nuts and seeds (e.g., almonds, walnuts, chia seeds): GI ranges from 0 to 20.
- Berries (e.g., strawberries, blueberries, raspberries): GI ranges from 25 to 40.
- Dairy products (e.g., yogurt, milk): GI ranges from 20 to 40.

Medium-GI Foods (GI value between 56 and 69):

- Whole wheat products (e.g., whole wheat bread, pasta): GI ranges from 55 to 69.
- Basmati rice: GI ranges from 50 to 58.
- Sweet potatoes: GI ranges from 50 to 70.
- Fruit (e.g., oranges, apples, pears): GI ranges from 40 to 60.

High-GI Foods (GI value of 70 or higher):

- White bread: GI ranges from 70 to 85.
- White rice: GI ranges from 70 to 87.
- Cornflakes: GI ranges from 70 to 85.
- Potatoes (white): GI ranges from 70 to 100.
- Watermelon: GI ranges from 70 to 80.

	Low	Medium	High
Glycaemic Index	55 or less	59-69	70 or higher
Glycaemic Load	10 or less	11-19	20 or higher

Figure 2.9: Indices of Glycaemic Index and Glycaemic Load

Notably, GI values can vary depending on factors such as stage of ripeness, processing methods, and individual variations. Additionally, the glycemic response to a food can be influenced by other factors such as portion size, food combinations, and individual metabolic differences.

Further, it's also important to view the overall nutritional quality of the food. Foods that have a high GI may still provide important nutrients and can be balanced with other foods to manage blood glucose levels.

Next, move to understand the physiological effects of the glycemic index which, summarized as follows:

Blood Glucose Response: Blood glucose levels rise quickly after consuming foods with a high glycemic index (GI). This causes the pancreas to release the hormone insulin, which aids in transferring glucose from the bloodstream into cells for storage or energy consumption. Foods with a high GI might cause blood glucose levels to surge sharply and then drop quickly, which can make you feel hungry and make you want more food.

Conversely, foods with a low glycemic index cause blood glucose levels to rise more slowly and gradually. As a result, glucose is released into the bloodstream more steadily and continuously, offering a longer-lasting and more balanced energy source. Hence, people with diabetes can better control their blood glucose levels by choosing low-GI foods because they cause a more controlled and slow release of glucose into the system.

- **Insulin Response:** The glycemic index of a food is closely related to the insulin response it elicits. High-GI foods cause a rapid release of insulin to help regulate the elevated blood glucose levels. This can lead to increased insulin secretion and potentially contribute to insulin resistance over time. In contrast, low-GI foods result in a more moderate and gradual release of insulin.
- **Satiety and Weight Management:** Foods with a low glycemic index tend to provide a greater feeling of satiety and fullness compared to high-GI foods. The slower and more sustained release of glucose from low-GI foods can help regulate appetite and prevent overeating. Including low-GI foods in the diet may contribute to better weight management and help prevent obesity.
- **Performance and Exercise:** The glycemic index can also have implications for athletic performance and exercise. Consuming high-GI carbohydrates before or during intense exercise can provide a quick source of energy and aid in performance. However, for activities of longer

duration or endurance exercises, low-GI carbohydrates may be more beneficial as they provide a sustained release of energy.

Hopefully, you understood that glycemic index of food help in managing blood glucose levels and overall nutrition. It is advisable to take low glycemic index by diabetes to maintain blood glucose level. Next, it is important to explore about Sweetener.

2.12 SWEETENERS

We all know sweeteners are simple carbohydrate and have impact on blood sugar levels. Sweeteners are can be natural or artificial and have effect on the glycemic index. Understanding of these can provide valuable insights into how they influence insulin response and overall blood sugar control.

Many people with conditions like diabetes use artificial sweeteners to help manage their blood sugar levels. By studying the effects of these sweeteners, we can determine whether they offer a safer alternative to regular sugar, especially for those who need to limit their sugar intake. Some artificial sweeteners have a low or zero glycemic index, which means they do not cause spikes in blood glucose, making them a potential tool for blood sugar management. However, it's also important to study the long-term effects of these sweeteners, as their impact on metabolism, insulin sensitivity, and gut health may not be fully understood. Additionally, the study of artificial sweeteners provides insights into the broader relationship between diet, blood sugar regulation, and health, enabling individuals to make more informed choices about sweeteners based on their glycemic response.

Types of Sweeteners:

1. **Natural Sweeteners:** Natural sweeteners are compounds used to sweeten food and drinks; these compounds derived from fruits, plants, or other natural sources. They are often considered healthier alternatives to refined sugar or artificial sweeteners due to their more natural origins and sometimes lower glycemic index. Some common types of natural sweeteners include fruits (such as apples, bananas, and berries), honey, maple syrup, stevia and certain vegetables like carrots and beets. Natural sweeteners provide sweetness along with other nutrients and phytochemicals found in these foods.

Beyond this, there is another group of low-calorie sweeteners that are chemically similar to both sugars and alcohols but do not contain ethanol, the type of alcohol found in alcoholic beverages, known as **Sugar alcohols**. They are derived from naturally occurring sugars in fruits and vegetables or synthesized through industrial processes. Common sugar alcohols include **sorbitol**, **xylitol**, **erythritol**, and **mannitol**. These sweeteners provide fewer calories than regular sugar because they are only partially absorbed by the body, resulting in a lower impact on blood sugar levels. As a result, sugar alcohols are often used in sugar-free or reduced-calorie products, such as candies, chewing gum, and baked goods. They also have the added benefit of not contributing to tooth decay, unlike traditional sugars. However, consuming large quantities of sugar alcohols can lead to digestive issues such as bloating, gas, and diarrhea, as they are fermented by bacteria in the gut. Despite these potential side effects, sugar alcohols remain a popular choice for people managing their calorie intake or blood sugar levels.

2. **Artificial Sweeteners:** They are the synthetic chemical substances which provide sweetness without the calories or metabolic impact of sugar. They are often used as sugar substitutes in various food products at home or in food industry. Common artificial sweeteners includes aspartame, sucralose, saccharin, and acesulfame potassium. These substances are intensely sweet, often many times sweeter than sugar, and provide a sweet taste without the associated rise in blood sugar levels.

Artificial sweeteners are synthetic substances that provide a sweet taste without the calories or metabolic impact of sugar. They are commonly used as sugar substitutes in various food and beverage products. Here are some of the most common types of artificial sweeteners:

- i. *Aspartame:* It has very few calorie and considered safe for general population, making it popular. It is approximately 200 times sweeter than sugar. Aspartame is often found in diet soft drink, sugar-free chewing gum, and various low-calorie or sugar-free products. It breaks down when heated, so it is not suitable for baking or cooking at high temperatures.
- ii. *Sucralose:* It is much sweeter than sugar; approximately 600 times sweeter than sugar. Since sucralose is not metabolized by the body, it has little to no effect on blood sugar levels, making it a popular choice for people with diabetes. It is considered safe for consumption by the general population. Additionally, heat-stable, making it suitable for use in cooking and baking without

losing its sweetness. It is often found in diet sodas, tabletop sweeteners, and processed foods marketed as "sugar-free" or "no sugar added."

- iii. *Saccharin*: It has been in use for over a century and is one of the oldest artificial sweeteners. It is intensely sweet and can be up to 700 times sweeter than sugar. Saccharin is heat-stable and is commonly used in tabletop sweeteners, diet sodas, and various processed foods. It has a slightly bitter aftertaste, which can be masked when combined with other sweeteners.
- iv. *Acesulfame Potassium (Ace-K)*: It is also heat stable, safe and not metabolized by body; making it suitable for widely use. It is known as Ace-K. It is intensely sweet, so only a small amount is needed to replace sugar in recipes or products. It is often used in combination with other sweeteners to enhance sweetness.
- v. *Neotame*: is chemically related to aspartame but with a modification that makes it more stable and much sweeter. Neotame's extreme sweetness allows it to replace sugar with only a tiny amount, making it ideal for low-calorie and "sugar-free" products. It is also heat-stable and safe.
- vi. *Advantame*: is one of the sweetest artificial sweeteners available, approximately **20,000 times sweeter than sucrose** (table sugar). It is also a derivative of aspartame. Advantame can be used in a wide range of food and beverage applications since it is heat-stable. It is often found in baked goods, frozen desserts, and beverages.

Some artificial sweeteners may have an aftertaste or flavor profile that differs from sugar. They can also have different levels of sweetness and may require smaller amounts to achieve the desired level of sweetness compared to sugar. It is recommended to consume them in moderation as part of a balanced diet.

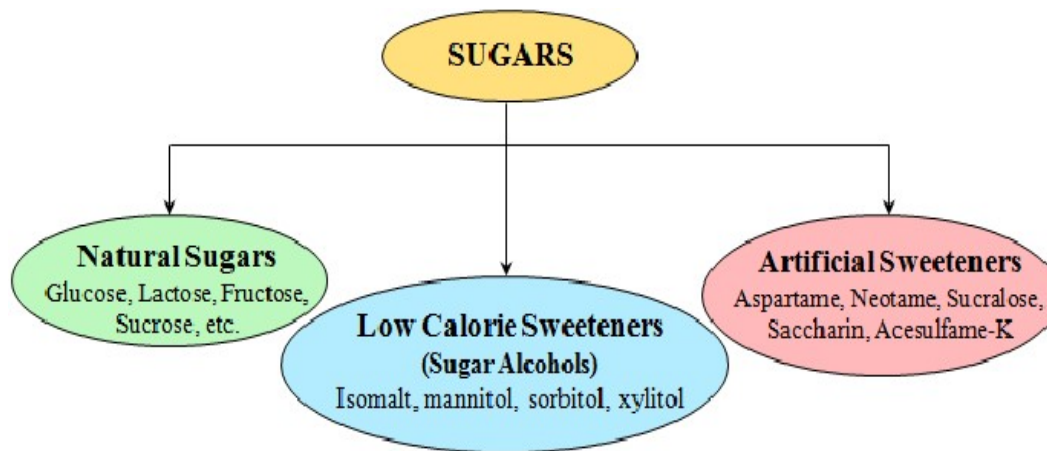


Figure 2.10: Types of Sweetners (Source: Yadav *et al.*,2014)

Notably, perception of sweetness can vary among individuals due to genetic factors, cultural influences, and personal preferences. Additionally, the type and intensity of sweetness can be influenced by factors such as temperature, pH level, and the presence of other flavors in a food or beverage.

CHECK YOUR PROGRESS EXERCISE 2

Q1. How does **insulin** help lower blood sugar levels in the body?

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Q2. What is glycemic index of food ? Give some examples of **low-GI foods** suitable for diabetic patients?

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Q 3. What are sweeteners? What are the types of sweeteners?

2.14 LET US SUM UP

In this unit, we learn about different types carbohydrate, which categorized into **monosaccharides** (single sugars), **disaccharides** (two sugar units e), and **polysaccharides** (complex sugars). their sources and functions. Each type plays a unique role, from immediate energy provision to maintaining overall metabolic health and supporting essential physiological functions. We then gain the concept of dietary fiber, a type of carbohydrate, is further divided into **soluble** and **insoluble fiber**, both essential for maintaining digestive health. The unit also highlights **resistant starch** and **oligosaccharides**, which promote gut health by supporting beneficial bacteria. Further, we learn the process of digestion which begins in the mouth, continues in the small intestine, and then, it absorbed into the bloodstream as glucose. This process is regulated by hormones like **insulin** and **glucagon** that maintain blood sugar levels. Then, we gain the concept of **glycemic index (GI)**, which measures how foods impact blood sugar levels, with low-GI foods being better for blood sugar control. Lastly, **sweeteners**, both natural and artificial, are used as alternatives to sugar, offering different benefits for health-conscious individuals or those managing conditions like diabetes.

2.14 GLOSSARY

1. Carbohydrates:	Compounds consisting of carbon, hydrogen, and oxygen.
2. Saccharides:	Sugars and starches.
3. Glycans:	Polysaccharides or carbohydrates.
4. Glucose (Glu):	Simple sugar, blood sugar.

5. Fructose (Fru):	Simple sugar, fruit sugar.
6. Galactose (Gal):	Simple sugar, component of lactose.
7. Ribose:	Pentose sugar, RNA component.
8. Xylose:	Pentose sugar.
9. Sucrose (Suc):	Table sugar, glucose + fructose.
10. Lactose (Lac):	Milk sugar, glucose + galactose.
11. Maltose (Mal):	Malt sugar, glucose + glucose.
12. Isomaltose:	Disaccharide, glucose + glucose.
13. Starch:	Plant energy storage, amylose + amylopectin.
14. Glycogen:	Animal energy storage.
15. Cellulose:	Plant cell wall component.
16. Dietary Fiber:	Indigestible carbohydrates.
17. Soluble Fiber:	Dissolves in water (e.g., oat bran).
18. Insoluble Fiber:	Doesn't dissolve in water (e.g., cellulose).
19. Glycemic Index (GI):	Measures carbohydrate impact on blood sugar.
20. Glycemic Load (GL):	Measures carbohydrate amount and GI.
21. Oligosaccharides:	Short-chain polysaccharides.

2.15 ANSWER TO CHECK YOUR PROGRESS

EXERCISE 1

A 1. Carbohydrates are one of the three primary macronutrients (along with proteins and fats) that provide energy to the body. They are classified into three main types based on their structure and function:

- **Monosaccharides** (Simple Sugars):The most basic units of carbohydrates, including glucose, fructose, and galactose. Example-Found in fruits, honey, and dairy.
- **Disaccharides**:Formed by two monosaccharides linked together, such as sucrose (table sugar), lactose (milk sugar), and maltose (found in malted foods).
- **Polysaccharides** (Complex Carbohydrates):Made up of long chains of sugar molecules.Examples- Includes starch (found in grains, potatoes) and fiber (indigestible, found in fruits, vegetables, and whole grains).

A 2. **Resistant starch** is a type of starch that is not fully digested or absorbed in the small intestine. Instead, it passes into the colon where it acts more like dietary fiber and serves as a food source for beneficial gut bacteria.Resistant starch is fermented by gut bacteria in the colon, producing short-chain fatty acids such as butyrate, which play a crucial role in maintaining colon health and reducing inflammation. By adding bulk to the stool, resistant starch helps improve digestive regularity and prevent constipation. These combined effects make resistant starch a valuable component of a balanced diet for promoting optimal digestive health.

A.3 Dietary fiber refers to the parts of plant foods that the body cannot digest or absorb. Unlike other food components like fats, proteins, or carbohydrates, fiber passes through the digestive system mostly intact, providing several important health benefits such as improved digestion, blood sugar regulation, and heart health.On average, **25–30 grams per day fiber is required for adult.**

Sources of Dietary Fiber:Oats, apples, citrus fruits, legume are source of **soluble fiber**. Whole grains, vegetables, nuts, seeds are source of **Insoluble Fiber**.

A. 4 **Oligosaccharides**are carbohydrates made of 3–10 sugar molecules. They are partially digestible and often act as prebiotics, supporting gut health.

Examples:

- **Fructooligosaccharides (FOS):** In onions and bananas.
- **Galactooligosaccharides (GOS):** In legumes and dairy.
- **Raffinose and Stachyose:** In beans and lentils.

A 5. **The difference between amylose and amylopectin.:**

Feature	Amylose	Amylopectin
Structure	Linear, unbranched chain of glucose units	Branched chain of glucose units
Solubility	Less soluble in water	More soluble in water
Digestibility	Digested more slowly, contributing to resistant starch	Digested more quickly
Gel Formation	Forms a firm gel upon cooling	Forms a less firm or no gel
Occurrence	Found in smaller proportion in starch (20–30%)	Found in larger proportion in starch (70–80%)

EXERCISE 2

A 1. Insulin plays a central role in **maintaining blood glucose homeostasis** by promoting glucose uptake into cells, stimulating glycogen storage, inhibiting glucose production in the liver, and promoting fat and protein storage. It also inhibits the liver from producing and releasing more glucose into the bloodstream. This combined action reduces blood glucose levels, helping to maintain normal blood sugar balance in the body.

A 2. The **glycemic index (GI)** of food measures how quickly a particular food raises blood sugar levels after being consumed. Foods with low GI result in a slower, more gradual increase; therefore better control blood sugar levels in **diabetic patients**. Some examples of low-GI foods include: **Whole grains** (Barley, quinoa, oats) **Legumes** (Lentils, chickpeas, kidney beans), whole fruits (pears, apple), and **non-starchy vegetables** (leafy greens, tomatoes, cucumbers).

A 3. **Sweeteners** are substances used to add sweetness to food and beverages, often as an alternative to sugar. They can be natural or artificial and are typically used to reduce calorie intake or for people with conditions like diabetes, as they don't cause significant increases in blood sugar levels.

Types of Sweeteners:

1. **Natural Sweeteners:**Honey, Stevia, Agave Nectar, Maple Syrup: Plant-based or naturally occurring sugars with varying calorie content.
2. **Artificial Sweeteners:**Aspartame, Sucralose, Saccharin, Acesulfame K: Synthetic, low-calorie sweeteners used in sugar-free products.
3. **Sugar Alcohols:**Xylitol, Erythritol, Sorbitol: Lower-calorie sweeteners that don't spike blood sugar, but can cause digestive issues in excess.

UNIT 3: PROTEIN

STRUCTURE

- 3.1 Introduction
- 3.2 Chemical Composition
- 3.3 Protein Structure
- 3.4 Types of Proteins
- 3.5 Protein Function
- 3.5 Digestion of Protein
- 3.6 Absorption and Utilization
- 3.7 Protein Metabolism
- 3.8 Regulation in Protein Metabolism
- 3.9 Protein Quality
- 3.10 Recommended Dietary Allowance (RDA) for protein
- 3.11 Protein Sources
- 3.12 Protein Requirements.
- 3.13 Therapeutic applications of specific amino
- 3.14 Glossary
- 3.15 Answer To Check Your Progress

3.1 INTRODUCTION

Have you ever wondered why nutritionists and health experts emphasize protein so much? Is it just for bodybuilders, or does it matter for everyone? Let's explore these questions together and understand why protein intake—and knowing where to get it from—is crucial for your health.

Think about what your body does every day—healing wounds, growing, digesting food, and fighting off infections. Did you know protein is the key player in all these processes? It is important to know that protein is the primary building block of muscles, skin, hair, nails, and other tissues and plays a critical role in repairing tissues, especially after injury or exercise. It is essential for the growth and development of individuals. In addition, protein plays important role in providing energy, transport oxygen, maintaining immunity and fluid balance. Without enough protein, you'd feel weak, and your body wouldn't function as it should.

Here's a question: how much protein do you think you need every day? Many people don't know the answer, yet it's vital for your health. The recommended daily requirement of protein is about 0.8 grams /Kg BW. That means if you weigh 60 kg, you'd need about 48 grams daily. However, this isn't a one-size-fits-all number. If you're pregnant, active, or recovering from an illness, you might need more. Understanding your personal protein needs helps you avoid two extremes—deficiency, which can cause fatigue and muscle loss, and excess, which may strain your kidneys.

After knowing your dietary requirement, next question from where you get protein. Proteins can be derived from both animal and plant sources; Some plant proteins may lack one or more essential amino acids, but combinations (e.g., rice and beans) can provide complete protein profiles. For example, choosing a mix of lean chicken, chickpeas, and seeds ensures you're not just hitting your protein goals but also getting a variety of nutrients. The more you learn about protein and its sources, the easier it is to balance your meals and feel energized. Proteins are indispensable for maintaining health and supporting bodily functions. Balancing protein intake from diverse sources, while considering individual needs and health conditions, is essential.

In this comprehensive overview, we discuss the types, source, structural characteristics of protein and their various functions within biological systems.

Expected Outcomes

The students will be able to:

- describe different protein and their structure and function
- Understand the process of digestion and absorption of protein
- explain the concept of protein turnover and protein quality

- Explain the importance of each amino acids

3.2 CHEMICAL COMPOSITION

Proteins are one of the three macro-molecules made up of 20 standard amino acids linked together in a specific order, which are linked together by peptide bonds to form polypeptide chains.

Each amino acid is made up of four groups: a hydrogen atom, an amino group (-NH₂), a carboxyl group (-COOH), a variable side chain, or R group, and a core carbon atom (the alpha carbon) as shown in figure 3.1. Each of the 20 amino acids has distinct chemical characteristics due to differences in their R groups. Some amino acids contain additional functional groups, such as sulfur-containing groups in cysteine and methionine, which contribute to protein structure and function.

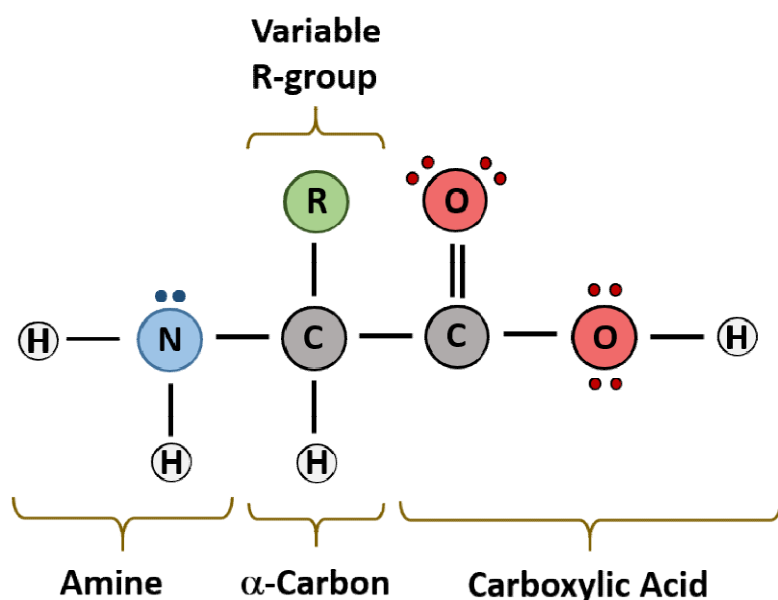


Figure 3.1: General Structure of Alpha Amino Acid

(Source:Retrieved from <https://wou.edu/Chapter 2>)

3.3 PROTEIN STRUCTURE

Understanding protein structure is crucial because a protein's shape determines its function, stability, and biological function. Their functionality is determined by their unique structures, which are organized into four levels: **primary**, **secondary**, **tertiary**, and **quaternary** structures. Let's delve into each level of protein structure to understand its significance.

1. Primary Structure

Linear sequence of amino acids joined by peptide bonds forms primary structure of protein. During formation of sequence, the carboxyl group (-COOH) of one amino acid combines with the amino group (-NH₂) of the next amino acid with release of a molecule of water as shown in figure 3.2. The primary structure has a specific direction: it starts with the **N-terminus** (free amino group) and ends with the **C-terminus** (free carboxyl group). This directionality is important for protein synthesis and function. Little modifications in primary structure significantly affect functionality. For example, hemoglobin's structure and function are changed in sickle cell anemia when valine is substituted for glutamic acid.

2. Secondary Structure

Chain of polypeptide strands repeatedly coiled or folded patterns that results secondary structure. The coiled structure are held by hydrogen bonding formed between amino acid residues within the polypeptide chain; which may be alpha helices or beta sheets. In an alpha helix, the polypeptide chain twists into a helical structure like a spring and stabilized by hydrogen bonds between the amino and carboxyl groups of neighboring amino acids. The α -helix provides structural support in fibrous proteins like keratin, found in hair, nails, and skin. The α -helix can stretch and recoil, providing both flexibility and resilience to proteins like myosin (in muscles). In beta sheets, the strands of polypeptide chain are running side by side and are held together by hydrogen bonds between adjacent strands. In beta sheets, the strands of the polypeptide chain run side by side and forming a sheet-like structure. It is stabilized by **hydrogen bonds** formed between the backbone atoms of adjacent polypeptide strands.

Strands run in the same direction (parallel) or opposite direction (antiparallel). Hydrogen bonds are slightly skewed, making them less stable than antiparallel arrangement. Beta sheets are commonly found in both fibrous proteins, where they provide structural strength and flexibility (e.g., silk fibroin), and globular proteins, where they contribute to the compact folding and functionality of the protein.

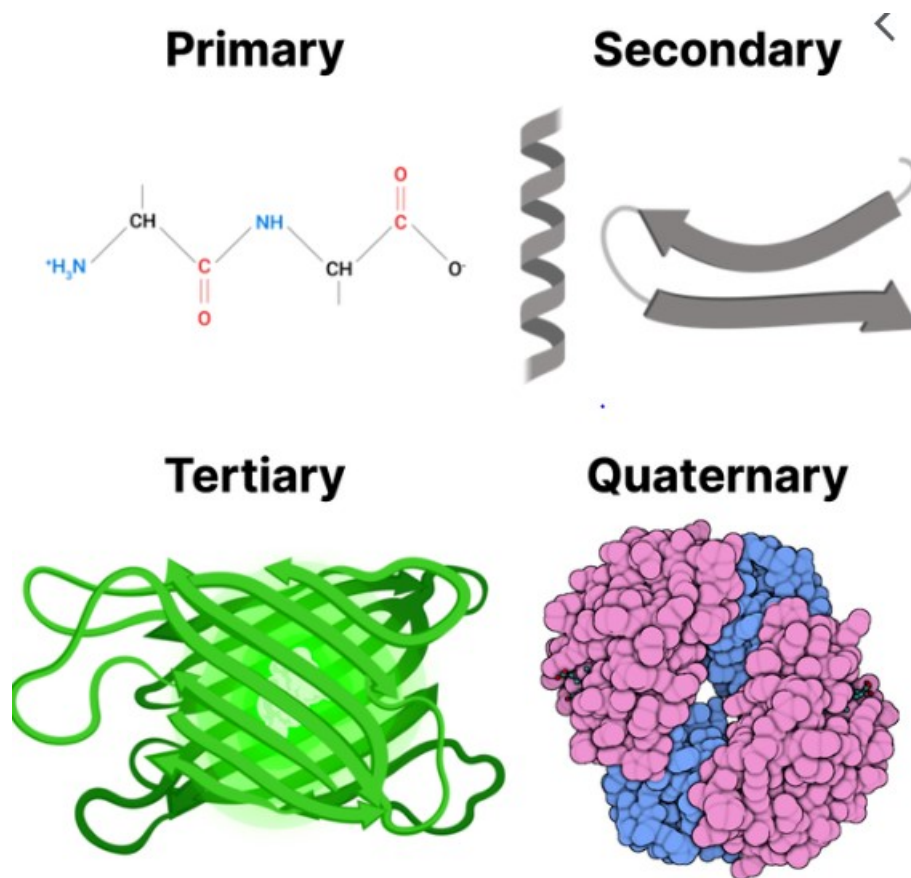
3. Tertiary Structure

Complex folding of polypeptide structure into three-dimensional (3D) shape results tertiary structure. It is stabilized by hydrogen bonds, hydrophobic interactions, ionic bond, van der Waals forces, and disulfide bonds. It determines the biological and functional properties of protein. Tertiary structures are not rigid; proteins can undergo conformational changes in response to environmental conditions or binding events. Various factors such as temperature, pH, and the presence of certain chemicals can affect the stability of the tertiary structure of a protein. If the tertiary structure is disrupted or altered, the protein may lose its function, a phenomenon known as denaturation.

4. Quaternary Structure

The quaternary structure represents the highest level of protein organization. This structure is the result of interactions between various protein subunits, which may stabilize by non-covalent bonds like hydrogen bonds, ionic bonds, van der Waals interactions, and hydrophobic interactions. The quaternary structure adds an additional layer of complexity and functionality to protein.

Overall, the hierarchical organization of protein structure is critical for determining its biological function, specificity, and interactions with other molecules in the cell. Each level of structure contributes to the overall stability and activity of the protein, allowing it to perform its specific roles within living organisms.



Figures: 3.1 Protein Structure

(Source:Anthony Agbay, 2021 by Creative Commons Attribution- 4.0)

3.4 CLASSIFICATION OF PROTEINS

Proteins are complex molecules made up of amino acids. They perform various functions in the body, including structural support, enzyme activity, immune defense, and transport. Based on their structure, function, and composition, proteins can be classified into several categories as depicted in figure 3.2.

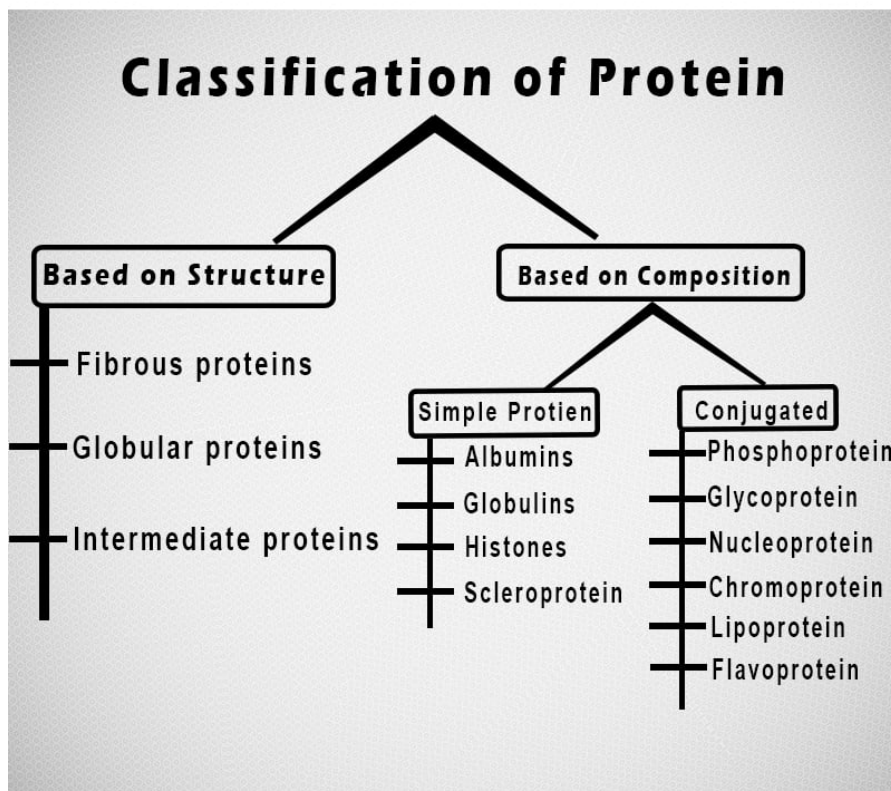


Figure 3.2 : Classification of Protein

1. Based on Composition:

1. **Simple Proteins:** These proteins are made up only of amino acids. When they are hydrolyzed (broken down), they yield only amino acids.

Examples: **Albumins** (found in egg whites, blood plasma), **Globulins** (found in antibodies, blood), **Histones** (proteins that help package DNA in the nucleus)

Conjugated Proteins: These proteins consist of a protein part (called the **apoprotein**) and a non-protein part (called the **prosthetic group**). The non-protein part can be a metal ion, carbohydrate, lipid, or nucleic acid. This non-protein component is covalently bonded to the protein and is essential for the protein's biological function.

Types of Conjugated Proteins:

Glycoproteins: These are proteins that have carbohydrate molecules attached to them. The carbohydrate portion can play a role in the protein's function, such as in cell recognition, immune response, or as a receptor for hormones or other molecules.

Example: Antibodies (Immunoglobulins): These glycoproteins are crucial for immune defense as they bind to antigens.

Lipoproteins: These proteins are bound to lipid molecules. Lipoproteins help in the transport of lipids (like cholesterol and triglycerides) in the bloodstream. The lipid component is hydrophobic, while the protein part allows the complex to be soluble in water, facilitating its transport. **Example: HDL (High-Density Lipoprotein) and LDL (Low-Density Lipoprotein):** These transport cholesterol in the body.

Nucleoproteins: These proteins are bound to nucleic acids (DNA or RNA). Nucleoproteins are involved in processes such as the synthesis and regulation of nucleic acids. **Example:**

Ribosomes: These consist of ribosomal RNA (rRNA) and proteins, and are essential for protein synthesis in cells.

Metalloproteins: Metalloproteins are proteins that contain metal ions as their prosthetic group. The metal ions can play a critical role in the protein's structure and function, particularly in enzyme catalysis or electron transport. **Example: Hemoglobin:** Contains iron (Fe) and is responsible for transporting oxygen in the blood.

11. **Derived Proteins:** These proteins are products of the breakdown or modification of simple or conjugated proteins. **Examples: Peptides** (short chains of amino acids), **Proteases** (enzymes that break down proteins).

3. **Based on Structure:** Proteins can be classified based on their structure into **two main types: Fibrous proteins** and **Globular proteins**. Each of these types has unique characteristics that relate to their functions in the body.

1. Fibrous Proteins:

- **Structure:** Fibrous proteins have long, linear, and elongated structures. They often form insoluble and tough fibers that provide structural support.
- **Solubility:** They are typically insoluble in water.
- **Function:** These proteins provide structural support, strength, and protection to cells, tissues, and organs.
- **Examples:**
 - **Collagen:** Found in connective tissues like tendons, skin, and cartilage, providing strength and elasticity.
 - **Keratin:** Found in hair, nails, and skin, contributing to their strength and protection.
 - **Elastin:** Found in elastic tissues like the lungs, blood vessels, and skin, providing elasticity.
 - **Fibroin:** Found in silk, providing strength and flexibility.

2. Globular Proteins:

- **Structure:** Globular proteins have a compact, spherical, or rounded structure, where the polypeptide chains are folded into a globular shape. This structure is more complex compared to fibrous proteins.
- **Solubility:** They are generally soluble in water and have a functional, active form.
- **Function:** Globular proteins are involved in a wide variety of biological processes, including catalysis, transport, and regulation.
- **Examples:**
 - **Enzymes:** Such as **amylase**, which catalyzes the breakdown of starches.
 - **Hemoglobin:** Found in red blood cells, it binds and transports oxygen throughout the body.
 - **Insulin:** A hormone that regulates blood sugar levels.
 - **Antibodies:** Involved in the immune response to fight infections.

Key Differences:

- **Fibrous proteins** are more structural, while **globular proteins** perform a wide range of biological functions, including catalysis (enzymes), transport, and regulation.
- **Fibrous proteins** are generally insoluble, whereas **globular proteins** are soluble in water.

3. Based on Function:

1. Structural Proteins

Structural proteins are the class of proteins that provide cells and tissues their strength, support, and shape. These proteins form the framework of biological structures and often exhibit high tensile strength and stability. Their unique physical properties make them essential for maintaining the integrity and organization of various biological systems.

Here are some key characteristics of structural proteins:

- Most structural proteins are fibrous, with elongated shapes that allow them to form strong, supportive fibers.
- Structural proteins are resistant to denaturation due to their robust primary and secondary structures.
- These proteins provide mechanical support, facilitate movement, and protect cells and tissues from physical stresses.

. Let's delve into some common examples of structural proteins include:

- **Collagen:** It is composed of a unique triple helix structure of polypeptide chains, giving it remarkable elasticity, tensile strength, and stability. Commonly found in connective tissues such as tendons, ligaments, and skin.
- **Keratin:** Keratin is a fibrous structural protein that gives tissues and epithelial cells resilience, strength, and protection. It is necessary for the longevity and defense of external body structures because it is an important part of hair, nails, skin, feathers, horns, and hooves. There are two types of keratin: beta-keratin, which is found in birds and reptiles, and alpha-keratin, which is found in mammals.

- **Actin and Myosin:** Actin filaments are a key component of the cytoskeleton, providing mechanical support and anchoring organelles within the cell. These filaments interact with other proteins, such as myosin, to drive cellular processes like muscle contraction, cell migration, and cytokinesis during cell division.

2. **Enzymes**

Enzyme facilitates metabolic processes by increasing the rate of specific reactions. Many enzymes that catalyze chemical reactions in cells are proteins in nature. Examples include:

- **Amylase:** It breaks down starch into sugars in the digestive system.
- **DNA polymerase:** It is involved in DNA replication during cell division.
- **Lipase:** It breaks down fats into fatty acids and glycerol.

3. **Transport Proteins**

Transport proteins are specialized proteins that facilitate the movement of molecules across cellular membranes or within the body. They regulate the passage of ions, nutrients, gases, and other essential substances across cells. For Examples: **hemoglobin**, which transports oxygen in the blood, and **albumin**, which carries fatty acids and hormones.

4. **Antibodies**

Antibodies are protein, that have central role in the immune system and their primary function is to recognize and neutralize foreign invaders, such as bacteria, viruses, and toxins, by binding to specific antigens. This binding helps the immune system identify and eliminate harmful substances, protecting the body from infections and disease.

5. **Hormones**

Many hormones are protein in nature, they are chemical messengers secreted directly into the bloodstream or extracellular fluid, and act on target organs or tissues for specific responses. Hormones play critical roles in maintaining homeostasis, coordinating growth, metabolism, reproduction, and the body's response to environmental stimuli.

6. Receptor Proteins

Receptor proteins are specialized proteins that regulate cell signaling by detecting specific molecules, or **ligands**, and triggering responses within the cell. Found either on the cell surface or inside the cell, these proteins act as communication hubs, allowing cells to perceive and respond to external and internal signals. Receptor proteins are highly specific, recognizing particular ligands such as hormones, neurotransmitters, growth factors, or nutrients.

7. Contractile Proteins

Contractile proteins are fundamental to movement and force generation in living organisms, with their precise interaction enabling processes ranging from muscle contraction to cell division. Understanding their mechanisms is crucial not only for studying physiology but also for addressing disorders caused by their dysfunction, paving the way for advancements in treatments for muscle and cell-movement-related diseases.. The examples of key contractile proteins include:

- Actin and Myosin: These proteins are essential for muscle contraction.
- Tubulin: It forms microtubules, which are involved in cell division and intracellular transport.

8. Storage Proteins

Storage proteins are specialized proteins that serve as reservoirs of essential nutrients, such as amino acids and minerals, for later use by the organism. These proteins are particularly important during periods of growth, development, or germination, providing the building blocks required for cellular processes. They are primarily found in seeds, eggs, and certain tissues, where they store energy and nutrients in a stable and compact form. Examples include: Ferritin (It stores iron in cells) and Casein (milk protein).

3.5 PROTEIN FUNCTION

Proteins are indispensable to life, contributing to nearly every biological process. Their versatility arises from the diversity of their structures and functions, enabling them to act as builders, catalysts, messengers, defenders, and regulators. Here are some of the key functions of proteins:

3. Proteins act as enzymes that accelerating chemical reactions in living organisms. This enzymatic function is critical for maintaining life processes includes metabolic pathways, DNA replication, protein synthesis, and cellular signaling.
4. Proteins provide mechanical support and maintain the structural integrity of cells, tissues, and organs. For example: collagen, keratin
5. It facilitate the movement of molecules, ions, and other substances across cell membranes or within the bloodstream. They play a vital role in nutrient uptake, waste removal, and the regulation of ion concentrations.
6. Many proteins act as receptors or participate in signaling pathways, allowing cells to detect and respond to external signals. These signaling proteins are involved in processes such as cell communication, growth and development, immune responses, and hormonal regulation.
7. Antibodies and other immune-related proteins play a critical role in defending the body against foreign invaders, such as bacteria, viruses, and toxins. They recognize and neutralize pathogens, activate immune responses, and contribute to immunological memory.
8. Contractile proteins enable muscle contraction, allowing for movement and locomotion. These proteins generate force and movement by interacting and sliding past each other.
9. Some proteins regulate gene expression by interacting with DNA and controlling the transcription of genes into messenger RNA.

In summary, proteins are highly diverse molecules with various types, structures, and functions. They play crucial roles in virtually every aspect of cellular and organismal function, including structural support, enzymatic catalysis, transport, signaling, defense, regulation, and storage. Understanding the types and functions of proteins is essential for comprehending the complexity and functionality of biological systems.

Let's take a moment to review the main concepts discussed.

3.5 DIGESTION OF PROTEIN

The digestion of proteins involves the break down of protein into their constituent amino acids by the enzymes present in the digestive system. Here's a simplified overview of how protein digestion occurs and illustrated in figure 3.3.

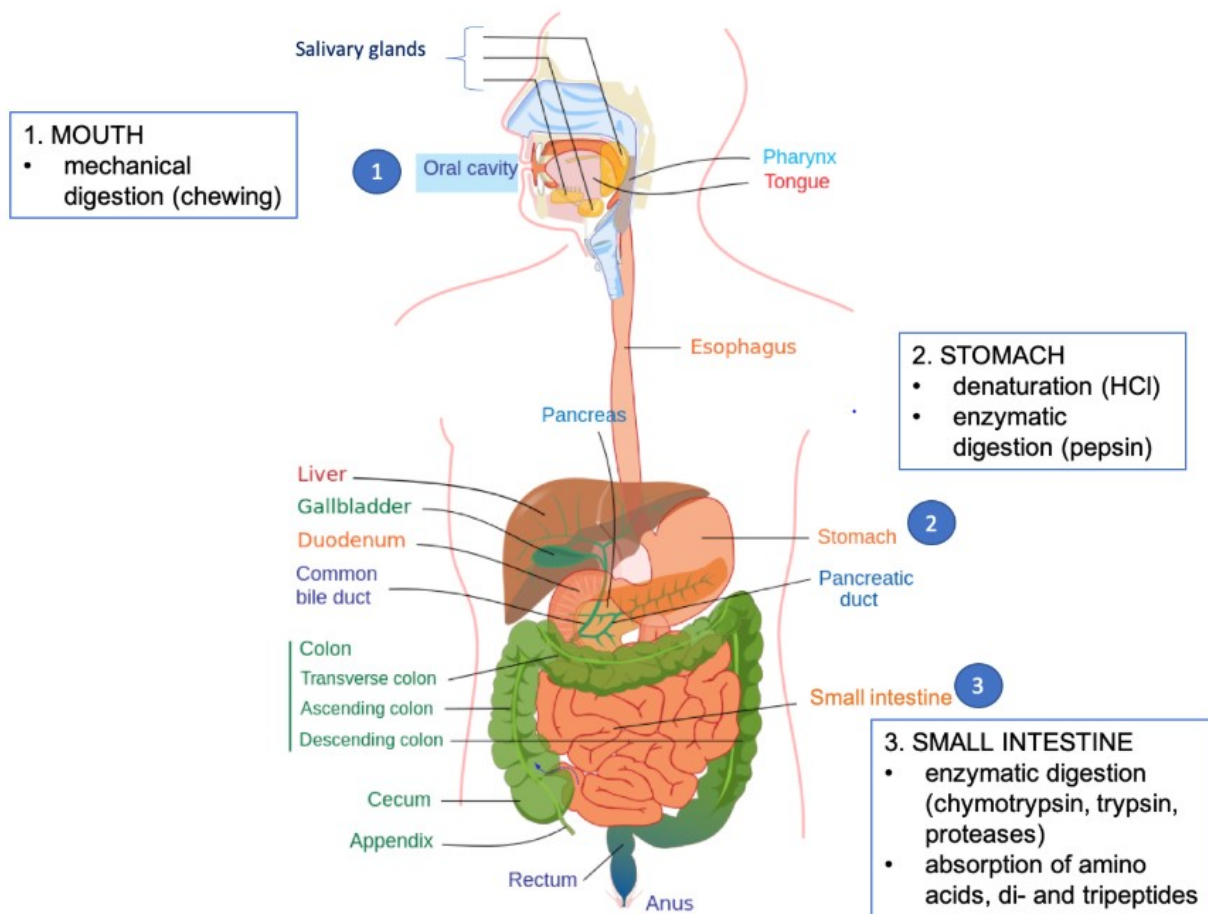


Figure 3.3: Digestion of Protein

(Source: Retrived from <https://openoregon.pressbooks.pub>)

Mouth: No enzymatic digestion of protein occurs in the mouth, as there are no enzymes in saliva specifically for protein breakdown. However, the teeth assist in the mechanical breakdown of large food particles into smaller pieces, increasing the surface area for digestion later in the digestive process.

Stomach: Protein digestion begins in the stomach, where it is broken down by the action of gastric juices, primarily hydrochloric acid (HCl) and an enzyme called pepsin. The stomach lining contains

gastric glands that secrete hydrochloric acid. HCl creates an acidic environment in the stomach, which is essential for activating the enzyme pepsin and denaturing proteins.

The stomach's acidity denatures dietary proteins, causing their three-dimensional structure to unfold and expose the polypeptide chain to the proteolytic enzyme pepsin in the acidic environment. The main cells of the stomach glands generate pepsin, a protease enzyme, in an inactive form known as pepsinogen. When HCl is released into the stomach, it converts pepsinogen into its active form, pepsin, through a process called proteolytic cleavage. Pepsin catalyzes the hydrolysis of peptide bonds between specific amino acid residues in the protein molecule and break down proteins into smaller peptide fragments. While some protein digestion occurs in the stomach, it is not complete. The resulting mixture of partially digested proteins, peptides, and other gastric contents is known as chyme.

Small Intestine: Partially digested proteins, along with other gastric contents, are released into the duodenum, the first segment of the small intestine. This triggers the release of secretin and cholecystokinin (CCK) hormones, which stimulate the pancreas to secrete pancreatic enzymes and bicarbonate ions into the duodenum. **Bicarbonate** from the pancreas, neutralizes the stomach acid, providing a more alkaline environment for digestive enzymes in the small intestine to function. .

Pancreatic enzymes, such as trypsin, chymotrypsin, and carboxypeptidase, further hydrolyze the peptides into smaller peptides, dipeptides, and amino acids. Enteropeptidase, an enzyme produced by the intestinal mucosa, activates trypsinogen to trypsin, which in turn activates other pancreatic proteases as shown in figure- The inner lining of the small intestine (called the brush border) contains enzymes (aminopeptidase & dipeptidase) that complete the breakdown of peptides into individual amino acids or small dipeptides.

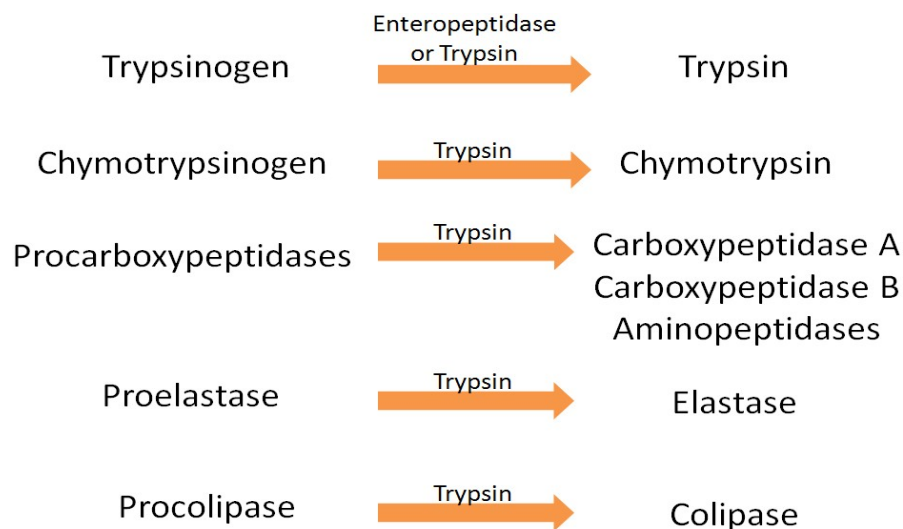


Figure 3.4: Enzymatic Digestion of Protein in Intestine

(Source: Retrived from Kansas State University Human Nutrition Flexbook. **Authored by:** Brian Lindshield)

In the small intestine, these peptidase enzymes play crucial roles in further breaking down larger polypeptides into smaller peptides and amino acids: aminopolypeptidase and dipeptidases. Aminopolypeptidase is an enzyme that acts on the remaining larger polypeptides in the chyme, splitting them into tripeptides and dipeptides. This enzyme specifically targets peptide bonds within polypeptide chains, cleaving them and forming smaller peptide fragments. Dipeptidases are enzymes that hydrolyze dipeptides, breaking them down into individual amino acids. They work on dipeptides, which are molecules composed of two amino acids linked by a peptide bond. By breaking dipeptides into individual amino acids, dipeptidases facilitate the final step in protein digestion before absorption.

Now, after gaining the understanding how the complex large molecules of protein breakdown into accessible, small molecules. Further, let's move to the concept to how the cell utilize these small molecules.

3.6 ABSORPTION AND UTILIZATION

Digestion allows proteins to be broken down into amino acids and small peptides, which are then absorbed and utilized by the body for a variety of essential functions, including protein synthesis, energy production, and cellular repair. In adults, the absorption of amino acids are predominantly occurs in the small intestine. They are transported across the intestinal wall into the bloodstream

through a process that involves specific transporters. Specialized transport proteins in the apical membrane of enterocytes facilitate the absorption of most amino acids directly from the intestinal lumen. This absorption process is mediated through either active transport or facilitated diffusion, depending on the specific amino acid and concentration gradient. Some small peptides are absorbed intact into the enterocytes by peptide transporters and are then broken down into amino acids within the cells.

Within the enterocyte, intracellular enzymes hydrolyze dipeptides and tripeptides into individual amino acids. These amino acids serve as essential building blocks for synthesizing various vital molecules, including proteins, enzymes, hormones, and neurotransmitters, as well as for repairing and maintaining tissues. Any excess amino acids are either metabolized in the liver or converted into glucose through gluconeogenesis, or stored as fat through lipogenesis for future energy needs.

CHECK YOUR PROGRESS EXERCISE 1

1. What is Protein and Give the classification.

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2. What are the main functions of Protein?

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3. Briefly discuss the process of protein digestion starting from the mouth to the small intestine.

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4. What is the difference between fibrous and globular proteins.

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3.7 PROTEIN METABOLISM

Protein metabolism encompasses the processes involved in the synthesis, breakdown, and utilization of proteins within the body. Proteins have specific lifespans and are degraded when they become damaged, misfolded, or are no longer needed by the cell. In living organisms, the process of protein turnover ensures that older proteins are constantly replaced by newer ones. This dynamic process involves the breakdown of proteins into their constituent amino acids (a process called proteolysis) and the subsequent synthesis of new proteins using these amino acids. It is a dynamic and tightly regulated system that is essential for various physiological functions. Enzymes such as proteases and cellular systems like the ubiquitin-proteasome pathway play a central role in this degradation process. The amino acids released are then recycled to synthesize new proteins, enabling the cell to adapt to changing physiological conditions, repair damage, and maintain cellular functions.

This continuous cycle of protein degradation and synthesis is essential for growth, development, immune response, and maintaining metabolic processes in living organisms. It also allows the body to respond efficiently to environmental changes and stressors. The balance between protein synthesis and breakdown within the body is referred to as Protein turnover. Protein turnover rates vary among different tissues and can be influenced by factors such as dietary protein intake, physical activity, and hormonal signals. It encompasses:

1. **Protein Synthesis:** It is a process in which cells use amino acids to synthesize new proteins as encoded in DNA. This process occurs primarily in the ribosomes, where the sequence of amino acid bonds to create a polypeptide chain is determined by messenger RNA (mRNA).

- Transamination is a key step in amino acid metabolism and is important for the maintenance of nitrogen balance in the body. It involves the transfer of an amino group $\text{(-NH}_2\text{)}$ from an amino acid to a keto acid (alpha-keto acid), forming a new amino acid and a new keto acid catalyzed by **aminotransferase** (transaminase) enzymes. The amino group is typically transferred to α -keto acids, which have a keto group at the alpha (α) carbon position. This reaction is reversible. It allows for the redistribution of nitrogen across different amino acids and generates non-essential amino acids needed for protein synthesis. It also plays a vital role in the synthesis of neurotransmitters, nucleotides, and other important molecules essential for various physiological processes.
- Transamination often precedes deamination, a process that removes excess amino groups, ensuring nitrogen excretion via urea formation.

2. Protein Breakdown (Catabolism)

Protein catabolism involves the breakdown of proteins into amino acids, which can then be used for energy production or other metabolic processes. The primary organs involved in protein breakdown are the liver and muscles. In conditions of fasting or low dietary protein intake, muscle proteins may be broken down to release amino acids into the bloodstream. Amino acids released from protein breakdown can be oxidized for energy production through various metabolic pathways, such as the citric acid cycle and gluconeogenesis. Liver is a key organ in regulating amino acid metabolism, where amino acids undergo processes such as transamination, deamination, and urea cycle to maintain amino acid balance and remove excess nitrogen. Overall, balancing protein synthesis and breakdown is essential for supporting growth, repair, maintaining overall health and homeostasis within the body.

3.8 REGULATION OF PROTEIN METABOLISM

The muscle, liver, and gastrointestinal (GI) tract play crucial roles in protein metabolism. Muscles synthesize and break down proteins, storing reserves and releasing amino acids into the bloodstream during fasting or stress, regulated by hormones like insulin and growth hormone. The liver deaminates amino acids, synthesizes urea, produces plasma proteins like albumin and globulins, and regulates amino acid metabolism through enzymes. The GI tract digests proteins, absorbs amino acids, synthesizes enzymes and hormones regulating protein metabolism, and excretes waste products. Let us know in detail:

Muscle: Muscle tissue acting as a reservoir of amino acids and regulate protein metabolism.

- **Protein Synthesis and Breakdown:** Muscles synthesize proteins for growth and repair, especially after exercise or injury, while breaking down proteins during fasting or stress to release amino acids.
- **Amino Acid Storage:** Muscles store amino acids in the form of muscle proteins, which can be mobilized during energy deficits.
- **Branched-Chain Amino Acids (BCAAs):** Muscles preferentially metabolize **branched-chain amino acids** (leucine, isoleucine, and valine), which are essential for muscle repair and energy production.

2. Liver: The liver is the central organ in protein metabolism, regulating amino acid levels and synthesizing critical proteins.

- **Deamination and Urea Cycle:** The liver removes the amino group from excess amino acids (deamination), converting it to ammonia and then to urea for excretion.
- **Protein Synthesis:** The liver produces plasma proteins, such as albumin and clotting factors.
- **Amino Acid Regulation:** It maintains amino acid homeostasis by converting surplus amino acids into glucose or fat through gluconeogenesis or lipogenesis.

3. Gastrointestinal Tract: It is the site of protein digestion and amino acid absorption.

Hormonal Regulation of Protein Metabolism

Hormones role is crucial in protein metabolism that involve balance protein synthesis and breakdown based on the body's energy and physiological demands.

Insulin plays a key anabolic role by enhancing protein synthesis and suppressing protein breakdown. It facilitates the uptake of amino acids into muscle and other tissues, and form new proteins. Insulin also prevents muscle protein degradation, especially in a fed state, ensuring efficient use of dietary proteins for growth and repair.

Glucagon, a catabolic hormone, acts primarily in the liver to enhance protein breakdown during fasting. It stimulates amino acid catabolism and directs these amino acids towards gluconeogenesis,

ensuring a continuous supply of glucose for energy. This process also increases urea production as nitrogen is removed from amino acids.

Cortisol, the stress hormone, increases protein breakdown, especially in muscle, to provide amino acids for gluconeogenesis during prolonged stress or fasting. While it helps maintain blood glucose levels, excessive cortisol can lead to muscle wasting due to the breakdown of structural proteins.

Growth Hormone (GH) and its mediator, **IGF-1 (Insulin-like Growth Factor-1)**, are critical for stimulating protein synthesis. They enhance amino acid uptake and protein assembly in muscles and tissues, promoting growth and reducing protein breakdown.

Thyroid Hormones, particularly thyroxine (T4) and triiodothyronine (T3), regulate basal protein turnover. While they promote protein synthesis at normal levels, excessive thyroid hormones accelerate both synthesis and breakdown, which can lead to muscle loss over time.

Epinephrine (adrenaline) triggers protein breakdown during acute stress, prioritizing energy production. It mobilizes amino acids for gluconeogenesis, ensuring energy availability in emergency situations.

Together, these hormones orchestrate a fine balance between protein anabolism and catabolism, adjusting to the body's metabolic state and environmental challenges. Understanding these roles is essential for addressing protein-energy malnutrition, surgical stress, and trauma. Nutrition and exercise also significantly impact protein metabolism, highlighting the importance of a balanced diet and regular physical activity.

3.9 PROTEIN QUALITY

Refers to the composition and balance of amino acids in a protein source, which determines how well the body can use it for growth, repair, and maintenance of tissues. The quality of a protein is primarily determined by two factors: its **amino acid profile** and its **digestibility**.

Amino Acid Profile refers to the specific composition and balance of amino acids in a protein source. A protein source contains all these essential amino acids in the right proportions for the body to use efficiently is referred as high quality protein. In addition, high-quality proteins should have high digestibility, and bioavailability, allowing the body to efficiently utilize them. Protein quality is vital

for overall health and is often assessed by measuring the amino acid profile and digestibility of a protein source.

Protein quality is assessed based on its ability to meet the body's essential amino acid requirements and its digestibility. Several methods are used to evaluate protein quality, each with unique approaches and applications:

1. Biological Value (BV):

The biological value measures how efficiently the protein consumed is converted into body protein. It evaluates the proportion of absorbed protein nitrogen retained in the body. Proteins with a BV close to 100, like eggs and milk, are considered high quality. This method highlights how well a protein source matches the body's needs.

2. Protein Efficiency Ratio (PER):

This method assesses protein quality based on the weight gain of a test animal (usually rats) relative to its protein intake over a specific period. Foods with higher PER values, like casein, support better growth. While useful, it may not always accurately reflect human protein requirements.

3. Net Protein Utilization (NPU):

NPU calculates the percentage of protein intake retained in the body, combining digestibility and utilization in a single measure. It compares dietary nitrogen retention to total intake and is a useful indicator of overall protein quality.

4. Digestible Indispensable Amino Acid Score (DIAAS):

DIAAS evaluates protein quality by measuring digestibility at the end of the small intestine (ileum) and comparing it with essential amino acid requirements. It provides more precise insights into protein utilization and is considered more accurate than older methods like the Protein Digestibility-Corrected Amino Acid Score (PDCAAS).

5. Protein Digestibility-Corrected Amino Acid Score (PDCAAS):

PDCAAS compares a protein's amino acid profile to human needs and adjusts for digestibility. It uses fecal nitrogen measurements to estimate protein absorption. While widely used, its limitations include overestimating the value of proteins with incomplete digestibility.

6. Amino Acid Score (AAS):

AAS measures the levels of essential amino acids in a protein relative to a reference protein. It highlights deficiencies in specific amino acids but does not account for digestibility or bioavailability.

7. Chemical Score:

This method calculates protein quality by comparing the lowest essential amino acid level in the test protein to that in a reference protein. It helps identify limiting amino acids that restrict protein utility.

These evaluations are critical for formulating diets that meet essential amino acid needs efficiently. Amino acid profile is crucial, as essential amino acids (EAAs) cannot be produced by the body. High-quality proteins provide all nine EAAs. Digestibility measures the body's ability to absorb amino acids, while bio-availability ensures protein is available for utilization. Adequate protein intake, its efficient digestion and bio-availability is necessary for muscle growth and maintenance, overall health, weight management, and immune function. Understanding protein quality helps individuals make informed choices about their diet and supplements.

3.10 PROTEIN REQUIREMENTS

The Recommended Dietary Allowance (RDA) for protein for an average adult is **0.8 grams per kilogram of body weight per day**. However, these requirements increase in specific situations such as in growing children and adolescents due to higher needs for growth and development. Furthermore, the protein requirement increases by approximately **23 grams/day** during the second and third trimesters to support fetal growth, placental development, and maternal physiological changes. In lactating mother, during the first six months postpartum, the requirement rises by **19 grams/day** to meet the demands of breast milk production. For the next six months, an additional **13 grams/day** is recommended as the infant begins complementary feeding but still relies partly on breast milk. The protein requirement in athletes ranging from **1.2 to 2.0 g/kg/day** to meet the increased needs for muscle repair and recovery.

Next, move to sources of protein to meet daily requirement of protein

3.11 PROTEIN SOURCES

High-Quality/Complete Protein: Proteins that contain all nine essential amino acids in the right proportions are considered complete proteins, typically found in animal-based foods like meat, eggs, and dairy.

Animal-Based Sources:

1. **Eggs:** Considered the "gold standard" for protein quality.
2. **Milk and Dairy Products:** Includes milk, cheese, and yogurt.
3. **Lean Meats:** Such as chicken, turkey, and lean beef.
4. **Fish and Seafood:** Salmon, tuna, and other seafood provide complete proteins.

Plant-Based Sources (Complete Proteins):

1. **Soy Products:** Tofu, soy milk, and tempeh.
2. **Quinoa:** A grain that provides all essential amino acids.
3. **Buckwheat:** A high-quality protein from a seed source.

Moderate-Quality Protein Sources: Moderate-quality proteins are often incomplete, meaning they lack one or more essential amino acids. However, when combined appropriately, they can provide a complete amino acid profile.

For example:

1. **Legumes:** Lentils, chickpeas, and black beans.
2. **Whole Grains:** Brown rice, oats, and whole wheat.
3. **Nuts and Seeds:** Almonds, peanuts, chia seeds, and sunflower seeds.
4. **Vegetables:** Broccoli, spinach, and mushrooms contain moderate amounts of protein.
5. **Dairy Alternatives:** Plant-based milks like almond or rice milk (fortified with proteins).

Pairing moderate-quality protein sources (e.g., rice with beans, whole wheat bread with peanut butter) can provide a complete amino acid profile, especially in vegetarian or vegan diets. This is known as **protein complementation**.

Low-Quality/ Incomplete Protein: Low-quality proteins, also known as **incomplete proteins**, do not contain all nine essential amino acids in sufficient amounts and proportion. They are often derived

from plant-based sources, and while they may still offer valuable nutrients, they may need to be combined with other protein sources to ensure the intake of all essential amino acids.

For example- Grains(White rice, Refined flour products, Corn), Pulses (when not paired with complementary protein sources) and Vegetables.

3.12 THERAPEUTIC APPLICATIONS OF SPECIFIC AMINO:

- 3 **L-Tryptophan:** An essential amino acid, crucial for serotonin synthesis, impacting mood, sleep, and appetite regulation. Supplementation may alleviate depression, anxiety, and insomnia by increasing serotonin levels. It supports cognitive function, aids in managing PMS symptoms, and can contribute to weight management by reducing appetite.
- 4 **L-Glutamine:** A conditionally essential amino acid crucial for gut health, aiding in the repair and maintenance of the intestinal lining. Its anti-inflammatory properties make it valuable in managing conditions like leaky gut syndrome and irritable bowel syndrome (IBS). Additionally, L-glutamine supports immune function, promoting tissue repair and reducing infections in the digestive tract. It may also benefit individuals undergoing intense physical training by supporting muscle recovery and reducing exercise-induced fatigue.
- 5 **L-Carnitine:** An amino acid derivative transport fatty acids into mitochondria for oxidation, and aid in cellular energy production. Its therapeutic applications include enhancing exercise performance and recovery by improving fat utilization, reducing muscle soreness, and increasing endurance. L-Carnitine supplementation may also benefit individuals with cardiovascular conditions, such as angina and heart failure, by improving cardiac function and reducing symptoms.
- 6 **L-Arginine:** A semi-essential amino acid, serves as a precursor to nitric oxide, a molecule that relaxes blood vessels, improving circulation and cardiovascular health. Its therapeutic applications include managing hypertension by dilating blood vessels and lowering blood pressure. L-Arginine may also enhance exercise performance by increasing blood flow to muscles, reducing fatigue, and promoting recovery. Furthermore, it shows promise in improving erectile dysfunction by enhancing blood flow to the genital area.
- 7 **L-Theanine:** An amino acid primarily found in tea leaves, offers therapeutic benefits for promoting relaxation and reducing stress without inducing drowsiness. Its ability to cross the blood-brain barrier allows it to modulate neurotransmitter activity, increasing levels of

serotonin, dopamine, and GABA, which contribute to mood regulation and stress reduction. L-Theanine inducing a state of calm alertness and improving focus and concentration. It may alleviate symptoms of anxiety, enhance cognitive function, and improve sleep quality.

- 8 Cysteine:** Cysteine is a precursor to glutathione, a powerful antioxidant and protect cells from oxidative damage; thereby reducing the risk of chronic diseases associated with oxidative stress, such as cardiovascular disease, cancer, and neurodegenerative disorders.

Deficiencies in certain B vitamins, including folate, vitamin B6, and vitamin B12 can lead to elevated homocysteine levels. Elevated homocysteine levels in the blood are linked to increased risk of cardiovascular disease, stroke, and neurodegenerative disorders. Homocysteine promotes inflammation, oxidative stress, and endothelial dysfunction, contributing to atherosclerosis and thrombosis.

- 9 Glycine:** Glycine, an amino acid with diverse roles in the body, exhibits therapeutic potential across multiple health domains. Its calming effect on the central nervous system makes it valuable in managing sleep disorders, anxiety, and stress-related conditions. Glycine's involvement in collagen synthesis promotes skin health and wound healing. Additionally, it may have anti-inflammatory properties, benefiting conditions such as arthritis and inflammatory bowel disease. Research suggests its potential in improving cognitive function and mood regulation.

- 10 Lysine:** An essential amino acid plays a crucial role in protein synthesis and numerous physiological functions, offering therapeutic benefits across various health conditions. Its antiviral properties make it valuable in managing and preventing herpes simplex virus outbreaks, including cold sores and genital herpes. Lysine supplementation may also support wound healing, enhance collagen production, and promote bone health by aiding in calcium absorption. Additionally, lysine is involved in neurotransmitter synthesis, potentially contributing to mood regulation and cognitive function.

- 11 Tryptophan:** Tryptophan, an essential amino acid, holds therapeutic significance across multiple health domains. As a precursor to serotonin, it plays a pivotal role in regulating mood, sleep, and appetite, making it valuable in managing depression, anxiety, and insomnia. Tryptophan supplementation may also enhance cognitive function, alleviate symptoms of premenstrual syndrome (PMS), and aid in weight management by reducing appetite. Additionally, it supports immune function and contributes to overall well-being.

12 Taurine:Taurine, a sulfur-containing amino acid, exhibits therapeutic potential in various health aspects. As a key component in bile salt formation, it aids in fat digestion and absorption, promoting gastrointestinal health. Taurine's role as a neurotransmitter modulator contributes to its ability to support cardiovascular function by regulating blood pressure and protecting against arrhythmias. Additionally, it acts as an antioxidant, reducing oxidative stress and inflammation, thereby benefiting metabolic disorders and neurological conditions

CHECK YOUR PROGRESS EXERCISE 2

1. What is Protein Quality?.Discuss any two methods for assessing protein quality.

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2. What do you understand by term “Protein Turnover”?

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3.Explain the role of insulin in protein metabolism

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3.13 LET US SUM UP

Proteins are essential for various physiological functions such as growth, tissue repair, and enzyme activity. The unit begins with the chemical composition and structure of protein. Amino acids are its building blocks unit, which fold into specific structures, enabling proteins to perform various biological functions. Then, classification of proteins, including simple and conjugated proteins, and their roles in different biological processes were discussed. During digestion, proteins break down into amino acids and peptides and then absorbed through the small intestine into the bloodstream. Amino acids are then utilized for protein synthesis or converted into other compounds as needed through the produce of transamination or deamination. The process of protein metabolism involves the synthesis and breakdown of proteins, primarily in the liver and muscles, regulated by hormones. Furthermore, importance of protein quality and sources were introduced to meet the daily requirement. The quality of a protein is determined by its amino acid composition and digestibility. Protein can be obtained from both animal (meat, eggs, dairy) and plant (legumes, grains, nuts) sources. Animal proteins are typically complete. In summary, this unit highlights the fundamental role of proteins in the body, their digestion, absorption, metabolism, and regulation. It also discusses protein quality, sources, and specific amino acid requirements for health and therapeutic purposes.

3.14 GLOSSARY.

1. Globular proteins:	Compact, spherical shape (e.g., enzymes, hormones)
2. Fibrous proteins:	Long, rod-like shape (e.g., collagen, keratin)
3. Membrane proteins:	Embedded in cell membrane (e.g., receptors, transporters)
4. Enzymes:	Catalyze chemical reactions (e.g., proteases, lipases)
5. Hormones:	Signaling molecules (e.g., insulin, growth hormone)
6. Transport proteins:	Facilitate molecule movement (e.g., hemoglobin, albumin)
7. Primary structure:	Amino acid sequence
8. Secondary structure:	α -helix, β -sheet
9. Tertiary structure:	3D shape
10. Quaternary structure:	Multiple polypeptide chains
11. Proteolysis:	Breakdown of proteins into peptides and amino acids

12. Pepsin:	Gastric enzyme breaking down proteins
13. Trypsin:	Pancreatic enzyme breaking down proteins
14. Chymotrypsin:	Pancreatic enzyme breaking down proteins
15. Aminopeptidase:	Enzyme removing amino acids from peptides
16. Protein synthesis:	Creation of protein from mRNA
17. Protein degradation:	Breakdown of protein
18. Protein turnover:	Balance between synthesis and degradation
19. Amino acid pool:	Available amino acids for protein synthesis
20. Deamination:	Removal of amino group from amino acids
21. Transamination:	Transfer of amino group between amino acids
22. Glycolysis:	Breakdown of glucose for energy
23. Gluconeogenesis:	Synthesis of glucose from amino acids
24. Ketogenesis:	Production of ketone bodies from amino acids
25. Urea cycle:	Removal of excess nitrogen from amino acids

3.15 ANSWER TO CHECK YOUR PROGRESS

EXERCISE 1

1. Protein is a macromolecule made up of amino acids linked by peptide bonds, essential for growth, repair, and various physiological functions in the body.

Classification of Proteins:. Based on their structure, function, and composition, proteins can be classified into several categories:

Based on Composition:

1. Simple Proteins: Composed only of amino acids (e.g., albumin, globulin).

2. Conjugated Proteins: Contain a non-protein group (e.g., glycoproteins, lipoproteins).

Based on Shape:

1. Fibrous Proteins: Long, insoluble, structural (e.g., collagen, keratin).
 2. Globular Proteins: Compact, soluble, functional (e.g., enzymes, hemoglobin).
2. Proteins perform several essential functions in the body, including:
 - **Structural Support:** Form the building blocks of tissues like muscles, skin, hair, and nails (e.g., collagen, keratin).
 - **Enzymatic Activity:** Act as enzymes to catalyze biochemical reactions (e.g., amylase, protease).
 - **Transport:** Carry molecules like oxygen (e.g., hemoglobin) and nutrients in the blood.
 - **Immune Defense:** Produce antibodies that protect against infections.
 - **Hormonal Regulation:** Function as hormones to regulate bodily processes (e.g., insulin, glucagon).
 - **Energy Source:** Provide energy when carbohydrate and fat stores are low.
 - **Repair and Growth:** Essential for tissue repair and development during growth or after injury.
 3. Protein digestion begins in the stomach as it is not significantly processed in the mouth. In the stomach, hydrochloric acid denatures proteins, and the enzyme pepsin breaks them into smaller peptides. The partially digested proteins (chyme) move to the small intestine, where enzymes from the pancreas, such as trypsin, chymotrypsin, and carboxypeptidase, further break peptides into smaller fragments and amino acids. Finally, enzymes like dipeptidases on the intestinal lining complete digestion, resulting in free amino acids, dipeptides, and tripeptides ready for absorption.
 4. Difference between fibrous and globular proteins:

Aspect	Fibrous Proteins	Globular Proteins
Shape	Long, thread-like	Spherical or compact
Solubility	Insoluble in water	Soluble in water

Function	Structural roles (e.g., support, strength)	Functional roles (e.g., enzymes, transport)
Examples	Collagen, keratin	Hemoglobin, enzymes
Stability	High mechanical stability	Less stable, easily denatured

EXERCISE 2

1. **Protein Quality** refers to the composition and balance of amino acids in a protein source, which determines how well the body can use it for growth, repair, and maintenance of tissues. The quality of a protein is primarily determined by two factors: its **amino acid profile** and its **digestibility**.

Two Methods for Assessing Protein Quality:

Biological Value (BV): Biological value measures the proportion of absorbed protein that is retained in the body for growth and maintenance. A high BV indicates that a protein is efficiently utilized by the body. Eggs, for example, have a BV of 100, meaning almost all the protein absorbed from eggs is used by the body for vital functions.

Protein Efficiency Ratio (PER): PER evaluates the weight gain of an organism (usually rats) per unit of protein consumed. It is a measure of how well a protein supports growth. Higher PER values indicate better quality proteins for promoting growth. For instance, casein and soy protein have high PER values, making them effective for growth and development.

2. Protein turnover is the continuous cycle of protein synthesis and breakdown in the body, where old proteins are degraded into amino acids, which are then reused to create new proteins. This dynamic process is essential for maintaining cellular function, repairing tissues, and adapting to changes in the body's needs.

3. Insulin regulate protein metabolism by promoting protein synthesis and inhibiting protein breakdown. When blood glucose levels rise after eating, insulin is released from the pancreas to regulate glucose levels, but it also affects amino acid metabolism. Insulin stimulates the uptake of amino acids into muscle cells and enhances the activity of enzymes involved in protein synthesis. It also inhibits the activity of catabolic enzymes that break down proteins, thus reducing protein

degradation. Additionally, insulin helps in the storage of excess amino acids by promoting their conversion into proteins for growth, repair, and maintenance of tissues. Therefore, insulin supports muscle building and tissue recovery, making it essential for overall protein metabolism.

3. Insulin plays a crucial role in protein metabolism by promoting the uptake of amino acids into cells and stimulating protein synthesis. It helps in reducing protein breakdown (catabolism) and enhances the storage of protein in tissues like muscles. Insulin activates enzymes involved in protein synthesis and inhibits those responsible for protein degradation. This anabolic effect of insulin contributes to muscle growth, repair, and overall protein retention in the body. Additionally, insulin helps regulate the balance between protein synthesis and breakdown in response to nutritional and hormonal signals.

Block II

INTRODUCTION

The aim of Block-II is to equip learners with an in-depth understanding of the physiological and nutritional importance of lipids, water, and minerals. This knowledge is intended to foster a holistic

appreciation of their roles in maintaining health, supporting growth, and preventing diseases, while also providing insights into dietary requirements and the health risks of imbalances or deficiencies.

This block is dedicated to exploring the critical roles of lipids, water, and minerals in human nutrition and their influence on physiological functions. The units aim to provide comprehensive insights into the classification, metabolism, and functional importance of these nutrients, with a focus on their requirements, bioavailability, and impact on health and disease.

UNIT-4: LIPIDS

This unit delves into the classification and metabolic dynamics of lipids, covering their digestion, absorption, and transport processes. It emphasizes the essential roles of fatty acids, particularly the essential fatty acids (EFAs), and highlights the significance of omega-3 (n-3) and omega-6 (n-6) fatty acids in maintaining health and preventing diseases. The unit also addresses the health implications of trans fatty acids and prostaglandins, along with the dietary requirements for total fat and fatty acids.

UNIT-5: WATER

The focus of this unit is the regulation and balance of water within the body. It explains the mechanisms of intra- and extracellular volume regulation, osmolality, and the physiological processes governing water balance. The unit seeks to explain how the body regulates hydration and the effects of any imbalances in fluid levels.

UNIT-6: MINERALS

This unit provides a detailed examination of macro and micro minerals essential for human health. Key macro minerals discussed include calcium, phosphorus, magnesium, sodium, potassium, and chloride. The micro minerals covered are iron, copper, zinc, magnesium, iodine, and chloride, while trace minerals like selenium, cobalt, chromium, vanadium, silicon, and boron are also explored. Each mineral is discussed in terms of its dietary sources, bioavailability, metabolism, and biological functions. Additionally, it includes daily requirements (RDA) for optimal health and potential toxicity from excessive intake.

UNIT 4: LIPID

STRUCTURE

4.1 Introduction

- 4.2 Chemical Composition of lipids
- 4.3 Classification of Lipids
 - 4.3.1 Simple Lipids
 - 4.3.2 Compound Lipids
 - 4.3.3 Derived Lipids
- 4.4 Function of Lipids
- 4.5 Types of Fatty Acids
 - 4.4.1 Saturated Fatty Acids
 - 4.4.2 Unsaturated Fatty Acids
- 4.5 Types of Unsaturated Fatty Acid
 - 4.5.1 Monounsaturated fatty acids (MUFA)
 - 4.5.2 Polyunsaturated Fatty Acids
- 4.6 Essential Fatty Acids (EFAs)
 - 4.6.1 Omega-3 Fatty Acids
 - 4.6.2 Omega-6 Fatty Acids
- 4.7 Prostaglandins
- 4.8 Digestion of Lipid
- 4.9 Absorption of Lipid
- 4.10 Transport of Lipid
- 4.11 Recommended Dietary Allowances (RDA)
- 4.12 Sources of Fat
- 4.13 Let Us Sum Up
- 4.14 Glossary
- 4.15 Answer to Check Your Progress

4.1 INTRODUCTION

Lipids are essential to human nutrition and physiology. They are hydrophobic or amphipathic molecules that are insoluble in water but soluble in organic solvents. such as ether, chloroform, or

benzene. Lipids serve multiple functions in the body, ranging from being a concentrated source of energy to providing structural components for cell membranes and acting as signaling molecules. They are more than just a source of energy; fats serve structural, functional, and regulatory purposes that influence overall health and well-being. Despite their historical reputation as a contributor to obesity and chronic diseases when consumed in excess, fats are vital for numerous physiological processes. Understanding their roles and studying their impact are crucial in nutrition science, public health, and medicine.

Fats are integral to human life, serving as energy sources, structural components, and regulators of physiological processes. Their roles extend far beyond nutrition, influencing health, disease prevention, and even cultural and culinary practices. Studying fats is essential to deepen our understanding of their complexities, optimize dietary strategies, and address the global health challenges of the modern era. By advancing our knowledge of fats, we can enhance health outcomes, improve quality of life, and foster a more informed approach to nutrition.

In this unit we shall unfold the chemical structure, classification, metabolism, biological functions, and implications of lipids for health and disease.

Expected Outcome

In this unit, you will learn and able be:

- Explain the chemical composition and types of lipids.
- Discuss the types, source and importance of different fatty acids
- Understand the process of digestion and metabolism of lipids.

4.2 CHEMICAL COMPOSITION OF LIPIDS

Let's start the unit with studying the chemical composition of lipids. Lipids are organic compounds composed of carbon (C), hydrogen (H), and oxygen (O), with some lipids containing other elements like nitrogen (N) and phosphorus (P). They are hydrophobic (water-insoluble) in nature, which makes them soluble in non-polar solvents like chloroform or ether. They are made up mainly of fatty acids and glycerol, with variations in their structure leading to different types of lipids. They are characterized by their chemical diversity, and their classification is based on their molecular structure

and functional properties. Each type of lipid serves distinct and vital functions in the body. Their basic structure can be broadly categorized into four main types based on their characteristics:

- **Fatty Acids:** is a basic building block of fats, consisting of a hydrocarbon chain with a carboxyl group (-COOH) at one end. They can be classified as saturated (no double bonds) or unsaturated (one or more double bonds), which affects their properties and functions.
- **Fats (Triglycerides):** It is a type of lipid composed of three fatty acid molecules attached to a glycerol backbone, forming a triglyceride.
- **Phospholipids:** It is a lipid molecule made up of two fatty acids, a glycerol backbone, and a phosphate group. The phosphate group is hydrophilic (water-attracting), while the fatty acid tails are hydrophobic (water-repelling). Phospholipids are key components of cell membranes, forming a bilayer that regulates what enters and exits the cell.
- **Sterols:** These are complex lipids with a four-ring carbon structure. Cholesterol is the most well-known sterol, playing a crucial role in membrane fluidity and serving as a precursor for steroid hormones and vitamin D.

While lipids vary greatly in their chemical structure, they all share certain common features; consist of a long hydrocarbon chain and carboxyl group (-COOH) as illustrated in figure 4.1.

The fundamental structure of fatty acid consists of:

- **Hydrocarbon Chain:** A lengthy chain of carbon (C) atoms joined to hydrogen (H) atoms makes up the backbone of fatty acids. This chain's length can vary, although it usually ranges between 4 and 28 carbon atoms.
- **Carboxyl Group:** The fatty acid molecule's -COOH group at one end. This category is hydrophilic, or attracted to water, and polar.

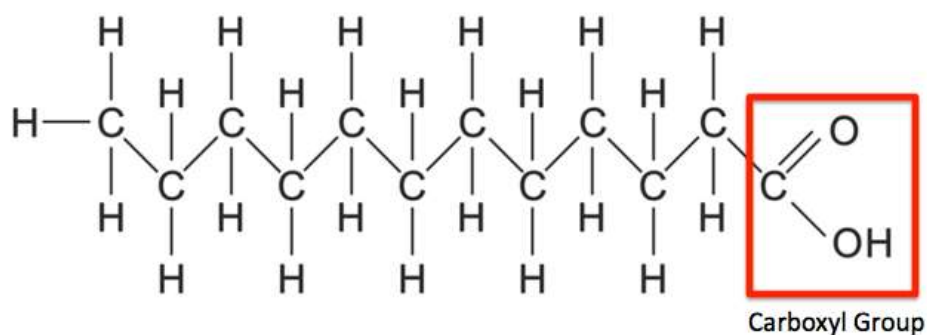


Figure 4.1: Basic Structure of Fatty Acid

(Source: Retrieved from Study.com)

4.3 CLASSIFICATION OF LIPIDS

Lipids are broadly classified into following categories (figure 4.2) based on their chemical structure and composition:

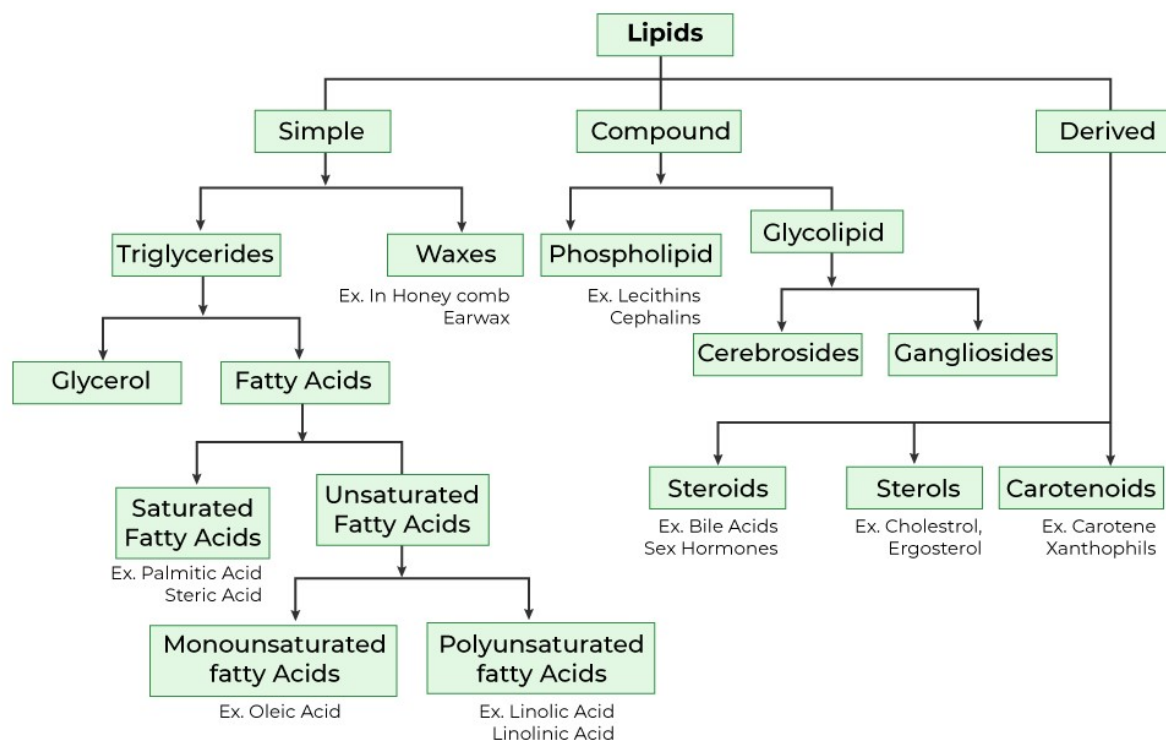


Figure 4.2: Classification of Lipids

(Source: Retrived from <https://www.geeksforgeeks.org>)

4.3.1 Simple Lipids

Simple lipids are straightforward in structure and composed of molecules of fatty acids and alcohols. Unlike compound lipid, they do not contain additional functional groups or non-lipid components such as phosphate or carbohydrates. Simple lipids play essential roles in energy storage and structural functions within organisms. The primary types of simple lipids are:

1. Fats and Oils (Triglycerides): Fats and oils, collectively known as triglycerides, are composed of three fatty acid molecules esterified to a single glycerol molecule. These lipids play a critical role in the body, serving as a primary energy reservoir, insulating the body against heat loss, and protecting vital organs. The physical state of triglycerides depends on their fatty acid composition. Fats, which are rich in saturated fatty acids, are typically solid at room temperature. In contrast, oils contain a higher proportion of unsaturated fatty acids, making them liquid at room temperature. This structural variation significantly influences their function and application in both biological systems and food products.

Most common example of simple lipids is triglycerides and serve primarily as energy storage molecules in the body. The structure of a triglyceride can be broken down into fatty acids and glycerol. Glycerol is trihydroxyl alcohol binds to three fatty acids through ester bonds to form backbone of the triglyceride.

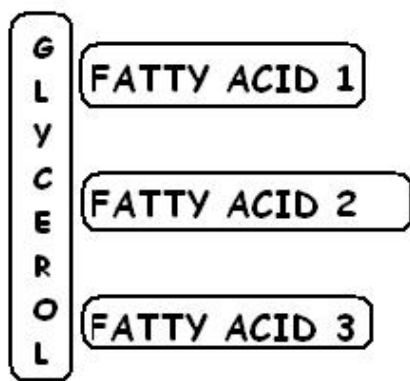


Figure 4.3: Structure of Triglyceride

(Source : Ruth Lawson, 2008; Wikimedia Creative Commons CC-3)

2. **Waxes:** Waxes are lipids composed of long-chain fatty acids esterified to long-chain alcohols. Their primary function is to provide a protective coating that minimizes water loss and offers a barrier against environmental factors. In plants, waxes such as cutin form a protective layer on leaves and stems, reducing water evaporation. In animals, waxes like beeswax and lanolin serve to waterproof and protect structures such as fur, feathers, and skin. These versatile compounds play an essential role in maintaining hydration and structural integrity in both plants and animals.

4.3.2 Compound Lipids

Compound lipids, also known as complex lipids, are composed of fatty acids, alcohols, and additional chemical groups such as phosphates, carbohydrates, or amino acids. They include phospholipids, glycolipids, and lipoproteins.

- **Phospholipids-** The structure of phospholipids are similar to triglycerides but with one key difference that they contain a phosphate group in place of one of the fatty acids. The structure of phospholipids consists of:
- **Glycerol Backbone:** Like triglycerides, phospholipids have a glycerol molecule as their backbone.
- **Two Fatty Acid Chains:** Two of the hydroxyl groups on the glycerol molecule are esterified with fatty acids, forming two hydrophobic (water-repelling) tails.
- **Phosphate Group:** The third hydroxyl group on glycerol is attached to a phosphate group, which is hydrophilic (water-attracting).

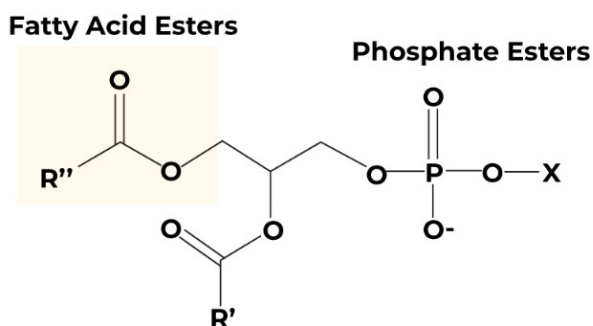


Figure 4.4: Structure of Phospholipid

(Source: Retrived from <https://www.geeksforgeeks.org>)

The phosphate group and attached molecules (e.g., choline, ethanolamine) form the polar, water-attracting head and form hydrophilic head. This head interacts with water and other polar

substances. Hydrophobic Tails, consist two fatty acid chains form the non-polar, water-repelling tails. These tails avoid water and prefer to interact with other lipids. This amphipathic nature allows phospholipids to arrange themselves into a bilayer in aqueous environments, forming the structural basis of cell membranes. In the bilayer, the hydrophilic heads face outward toward the water, while the hydrophobic tails are tucked inward, creating a stable barrier that separates the internal and external cellular environments. This property is essential for membrane function, including compartmentalization, selective permeability, and communication.

ii. Glycolipids- Glycolipids are lipids that have a carbohydrate (sugar) group attached to them. They are composed of a lipid molecule (typically a sphingolipid or glycerolipid) bonded to one or more sugar molecules. Glycolipids are s, where they contribute to cellular recognition, communication, and stability.

The Structure of glycolipid primarily found in cell membrane is presented in figure 4.5 and consist of:

- **Lipid Backbone:** The lipid component of a glycolipid is typically a fatty acid (as part of a sphingolipid or glycerolipid). The lipid tail is hydrophobic and embedded in the lipid bilayer of the cell membrane. The lipid tail is attached to the hydrophilic head group of the lipid and is exposed to the aqueous environment outside the cell. The sugar groups can be simple sugars (monosaccharides) or more complex oligosaccharides.

Functions:

- **Cell Recognition:** Glycolipids play a crucial role in cell-to-cell recognition. The sugar chains attached to the lipids serve as recognition sites for other molecules, aiding in immune responses and tissue formation.
- **Membrane Structure:** They help maintain the integrity and fluidity of cell membranes. Glycolipids are particularly abundant in the nervous system and in the outer layer of cell membranes, contributing to membrane stability.
- **Blood Group Antigens:** In the context of human blood types, glycolipids on red blood cells determine the blood group (e.g., A, B, AB, O). These blood group antigens are determined by the specific carbohydrate groups attached to glycolipids on the surface of red blood cells.

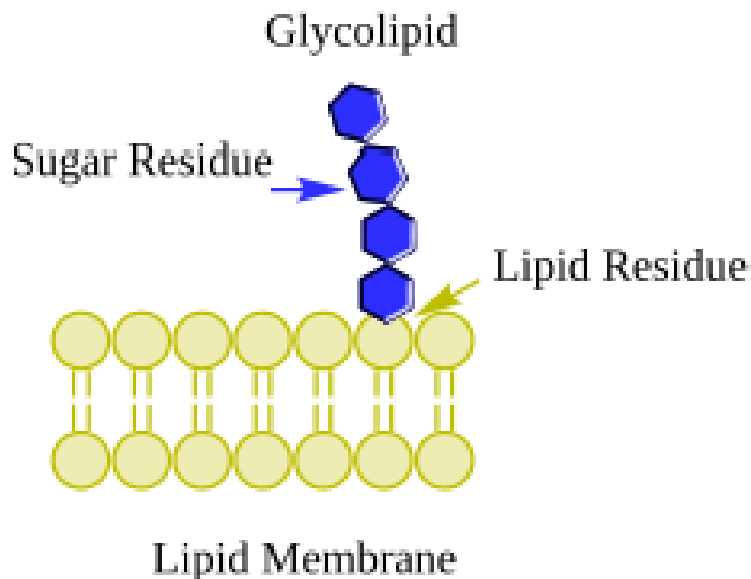


Figure 4.5: Glycolipid

(Source: Wpcrosson, 2015 Creative Commons Attribution-CC-4.0)

4.3.3 Derived lipids :

Derived Lipids are a class of lipids obtained through the hydrolysis of simple and compound lipids. They include substances such as fatty acids, glycerol, sterols, and fat-soluble vitamins, which are derived from the breakdown of triglycerides, phospholipids, and other complex lipids. These lipids are not ester-linked but retain important lipid-like characteristics. Derived lipids serve various functions in the body, such as providing essential fatty acids, aiding in the synthesis of hormones (e.g., sterols like cholesterol), and playing roles in cellular signaling and membrane structure. Examples include free fatty acids, cholesterol, and steroid hormones.

4.4 Function of Lipid

Lipids are versatile biomolecules that perform a wide array of essential functions in living organisms. Here is an in-depth exploration of their key roles:

1. Energy Storage and Supply: Lipids, particularly triglycerides, are the body's most efficient form of energy storage. They provide approximately 9 kcal of energy per gram, more than twice the energy provided by carbohydrates or proteins. Stored in adipose tissue, lipids serve as a long-term energy

reservoir that the body can tap into during fasting, prolonged exercise, or when energy intake is insufficient.

2. Structural Role in Cell Membranes: Phospholipids are the primary structural components of cell membranes. The unique properties of lipids enable them to form a flexible, dynamic barrier that separates the interior of the cell from its external environment

3. Insulation and Protection: Lipids provide thermal insulation by reducing heat loss from the body. Adipose tissue also serves as a cushion, protecting internal organs from mechanical shocks and injuries.

4. Hormonal and Signaling Functions: Certain lipids, such as steroids (e.g., cholesterol derivatives like estrogen, testosterone, and cortisol), act as hormones that regulate diverse physiological processes, including reproduction, metabolism, and immune response.

5. Transport and Absorption of Fat-Soluble Vitamins: Lipids facilitate the absorption and transport of fat-soluble vitamins (A, D, E, and K).

6. Waterproofing and Barrier Formation: Waxes, a type of lipid, form protective layers in plants (on leaves and fruits) and animals (e.g., in fur, feathers, and skin). These layers prevent excessive water loss and protect against environmental factors like rain and microbial invasion.

7. Energy Reserve and Metabolic Fuel

Lipids are stored in adipose tissue as an energy reserve that can be mobilized when needed. During times of fasting or low carbohydrate availability, lipids are metabolized to produce energy through β -oxidation and the citric acid cycle.

8. Buoyancy in Aquatic Animals:

In marine mammals, lipids such as blubber not only provide insulation but also help maintain buoyancy, allowing these animals to float and swim efficiently in water.

9. Essential Fatty Acids

Lipids are a source of essential fatty acids (e.g., omega-3 and omega-6), which the body cannot synthesize and must obtain from the diet. These fatty acids are crucial for brain development, inflammation regulation, and cardiovascular health.

10. Role in Taste and Texture

In food systems, lipids enhance flavor and provide a creamy texture, contributing to palatability and satiety. They act as carriers for fat-soluble flavors and play a role in the texture of baked and fried foods.

4.5 TYPES OF FATTY ACID

After studying the basic composition of lipid. Let's learn about types of fatty acids.

Fatty acids can vary in chain length, saturation, and functional groups, giving rise to different types with distinct properties. Here are some common types of fatty acids based on number of double bonds present:

4.5.1 Saturated Fatty Acids

Saturated fatty acids are a particular kind of fatty acid where all of the carbon atoms are joined by single bonds. The majority of saturated fatty acids pack closely together because of their straight-chain structure, which makes them solid at room temperature. This explains why fats that are solid at room temperature include butter, lard, and coconut oil.

Due to their capacity to bind tightly together, saturated fatty acids often have greater melting points than unsaturated fatty acids. The melting point rises in tandem with the carbon chain's length. Common dietary sources include: **Animal Fats** (Meat, butter, and lard), **Plant Oils** (Vegetable oils such as coconut oil, and palm oil).

Examples of Common Saturated Fatty Acids

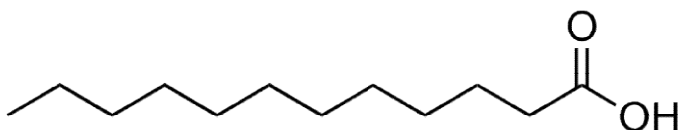
The specific properties and health implications of saturated fatty acids can vary depending on their carbon chain length and structure. Common saturated fatty acids include:

Lauric Acid (C12:0): Found in coconut oil and palm kernel oil, lauric acid has a medium chain length and is believed to have certain health benefits, such as antimicrobial properties.

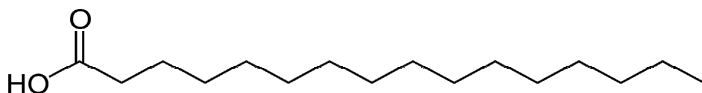
Palmitic Acid (C16:0): One of the most common saturated fatty acids, found in palm oil, meat, and dairy products. It is associated with raising cholesterol levels in the blood.

Stearic Acid (C18:0): Found in animal fat, cocoa butter, and some plant oils, stearic acid is unique among saturated fatty acids because it does not appear to raise cholesterol levels in the same way as other saturated fats.

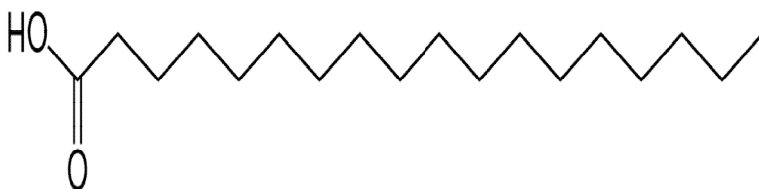
Myristic Acid (C14:0): Found in coconut oil, dairy products, and some animal fats, myristic acid is another common saturated fatty acid that may affect cholesterol levels.



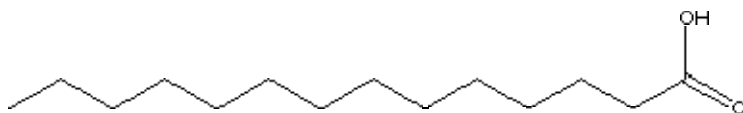
Lauric Acid (C12:0)



Palmitic acid (16:0)



Stearic Acid (C18:0)



Myristic Acid (C14:0)

Figure 4.6: Structure of Saturated Fatty Acids

(Source: Calvero, 2010; Wikimedia Creative Commons Attribution)

Saturated Fatty Acids exhibit various important role in the body as follow:

- Adipose tissue stores excess energy as triglycerides, which contain saturated fatty acids, when the body has a surplus of energy.
- Saturated fatty acids contribute to the stability and stiffness of cell membranes, influencing their fluidity and functionality.
- Saturated fatty acids are involved in the production of steroid hormones like cortisol, testosterone, and estrogen, as well as bile acids, which are essential for digestion and fat absorption.
- Fatty tissues rich in saturated fats provide insulation and protect vital organs from mechanical damage.

4.5.2 Unsaturated Fatty Acids

An unsaturated fatty acid is a type of fat molecule that contains one or more double bonds between the carbon atoms in the hydrocarbon chain. Because of the "kinks" created by these double bonds, the molecules are unable to pack tightly together. Consequently, at normal temperature, unsaturated fatty acids are usually liquid.

Two different arrangements of double bonds can be seen in unsaturated fatty acids:

Trans fats are a type of unsaturated fat where hydrogen atoms are positioned on opposite sides of the carbon double bond. This configuration makes them more stable and solid at room temperature, but they are associated with significant health risks. Trans fats can be found naturally in small amounts in some animal products, but most are artificially created through industrial processes like **partial hydrogenation** of vegetable oils. Commonly, these trans or partially hydrogenated oils used in fried foods, baked goods, processed snacks like chips, crackers.

Trans fats are a significant public health concern due to their adverse effects on heart health and other chronic diseases. Avoiding processed and fried foods, checking food labels for "partially hydrogenated oils," and choosing healthier fat sources are essential steps in maintaining a balanced and heart-healthy diet.

The **cis configuration** in unsaturated fatty acids refers to the orientation of the hydrogen atoms attached to the carbon atoms involved in a double bond. In a cis configuration, the hydrogen atoms are on the same side of the double bond, causing a bend or kink in the fatty acid chain. This kink prevents the molecules from packing closely together, leading to a liquid state at room temperature, which is characteristic of oils. The cis configuration is common in naturally occurring unsaturated fatty acids, such as oleic acid (found in olive oil). This configuration is contrasted with the trans configuration, where the hydrogen atoms are on opposite sides of the double bond, leading to a straighter chain and more solid-like properties. The cis configuration is important for maintaining the fluidity and flexibility of cell membranes and plays a role in the health benefits associated with unsaturated fats.

Types of Fatty Acid Configurations

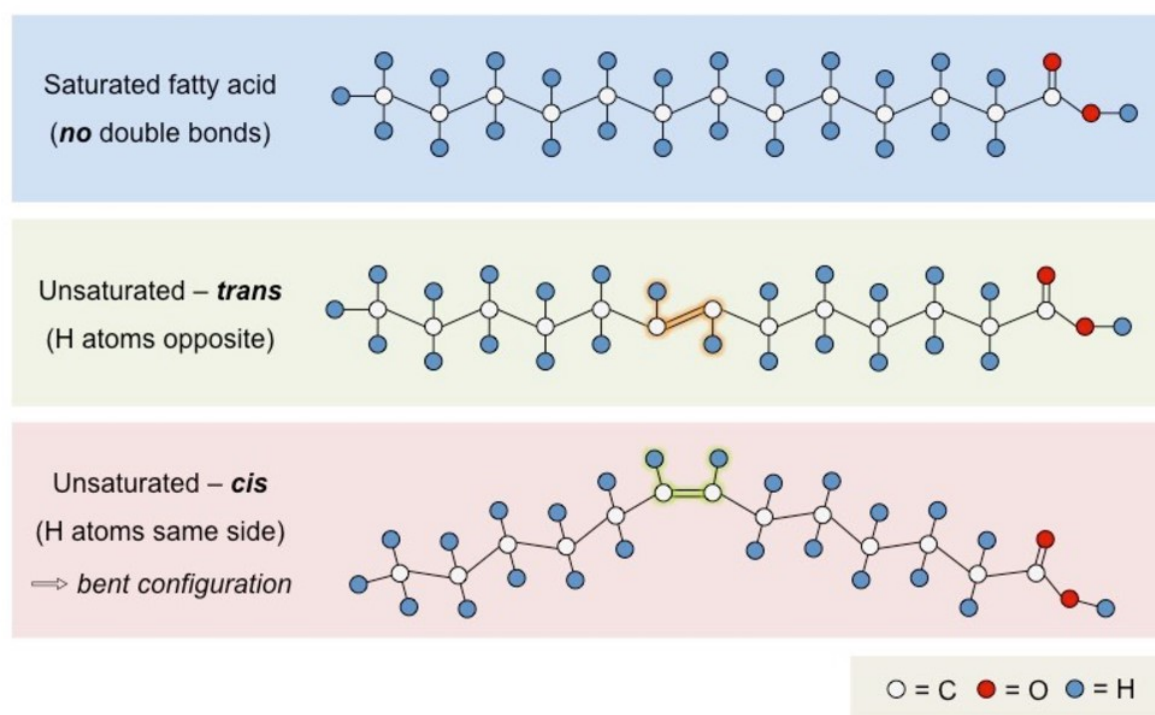


Figure 4.7: Type of Fatty Acid Configuration

(Source:Retrived from <https://old-ib.bioninja.com.au>)

CHECK YOUR PROGRESS EXERCISE 1

1. What are the three main classes of lipids?

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2. What are the roles of phospholipids in cellular membranes?

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3. How does the saturation level of fatty acids affect their physical state at room temperature?

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Next, move to understand the different types of unsaturated fatty acids and its importance in diet

4.6 TYPES OF UNSATURATED FATTY ACIDS

Understanding the types of fatty acids is essential as they influence the properties and functions of lipids in biological systems and have implications for human health.

Let's discuss types of unsaturated fatty acids

4.6.1 Monounsaturated Fatty Acids (MUFA)

It is a fatty acid with a only one double bond in the carbon chain typically located in the middle of the chain. The structure is kinked or bent by this solitary double bond, which alters the molecule's characteristics and interactions with other molecules. MUFAs are commonly found in plant-based oils, like olive oil, nuts, seeds, and some animal products. Key sources include:

- **Olive Oil:** One of the most well-known sources of MUFAs, with oleic acid being the primary monounsaturated fatty acid.
- **Avocados:** These fruits are rich in MUFAs and are considered a healthy fat option.
- **Nuts&Seeds:** Almonds, cashews, peanuts, Sunflower seeds, pumpkin seeds, and sesame seeds
- **Animal Sources:** While plant-based oils are the most common sources, some animal products, such as chicken and some cuts of pork, contain small amounts of MUFAs.

Health Benefits of Monounsaturated Fatty Acids (MUFAs)

MUFAs are often considered "heart-healthy" fats because of their positive effects on cardiovascular health and other benefits. Here are some of the key health benefits:

- **Improved Cholesterol Levels:** Lower LDL cholesterol levels can be achieved by substituting MUFAs for trans and saturated fats in the diet. MUFAs may contribute to a lower risk of heart disease by raising HDL cholesterol and lowering LDL ("bad") cholesterol.
Decreased Heart Disease Risk: Diets high in monounsaturated fats, especially from foods like avocados and olive oil, are linked to a decreased risk of heart disease and stroke as well as other cardiovascular conditions. A decreased prevalence of chronic diseases and better heart health have been associated with the Mediterranean diet, which places a strong emphasis on MUFAs, especially olive oil.
- **Anti-Inflammatory Effects:** Because MUFAs have anti-inflammatory qualities, they may help lessen chronic inflammation, which is linked to diseases like diabetes, cardiovascular disease, and arthritis. For example, olive oil

- **Improved Insulin Sensitivity:** Some studies suggest that monounsaturated fats can improve insulin sensitivity, which is beneficial for people with or at risk for type 2 diabetes. Replacing refined carbohydrates with MUFAs in the diet may help stabilize blood sugar levels.
- **Weight Management:** Monounsaturated fats can aid in weight management and encourage feelings of fullness and satiety, lowering total calorie intake, even though fats are high in calories. Monounsaturated fats may help reduce visceral fat, or the fat surrounding the abdominal organs, which is linked to metabolic disorders, according to some study.

4.6.2 Polyunsaturated Fatty Acids

Unsaturated fats with two or more double bonds in their hydrocarbon chain are known as polyunsaturated fatty acids (PUFAs). Because the hydrogen atoms are arranged on the same side of the double bond, creating a bend in the structure, the majority of natural PUFAs have double bonds in the cis configuration. The fluidity of these fats is caused by this arrangement.

PUFAs are regarded as necessary fats, which means that the body needs to get them from food because it cannot produce them on its own. They are essential for several biological processes, including as cell membrane formation, inflammation control, and brain development.

A. Physical Properties of Polyunsaturated Fatty Acids

· **Liquid at Room Temperature:** PUFAs have lower melting points due to their double bonds, making them liquid at room temperature.

· **Flexible Structure:** The kinks caused by double bonds result in a less rigid structure compared to saturated fats.

· **Susceptible to Oxidation:** PUFAs are prone to oxidative rancidity because double bonds are reactive to oxygen.

· **Hydrophobic:** Like all fatty acids, PUFAs are insoluble in water but soluble in organic solvents.

· **Light and Heat Sensitivity:** Easily degraded by exposure to light, heat, or air, requiring proper storage.

Figure 4.8: Unsaturated Fatty Acid

4.7 ESSENTIAL FATTY ACIDS (EFAS)

Essential fatty acids are polyunsaturated fats that are vital for various physiological functions, including brain health, cell structure, and inflammation regulation. Since the body is unable to produce these fatty acids on its own, they must be obtained through dietary sources. The types of essential fatty acids are :

4.7.1 Omega-3 fatty acids : Omega-3 fatty acids are class of polyunsaturated fatty acids (PUFAs), distinguished by the presence of a double bond three carbons away from the methyl terminus of the carbon chain. Three primary categories of omega-3 fatty acids are as follows:

1. alpha-linolenic acid (ALA)
2. Eicosapentaenoic acid (EPA)
3. Docosahexaenoic acid (DHA)

Let's talk about alpha-linolenic acid (ALA) in detail:

1. **alpha-linolenic acid (ALA):** The main omega-3 fatty acid, ALA, is present in plant sources such hemp seeds, walnuts, chia seeds, and flaxseeds. Through a sequence of biochemical events in the body, it acts as a precursor for the synthesis of longer-chain omega-3 fatty acids, such as docosahexaenoic acid (DHA) and eicosapentaenoic acid (EPA).

These steps include:

- a. **Desaturation Reaction (Δ -6 Desaturase):** The enzyme Δ -6 desaturase catalyses a desaturation reaction that transforms ALA into stearidonic acid (SDA) by introducing a double bond at the sixth carbon from the methyl end of the ALA molecule. This is the first step in the conversion of ALA to EPA.
- b. **Elongation Reaction:**After the desaturation phase, elongase enzymes catalyse the elongation of stearidonic acid (SDA), which adds two carbon atoms to the carbon chain. Eicosatetraenoic acid (ETA), which has four double bonds and 20 carbons, is the product of elongation.
- c. **Desaturation Reaction (Δ -5 Desaturase):**The enzyme Δ -5 desaturase adds another double bond at the fifth carbon from the methyl end of eicosatetraenoic acid (ETA), further desaturating it.

Eicosapentaenoic acid (EPA), the first in the omega-3 family of long-chain fatty acids, is the product of this process. It has five double bonds and 20 carbons.

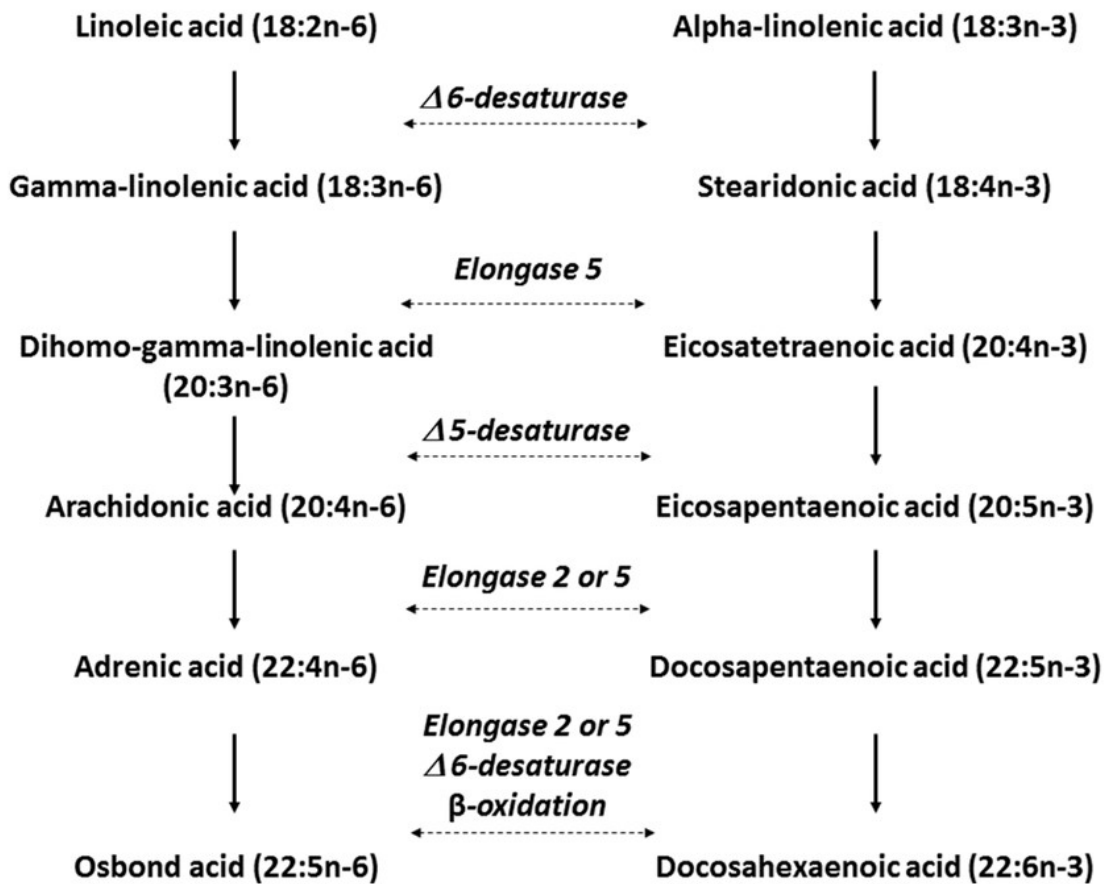


Figure 4.9: Formation of Long-Chain Fatty Acids from Linolenic Acid

(Source:Hussain *et al* 2020)

It is important to note that body can interconvert essential fatty acids (EFAs), primarily omega-3 and omega-6, but the process is limited and depends on the availability of specific enzymes.

Eicosapentaenoic acid (EPA): Eicosapentaenoic acid, often abbreviated as EPA, is an omega-3 fatty acid found in oily fish and algae. It is also an essential fatty acids that cannot be synthesize by body on its own, therefore it must be obtained from the diet or supplements.

It is considered a beneficial fatty acid with significant health benefits, particularly for cardiovascular health, inflammation reduction, brain function, and mental well-being. Its unique structure, with multiple double bonds, gives it the ability to influence various biological pathways, making it a valuable component of the diet. Since the human body cannot synthesize EPA, it is vital to obtain it from dietary sources, particularly fatty fish, algae, and supplements, to support overall health.

EPA is composed of a 20-carbon chain with five double bonds, making it a polyunsaturated fatty acid. Its chemical formula is **C₂₀H₃₀O₂**, and it is often denoted as **20:5(n-3)**. This unique structure, characterized by multiple double bonds, gives EPA its distinct properties, such as fluidity at room temperature and the ability to exert various physiological effects through its metabolism.

Functions of EPA:

Anti-Inflammatory Effects:

EPA helps reduce inflammation in the body, which is a key factor in preventing chronic diseases, including cardiovascular diseases. By lowering inflammation in blood vessels, it helps reduce the risk of plaque buildup in arteries.

Lowering Triglyceride Levels:

EPA has been shown to effectively lower high triglyceride levels in the blood, reducing the risk of heart disease, atherosclerosis, and stroke.

Improving Heart Rhythm:

EPA helps stabilize the electrical activity of the heart, reducing the risk of arrhythmias (abnormal heart rhythms) and preventing sudden cardiac events.

Blood Clot Prevention:

EPA reduces platelet aggregation (the clumping together of blood cells), which can lower the risk of dangerous blood clots that can lead to heart attacks or strokes.

Vascular Health:

By promoting healthy blood vessel function and reducing blood pressure, EPA contributes to overall vascular health. This helps in maintaining proper circulation and reducing strain on the heart.

Supporting Cholesterol Balance:

EPA may help increase levels of high-density lipoprotein (HDL), the "good" cholesterol, while lowering levels of low-density lipoprotein (LDL), the "bad" cholesterol, further supporting cardiovascular health.

Overall, **EPA** is essential for reducing inflammation, promoting heart health, and improving lipid profiles, making it an important component of omega-3 fatty acids for preventing and managing cardiovascular diseases.

2. Docosahexaenoic acid (DHA):

Docosahexaenoic acid (DHA) is a type of omega-3 fatty acid consist of long chain of 22 carbon atoms, with six double bonds along the chain, commonly noted with **22:6(n-3)**. This structure makes DHA highly unsaturated and flexible, which is essential for its role in maintaining the fluidity of cell membranes particularly in the brain and retina.. Its chemical formula is $C_{22}H_{32}O_2$.

It is one of the component in cell membranes, especially in the brain and retina, allows it to influence key physiological processes like neurotransmission, inflammation, and cardiovascular health. Given its significant impact on health, ensuring adequate DHA intake through diet or supplementation is essential, particularly for optimal brain and eye development in infants, and for maintaining cognitive function and reducing inflammation throughout life.

Functions of DHA:

- **Brain Health:** DHA is a crucial component of the brain, making up a significant portion of the **gray matter** and playing an essential role in brain development and function. It is particularly abundant in neuronal membranes, where it helps maintain the structural integrity and fluidity of cell membranes. DHA is involved in neurotransmission, signal transduction, and synaptic plasticity. Adequate levels of DHA support cognitive function, learning, and memory.

DHA is also important in preventing and managing neurodegenerative diseases, including **Alzheimer's disease** and other forms of **dementia**. Low levels of DHA have been linked to cognitive decline, and supplementation may help slow the progression of neurodegenerative diseases.

- **Mental Health:** DHA is crucial for maintaining mental well-being. It has been shown to play a role in reducing symptoms of **depression**, **anxiety**, and other mood disorders. It has been shown to help regulate **mood** and may support overall mental well-being.
 - **Eye Health:** DHA is a major component of the **retina** in the eye, where it plays a critical role in maintaining retinal function and supporting visual health. Adequate levels of DHA are vital for proper visual development, especially in infants and young children.
 - **Anti-inflammatory Effects:** DHA has potent **anti-inflammatory** properties that help reduce chronic inflammation, which is associated with conditions like **arthritis**, **inflammatory bowel disease**, and **heart disease**.
 - **Cardiovascular Health:** DHA reduces the risk of cardiovascular diseases by lowering triglyceride and promoting a healthier cholesterol profile. It supports the health of blood vessels, reducing the risk of **atherosclerosis** (plaque buildup in the arteries), and may help prevent **arrhythmias** (irregular heartbpromoting a healthier cholesterol profile, eats).
 - **Cell Membrane Fluidity:** As a major component of cell membranes, DHA helps maintain membrane fluidity, which is critical for proper cell signaling, nutrient transport, and cellular function. In the brain, DHA contributes to the flexible and responsive nature of neuronal membranes, allowing for efficient communication between nerve cells.
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4.7.2 Omega-6 fatty acids

Omega-6 polyunsaturated fatty acids (PUFAs) are a group of essential fatty acids that play a critical role in human health, particularly in cellular functions, inflammation regulation, and overall metabolic processes. Omega-6 fatty acids have a carbon chain with two or more double bonds. The defining feature of omega-6 PUFAs is that the first double bond is located at the sixth carbon atom from the methyl (omega) end of the fatty acid chain.

The most common omega-6 PUFAs include:

1. **Linoleic Acid (LA):**
2. **Arachidonic Acid (AA):**

Let's discuss it detail

1. **Linoleic Acid (LA):** Linoleic acid (LA) has an 18-carbon chain with two double bonds, Its chemical formula is **C₁₈H₃₂O₂**, and it is represented as **18:2(n-6)**. LA undergoes desaturation and elongation reactions in the body, primarily in the liver to produce **arachidonic acid (AA)** through a series of enzymatic reactions as shown in figure 4.9. This conversion involves several steps:

- **Delta-6 desaturase** enzyme converts linoleic acid (18:2, n-6) into **gamma-linolenic acid (GLA)** (18:3, n-6).
- **Elongase** adds two carbon atoms to GLA, forming **dihomo-γ-linolenic acid (DGLA)** (20:3, n-6).
- **Delta-5 desaturase** then converts DGLA into arachidonic acid (AA) (20:4, n-6).

Arachidonic acid is further metabolized into various bioactive molecules involved in inflammatory responses, immune function, and other physiological processes.

Like omega-3 fatty acids, our bodies cannot produce omega-6 fatty acids on their own and must obtain them from the diet. Foods rich in omega-6 fatty acids include certain vegetable oils (such as corn, soybean, and sunflower oil), nuts, and seeds. While omega-6 fatty acids are important for overall health and have benefits such as supporting brain function, promoting skin health, and aiding in muscle growth, it is also essential to maintain a balanced ratio of omega-6 to omega-3 fatty acids. An imbalance, where omega-6 intake is significantly higher than omega-3 intake, can contribute to inflammation and various health issues. Therefore, it's recommended to consume omega-6 fatty acids as part of a well-rounded diet that includes a variety of healthy fats to support optimal health and well-being.

Linoleic acid is crucial for various biological functions and plays an essential role in maintaining the structure and function of cell membranes. As an omega-6 fatty acid, it contributes to the production of eicosanoids (hormone-like substances), which are involved in regulating inflammation, blood clotting, and immune responses.

Here, some common and important function of Linoleic Acid (LA):

- **Structural Component of Cell Membranes:** LA is a major constituent of phospholipids in cell membranes, contributing to their fluidity and function. It maintains the integrity and permeability of the cellular structure.
- **Precursor for Arachidonic Acid (AA):** LA is metabolized in the body to form **arachidonic acid (AA)**, essential for the synthesis of eicosanoids, which regulates inflammation, immune responses, and blood clotting.
- **Energy Source:** Like other fatty acids, linoleic acid provides energy to the body. It contributes to the caloric content of dietary fats, delivering approximately 9 kcal per gram.
- **Skin Health:** LA is crucial for maintaining healthy skin by helping to retain moisture and promoting the production of the skin's natural barrier. It can help prevent conditions such as dry skin and eczema.
- **Cholesterol Regulation:** Linoleic acid involves lower the risk of heart disease by improving lipid profiles and preventing atherosclerosis.
- **Inflammatory Regulation:** While LA itself is not directly inflammatory, its conversion to arachidonic acid and subsequent eicosanoids can influence inflammatory responses. Balancing omega-6 and omega-3 intake is essential to maintaining a healthy inflammatory state.

2.Arachidonic Acid (AA): Arachidonic acid (AA) is a polyunsaturated omega-6 fatty acid with a 20-carbon chain and four double bonds located at the 5th, 8th, 11th, and 14th carbon atoms from the carboxyl (COOH) end of the molecule. Commonly, it is denoted as **20:4(n-6)**. It is essential in the production of eicosanoids crucial for normal bodily functions, their overproduction or dysregulation can lead to pathological conditions, including chronic inflammation, cardiovascular diseases, and respiratory disorders, highlighting the importance of maintaining a balance in their production.

Arachidonic acid (AA) can also be synthesized in the body from linoleic acid (an omega-6 fatty acid). The conversion of linoleic acid into arachidonic acid occurs through enzymatic processes involving delta-6 desaturase, elongase, and delta-5 desaturase enzymes. Although, the efficiency of this conversion is relatively low in humans. A significant portion of linoleic acid is not converted into arachidonic acid. Various factors, such as age, dietary intake, and enzyme activity, affect conversion efficiency. For example, high intake of omega-6 fatty acids may inhibit the activity of the delta-5 desaturase enzyme, reducing the conversion of DGLA to AA. Therefore, it is important to take

Arachidonic Acid through food. Arachidonic acid is found primarily in animal-based foods, such as Meat, poultry, and eggs. Fish and seafood (though in smaller amounts).

Arachidonic acid (AA) plays a crucial role in cellular functions and is involved in various physiological processes, particularly those related to inflammation, immune response, and cell signaling. Let us delve in detail:

- Arachidonic acid serves as a precursor for a group of signaling molecules known as **eicosanoids**, which include **prostaglandins**, **thromboxanes**, and **leukotrienes**. These molecules play essential roles in regulating various physiological processes. **Prostaglandins** are involved in the regulation of inflammation, pain, and fever, helping the body respond to injury or infection. In next section of this unit, we explore more about prostaglandins. **Thromboxanes** contribute to blood clotting and the regulation of vascular tone, playing a key role in hemostasis and blood pressure regulation. **Leukotrienes**, on the other hand, are important in immune responses and inflammation, particularly in allergic reactions and conditions like asthma.
- AA is a key component of phospholipids in cell membranes, particularly in the brain, muscles, and liver. It helps maintain membrane fluidity and integrity, influencing signal transduction, receptor function, and membrane-associated enzyme activity.
- AA is abundant in the brain and supports the growth and repair of neurons. It contributes to synaptic function and plays a role in memory formation and learning. In infants and young children, AA is crucial for brain development.
- Arachidonic acid plays a role in muscle repair and hypertrophy (growth). It activates pathways that stimulate muscle protein synthesis and regeneration following exercise-induced damage.
- Through its role as a precursor to eicosanoids, AA helps regulate the immune response. It can promote inflammation to defend against infection and injury, but it also participates in resolving inflammation when no longer needed.
- AA is involved in reproductive processes, including implantation, placental function, and fetal development. It supports the synthesis of prostaglandins, which are necessary for labor and delivery.

4.8 Prostaglandins

Prostaglandins are a group of lipid-derived signaling molecules that play diverse roles in regulating physiological processes and mediating inflammatory responses. They belong to a larger class of compounds called eicosanoids, which are synthesized from arachidonic acid, a 20-carbon polyunsaturated fatty acid. Prostaglandins are not stored in cells but are produced on demand and act locally due to their short half-life. They are versatile signaling molecules with critical roles in inflammation, pain, fever, reproduction, and vascular regulation. While they are essential for maintaining health, their overproduction or imbalance can contribute to various diseases, making them important targets for therapeutic intervention.

Functions and Therapeutic Applications of Prostaglandins

Prostaglandins are lipid-derived signaling molecules that play essential roles in regulating physiological processes and mediating responses to injury and disease. They are synthesized from arachidonic acid through the action of cyclooxygenase (COX) enzymes and act locally due to their short half-life.

Functions of Prostaglandins:

Their functions are diverse, spanning inflammation, reproduction, cardiovascular health, and more, making them both critical for homeostasis and significant therapeutic targets.

1. Inflammation and Pain Regulation: Prostaglandins such as PGE₂ and PGI₂ amplify the inflammatory response by increasing vascular permeability, facilitating immune cell infiltration, and enhancing blood flow to injured tissues. They also sensitize nerve endings, increasing the perception of pain during tissue damage or inflammation. They have an important role in pain management and nonsteroidal anti-inflammatory drugs (NSAIDs) like ibuprofen and aspirin inhibit COX enzymes, reducing prostaglandin synthesis to alleviate pain, inflammation, and fever.

2. Fever Induction: PGE₂ acts on the hypothalamus, the body's temperature regulation center, to elevate the temperature set point in response to infections or inflammatory mediators, resulting in fever.

3. Reproductive and Uterine Functions: Prostaglandins like PGF₂ α and PGE₂ play critical roles in reproduction. They induce uterine contractions during labor and menstruation, regulate ovulation, and support sperm motility, contributing to fertility and parturition. Commonly, prostaglandin analogs like

dinoprostone (PGE₂) and carboprost (PGF₂α) are used to induce labor, manage postpartum hemorrhage, and in certain cases, facilitate therapeutic abortion.

4. Gastrointestinal Protection: PGE₂ is pivotal in maintaining gastric mucosal integrity by stimulating the secretion of mucus and bicarbonate, creating a protective barrier against stomach acid. It also inhibits gastric acid secretion, reducing the risk of ulcers. Misoprostol, a PGE₁ analog, is used to protect against NSAID-induced gastric ulcers by enhancing mucus and bicarbonate secretion.

5. Cardiovascular Regulation: Prostaglandins maintain a delicate balance in vascular tone and platelet activity:

- **Thromboxane A₂ (TXA₂)** promotes platelet aggregation and vasoconstriction, aiding in clot formation.
- **Prostacyclin (PGI₂)** counteracts TXA₂ by inhibiting platelet aggregation and promoting vasodilation, ensuring normal blood flow and preventing excessive clotting.

6. Bronchial and Pulmonary Function: Prostaglandins mediate bronchial tone, contributing to bronchoconstriction or bronchodilation, and are particularly significant in asthma and allergic reactions.

7. Renal Function: Prostaglandins regulate renal blood flow, sodium excretion, and glomerular filtration rate, which are essential for maintaining fluid balance and blood pressure.

Hopefully, you all gain the understanding of different types of lipids and fatty acids along with its importance and structural difference.

4.9 DIGESTION OF LIPIDS

Here is an overview of how lipid digestion occurs:

Mouth: The breakdown of lipids (fats) primarily begins with mechanical digestion through chewing. While lipids are not chemically broken down in the mouth like carbohydrates by enzymes in saliva, the physical breakdown of food into smaller particles helps prepare them for further digestion. Saliva, which contains some enzymes like lipase, begins the initial process of breaking down of lipids in small quantities. Lipase is an enzyme that starts to break down triglycerides into smaller molecules called fatty acids and glycerol.

Overall, the mouth's role in lipid digestion is more focused on mechanical processing and the initial steps of chemical breakdown, setting the stage for further digestion in the stomach and small intestine, where the majority of lipid digestion takes place.

Stomach: The digestion of lipids primarily occurs in the small intestine rather than the stomach. When you consume foods containing fats, they are broken down in a multi-step process that starts in the mouth with the action of lingual lipase, continues in the stomach briefly, and then intensifies in the small intestine with the help of bile acids and pancreatic enzymes.

In the stomach, gastric lipase, an enzyme secreted by the stomach's chief cells, begins the digestion of some triglycerides. However, the acidic environment of the stomach mainly serves to break down proteins, not fats. The majority of lipid digestion and absorption takes place in the small intestine where bile from the liver emulsifies fats, pancreatic lipase breaks down triglycerides into fatty acids and glycerol, and other enzymes act on different types of fats like cholesterol and fat-soluble vitamins.

So, while there is some lipid digestion occurring in the stomach, the primary site for the breakdown and absorption of fats is the small intestine where the process is more extensive and efficient.

Small Intestine: The majority of enzymatic lipid digestion occurs in the small intestine. Initially, large lipid droplets are broken down into smaller droplets to increase their surface area and make them accessible to digestive enzymes. This process is called emulsification and is primarily facilitated by bile salts secreted from the liver and stored in the gallbladder. Bile, which contains bile salts, lecithin, and cholesterol derivatives, acts as an emulsifier.

Once the stomach contents have been emulsified, pancreatic lipase, released by the pancreas, is the primary enzyme responsible for breaking down triglycerides (the main form of dietary fats) into fatty acids and glycerol. This enzyme works at the surface of lipid droplets. Colipase is another enzyme that works with pancreatic lipase to aid in the digestion of fats. Colipase helps pancreatic lipase anchor to the lipid droplets, allowing for more effective breakdown of triglycerides.

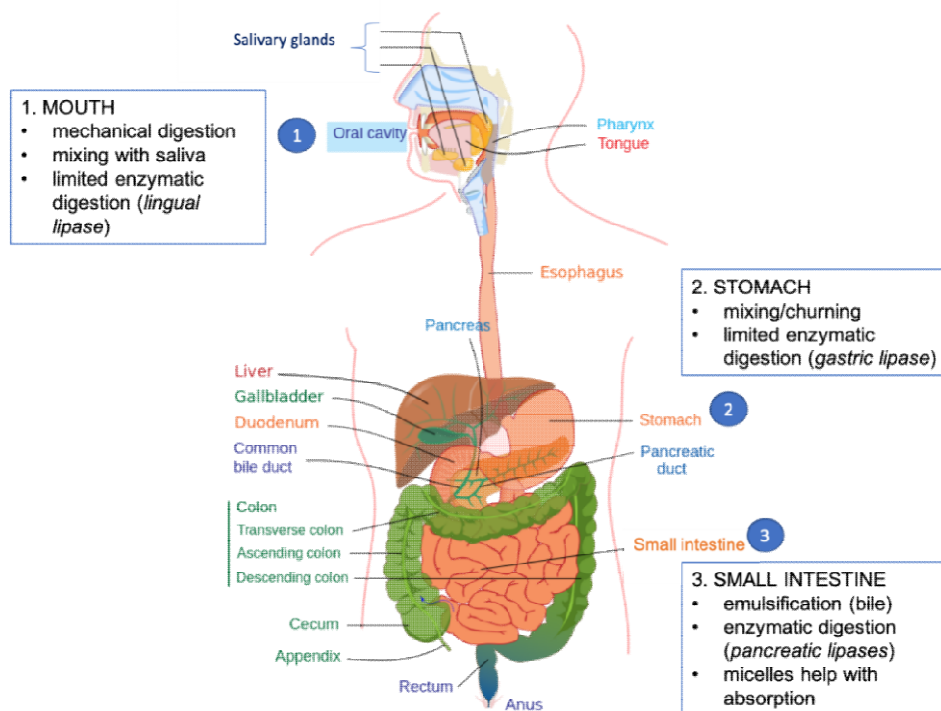


Figure 4.10: Overview of lipid digestion in the human gastrointestinal tract

4.10 ABSORPTION OF LIPID

The products of lipid digestion—free fatty acids and monoglycerides, which are hydrophobic molecules and cannot be directly absorbed across the water-based environment of the intestinal lumen. lipid digestion products combine with bile salts to form micelles. These micelles function to solubilize the lipids and carry them to the absorptive cells (enterocytes) lining the small intestine. Upon reaching the enterocyte surface, the free fatty acids and monoglycerides are reassembled into triglycerides.

Free Fatty Acid + Glycerol-3-phosphate → Triglyceride

The newly formed triglycerides are packaged into chylomicrons, which are lipoproteins that enter the lymphatic system and then the bloodstream to be transported to tissues. In the bloodstream, lipids are transported by different types of lipoproteins, categorized based on their density. Let's discuss in detail in next section

4.11 TRANSPORT OF LIPID

Lipids, such as cholesterol and triglycerides, are transported in the bloodstream within lipoproteins. Here is a brief overview of how lipids are transported within the body:

Chylomicrons: Chylomicrons involve in transporting dietary lipids from the intestines to various tissues, facilitating energy storage, use, and metabolism. Inside these cells, fatty acids and monoglycerides are reassembled into **triglycerides**. These triglycerides, along with cholesterol and phospholipids, are packaged into **chylomicrons**, which are large lipoprotein particles. These are too large to directly enter the bloodstream. Instead, they are released into the **lymphatic system**, bypassing the liver initially. They enter the bloodstream through the thoracic duct, delivering dietary triglycerides to tissues such as muscle and adipose tissue. The remnants of chylomicrons are taken up by the liver for processing.

VLDL (Very-Low-Density Lipoproteins): These particles are produced by the liver to transport endogenous triglycerides (triglycerides and cholesterol synthesize from carbohydrates and other precursors). They deliver triglycerides to various tissues and eventually become LDL after losing triglycerides.

LDL (Low-Density Lipoproteins): LDL particles transport cholesterol from the liver to the body's tissues. Because high amounts of LDL can cause plaque to accumulate in arteries, it is frequently referred to as "bad" cholesterol.

HDL (High-Density Lipoproteins): They assist in removing cholesterol from the bloodstream and artery walls and return it to the liver for processing and excretion and are referred to be "good" cholesterol.

Efficient lipid transport is crucial for maintaining overall health, as imbalances in lipid levels can contribute to heart disease, atherosclerosis, and other health problems. A healthy diet, regular exercise, and monitoring lipid levels are important for ensuring proper lipid transport and metabolism in the body.

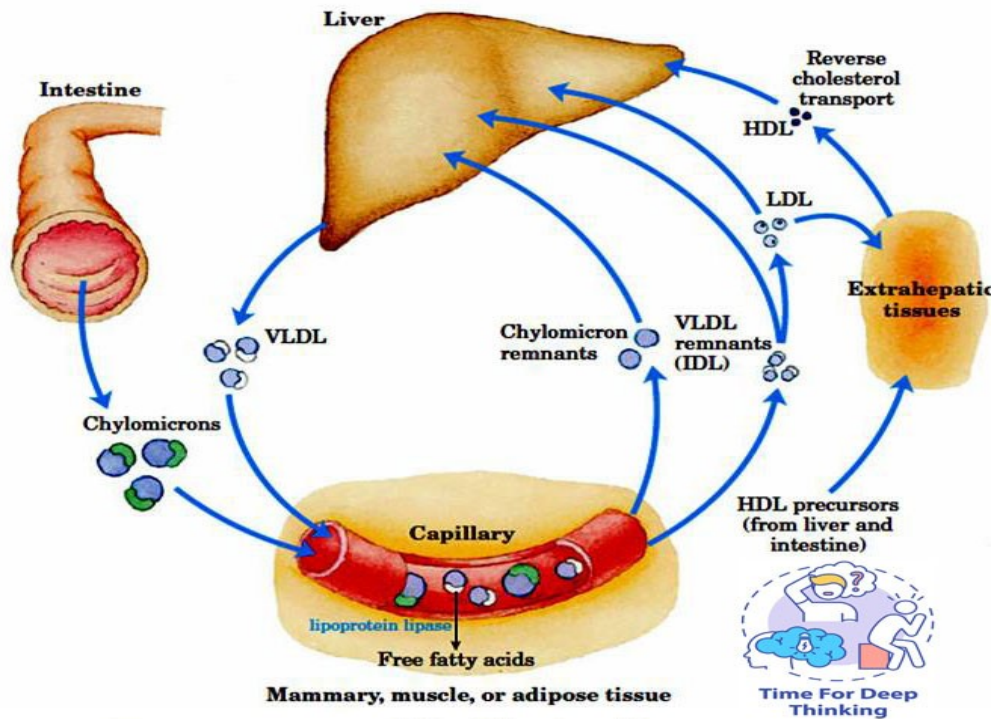


Figure 4.11

4.12 RECOMMENDED DIETARY ALLOWANCES (RDA)

The Recommended Dietary Allowance (RDA) for fat varies depending on factors such as age, sex, activity level, and physiological conditions like pregnancy and lactation. For adults, fat intake should comprise 20–35% of total daily calories, while children require slightly higher proportions—30–40% for ages 1–3 years and 25–35% for ages 4–18 years. Trans fats should be reduced or avoided completely because of their detrimental effects on heart health, and saturated fat consumption should be kept to less than 10% of daily calories to lower the risk of cardiovascular disease. With recommended intakes of omega-6 fatty acids (linoleic acid) at 17 g/day for men and 12 g/day for women, and omega-3 fatty acids (alpha-linolenic acid) at 1.6 g/day for males and 1.1 g/day for women, essential fatty acids (EFAs) are very significant. During pregnancy and lactation, increased fat intake is critical for fetal brain and eye development, particularly omega-3 fatty acids like DHA.

4.13 SOURCES OF FAT

Fats in the diet can be classified as visible and non-visible based on how they are consumed and perceived.

Visible fats are those that are easily identifiable and directly added to foods, such as oils, butter, ghee, and cream. They are apparent in cooking and meal preparation, making their consumption more deliberate. In contrast, **non-visible fats** are hidden within foods and often go unnoticed, despite contributing significantly to the overall fat intake. These include fats found in dairy products, meats, nuts, seeds, processed foods, and baked goods. Understanding the distinction between visible and non-visible fats is crucial for making informed dietary choices and managing fat intake effectively.

· **Visible Fats:** Oils, butter, ghee, cream, margarine.

Non-Visible Fats: Fat in dairy products, nuts, seeds, meat, processed foods, baked goods.

Fats are derived from both animal and plant-based sources and can be categorized into healthy and less healthy types based on their composition.

Healthy Fat Sources- These fats are primarily unsaturated, including monounsaturated and polyunsaturated fats. Example: olive oil (MUFA), walnuts, marine sources, chia seed, flaxseed, (Omega-3 Fatty Acids), Sunflower oil, safflower oil, soybean oil. Corn oil, cottonseed oil (omega-6 Fatty Acids).

Less Healthy Fat Sources- These fats are primarily saturated, and trans fats. These fats should be consumed in moderation as they may contribute to cardiovascular disease.

- **Sources of Saturated fat:** Animal-Based Sources: Butter, ghee, Fatty cuts of meat, Dairy products (cheese, cream, whole milk). Plant-Based Sources: Coconut oil, palm oil.
- **Trans Fats:** These fats are harmful to heart health and should be avoided. It is found in partially hydrogenated oils (margarine, shortening), processed foods (pastries, cakes, cookies), Fried fast foods.

CHECK YOUR PROGRESS EXERCISE 2

1. How do the chemical structures of monounsaturated and polyunsaturated fatty acids influence their physical properties?

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2. Discuss the role of prostaglandins in inflammation and pain regulation.

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3. What role does bile play in lipid digestion?

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4. Differentiate between HDL, LDL, and VLDL in terms of lipid transport.

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4.14 LET US SUM UP

In this unit, you learn that lipids are a diverse group of biomolecules essential for human health, with roles ranging from energy storage to cellular structure and signaling. Chemically, lipids consist of carbon, hydrogen, and oxygen, with their basic building blocks being fatty acids and glycerol. Lipids serve critical functions, including energy storage, cell membrane integrity, insulation, hormone production, and vitamin absorption.

They can be broadly divided into three categories: Simple, compound and derived lipid. Further, Lipids are primarily composed of fatty acids, which can be classified as either saturated or unsaturated. Monounsaturated (MUFA) and polyunsaturated fatty acids (PUFA) are subtypes of unsaturated fatty acids. Essential fatty acids, such as omega-3 and omega-6, are vital for good health but must be consumed through food. Derived from fatty acids, prostaglandins are essential for controlling pain, inflammation, and other physiological functions.

Lipid digestion and absorption occur in the small intestine, where they are emulsified by bile and absorbed as micelles. They are transported via lipoproteins to tissues. Dietary fat intake should align with RDAs, emphasizing healthy fats like those from nuts, seeds, and fish while minimizing trans and saturated fats for optimal health.

4.15 GLOSSARY

- **Lipids:** Organic compounds, insoluble in water but soluble in organic solvents.
- **Fatty Acids:** Building blocks of lipids, consisting of a hydrocarbon chain and a carboxylic acid group.
- **Triglycerides:** Simple lipids formed by glycerol and three fatty acids; main form of stored energy in the body.
- **Saturated Fatty Acids:** Fatty acids without double bonds, typically solid at room temperature.
- **Unsaturated Fatty Acids:** Fatty acids with one or more double bonds, usually liquid at room temperature.
- **Monounsaturated Fatty Acids (MUFA):** Unsaturated fatty acids with one double bond;
Polyunsaturated Fatty Acids (PUFA): Fatty acids with multiple double bonds, including omega-3 and omega-6 fatty acids.

- **Omega-3 Fatty Acids:** Essential PUFAs found in fish, flaxseeds, and walnuts; support brain and heart health.
- **Omega-6 Fatty Acids:** Essential PUFAs found in vegetable oils; crucial for growth and development.
- **Prostaglandins:** Hormone-like compounds derived from fatty acids, involved in inflammation and other physiological functions.
- **Emulsification:** Process by which bile salts break down fats into smaller droplets for digestion.
- **Micelles:** Tiny aggregates of lipid molecules that facilitate fat absorption in the intestine.
- **Lipoproteins:** Particles that transport lipids in the bloodstream, classified as HDL, LDL, and VLDL.
- **Phospholipids:** Compound lipids that form the structural components of cell membranes.
- **Steroids:** Derived lipids with a characteristic ring structure; include cholesterol and hormones.
- **Essential Fatty Acids (EFAs):** Fatty acids the body cannot synthesize, such as linoleic and alpha-linolenic acid.
- **Trans Fats:** Artificially produced fats with a trans configuration, linked to cardiovascular diseases.
- **Bile Salts:** Substances produced by the liver that emulsify fats during digestion.
- **Hydrogenation:** Industrial process that converts unsaturated fats to saturated or trans fats, enhancing shelf life.
- **Cholesterol:** A sterol found in cell membranes and used in the synthesis of hormones and bile acids.

4.16 ANSWER TO CHECK YOUR PROGRESS

Exercise 1

1. The three main classes of lipids are:
 - i. **Simple Lipids:** These include triglycerides (fats and oils) and waxes, composed of fatty acids and alcohol.
 - ii. **Compound Lipids:** These lipids contain additional components, such as phospholipids (with phosphate groups) and glycolipids (with carbohydrate groups).
 - iii. **Derived Lipids:** These are substances derived from simple or compound lipids, including steroids, cholesterol, and fat-soluble vitamins.

2. Phospholipids are the primary structural components of cell membranes. The unique properties of lipids enable them to form a flexible, dynamic barrier that separates the interior of the cell from its external environment. They are amphipathic in nature, meaning they have hydrophilic (water-attracting) heads and hydrophobic (water-repelling) tails. In aqueous environments, phospholipids naturally arrange into a bilayer, with the hydrophilic heads facing the water on either side of the membrane and the hydrophobic tails facing inward, avoiding water.

3. The saturation level of fatty acids affects their physical state at room temperature. Saturated fatty acids, with no double bonds, are typically solid at room temperature because their straight chains pack closely together. In contrast, unsaturated fatty acids, with one or more double bonds, are usually liquid at room temperature because the double bonds create bends in their chains, preventing tight packing.

Exercise 2

1. The chemical structure of monounsaturated fatty acids (MUFA) contains one double bond, which creates a bend in the carbon chain, preventing tight packing. This results in a liquid state at room temperature. Polyunsaturated fatty acids (PUFA) have multiple double bonds, causing more bends in the chain, which further reduces packing and also keeps them in a liquid state at room temperature. These structural differences contribute to the lower melting points of both MUFAs and PUFAs compared to saturated fatty acids, which have straight chains and are solid at room temperature.

2. Prostaglandins are lipid compounds that play a key role in inflammation and pain regulation. They are produced at sites of tissue damage or infection, where they help initiate the inflammatory response by promoting vasodilation, increasing blood flow, and sensitizing nerve endings to pain. Inflammation is amplified through the actions of prostaglandins, which also contribute to fever. By increasing the sensitivity of pain receptors, prostaglandins make the body more responsive to painful stimuli. Non-steroidal anti-inflammatory drugs (NSAIDs) work by inhibiting the enzymes responsible for prostaglandin production, thus reducing inflammation and pain.

3. Bile plays a crucial role in lipid digestion by emulsifying dietary fats, breaking them down into smaller droplets. This increases the surface area for the action of digestive enzymes, like lipase, which can then more effectively break down triglycerides into fatty acids and monoglycerides. Bile salts also help form micelles, which transport the products of lipid digestion to the intestinal cells (enterocytes) for absorption.

4. HDL, LDL, and VLDL are all types of lipoproteins involved in lipid transport, but they differ in their composition and function:

HDL (High-Density Lipoprotein): Known as "good cholesterol," HDL carries cholesterol from peripheral tissues back to the liver for excretion or recycling. It is high in protein and low in lipid content, helping to reduce cholesterol buildup in the arteries and protect against cardiovascular diseases.

LDL (Low-Density Lipoprotein): Often referred to as "bad cholesterol," LDL carries cholesterol from the liver to peripheral tissues. High levels of LDL can lead to cholesterol deposition in the arterial walls, contributing to plaque formation and increasing the risk of atherosclerosis and heart disease.

VLDL (Very Low-Density Lipoprotein): VLDL primarily transports triglycerides from the liver to adipose tissue and muscles. It is high in triglycerides and low in cholesterol. As VLDL circulates in the bloodstream, it is converted into LDL, increasing the risk of cardiovascular issues if levels are elevated.

In summary, HDL helps remove excess cholesterol, LDL delivers cholesterol to cells, and VLDL primarily carries triglycerides.

UNIT 5: WATER

STRUCTURE

5.1 Introduction

5.2 Chemical Structure of Water

5.3 Properties of Water

5.4 Requirement of Water

5.5 Distribution of Water

5.5.1. Intracellular Fluid (ICF)

5.5.2. Extracellular Fluid (ECF)

5.6 Water Balance

5.7 Regulation of Intra and Extracellular Volume

5.8 Factors Affecting Water Balance

5.9 Osmolality

5.10 Water Deprivation

5.11 Water Intoxication

5.12 Let Us Sum Up

5.13 Glossary

5.14 Answer to Check Your Progress

5.1 INTRODUCTION

Water is a basic substances that is necessary for life on Earth, playing a central role in countless biological processes. Its unique properties make it indispensable for the functioning of organisms, ecosystems, and the planet as a whole. An essential component of human physiology is the equilibrium of water and electrolytes, affecting cellular function, metabolism, and overall health. Maintaining this balance ensures that vital body functions operate smoothly, supporting homeostasis—the state of internal stability required for optimal bodily function. The main component of bodily fluids, water, is crucial for the movement of nutrients, regulating body temperature, and enabling biochemical reactions. Electrolytes, including calcium, magnesium, potassium, sodium, and chloride, are charged ions that help transmit electrical impulses, maintain fluid balance, and support cellular functions.

The body's water and electrolyte levels are closely interconnected. Water intake and output, primarily through urine, sweat, and respiration, affect electrolyte concentrations. For instance, sodium and potassium are key to regulating blood pressure and muscle contraction, and an imbalance in these electrolytes can result in issues like hypertension, muscle cramps, or dehydration. This regulation is managed by organs such as the kidneys, which filter and reabsorb water and electrolytes to maintain optimal levels, releasing excess through urine. Water reabsorption rates and electrolyte balance are regulated by hormones such as aldosterone and antidiuretic hormone (ADH), which adapt to the body's requirements.

The importance of this balance is underscored in conditions like dehydration, where excessive water loss through sweating, vomiting, or diarrhea can disturb electrolyte balance, leading to symptoms such as weakness, confusion, and even organ failure. Similarly, overhydration can dilute electrolytes, particularly sodium, causing hyponatremia, which leads to nausea, headaches, and in severe cases, seizures or coma.

Electrolytes also have critical functions in muscle and nerve cells. Sodium and potassium gradients across cell membranes generate action potentials, allowing nerve signal transmission and muscle contraction. Without proper balance, these functions are compromised. Calcium and magnesium contribute to heart function, muscle contraction, and bone health, with deficiencies potentially leading to arrhythmias, muscle spasms, or osteoporosis.

Expected Outcomes

This unit help you to describe:

- the chemical structure, properties, requirement and importance of water
- the composition and functions of intracellular and extracellular fluid
- the mechanisms involved in the regulation of water volume
- osmolality and explain various factor affecting it.
- physiological effects of water deprivation and water intoxication

5.2 CHEMICAL STRUCTURE OF WATER

Water is made up of one oxygen atom and two hydrogen atoms bound together by a covalent connection. Hydrogen and oxygen atoms share electrons unevenly in the special structure of water molecules, which gives hydrogen a tiny positive charge and oxygen a slight negative charge. This unique structure of water molecules makes it polar compounds. This arises polarity due to differences in electronegativity between oxygen and hydrogen atoms. The arrangement of these atoms gives water its distinctive bent shape, with a bond angle of approximately 104.5 degrees.

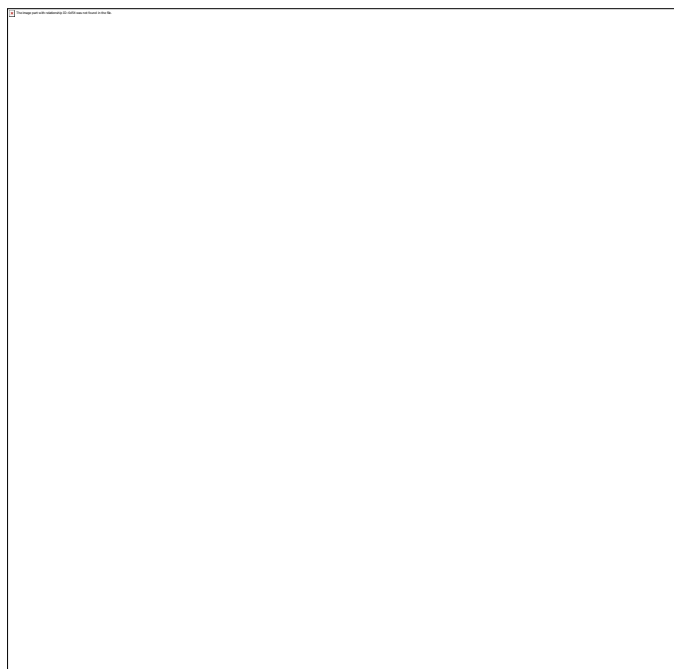


Figure 8.1: Water Molecule

(Source: Chris Martin/Public Domin)

Water can also dissolve polar molecules, such as sugars, alcohols, and organic acids, due to the hydrogen bonds that are formed between molecules of water and functional groups (e.g., hydroxyl and carbonyl groups) in the solute molecules. The hydrophilic ("water-loving") nature of polar molecules allows them to interact favorably with water molecules, leading to their dissolution. Water's polar nature enables it to dissolve ionic compounds by surrounding individual ions and separating them from the crystal lattice through hydration. This process, known as hydration or solvation, disrupts the ionic bonds between ions, allowing them to disperse uniformly in the solution. For example, salts like sodium chloride (NaCl) dissociate into sodium (Na^+) and chloride (Cl^-) ions when dissolved in water, forming an aqueous solution.

5.3 PROPERTIES OF WATER

Water serves as a versatile transporter in the human body, facilitating the movement of nutrients, gases, hormones, waste products, and heat energy between cells, tissues, and organs. Its role in nutrient absorption, oxygen transport, waste removal, hormone regulation, temperature regulation, and lubrication is essential for maintaining optimal health and physiological function.

Let's discuss the several unique properties of water that are critical for life:

- i. **Universal Solvent:** Water has an exceptional ability to dissolve a large range of compounds, often referred to as the "universal solvent". This unique property is fundamental to many biological, chemical, and environmental processes.
- ii. **Reactant:** Water's role as a reactant extends beyond its function as a solvent. It participates in a variety of chemical reactions, including hydrolysis, acid-base reactions, redox reactions, dehydration synthesis, and combustion reactions. Understanding water's reactivity is essential for comprehending its involvement in biological, environmental, and industrial processes. For example, in biological systems, hydrolysis reactions are essential for the breaking down complex compounds like proteins, lipids, and carbohydrates into their component monomers (such as glucose, fatty acids, and amino acids) for cellular functions and energy production.
- iii. **Cellular Function:** Within cells, water acts as a mediator for metabolic activities, facilitating processes such as metabolism, protein folding, and signal transduction. It also helps maintain the structural integrity of cells and organelles.

- iv. **Transport Medium:** Water is the primary component of blood plasma, the fluid portion of blood. Water transports essential nutrients like glucose, fatty acids, amino acids, etc from the digestive system to cells. It also facilitates the transport of hormones through the bloodstream to target cells and tissues. Hormones are chemical messengers that control the body's growth, metabolism, reproduction, and stress response, among other physiological functions. Water also helps to maintain blood viscosity, ensuring smooth flow through blood vessels and efficient delivery of oxygen to cells throughout the body.
- v. **Lubrication:** Water acts as a lubricant in various physiological systems, such as the joints, digestive tract, and respiratory tract. It reduces friction between moving parts, facilitates smooth movement, and protects tissues from damage or irritation.
- vi. **Removal of Waste Products:** The elimination of metabolic waste products from cells and tissues, including carbon dioxide, ammonia, and urea, is facilitated by water. Waste products are transported via the circulatory system to organs such as the kidneys, lungs, and liver for excretion from the body.
- vii. **Gas Exchange:** Extracellular fluids, including blood plasma and interstitial fluid, support gas exchange processes through inhalation and exhalation. Intercellular fluid ensures proper gas exchange within cells during cellular respiration and metabolic processes.
- viii. **Redox Reactions:** Water can participate in redox (oxidation-reduction) reactions, where it either gains or loses electrons. While water itself is not easily oxidized or reduced under normal conditions, it can act as a reactant in redox reactions involving other substances. For example, in photosynthesis, water molecules are oxidized to release oxygen gas (O_2) while donating electrons to chlorophyll molecules, which are subsequently used in the reduction of carbon dioxide to glucose. In electrolysis, water can be split into hydrogen (H_2) and oxygen (O_2) gases through the application of an electric current, a process known as water electrolysis.
- ix. **Regulation of pH Balance:** Both an acid and a base can be formed from water, participating in acid-base reactions and helps to maintain the body's acid-base balance. In these reactions, water donates or accepts protons (H^+) to or from other substances. For example, in the dissociation of acids in aqueous solution, water acts as a reactant by accepting a proton (H^+) to form hydronium ions (H_3O^+) and the conjugate base of the acid. Similarly, in the hydrolysis of bases, water donates a proton to form hydroxide ions (OH^-) and the conjugate acid of the base. This properties of fluids

maintains the pH of bodily fluids and tissues. Buffers present in intercellular and extracellular fluids help minimize changes in pH, preventing acidosis (excessive acidity) or alkalosis (excessive alkalinity).

- x. **Electrolyte Balance:** Electrolytes, including as sodium, potassium, chloride, calcium, and magnesium, are found in intercellular and extracellular fluids and are necessary for a number of physiological processes, such as fluid balance, muscle contraction, and nerve transmission. Electrolyte balance is crucial for maintaining proper hydration, cellular function, and overall homeostasis.
- xi. **Cellular Communication:** Intercellular fluid facilitates cellular communication and signaling by allowing the exchange of signaling molecules, hormones, and neurotransmitters between cells. Extracellular fluid, particularly interstitial fluid, supports communication between cells in tissues and organs, coordinating physiological processes and responses to internal and external stimuli. In summary, intercellular and extracellular fluids play essential roles in supporting cellular function, nutrient transport, waste removal, gas exchange, pH regulation, temperature regulation, electrolyte balance, and cellular communication. Maintaining proper hydration and balance of these fluids is crucial for overall health and physiological function.
- xii. **Temperature Regulator (thermoregulation):** Water is essential for thermoregulation, or regulating body temperature. process around 37°C (98.6°F) through various mechanisms such as sweating, evaporative cooling, circulatory system regulation, and hydration maintenance. It transports heat energy away from internal organs to the skin's surface, where it can be dissipated through processes such as sweating and evaporation. Its unique properties allow it to absorb, store, and release heat energy, helping to stabilize temperatures and maintain thermal equilibrium. The body's capacity to disperse heat and maintain thermal balance is improved when perspiration evaporates off the skin's surface. This process helps to dissipate excess heat generated during physical activity or exposure to high temperatures.

Adequate hydration is essential for effective thermoregulation because proper hydration levels ensures that the body can produce an adequate amount of sweat to cool itself efficiently.

Let's take a look at how much water our body actually needs.

5.4 REQUIREMENT OF WATER

The human body is largely composed of water, with adults containing about 37 to 42 liters, or roughly 80 pounds, of water. Thankfully, our bodies are made up of compartmentalized tissues, preventing us from resembling a water balloon! Newborns are about 70% water, while adult males typically have around 60% water, and adult females about 55%. The difference between genders is due to variations in body fat, as fat contains little to no water. As we age, the percentage of body water decreases, dropping to around 45% by the time we reach our eighties. The total daily recommended water requirements for adults about 2.7 litres, or roughly 91 ounces, for women and 3.7 litres, or roughly 125 ounces, for men. This total water intake comprises fluids from all sources, including foods high in moisture (such fruits and vegetables), beverages (including water, milk, juice, and tea), and metabolic water generated during the metabolism of macronutrients. Gender, age, body weight, degree of activity, and other factors all affect how much water a person needs.

Let's discuss the water requirements for different age group:

- Adequate hydration is essential for infants, typically they receive sufficient hydration from breast milk. Children aged 1 to 3 years typically require about consuming 4–6 cups (32–48 ounces) of water daily, while children aged 4 to 8 years may need about 5 to 7 cups (40 to 56 ounces) per day.
- Adolescents aged 9 to 13 years may require about 7 to 11 cups (56 to 88 ounces) of water per day, while those aged 14 to 18 years may need about 8 to 13 cups (64 to 104 ounces) per day.
- Pregnant and breastfeeding women have increased fluid needs to support maternal hydration, fetal development, and milk production.
- Older adults may have altered thirst perception, decreased kidney function, and increased risk of dehydration due to age-related changes.
- Individuals who engage in physical activity or exercise may have increased fluid needs to replace fluids lost through sweat and respiration. Hydration recommendations for athletes and active individuals differ according on elements like the length, intensity, and surroundings of the activity.

Please note that these are general guidelines, and it is essential to pay attention to thirst cues and drink water regularly throughout the day to maintain proper hydration

Next, let us study about the distribution of water.

5.5 DISTRIBUTION OF WATER

Water constitutes the majority of the body's volume, it contains a complex mixture of cells, nutrients, electrolytes, and other dissolved substances. Electrolytes are compounds that separate into charged ions when dissolved in water, with cations carrying a positive charge and anions a negative charge. In the human body, water and solutes (dissolved substances in fluids) are distributed across two primary compartments: Intracellular and Extracellular fluid. In the human body, fluid playing essential roles in maintaining cellular function, hydration, and overall homeostasis.



Figure 8.2: Body water distribution by Allison Calabrese/CC BY 4.0

Here's how water functions in both compartments:

5.5.1. Intracellular Fluid (ICF):

The intracellular fluid constituting about two-thirds of the body's total water content. It encompasses fluid inside cells and is essential for various cellular processes. It provides a medium for biochemical reactions within cells, including metabolism, protein synthesis, and cellular respiration. It also helps maintain cell structure, shape, and volume. The interchange of nutrients, waste products,

and signalling molecules across cellular compartments is made possible by the mobility of molecules and ions within cells, which is facilitated by water.

5.5.2. Extracellular Fluid (ECF):

The extracellular fluid constitutes about one-third of the body's total water content. It includes all the fluids located outside of the body's cells. For example- blood plasma, interstitial fluid, and transcellular fluid. They act as a conduit for hormones, nutrition, and the elimination of waste from the body. They also make it easier for cells and blood vessels to exchange gases, nutrients, and signalling molecules. Specialised fluids located in certain compartments are known as transcellular fluids. Examples of these include aqueous humour in the eyes, synovial fluid in joints, and cerebrospinal fluid in the central nervous system. These fluids serve various functions, including cushioning, lubrication, and protection of organs and tissues. The movement of water between intracellular and extracellular compartments is crucial for maintaining cell volume, osmotic balance, and overall fluid homeostasis in the body.

Now, move to learn about the concept of water balance.

5.6 WATER BALANCE

When a person's water intake is equal to water output then it is said to be in water equilibrium or water balance. Water balance is to ensure the balance between water intake and water output to maintain proper hydration and physiological function. The regulation of water balance is crucial for maintaining overall health and homeostasis.

Here's an overview of water balance and its regulation mechanisms:

1. Water Intake: The primary source of water intake is through drinking fluids, such as water, beverages, and foods with high water content. Fluid intake is a crucial determinant of water balance. Drinking an adequate amount of water and other fluids is essential for replenishing lost fluids, supporting cellular function, and maintaining hydration. Factors influencing fluid intake include thirst, access to clean drinking water, individual hydration needs, cultural habits, and environmental conditions (e.g., temperature, humidity).

2. Water Loss: The body loses water in a number of ways, including through urine, feces, sweating, evaporation from the skin and respiratory tract, and metabolic processes. The kidneys play an important role in regulating water balance by adjusting urine production and excretion based on the body's

hydration status and electrolyte levels. Environmental factors, health status, and physical activity level all affect the amount fluid gets lost. Factors affecting fluid loss include sweating during exercise or in hot environments, increased respiratory water loss (e.g., during breathing or respiratory illnesses), and conditions that increase urine output (e.g., diuretic medications, diabetes insipidus).

Maintaining a proper water balance is crucial for optimal bodily functions, including temperature regulation, waste removal, and nutrient transport.

Negative Water Balance- A negative water balance occurs when water loss from the body exceeds water intake, leading to dehydration. This imbalance can result from insufficient water consumption, excessive sweating, vomiting, diarrhea, or conditions like diabetes insipidus. Dry mouth, exhaustion, reduced urine production, and in extreme situations, confusion, are signs of dehydration. Long-term negative water balance can impair bodily functions such as thermoregulation, digestion, and kidney function.

Positive Water Balance- A positive water balance happens when water intake exceeds the body's needs, leading to overhydration or water retention. This can occur due to excessive water consumption, kidney issues, or hormonal imbalances like those caused by ADH (antidiuretic hormone). In extreme cases, it may lead to hyponatremia (low sodium levels in the blood), causing symptoms like nausea, headache, confusion, and in severe instances, seizures or coma.

Electrolyte Balance: **Electrolytes that are important for fluid balance include sodium (Na⁺), potassium (K⁺), calcium (Ca²⁺), and chloride (Cl⁻).** Sodium is the primary extracellular electrolyte, while potassium is the main intracellular electrolyte.

In the extracellular fluid, sodium is the most prevalent cation, with a typical concentration of around 135-145 milliequivalents per liter (mEq/L). It accounts for over 90% of the cations in the extracellular space, playing a vital part in preserving the fluid equilibrium of the body. The distribution of sodium between the extracellular and intracellular spaces is strictly controlled; the majority of sodium is found outside cells, while only a small fraction is inside. This distribution is crucial for maintaining the proper osmolarity, or solute concentration, of body fluids.

Potassium is the primary cation within the intracellular fluid, with a typical concentration of about 140-150 milliequivalents per liter (mEq/L) inside cells, compared to only between 3.5 to 5.0 mEq/L in

the extracellular fluid. Cellular processes closely regulate this distribution, especially the sodium-potassium pump, which actively moves potassium into cells and sodium out, preserving a high potassium content within the cell and a low concentration outside. This gradient is essential for various cellular functions, including maintaining cell membrane potential and regulating cell volume. Proper potassium regulation is crucial for muscle contraction, heart function, and nerve signal transmission, highlighting its importance in maintaining cellular and physiological stability.

The main negatively charged ion (anion) in the extracellular fluid is chloride, with typical concentrations ranging from 96 to 106 milliequivalents per liter (mEq/L). It is the most abundant extracellular anion, complementing the high concentration of sodium outside cells. The distribution of chloride between the intracellular and extracellular compartments is crucial for maintaining the electrical neutrality of body fluids, as it often pairs with positively charged cations like sodium. Inside cells, chloride levels are much lower, reflecting its role predominantly in the extracellular space.

An imbalance in these electrolytes can cause shifts in fluid distribution, leading to conditions like dehydration or edema (swelling).

5.7 REGULATION OF INTRA AND EXTRACELLULAR VOLUME

Maintaining proper fluid balance within the body, which is essential for various physiological functions, which regulated by selective permeability of cell membranes.

Here's an overview of the mechanisms involved in regulating intra- and extracellular volume:

13 Osmoregulation: The body maintains the balance of water and electrolytes (salts) to ensure a stable internal environment through the process of Osmoregulation. It is a crucial process for proper cell function and overall homeostasis. This regulation involves managing the body's fluid levels, solute concentrations, and maintaining the correct osmotic pressure in order to ensure that cells do not enlarge or contract. Osmoregulation is largely controlled by the kidneys, which filter blood to eliminate waste, excess water, and salts. They control the solute concentration in the blood.

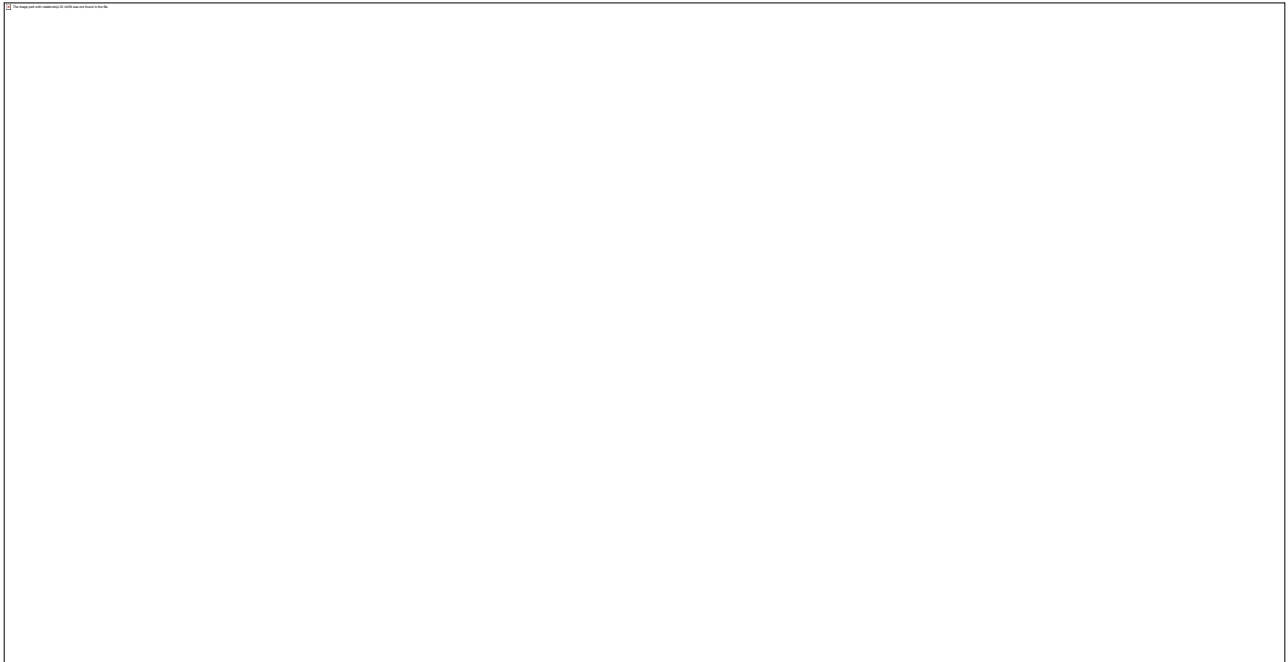


Figure 8.3 : Osmoregulation

(Source: Mariana Ruiz/ Public domin)

- 14 Role of the Kidneys:** The kidneys are the central organs responsible for regulating water and electrolyte balance. They filter blood, removing excess waste, electrolytes, and water, while reabsorbing the necessary amounts back into the bloodstream. Water and electrolytes like salt, potassium, and chloride are filtered out of the blood in the nephrons, the kidney's functional units, and then either selectively reabsorbed or expelled based on the body's requirements. The kidneys produce more urine when the body has too much fluid, eliminating the extra water and preserving electrolyte balance. On the other hand, the kidneys preserve water when the body is dehydrated by producing less urine, ensuring that fluid balance and electrolyte levels remain stable. This precise control helps maintain blood pressure and ensures that cells have the right environment for optimal functioning.
- 15 Antidiuretic Hormone (ADH):** This hormone, also referred to as vasopressin, is released by the posterior pituitary gland in reaction to high blood osmolarity, or low water concentration. Osmoreceptors trigger the production of ADH when plasma osmolality rises (hyperosmolality), which causes the kidneys to reabsorb water and retain fluid. Conversely, when the body has adequate or excess water or plasma osmolality decreases (hyposmolality), ADH

secretion decreases, resulting in increased urine output and excretion of excess water. Hence, it increases water reabsorption in the kidneys, concentrating urine and conserving water.

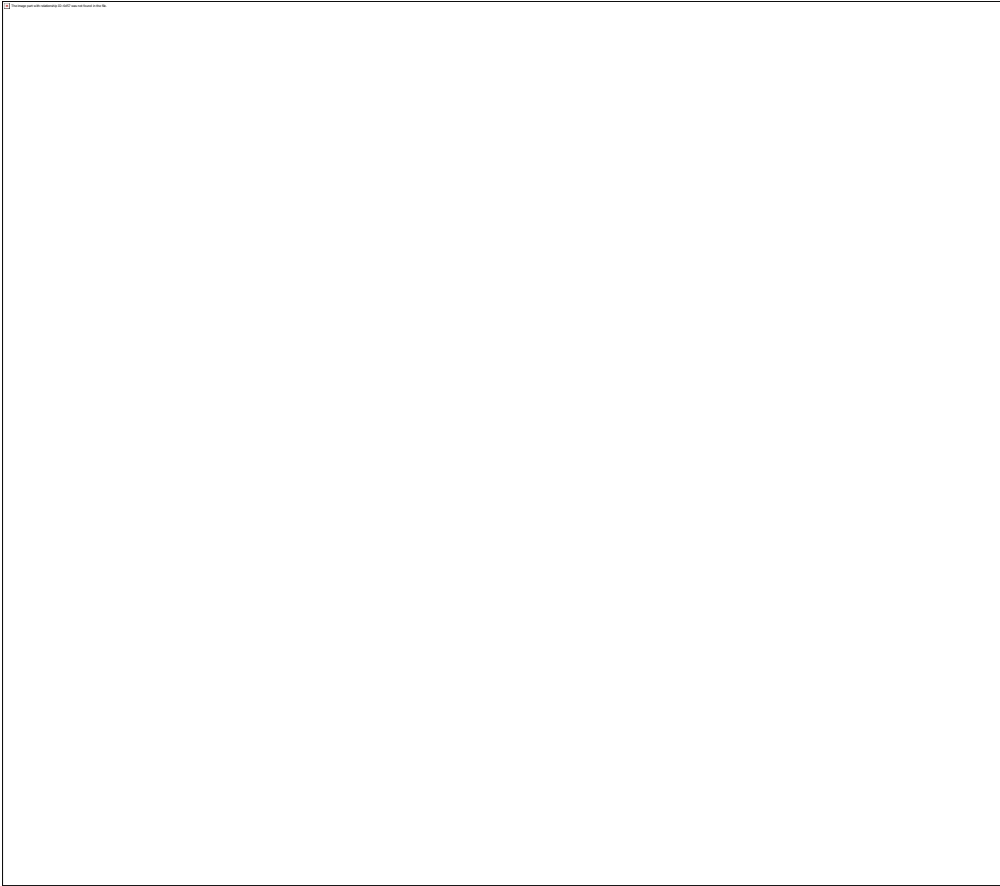


Figure 8.4: Mechanism of Regulating Water Output

(Source: Allison Calabrese/CC BY 4.0)

16 Aldosterone: The adrenal glands, which are located above the kidneys, create the hormone **aldosterone**. Aldosterone is a hormone essential for regulating sodium and potassium levels and secreted by the adrenal glands, which sit atop the kidneys. It is key to maintaining water balance in the body.

When blood pressure is low or sodium levels are reduced, aldosterone is released. It influences the kidneys, encouraging them to return more salt to the bloodstream through reabsorption from the urine. This reabsorption raises blood volume because water follows sodium, which aids in bringing blood pressure back to normal. Aldosterone simultaneously encourages potassium excretion, ensuring

that potassium levels in the blood remain balanced. This regulation of sodium and potassium is crucial for maintaining proper electrolyte balance, fluid levels, and blood pressure.

The body's electrolyte and water balance is a finely regulated process, primarily controlled by the kidneys, Antidiuretic Hormone (ADH), and aldosterone. The kidneys serve as the main regulator, adjusting urine composition based on signals from ADH and aldosterone. ADH directly controls the amount of water reabsorbed, influencing blood volume and osmolality. Aldosterone, meanwhile, adjusts sodium and potassium levels, indirectly affecting water retention. These systems work together to ensure the body maintains proper hydration, electrolyte levels, and blood pressure. This coordination ensures that the body maintains a stable internal environment, or homeostasis, which is essential for healthy cellular function, stable blood pressure, and overall well-being.

Hopefully you get understand, how each plays a role in maintain the body's water-electrolyte balance. Impaired kidney function can lead to fluid imbalances, either through fluid retention (leading to swelling) or excessive fluid loss (causing dehydration).

Let's study another important mechanism for fluid balance in body.

Osmosis: Osmosis is the main mechanism by which fluid moves between the intracellular and extracellular compartments in response to changes in hydrostatic or oncotic pressure. In order to maintain fluid distribution equilibrium, water travels by osmosis from an area with a lower solute concentration to one with a higher solute concentration. For instance Increases in hydrostatic pressure, or the force that a fluid exerts on the capillary walls, cause fluid to be forced out of the blood vessels and into the interstitial space, which is the surrounding tissue. This may result in edema, a disorder in which tissues enlarge due to fluid buildup. Similarly, the pressure that proteins (mostly albumin) in the plasma apply to assist draw water into the capillaries is called oncotic pressure, also referred to as colloid osmotic pressure. Fluid may move from the blood vessels into the tissues as a result of a drop in oncotic pressure brought on by low blood protein levels, which can exacerbate swelling and fluid imbalance. These pressures are crucial for maintaining the correct volume and composition of fluids in the body's compartments. Any alteration in these pressures—whether from injury, disease, or changes in blood protein levels—can disrupt fluid balance, affecting hydration and organ function.

- 17 Atrial Natriuretic Peptide (ANP):** Atrial natriuretic peptide (ANP) is stored in granules within the atrial muscle and is released when sodium retention occurs. Sodium retention leads to **hypertension** and an expansion of the extracellular fluid (ECF), causing the atria to become distended due to increased blood flow. This distension stretches the atrial muscle, triggering the release of ANP from its stored granules. ANP functions in opposition to angiotensin II; it inhibits sodium reabsorption in the renal tubules, which helps the kidneys excrete more water and sodium. This leads to increased urine output and a reduction in ECF volume, ultimately causing **hypotension** and reducing heart strain.
- 18 Neural Regulation:** Vasoconstriction and elevated blood pressure can result from sympathetic nervous system activation. renal sodium and water retention, contributing to increased extracellular fluid volume. Conversely, inhibition of the SNS can lead to vasodilation and increased renal blood flow, promoting sodium and water excretion.
- 19 Thirst Mechanism:** The primary mechanism for regulating water intake is sensation of thirst. It is triggered by changes in blood osmolality and volume, detected by specialized osmoreceptors and baroreceptors located in the brain and blood vessels. When the concentration of solute increases or blood volume decreases, osmoreceptors and baroreceptors signal the brain's thirst center, prompting individuals to feel thirsty. Thirst prompts individuals to drink fluids, leading to increased water intake and replenishment of water stores in the body. Once hydration levels are restored, the sensation of thirst diminishes, helping to maintain proper hydration.



Figure 8.5: Mechanism of Water Intake

(Source: Allison Calabrese/CC BY 4.0)

Renin-Angiotensin-Aldosterone System (RAAS): The RAAS hormonal system regulates blood pressure, salt balance, and water retention in response to changes in blood volume and pressure. A decrease in blood volume or pressure causes the kidneys to release renin. Angiotensin-converting enzyme (ACE) converts angiotensin I, which is produced by renin, into angiotensin II. Angiotensin II stimulates the release of aldosterone via acting on the adrenal cortex. Aldosterone causes the kidneys to better absorb sodium, which increases water retention and the level of extracellular fluid. This mechanism helps restore blood volume and pressure by conserving water and sodium in the body. Conversely, when blood volume or pressure is high, RAAS activity is inhibited, leading to decreased aldosterone secretion and increased water excretion.

In conclusion, regulation of intra- and extracellular volume involves complex interactions between the kidneys, hormones, neural pathways, and osmoregulatory mechanisms. Proper fluid balance is necessary to keep homeostasis and ensuring optimal physiological function. Dysregulation of fluid volume can lead to various health problems, including dehydration, edema, and electrolyte

imbalances. Overall, these mechanisms work synergistically to maintain water balance in the body, ensuring proper hydration levels and supporting overall health and physiological function. Dysregulation of these mechanisms can lead to dehydration, overhydration, electrolyte imbalances, and other health issues.

CHECK YOUR PROGRESS EXERCISE 1

1. Why water is known as universal solvent?

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2. What is osmosis, and how does osmosis contribute to the movement of water across cell membranes?

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3. What is the role of antidiuretic hormone (ADH) in regulating fluid balance?

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4. How does aldosterone influence sodium and water reabsorption in the kidneys?

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5.8 FACTORS AFFECTING WATER BALANCE

Several factors can influence water balance in the body, affecting the intake, retention, and excretion of water. Understanding these factors is essential for maintaining proper hydration levels and overall health. Here are the key factors affecting water balance:

- **Environmental Factors:** Environmental factors, such as temperature, humidity, and altitude, can influence water balance by affecting fluid loss through sweating and respiration. Hot and humid conditions increase the risk of dehydration due to excessive sweating, while dry or cold environments may lead to increased respiratory water loss and fluid requirements.
- **Diet:** Dietary factors play a role in water balance by contributing to both fluid intake and output. Hydration can be facilitated by foods high in water content, such as fruits, vegetables, soups, and drinks. Certain foods and beverages, such as salty snacks, caffeinated drinks, and alcoholic beverages, can increase urine output and fluid loss, potentially affecting water balance.
- **Physical Activity:** Physical activity influences water balance by increasing fluid loss through sweating and respiration. Intense or prolonged exercise can lead to significant fluid loss and electrolyte depletion, requiring increased fluid intake to maintain hydration. Athletes and individuals engaged in strenuous activities should monitor their fluid intake and electrolyte levels to prevent dehydration and optimize performance.

5.9 OSMOLALITY

Osmolality, or the number of moles of solute per kilogramme of solvent, is a measure of the concentration of solutes in a solution. It is frequently used to evaluate the body's fluid and electrolyte

balance and is a measurement of the solute concentration in a fluid. Osmolality is important for maintaining proper cellular function, osmotic pressure, and hydration status in the body. Solutions with higher osmolality have a greater concentration of solutes and exert higher osmotic pressure than solutions with lower osmolality.

The body's fluid equilibrium depends on solutes because they affect how water moves between cells and compartments. They also play a critical role in physiological functions like nerve signaling, muscle contraction, and nutrient transport. Next, we discussed the role of key solute in osmolality is discussed below:

9. Sodium contributes significantly to the osmolality of the extracellular fluid, affecting the movement of water across cell membranes. When sodium levels increase, osmolality rises, causing water to move out of cells to restore balance, and when sodium levels decrease, osmolality drops, leading to water movement into cells. This regulation of sodium and osmolality is vital for normal cell function and overall fluid homeostasis.
10. Potassium's role in osmolality is primarily within the intracellular compartment, where it significantly contributes to the osmolarity of the fluid inside cells. The concentration of potassium influences water movement across the cell membrane, impacting cell hydration and function. Changes in potassium levels can lead to shifts in intracellular and extracellular water, which can affect cell volume and overall fluid balance in the body.
11. Chloride plays a key role in regulating osmolality, particularly in the extracellular fluid. It contributes significantly to the osmolarity of blood plasma, influencing the movement of water between the intracellular and extracellular compartments. Chloride's ability to follow sodium, both electrically and osmotically, ensures that water distribution is balanced, impacting hydration status, blood pressure, and overall fluid equilibrium. Additionally, chloride is involved in the production of hydrochloric acid in the stomach for digestion and in maintaining acid-base balance in the blood, highlighting its importance for both fluid regulation and metabolic functions.

Importance:

Osmolality, or the number of moles of solute per kilogramme of solvent, is a measure of the concentration of solutes in a solution. It is frequently used to evaluate the body's fluid and electrolyte balance and is a measurement of the solute concentration in a fluid. Osmotic pressure, cellular activity,

and the body's level of hydration are all dependent on osmolality. Solutions with higher osmolality have a greater concentration of solutes and exert higher osmotic pressure than solutions with lower osmolality.

Osmolality is essential for maintaining the body's osmotic equilibrium and fluid balance. In order to support cellular function and homeostasis, it aids in maintaining the appropriate distribution of water and solutes between intracellular and extracellular compartments. Osmolality affects how water moves through cell membranes through osmosis; in order to equalise osmotic pressure, water moves from areas of lower osmolality (lower solute concentration) to areas of higher osmolality (higher solute concentration). Proper osmolality is essential for maintaining hydration status, electrolyte balance, blood pressure, and renal function. Deviations from normal osmolality levels can have significant physiological consequences and may indicate underlying health conditions.

Osmolality measurements are used clinically to assess fluid and electrolyte balance, diagnose and monitor various medical conditions. Abnormal osmolality levels may indicate conditions such as dehydration, overhydration, electrolyte imbalances, renal dysfunction, diabetes mellitus, and disorders of water metabolism.

5.10 WATER DEPRIVATION

Water deprivation, or insufficient water intake relative to the body's needs, can have various effects on the body ranging from mild dehydration to severe complications. The impact of water deprivation depends on factors such as the duration and severity of dehydration, individual differences in hydration status, and underlying health conditions.

The most immediate and noticeable effect of water deprivation is dehydration. Dehydration leads to a decrease in plasma volume (blood volume) and a rise in blood osmolality, affecting cellular function and overall health.

Let's discuss it further in detail:

Water deprivation is characterized by dry mouth followed by dry skin, fatigue and dizziness. Dehydration causes the body to pull water from the extracellular fluid (ECF), which in turn draws water from the intracellular fluid (ICF) to restore balance, leading to a decrease in both ECF and ICF volumes. Further, cell metabolism is disturbed and leads to loss of potassium. Further, to conserve water in the body, urine output decreases by increased secretion of ADH. Excretion of electrolytes also

decreases and produces dark urine. Moreover, dehydration decreases blood volume can lead reduced cardiac output and cardiac arrest. Severe dehydration and vomiting, which are more common in infants and children, make them particularly vulnerable to fluid loss and dehydration.

Dehydration can impair alertness, memory, cognitive abilities and overall cognitive performance. Additionally, water deprivation can negatively impact physical performance and exercise capacity by impairing thermoregulation and decreased blood flow to muscles and organs. Athletes and individuals engaged in strenuous physical activity are particularly susceptible to the effects of dehydration, as even mild fluid loss can lead to decreased exercise performance, increased fatigue, and impaired recovery.

In Water deprivation, there is not only water loss but also losses of both sodium and potassium and can disrupt electrolyte balance (abnormalities in sodium, potassium, chloride, and other electrolyte levels) in the body. Dehydration can result in electrolyte imbalances sodium, potassium and chloride, which can have serious health consequences if left untreated.

Prolonged water deprivation can cause kidney dysfunction and increase the risk of kidney stones, urinary tract infections, and other renal complications. Dehydration reduces urine output and can lead to concentrated urine, which may contribute to the formation of kidney stones. Chronic dehydration may also increase the risk of urinary tract infections by reducing urinary flow and impairing the body's ability to flush out bacteria and toxins from the urinary tract.

Water deprivation can affect digestive function and contribute to gastrointestinal problems such as constipation, bloating, and indigestion. Adequate hydration is essential for maintaining bowel regularity and preventing constipation by softening stool and promoting gastrointestinal motility. Chronic dehydration may exacerbate digestive issues and increase the risk of gastrointestinal disorders such as gastritis, ulcers, and irritable bowel syndrome (IBS).

Heat cramps, heat exhaustion, raised core body temperature, and potentially fatal heatstroke can result from the body's inability to dissipate heat due to inadequate fluid intake.

Overall, water deprivation can have significant adverse effects on physical and mental health, ranging from mild discomfort to severe complications. It is essential to stay adequately hydrated by drinking water regularly throughout the day and paying attention to thirst cues to prevent dehydration and maintain optimal hydration status.

5.11 WATER INTOXICATION

A potentially harmful disease known as water intoxication, or hyponatraemia, happens when consuming too much water causes the blood's salt levels to drop dangerously low. An essential electrolyte, sodium is essential for sustaining proper cellular function and controlling fluid balance. The equilibrium of fluids inside and outside the body's cells is upset when sodium levels fall sharply. This imbalance causes cells to swell, leading to severe complications, especially in the brain.

Water intoxication is typically caused by consuming large amounts of water in a short period, overwhelming the kidneys' ability to excrete it. The kidneys can process around 0.8-1.0 liters of water per hour, but consuming more than this can result in excess water accumulating in the body. This dilutes sodium levels in the blood, triggering hyponatremia.

Certain situations increase the risk of water intoxication:

12. **Endurance sports:** Athletes, particularly those participating in long-duration activities like marathons, triathlons, or long-distance running, often drink large amounts of water to stay hydrated. However, excessive water intake without replenishing electrolytes can lead to a dilution of sodium levels.
13. **Drug-induced polydipsia:** Certain medications (such as antipsychotic drugs) or recreational drugs can increase thirst or alter the body's ability to regulate water balance, leading to excessive water consumption.
14. **Psychogenic polydipsia:** Some individuals have a psychological disorder that leads to compulsive water drinking. This condition is often seen in individuals with mental health issues like schizophrenia, where an uncontrollable urge to drink water can result in water intoxication.
15. **Medical conditions:** Diseases that affect the body's ability to manage fluids and electrolytes include kidney problems, heart failure, and hormonal imbalances like adrenal insufficiency. This makes it easier for water intoxication to occur when large amounts of water are consumed.

Effects and Symptoms:

The symptoms of water intoxication arise due to the dilution of sodium levels in the bloodstream, which disrupts the normal functioning of cells. As sodium becomes diluted, water flows into the cells,

causing them to swell. This is particularly harmful for the brain, where swelling can cause cerebral oedema, or swelling of the brain, which manifests as symptoms like:

16. Nausea and vomiting
17. Headache
18. Lethargy and confusion
19. Muscle weakness
20. Seizures
21. Cerebral edema, leading to brain swelling
22. Respiratory distress
23. Coma
24. In extreme cases, death can occur due to severe brain swelling or complications like cardiac arrest and organ failure.

Water intoxication is a medical emergency that requires prompt attention. The primary goal of treatment is to restore sodium levels in the body and reduce the swelling in the brain. This is typically done through controlled intravenous (IV) administration of saline solutions to gradually raise sodium levels and correct the electrolyte imbalance. In severe cases, medications may be given to control brain swelling and reduce the risks of seizures or other complications.

In conclusion, excessive water consumption that results in a severe drop in blood sodium levels can produce water intoxication, a serious and sometimes fatal illness. It can occur in specific circumstances such as extreme physical exertion, certain medical conditions, or psychological disorders. Immediate medical intervention is crucial to prevent severe complications and restore the body's electrolyte balance.

CHECK YOUR PROGRESS EXERCISE 2

- How does osmolality influence the movement of water between cells and extracellular fluid?

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2. What are the effects of water deprivation?

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3. What is water intoxication ?

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5.12 LET US SUM UP

In this unit, the importance of water and electrolytes in sustaining the body's many physiological processes becomes clear to us. Water represents around 60% of the weight of the human body and is essential for several functions, such as waste elimination, nutrient transport, and temperature regulation. In addition to helping to maintain blood pressure and volume, it acts as the medium for the majority of metabolic reactions. Proper hydration is crucial for the optimal functioning of organs and tissues, as even mild dehydration can impair cognitive function, physical performance, and organ efficiency.

Electrolytes are essential for preserving fluid balance, neurone function, and muscular contraction, as we have previously discussed. Sodium, potassium, chloride, calcium, and magnesium are examples of common electrolytes. Sodium and potassium are particularly important for regulating fluid balance and maintaining proper cell function. These electrolytes help generate electrical impulses that control muscle contractions, including those of the heart.

Further, the balance between water and electrolytes is tightly regulated by the kidneys, which filter excess water and electrolytes to maintain homeostasis. Imbalances, such as dehydration, overhydration, or electrolyte disturbances, can lead to serious health issues, including muscle cramps, confusion, and in severe cases, heart arrhythmias or organ failure. Thus, adequate hydration and electrolyte balance are critical for overall health and well-being.

5.13 GLOSSARY

1. Dehydration: Loss of body fluids, leading to an imbalance in electrolytes and water.
2. Desiccation: State of extreme dryness, often caused by prolonged water deprivation.
3. Water stress: Condition where the body's water requirements are not met, leading to impaired physiological function.
4. Hyponatremia: Condition in which drinking too much water dilutes the body's salt levels.
5. Water poisoning: Rare condition where excessive water consumption leads to an imbalance of electrolytes in the body.
6. Dilutional hyponatremia: Condition where excessive water consumption dilutes the body's sodium levels.
7. pH: Measure of water's acidity or basicity, ranging from 0 to 14.
8. Alkalinity: Measure of water's ability to neutralize acids.
9. Hardness: Measure of water's calcium and magnesium content.
10. Solubility: Ability of water to dissolve substances.
11. Viscosity: Measure of water's resistance to flow.

- 12. Hydrophilic: Property of a substance that attracts and holds water.
- 13. Hydrophobic: Property of a substance that repels water.
- 14. Emulsification: Ability of water to mix with oils and fats.
- 15. Gelation: Ability of water to form a gel-like substance when combined with other ingredients.
- 16. Hydration: Ability of water to absorb and retain moisture in food.

5.14 ANSWER TO CHECK YOUR PROGRESS

EXERCISE 1

10. Water's capacity to dissolve a broad range of compounds received it the term "universal solvent." This is because it is polar, with the hydrogen atoms having a slight positive charge and the oxygen atoms having a slight negative charge. Water's polarity permits it to interact with and dissolve many ionic compounds (like salts) and polar molecules (such as sugars) by surrounding and breaking their bonds. The dissolving process can be helped by the attraction of positively charged ions by the negative oxygen atoms and negatively charged ions by the positive hydrogen atoms. As a result, water can dissolve more substances than most other liquids, making it essential for various biological and chemical processes.

11. Osmosis is the process by which water molecules migrate from a region of lower solute concentration to one of higher solute concentration through a selectively permeable membrane. The purpose of this procedure is to balance the solute concentrations on both sides of the membrane. Osmosis contributes to the movement of water across cell membranes, maintaining proper cell hydration, and regulating the balance of fluids within and outside the cell. It helps cells maintain their shape and volume by controlling water intake and removal based on osmotic gradients.

12. Vasopressin, an alternative term for antidiuretic hormone (ADH), is a hormone that regulates the quantity of water that the kidneys reabsorb, which is essential for maintaining fluid balance. The pituitary gland releases ADH when the body is dehydrated when the blood osmolarity is high. By increasing the permeability of the collecting ducts and distal convoluted tubules, ADH instructs the kidneys to retain more water, enabling more water to be reabsorbed into the bloodstream. This helps conserve water, dilute the blood, and restore proper fluid balance. Conversely, when fluid levels are adequate, ADH release is reduced, allowing excess water to be excreted in urine.

13. The adrenal glands produce the hormone aldosterone, which is essential for controlling the kidneys' sodium and water balance. Aldosterone is released into the bloodstream when potassium or sodium levels are low or high, respectively. It enhances the reabsorption of sodium ions into the bloodstream by acting on the kidneys' collecting ducts and distal convoluted tubules. Through osmosis, water passively follows salt as it is reabsorbed, assisting in water retention and blood volume expansion. This process also helps to increase blood pressure. Additionally, aldosterone promotes the excretion of potassium to maintain electrolyte balance. Through this mechanism, aldosterone helps maintain proper sodium levels, water balance, and blood pressure.

EXERCISE 2

1. Osmolality influences the movement of water between cells and extracellular fluid through osmosis. Water moves from areas of lower osmolality (where there is less solute) to areas of higher osmolality (where there is more solute) to balance the concentration. Water goes out of cells and causes them to shrink if the extracellular fluid's osmolality is higher than the cells' internal osmolality (hypertonic solution). On the other hand, water enters the cells and may cause them to swell if the osmolality of the extracellular fluid is lower than that of the hypotonic solution inside the cells. Maintaining proper osmolality is essential for cell function and overall fluid balance.

2. Water deprivation leads to dehydration, where the body lacks sufficient water to carry out its normal functions. This can affect a number of physiological functions, such as waste elimination, nutrition delivery, and temperature regulation. Symptoms of dehydration include dry mouth, exhaustion, lightheadedness, disorientation, and decreased urine production. Extreme dehydration can cause organ dysfunction, electrolyte imbalances, and in severe cases, heatstroke, kidney failure, or even death. In an effort to save water, the body increases thirst and decreases urine production. Prolonged dehydration can lead to kidney stones and urinary tract infections, among other chronic health problems.

3. Water intoxication, sometimes referred to as hyponatraemia or water poisoning, happens when consuming too much water causes the blood's sodium levels to drop dangerously low. Symptoms including headache, nausea, confusion, seizures, and in extreme situations, coma or death, can result from this imbalance, which impairs normal cell activity and causes swelling, especially in brain cells. It typically happens when large amounts of water are consumed over a short period, overwhelming the kidneys' ability to excrete it.

Structure

6.1 Introduction

6.2 Calcium

6.2.1 Functions of Calcium

6.2.2 Source

6.2.3 Bio-availability

6.2.4 Metabolism

6.2.4.1 Absorption

6.2.4.2 Distribution

6.2.4.3 Excretion

6.2.5 Factors Affecting Calcium Metabolism

6.2.6 Regulation of Calcium Homeostasis

6.2.7 Recommended Dietary Allowances(RDA)

6.2.8. Calcium Deficiency

6.2.8.1 Hypocalcemia

6.2.8.2 Osteoporosis

6.2.9 Hypercalcemia

6.3 Phosphorus

6.2.1 Function

6.2.2 Source

6.2.3 Bio-availability

6.2.4 Metabolism

6.2.4.1 Absorption

6.2.4.2 Distribution

6.2.4.3 Excretion

6.2.5 Factors Affecting Phosphorus Metabolism

6.2.6 Regulation of Phosphorus Homeostasis

6.2.7 Recommended Dietary Allowances(RDA)

6.2.8 Phosphorus Imbalance and Health Implications

6.4 Magnesium

6.4.1 Function

6.4.2 Source

6.4.3 Bio-availability

6.4.4 Metabolism

6.4.4.1 Absorption

6.4.4.2 Distribution

6.4.4.3 Excretion

6.4.5 Factors Affecting Phosphorus Metabolism

6.4.6 Regulation of Phosphorus Homeostasis

6.4.7 Recommended Dietary Allowances(RDA)

6.4.8 Phosphorus Imbalance and Health Implications

6.5 Sodium, Potassium and Chloride

6.5.1 Function

6.5.2 Source

6.5.3 Bio-availability

6.5.4 Metabolism

6.5.4.1 Absorption

6.5.4.2 Distribution

6.5.4.3 Excretion

6.5.5 Factors Affecting **Sodium**,potassium, and chloride Levels

6.5.6 Regulation of Sodium,potassium, and chloride Levels

6.5.7 Disorders Related to Imbalance

6.5.8 Disorders Associated with Combined Imbalances

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6.1 INTRODUCTION

As we know human body needs a variety of minerals to maintain a good health. But what are minerals? Minerals are chemical elements that originate from the Earth's crust, soil, and water (**Joseph Black, 1755**). In this unit we shall brief ourselves about several minerals. These minerals are inorganic elements that are essential for human health and are required in small amounts in the diet. There are 20 types of minerals required by body; which play a fundamental role in maintaining various physiological functions essential for human health. Minerals are broadly categories into two groups: **major minerals** (macrominerals) and **trace minerals** (microminerals), as shown in figure 6.1

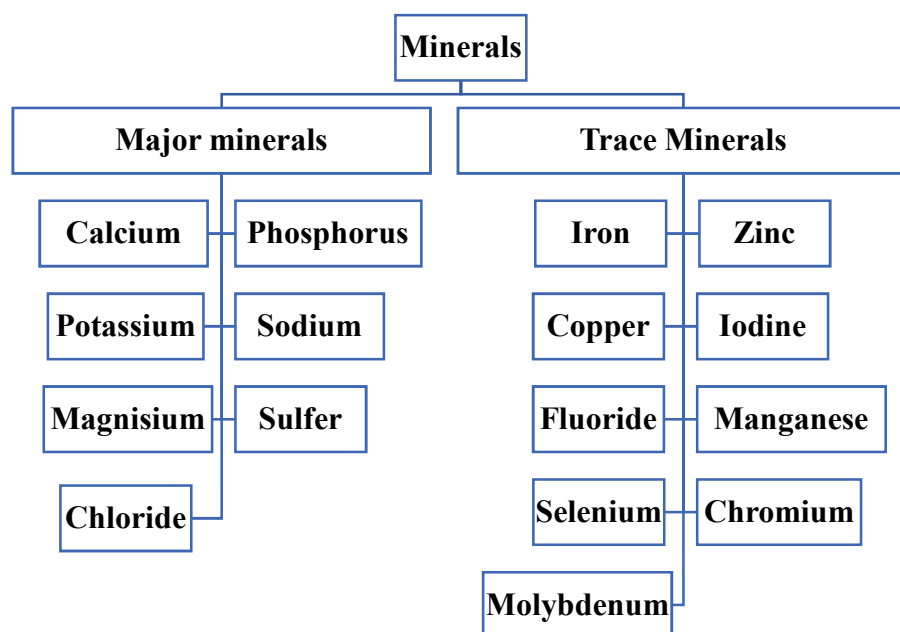


Figure 6.1 : Classification of Minerals

The term "major minerals" refers to those that the body needs in greater quantities than 100 milligrams per day. These minerals, which are present in large quantities in food and the human body, are essential for controlling physiological processes. Calcium, phosphorus, magnesium, sodium, potassium, and chloride are among its constituents. Even though they are required in smaller quantities, trace minerals including copper, manganese, fluoride, chromium, and molybdenum are just as crucial for bone development, glucose metabolism, enzyme function, and cavity prevention.

Maintaining general health and avoiding deficiencies that might result in a number of health problems depend on consuming these minerals in a balanced manner, which is usually accomplished through a varied diet.

This article delves into the multifaceted roles of key minerals, its sources, bio-availability, metabolism, physiological functions, recommended dietary allowances, and the potential consequences of both deficiency and toxicity.

Objectives:

After studying this unit you are able to:

- understand essential minerals and their role in human body.
- describe the requirements and sources of different key minerals.
- discuss how minerals are absorbed, distributed, stored, and excreted by the body.
- Explain how the body regulates mineral homeostasis to maintain optimal health.
- Identify symptoms and health consequences of imbalance of essential minerals

6.2 CALCIUM

Among minerals, calcium is most abundantly present in human body with over 99% of it stored in bone tissue. While only about 1% of calcium is found in the blood and soft tissues, this small fraction is crucial for performing essential functions within the body. It is best known for its contribution to bone health, but in this unit you will learn its functions extend far beyond. Ensuring adequate intake through a balanced diet is essential for maintaining optimal health. Both deficiency and excess of calcium can have serious health consequences. It is crucial to adhere to the recommended dietary allowances and be mindful of the sources of calcium to achieve a balanced intake. By understanding the various aspects of calcium metabolism, bio-availability, and its physiological functions, individuals can make informed dietary choices to support their overall well-being.

Let's explore in detail:

6.2.1 Function

The importance of calcium in bones cannot be overstated. It provides the necessary hardness and structural support that bones need to protect vital organs and support the body's framework. Furthermore, bones serve as a critical reservoir for calcium, which is vital for various physiological processes, such as muscle contraction, blood clotting, and nerve function as depicted in figure 6.2.

Understanding the structure and role of calcium in bones is essential for appreciating how bones function and how they adapt to various physiological and pathological conditions.

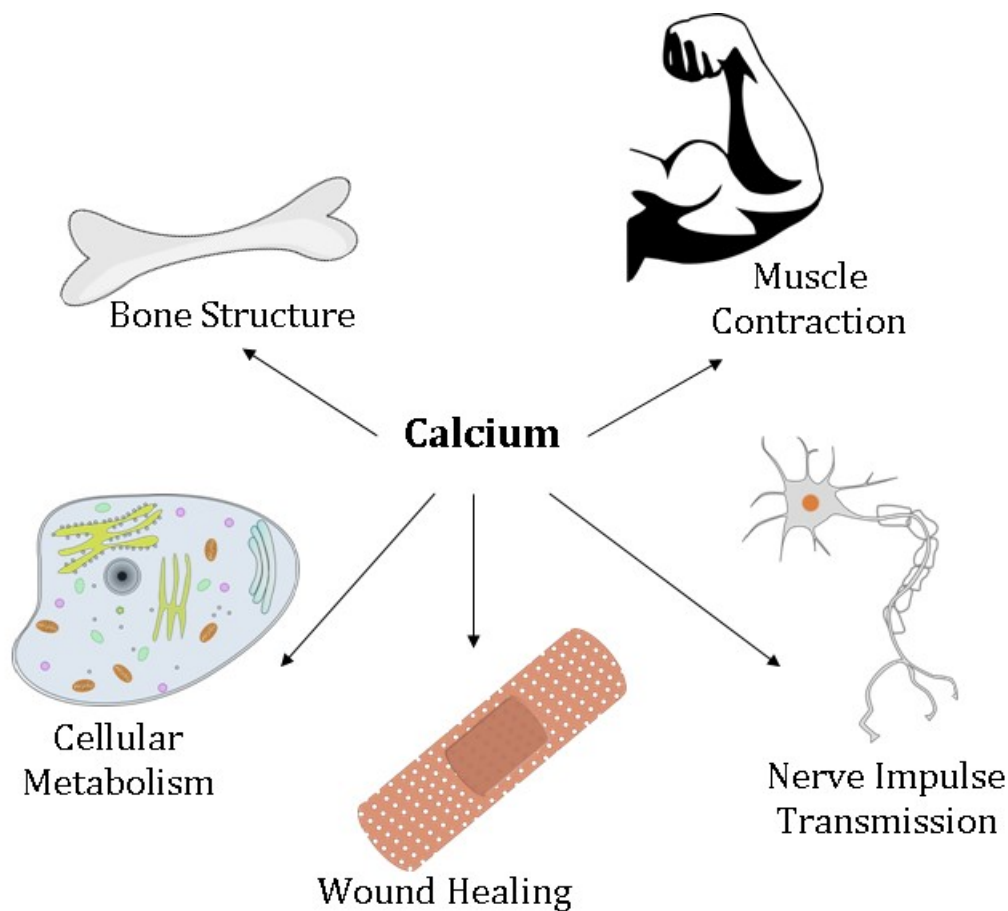


Figure 6.2: Function of Calcium

(Source: Retrived from <https://images.ctfassets.net>)

Here we discuss the role of Calcium in various bodily functions:

1. **Bone Health:** Bone is the reservoir of calcium and store almost 98% of total body's calcium. Calcium contributes significantly to the their strength and durability. The organic matrix primarily consists of collagen, which provides a flexible framework that supports the deposition of minerals. In addition to collagen, various non-collagenous proteins are present, contributing to the overall structure and function of the bone. The inorganic matrix is

predominantly made up of hydroxyapatite (HA), a mineral composed mainly of calcium and phosphate ($\text{Ca}_{10}(\text{PO}_4)_6(\text{OH})_2$). This mineral is responsible for the hardness and rigidity of bones, which allows them to support the body's weight and withstand physical stress. Besides hydroxyapatite, small amounts of other minerals, such as calcium carbonate, also contribute to bone mineralization.

Within the bone matrix, calcium exists primarily in the form of hydroxyapatite crystals. These crystals are intricately embedded within the collagen matrix, creating a composite material that is both strong and resilient. The arrangement of these crystals provides bones with resistance to compression and the ability to bear loads. Additionally, bones contain amorphous calcium phosphate (ACP), a less organized form of calcium phosphate that is typically found in newly formed bone or regions undergoing remodeling. Over time, ACP is transformed into the more structured hydroxyapatite. Calcium intake is essential for developing peak bone mass and maintaining bone density throughout life.

2. **Muscle Function:** The sarcoplasmic reticulum, a storage organelle in the muscle cell, releases calcium ions in response to a nerve impulse that reaches the muscle. As a result of this release, calcium can attach to the protein troponin, shifting tropomyosin and revealing actin binding sites.

Actin filaments can be attached to myosin heads as a result of this exposure, which sets off a chain of events that causes myosin to draw actin into the sarcomere's core and induce muscle contraction. As long as ATP and calcium are available, the cycle will continue. Calcium ions are pushed back into the sarcoplasmic reticulum at the end of the nerve signal, which stops the contraction and permits the muscle to relax. Thus, calcium regulation is key for the precise and coordinated contraction and relaxation of muscles, essential for movement and maintaining posture.

3. **Nerve Transmission:** Calcium ions play a key role in transmitting nerve impulses and synaptic transmission, the process by which neurons communicate with each other. They facilitate the release of neurotransmitters at synaptic junctions, allowing nerve cells to communicate with each other.

When an action potential reaches the axon terminal of a presynaptic neuron, it causes depolarization of the terminal membrane. This depolarization opens voltage-gated calcium

channels, allowing calcium ions (Ca^{2+}) to flow into the neuron. The influx of calcium is a critical signal that triggers the release of neurotransmitters. Calcium ions bind to synaptotagmin, a protein on the membrane of synaptic vesicles, which contain neurotransmitters. This binding induces a series of events that lead to the fusion of synaptic vesicles with the presynaptic membrane, resulting in the release of neurotransmitters into the synaptic cleft through exocytosis. The neurotransmitters then diffuse across the synaptic cleft and bind to receptors on the postsynaptic membrane, generating a postsynaptic potential. Depending on the nature of the neurotransmitter and receptors, this potential can be excitatory or inhibitory, thus influencing whether the postsynaptic neuron will generate its own action potential. In this way, calcium ions are essential for converting electrical signals in the presynaptic neuron into chemical signals that can be transmitted to and interpreted by the postsynaptic neuron, facilitating communication within the nervous system.

4. **Blood Clotting:** Calcium is essential in the blood clotting process, playing a critical role in ensuring that bleeding is effectively controlled when blood vessels are injured. The blood clotting process, also known as coagulation, involves a series of intricate biochemical reactions that ultimately result in the formation of a stable blood clot.

In this pathway, calcium ions (Ca^{2+}) are crucial for the activation of several clotting factors, including factors IX and X, which bind to the phospholipid surfaces of activated platelets in a calcium-dependent manner. Additionally, calcium ions help stabilize the formed fibrin clot by promoting the cross-linking of fibrin fibers through the activation of factor XIII.

5. **Cell Signaling:** Calcium ions (Ca^{2+}) play a pivotal role in cell signaling, acting as a universal secondary messenger in numerous physiological processes. It influencing activities such as enzyme activation, gene expression, and cell differentiation. When cells receive an external signal, such as a hormone or neurotransmitter, it often leads to a transient increase in intracellular calcium levels. Furthermore, calcium signaling is crucial in processes like synaptic transmission, where it facilitates neurotransmitter release, and in fertilization, where it triggers the developmental processes in the egg.

6.2.2 Sources of Calcium

Calcium can be obtained from a variety of dietary sources as it is present in both animal and plant foods. The richest source of calcium in animal products is dairy products such as milk, and yogurt.

These provide a highly bio available form of calcium that is easily absorbed by the body. The green leafy vegetables especially amaranths, fenugreek leaves are the rich sources in vegetable sources. However, it is important to note that some green vegetable such as spinach contain oxalates that can inhibit calcium absorption. Nuts and Seeds such as almonds, chia seeds, and sesame seeds (including tahini) are good sources of calcium. Cereals especially ragi are good source of calcium and **legumes such as beans** and lentils also provide calcium, though their bio availability can be lower due to the presence of phytates.

6.2.3 Bio-availability of Calcium

Bio-availability is the efficiency of body to absorb and utilize the nutrients from the food. Calcium bio-availability varies significantly among different foods. Dairy products are highly bio-available, meaning a large percentage of the calcium they contain is absorbed. Fortified foods also generally offer good bio availability.

Vegetables can be a good source of calcium, but factors such as oxalates and phytates can bind calcium and inhibit its absorption. For example, while spinach is high in calcium, the presence of oxalates makes it less available to the body. On the other hand, kale and broccoli are low in oxalates, making their calcium more bio-available.

6.2.4 Metabolism

The metabolism of calcium involves its absorption, distribution, utilization, and excretion, regulated by a complex interplay of hormones and influenced by various dietary and physiological factors. This article explores the intricacies of calcium metabolism and the factors affecting it.

Here's an overview of the main steps involved:

6.2.4.1. Absorption

The small intestine is the primary site of calcium absorption, and a number of factors affect this process. Vitamin D is essential for improving calcium absorption and assisting the body in making effective use of calcium from food. The effectiveness of this process depends on the body's calcium needs, vitamin D levels, and dietary calcium intake. Calcium absorption occurs through two primary

mechanisms: an active, vitamin D-dependent route and a passive pathway called paracellular absorption. These processes work together to ensure adequate calcium uptake, contributing to overall calcium balance in the body.

Calcium absorption occurs primarily in the small intestine, with two main pathways:

Active Transport: This process is energy-dependent and mostly takes place in the proximal jejunum and duodenum. It is controlled by calcitriol (1,25-dihydroxyvitamin D), the active form of vitamin D. Calcitriol increases the synthesis of calcium-binding proteins, which facilitate calcium transport across the intestinal cells into the bloodstream.

Passive Diffusion: This process occurs throughout the intestine, especially in the ileum, and depends on the concentration gradient of calcium. When dietary calcium intake is high, passive diffusion becomes more significant.

6.2.4.2. Distribution of Calcium

Once calcium is absorbed, it enters the bloodstream in three forms: ionized calcium (around 50%), which is biologically active and unbound; calcium bound to proteins like albumin (about 40%), serving as a reserve; and calcium complexed with anions like phosphate (approximately 10%), involved in various biochemical processes. This distribution ensures calcium's availability for essential physiological tasks. Calcium is then circulated and primarily stored in bones and teeth (99%), giving them structural support and serving as a reservoir to regulate blood calcium levels. The remaining approximately 1% of the body's calcium resides in the bloodstream and extracellular fluids that surround the body's tissues. This small portion is crucial for a range of physiological processes. Cells absorb calcium from these extracellular fluids to support their normal function and growth. Circulating calcium is readily accessible for muscle contractions, the transmission of nerve signals, and initiating blood clotting. These activities underscore the essential role of calcium in maintaining various body systems, despite it being a minor fraction compared to the calcium stored in bones.

6.2.4.3 Excretion of Calcium: Excess calcium is excreted primarily through the urine and feces:

1. **Urinary Excretion:** The kidneys filter calcium from the blood, with a significant portion reabsorbed back into the bloodstream. PTH and calcitriol enhance renal calcium reabsorption, while high dietary calcium intake increases urinary excretion.
2. **Fecal Excretion:** Unabsorbed dietary calcium and calcium secreted into the gastrointestinal tract are excreted in the feces. Approximately 100 to 150mg calcium is lost per day in faceces regardless their dietary intake.

6.2.5 Factors Affecting Calcium Metabolism

Hopefully you understand the key processes involves in calcium metabolism. Also, several factors influence calcium absorption, utilization, and excretion, impacting overall calcium metabolism. Let's discuss the different factors in details:

1. **Dietary Factors:**Main dietary factors influence the calcium metabolism are:
 - **Calcium Intake:** Higher dietary calcium intake generally leads to increased absorption, though the efficiency of absorption decreases as intake rises.
 - **Vitamin D:** Adequate vitamin D levels are crucial for optimal calcium absorption. Deficiency can lead to reduced absorption and impaired bone health.
 - **Phytates and Oxalates:** Found in certain plant foods (e.g., grains, spinach), these compounds can bind calcium and inhibit its absorption.
 - **Protein and Sodium:** High dietary protein and sodium can increase urinary calcium excretion, potentially leading to negative calcium balance if not compensated by adequate intake.
2. **Physiological Factors:**
 - **Age:** Calcium absorption efficiency decreases with age, necessitating higher intake to maintain bone health.
 - **Sex:** Women are more susceptible to calcium insufficiency because of hormonal changes that impact bone resorption, especially in postmenopausal women.
 - **Hormonal Status:** Estrogen enhances calcium absorption and retention, explaining increased calcium needs in postmenopausal women.

- **Pregnancy and Lactation:** Increased calcium needs during these periods support fetal bone development and milk production.

3. **Lifestyle Factors:**

- **Physical Activity:** Weight-bearing exercises stimulate bone formation and enhance calcium retention in bones.
- **Smoking and Alcohol:** Both can negatively impact bone health and calcium metabolism. Smoking reduces estrogen levels, while excessive alcohol intake interferes with vitamin D metabolism and calcium absorption.
- **Medications:** Certain medications, such as corticosteroids and anticonvulsants, can affect calcium balance by altering absorption or increasing excretion

6.2.6 Regulation of Calcium Homeostasis

Proper calcium balance is crucial for maintaining strong bones and preventing conditions like osteoporosis. It also affects heart rhythm and muscle function, making it vital for overall health. Factors such as vitamin D levels, dietary calcium intake, hormone regulation, and kidney function significantly influence calcium metabolism and maintained its level within narrow range of 9-11mg/dl. This highlighting the need to understand how they work together to maintain optimal calcium levels in the body.

Let's discuss:

Vitamin D Levels: Calcium absorption in the intestines depends on vitamin D. In order to maintain appropriate blood calcium levels, calcitriol, the active form of vitamin D, improves the absorption of calcium from the food.

Kidney Function: The kidneys play a vital role in regulating calcium balance by filtering and reabsorbing calcium. Healthy kidney function ensures that the appropriate amount of calcium is retained or excreted to maintain optimal blood levels. Impaired kidney function can disrupt this regulation, leading to imbalances in calcium levels.

Hormone Regulation: Calcium levels are controlled by hormones such as calcitonin, calcitriol, and parathyroid hormone (PTH) as illustrated in figure 6.3. Low blood calcium levels cause the release of PTH, which increases calcium reabsorption in the kidneys, stimulates the release of calcium from

bones, and improves intestinal calcium absorption by activating more vitamin D. On the other hand, the thyroid gland releases calcitonin, which inhibits bone resorption and decreases calcium levels.

These factors work together to tightly control calcium levels, ensuring that calcium is available for critical functions like bone health, muscle contraction, and nerve signaling while preventing the risks associated with both high and low calcium levels.

Here, we discuss the role of three primary hormones in maintaining calcium levels in detail:

Parathyroid Hormone (PTH): When blood calcium levels drop, the parathyroid glands release parathyroid hormone (PTH) to raise calcium levels again by:

- It stimulates osteoclasts, which are the cells that tear down bone tissue, within hours. Calcium is released from the bone matrix into the bloodstream during this process, known as bone resorption, raising blood calcium levels.
- Within minutes, it enhances calcium reabsorption from the distal tubules in the kidneys, reducing urinary excretion.
- It encourages the kidneys to transform inactive vitamin D into its active form, calcitriol. The intestinal absorption of calcium is increased by active vitamin D, which contributes to restoring normal calcium levels.

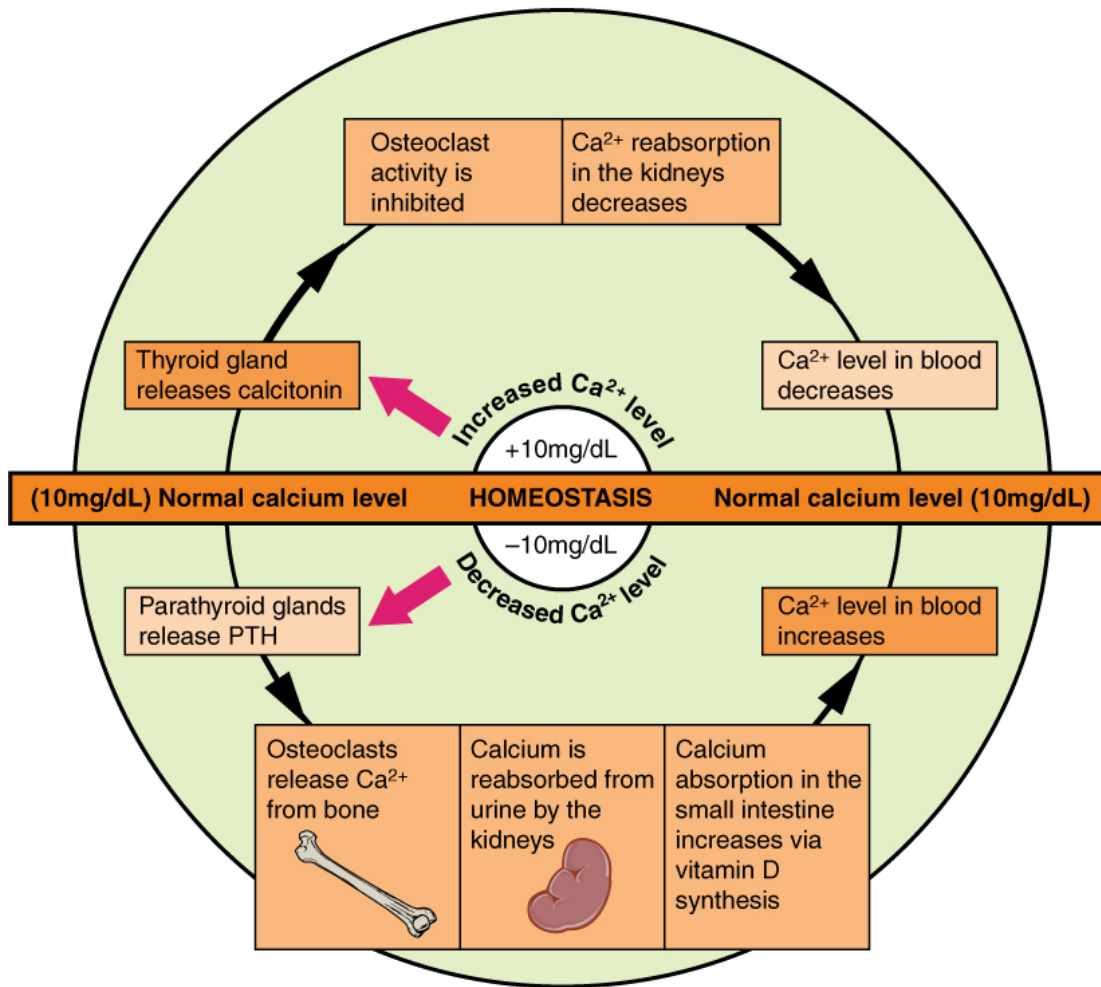


Figure 6.3: Calcium Homeostasis

(Source: Betts et al 2013)

Vitamin D (Calcitriol): The kidneys produce the active form of vitamin D from its precursor, calcidiol, which is generated in the liver from either dietary vitamin D or vitamin D₃ produced by the skin. Calcitriol improves intestinal absorption of calcium and synergistically with PTH to preserve calcium homeostasis.

2. Calcitonin: The thyroid gland releases this hormone in reaction to high blood calcium levels. It lowers calcium by encouraging calcium deposition in the bones and decreasing bone resorption.

6.2.7 Recommended Dietary Allowances (RDA)

The **Recommended Dietary Allowances (RDA)** for calcium, as per the **Indian Council of Medical Research (ICMR) 2020**, vary across different age groups to account for the specific needs of growth, development, and maintenance of optimal health. For **infants** (0-6 months), the RDA is set at around 200 mg/day, increasing to 500 mg/day for **infants aged 7-12 months** to support rapid bone development. For **children aged 1-9 years**, the calcium requirement is between 600-700 mg/day to accommodate growing bones and teeth. During **adolescence** (10-18 years), the need rises significantly to 800-1000 mg/day due to the rapid growth spurts and peak bone mass accumulation, which is critical for preventing osteoporosis later in life. For **adults** (19-50 years), the RDA stabilizes at 600 mg/day, considering the maintenance of bone density and overall health. In **pregnant and lactating women**, the RDA is increased to 1200 mg/day to ensure sufficient calcium for both the mother and the developing fetus or breastfeeding infant. For **elderly adults** (above 50 years), the recommendation is around 800 mg/day to prevent age-related bone loss and the risk of fractures. These RDAs are carefully adjusted based on physiological changes, hormonal shifts, and the body's varying ability to absorb and utilize calcium efficiently at different life stages.

6.2.8 Calcium Deficiency

Calcium deficiency can have significant health implications. A normal calcium range in the blood is typically between 8.5 and 10.5 mg/dL. When levels fall below this range, it presents with a range of symptoms depending on the severity and duration of calcium deficiency. Hypocalcemia, a disorder in which the blood's calcium content is abnormally low, can result from an abnormally low level of calcium in the blood. Since calcium is necessary for bone strength, blood coagulation, muscular contraction, and nerve transmission, this deficit can impair a number of physiological processes. Symptoms of hypocalcemia include muscle cramps, spasms, tingling in the fingers, and in extreme situations, cardiac arrhythmias. These symptoms are mostly associated with the increased excitability of the neurological system and muscles. Chronic calcium deficiency can also impact overall bone health, making bones more susceptible to fractures, a condition called osteoporosis, which we will discuss later in this chapter.

Causes of Hypocalcemia

The underlying causes of hypocalcemia are diverse and can range from dietary deficiencies to more complex metabolic disorders:

- **Vitamin D Deficiency:** The active form of vitamin D, known as 1,25-dihydroxycholecalciferol, plays a crucial role in calcium absorption by promoting the synthesis of a calcium-binding protein in the intestinal cells. This protein facilitates the transport of calcium across the intestinal wall into the bloodstream. The presence of this active form of vitamin D can enhance calcium absorption by 10-30%. A deficiency in vitamin D can severely reduce calcium absorption, potentially leading to hypocalcemia. Such a deficiency may arise due to inadequate dietary intake, limited sunlight exposure, or malabsorption conditions.
- **Hypoparathyroidism:** In hypoparathyroidism, the parathyroid glands fail to produce sufficient parathyroid hormone (PTH), resulting in low calcium levels in the blood.
- **Renal Failure:** Chronic kidney disease can cause hypocalcemia as the kidneys are essential for converting vitamin D into its active form. Kidney dysfunction can also lead to increased phosphate levels, which can bind with calcium and lower its blood levels.
- **Magnesium Deficiency:** Magnesium is necessary for the secretion of PTH. Low magnesium levels can impair PTH secretion, causing hypocalcemia.
- **Malabsorption Syndromes:** Conditions like celiac disease, inflammatory bowel disease (IBD), or surgical removal of part of the intestine can reduce calcium absorption, leading to low calcium levels.
- **Medications:** Certain medications, such as bisphosphonates, anticonvulsants, and diuretics, can interfere with calcium metabolism, causing hypocalcemia.

6.2.8.2 Osteoporosis: Osteoporosis, a disorder linked to a decrease in bone mass and density, can result from a chronic calcium deficit. It is characterized by weak and brittle bones with increased vulnerability to bone fractures.

Throughout life, the dynamic processes of bone mineralization and demineralization take place. Bone demineralization dominates the mineralization process in osteoporosis. Osteoporosis predominantly occurs in late middle age and old age women.

The process by which minerals, especially calcium and phosphorus, are deposited into the bone matrix and give the bones their strength and structure is known as bone mineralization. This process is crucial for developing strong, dense bones during growth and for maintaining bone health throughout life. The minerals bind to collagen fibers in the bone matrix, forming hydroxyapatite crystals, which contribute to the bone's rigidity. In healthy bone metabolism, the process of **bone mineralization** is balanced by

bone resorption, where old or damaged bone tissue is broken down by cells called osteoclasts. This balance between mineralization and resorption is essential for maintaining bone density and strength. However, if the balance shifts toward more resorption than mineralization, the bone becomes weaker and more prone to fractures. **Osteoporosis** is a condition that results from an imbalance between bone mineralization and bone resorption, particularly when the rate of bone resorption exceeds that of mineralization. This leads to a reduction in bone density, making bones fragile and more susceptible to fractures.

Calcium deficiency is a key factor that contributes to osteoporosis, as inadequate calcium intake or poor calcium absorption can impair the mineralization process. Without sufficient calcium, bones cannot form or maintain optimal mineral content, which weakens their structure. Over time, this can lead to the development of osteoporosis, especially in older adults, who naturally experience a decrease in bone mass due to aging.

6.2.9 Hypercalcemia

Elevated blood calcium levels can result in hypercalcemia, characterized by fatigue, confusion, nausea, vomiting, constipation, and in severe cases, cardiac arrhythmias and kidney stones. Hypercalcemia significantly increases the risk of developing kidney stones due to elevated urinary calcium excretion. This condition can lead to the formation of calcium oxalate or calcium phosphate stones. Effective management involves addressing the underlying cause of hypercalcemia, maintaining proper hydration, making dietary adjustments, and using medications to reduce stone formation. Early diagnosis and treatment are crucial to prevent complications and ensure optimal kidney health.

High calcium levels, or hypercalcemia, can have serious repercussions beyond bone health, notably leading to the calcification of soft tissues, including blood vessels. This pathological process, known as vascular calcification, involves the deposition of calcium phosphate crystals in the walls of blood vessels, which can significantly impair their function. Normally, blood vessels are flexible and elastic, allowing them to effectively transport blood throughout the body. However, when calcification occurs, these vessels become stiff and less compliant. This rigidity can lead to increased blood pressure and a higher workload for the heart, as it must pump blood through these narrowed and less flexible vessels. Over time, this strain can contribute to the development of hypertension and left ventricular

hypertrophy. Additionally, calcified blood vessels are more prone to atherosclerosis, where plaques build up on the artery walls, further narrowing the arteries and impeding blood flow. This can increase the risk of cardiovascular events such as heart attacks and strokes. The calcification process is particularly dangerous in the coronary arteries, which supply blood to the heart muscle itself. Reduced blood flow in these arteries can lead to ischemia and potentially fatal cardiac conditions. Chronic kidney disease and certain metabolic disorders often exacerbate vascular calcification due to disrupted calcium and phosphate metabolism. Moreover, factors such as aging, diabetes, and prolonged exposure to high calcium levels from dietary supplements or underlying medical conditions can accelerate this process. Therefore, managing calcium levels within a normal range is crucial to prevent the calcification of soft tissues and mitigate the associated risks of cardiovascular diseases, underscoring the importance of regular monitoring and appropriate medical intervention in individuals with hypercalcemia.

Causes of Hypercalcemia

- **Primary Hyperparathyroidism:**Overactivity of one or more of the parathyroid glands, which increases the release of parathyroid hormone (PTH). PTH increases calcium levels in the blood by stimulating calcium release from bones, increasing calcium absorption in the intestines, and reducing calcium excretion by the kidneys.
- **Malignancies:**Certain cancers, particularly those that metastasize to the bone (like breast cancer, lung cancer, and multiple myeloma), can cause hypercalcemia. Tumors may produce substances that mimic PTH or directly dissolve bone, releasing calcium into the bloodstream.
- **Medications:**Some medications, such as thiazide diuretics, lithium, and excessive vitamin D or calcium supplements, can contribute to elevated calcium levels.
- **Other Causes:**Conditions like sarcoidosis and tuberculosis can increase vitamin D production, leading to increased calcium absorption. Prolonged immobilization, certain genetic disorders, and excessive intake of calcium-rich foods or supplements can also cause hypercalcemia.

6.3 PHOSPHORUS

Phosphorus constitute approximately 1 per cent of the weight of the human body, largely in the form of phosphate. Bone and teeth store upto 90 percent of phosphorus in form of calcium phosphate crystals. Phosphorus is a multifaceted mineral that is indispensable for human health. From building strong bones to fueling energy production, regulating cell function, and supporting neurological and muscular health, phosphorus is involved in nearly every aspect of the body's physiology. Its bio availability, metabolism, and functions are fundamental to human health. Maintaining a balanced phosphorus intake through a nutrient-rich diet is crucial for supporting overall health and avoiding deficiencies or excesses that could result in significant health issues.

6.3.1 Functions

Understanding the role of phosphorus is crucial because it is involved in many vital processes that keep the body functioning properly. It is essential for building and maintaining healthy bones and teeth, generating energy, supporting cell structure, and regulating key cellular functions as depicted in figure 6.4. A clear understanding of phosphorus helps ensure proper nutrition and avoid health problems related to deficiency or excess, making it a critical area of study for overall well-being.

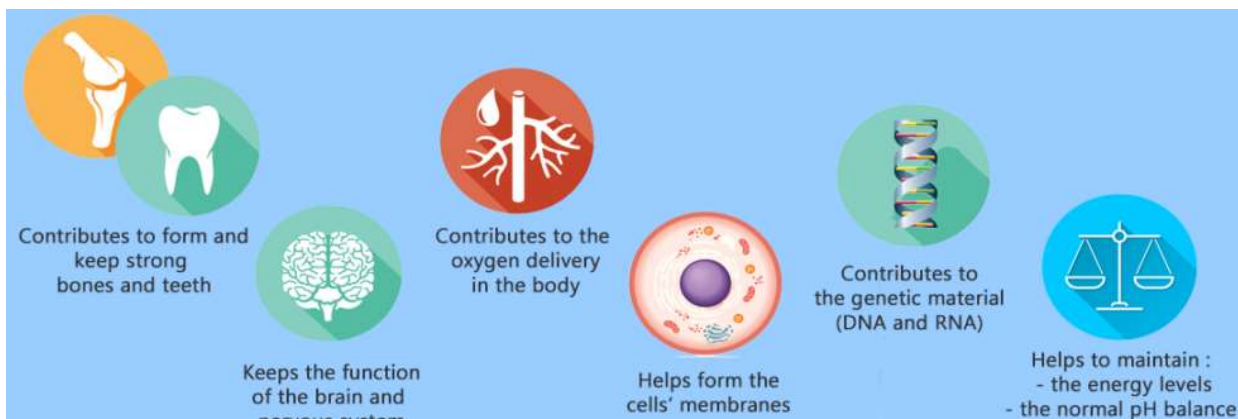


Figure 6.4 : Function of Phosphorus

(Source: <https://www.yogurtinnutrition.com/>)

Here's a detailed explanation of phosphorus's functions:

1. **Bone and Teeth Health:** Approximately 85-90% of the body's phosphorus present in bones and teeth in the form of **calcium phosphate**, specifically as **hydroxyapatite crystals**. Hydroxyapatite, a mineral complex composed of calcium and phosphate, provides bones and teeth with their hardness and structural strength. These crystals are embedded within a collagen matrix, which gives bones a combination of strength and flexibility. The mineralization of bones and teeth depends on an adequate supply of calcium and phosphate, allowing hydroxyapatite to form and maintain the integrity of the skeletal structure. This makes phosphorus, in the form of hydroxyapatite, a crucial component for healthy bone and dental development. This mineral structure not only supports skeletal health but also plays a role in bone mineralization, making phosphorus essential for growth and maintenance of bones.

2. **Energy Production and Metabolism:** Phosphorus plays a crucial role in energy metabolism as a key component of **adenosine triphosphate (ATP)**, the primary energy carrier in cells. ATP is a molecule that stores and provides energy for nearly all cellular processes. During energy metabolism, ATP molecules broken down into into adenosine diphosphate (ADP) and inorganic phosphate, releasing energy that cells use to perform functions such currency, fueling muscle contractions, nerve transmission, and biochemical reactions. Phosphorus is also involved in the synthesis of creatine phosphate, which supplies quick bursts of energy during activities like sprinting. Thus, without sufficient phosphorus, the body's energy metabolism would be impaired, affecting overall cellular function and vitality.

3. **Cell Structure and Membrane Integrity:** **An essential component of cell membrane structure is phosphorus. It is a component of the phospholipids that comprise the lipid bilayer found in cell membranes.** This layer is essential for protecting cells, regulating transport in and out of cells, and maintaining cell communication. Proper membrane function is crucial for nutrient absorption, waste elimination, and cellular signaling.

4. **Nucleic Acids and Genetic Information:** Phosphorus is a fundamental component of DNA and RNA, the molecules that carry genetic information. The phosphate backbone in DNA and RNA is responsible for holding the genetic code together, making phosphorus essential for cell division, replication, and protein synthesis. These processes are vital for growth, development, and maintaining the integrity of tissues.

5. Enzyme Activation and Metabolic Pathways: Many enzymes require phosphorus to function properly. It is involved in phosphorylation, a process in which a phosphate group is added to a molecule to activate or deactivate an enzyme; which are essential for maintaining energy balance.

6. Acid-Base Balance: Phosphorus acts as a buffer, helping to maintain the body's pH balance. The phosphate buffer system regulates the acid-base balance in blood and other body fluids, ensuring that pH levels remain stable. This is crucial for proper physiological function, as even slight deviations in pH can impact enzyme activity and overall health.

7. Muscle Function and Contraction: Phosphorus plays an essential role in muscle function, particularly in muscle contractions. It contributes to the storage and release of energy in muscle cells, allowing them to contract efficiently. In addition, the presence of phosphorus in cellular energy molecules like ATP is critical for maintaining sustained muscle activity and endurance.

8. Nervous System Function: Phosphorus is necessary for the transmission of nerve impulses. It is involved in the synthesis of phosphatidylserine, a phospholipid that contributes to cognitive function, memory, and mood regulation. Proper phosphorus levels help ensure the efficient communication between nerve cells, supporting overall neurological health.

9. Hormonal Regulation and Signaling: Phosphorus plays a part in intracellular signaling pathways, which are involved in hormonal regulation. It helps in the transmission of signals from the surface of cells to their interior, influencing cellular responses to hormones like insulin. This makes phosphorus crucial for glucose metabolism, energy regulation, and maintaining normal blood sugar levels.

10. Repair and Maintenance of Tissues: Phosphorus is involved in the repair and regeneration of tissues. It plays a role in cell growth and differentiation, aiding in the development of tissues during healing processes. Additionally, phosphorus contributes to the maintenance of cellular structures and the synthesis of proteins, which are necessary for replacing damaged or worn-out cells.

6.3.2 Sources of Phosphorus

Practically all food contain significant amounts of phosphorus, although it is particularly abundant in protein rich foods. Phosphorus is found in a variety of foods, including both animal-based and plant-

based sources. Phosphorus is readily available in a wide variety of foods and common sources is presented in figure 6.5. Here are some of the primary sources of phosphorus:

- **Animal Products:** Meat, poultry, fish, eggs, and dairy products are excellent sources of phosphorus.
- **Plant-Based Sources:** Nuts, seeds, beans, lentils, and whole grains provide significant amounts of phosphorus.
- **Processed Foods:** Many processed foods contain added phosphates, which are used as preservatives and flavor enhancers.

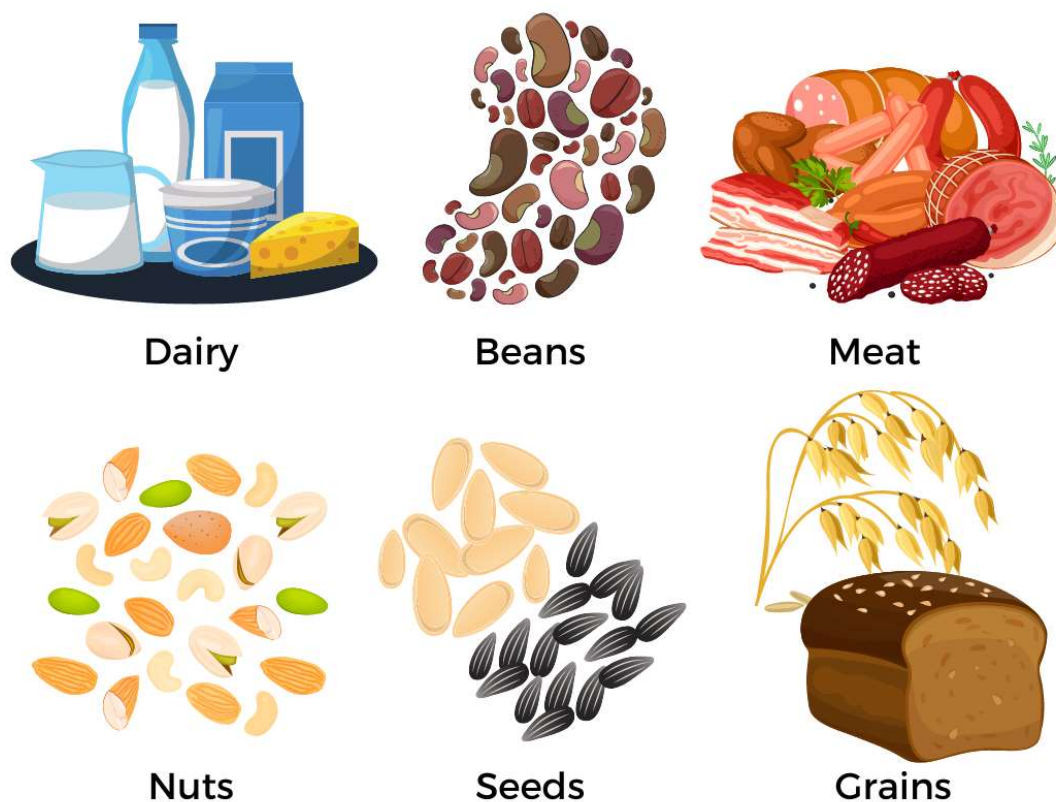


Figure 6.5: Common sources of Phosphorus

(Source: <https://www.plantpoweredkidneys.com/>)

6.3.3 Bio-availability

The bio availability of phosphorus, or the extent to which phosphorus from dietary sources is absorbed and utilized by the body, varies significantly depending on the type of food and its phosphorus content. Phosphorus is found in both plant and animal foods, but its bio-availability differs between these sources. Animal-based foods, such as meats, dairy products, and eggs, contain phosphorus in the form of organic phosphate, which is highly bio-available. Typically, the body absorbs about 40% to 60% of the phosphorus from these sources due to the presence of phosphorus in forms that are readily absorbed in the gastrointestinal tract. Conversely, plant-based foods, including grains, nuts, seeds, and legumes, contain phosphorus bound in the form of phytates, which are less bio-available. Phytates are complexes of phosphorus with inositol, and their presence reduces the efficiency of phosphorus absorption because the body lacks the enzyme phytase needed to break these complexes down effectively. Consequently, the absorption rate of phosphorus from plant sources is generally lower, ranging from 20% to 50%. Additionally, food processing techniques can influence phosphorus bio-availability. For example, the use of phosphates as food additives in processed foods can enhance phosphorus bio-availability, often approaching nearly 100%, as these phosphates are readily absorbed by the body. Factors such as the presence of other nutrients also affect phosphorus bio-availability; for instance, high dietary calcium can inhibit phosphorus absorption, as both minerals compete for absorption in the intestines. Similarly, vitamin D plays a crucial role in enhancing phosphorus absorption by increasing the expression of phosphate transporters in the intestinal lining. Overall, while animal-derived phosphorus is more readily absorbed, the bio-availability of phosphorus from plant sources can be influenced by various dietary and physiological factors. Ensuring a balanced diet that includes both animal and plant sources, and considering the impact of other nutrients, is essential for optimizing phosphorus absorption and maintaining overall nutritional health.

6.3.4 Metabolism

Phosphorus metabolism is a complex and finely tuned process critical for maintaining numerous physiological functions, involving the absorption, transport, utilization, storage, and excretion of phosphorus within the body. This metabolism is crucial for maintaining phosphorus homeostasis, which is essential for various physiological functions, including energy production, bone health, and cellular processes. Here's a detailed overview of phosphorus metabolism involves several steps, including absorption, distribution, storage, and excretion:

6.3.4.1 Absorption: Initially, phosphorus is ingested through dietary sources, including meats, dairy products, nuts, seeds, and grains, as well as through food additives. Phosphorus is primarily absorbed in the small intestine, with vitamin D enhancing its absorption. Approximately 60-70% of dietary phosphorus is absorbed under normal conditions. Once consumed, phosphorus is absorbed in the small intestine, primarily the jejunum, via two mechanisms: Passive diffusion and Active transport facilitated by vitamin D.

- **Passive Diffusion:** This occurs when dietary phosphorus concentration is high.
- **Active Transport:** This process is regulated by vitamin D (specifically, calcitriol). Calcitriol enhances the expression of sodium-phosphate cotransporters (NaPi-IIb) in the intestinal lining, increasing phosphorus absorption.

6.3.4.2 Transport and Storage: After absorption, phosphorus is transported in the bloodstream mainly as inorganic phosphate. It is distributed throughout the body, with some of it being used immediately for various metabolic processes. About 85% of the body's phosphorus is stored in bones and teeth in the form of hydroxyapatite crystals, which provide structural strength and rigidity. Bone acts as a reservoir, releasing phosphorus into the bloodstream when needed and storing excess phosphorus.

6.3.4 Excretion: Excess calcium is excreted primarily through the urine and feces:

1. **Renal Excretion:** The kidneys excrete excess phosphorus in the urine. Renal excretion is the primary route for phosphorus elimination and is adjusted based on dietary intake and the body's phosphorus levels.
2. **Fecal Excretion:** A smaller amount of phosphorus is excreted through the feces, representing unabsorbed dietary phosphorus and endogenous phosphorus secreted into the digestive tract.

6.3.5 Factors Affecting Phosphorus Metabolism

The metabolism of phosphorus is a complex interplay of dietary intake, hormonal regulation, kidney function, and genetic factors. Understanding these influences is crucial for maintaining phosphorus balance. Proper management of phosphorus metabolism can promote bone health, enhance cellular function, and prevent complications associated with imbalances in phosphorus and related minerals.

like calcium. Phosphorus plays a central role in numerous physiological processes, and its metabolism is affected by a range of internal and external factors.

Here is an in-depth look at how various elements influence phosphorus metabolism:

1. Dietary Intake: Phosphorus is mainly obtained from the diet, and dietary intake is the primary determinant of phosphorus availability in the body. Foods rich in phosphorus include dairy products, meats, fish, poultry, nuts, seeds, legumes, and whole grains. Inorganic phosphorus, often found in food additives, is more readily absorbed in the intestine compared to organic phosphorus present in natural foods. This difference in absorption can lead to varying phosphorus levels in individuals with different diets. For instance:

- **High-Phosphorus Diet:** Excessive intake may lead to elevated serum phosphorus, impacting calcium metabolism.
- **Low-Phosphorus Diet:** Insufficient dietary phosphorus can result in hypophosphatemia, affecting energy production, bone health, and cellular processes.

2. Role of Vitamin D: Vitamin D is a crucial factor for phosphorus metabolism because it regulates phosphorus absorption in the intestines. When vitamin D levels are adequate, it enhances the efficiency of phosphorus absorption, leading to optimal phosphorus levels in the bloodstream. Specifically:

- **Active Form of Vitamin D (Calcitriol):** Increases the absorption of phosphorus from the intestine by promoting the synthesis of phosphorus transport proteins.
- **Deficiency in Vitamin D:** Can lead to decreased phosphorus absorption, causing low serum phosphorus and potentially leading to conditions like rickets or osteomalacia.

3. Parathyroid Hormone (PTH) Regulation: PTH is a key hormone in maintaining phosphorus balance as already discussed in previous section calcium. It exerts its effects on phosphorus metabolism in three primary areas:

- **Bone Resorption:** PTH promotes the release of phosphorus from bones, increasing serum phosphorus levels.
- **Renal Excretion:** It increases the excretion of phosphorus in the kidneys, reducing serum phosphorus when necessary.

- **Intestinal Absorption:** PTH indirectly increases phosphorus absorption by stimulating the production of active vitamin D. Elevated PTH levels, often seen in chronic kidney disease, can lead to secondary hyperparathyroidism, which disrupts the balance between calcium and phosphorus.

4. **Kidney Function:** The kidneys are the primary regulators of phosphorus homeostasis, excreting excess phosphorus when necessary to maintain appropriate levels:

- **Healthy Kidneys:** Filter excess phosphorus efficiently, keeping serum levels within the normal range.
- **Chronic Kidney Disease (CKD):** Impaired renal function reduces phosphorus excretion, leading to hyperphosphatemia. This can result in mineral and bone disorders, and increased cardiovascular risk. In CKD, phosphorus retention can stimulate elevated PTH secretion, exacerbating calcium and phosphorus imbalance.

5. **Calcium-Phosphorus Relationship:** Calcium and phosphorus have an inverse relationship in the body, often competing for similar absorption pathways in the intestine. Proper calcium-phosphorus balance is vital for bone health and other physiological functions:

- **Calcium Inhibits Phosphorus Absorption:** High levels of calcium can reduce phosphorus absorption, as both minerals use similar transport mechanisms in the intestine.
- **Phosphorus Enhances Calcium Excretion:** Elevated phosphorus levels can increase calcium excretion from the kidneys, affecting bone mineralization and potentially leading to bone demineralization.
- **Calcium-Phosphorus Product:** A calculation used to evaluate the risk of ectopic calcification in patients with chronic kidney disease; an imbalance can lead to vascular calcification and other complications.

6. **Acid-Base Balance:** The body's pH level can significantly impact phosphorus metabolism:

- **Acidosis (Low pH):** Increases phosphorus release from bones into the bloodstream, raising serum phosphorus levels.

- **Alkalosis (High pH):** Decreases the release of phosphorus from bones, leading to lower serum phosphorus levels. Acid-base imbalances can therefore impact bone health, as shifts in pH can trigger changes in bone mineral content to stabilize blood pH.

7. **Hormonal Influence:** Several hormones, apart from PTH and vitamin D, play a role in phosphorus metabolism:

- **Fibroblast Growth Factor-23 (FGF-23):** Secreted primarily by osteocytes in bones, FGF-23 regulates phosphorus homeostasis by decreasing phosphorus reabsorption in the kidneys and suppressing vitamin D synthesis. Elevated levels of FGF-23 are often seen in CKD, contributing to disturbances in phosphorus balance.
- **Insulin:** Facilitates phosphorus uptake by cells during periods of high carbohydrate consumption. Insulin deficiency, as seen in diabetes, can lead to disturbances in phosphorus metabolism.
- **Growth Hormone:** Increases renal reabsorption of phosphorus and enhances its absorption in the intestine, supporting bone and tissue development.

8. **Genetic Factors:** Genetic variations can impact phosphorus metabolism by influencing hormone regulation, transport proteins, and renal function.

9. **Gut Health and Microbiota-** The gut microbiota can also impact phosphorus metabolism. Beneficial bacteria can influence the absorption of nutrients, including phosphorus. Disruptions in gut flora, such as from antibiotics or dietary changes, can alter phosphorus absorption and utilization.

10. **Age and Life Stages:** Phosphorus needs change throughout life to support various physiological demands. During infancy and childhood, higher phosphorus levels are essential for rapid bone growth and development, as bones are actively growing and mineralizing. In adolescence, phosphorus intake remains crucial to support the growth spurt and peak bone mass accumulation, which lays the foundation for a strong skeletal structure later in life. For adults, phosphorus requirements stabilize, with the primary goal of maintaining bone health and supporting essential metabolic functions, as bone growth has largely concluded. In older adults, phosphorus management can become more challenging due to decreased absorption and potential changes in kidney function, impacting the body's ability to

regulate phosphorus levels. These changes make careful phosphorus management important, particularly if renal function declines with age.

11. Medical Conditions: Certain medical conditions, medications, lifestyle factors, and nutrient interactions can significantly influence phosphorus metabolism. Conditions like hyperparathyroidism, osteoporosis, diabetes, and liver disease are known to impact phosphorus balance. For example, hyperparathyroidism leads to excessive parathyroid hormone (PTH) secretion, which increases phosphorus excretion through the kidneys, causing hypophosphatemia. Osteoporosis affects bone metabolism, altering the balance of phosphorus and calcium, while diabetes and liver disease can both impact phosphorus by altering renal function, hormone regulation, or vitamin D activation.

12. Medications: Certain medications also play a role in phosphorus levels. Diuretics may increase renal excretion, resulting in hypophosphatemia, while calcium or aluminum-based antacids can bind to phosphorus in the gut, reducing absorption. In cases of chronic kidney disease (CKD), phosphate binders are often prescribed to prevent hyperphosphatemia. Hormone replacement therapy can additionally affect bone turnover and, consequently, phosphorus metabolism.

13. Physical Activity and Lifestyle: Lifestyle factors like physical activity and smoking also influence phosphorus needs and utilization. Physical activity supports bone remodeling and phosphorus use in muscles and bones, while smoking can negatively impact bone health, affecting the balance of phosphorus and calcium. Lastly, nutrient interactions are important for phosphorus metabolism. Magnesium works in tandem with phosphorus for bone health, while high protein intake increases phosphorus absorption as phosphorus is a component of protein-rich foods. Conversely, excessive iron and zinc supplementation may compete with phosphorus absorption, potentially affecting its levels in the body.

6.3.6 Regulation of Phosphorus Homeostasis

It is important to regulate the levels of phosphorus as it is crucial for maintaining healthy bones, cellular energy production, and overall metabolic balance. The regulation of phosphorus involves a delicate balance maintained by hormones such as PTH, calcitriol, and FGF23, and the kidneys play a central role in adjusting phosphorus excretion to maintain homeostasis. Let us learn about how phosphorus homeostasis is achieved:

Parathyroid Hormone (PTH): When blood calcium levels are low, the parathyroid glands release parathyroid hormone (PTH). It raises blood calcium levels by promoting bone resorption, which causes the blood to fill with calcium and phosphorus. To maintain calcium and phosphorus in balance, PTH also enhances renal excretion of phosphorus.

Vitamin D (Calcitriol): The active form of vitamin D, calcitriol, improves intestinal absorption of phosphorus and calcium. Additionally, it contributes to bone remodeling by encouraging the bones to release calcium and phosphorus. Osteocytes create fibroblast growth factor 23 (FGF23) in reaction to elevated phosphorus levels.

Fibroblast Growth Factor 23 (FGF23): FGF23 is produced by osteocytes in response to high phosphorus levels. It reduces phosphorus reabsorption in the kidneys, increasing urinary excretion, and decreases the production of calcitriol, reducing intestinal absorption of phosphorus.

Kidneys: The kidneys are crucial in regulating phosphorus levels. They filter and reabsorb phosphorus, with excess phosphorus being excreted in the urine. PTH and FGF23 modulate renal reabsorption and excretion of phosphorus.

6.3.7 Recommended Dietary Allowances (RDA)

The Recommended Dietary Allowance (RDA) for phosphorus varies by age, reflecting the body's changing needs throughout different life stages. For infants (0-6 months), the RDA is 100 mg per day, primarily to support rapid growth and the development of bones and tissues. For children aged 1-3 years, it increases to 460 mg per day, and from 4-8 years, it's set at 500 mg per day, to accommodate the body's higher demands as they grow and develop.

During adolescence (9-18 years), the RDA rises significantly to 1,250 mg per day. This increase is due to the accelerated bone development and increased demand for energy during puberty. In adulthood (19 years and older), the requirement stabilizes at 700 mg per day to maintain healthy bones, teeth, and cellular functions. Pregnant and lactating women also require 700 mg per day to support fetal development and the production of breast milk.

These recommendations ensure adequate phosphorus intake for bone mineralization, energy production, and cellular maintenance. Proper phosphorus levels are crucial for preventing deficiencies that could impact growth, bone health, and overall metabolic function.

6.3.8 Phosphorus Imbalance and Health Implications

Proper phosphorus metabolism is essential for numerous physiological functions, and disruptions can lead to health issues such as bone disorders and impaired cellular functions. Let's discuss the complications of imbalance of phosphorus :

1. Hypophosphatemia (Low Phosphorus Levels)

Hypophosphatemia can result from malnutrition, chronic alcohol use, certain medications, or medical conditions like kidney disorders. Symptoms of low phosphorus levels include:

- Weakness and fatigue
- Muscle pain and cramps
- Bone pain and fractures
- Respiratory difficulties
- Confusion and neurological disturbances

Chronic low phosphorus levels can impair bone health, energy production, and immune function, increasing the risk of bone diseases like osteomalacia and compromising overall vitality.

2. Hyperphosphatemia (High Phosphorus Levels)

Hyperphosphatemia is often linked to kidney dysfunction, as the kidneys regulate phosphorus levels. Excess phosphorus can lead to:

- Itching and rashes
- Joint pain and calcification of soft tissues
- Cardiovascular complications due to calcification of arteries
- Bone loss and imbalances in calcium metabolism

Chronic high phosphorus levels can increase the risk of cardiovascular disease, bone disorders, and complications in individuals with kidney disease.

CHECK YOUR PROGRESS EXERCISE 1

1. Write the role of parathyroid hormone in calcium homeostasis.

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1. Describe the disease osteoporosis.

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2. What are some foods that are high in calcium?

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4. What are the factors affecting phosphorus metabolism ?

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4. How is phosphorus absorbed by humans?

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6.4 MAGNESIUM (MG)

An important mineral that is necessary for many physiological processes is magnesium including bone health, energy production, and muscle function. Understanding its bioavailability, metabolism, and regulation is key for maintaining optimal health and preventing deficiencies.

Here's a detailed overview of its functions, sources, bioavailability, metabolism, and more:

6.4.1 Function of Magnesium

In the body, magnesium is involved in over 300 enzymatic processes

Here Figure 6.6 presented the some of its key functions include:

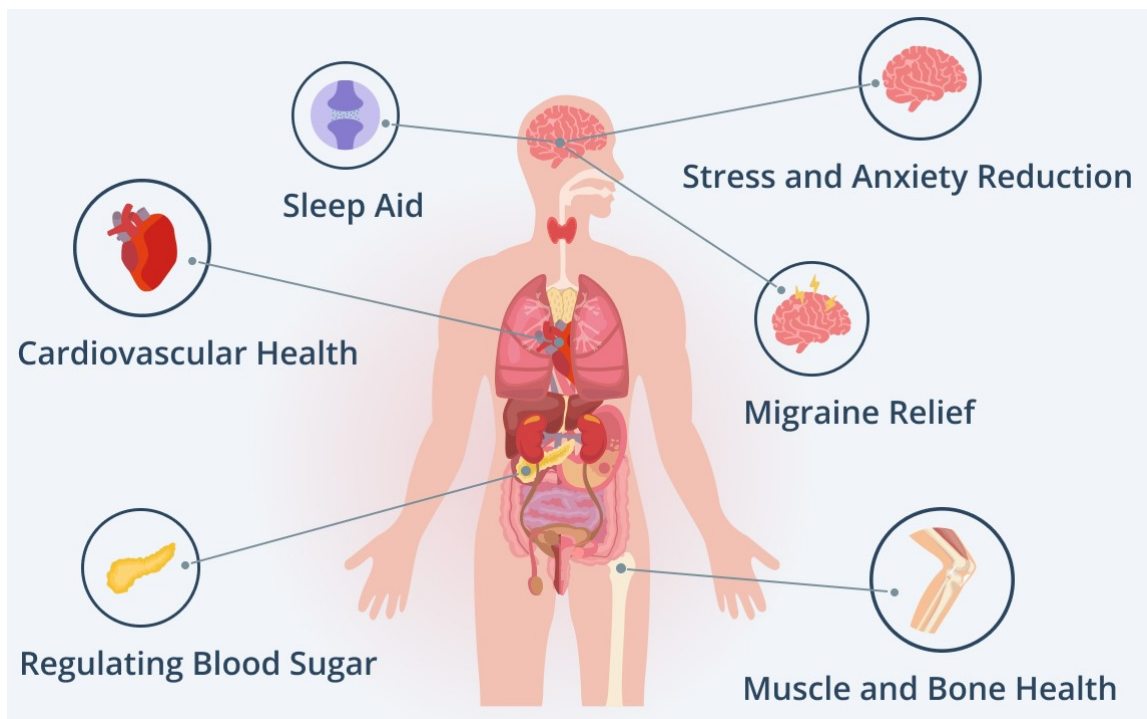


Figure 6.6: Function of Magnesium

(Source: <https://cdn.prod.website-files.com/>)

- **Muscle and Nerve Function:** Magnesium play important role in normal muscle contraction and relaxation, as well as nerve function. It helps in the transmission of electrical signals across cells.
- **Energy Production:** Magnesium acting acting as a cofactor in numerous enzymatic reactions that are essential for cellular energy metabolism especially in the production and utilization of **adenosine triphosphate (ATP)**, which is the main energy currency of the cell.
- **Bone Health:** Magnesium contributes to bone structure and works with calcium to regulate bone density and strength.
- **DNA and Protein Synthesis:** It is essential for the synthesis of DNA, RNA, and proteins, which are fundamental to cell division and growth.
- **Cardiovascular Health:** Magnesium helps maintain normal heart rhythm, and it has a role in regulating blood pressure.

6.4.2 Source of Magnesium

Green leafy vegetables contain high amounts of magnesium in the form of chlorophyll. Nuts and seeds, especially cashews, almonds, and pumpkin seeds, are other great sources. Legumes like beans, lentils, and chickpeas, as well as whole grains like quinoa, brown rice, and oats, are additional important sources. Additionally, dairy products like milk and yogurt, along with fortified cereals, may offer magnesium, particularly in individuals who may not consume a varied diet.



Figure 6.7: Common Sources of Magnesium

(Source: <https://images.squarespace-cdn.com/>)

6.4.3 Bio-availability of Magnesium

Magnesium bio-availability means how effectively the body can absorb and utilize this essential mineral from food or supplements. If magnesium has low bioavailability, even with sufficient intake, the body may not be able to absorb enough of it to meet its needs, leading to potential deficiencies. Therefore, it is important to study the factors affecting its bio-availability. Let's discuss:

- **Form of Magnesium:** Magnesium from food sources is better absorbed than from supplements. Magnesium compounds, such as magnesium citrate, magnesium oxide, or magnesium chloride, vary in their absorption efficiency.
- **Dietary Factors:** The presence of fiber, phytates (found in grains and legumes), and calcium can reduce magnesium absorption. However, dietary fats may enhance absorption.
- **Gastrointestinal Health:** Disorders that affect the digestive system, like Crohn's disease, celiac disease, or irritable bowel syndrome (IBS), might decrease the absorption of magnesium.

6.4.4 Metabolism of Magnesium

Magnesium is absorbed, distributed, and excreted through several processes in the body as discussed below:

6.4.4.1 Absorption: Magnesium is absorbed primarily in the small intestine, with about 30-40% of ingested magnesium being absorbed. The absorption process is influenced by the following:

- **Active Transport:** In the presence of low magnesium levels, active transport mechanisms in the gut increase magnesium absorption.
- **Passive Diffusion:** At higher magnesium concentrations, absorption occurs through passive diffusion.
- **Influence of Other Nutrients:** High levels of calcium, phosphorus, and fiber can reduce magnesium absorption.

6.4.4.2 Distribution: Magnesium is primarily distributed in the body in bone, muscle, and soft tissues, with a small percentage present in the blood. About **60% of the body's total magnesium** is stored in the bones, where it plays a vital role in bone structure and strength. **Approximately 27%** is found in the muscles, where it supports muscle function, including contraction and relaxation. The remaining **1% to 2%** of magnesium is present in the blood and extracellular fluids, where it is critical for regulating various physiological processes such as enzyme activity, nerve transmission, and the

maintenance of electrolyte balance. Despite its relatively low concentration in the blood, the body tightly regulates magnesium levels in the extracellular fluid to ensure proper cellular function

6.4.4.3 Excretion: Magnesium is excreted primarily through the kidneys. The kidneys filter magnesium, and most of it is reabsorbed, with only a small amount excreted in the urine. The body's magnesium balance is largely dependent on renal function. If magnesium levels are low, the kidneys reduce excretion to conserve magnesium. High Magnesium Levels: In contrast, excess magnesium is excreted in the urine. Smaller amounts of magnesium are also lost through feces and sweat.

6.4.5 Factors Affecting Phosphorus Metabolism

Phosphorus metabolism is closely related to magnesium, as both are involved in bone health and energy production. The following factors can affect phosphorus metabolism:

- **Calcium and Vitamin D Levels:** Calcium and vitamin D work in tandem with magnesium to regulate phosphorus metabolism, especially in the context of bone mineralization.
- **Parathyroid Hormone (PTH):** PTH regulates both magnesium and phosphorus levels by influencing kidney excretion and absorption in the intestines.
- **Acid-Base Balance:** The body's pH level affects the absorption and excretion of both magnesium and phosphorus.
- **Renal Function:** Impaired kidney function can lead to disturbances in phosphorus metabolism, resulting in either low or high phosphorus levels.

6.4.6 Regulation of Phosphorus Homeostasis

Phosphorus homeostasis is regulated by a balance between intake, absorption, utilization, and excretion. The key regulators include:

- **Parathyroid Hormone (PTH):** PTH increases the excretion of phosphorus by the kidneys and increases calcium levels in the blood, helping to maintain calcium-phosphorus balance.
- **Fibroblast Growth Factor 23 (FGF23):** This hormone is secreted by bones and helps regulate phosphorus by promoting its excretion in urine.
- **Vitamin D:** Vitamin D enhances intestinal absorption of phosphorus and works in conjunction with magnesium to maintain bone mineralization.

- **Kidneys:** The kidneys play a crucial role in phosphorus regulation by filtering and excreting excess phosphorus.

6.4.7 Recommended Dietary Allowances (RDA) for Magnesium

The Recommended Dietary Allowance (RDA) for magnesium varies based on age, gender, and life stage to ensure adequate intake for maintaining overall health. For adult men, the RDA is 400 mg per day for those aged 19-30 and increases to 420 mg per day for men over 31. For adult women, the recommended intake is 310 mg per day for those aged 19-30, and 320 mg per day for women aged 31 and older. Special considerations are made for pregnant and lactating women, with the RDA set at 350-360 mg per day during pregnancy and 310-320 mg per day while breastfeeding, to support both maternal and fetal health. For children, the RDA varies by age, starting from 80 mg per day for infants aged 0-6 months and rising to 240 mg per day for children between 9 and 13 years. These guidelines are designed to ensure sufficient magnesium intake across different life stages to support critical functions like energy production, bone health, and nerve function.

6.4.8 Magnesium Imbalance and Health Implications

We have already discussed the recommended daily intake (RDI) of magnesium varies by age and gender, but for adults, it generally ranges from 310 to 420 milligrams per day. However, both magnesium deficiency and excess can have significant health implications. Let's learn:

6.4.8.1 Magnesium Deficiency: Magnesium deficiency can occur due to inadequate dietary intake, excessive loss through urine (e.g., due to certain medications or conditions like diabetes), or gastrointestinal diseases that impair nutrient absorption. Symptoms of magnesium deficiency can be subtle at first, but as it progresses, it can lead to more serious health problems:

- **Muscle Cramps and Spasms:** Magnesium plays a key role in muscle contraction and relaxation. A deficiency can cause muscle weakness, cramps, and spasms.
- **Fatigue and Weakness:** Magnesium is involved in energy production. Without enough magnesium, individuals may experience persistent fatigue and a lack of energy.
- **Heart Arrhythmias:** Magnesium helps regulate heart rhythm. Low magnesium levels can cause irregular heartbeats (arrhythmias), increasing the risk of cardiovascular problems.

- **Osteoporosis:** Magnesium is important for bone health. Chronic deficiency can lead to weakened bones, increasing the risk of osteoporosis.
- **Mental Health Issues:** Magnesium deficiency has been linked to symptoms of anxiety, depression, and irritability, as it helps regulate neurotransmitters in the brain.

6.4.8.2 Magnesium Excess: While magnesium toxicity is rare, it can occur when excessive amounts of magnesium are consumed, typically through supplements. The body usually regulates magnesium levels effectively through the kidneys, but in cases of kidney dysfunction or over-supplementation, excessive magnesium can lead to:

- **Diarrhea:** One of the most common symptoms of magnesium excess is diarrhea, as the body attempts to rid itself of excess magnesium.
- **Heart Problems:** High magnesium levels can interfere with heart function, leading to arrhythmias or even cardiac arrest in severe cases.
- **Respiratory Issues:** Excess magnesium can depress the respiratory system, leading to breathing difficulties or even respiratory failure in extreme cases.
- **Kidney Damage:** In individuals with pre-existing kidney problems, too much magnesium can exacerbate kidney damage, as the kidneys are responsible for eliminating excess magnesium.

6.5 SODIUM, POTASSIUM AND CHLORIDE

Sodium, potassium, and chloride are essential minerals and key electrolytes that play interconnected roles in maintaining the body's physiological balance. These electrolytes are critical for a wide range of bodily functions, including fluid and electrolyte balance, nerve impulse transmission, muscle contraction, acid-base regulation, and blood pressure control. Each mineral has a distinct function, yet they work in tandem to support the overall stability and health of the body. Sodium and chloride are primarily found in the extracellular fluid, where they help regulate hydration and blood volume, while potassium is predominantly an intracellular ion, essential for cell function and electrical signaling. Together, sodium, potassium, and chloride create the foundation for the body's internal communication and energy management, making them indispensable for sustaining life and promoting overall well-being. Proper intake and balance of these electrolytes are crucial to avoid health complications, ranging from dehydration and muscle cramps to hypertension and cardiovascular issues. Understanding the health implications of these minerals, both in terms of its essential benefits and

potential risks when consumed in excess, is critical to promoting better health and reducing the burden of related health issues.

Let's discuss function, Recommended Dietary Allowance (RDA) and its implication in detail:

6.5.1 Functions of Sodium, Potassium, and Chloride

Sodium, potassium, and chloride are three key electrolytes that work together to maintain critical bodily functions. The key function of Sodium, Potassium and Chloride is presented in figure 6.8 and combined overview of their roles and interactions are discussed as:

Macromineral	Major roles in the body	Too little	Too much
Sodium 	Helps maintain blood volume (hydration), nerve impulse generation, muscle contraction, acid-base balance	Hyponatremia, dizziness, coma, muscle cramps, nausea, vomiting, loss of appetite, seizures	Hypertension, nausea
Potassium 	Promotes membrane potential, nerve impulse generation, muscle contraction, acid-base balance	Hypokalemia, muscle cramps, apathy, loss of appetite, irregular heartbeat	Hyperkalemia, cardiac arrhythmia, cardiac failure
Chloride 	Promotes nerve impulse conduction and hydrochloric acid formation in the stomach	Convulsions (muscle spasms with loss of consciousness)	Hypertension

Figure 6.8: Major Role of Sodium, Potassium and Chloride

(Source: <https://static.wixstatic.com/media/>)

1. **Fluid and Electrolyte Balance:** Sodium, potassium, and chloride are essential in regulating the body's fluid balance. Sodium and chloride are predominantly found in the extracellular fluid

(outside the cells), while potassium is primarily found inside the cells. Sodium and chloride work together to control the volume of fluids outside cells, while potassium maintains fluid balance within the cells. This balance is crucial for normal cell function, nutrient transport, and waste removal. The movement of these electrolytes across cell membranes helps regulate the osmotic pressure (water movement), ensuring that cells remain hydrated and functioning optimally.

2. **Nerve Impulse Transmission and Muscle Contraction:** Sodium and potassium are fundamental in generating and transmitting electrical impulses in the nervous system. The balance of sodium and potassium across cell membranes creates an electrical gradient, known as the "resting membrane potential," necessary for nerve impulse conduction. During nerve signaling, sodium ions flow into nerve cells, causing depolarization (electrical charge change), followed by potassium ions flowing out, repolarizing the cell and resetting it for the next impulse. Chloride, with its negative charge, contributes to maintaining the electrical neutrality of cells and influences the excitability of nerve and muscle cells. This interaction is crucial for muscle contraction, including the contraction of the heart and skeletal muscles.
3. **Acid-Base Balance (pH Regulation):** Sodium, potassium, and chloride are all involved in maintaining the body's acid-base balance, ensuring that the pH levels in blood and other bodily fluids remain within a narrow range. Sodium and chloride are part of bicarbonate and phosphate buffering systems, which help neutralize acids and bases in the body. Potassium also contributes to this balance, particularly through its role in exchanging with hydrogen ions in the kidneys, aiding in pH regulation. Chloride, as a component of hydrochloric acid in the stomach, also helps regulate acidity during digestion, while sodium and potassium's roles in electrolyte shifts aid in overall acid-base homeostasis.
4. **Blood Pressure Regulation:** Sodium, potassium, and chloride play essential roles in controlling blood pressure. Sodium helps maintain blood volume, and an excess of sodium can lead to fluid retention, increasing blood pressure. By encouraging the elimination of sodium through urine and relaxing blood vessel walls, potassium, counter balance the effects of sodium and reduce blood pressure.
5. Chloride's influence on fluid balance indirectly affects blood pressure regulation. Together, these electrolytes help ensure proper blood pressure control, essential for cardiovascular health.
6. **Nutrient Transport and Cellular Function:** Sodium and potassium are involved in the active transport of nutrients and other substances across cell membranes. This transport is powered by the sodium-potassium pump, a cellular mechanism that moves sodium out of cells and potassium

into cells using energy from ATP. This pump is crucial for maintaining cellular homeostasis, supporting nutrient uptake (like glucose and amino acids), and facilitating waste removal. Chloride, while not directly involved in nutrient transport, contributes to creating the ideal environment for cellular enzyme activity and facilitates the movement of other ions across membranes.

6.5.2 How Sodium, Potassium, and Chloride Work Together

- **Electrochemical Gradient:** Sodium and potassium maintain the electrochemical gradient across cell membrane, which is essential for nerve impulse transmission, muscle contraction, and cell signaling. Chloride helps stabilize this gradient by balancing the positive charges of sodium and potassium.
- **Hydration and Osmotic Balance:** Sodium and chloride control the extracellular fluid volume, while potassium regulates intracellular fluid. This coordinated regulation ensures that water is appropriately distributed in and out of cells, which is vital for maintaining hydration, blood volume, and cellular integrity.
- **pH Stability:** Sodium and potassium play a role in the kidneys' regulation of acid-base balance, while chloride, often exchanged with bicarbonate in the kidneys, helps to stabilize pH. This interplay is crucial for maintaining metabolic stability and preventing conditions like acidosis or alkalosis.

By understanding the interconnected roles of sodium, potassium, and chloride, it becomes clear how critical they are for the body's overall function, from cellular health to systemic regulation, including hydration, nerve signaling, and blood pressure control. Proper dietary intake of these electrolytes and maintaining their balance is vital for optimal health and well-being. Let's discuss it in next section

6.5.3 Sources of Sodium, Potassium, and Chloride

These three minerals are readily available through a variety of dietary sources, ensuring that with a balanced diet, the body's electrolyte needs are met:

Sodium Sources

Sodium is commonly found in a variety of everyday foods, both in natural and processed forms. Common sources of sodium are given in figure 6.9. The most prevalent source is table salt (sodium chloride), which is widely used in cooking and seasoning. Processed foods, including canned soups, snacks, ready-to-eat meals, sauces, deli meats, and pickled products, often contain high levels of added sodium to enhance flavor and extend shelf life. Cheese and dairy products, particularly processed cheeses and cheese spreads, are also significant sources of sodium. Additionally, bread and baked goods, such as rolls and pastries, typically include added sodium for leavening and flavor. Cured meats, like bacon, ham, sausage, and salami, are another major source due to the salt used in their preservation and seasoning. These foods contribute significantly to daily sodium intake and are often the focus when considering dietary sodium reduction for better health.

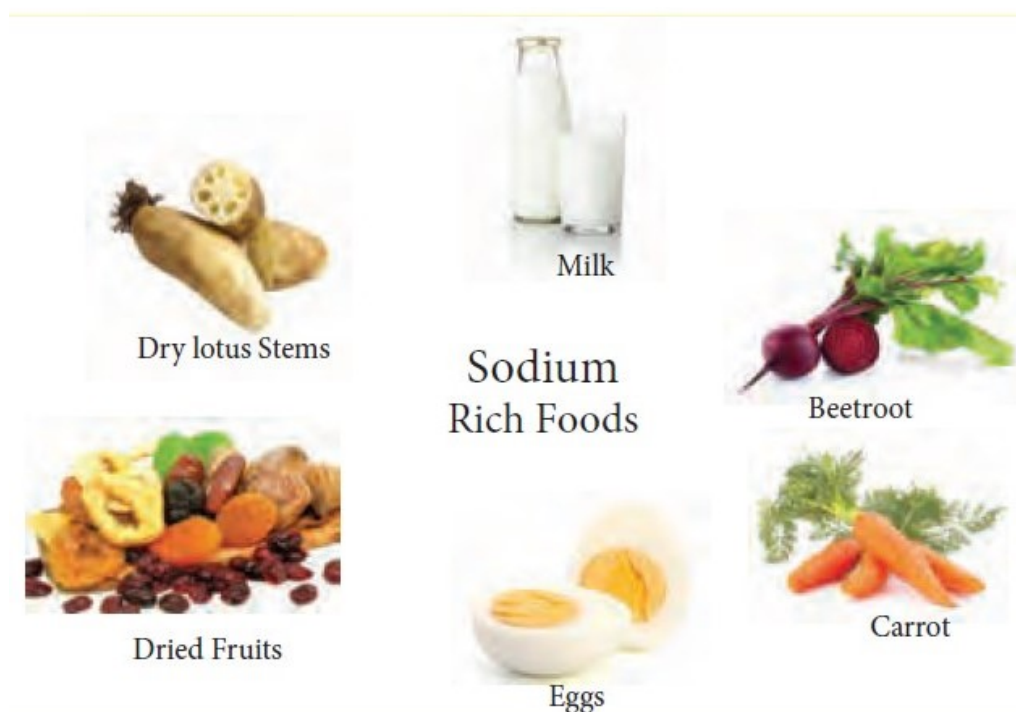


Figure 6.9: Sources of Sodium

Source: <https://img.brainkart.com/imagebk35/P1VX9oQ.jpg>

Potassium Sources

Potassium can be found in a variety of nutritious foods that are beneficial for maintaining overall health. Common sources of potassium is given in figure 6.10. Fruits such as bananas, oranges, apricots, kiwi, and avocados are particularly rich in potassium, making them excellent choices for a

healthy diet. Vegetables, especially leafy greens are also high in potassium, along with potatoes (especially the skins), sweet potatoes, and tomatoes. Legumes, including beans, lentils, and peas, not only provide ample potassium but are also good sources of fiber and other essential nutrients. Nuts and seeds, like almonds, cashews, and sunflower seeds, offer a convenient way to boost potassium intake while also providing healthy fats and proteins. Additionally, dairy products such as milk, yogurt, and cheeses like ricotta and mozzarella are valuable sources of potassium, along with their calcium and vitamin D content.

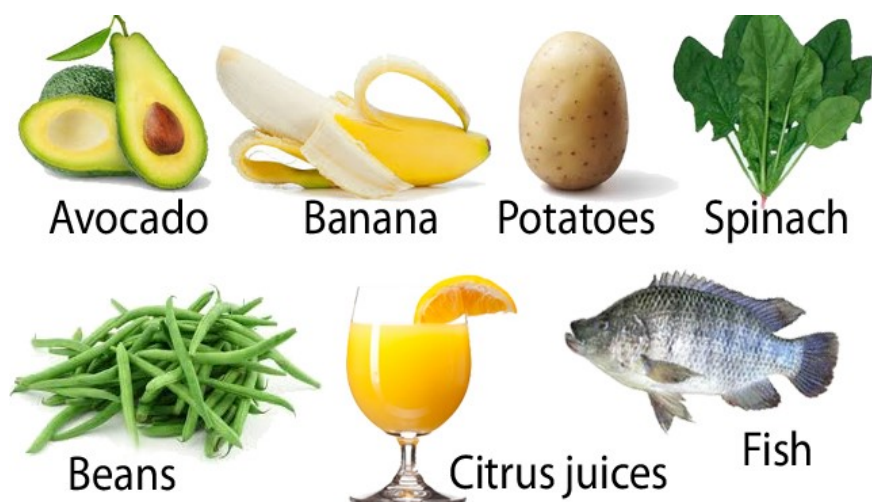


Figure 6.10: Sources of Potassium

(Source: <https://www.nutrientsreview.com/>)

Chloride Sources

Chloride, an essential mineral, is found in a variety of foods, with table salt (sodium chloride) being the primary source, as it contains a significant amount of chloride. Like sodium, chloride is commonly present in processed foods, including canned items and snacks, where added salt enhances flavor and preserves freshness. Natural sources of chloride include meats and fish such as beef, pork, poultry, and seafood, all of which provide moderate amounts of this mineral. Dairy products, like milk, cheese, and yogurt, also contribute to dietary chloride intake. Vegetables such as seaweed, lettuce, celery, olives, and tomatoes are notable for their natural chloride content, making them a healthy way to include this mineral in the diet. Chloride is crucial for maintaining fluid balance, digestive health, and proper muscle and nerve function.

By incorporating a variety of whole foods and limiting excessive intake of processed and salty foods, it is possible to maintain a healthy balance of sodium, potassium, and chloride in the diet, ensuring proper body function and reducing the risk of related health issues.

6.5.4 Metabolism of Sodium, Potassium, and Chloride

As we discuss metabolism refers to the processes by which the body regulates the intake, absorption, distribution, storage, and excretion of sodium. Sodium is crucial for maintaining fluid balance, nerve function, muscle contraction, and blood pressure regulation. The body carefully controls sodium levels to ensure proper functioning of cells and overall health. Here's a detailed overview of sodium metabolism:

6.5.4.1 Absorption: Sodium, potassium, and chloride are absorbed primarily in the small intestine, each through different mechanisms that help regulate the body's electrolyte balance. Let's discuss:

- **Sodium:** Absorption of sodium occurs mostly in the small intestine, with a smaller amount absorbed in the colon. This process is efficient, utilizing both **active transport** and **sodium-dependent co-transporters**, which facilitate the uptake of sodium alongside glucose and amino acids. These transporters help move sodium across the cell membranes, drawing water into the bloodstream and supporting hydration. The **sodium-potassium pump** plays a crucial role in maintaining sodium levels, actively moving sodium out of cells and potassium into cells, a process that requires ATP.
- **Potassium:** Potassium is absorbed in the small intestine through both **passive diffusion** and **active transport**. Unlike sodium, potassium does not require specific carriers for absorption, making the process highly efficient. However, potassium absorption is more tightly regulated, as excess potassium is primarily managed and excreted by the kidneys, ensuring proper balance within the body.
- **Chloride:** Chloride absorption in the small intestine occurs alongside sodium, as both ions are often co-transported to maintain **electrical neutrality** and fluid balance. Chloride can also be absorbed passively through cell membranes, following sodium's movement to maintain osmotic balance and support the overall electrolyte homeostasis in the body.

Together, these processes ensure that sodium, potassium, and chloride are efficiently absorbed and distributed throughout the body, playing vital roles in hydration, nerve signaling, muscle contraction, and overall fluid balance.

6.5.4.2 Distribution of Sodium: Sodium, potassium, and chloride are distributed throughout the body in different compartments, each serving essential roles in maintaining fluid balance, nerve transmission, muscle function, and overall homeostasis. Sodium and chloride are primarily found in the **extracellular fluid** (ECF), including blood plasma and interstitial fluid, where it is the major cation. Potassium is concentrated inside cells (intracellular fluid). It helps maintain osmotic balance and fluid distribution between the intracellular and extracellular compartments. The body maintains a high concentration of sodium in the ECF compared to the intracellular fluid (ICF). This gradient is crucial for generating electrical signals in nerves and muscles.

1. Sodium

- **Extracellular Fluid:** Sodium is predominantly (about 90%) found in the extracellular fluid (ECF), such as blood, plasma, interstitial fluid, and lymph.
- **Blood Plasma:** Sodium plays a critical role in regulating blood volume and blood pressure. It helps maintain the osmotic pressure of the blood, ensuring proper fluid balance between the blood and tissues.
- **Interstitial Fluid:** Sodium is essential for controlling the fluid in spaces between cells, helping to maintain cell turgidity and preventing dehydration or swelling.
- **Role in Fluid Balance:** Sodium works with chloride to regulate water retention, hydration status, and the movement of fluids between compartments in the body.

2. Potassium

- **Intracellular Fluid:** The main cation (positively charged ion) in the intracellular fluid is potassium, making up about 98% of the body's total potassium. It is primarily found inside the cells, where it is crucial for cellular functions like protein synthesis, enzyme activation, and maintaining cellular integrity.

- **Cell Membrane Potential:** Potassium is key in maintaining the **resting membrane potential** and the electrical gradient across the cell membrane, which is essential for nerve impulses, muscle contractions, and heart function.
- **Blood Plasma:** A small amount of potassium is found in the extracellular fluid, particularly in the blood plasma, but the levels are tightly regulated to prevent disruptions in normal cellular functions.

3. Chloride

- **Extracellular Fluid:** Chloride, like sodium, is predominantly found in the extracellular fluid, including blood plasma and interstitial fluid. It is the most abundant anion (negatively charged ion) in the extracellular space.
- **Blood Plasma:** Chloride helps balance sodium in the plasma and maintains the electrical neutrality of the fluid, assisting in maintaining osmotic pressure and fluid balance in the circulatory system.
- **Gastric Fluids:** Chloride is also found in the stomach as part of hydrochloric acid (HCl), which is essential for digestion. It aids in the breakdown of food and the absorption of nutrients in the digestive tract.
- **Interstitial Fluid:** Chloride, alongside sodium, helps regulate the fluid in spaces between cells, ensuring that the body's fluid compartments are balanced.

6.5.4.3 Excretion of Sodium:

1. **Sodium:** Sodium is primarily excreted through the kidneys in urine. The amount of sodium excreted depends on dietary intake, fluid status, and the body's sodium needs. A healthy body adjusts urinary sodium excretion to maintain balance. For example, low sodium intake leads to decreased excretion, while high intake increases sodium excretion. A small amount of sodium is also lost through sweat and feces. Sweat loss can be significant in hot climates or during intense physical activity.
2. **Potassium:** Potassium is also primarily excreted through the urine. The kidneys carefully regulate potassium levels to prevent imbalances, as even small fluctuations can affect heart and muscle function. The kidneys are the primary regulators of potassium balance, filtering the blood and excreting excess potassium in the urine. They adjust the amount of potassium

excreted based on the body's needs, which ensures that potassium levels remain within a narrow and healthy range. A small amount of potassium is also lost through sweat, which can be significant during intense physical activity or in hot climates.

3. **Chloride:** Chloride excretion follows a similar pattern to sodium, as both are filtered and reabsorbed together in the kidneys. The kidneys play a crucial role in regulating chloride levels, excreting any excess through urine. Chloride excretion is tightly linked to sodium, as they are typically lost together. In addition to urinary excretion, chloride can also be lost through sweat, especially during vigorous exercise or in hot and humid environments.

The kidneys adjust the amount of chloride excreted based on the body's needs, ensuring a stable chloride balance. Additionally, chloride loss through sweat increases during intense physical activity or exposure to high temperatures, further contributing to the regulation of chloride levels in the body.

6.5.5 Factors Influencing Sodium, Potassium, and Chloride Metabolism

The metabolism of sodium, potassium, and chloride is influenced by various factors that regulate their absorption, distribution, and excretion. These factors ensure that the body maintains electrolyte balance and homeostasis, preventing disruptions in physiological functions. Here are some key factors that influence the metabolism of these minerals:

1. Dietary Intake

- **Sodium:** A high-sodium diet, often from processed foods and salt, can lead to increased sodium levels in the blood, which may raise blood pressure. Conversely, a low-sodium diet can result in sodium deficiency, impacting fluid balance and organ function.
- **Potassium:** The amount of potassium consumed through fruits, vegetables, and legumes directly influences potassium levels in the body. A potassium-rich diet helps regulate blood pressure and supports muscle and nerve function. A deficiency can lead to hypokalemia, causing muscle weakness and cardiac arrhythmias.
- **Chloride:** Chloride intake typically follows sodium consumption, as it is present in table salt (sodium chloride) and many processed foods. Low chloride levels are rare, but excessive chloride intake from high-sodium diets can contribute to imbalances in fluid and electrolyte homeostasis.

2. Kidney Function

- **Sodium and Chloride:** The kidneys are the primary regulators of sodium and chloride levels, filtering and reabsorbing these minerals as needed. Impaired kidney function can lead to either sodium and chloride retention (causing hypertension and fluid overload) or excessive loss, resulting in dehydration and electrolyte imbalances.
- **Potassium:** The kidneys also play a crucial role in potassium homeostasis by excreting excess potassium through urine. In kidney dysfunction, potassium excretion may be reduced, leading to hyperkalemia, which can have dangerous effects on heart rhythm.

4. Fluid Balance

- **Dehydration:** When the body is dehydrated, sodium and chloride levels may rise due to reduced water volume, leading to higher concentrations in the blood. Potassium levels may also fluctuate, as cellular function and water movement are altered.
- **Overhydration:** Conversely, excess water intake can dilute sodium and chloride concentrations in the extracellular fluid, leading to hyponatremia and low chloride levels, which can disrupt normal cellular processes.

5. Physical Activity

- **Exercise and Sweat:** During physical activity, especially in hot climates or vigorous exercise, sodium, potassium, and chloride are lost through sweat. This loss can lead to electrolyte imbalances if not replenished through hydration and diet.
- **Heat Stress:** In hot and humid conditions, excessive sweating can result in a loss of both sodium and chloride. Inadequate electrolyte replacement can lead to dehydration, muscle cramps, and low blood pressure.

6. Medications

- **Diuretics:** Certain medications, particularly diuretics, promote sodium and potassium excretion by the kidneys. These medications can disrupt the balance of sodium, potassium, and chloride, leading to electrolyte imbalances.

- **Corticosteroids:** These drugs can increase sodium retention and potassium excretion, which may lead to fluid retention and elevated blood pressure.
- **Antihypertensive Drugs:** Some medications used to lower blood pressure, like ACE inhibitors or angiotensin II receptor blockers, can affect sodium and potassium levels by influencing the hormonal regulation of these minerals.

7. Disease Conditions

- **Chronic Kidney Disease (CKD):** Impaired kidney function can lead to an inability to regulate sodium, potassium, and chloride effectively. This can cause imbalances in fluid and electrolyte levels, leading to conditions like hyperkalemia or hyponatremia.
- **Addison's Disease:** This condition involves adrenal insufficiency, which results in reduced aldosterone production. Low aldosterone levels impair sodium retention and potassium excretion, leading to sodium loss, potassium retention, and dehydration.
- **Hyperaldosteronism:** Excessive aldosterone production causes increased sodium reabsorption and potassium excretion, which frequently leads to low potassium levels and high blood pressure. This disease is known as hyperaldosteronism.

8. Age and Gender

- **Age:** As people age, kidney function may decline, making it more challenging to regulate levels of sodium, potassium, and chloride effectively.
- **Gender:** Hormonal differences between men and women, particularly during pregnancy or menstruation, can influence fluid and electrolyte balance. For example, pregnancy can alter potassium levels, while menstruation can lead to fluctuations in sodium and chloride balance due to hormonal shifts.

6.5.6 Regulation of Sodium, **potassium**, and **chloride** Levels

The levels of sodium, potassium, and chloride in the body are tightly regulated through a combination of hormones, organs (primarily the kidneys), and feedback mechanisms that ensure the proper balance of electrolytes for optimal physiological function. The kidneys play a central role in the regulation of sodium, potassium, and chloride, ensuring that their levels remain within the appropriate range.

Hormonal regulation of sodium, potassium, and chloride levels in the body is essential for maintaining fluid balance, electrolyte equilibrium, and proper physiological function. The primary hormones involved in this regulation are **aldosterone**, **antidiuretic hormone (ADH)**, **atrial natriuretic peptide (ANP)**, and **insulin**, each playing a unique role in managing these minerals.

Let's discuss in brief:

1. **Aldosterone**: Aldosterone, a steroid hormone produced by the adrenal glands, plays a central role in regulating sodium and potassium levels. It is part of the **renin-angiotensin-aldosterone system (RAAS)**, which responds to changes in blood pressure, blood volume, and sodium levels.

- **Sodium Regulation**: Aldosterone increases sodium reabsorption in the **distal convoluted tubule** and **collecting ducts** of the kidneys. When sodium levels in the blood are low or blood pressure drops, aldosterone is released to promote sodium retention, which helps to increase blood volume and pressure.
- **Potassium Regulation**: Aldosterone also increases the excretion of potassium into the urine. As sodium is reabsorbed, potassium is secreted into the tubular fluid to maintain electrochemical balance. High potassium levels in the blood (hyperkalemia) trigger aldosterone release to enhance potassium excretion.
- **Chloride Regulation**: Since chloride follows sodium passively to maintain electrical neutrality, aldosterone's action on sodium reabsorption also indirectly promotes chloride retention. Chloride reabsorption in the kidneys occurs along with sodium, ensuring that the electrolyte balance is preserved.

2. Antidiuretic Hormone (ADH)

The posterior pituitary gland releases ADH, also referred to as vasopressin, which is generated by the hypothalamus. It primarily regulates water balance, but also influences sodium concentration and fluid volume.

- **Sodium Regulation**: ADH promotes water reabsorption in the kidneys by increasing the permeability of the **collecting ducts** to water. This process concentrates urine and helps retain water in the body, indirectly increasing sodium concentration in the extracellular fluid. When

water is retained, sodium levels may become more concentrated in the blood (leading to higher sodium levels in the blood plasma).

- **Potassium Regulation:** ADH also plays a role in potassium balance, although its effects are less direct. By regulating water retention, ADH helps control the volume of extracellular fluid, which can influence the distribution of potassium between the intracellular and extracellular spaces.
- **Chloride Regulation:** As with sodium, the effects of ADH on water reabsorption can indirectly influence chloride concentrations. Retained water increases the dilution of chloride in the blood, especially during situations of dehydration when chloride is conserved in response to water loss.

3. Atrial Natriuretic Peptide (ANP)

The heart's atria release the hormone known as atrial natriuretic peptide (ANP) in reaction to increased blood pressure and volume. It has the opposite effect of aldosterone and acts as a counter-regulatory hormone to sodium and fluid retention.

- **Sodium Regulation:** ANP promotes sodium excretion in the kidneys by inhibiting sodium reabsorption in the **distal tubules** and **collecting ducts**. When blood volume increases, ANP is released to reduce sodium retention, which helps lower blood pressure and volume by promoting diuresis (increased urine production).
- **Chloride Regulation:** As ANP increases sodium excretion, chloride is also excreted along with sodium to maintain electrical neutrality. This helps regulate the balance between sodium and chloride in the extracellular fluid.
- **Potassium Regulation:** While ANP's effects on potassium are less pronounced, its action on sodium excretion can indirectly affect potassium homeostasis by influencing overall fluid balance and kidney function.

4. Insulin

Insulin, a hormone produced by the **pancreas**, is primarily known for regulating glucose metabolism, but it also plays a significant role in potassium homeostasis.

- **Potassium Regulation:** Insulin promotes the uptake of potassium into cells, particularly muscle and liver cells. This is important after meals when blood glucose levels rise, as insulin facilitates

the movement of both glucose and potassium into cells, lowering potassium levels in the bloodstream. This is a crucial mechanism for preventing hyperkalemia (high potassium levels).

Sodium and Chloride Regulation: Although insulin's effects on sodium and chloride are less direct, the hormone's role in glucose and potassium uptake can influence overall cellular function and fluid balance. Insulin indirectly affects the distribution of electrolytes within cells and between compartments.

4. **Renin-Angiotensin-Aldosterone System (RAAS):** The RAAS responds to low blood pressure or low sodium levels, and essential mechanism in the regulation of sodium, potassium, and chloride.

Let's discuss

- **Renin Release:** When sodium levels drop or blood pressure decreases, the kidneys release **renin**, which catalyzes the conversion of **angiotensinogen** (produced by the liver) into **angiotensin I**, which is then converted to **angiotensin II** by an enzyme called **angiotensin-converting enzyme (ACE)**.
- **Angiotensin II:** Angiotensin II stimulates the release of aldosterone from the adrenal glands. It also causes vasoconstriction (narrowing of blood vessels), which increases blood pressure. Additionally, it promotes sodium and chloride reabsorption in the kidneys and stimulates thirst, further increasing water intake.

6.5.7 Imbalance and Disorders

Hopefully, hormonal regulation of sodium, potassium, and chloride levels is a highly coordinated process involving aldosterone, ADH, ANP, insulin, and the RAAS system. These hormones ensure that electrolyte balance is maintained, blood pressure is regulated, and fluid volume is controlled. Disruptions in any of these hormonal systems can lead to significant health issues, highlighting the importance of their precise regulation in maintaining overall body function.

Imbalances in the levels of sodium, potassium, and chloride can lead to a variety of disorders, each with significant physiological consequences. These disorders can arise from insufficient or excessive levels of these electrolytes in the body, resulting in disruptions to fluid balance, nerve and muscle

function, and cardiovascular health. Let's discuss some common disorders related to imbalances of sodium, potassium, and chloride:

1. Sodium Imbalance Disorders: Sodium (Na^+) is an essential electrolyte for regulating fluid balance and blood pressure. Disorders related to sodium imbalances are typically classified as either **hyponatremia** (low sodium levels) or **hypernatremia** (high sodium levels).

a. **Hyponatremia (Low Sodium Levels):** A condition known as hyponatremia results when sodium levels fall below 135 mEq/L. It may result from kidney failure, excessive fluid intake (water intoxication), or severe salt loss (due to vomiting, diarrhea, or diuretics). Headache, nausea, disorientation, seizures, and in extreme situations, coma or death, are possible symptoms.

- **Management:** Treatment involves correcting the underlying cause, restricting fluid intake, and administering intravenous (IV) fluids with a controlled amount of sodium.

b. **Hypernatremia (High Sodium Levels)**

- Hypernatremia results when sodium levels exceed 145 mEq/L, usually caused by dehydration, excessive salt intake, or conditions such as diabetes insipidus (which impairs water retention). Symptoms include extreme thirst, dry mouth, confusion, muscle twitching, and in severe cases, seizures and coma. The body attempts to compensate by retaining water, leading to cellular dehydration.
- **Management:** Treatment involves rehydrating the patient with IV fluids, typically with a low sodium concentration, and addressing the underlying cause (e.g., diabetes insipidus or excessive salt intake).

2. Potassium Imbalance Disorders: **Potassium (K^+)** is critical for maintaining normal cell function, especially in nerve and muscle cells, including the heart. Potassium imbalances can cause serious disturbances in cardiac and muscular function.

a. **Hypokalemia (Low Potassium Levels)**

- Hypokalemia is a condition that results when potassium levels fall below 3.5 mEq/L. It can result from excessive potassium loss (due to prolonged vomiting, diarrhea, or use of diuretics) or

inadequate intake of potassium-rich foods. Symptoms of hypokalemia include muscle weakness, cramps, fatigue, arrhythmias (irregular heartbeats), and constipation. In severe cases, it can lead to paralysis and cardiac arrest.

- **Management:** Treatment involves potassium supplementation (oral or IV) and addressing the underlying cause of the deficiency (e.g., adjusting diuretic use or treating diarrhea).

b Hyperkalemia (High Potassium Levels)

- Hyperkalemia occurs when potassium levels exceed 5.0 mEq/L, often due to kidney dysfunction (e.g., chronic kidney disease), excessive potassium supplementation, or certain medications (e.g., ACE inhibitors, potassium-sparing diuretics). Symptoms include muscle weakness, fatigue, arrhythmias (especially life-threatening ones like ventricular fibrillation), and in extreme cases, cardiac arrest.
- **Management:** Treatment may involve discontinuing potassium-sparing medications, administering medications to shift potassium into cells (e.g., insulin and glucose), and using diuretics or dialysis to remove excess potassium from the body.

3. Chloride Imbalance Disorders: **Chloride (Cl⁻)** is an essential anion that works with sodium to maintain osmotic pressure and fluid balance. Chloride imbalances often occur alongside sodium imbalances, as chloride typically follows sodium to maintain electrical neutrality.

- a. Hypochloremia (Low Chloride Levels): Hypochloremia is often caused by conditions that lead to the loss of both chloride and sodium, such as vomiting, prolonged diarrhea, excessive sweating, or certain medical treatments. It can also result from metabolic alkalosis, a condition characterized by an increase in blood pH. Symptoms of hypochloremia include muscle twitching, weakness, breathing difficulties, and, in severe cases, seizures or coma. These symptoms are often accompanied by signs of alkalosis, such as confusion or irregular breathing. Management of hypochloremia focuses on addressing the underlying cause, which may involve replenishing chloride levels through intravenous fluids like saline solution and correcting any associated metabolic imbalances.

b Hyperchloremia (High Chloride Levels): Hypochloremia is commonly caused by conditions that result in the loss of both chloride and sodium, such as vomiting, prolonged diarrhea, excessive

sweating, or certain medical treatments. It can also occur in conjunction with metabolic alkalosis, a condition characterized by an elevated blood pH. The symptoms of hypochloremia include muscle twitching, weakness, difficulty breathing, and in severe cases, seizures or coma. These symptoms are often accompanied by signs of alkalosis, such as confusion or irregular breathing. Treatment involves addressing the underlying cause, which may include replenishing chloride levels through intravenous fluids, like saline solution, and correcting any associated metabolic imbalances.

6.5.8 Disorders Associated with Combined Imbalances

Disorders related to imbalances in sodium, potassium, and chloride can have serious consequences, affecting nerve and muscle function, cardiovascular health, and overall fluid balance. Proper diagnosis and management are crucial to correcting these imbalances and preventing complications. The treatment of these disorders often involves addressing the underlying cause, correcting electrolyte levels with oral or intravenous fluids, and using medications to regulate hormone levels or kidney function.

Sometimes, sodium, potassium, and chloride imbalances occur together, typically as a result of kidney dysfunction, dehydration, or inappropriate fluid management. The most common scenarios include:

1. **Dehydration:** Loss of both chloride and sodium, which can occur due to factors such as vomiting, prolonged diarrhea, excessive sweating, or certain medical treatments. It may also be associated with metabolic alkalosis, a condition where the blood pH becomes abnormally high. Symptoms of hypochloremia include muscle twitching, weakness, difficulty breathing, and, in severe cases, seizures or coma. These symptoms are typically accompanied by signs of alkalosis, such as confusion or irregular breathing. Management of hypochloremia focuses on treating the underlying cause, which may involve replenishing chloride levels through intravenous fluids, such as saline solution, and addressing any metabolic imbalances to restore normal electrolyte levels.
2. **Renal Failure and Electrolyte Imbalance:** Chronic kidney disease or acute renal failure can impair the kidneys' ability to filter and balance sodium, potassium, and chloride, leading to electrolyte imbalances such as hyperkalemia, hyponatremia, and hyperchloremia. This occurs because the kidneys are unable to properly excrete excess electrolytes. Symptoms of these imbalances may include swelling (edema), fatigue, confusion, and changes in urine output. If left untreated, the condition can progress to life-threatening complications, such as cardiac arrest due to

hyperkalemia. Management typically involves dialysis to remove excess electrolytes and fluids, along with adjusting medications that influence electrolyte balance.

6.5.9 Recommended Dietary Allowances (RDA)

The Recommended Dietary Allowance (RDA) varies based on age, sex, and life stage. Here are the general guidelines for RDA are given below:

1. **RDA for Sodium:** Unlike other nutrients, sodium does not have an RDA per se but instead has **arecommended intake range** or **Adequate Intake (AI)**. The adequate intake **for sodium** is set at **1,500 milligrams (mg) per day** for adults. This level is considered adequate for most people to maintain normal physiological functions.
2. **RDA for Potassium:** There is no specific RDA for potassium, but the **Adequate Intake (AI)** for adults is set at around **2,500 to 3,400 milligrams per day** depending on age, sex, and individual needs. Higher potassium intake is generally recommended for individuals with high blood pressure or those seeking to improve cardiovascular health.
3. **RDA for Chloride:** The **Adequate Intake (AI)** for chloride varies by age and sex, but for adults, it is generally set at around **2,300 milligrams per day**. This corresponds to a moderate intake of salt, which is the primary source of dietary chloride. Pregnant and breastfeeding women may require slightly higher chloride intake to support fetal and infant development. Most people meet their chloride needs through a typical diet that includes salt, but excessive intake of processed foods can lead to an overconsumption of chloride.

CHECK YOUR PROGRESS EXERCISE 2

1. How is magnesium absorbed in the body?

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2. What is the role of sodium in metabolism?

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3. How is potassium distributed in the body ?

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4. What is the RDA for calcium and magnesium?

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Let us get to know more about these micro-minerals:

Micro Minerals (also called Trace Minerals): These minerals are required by the body in very small amounts, but they are crucial for various physiological functions. The key micro-minerals discussed in this section are iron, copper, zinc, magnesium and iodine.

Let us get to know more about these micro-minerals:

6.6 IRON

Iron is an important mineral that the human body needs for many physiological functions. About 25% of the iron in the body is kept in the liver, spleen, and bone marrow, while the remaining 70% is bonded to hemoglobin. It is an essential part of hemoglobin, the red blood cell protein that carries oxygen from the lungs to the body's tissues and organs. The synthesis of myoglobin, which aids in the storage and utilization of oxygen by muscles, also depends on iron. Iron also has a role in DNA synthesis, immunological response, and energy consumption.

Understanding the function, metabolism, sources, and deficiency of iron is essential for maintaining overall health. Let's explore each aspect in detail.

Function

The main functions of iron can be categorized into the following key areas:

Oxygen Transport: Iron is an important component of hemoglobin, a protein, enabling efficient oxygen transport in the body. Additionally, myoglobin, a protein in muscle tissue that helps store oxygen, depends heavily on iron.

1. **Energy Production:** Iron plays a crucial role in energy production by supporting cellular respiration. It is an essential component of hemoglobin, which transports oxygen to tissues, allowing cells to generate energy through aerobic metabolism. Iron is also a key part of enzymes involved in the electron transport chain, which is responsible for producing ATP, the body's primary energy currency. Additionally, iron supports the function of myoglobin in muscles, aiding in oxygen storage and enabling efficient energy production during physical activity.

3. **DNA Synthesis:** Iron plays a crucial role in DNA synthesis by supporting the function of ribonucleotide reductase, an enzyme required for converting ribonucleotides into deoxyribonucleotides, the building blocks of DNA. This process is essential for cell division and the formation of new DNA strands during cell replication. Iron also supports the function of other enzymes involved in the synthesis and repair of DNA. Without adequate iron, DNA synthesis is impaired, which can lead to cell growth issues, impaired immune function, and overall compromised health. Therefore, maintaining optimal iron levels is vital for healthy cellular function and tissue growth.

4. **Immune Function:** Iron is necessary for healthy immune function because it is important for the development and multiplication of immune cells, especially lymphocytes, which are part of the body's

defense against infections. Iron is also a critical component of enzymes that produce reactive oxygen species (ROS) to help neutralize pathogens. A deficiency in iron can impair immune response, leading to increased susceptibility to infections. Thus, maintaining adequate iron levels supports a robust immune system.

5. Cognitive Function: Cognitive function and brain health depend on iron. It facilitates the production of neurotransmitters that are important for mood management, concentration, and general brain function, including dopamine, serotonin, and norepinephrine. Low iron levels may contribute to issues with concentration, memory, and mood disorders such as depression or irritability.

6. Detoxification and Antioxidant Function: Iron helps reduce oxidative stress by serving as a cofactor for antioxidant enzymes, which neutralize reactive oxygen species (ROS). It is also vital in oxygen transport through hemoglobin and myoglobin, preventing ROS buildup in tissues. Additionally, iron is essential in the electron transport chain in mitochondria, supporting efficient energy production and reducing ROS formation. However, excess iron can increase oxidative stress by promoting the generation of harmful free radicals, so maintaining balanced iron levels is crucial for optimal antioxidant defense.

7. Transport and Storage: Iron is transported in the blood by a protein called transferrin, which binds to iron and carries it to tissues and organs that require it, including the bone marrow (for the production of red blood cells), muscles (for myoglobin), and the liver (for storage). The liver stores iron in the form of ferritin, a protein that safely binds iron and releases it when the body needs it. This regulated system helps ensure that iron is available where it is needed most, and prevents harmful free iron from accumulating in tissues, which can be toxic.

8. Maintenance of Skin, Hair, and Nails: Iron also plays a role in maintaining healthy skin, hair, and nails. Hemoglobin delivers oxygen to the skin and hair follicles, promoting healthy growth and repair of these tissues. Iron deficiency can lead to conditions like pale skin, hair thinning, and brittle nails, which are common symptoms of anemia.

9. Regulation of Body Temperature: Iron is involved in regulating body temperature by supporting the function of enzymes that control the thermoregulatory centers in the brain. These enzymes are important for maintaining internal body temperature within the optimal range for cellular functions.

Metabolism

Iron metabolism regulates the level of iron to maintain proper physiological function and prevent iron deficiency or overload as shown in figure 6.11. The absorption and metabolism of iron are tightly regulated processes that ensure the body maintains adequate iron levels. The absorption of iron from food is influenced by its form (heme or non-heme), and various dietary factors can enhance or inhibit its uptake. Once absorbed, iron is transported by transferrin and stored in the liver and other tissues, while its levels in the body are regulated by hormones such as hepcidin. The efficient recycling of iron from old red blood cells further helps maintain iron homeostasis. Proper iron metabolism is essential for health, and both deficiencies and excesses of iron can lead to serious health issues.

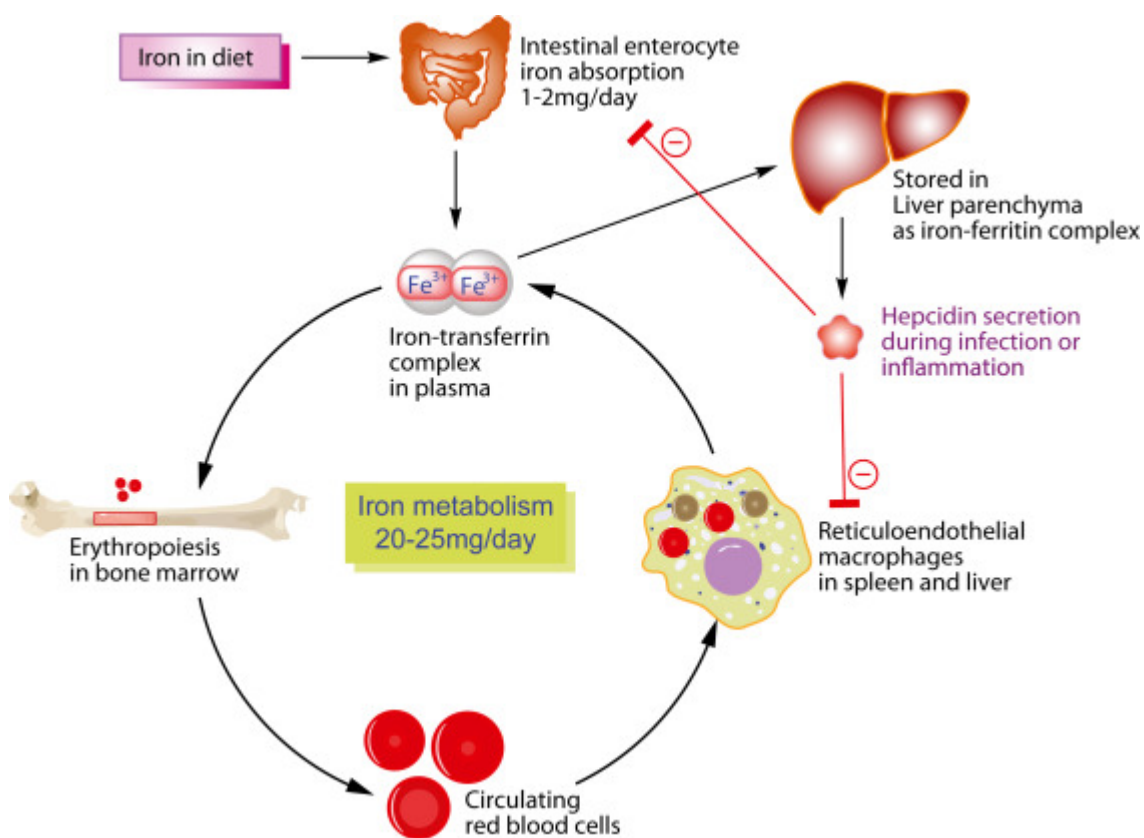


Figure 6.11: Iron Metabolism

(Source: <https://ars.els-cdn.com/content/>)

Next, we discuss them in detail:

Absorption of Iron

Primarily, iron absorb in the small intestine, particularly in the duodenum (the first part of the small intestine). The form of iron in food is either **heme iron** (from animal sources) or **non-heme iron** (from plant-based sources). Heme iron is more efficiently absorbed than non-heme iron. Each following a distinct absorption pathway and influenced by different factors.

Heme Iron Absorption:

Animal food are good source of heme iron, where it is part of hemoglobin and myoglobin. This form of iron is highly bioavailable, with an absorption rate of 15-35%. The enzyme heme oxygenase breaks down heme once it enters intestinal cells (enterocytes), releasing the useable form of iron, ferrous iron (Fe^{2+}). A protein known as ferroportin can carry this iron into the bloodstream, where it links to transferrin, a blood protein that carries iron throughout the body, or it can be stored in the cell as ferritin. Heme iron is a more stable supply of iron since its absorption is mostly unaffected by dietary enhancers or inhibitors.

Non-Heme Iron Absorption:

Pant-based foods are rich in non-heme iron and is less readily absorbed, with rates varying between 2-20%. This form of iron is primarily in the ferric (Fe^{3+}) state, which is not easily absorbed. In the stomach, gastric acid helps convert ferric iron to the more absorbable **ferrous (Fe^{2+})** form. However, non-heme iron absorption is highly sensitive to dietary factors: it can be enhanced by vitamin C (which keeps iron in the ferrous form) and by the presence of animal proteins. Conversely, it is inhibited by compounds like **phytates** (found in whole grains and legumes), **polyphenols** (in tea and coffee), **calcium**, and **oxalates** (in certain leafy greens), which bind iron and reduce its availability.

Regulation of Iron Absorption:

There are several factors that can regulate absorption of iron, which includes the form of iron, the presence of other dietary components, and the overall nutritional status of the individual.

Below are the key details of factors affecting iron absorption:

Enhancers of Iron Absorption:

- **Acidic Foods:** Increased acidity either from food or through gastric secretions enhances non-heme iron absorption. Foods containing citric acid or lactic acids, found in fruits and fermented foods, can increase non-heme iron absorption by maintaining an acidic environment in the stomach that helps reduce iron to its ferrous form. A more acidic environment, primarily from gastric acid (hydrochloric acid) in the stomach, converts ferric iron into the **ferrous (Fe^{2+})** form, which is more soluble and more readily absorbed by the intestinal cells. The lower the pH (higher acidity), the better the conversion of iron into its absorbable ferrous form.
- **Vitamin C (Ascorbic Acid):** Vitamin C (ascorbic acid) enhances iron absorption by acting as a reducing agent. It keeps iron in its reduced ferrous state even in the mildly acidic environment of the intestines, preventing it from reverting to the less absorbable ferric form. Additionally, vitamin C can form a stable soluble complex with iron (iron chelates) increasing its solubility and making it easier to absorb.

Animal Protein: Absorption of non-heme iron (found in plant-based foods) enhanced by two to four times when consumed alongside heme iron, which is found in animal products such as meat, fish called as meat factor. Most possible reason due to release of cysteine or cysteine containing peptides during digestion of animal protein, which combine with iron chelates that improve iron bio availability.

Inhibitors of Iron Absorption:

- **Phytates:** These are found in plant-based foods such as whole grains, legumes, nuts, and seeds and can bind iron, reducing its bioavailability. Increased gastric motility may minimize the time these inhibitors are in contact with iron, potentially reducing their negative impact on absorption. Reduce the amount of time that iron comes into contact with substances that inhibit its absorption, such as phytates or polyphenols. Present in , phytates bind iron and form insoluble complexes that decrease iron absorption.
- **Polyphenols:** Tea, coffee, red wine, and some vegetables contain organic chemicals that can bind to iron in the digestive tract and form an insoluble complex, which can limit iron absorption.

- **Calcium:** High amounts of calcium (from dairy products or supplements) can inhibit the absorption of both heme and non-heme iron by competing for the same absorption pathways.
- **Oxalates:** Present in spinach, rhubarb, and certain greens, oxalates bind iron and reduce its bioavailability.

Body Needs: Individuals with low iron stores (iron deficiency) have increased iron absorption due to upregulated intestinal transporters. Conversely, those with adequate or high iron levels absorb less to avoid iron overload.

•

Age and Growth: When the body's iron levels are low, such as during **iron deficiency**, increased blood loss, or periods of heightened demand (like growth spurts in children, adolescence, pregnancy, or breastfeeding), the intestines increase the expression of iron transport proteins to boost absorption. For example, during periods of rapid growth in children or adolescence, absorption rates increase significantly to meet the demand of increased blood volume, cognitive development, and muscle growth. During pregnancy, the body increases iron absorption to meet the demands of expanded blood volume, fetal development, and placental growth. Adolescent girls typically have higher iron requirements than boys, especially after menstruation begins, as they lose iron through menstrual blood. As a result, iron absorption in adolescent girls is more about 5% than boys or girls of other age (3%).

Lactoferrin and lactoalbumin: These are two important proteins found in milk, each with distinct roles in iron absorption.

Lactoferrin is an iron-binding glycoprotein that helps regulate the absorption and distribution of iron in the body. It plays a key role in the immune system by preventing the growth of harmful bacteria, as it sequesters iron, depriving pathogens of this essential nutrient. It is primarily found in breast milk, with higher concentrations in colostrum (the first milk produced after birth), and also in smaller amounts in cow's milk.

The presence of high-quality proteins like lactoalbumin in foods, particularly in infant formulas, enhances the overall digestibility and nutritional uptake, which can indirectly

benefit iron absorption. Additionally, lactoalbumin's rich amino acid profile, including essential amino acids like leucine, supports growth and tissue repair, ensuring the body is in optimal condition to utilize iron effectively.

3. Health-Related Conditions:

- **Intestinal Health:** Conditions affecting the small intestine, such as **celiac disease**, **Crohn's disease**, or intestinal surgery, can reduce iron absorption due to damage or removal of parts of the duodenum, where iron is primarily absorbed.
- **Chronic Inflammation:** Chronic diseases, infections, or inflammation can elevate levels of the hormone **hepcidin**, which reduces iron absorption by decreasing the expression of ferroportin (an iron transporter in the gut).
- **Medications:** Certain medications, such as antacids, proton pump inhibitors (PPIs), or calcium supplements, can interfere with iron absorption by reducing stomach acidity or competing for absorption pathways.

Transport of Iron in the Bloodstream

Once absorbed by the enterocytes, iron must be transported from the intestines to various parts of the body, where it is utilized or stored. The iron is transported in the blood by a glycoprotein called **transferrin**.

- **Transferrin:** After iron enters the bloodstream from the enterocytes, it binds to transferrin, which serves as a carrier protein. Transferrin delivers iron to tissues and organs that need it, particularly the bone marrow, liver, and muscles. Transferrin binds iron in a 2:1 ratio (two iron atoms per transferrin molecule), and the transferrin-iron complex is recognized by transferrin receptors on the surface of target cells.
- **Ferritin:** Iron that is not immediately needed for use or transport is stored within the enterocyte in the protein **ferritin**, where it is stored in its ferric (Fe^{3+}) form. Ferritin serves as a storage form of iron, which can be mobilized when the body requires additional iron. When iron enters the bloodstream, ferritin levels are regulated based on the body's iron stores. If the body has sufficient iron, ferritin levels are higher to store excess iron; if iron is low, ferritin stores are used to release iron into circulation.

Iron Storage and Regulation

Iron storage and regulation are controlled primarily by the liver, which maintains iron homeostasis through a tightly regulated system. The key protein involved in the regulation of iron storage and release is **hepcidin**, a hormone produced by the liver.

- **Hepcidin Regulation:** Hepcidin acts as the central regulator of iron homeostasis by controlling the amount of iron released into the bloodstream. When iron stores are sufficient or high, hepcidin levels increase, inhibiting the activity of ferroportin, a protein responsible for exporting iron from enterocytes and macrophages into the blood. This reduces the amount of iron circulating in the blood.
 - Conversely, when iron stores are low or the body needs more iron (for example, during anemia), hepcidin levels decrease, allowing more iron to be absorbed from the intestines and released from storage sites.
- **Ferritin and Hemosiderin:** Iron is stored in the liver, spleen, and bone marrow as ferritin, a protein that binds iron in a non-toxic form. When iron stores are high, ferritin helps keep iron safely stored. In cases of excess iron, ferritin can eventually form hemosiderin, a less readily available form of iron storage.

Excretion of Iron

Unlike other nutrients, the human body does not have a physiological mechanism for actively excreting iron. Iron is lost from the body through several pathways:

- **Sloughing of Enterocytes:** The enterocytes that absorb iron in the small intestine have a lifespan of 3 to 5 days. These cells are continuously shed into the gut lumen and excreted in the feces, carrying small amounts of iron with them.
- **Blood Loss:** Iron is also lost through blood loss, which may occur due to menstruation in women, gastrointestinal bleeding, or other medical conditions. Blood loss is one of the primary ways the body loses iron, and it must be replenished through diet or supplementation.

Iron Recycling

Iron is not only absorbed from food but also efficiently recycled within the body. Most of the iron used for hemoglobin production is recycled from old or damaged red blood cells. The liver and spleen contain specialized macrophages that break down aged red blood cells and release iron from hemoglobin. This recycled iron is then transported back to the bone marrow for the production of new red blood cells.

Hopefully, you understand that iron is absorbed in the small intestine, where it enters the bloodstream and is transported by transferrin, a protein that delivers iron to tissues and organs. The liver regulates iron storage and release based on the body's needs, while the kidneys help excrete excess iron through urine. The balance between iron absorption, storage, and excretion is essential to prevent deficiencies or iron overload.

Sources of Iron

Iron is found in a wide range of foods, with its form—heme or non-heme—playing a significant role in how well it is absorbed by the body. **Heme iron**, which comes from animal sources, is found in foods like red meat, poultry, fish, and organ meats (such as liver and kidneys). This type of iron is bound to hemoglobin and myoglobin, making it more easily absorbed by the digestive system, with an absorption rate of 15-35%. Foods like beef, chicken, seafood, and liver are rich sources of heme iron and are particularly beneficial for individuals at risk of iron deficiency because the body can readily utilize this type of iron.



Figure 6.12: Sources of Iron

(Source: <https://sixfishes.com/wp-content/>)

On the other hand, **non-heme iron** is found in plant-based sources, including legumes (like beans, lentils, and chickpeas), dark leafy greens (such as spinach and kale), nuts, seeds, whole grains, and iron-fortified foods (like breakfast cereals, bread, and plant-based milk alternatives). Non-heme iron is not as easily absorbed by the body, with an absorption rate of about 2-10%, and its absorption can be affected by various dietary components. For instance, substances like phytates (found in whole grains and legumes), calcium (from dairy products), and tannins (in tea and coffee) can inhibit the absorption of non-heme iron. However, the presence of **vitamin C-rich foods** (like oranges, strawberries, bell peppers, and tomatoes) can significantly enhance non-heme iron absorption by converting it into a more absorbable form.

While heme iron is generally absorbed more efficiently, non-heme iron remains a valuable part of a balanced diet, especially for vegetarians and vegans who rely on plant-based foods for their iron intake.

By including vitamin C-rich foods and managing inhibitors, individuals can improve the bioavailability of non-heme iron, making plant-based sources an effective part of iron nutrition.

Recommended Dietary Allowance (RDA) for Iron

Iron needs during pregnancy are higher to support increased blood volume and the growing fetus. Post-menopausal women and older adults generally have lower iron requirements.

Disorders Associated with Iron

Iron imbalance in the body can lead to various disorders, primarily associated with either iron deficiency or iron overload.

1. **Iron Deficiency:** Iron deficiency is the most common nutritional deficiency worldwide. It typically results from inadequate iron intake, increased iron requirements (such as during pregnancy), or poor absorption.

Iron Deficiency Anemia is the most common form of anemia and occurs when the body does not have enough iron to produce hemoglobin. As a result, red blood cells are unable to carry adequate oxygen to tissues and organs, leading to symptoms like fatigue, weakness, pallor, dizziness, shortness of breath, and reduced exercise tolerance. The common sign and **symptoms of Iron Deficiency** are individuals may also experience brittle nails, hair loss, headaches, cold hands and feet, and poor concentration. In severe cases, iron deficiency can also cause cognitive and developmental delays in children.

Pregnant women, young children, menstruating women, vegetarians/vegans, and individuals with gastrointestinal disorders (like celiac disease) or blood loss (e.g., heavy menstrual bleeding, gastrointestinal bleeding) are particularly at risk of iron deficiency.

2. **Iron Overload:** Excessive iron accumulation in the body can also lead to serious health problems. This condition is typically caused by **hemochromatosis**, a genetic disorder that leads to excessive iron absorption. In addition, excessive iron supplementation without medical supervision can lead to iron overload.

Hemochromatosis: This is a hereditary condition in which the body absorbs too much iron from the diet. The excess iron is stored in organs such as the liver, heart, and pancreas, leading to tissue damage over time. Symptoms may include joint pain, fatigue, abdominal pain, liver dysfunction, heart disease, and diabetes. If left untreated, iron overload can result in serious conditions like liver cirrhosis, heart failure, and diabetes.

Iron Toxicity: Acute iron toxicity is rare and usually occurs from the ingestion of large amounts of iron supplements. Symptoms of toxicity include nausea, vomiting, diarrhea, abdominal pain, and, in severe cases, organ failure and death. Chronic iron overload can result in organ damage, particularly to the liver and heart. The most common signs of iron overload are fatigue, joint pain, abdominal pain, and in more advanced cases, organ damage such as liver cirrhosis or diabetes.

Conclusion

Iron is a critical mineral that plays essential roles in oxygen transport, energy production, immune function, and overall cellular health. It is obtained from both heme (animal-based) and non-heme (plant-based) sources, and its absorption is influenced by various factors such as the presence of other nutrients. Adequate iron intake is necessary to maintain health, but both iron deficiency and overload can lead to serious health conditions. Maintaining a balanced iron intake in accordance with the recommended dietary allowances is crucial to ensure optimal health and prevent iron-related disorders.

4o mini

6.7 COPPER

Copper is a vital trace mineral that supports numerous physiological functions in the human body. It plays a crucial role in the formation of red blood cells and the absorption of iron, contributing to overall blood health. These functions are accomplished by enzymes that either have copper as prosthetic group or require the participation of copper for their activity.

These diverse roles highlight copper's importance in maintaining overall health, from bone strength and cardiovascular health to neurological and immune function are presented in figure 6.13 and as follows:

- Copper is involved in the functioning of key enzymes, such as cytochrome c oxidase, a key enzyme in the mitochondrial electron transport chain, which is involved in cellular energy production.
- Copper is involved in the functioning of tyrosinase, involve in formation of melanin.Copper also supports brain function, and serves as an antioxidant, helping to neutralize free radicals and prevent cellular damage.
- Copper is required for the activity of tyrosinase, an enzyme necessary for melanin synthesis, which affects skin, hair, and eye pigmentation.
- Copper facilitates the absorption of iron, aids in the synthesis of hemoglobin, and assists in the release of stored iron from the liver, preventing anemia.
- copper is a component of the enzyme superoxide dismutase, which helps neutralize free radicals and protects cells from oxidative damage.
- Additionally, it aids in the synthesis of collagen and elastin, crucial components for maintaining the integrity of connective tissues as it involved in the functioning of lysyl oxidase,an enzyme that cross-links collagen and elastin, providing strength and elasticity to connective tissues.

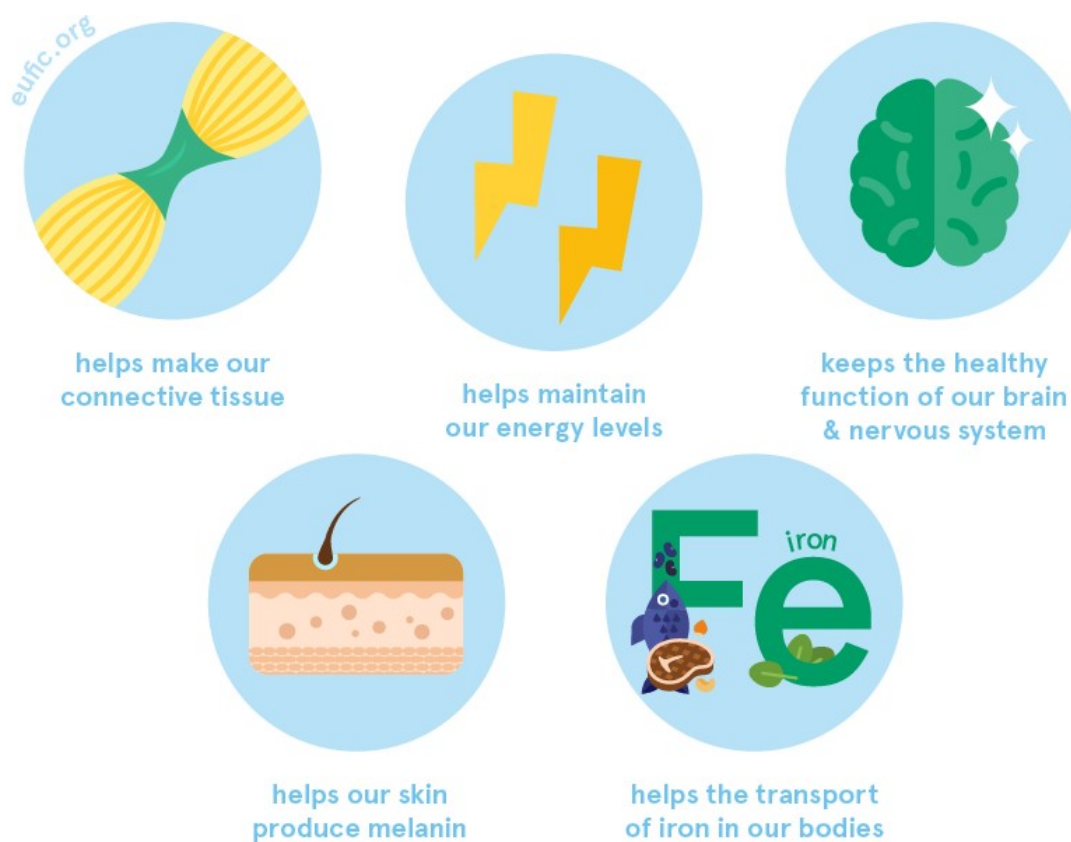


Figure 6.13: Functions of Copper

(Source: <https://www.eufic.org/en/images/>)

Copper-rich foods include shellfish, liver, nuts, seeds, whole grains, legumes, dark chocolate, and leafy green vegetables. These sources provide a natural and accessible means of meeting daily copper requirements. The **Recommended Dietary Allowance (RDA)** for copper is tailored to meet the needs of different life stages and physiological conditions. For adults, the RDA is 900 micrograms (μg) per day to support essential functions such as iron metabolism, nervous system health, and antioxidant defense. Pregnant women are advised to increase their intake to 1,000 μg per day to accommodate the heightened demands for copper during fetal development. Lactating women need even more, with an RDA of 1,300 μg per day, to ensure sufficient copper for both the mother and the breastfeeding infant. In children, the RDA varies from 340 to 890 μg per day, depending on age, to support proper growth, development, and immune function.

Metabolism: Typical diets provide about 1 mg of copper per day about 25-40 percent of which is absorbed. Copper is absorbed from all parts of gastro-intestinal tract including the stomach and large intestine. Once absorbed into the cells of the intestinal wall, most is transported through the bloodstream bound to ceruloplasmin, a copper-carrying protein. The liver is the primary storage site for copper, and any excess is excreted through bile. The body maintains copper balance by regulating absorption rates; when copper levels are low, absorption increases to ensure adequate supply. High intakes of either iron or vitamin C are found to decrease absorption of copper. Factors which increase the bioavailability are high level of protein intake and low intake of dietary copper itself. It is found that higher the Zn: Cu ratio in the diets, higher is the concentration of cholesterol in plasma.

Copper is removed from plasma by the liver, from where it is either excreted into bile, or stored in a protein complex containing copper or used in the synthesis of the copper-containing plasmin, which is released back into the blood. Ceruloplasmin is 90 percent of plasma copper. Some plasma copper enters the bone marrow, where synthesis of the copper-containing enzyme superoxide dismutase is found in red blood cells and it is responsible for protecting against toxic effects of oxygen. SOD content of red blood cells is an indicator of long standing copper status.

DEFICIENCY: Normal serum copper is 0.64-1.56 $\mu\text{g}/\text{ml}$.

Copper deficiency is rare in humans. It occurs mainly in infants resulting in psychomotor retardation, hypotonia (low osmotic pressure of blood) hypopigmentation, pallor, anaemia, osteoporosis, low concentrations of plasma copper and ceruloplasmin.

Low serum copper and ceruloplasmin levels are also found in an inherited condition known as Menkes' kinky hair syndrome. This is characterised by slow growth, degeneration of brain tissue, hypothermia, seizures, defective arterial walls, depigmentation of skin and hair and peculiarly stubby white hair (Pili torti). The syndrome results from defective absorption of copper, abnormal transport of copper and increased excretion of copper through urine (Figure 8b).

When the body accumulates too much copper, it can cause copper toxicity, which can result in neurological issues, liver damage, and renal failure. Wilson's illness is a hereditary condition that causes chronic copper toxicity, however it is comparatively uncommon. If left untreated, this disease's inability to eliminate copper in the bile causes it to build up in the liver, brain, and kidneys, which can cause serious health issues.

Consuming larger amounts of copper salt or contaminating food with copper from containers might result in copper poisoning. Excessive salivation, epigastric discomfort, nausea, vomiting, and diarrhea are signs of acute copper poisoning. It could be dangerous to eat formula foods made with milk or weaning foods kept in brass containers.

Liver failure is often associated with massive accumulation of liver copper.

After learning about copper, let's move to next important micro-minerals ie. zinc

6.8 ZINC

Zinc is a critical trace mineral that plays important role in numerous body functions such as, enhancing immunity, wound healing and protein synthesis etc. Each adult contains between 15 and 25 g of zinc. Most of the body's zinc occurs within various metalloenzymes of cells and cell membranes. Additionally, zinc supports healthy cell division and is integral to the metabolism of proteins, nucleic acids, and carbohydrates. It is also vital for healthy growth, neurological function, and is necessary for maintaining the senses of taste and smell.

Some important functions of Zinc :

There are over 200 enzymes in human and animal tissues, and their activity is dependent on zinc levels. Alkaline phosphatase, carbonic anhydrase, carboxypeptidase, deoxynucleotidyl transferase, glutamic acid dehydrogenase, alcohol dehydrogenase, DNA polymerase, and superoxide dismutase are a few important enzymes. These enzymes are essential for cellular defense, metabolism, and detoxification.

- Zinc is crucial for maintaining the structure of proteins and the metabolism of both proteins and nucleic acids. It is integral to the replication and maintenance of genetic material, including DNA and RNA, and the expression of genetic information to generate specific proteins. Without zinc, these critical processes would be compromised, affecting cell division, growth, and repair.
- In addition to its role in genetic material maintenance, zinc is involved in cholesterol transport and helps stabilize lipids within cell membranes. Zinc-dependent enzymes contribute to the synthesis of long-chain fatty acids and prostaglandins, both of which are essential for various cellular functions and inflammatory responses.
- Furthermore, zinc is crucial for the immune system, supporting its function and enhancing resistance to infections. It helps in the development and activation of immune cells, ensuring the body's defense mechanisms remain effective. Thus, zinc plays a fundamental role in numerous biological processes, from enzyme activity and protein synthesis to immune defense and cellular health.

Zinc can be obtained from a variety of dietary sources, including meat, shellfish, legumes, seeds, nuts, dairy products, whole grains, and fortified cereals. These foods provide an accessible means to ensure adequate zinc intake. The **Recommended Dietary Allowance (RDA)** for zinc varies according to age, sex, and life stage. For adults, the RDA ranges from 8 to 11 milligrams (mg) per day, with men generally requiring more zinc than women. During pregnancy, the RDA increases to 11 mg per day to support fetal development, while lactating women need 12 mg per day to meet the demands of breastfeeding. For children, the RDA ranges from 2 to 11 mg per day, depending on age, to support growth and development.

- **Adults:** 8-11 mg per day (varies by sex)
- **Pregnant women:** 11 mg per day
- **Lactating women:** 12 mg per day
- **Children:** 2-11 mg, depending on age

ABSORPTION

Normal zinc plasma level in an adult is 96 $\mu\text{g}/100\text{ ml}$ and in a child 89 $\mu\text{g}/100\text{ ml}$. Absorption may vary from 10 to 80 per cent depending on the chemical form in which zinc is present, constituents of

the diet and the nutritional status of the subjects just before ingestion. The average absorption is 20 per cent unless the content of fibre and phytate are exceptionally high. Amino acids and peptides increase its absorption. Bioavailability of zinc from human milk is high. Elevated zinc concentrations of milk is found in early stages of lactation.

In terms of **metabolism**, zinc is absorbed in the small intestine through active transport, where it is then distributed to various tissues and stored primarily in the liver and muscles. The body regulates zinc levels closely, and excess zinc is excreted mainly through feces and urine. The absorption of zinc can be influenced by the presence of other minerals like calcium and iron, which can compete for absorption and impact overall zinc status.

Zinc deficiency can lead to several health problems, including delayed wound healing, impaired immune function, reduced appetite, and stunted growth in children. Inadequate zinc levels can also result in skin lesions, hair loss, and cognitive impairments. In addition Zinc deficiency is associated with impaired glucose tolerance, implying a role for the mineral in carbohydrate metabolism, Zinc may interact with insulin and influences the uptake of glucose by the cells of adipose tissue Zinc also interacts with growth hormone, various sex hormones, thyroid hormones, prolactin and corticosteroids. Hormones in turn influence the absorption and metabolism of zinc.

On the other hand, **zinc toxicity** may occur from excessive supplementation, leading to symptoms such as nausea, vomiting, loss of appetite, and disruptions in immune function.

Zinc's diverse roles make it a vital nutrient for overall well-being, impacting everything from immune defense to growth and metabolism. A balanced diet that includes zinc-rich foods helps to maintain adequate levels and supports numerous bodily functions critical to health.

6.9 IODINE

Iodine is a naturally occurring element found in soil, water, and the atmosphere. However, its distribution in the environment is uneven, with certain regions having higher or lower levels. Coastal areas tend to have higher iodine levels due to the presence of iodine in seawater, which is released into the air and deposited back onto the land. Conversely, inland areas, particularly mountainous regions and areas affected by past glaciation, may have lower iodine levels in the soil, leading to a higher risk of iodine deficiency in the local population.

In the human body, iodine is primarily concentrated in the **thyroid gland**, which stores about 70-80% of the body's total iodine. The thyroid uses iodine to produce thyroid hormones, which are crucial for regulating metabolism, growth, and development. Smaller amounts of iodine are found in other tissues, including the mammary glands, salivary glands, stomach lining, and the bloodstream. These tissues utilize iodine for various biological functions, including immune response and gastric health.

Function:

The primary functions of iodine in the body include:

- 1. Thyroid Hormone Production:** Iodine is a key component in the synthesis of thyroid hormones, namely **thyroxine (T4)** and **triiodothyronine (T3)**. These hormones are produced by the thyroid gland, which is located in the neck. Thyroxine (T4) and triiodothyronine (T3) are two thyroid hormones that are synthesized using iodine in the thyroid gland. T3 and T4 regulate **metabolism, growth, development, and energy production** in the body. These hormones control how quickly the body uses energy, makes proteins, and regulates the body's sensitivity to other hormones.
- 2. Metabolic Regulation:** Iodine, through its role in thyroid hormone production, helps **regulate metabolism**. Adequate thyroid hormone levels ensure proper metabolism of fats, carbohydrates, and proteins. It influences **caloric burn, body temperature**, and the maintenance of energy levels throughout the day.
- 3. Growth and Development:** Pregnancy, infancy, and childhood are very important times for iodine. It aids in the fetal brain and neurological system's development. Pregnant women who consume enough iodine are less likely to experience cognitive impairments and developmental delays. The healthy growth and development of bones, tissues, and organs also depend on iodine.

4. Cognitive Function: Iodine is essential for proper brain development, especially during the early stages of life. A deficiency in iodine can lead to **mental retardation, learning disabilities, and impaired cognitive abilities**, particularly in children.

5. Immune System Support: Iodine plays a role in maintaining the **immune system**. Thyroid hormones, which are dependent on iodine, help regulate immune function and protect the body from infections and illnesses.

6. Detoxification: Iodine also plays a role in the body's ability to **detoxify** by promoting the excretion of harmful substances, such as heavy metals, from the body. It has been shown to have antimicrobial and antioxidant properties, helping to neutralize harmful free radicals and bacteria.

In summary, iodine is indispensable for thyroid function, metabolic regulation, growth, cognitive health, and immune support. Adequate iodine intake is crucial for maintaining overall health and preventing disorders such as hypothyroidism, goiter, and developmental delays.

ABSORPTION AND METABOLISM

The **absorption and metabolism of iodine** are essential for the production of thyroid hormones, which regulate metabolism, growth, and development in the body. Here's a breakdown of how iodine is absorbed, utilized, and metabolized:

Absorption: Iodine is primarily absorbed in the small intestine, where it enters the bloodstream quickly after being consumed through dietary sources like iodized salt, seafood, dairy, and certain vegetables. In food, iodine is usually present in the form of iodide, the ionized form of iodine, which is highly absorbable. Absorption is generally very efficient, with more than 90% of ingested iodine entering the bloodstream. Once absorbed, iodine circulates in the blood primarily as free iodide.

Transport and Uptake: After absorption, iodide is transported to the **thyroid gland**, where it plays a crucial role in thyroid hormone synthesis. The thyroid gland actively concentrates iodide from the bloodstream using a specific transport mechanism called the **sodium-iodide symporter (NIS)**. This transporter allows the thyroid to accumulate high levels of iodide, essential for hormone production.

Thyroid Hormone Synthesis: In the thyroid, iodide is oxidized to iodine, which is then incorporated into the amino acid **tyrosine** to form thyroid hormones. The two main thyroid hormones produced are **thyroxine (T4)** and **triiodothyronine (T3)**. T4 contains four iodine atoms, while T3, the more active form, contains three. These hormones are stored in the thyroid and released into the bloodstream as needed to regulate metabolic activity throughout the body.

Metabolism and Conversion: Once thyroid hormones are released into the bloodstream, T4 can be converted to T3 in various tissues, including the liver, kidneys, and muscles. This conversion is crucial because T3 is the more biologically active hormone that directly influences metabolic processes like energy production, protein synthesis, and oxygen consumption.

Excretion: Excess iodine that is not utilized by the thyroid is excreted through the urine, which is the primary route of elimination. This efficient excretion mechanism helps maintain a balance of iodine in the body and prevents toxicity. A small amount of iodine is also lost through sweat and feces.

Proper iodine metabolism is critical for maintaining normal thyroid function. Inadequate iodine intake can lead to conditions like **goiter** (enlarged thyroid) or hypothyroidism, while excess iodine can sometimes cause hyperthyroidism or other thyroid disorders. Thus, a balanced iodine intake is essential for optimal thyroid health and overall well-being.

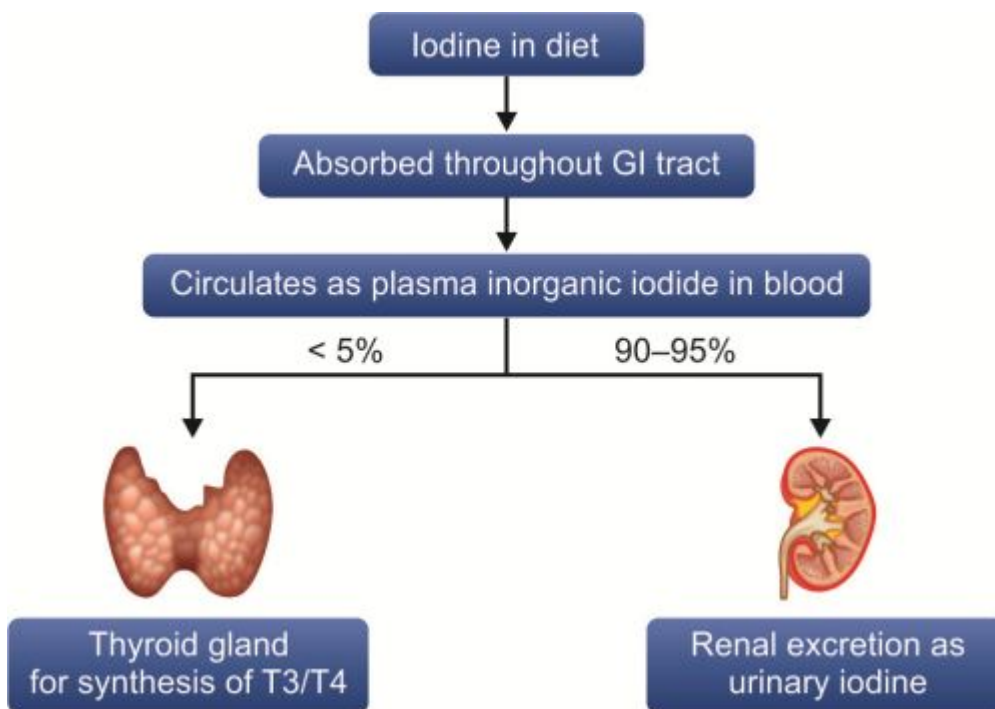


Figure 6.14: Iodine Metabolism

(Source: <https://d45jl3w9libvn.cloudfront.net/>)

Goitrogens can interfere at various stages of thyroid hormone homeostasis. The steps include uptake of iodine, its oxidation followed by thyroxine to triiodothyronine. Tapioca cabbage, cauliflower, groundnuts and finger millets are some known foods which contain goitrogens.

RDA: According to the **Indian Council of Medical Research (ICMR) 2020**, the **Recommended Dietary Allowance (RDA) for iodine** varies by age, gender, and physiological state to ensure adequate thyroid function and overall health. For adults, the RDA is set at **150 micrograms per day**, which supports the synthesis of thyroid hormones necessary for regulating metabolism. For pregnant women, the requirement is higher at **250 micrograms per day** due to increased thyroid activity and the need to support fetal development. Lactating women also require more iodine, with an RDA of **250 micrograms per day**, as iodine is essential for ensuring adequate levels in breast milk to support the infant's growth and brain development. For children, the recommended iodine intake ranges from **90 to 120 micrograms per day** depending on their age group, to support their rapid growth and development. These guidelines emphasize the importance of adequate iodine consumption through dietary sources such as iodized salt, seafood, dairy, and certain vegetables to prevent iodine deficiency disorders like goiter, hypothyroidism, and cognitive impairments.

Table: The recommended dietary allowance of iodine are:

Sources: Iodized salt, seafood, dairy products, and certain plant-based foods grown in iodine-rich soil (e.g., seaweed).

Disorders: A deficiency or excess of iodine can lead to several disorders, some of which can have severe consequences, particularly for growth and development. **Iodine deficiency** occurs when there is an insufficient intake of iodine, a crucial mineral for the production of thyroid hormones. These hormones play a vital role in regulating metabolism, growth, and brain development, making adequate iodine intake essential for overall health as presented in figure 6.15.

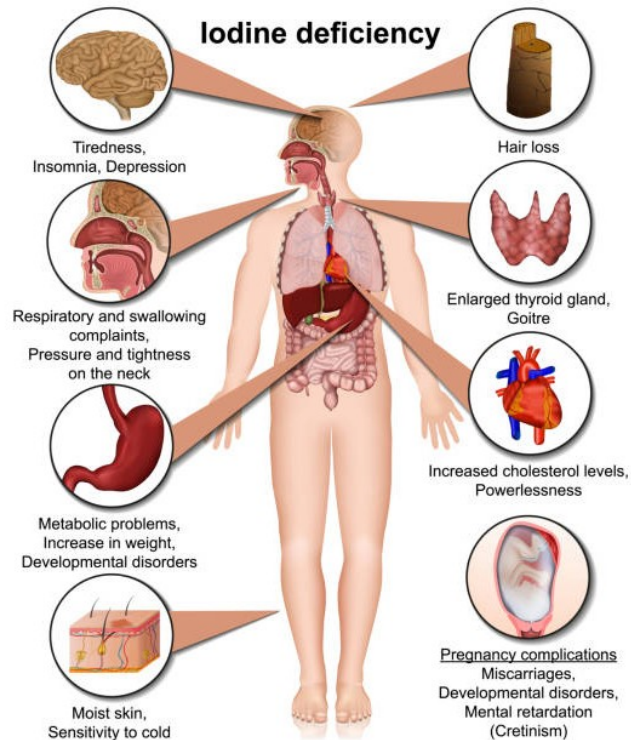


Figure 6.15: Signs and Symptoms of Iodine Deficiency

(Source: <https://www.birlahospital.com/>)

Iodine deficiency can lead to a variety of health problems, ranging from mild to severe, depending on the extent of the deficiency. Let's discuss in detail:

Goitre: Goiter, an abnormal growth of the thyroid gland that can cause neck swelling in front of the thyroid gland, is one of the most obvious symptoms of an iodine deficit. The thyroid gland enlarges in an attempt to make up for the body's shortage of iodine because it has to work harder to create enough thyroid hormones. Goitre is more common in hilly area.

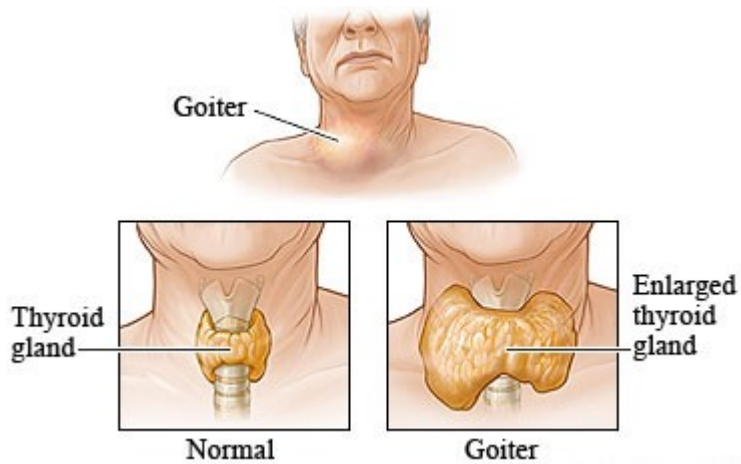


Figure 6.16: Goitre

(Source: <https://content.ca.healthwise.net/resources/>)

Hypothyroidism: Hypothyroidism may develop in more severe situations of iodine deprivation. The thyroid gland cannot create enough thyroid hormones (thyroid, T4, and triiodothyronine T3) to meet the body's needs when hypothyroidism is present. These hormones have a crucial role in controlling energy production, metabolism, and organ function. The body's metabolic functions slow down when thyroid hormone levels are low, resulting in a number of symptoms and health problems as shown in figure 6.17. Fatigue, weight gain, dry skin, cold sensitivity, and muscle weakness as a result of decreased metabolic activity are typical symptoms.

Symptoms of HYPOTHYROIDISM

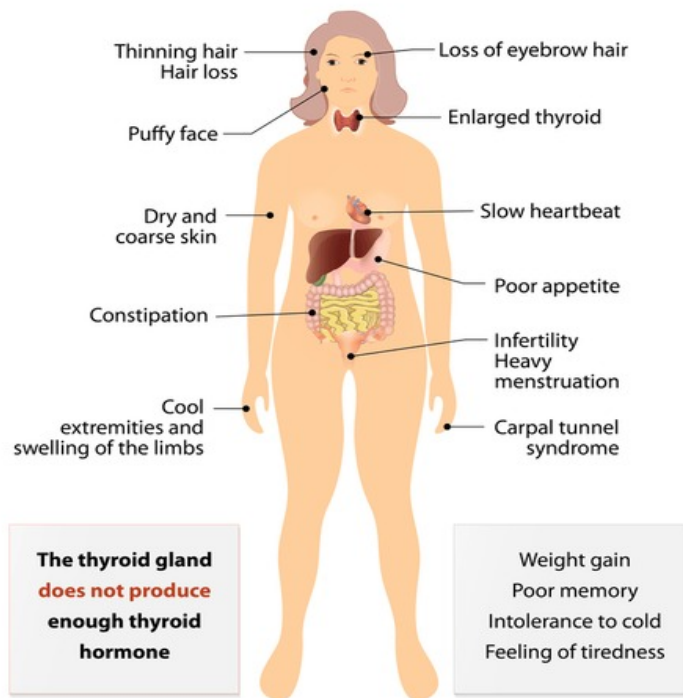


Figure 6.17: Symptoms of Hyperthyroidism

(Source: <https://www.shutterstock.com/image-illustration/>)

1. **Cretinism:** In children, even mild iodine deficiency can impact brain development, lowering IQ and affecting academic performance. Severe iodine deficiency during pregnancy can cause cretinism in the child, a condition that leads to mental and physical developmental delays. This is often due to insufficient thyroid hormone production during fetal development. The **symptoms includes** severe intellectual disability, stunted growth, deafness, and physical deformities. Cretinism can be prevented through adequate iodine intake during pregnancy.
2. **Developmental Delays in Children:** Inadequate iodine levels during pregnancy or early childhood can impair brain development, leading to cognitive and developmental delays. It leads to the common sign of reduced IQ, learning disabilities, and delayed physical development. This condition can affect school performance and overall development.

Adults may also experience **reduced cognitive function** and general fatigue if they are deficient in iodine. Iodine deficiency is a major public health concern in many parts of the world, particularly in regions where the soil is iodine-deficient, affecting the iodine content of local food sources.

To prevent iodine deficiency, public health measures such as the **universal iodization of salt** have been implemented in many countries, ensuring a reliable source of iodine in the diet. Regular consumption of iodine-rich foods, such as seafood, dairy products, and iodized salt, is crucial to maintaining adequate iodine levels and preventing deficiency-related disorders.

Iodine Excess (Iodine Toxicity)

Hyperthyroidism: Excessive iodine intake can lead to hyperthyroidism, particularly in individuals with preexisting thyroid conditions (such as autoimmune thyroid disease). This occurs when the thyroid becomes overstimulated and produces excess thyroid hormones. The common **symptoms includes** weight loss, rapid heartbeat, nervousness, sweating, irritability, and bulging eyes. Severe cases can lead to thyroid storm, a medical emergency.

Thyroid Dysfunction: Both very high and very low iodine levels can disrupt thyroid function, leading to thyroid hormone imbalances. Symptoms of both hyperthyroidism (excessive iodine) and hypothyroidism (iodine deficiency) can occur, including fatigue, weight changes, and altered metabolism.

Iodine-Induced Thyroid Autoimmunity: Excessive iodine intake can trigger autoimmune thyroid disorders, where the body's immune system attacks the thyroid gland. Symptoms may vary depending on the specific autoimmune thyroid disorder but can include swelling of the thyroid gland, difficulty swallowing, and abnormal thyroid hormone levels.

Iodine-related disorders are preventable with proper dietary management, by ensuring adequate iodine intake, which is often achieved through the use of iodized salt. The use of iodized salt has been a key public health strategy to prevent iodine deficiency globally. Pregnant and breastfeeding women, in particular, need to ensure they receive enough iodine to support fetal and infant thyroid health.

After discussing minor minerals. Let's explore trace minerals. What is trace minerals?

Trace minerals, also known as **microminerals**, are essential nutrients required by the body in very small amounts, typically less than 100 milligrams per day. Despite their small required quantities, trace minerals are crucial for various physiological functions such as enzyme activity, immune function, tissue repair, and the regulation of metabolism. These minerals play important roles in maintaining overall health, supporting growth, and preventing certain diseases. Their balance is important, as both deficiencies and excesses can lead to health complications. Common trace minerals include iron, zinc, copper, selenium, iodine, chromium, and others.

Let's begin to learn about them individually

6.10 SELENIUM

Selenium is a vital trace mineral that contributes significantly to antioxidant defense by being a component of enzymes like glutathione peroxidase, which protects cells from oxidative damage. It is also important for thyroid hormone metabolism, immune function, and DNA synthesis. Selenium is found in foods like Brazil nuts, seafood, organ meats (especially liver), eggs, whole grains, and dairy products.

Most of selenium is absorbed in the small intestine and transported in the bloodstream in its selenoprotein form. It is stored primarily in the liver, kidneys, and muscles. It is excreted mainly in the urine, with small amounts lost through sweat and feces.

The **Recommended Dietary Allowance (RDA)** of selenium for **adults**, is 55 micrograms (μg) per day, ensuring optimal function of antioxidant enzymes and supporting immune health. **Pregnant women** require a slightly higher intake of 60 μg per day to support both maternal health and fetal development, while **lactating women** need 70 μg per day to meet the increased demands for selenium in breast milk. The RDA for **children** varies depending on age, ranging from 20 μg to 40 μg per day to support growth and immune function.

Selenium Deficiency:

The sign and symptoms due to deficiency of selenium is presented in figure 6.18. Selenium deficiency can lead to a variety of health issues, as selenium is an essential trace mineral involved in antioxidant defense, thyroid hormone metabolism, and immune system function. A deficiency can

result in conditions like **Keshan disease**, a type of heart disease, and **Kashin-Beck disease**, which affects joints and bones. Symptoms of selenium deficiency also include weakened immune function, fatigue, hair loss, and an increased risk of infection. Low selenium levels are linked to thyroid dysfunction, as selenium is crucial for the conversion of thyroid hormones.

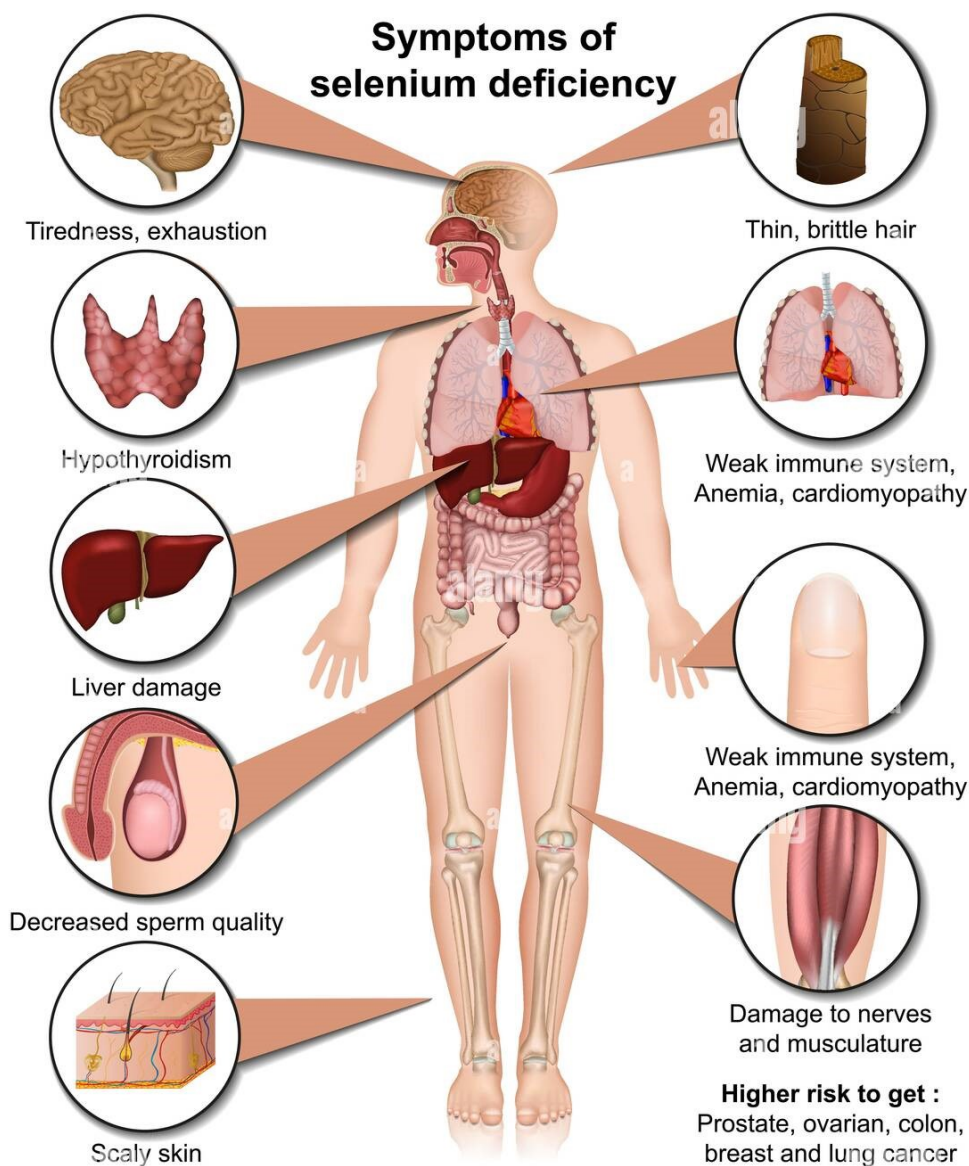


Figure 6.18: Symptoms of Selenium Deficiency

(Source: <https://c8.alamy.com/comp/>)

On the other hand, **selenium toxicity** can occur if selenium is consumed in excessive amounts, either from supplements or contaminated food sources. The symptoms of toxicity, known as **selenosis**,

include gastrointestinal disturbances, hair and nail loss, fatigue, irritability, and a garlicky odor on the breath. Chronic selenium toxicity can lead to more serious health problems, including nerve damage, and in extreme cases, it may affect the liver and kidneys. The narrow margin between selenium deficiency and toxicity highlights the importance of maintaining a balanced intake of this vital mineral. Proper dietary intake, primarily from sources like nuts (especially Brazil nuts), seafood, and whole grains, is essential for health without the risk of either deficiency or toxicity.

6.11 COBALT

Cobalt's most significant biological function lies in its role as a central component of vitamin B12. Vitamin B12, also known as cobalamin, is essential for the production of red blood cells, the synthesis of DNA, and proper neurological function. In terms of dietary sources, cobalt is not typically consumed directly as cobalt itself but rather through its presence in vitamin B12, which is found in animal-based foods. The richest sources of vitamin B12 are meat, particularly liver, poultry, fish, eggs, and dairy products. These foods are considered the primary means through which most individuals obtain their daily cobalt requirements, as vitamin B12 is synthesized only by bacteria, fungi, and algae. This biological synthesis of vitamin B12 is incorporated into animal tissues, which humans consume. For people who follow a vegetarian or vegan diet, the intake of vitamin B12 and, by extension, cobalt, can be a concern, as plant-based foods do not naturally contain this essential nutrient.

Metabolism: The absorption of cobalt occurs as part of the absorption of vitamin B12 in the small intestine, where it binds to intrinsic factor and is absorbed into the bloodstream. Once absorbed, cobalt is transported to the liver, where it is incorporated into vitamin B12. The liver serves as the primary storage site for vitamin B12, and it can retain large amounts for extended periods—up to several years in some cases. This storage capacity helps to prevent immediate deficiency in the case of dietary inadequacy, as the body can draw upon the liver's reserves when necessary.

Once vitamin B12 is absorbed and stored, it is released into the bloodstream, where it is transported to various tissues and organs. In the blood, vitamin B12 binds to transport proteins known as transcobalamins, which help to deliver it to cells throughout the body. This process allows cobalt, as part of vitamin B12, to support cellular processes involved in the production of red blood cells, DNA synthesis, and the maintenance of the nervous system.

The body regulates cobalt levels through a complex system of absorption, storage, and excretion. The kidneys play a role in excreting excess vitamin B12 and cobalt, ensuring that the body does not accumulate too much of this trace element. However, the regulation of cobalt is mainly indirect, via the regulation of vitamin B12, since cobalt itself is not metabolized independently but rather as a part of this essential vitamin.

Recommended Daily Allowance (RDA): Unlike other nutrients, the Recommended Daily Allowance (RDA) for cobalt is not typically specified on its own. Instead, cobalt's intake is indirectly guided through the recommended intake for vitamin B12. The RDA for vitamin B12 for adults is generally set at 2.4 micrograms (µg) per day, a quantity sufficient to meet the needs of the average adult for maintaining healthy red blood cells and neurological function. This amount of vitamin B12 ensures that adequate levels of cobalt are available to the body for its various metabolic functions.

Cobalt Disorder: While cobalt deficiency is rare due to its presence in animal-derived foods, it can result in serious health issues, particularly when it leads to a deficiency of vitamin B12, as cobalt is a key component of this vitamin. The signs and symptoms of cobalt deficiency are largely related to the effects of vitamin B12 insufficiency. Common symptoms include fatigue and weakness, caused by anemia due to decreased red blood cell production. Neurological issues like numbness, tingling in the hands and feet, and difficulty walking can arise due to impaired nerve function. Additionally, individuals may experience glossitis (inflammation of the tongue), mouth ulcers, and shortness of breath or dizziness from anemia. In more severe cases, jaundice (yellowing of the skin and eyes) may occur due to the breakdown of red blood cells, and cognitive issues such as memory problems and confusion can develop. Heart palpitations are also possible as the body compensates for reduced oxygen-carrying capacity. Treatment typically involves addressing the vitamin B12 deficiency, which can be done through dietary adjustments or supplementation, effectively resolving the symptoms of cobalt deficiency.

On the other hand, excessive cobalt intake can lead to cobalt toxicity, though this is a relatively rare condition. Cobalt toxicity is often linked to prolonged exposure to high levels of cobalt, such as in industrial settings or through the use of cobalt-containing implants, such as hip replacements. In such cases, excessive cobalt can accumulate in the body and lead to a condition known as "polycythemia," where an abnormal increase in red blood cells occurs, resulting in thickened blood, reduced circulation, and increased risk of blood clots.

Cobalt toxicity can also affect other organs, including the heart and thyroid. Symptoms of toxicity can include heart arrhythmias, thyroid dysfunction, and gastrointestinal disturbances. In severe cases, excessive cobalt exposure can lead to organ damage, necessitating medical intervention to remove the excess cobalt and manage the associated symptoms.

6.12 CHROMIUM

Chromium is an important trace mineral and exhibits several essential bodily functions include:

1. Chromium plays a crucial role in enhancing insulin action, which is vital for regulating blood sugar levels. It boosts insulin sensitivity by improving the effectiveness of insulin receptors, allowing for more efficient glucose uptake into cells. This is essential for carbohydrate metabolism and maintaining stable blood glucose levels. By supporting insulin function, chromium also helps regulate blood sugar, reducing the risk of insulin resistance and type 2 diabetes. Additionally, chromium is involved in the metabolism of carbohydrates, fats, and proteins, assisting in converting these macronutrients into energy, thereby supporting overall metabolic health and energy production.

4. Chromium may help regulate cholesterol levels by improving lipid metabolism. Some studies suggest that adequate chromium levels can contribute to lowering LDL (bad) cholesterol and increasing HDL (good) cholesterol, thereby supporting cardiovascular health.

5. Role in Appetite Regulation: Some research indicates that chromium can help reduce hunger and cravings, potentially aiding in weight management. This effect is thought to be linked to chromium's role in stabilizing blood sugar levels and influencing neurotransmitters that regulate appetite.

Overall, the sources and metabolism of chromium are crucial for maintaining healthy blood sugar levels and efficient insulin function. Proper chromium intake supports carbohydrate, fat, and protein metabolism, promoting overall metabolic health.

Next, It is important to know the foods or substances from which this nutrient is obtained.

Sources of Chromium

The rich dietary sources of chromium include meat (particularly liver and lean cuts of pork and beef), whole grains such as oats and barley, and vegetables like broccoli and potatoes. And fruits such as apples, bananas, and grapes, as well as nuts and seeds, also contain small amounts of chromium. The chromium level of the soil in which these foods are cultivated, however, can affect how much

chromium is present in them. As a result, the actual intake of chromium from diet may differ among individuals depending on local agricultural practices and food choices.



Figure 6.19: Sources of Chromium

(Source: <https://i.pinimg.com/736x/f1/ba/24/f1ba246f25fab6ebfac072d85bea3506.jpg>)

Chromium Metabolism

The bio-availability of chromium from food is influenced by the form of chromium present and the composition of the diet. Chromium in food is typically found in its trivalent form (Cr^{3+}), which is the form that is absorbed and utilized by the body. However, the absorption of chromium is quite low, with estimates suggesting that less than 2% of dietary chromium is absorbed by the small intestine. Despite this low absorption rate, the body has a relatively small requirement for chromium, and even small amounts can contribute to its essential roles in metabolism and blood sugar regulation. Factors influencing chromium absorption include the chemical form of chromium, with organic forms like chromium picolinate being more readily absorbed than inorganic forms like chromium chloride. Certain dietary factors, such as vitamin C and niacin, can enhance chromium absorption, while others, like high levels of simple sugars or diets rich in phytic acid (found in whole grains), can inhibit absorption.

Once absorbed, chromium is transported in the blood, mostly bound to a protein called **transferrin**, which also carries iron. It can also bind to albumin or globulins, which are other proteins in the blood. Chromium is then distributed to various tissues, including the liver, kidneys, spleen, and bones, with the highest concentrations found in the liver.

The mineral is excreted primarily through urine, with minor amounts lost in feces and sweat. Urinary excretion of chromium can increase under certain conditions, such as during high-intensity exercise, physical stress, infection, pregnancy, or with high sugar intake. Since chromium is a trace element, the body does not require large quantities, and its excretion is well regulated to prevent both deficiency and toxicity. The kidneys maintain the body's chromium balance by filtering excess chromium from the bloodstream and eliminating it in urine.

Although the body has a mechanism for regulating chromium levels, deficiencies and imbalances can still occur, especially when the diet is inadequate or when the body's chromium utilization is compromised.

Recommended Dietary Allowance (RDA)

For adults, the RDA for chromium is 25-35 micrograms (μg) per day, a quantity that is sufficient to support the mineral's role in insulin function and metabolic regulation. Pregnant and lactating women

require slightly more chromium to support the metabolic changes associated with pregnancy and breastfeeding, with an RDA of 30-35 µg/day. For children, the RDA for chromium ranges from 11 µg/day for younger children to 25 µg/day for adolescents, depending on their age.

While chromium deficiencies are rare in developed countries, inadequate intake can occur, especially in populations with limited access to a varied and balanced diet. For individuals who may not meet their chromium needs through food alone, supplementation is an option, though it should be approached cautiously, as excess chromium can be harmful.

Chromium Deficiency and Disorders

Chromium deficiency, although rare, can lead to significant health issues. One of the most prominent symptoms of chromium deficiency is impaired glucose tolerance, which can result in symptoms that resemble those of diabetes. In this state, the body's ability to utilize insulin efficiently is diminished, and raises the risk of developing type 2 diabetes. In some cases, chromium deficiency can lead to a condition known as “diabetes-like syndrome,” where individuals experience high blood sugar, insulin resistance, and impaired carbohydrate metabolism.

Chromium deficiency can also have an impact on other aspects of metabolism, such as fat storage and protein synthesis. A lack of chromium can result in poor fat metabolism and may contribute to an increase in body fat. Additionally, impaired protein metabolism may affect the synthesis of muscle mass and other tissues, leading to a general decline in metabolic health.

The most common causes of chromium deficiency are poor diet, excessive sugar intake, and certain medical conditions that impair nutrient absorption, such as malabsorption syndromes or gastrointestinal surgeries. Chromium deficiency is also more likely in individuals with poorly controlled diabetes or obesity, as their bodies may have an increased demand for chromium to maintain proper insulin function.

Chromium Toxicity and Potential Risks

While chromium deficiency is a concern for metabolic health, chromium toxicity is much rarer but can occur, particularly with excessive supplementation. High doses of chromium, especially in the form of chromium picolinate (a commonly used supplement), can lead to serious health complications,

including kidney and liver damage. Excess chromium can accumulate in the body, resulting in toxicity that may manifest as symptoms like gastrointestinal distress, liver and kidney dysfunction, and a general feeling of malaise.

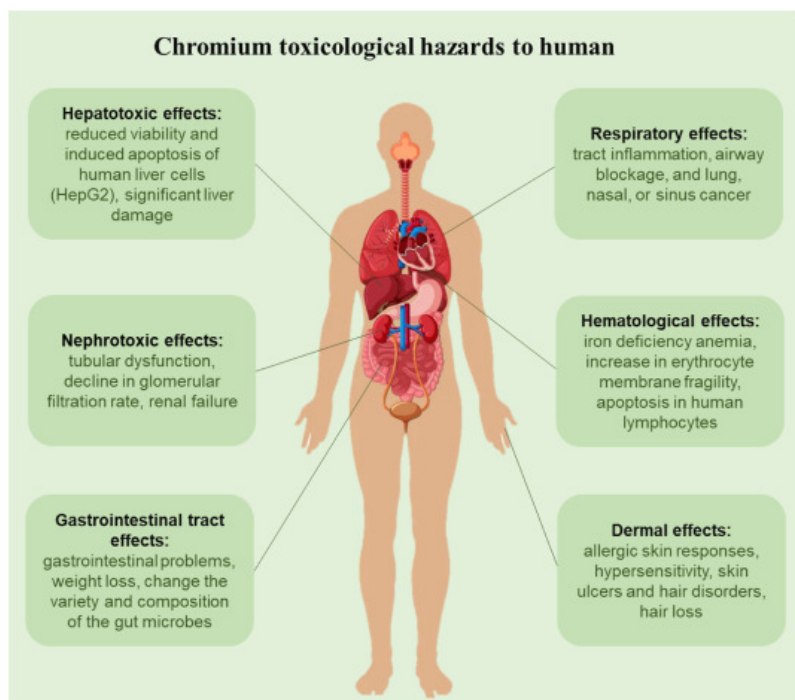


Figure 6.19: Effects of Chromium toxicity

(Source: <https://ars.els-cdn.com/content/image/>)

Chromium toxicity is most often seen in individuals who take chromium supplements in excess or are exposed to high levels of chromium in industrial settings. For example, workers in industries that process chromium may be at risk of inhaling chromium fumes or dust, leading to respiratory and systemic toxicity. Chromium VI (hexavalent chromium), a more toxic form of chromium, is particularly dangerous and can cause lung cancer, kidney damage, and other severe health problems when inhaled or absorbed through the skin.

6.13. VANADIUM

Function:

- Vanadium is believed to play a role in regulating blood sugar levels by enhancing the action of insulin.
- It may also be involved in bone health and tissue growth.

Sources:

- Vanadium is found in seafood, mushrooms, parsley, whole grains, and some vegetables.

Metabolism:

- Vanadium is absorbed in the gastrointestinal tract, but only in small amounts.
- It is stored in the liver, kidneys, and bones, and is excreted primarily in urine.

RDA:

- There is no established RDA for vanadium, as its exact nutritional requirement in humans is not well defined.

Disorders:

- **Vanadium Deficiency:** Not well studied, but may impact insulin regulation and metabolic processes.
- **Vanadium Toxicity:** High intake can lead to gastrointestinal disturbances and liver damage.

6.14 SILICON

Function:

- Silicon is important for the formation of collagen and connective tissue.
- It supports bone health by aiding in the deposition of calcium in the bones and enhances skin health by contributing to the structure of collagen.

Sources:

- Silicon is found in foods like whole grains, bananas, leafy vegetables, beer, and nuts.

Metabolism:

- Silicon is absorbed in the small intestine and is primarily stored in the bones, skin, and connective tissues.
- It is excreted mainly through the urine and to a lesser extent through feces.

RDA:

- There is no specific RDA for silicon, but typical intake is around 20-50 mg/day.

Disorders:

- **Silicon Deficiency:** May affect bone health and cause joint problems, though deficiency is rare.
- **Silicon Toxicity:** Excessive silicon intake is generally considered safe, as the body efficiently excretes excess amounts.

6.15 BORON

Function:

- Boron plays a role in bone health by enhancing calcium and magnesium absorption.
- It supports brain function, hormonal regulation, and wound healing.

Sources:

- Boron is found in foods such as nuts, raisins, avocados, prunes, and leafy vegetables.

Metabolism:

- Boron is absorbed in the small intestine and is stored in the bones and other tissues.
- It is excreted through urine, with excess amounts being filtered by the kidneys.

RDA:

- There is no established RDA for boron, but typical intake ranges from 1 to 3 mg/day.

Disorders:

- **Boron Deficiency:** Can result in impaired bone development, hormonal imbalance, and cognitive dysfunction.
- **Boron Toxicity:** Excessive boron intake (through supplementation) can cause symptoms such as nausea, vomiting, and inflammation of the skin and eyes.

CHECK YOUR PROGRESS EXERCISE 3

1. Why is iron deficiency more common in India?

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2. What is the role of sodium in metabolism?

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3. What is the function of iodine in the body?

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4. What is the RDA for silicon and boron?

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6.15 GLOSSARY

1. Calcification: The process of depositing calcium salts in tissues.
2. Calcium Absorption: The process by which the body absorbs calcium from food.
3. Calcium Deficiency: A condition where the body does not have enough calcium.
4. Calcium Fortification: The process of adding calcium to foods.
5. Hypercalcemia: A condition where there is too much calcium in the blood.
6. Hypocalcemia: A condition where there is not enough calcium in the blood.
7. Boron Deficiency: A condition where the body does not have enough boron.
8. Boron Excess: A condition where the body has too much boron.
9. Boronic Acid: A compound that contains boron and is used in various industrial applications.
10. Hyperkalemia: A condition where there is too much potassium in the blood.
11. Hypokalemia : A condition where there is not enough potassium in the blood.
12. Potassium Channel: A type of protein that helps regulate the flow of potassium ions in and out of cells.
13. Potassium Citrate: A compound that contains potassium and is used to treat certain medical conditions.

14. Magnesium Deficiency: A condition where the body does not have enough magnesium.
15. Magnesium Excess: A condition where the body has too much magnesium.
16. Magnesium Oxide: A compound that contains magnesium and is used in various industrial applications.
17. Magnesium Sulfate: A compound that contains magnesium and is used to treat certain medical conditions.
18. Anemia: A condition where the body does not have enough red blood cells or hemoglobin, often due to iron deficiency.
19. Ferritin: A protein that stores iron in the body.
20. Ferrochelatase: An enzyme that helps convert iron into heme.
21. Heme: A molecule that contains iron and is essential for transporting oxygen in the blood.
22. Hemochromatosis: A genetic disorder that causes the body to absorb too much iron.
23. Hemoglobin: A protein in red blood cells that carries oxygen to the body's tissues.
24. Iron Absorption: The process by which the body absorbs iron from food.
25. Iron Deficiency: A condition where the body does not have enough iron or haemoglobin

6.16 ANSWER TO CHECKYOUR PROGRESS

EXERCISE 1

1. In response to low blood calcium levels, parathyroid hormone (PTH) acts on three primary targets: bones, kidneys, and the intestines. In bones, PTH stimulates osteoclast activity, leading to the breakdown of bone tissue and the release of calcium into the bloodstream. In the kidneys, PTH reduces calcium excretion by enhancing its reabsorption and stimulates the production of active vitamin D (calcitriol).

2. Osteoporosis is a chronic bone disease characterized by decreased bone density and strength, making bones fragile and prone to fractures. It occurs when the rate of bone resorption by osteoclasts outpaces the rate of bone formation by osteoblasts, leading to a loss of bone mass. Commonly associated with aging, osteoporosis is particularly prevalent in postmenopausal women due to reduced estrogen levels, which play a critical role in maintaining bone density. Risk factors include a diet low in calcium and vitamin D, sedentary lifestyle, smoking, excessive alcohol consumption, and certain medical conditions or medications.

3. Phosphorus metabolism is influenced by several factors that regulate its absorption, utilization, and excretion in the body. Key factors include **dietary intake**, where phosphorus availability depends on its source (animal-based phosphorus is more bioavailable than plant-based); **vitamin D levels**, which enhance intestinal absorption of phosphorus; and **parathyroid hormone (PTH)**, which regulates phosphorus reabsorption in the kidneys and influences its release from bones. **Kidney function** is critical, as impaired kidneys can lead to phosphorus retention. Additionally, factors such as **age**, **hormonal balance**, and **calcium levels** play significant roles, as phosphorus metabolism is closely linked with calcium homeostasis. Conditions like malabsorption syndromes or certain medications can also affect phosphorus balance.

4. Phosphorus is absorbed in humans primarily in the small intestine, particularly the jejunum. The absorption occurs through two mechanisms: **active transport** and **passive diffusion**.

- **Active transport** is regulated by vitamin D, which enhances the efficiency of absorption, especially when phosphorus levels are low.
- **Passive diffusion** occurs along a concentration gradient and is more significant when dietary phosphorus intake is high.

Most dietary phosphorus is absorbed in its inorganic form, while some forms, such as phytate (found in plants), require enzymatic breakdown for absorption. Typically, about 60-70% of dietary phosphorus is absorbed under normal conditions.

EXERCISE 2

1. Magnesium is absorbed mainly in the small intestine through two processes: passive diffusion when intake is high and active transport when magnesium levels are low. The efficiency of absorption can

vary depending on dietary factors and overall magnesium status, with about 30-50% of dietary magnesium typically absorbed.

2. Sodium helps maintain fluid balance by regulating osmotic pressure in extracellular fluids. It plays a critical role in transmitting nerve impulses and ensuring proper muscle contractions. Sodium also supports glucose and amino acid absorption in the intestines and helps regulate blood pressure and blood volume.

3. Potassium is predominantly an intracellular electrolyte, with about 98% found inside cells, helping maintain intracellular fluid balance. It is essential for cellular functions, including nerve impulse transmission, muscle contractions, and maintaining normal heart rhythm. Only 2% is found in extracellular fluids, but even small changes here can significantly affect physiological functions.

4. The RDA for calcium is 1000-1300 mg/day, depending on age and gender, and for magnesium, it is 310-420 mg/day for adults.

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EXERCISE 3

1, Iron deficiency is more common in India due to a combination of dietary, socioeconomic, and health factors. The Indian diet is predominantly plant-based, relying on cereals and legumes that contain non-heme iron, which is less bioavailable compared to heme iron from animal sources. High consumption of phytates, tannins, and calcium-rich foods further inhibits iron absorption. Socioeconomic challenges like poverty and limited access to diverse, iron-rich foods exacerbate the issue. Additionally, conditions such as **malnutrition, frequent infections** (e.g., malaria and hookworm), and **high rates of anemia in women due to menstrual blood loss and pregnancy** contribute significantly. Public health issues, such as lack of awareness and inadequate implementation of supplementation programs, further compound the problem.

2. Sodium is essential for various metabolic processes, primarily maintaining the balance of fluids and electrolytes in the body. It helps regulate osmotic pressure, ensuring that cells remain properly hydrated and that nutrients are transported efficiently. Sodium is critical for generating and transmitting nerve impulses, which are necessary for communication between cells, and it plays a key

role in muscle contractions, including the functioning of the heart. In the digestive system, sodium supports the absorption of glucose and amino acids, aiding energy production and cellular repair. Furthermore, sodium contributes to regulating blood pressure and blood volume, ensuring the proper functioning of vital organs and overall metabolic homeostasis.

3. Iodine is a crucial trace element required for the synthesis of thyroid hormones, thyroxine (T4) and triiodothyronine (T3), which regulate various metabolic processes in the body. These hormones are essential for maintaining normal growth, development, and energy production. Iodine is particularly important for brain development during fetal and early childhood stages. It also plays a role in regulating body temperature, heart rate, and protein synthesis. A deficiency in iodine can lead to thyroid gland enlargement (goiter) and disorders such as hypothyroidism, impacting overall health and metabolic efficiency.

4. Currently, there are no established Recommended Dietary Allowances (RDA) for silicon and boron because they are not considered essential nutrients for humans. However, **adequate intake (AI) levels or estimated safe ranges** have been suggested based on their potential roles in health:

1. **Silicon:** An intake of **20-50 mg/day** is considered typical and potentially beneficial for bone and connective tissue health.
2. **Boron:** A suggested intake range is **1-13 mg/day**, as it may support bone health, hormone metabolism, and cognitive function.

**BLOCK-III: VITAMINS, NON-NUTRITIVE FOOD COMPONENTS, AND NUTRITION
MANAGEMENT**

INTRODUCTION

Block-III integrates foundational knowledge of essential nutrients, emerging insights into non-nutritive components, and innovative approaches to nutrition management in extreme scenarios. This block delves into the critical roles of vitamins, non-nutritive food components, and nutrition management in specialized conditions.

UNIT 7: VITAMINS

Explores the historical background, structure, dietary sources, absorption, transport, and metabolism of vitamins. It details their biochemical functions, physiological and therapeutic effects, and interactions with other nutrients, methods to assess their status, as well as deficiencies and toxicities. Coverage includes both fat-soluble vitamins (A, D, E, K) and water-soluble vitamins (thiamin, riboflavin, pyridoxine, folic acid, pantothenic acid, ascorbic acid, cyanocobalamin, and inositol).

UNIT 8: NON-NUTRITIVE FOOD COMPONENTS WITH POTENTIAL HEALTH EFFECTS

Focuses on bioactive compounds like polyphenols, phytoestrogens, saponins, lectins, and others, highlighting their potential health benefits. It also covers the emerging field of nutritional regulation of gene expression, emphasizing the interaction between diet and genetic health.

UNIT 9: NUTRITION MANAGEMENT IN SPECIAL CONDITIONS

Addresses the unique nutritional challenges faced during space travel, at high altitudes, in low-temperature environments, and in submarine settings. It examines tailored dietary strategies to ensure optimal health and performance in these extreme conditions.

This block underscores the diverse aspects of nutrition, from essential micronutrients to advanced applications in specialized environments.

UNIT 7: VITAMINS

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Vitamins

Today, let's dive into an important topic that often gets overlooked in our busy lives: vitamins. These substances are required in small quantities, although, their impact on our health is huge as act as helpers, supporting various biochemical processes essential for growth, immunity, and overall well-being. Unlike carbohydrates, proteins, and fats, vitamins, they are not taken to provide energy. They keep us energized, protect us from illnesses, and ensure our bodies function smoothly.

Vitamins are tiny, organic compounds that our bodies need to function properly. Vitamins may be small, but their impact on our health is huge. They keep us energized, protect us from illnesses, and ensure our bodies function smoothly. They are necessary for growth, development, and maintenance of the body. There are 13 essential vitamins that our bodies cannot produce in sufficient amounts, so we must get them from the foods we eat. They cannot synthesis in the body and therefore, need to be supplied from outside. However, there are a few exceptions. Vitamin D can be synthesized in the skin when exposed to sunlight, but dietary sources like fatty fish and fortified milk are essential for individuals with limited sun exposure. Vitamin K is partially produced by gut bacteria in the colon, yet dietary intake from green leafy vegetables and fermented foods is necessary to meet the body's needs. Niacin (Vitamin B3) can be made from the amino acid tryptophan, but this conversion is often insufficient, requiring additional intake from sources like meat and whole grains. Similarly, Biotin (Vitamin B7) is produced in small amounts by gut microbiota, but dietary sources such as eggs, nuts, and seeds remain crucial. While Vitamin B12 cannot be synthesized by humans, it is derived from animal-based foods due to bacterial synthesis in animals. Even for these exceptions, external sources are vital, as natural synthesis or bacterial production alone is usually inadequate. Ensuring a balanced diet rich in diverse vitamins is essential to maintain optimal health and address potential deficiencies.

At the end of the chapter, the reader will be able to describe the following:

Historical background structure

Long before vitamins were scientifically identified, ancient civilizations recognized the significance of certain foods in preventing illnesses. For instance, the Greek physician Hippocrates (460–370 BCE) recommended liver for treating night blindness, unknowingly prescribing a source of vitamin A. Sailors during long sea voyages often suffered from scurvy, caused by a lack of fresh fruits and vegetables, while the Chinese discovered that consuming citrus fruits could prevent this disease.

Vitamin C was later discovered in 1747 by Scottish physician James Lind, who showed that citrus fruits could both prevent and treat scurvy. Dutch physician Christiaan Eijkman, in the late 19th century, observed that unpolished rice cured beriberi, eventually leading to the discovery of vitamin B1 (thiamine). In 1906, English biochemist Sir Frederick Gowland Hopkins introduced the idea of "accessory food factors," which were later

recognized as vitamins. The term "vitamin" itself was coined in 1912 by Polish scientist Casimir Funk, derived from "vital amine," as he believed these compounds contained amine groups, though not all did.

Advancements followed rapidly. Vitamins were classified into fat-soluble (A, D, E, K) and water-soluble (B-complex and C) groups. In 1913, vitamin A was the first to be isolated, and subsequent discoveries included vitamins D, E, and K. The isolation of vitamin C by Albert Szent-Györgyi in 1932 was a landmark achievement, earning him the Nobel Prize in 1937. The discovery of vitamin B12 in the 1940s marked the identification of the last of the 13 essential vitamins.

The modern era brought the chemical synthesis of vitamins, making supplements widely available. Today, vitamins are recognized as crucial for various biological processes, such as metabolism, immune function, and cellular repair. Their role in preventing diseases and maintaining health remains a vital area of research, building on centuries of discovery and understanding.

Types of Vitamins

Vitamins are classified into two main types based on their solubility: **fat-soluble vitamins** and **water-soluble vitamins**. Both types are essential for maintaining various physiological functions, supporting growth, immunity, and overall health. Let's discuss in detail:

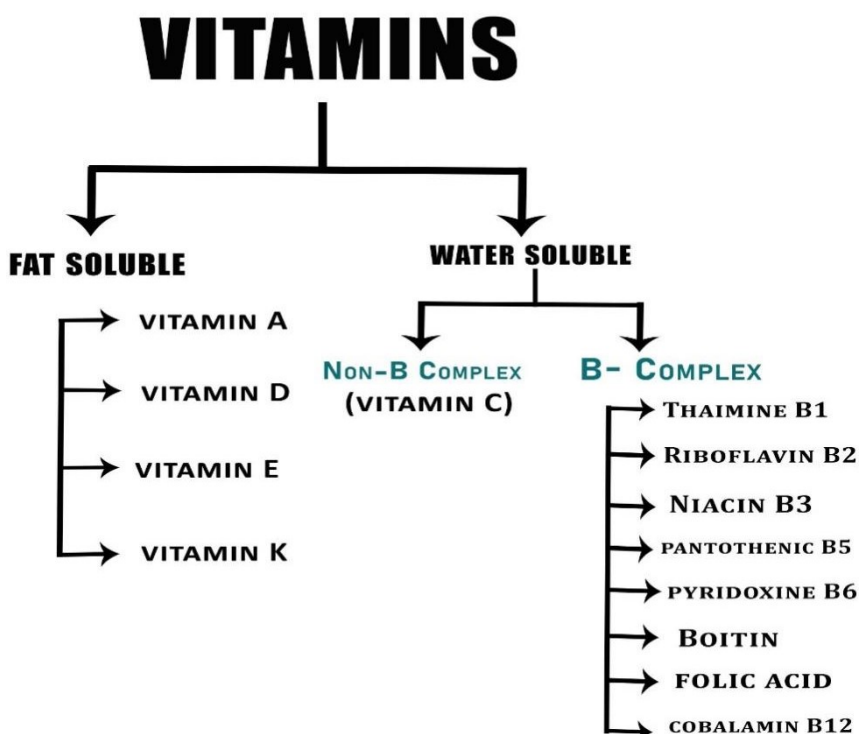


Figure 1 : Types of Vitamins

Fat-soluble vitamins

An important group of nutrients that are vital to sustaining general health and wellbeing are fat-soluble vitamins. Unlike water-soluble vitamins, they dissolve in fats and oils and are stored in the body's fatty tissues and liver, allowing for reserves that can be utilized when dietary intake is insufficient. There are four types of fat-soluble vitamins -

- Vitamin A
- Vitamin D
- Vitamin E
- Vitamin K

These vitamins are absorbed alongside dietary fats in the small intestine and depend on the presence of bile for optimal absorption. Found in foods like fatty fish, dairy products, nuts, seeds, and green leafy vegetables, fat-soluble vitamins are indispensable for sustaining life processes. However, due to their storage capacity, excessive intake can lead to toxicity, underscoring the need for balanced consumption. Their unique solubility and storage properties highlight their significance in long-term nutritional health and their potential risks when taken in inappropriate amounts.

Vitamin - A

Vitamin A is a fat-soluble vitamin that is essential for many body processes, such as immune system health, reproduction, cellular communication, and eyesight. The history of Vitamin A dates back thousands of years when the health benefits of certain foods for skin and vision were recognized, even though the specific nutrient responsible remained unknown. The scientific understanding of Vitamin A advanced significantly in the early 20th century. In 1909, preliminary studies suggested that fats from certain foods were crucial for health, but the exact nutrient was not yet identified. In 1913, Elmer McCollum and Marguerite Davis made a breakthrough by discovering a fat-soluble substance in butter and egg yolks that was essential for growth and overall health, marking the first clear identification of what would later be known as Vitamin A. By 1920, the term "Vitamin A" was officially introduced. Although, the chemical structure of Vitamin A determined by Swiss chemist Paul Karrer in 1931 and got a Nobel Prize in Chemistry in 1937 for successfully synthesized of it. These discoveries collectively laid the foundation for understanding the critical role of Vitamin A in human health.

Chemistry

Vitamin A is an organic compound with a structure that includes a hydroxyl group (-OH), characteristic of alcohols, attached to a polyunsaturated hydrocarbon chain. The general chemical formula of Vitamin A (retinol) is **C₂₀H₃₀O**. This chain consists of alternating single and double bonds, providing the molecule with stability and functionality. At one end of the chain, the structure terminates in a beta-ionone ring, a cyclic hydrocarbon essential for its biological activity. The **basic structure of Vitamin A** includes a **beta-ionone ring** and a **polyunsaturated isoprenoid side chain** with conjugated double bonds, making it a fat-soluble compound. This structure allows Vitamin A to exist in multiple forms, each with specific biological functions:

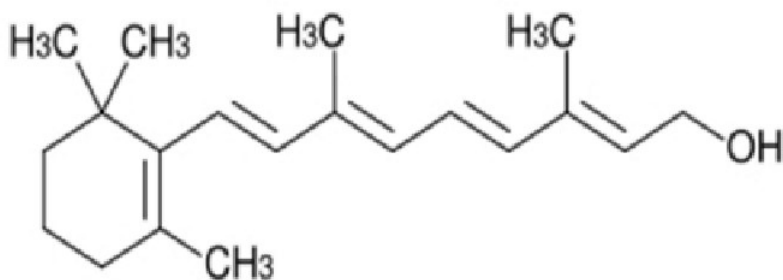


Figure 2 : Chemical Structure of vitamin A (Retinol).

Reference: Antioxidant vitamins and their effect on immune system - Scientific Figure on ResearchGate. Available from: https://www.researchgate.net/figure/Chemical-Structure-of-vitamin-A-Retinol_fig1_350777158

Components of the Structure:

Beta-Ionone Ring: It is a six-membered ring with a methyl group attached. This ring is essential for Vitamin A's biological activity, particularly for binding to receptors and interacting with enzymes.

Polyunsaturated Isoprenoid Side Chain: It consists of four isoprene units, forming an 11-carbon chain. This chain contains alternating single and double bonds, known as **conjugated double bonds**, which give Vitamin A its characteristic stability and reactivity.

Functional Group: The functional group at the end of the isoprenoid chain determines the specific form of Vitamin A, which are discussed as follows:

- **Retinol:** A hydroxyl (-OH) group, making it an alcohol.
- **Retinal:** An aldehyde (-CHO) group.
- **Retinoic Acid:** A carboxyl (-COOH) group.
- **Retinyl Esters:** An esterified form of retinol, commonly stored in the liver.

Forms of vitamin A

Vitamin A is essential for healthy cells, the immune system, and vision. The body contains it in two main forms: provitamin A (carotenoids) and preformed vitamin A (retinoids), both are essential but have distinct chemical structures and functions.

Retinoids (Preformed Vitamin A)

Retinoids are the active forms of Vitamin A and are primarily found in animal sources like liver, dairy, and fish. The main retinoids are:

- **Retinol:** Retinol is the alcohol form of Vitamin A and the most commonly found form of Vitamin A in the bloodstream, being easily transported and utilized by the body. Its structure consists of a **beta-ionone ring** connected to a **polyunsaturated isoprenoid chain** of 11 conjugated double bonds, forming a hydrophobic molecule. The beta-ionone ring is responsible for much of its biological activity, particularly its interaction with retinoic acid receptors (RARs) and retinoid X receptors (RXRs). Retinol has a hydroxyl group (-OH) at one end of its isoprenoid chain, making it soluble in fat and easily absorbed in the gastrointestinal tract. The hydroxyl group can be oxidized to form **retinal** (the aldehyde form) or converted into **retinoic acid** (the active form that influences gene expression). This facilitates its easy conversion into other active forms- retinal and retinoic acid. It is absorbed in the small intestine and carried by retinol-binding proteins in the bloodstream.
- **Retinal:** Retinal is the aldehyde form of Vitamin A, essential for vision. Its structure is similar to that of retinol, but with an aldehyde group (-CHO) at the end of the molecule instead of a hydroxyl group. This structural change enables retinal to participate directly in the visual cycle. In the retina, retinal binds to opsin proteins to form **rhodopsin**, a photoreceptor pigment necessary for vision, particularly in low-light conditions. When light hits rhodopsin, retinal undergoes a conformational change, which leads to a nerve impulse being sent to the brain. Retinal's key feature is the conjugated double bond system in its polyene chain, which plays a crucial role in its light absorption properties.
- **Retinoic Acid:** Retinoic acid, also known as vitamin A acid, is a form of vitamin A that plays a crucial role in various biological processes, including growth, development, and maintenance

of the skin. Its structure is very similar to retinal, but the aldehyde group of retinal is oxidized to a carboxyl group (-COOH) in retinoic acid. This carboxyl group makes retinoic acid the most polar form of Vitamin A, which allows it to interact more easily with nuclear receptors in cells. Retinoic acid does not require conversion to another form, and it directly affects cellular processes. It binds to **retinoic acid receptors** in the nucleus, influencing the transcription of genes that regulate development, immune response, and the maintenance of epithelial tissues.

It is important to note that retinol and retinal can be readily inter converted but retinoic acid cannot be converted back to either retinol or retinal.

➤ **Carotenoids (Provitamin A):**

- Carotenoids are plant-derived compounds that can be converted into Vitamin A in the body. The most notable provitamin A carotenoids are **beta-carotene**, **alpha-carotene**, and **beta-cryptoxanthin**, all of which have similar chemical structures. Carotenoids are characterized by a long **polyene chain** of conjugated double bonds (alternating single and double bonds), which contribute to their antioxidant properties and their distinctive color (yellow, orange, red) in fruits and vegetables. Beta-carotene, the most well-known carotenoid, has two **beta-ionone rings** connected by a polyene chain, with the potential to be split into two molecules of **retinal** upon enzymatic cleavage in the body. This ability to generate retinal makes beta-carotene a significant source of Vitamin A. Carotenoids lack the hydroxyl or aldehyde groups found in retinoids, but their polyene structure plays a key role in the conversion to retinal and retinol. Carotenoids also have strong antioxidant properties, helping to protect cells from oxidative damage.
- **Beta-Carotene:** The most well-known carotenoid, beta-carotene is a precursor to Vitamin A. It has a characteristic orange color due to its conjugated double-bond structure, which gives it antioxidant properties. The body can convert beta-carotene into retinal and ultimately retinol, though this conversion is less efficient compared to retinoid intake.
- **Alpha-Carotene:** Similar to beta-carotene, alpha-carotene can also be converted into retinol, but it is less potent than beta-carotene in terms of Vitamin A activity.

➤ **Conversion Factor of Carotenoids to Retinoids**

Carotenoids are plant pigments that can be converted to retinoids (vitamin A) in the body, but the efficiency of this conversion is not the same for all carotenoids.

For example, beta-carotene is most efficiently converted to retinol (the active form of vitamin A) in the body, while other carotenoids like lutein and zeaxanthin have lower conversion rates. The conversion rate for beta-carotene to retinol is estimated to be around 12:1, meaning 12 units of beta-carotene are needed to produce 1 unit of retinol.

It's essential to consume a variety of carotenoid-rich foods to ensure an adequate intake of vitamin A, whether through direct consumption of vitamin A or through the conversion of carotenoids in the body. However, it's always recommended to consult with a healthcare provider or a nutritionist for personalized advice on meeting your body's vitamin A needs.

It's crucial to remember that conversion of carotenoid (like beta-carotene) into active Vitamin A is a critical process and its efficiency of conversion can vary depending on several factors such as dietary composition, genetic variations, and vitamin A status. Generally, one molecule of **beta-carotene** can be converted into two molecules of **retinal** (the aldehyde form of Vitamin A), and **retinal** can then be further reduced to **retinol**. beta-carotene is most efficiently converted to retinol (the active form of vitamin A) in the body, while other carotenoids like lutein and zeaxanthin have lower conversion rates. The **conversion factor** can vary and is generally less efficient than directly consuming retinoids. The conversion rate for beta-carotene to retinol is estimated to be around 12:1, meaning 12 units of beta-carotene are needed to produce 1 unit of retinol. On average, **12 µg of beta-carotene** from food yields **1 µg of retinol** and **3.6 µg of beta-cryptoxanthin** is equivalent to **1 µg of retinol activity**. Synthetic forms of beta-carotene have higher conversion efficiency than those from whole foods.

However, the efficiency of conversion may be less in individuals with certain genetic variations, poor health, or insufficient fat intake, as fat is required for the absorption of carotenoids.

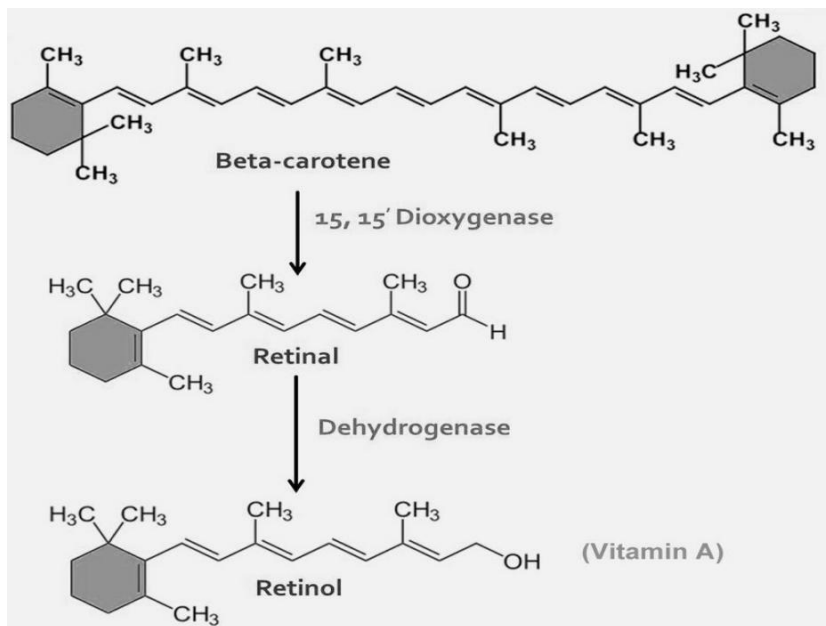


Figure 3 : Pathway of conversion of carotenoid in vitamin A

Referenc ResearchGate.

➤ Source

Vitamin A is found in a variety of both animal and plant-based foods. In plant based foods, vitamin A is present in form of **carotenoids**, such as **beta-carotene**, **alpha-carotene**, and **beta-cryptoxanthin**, and require conversion by the body into active Vitamin A forms. These carotenoids are particularly found in **colorful fruits and vegetables**, including pumpkin, carrots, **sweet potatoes**, **dark greensleafy vegetables**. Fruits like **mangoes**, **apricots**, and papaya, also provide carotenoids. Furthermore, animal-based foods, directly provide active forms of Vitamin A (retinol, retinal, and retinoic acid). Rich sources include **liver** (particularly beef and chicken liver), which provides a concentrated form of retinol, **fish oils** (like cod liver oil), and **dairy products** (such as milk, butter, and cheese). Eggs, especially the yolks, also contain significant amounts of Vitamin A

• Absorption and transport

Retinol can be absorbed from food directly into intestinal wall cells. **Retinyl esters** (from animal sources) are hydrolyzed into **retinol** by enzymes such as **pancreatic lipase**. Vitamin A are absorbed in the **small intestine** after being emulsified by bile acids and incorporated into **micelles**, which facilitate their passage through the intestinal mucosal cells. Once inside the enterocyte (intestinal cells), retinol is esterified to **retinyl esters**, which are then transported via the lymphatic system and incorporated into **chylomicrons** (lipoproteins) to enter the bloodstream. The absorption efficiency of preformed Vitamin A is typically **70-90%**, making it one of the most bioavailable forms of the vitamin. Preformed Vitamin A, found in animal-based foods as **retinol**, **retinal**, and

retinoic acid, is more efficiently absorbed than provitamin A carotenoids. The absorption of retinoids is influenced by factors such as **fat consumption**, because fat enhances the solubility of Vitamin A, facilitating its incorporation into micelles. Additionally, factors like **intestinal health** (e.g., the presence of malabsorption disorders) can affect the efficiency of absorption.

Carotenoids, which are primarily derived from plant-based sources, must be converted into active Vitamin A (retinol) within the body. **Retinol** is the most readily absorbed and utilized form. This conversion occurs in the **intestinal mucosa**, where carotenoids such as **beta-carotene** are enzymatically cleaved into retinal, which can then be further reduced to retinol. However, the **absorption efficiency** of carotenoids is generally lower than that of retinoids, and it varies significantly. The conversion of carotenoids to active Vitamin A (retinol) varies between individuals and depends on factors like genetics, diet, and metabolic efficiency. Carotenoids are typically bound to plant cell walls, which must be broken down during digestion. Cooking and processing can help release carotenoids from plant cells, improving bioavailability. Like retinoids, carotenoids are also fat-soluble, and their absorption improves in the presence of dietary fat. Studies show that a moderate amount of dietary fat can significantly enhance carotenoid absorption. Studies show that only about **5-30%** of carotenoids from dietary sources are absorbed and converted to active Vitamin A, with **beta-carotene** being the most efficient provitamin A carotenoid in terms of conversion.

- **Factors Affecting Absorption Efficiency:**

The absorption of Vitamin A is significantly more efficient from animal sources (retinoids) compared to plant sources (carotenoids). While retinoids are absorbed at rates of **70-90%**, carotenoids have a lower absorption rate, with efficiency varying widely between **5-30%**. The absorption and conversion of carotenoids into active Vitamin A depend on several factors, like:

Dietary fat: For both retinoids and carotenoids to be absorbed, fat in the diet is essential. Micelles, which are necessary for the absorption of fat-soluble vitamins like vitamin A, are formed with the aid of fatty acids.

Digestive health: Diseases such as Crohn's disease, celiac disease, and other malabsorption syndromes can drastically impair the body's ability to absorb fat-soluble vitamins, even vitamin A.

Age and health status: Older adults or individuals with compromised health may experience a decline in absorption efficiency due to changes in gastrointestinal function or enzyme activity. Additionally, certain genetic variations can influence how effectively an individual converts carotenoids into active Vitamin A.

- **Dietary fiber:** High-fiber diets can bind to Vitamin A and carotenoids, reducing their absorption.

- **Interactions with other micronutrients:** The presence of other vitamins and minerals, such as **zinc**, can enhance the conversion of carotenoids into retinol. Conversely, deficiencies in certain nutrients (like **protein** or **fat**-soluble vitamins) may impair Vitamin A absorption and utilization.

- **Transport and storage**

Chylomicrons, which are lipoprotein particles that carry dietary lipids through the lymphatic system and into the bloodstream, are crucial for transporting absorbed vitamin A from the intestine to other areas of the body. This system facilitates the transport of fat-soluble vitamin A in aqueous medium. In the intestinal mucosal cells (**enterocytes**), free retinol is re-esterified into **retinyl esters**. Retinyl esters, along with dietary lipids like triglycerides and cholesterol, are packaged into **chylomicrons**. The chylomicrons are released into the **lymphatic system** rather than directly into the bloodstream, bypassing the liver initially. This transport allows Vitamin A and other dietary fats to circulate without immediate liver processing. Further, chylomicrons enter the bloodstream and enzymes such as **lipoprotein lipase** act on them to release fatty acids for energy or storage. The remnants of chylomicrons, including retinyl esters, are taken up by the **liver**, where Vitamin A is stored or further processed for use by the body.

When vitamin A required by other part of body, it is released by liver and transported to target tissues through the bloodstream primarily by **retinol-binding protein (RBP)**, a specialized carrier protein. This system ensures the safe and efficient delivery of Vitamin A to cells while preventing its degradation or accumulation in non-target tissues. First, retinyl esters are hydrolyzed to yield free retinol, which binds to the liver-synthesised retinol-binding protein (RBP) to be released from liver storage. Within plasma, the retinol-RBP complex further binds to **transthyretin (TTR)** (previously called prealbumin, also produced by the liver). This retinol-RBP-TTR complex circulates in the bloodstream, delivering retinol to target cells, such as epithelial cells, immune cells, and retinal cells. This association stabilizes the complex and prevents loss of RBP through kidney filtration, ensuring efficient delivery to target tissues.

Notably, the transport of Vitamin A through retinol-binding protein (RBP) is a highly significant process that ensures its efficient delivery and utilization in the body. RBP provides **specificity** by directing Vitamin A to tissues where it is critically needed, such as the retina for vision and epithelial tissues for cell differentiation. Additionally, RBP offers **protection** by binding to retinol, shielding it from oxidation and degradation during circulation in the bloodstream. The liver plays a vital role in the **regulation** of this system by adjusting RBP production based on the body's Vitamin A requirements, preventing excessive retinol circulation and reducing the risk of toxicity. This tightly controlled mechanism underscores the importance of RBP in maintaining Vitamin A homeostasis and ensuring its availability for essential biological processes, including vision, cellular growth and immune function.

- **Biochemical Functions of Vitamin A**

Vitamin A plays a crucial role in a variety of biochemical processes essential for maintaining overall health. Its functions are primarily mediated through its active forms, **retinol**, **retinal**, and **retinoic acid**, each contributing to distinct physiological and cellular functions.

- **Vision:** Vitamin A plays a critical role in vision, particularly in maintaining the health of the retina and supporting the visual cycle. The active form of vitamin A in the eye, **retinal**, is essential for the function of photoreceptor cells in the retina. In rod cells, retinal combines with the protein **opsin** to form **rhodopsin**, a light-sensitive pigment necessary for scotopic vision (vision in low light). When light enters the eye, rhodopsin undergoes a photochemical reaction where retinal changes from its **cis-** to **trans-** configuration, triggering a signal to the brain that enables the perception of light. This process is crucial for adapting to darkness and for night vision. Additionally, vitamin A supports the maintenance of epithelial tissues, including the conjunctiva, preventing dryness and maintaining a clear, healthy cornea. A deficiency in vitamin A can lead to impaired dark adaptation (night blindness) and more severe eye conditions such as **xerophthalmia**, **Bitot's spots**, and corneal damage, highlighting its indispensable role in preserving vision.

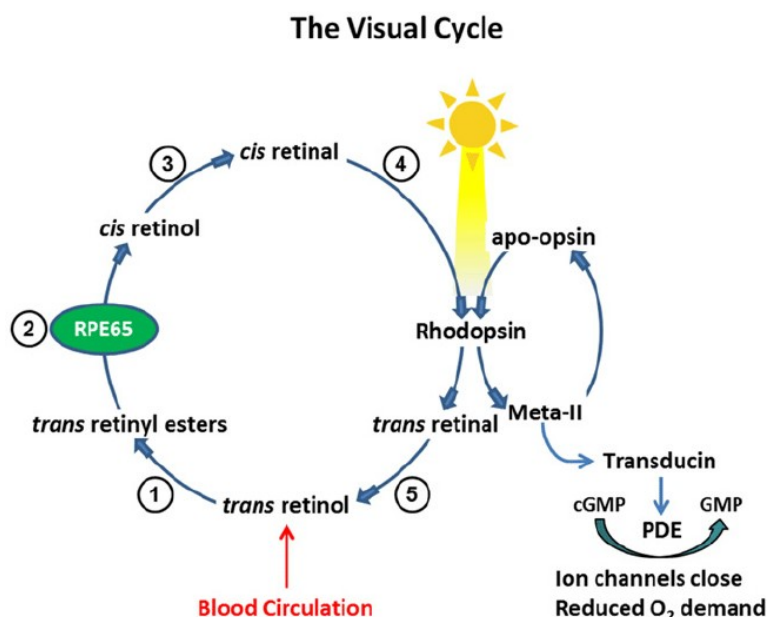


Figure 4 : The Visual Cycle

- **Gene Expression and Cell Differentiation:** Vitamin A, particularly in its active form **retinoic acid**, plays a vital role in regulating gene expression and promoting cell differentiation. Retinoic acid acts as a signaling molecule that binds to nuclear receptors, such as **retinoic acid receptors (RARs)** and **retinoid X receptors (RXRs)**. These complexes interact with specific DNA sequences known as **retinoic acid response elements (RAREs)** to modulate the transcription of genes involved in cellular processes. This regulation is crucial for cell differentiation, ensuring that undifferentiated cells develop into specialized cells required for the proper functioning of tissues and organs. In epithelial tissues, retinoic acid maintains the integrity and functionality of the mucosal barriers by promoting the differentiation of keratinocytes into mature epidermal cells. Additionally, during embryonic development, vitamin A is essential for the proper formation of organs and tissues, including the heart, lungs, and nervous system. Its role in gene expression underpins critical biological processes, emphasizing the importance of adequate vitamin A levels for growth, immunity, and overall health.
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- **Immune Function:** Vitamin A plays a pivotal role in supporting immune function by maintaining the integrity of epithelial barriers and modulating immune cell activity. As a key regulator of **gene expression**, vitamin A, particularly in the form of **retinoic acid**, enhances the differentiation and function of immune cells, such as **T-cells** and **B-cells**, which are essential for adaptive immunity. It helps preserve the structure and function of epithelial tissues in the respiratory, gastrointestinal, and urogenital tracts, acting as the first line of defense against pathogens. Vitamin A also promotes the production of **antibodies** and regulates the activity of cytokines, ensuring a balanced immune response. Deficiency in vitamin A compromises mucosal integrity and weakens the immune system, leading to an increased susceptibility to infections such as respiratory illnesses and diarrhea. It also impairs recovery from infections and reduces vaccine efficacy, underscoring its critical role in both innate and adaptive immunity.
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- **Reproduction and Development:** Vitamin A is essential for reproduction and development, playing critical roles in both male and female fertility as well as embryonic growth. In males, vitamin A is required for the maintenance of normal spermatogenesis, ensuring the production and maturation of healthy sperm. In females, it supports ovarian function, helping regulate the menstrual cycle and maintaining optimal conditions for conception. During pregnancy, vitamin A becomes even more crucial as it aids in the development of the embryo, particularly the formation of organs such as the heart, lungs, kidneys, and eyes. Its active form, **retinoic acid**, regulates the expression of genes involved in cellular differentiation and tissue development, ensuring proper growth and morphogenesis. A deficiency in vitamin A during pregnancy can lead to impaired fetal development, while excess vitamin A can be teratogenic, causing birth defects. This highlights the need for carefully balanced vitamin A levels to support reproductive health and ensure healthy development from conception through birth.
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- **Antioxidant Properties** (through Carotenoids): Vitamin A, particularly through its carotenoid forms such as **beta-carotene**, exhibits powerful antioxidant properties that contribute to overall health. As antioxidants, carotenoids neutralize harmful **free radicals**—unstable molecules generated by environmental stressors like pollution, ultraviolet light, and metabolic processes. By scavenging these reactive oxygen species, carotenoids help protect cellular structures, including lipids, proteins, and DNA, from oxidative damage, which can lead to chronic diseases such as cancer, cardiovascular disease, and neurodegenerative disorders. Beta-carotene, a provitamin A carotenoid, is especially significant because it not only functions as an antioxidant but also serves as a precursor to active vitamin A, supporting vision, immune health, and cellular integrity. The dual role of carotenoids highlights their importance in preventing oxidative stress while also fulfilling essential physiological needs. A diet rich in carotenoid-containing foods, such as carrots, spinach, and sweet potatoes, helps harness these protective benefits and supports overall health.
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- **Skin Health:** Vitamin A is crucial for maintaining healthy skin by supporting cell growth, repair, and differentiation. Its active forms, **retinol** and **retinoic acid**, play key roles in regulating the turnover of skin cells, ensuring that new, healthy cells replace older, damaged ones. Vitamin A promotes the production of **collagen**, a protein that provides skin with structure and elasticity, helping to reduce wrinkles and improve skin texture. Additionally, it supports the integrity of the skin barrier, which protects against environmental damage, prevents moisture loss, and reduces the risk of infections.

Retinoids are widely used in dermatology to treat various skin conditions, including acne, psoriasis, and hyperpigmentation, due to their ability to normalize keratinization and reduce inflammation. Furthermore, the antioxidant properties of provitamin A carotenoids, such as beta-carotene, protect skin cells from oxidative stress caused by UV radiation and pollution, reducing premature aging and enhancing skin health. A balanced intake of vitamin A through diet and topical applications is essential for vibrant, resilient skin.

- **Assessment of Vitamin A Status**

The assessment of Vitamin A status is critical for identifying deficiency or excess, which can have significant health implications. Several biochemical, clinical, and dietary assessment methods are used to evaluate Vitamin A status, each with its strengths and limitations.

Serum retinol concentration: Serum retinol concentration is a widely used biochemical marker for assessing Vitamin A status, providing insight into both recent dietary intake and body stores to some extent.

Normal levels range from 20–50 µg/dL (0.7–1.75 µmol/L), with values below 20 µg/dL indicating deficiency and levels below 10 µg/dL suggesting severe deficiency.

This measure reflects liver Vitamin A stores, which are mobilized to maintain serum levels when dietary intake is inadequate. However, serum retinol is influenced by several factors, including infections, inflammation, protein and lipid status, and liver function, all of which can lower retinol levels independently of Vitamin A status. While serum retinol concentration is accessible and quantitative, it is less sensitive to marginal deficiencies and reflects short-term dietary intake rather than long-term stores in some cases.

- **Liver Vitamin A concentration:**

Liver Vitamin A concentration is the most reliable indicator of total body Vitamin A stores, as the liver holds approximately 90% of the body's reserves in the form of retinyl esters. Normal liver concentrations range from 20–300 µg/g of liver tissue, with levels below 20 µg/g indicating depletion and a high risk of Vitamin A deficiency. Unlike serum Vitamin A, liver stores are stable and not influenced by short-term dietary intake or infections, making this measure a gold standard for assessing long-term Vitamin A status. However, measuring liver Vitamin A requires invasive methods, such as biopsies or autopsies, and specialized facilities, which limits its use to research or diagnostic settings. Despite its accuracy, the invasive nature of liver Vitamin A

measurement makes it impractical for routine or large-scale assessments, though it remains invaluable for understanding the true extent of Vitamin A deficiency or toxicity in the body.

Retinol-binding protein (RBP): Retinol-binding protein (RBP) is a carrier protein synthesized in the liver that plays a crucial role in transporting Vitamin A (retinol) from the liver to target tissues through the bloodstream. Measuring RBP levels serves as an indirect method for assessing Vitamin A status, as RBP binds retinol in a 1:1 ratio under normal physiological conditions. This method is particularly useful in resource-limited settings because it is simpler and less costly than direct serum retinol measurements. However, RBP levels can be affected by non-nutritional factors, such as infections, inflammation, protein-energy malnutrition, and liver disease, which can alter its synthesis and stability. While RBP correlates well with serum retinol under stable conditions, its reliability decreases during periods of acute or chronic illness. Despite these limitations, RBP assessment remains a valuable tool for population-level surveys and Vitamin A deficiency monitoring, especially when interpreted alongside other biochemical and clinical markers.

- **Recommended Dietary Allowance (RDA)**

The Indian Council of Medical Research (ICMR) provides the Recommended Dietary Allowance (RDA) for various nutrients, including vitamin A, to guide individuals on their daily intake requirements.

According to ICMR, 2020 for Indians RDA for vitamin A is as follows:

- Children (1-3 years): 300 mcg per day
- Children (4-9 years): 400 mcg per day
- Boys and Girls(10-15 years): 600 mcg per day
- Boys (16-18 years): 900 mcg per day
- Girls (16-18 years): 700 mcg per day
- Men (19 years and above): 900 mcg per day
- Women (19 years and above): 700 mcg per day
- Pregnant Women: 770 mcg RAE
- Lactating Women:19 years and older: 1,300 mcg RAE

The **Recommended Dietary Allowance (RDA)** for vitamin A, as outlined by the **Indian Council of Medical Research (ICMR) in 2020**, is designed to meet the specific needs of various age groups and genders. For **children** aged 1 to 3 years, the RDA is **300 mcg per day**, and for children aged 4 to 9

years, it increases to **400 mcg per day** to support growth, development, and the maintenance of healthy vision and immune function. As children grow older, the requirement for vitamin A increases, with **boys and girls aged 10 to 15 years** needing **600 mcg per day** to meet their higher metabolic demands. For **boys aged 16 to 18 years**, the RDA is raised to **900 mcg per day**, while **girls in the same age group** require **700 mcg per day**, reflecting gender differences in growth, hormonal changes, and metabolic needs.

For **adults**, the RDA is set at **900 mcg per day** for **men** and **700 mcg per day** for **women**. During **pregnancy** and **lactation**, the requirement for vitamin A is higher to support both the mother's health and the development of the fetus or infant. Vitamin A plays a critical role in **embryonic development**, particularly in the formation of essential organs and tissues, including the heart, lungs, eyes, and nervous system. Adequate levels of vitamin A are essential for proper fetal **growth** and **development**, particularly in the first trimester when cellular differentiation and organogenesis occur. **Retinoic acid**, the active form of vitamin A, regulates gene expression that is critical for these developmental processes.

During **lactation**, vitamin A is needed to ensure that the breast milk contains adequate levels of the vitamin to support the infant's **immune system**, **growth**, and **vision**. The increased requirement is due to the fact that vitamin A is passed from mother to infant through breast milk, contributing to the infant's nutrition and providing immune support, especially in the first few months when the infant's immune system is still developing.

- **Signs and Symptoms of Vitamin A Deficiency**

Vitamin A deficiency can manifest in a range of clinical signs and symptoms that affect vision, skin, immune function, and overall health. These symptoms are categorized based on their impact on different physiological systems:

Xerophthalmia

Xerophthalmia refers to a spectrum of eye disorders resulting from prolonged Vitamin A deficiency. It progresses through distinct stages, affecting the structure and function of the eye, ultimately leading to blindness if untreated. Below are the stages explained in detail:

- **Night Blindness (Nyctalopia): Night blindness**

Night blindness, also known as nyctalopia, is a condition that makes it difficult to see in low light or darkness. It can be caused by various factors, including vitamin A deficiency, certain genetic disorders, cataracts, diabetes, and other eye conditions. People with night blindness may have trouble driving at night or navigating in dimly lit places. It is one of the earliest signs of Vitamin A deficiency and this condition arises from impaired functioning of the **rod cells** in the retina, which are essential for vision in low-light conditions.

When individual moves from a bright to a dark environment, the eyes take time to adjust to low-light conditions as rod cells require some time to regenerate rhodopsin from opsin and retinal. Vitamin A deficiency leads to insufficient retinal, reducing the synthesis of rhodopsin. This diminishes the sensitivity of rod cells to low light, causing difficulty seeing in dim conditions and prolonging the time needed to adapt to darkness. This delay is noticeable during transitions, such as entering a dark room from a bright area. Night blindness is a functional, reversible sign of Vitamin A deficiency, signaling the need for intervention.

Supplementation with Vitamin A restores rhodopsin synthesis, resolving night blindness and improving dark adaptation.

- **Conjunctival xerosis** : Conjunctival xerosis is an early clinical manifestation of Vitamin A deficiency, characterized by dryness and a dull, rough appearance of the conjunctiva. This condition arises due to a lack of Vitamin A, which is essential for maintaining healthy epithelial cells. Without adequate Vitamin A, the conjunctival epithelium undergoes keratinization, losing its normal ability to retain moisture. Patients with conjunctival xerosis may experience dryness, irritation, and discomfort in the eyes. Upon examination, the conjunctiva appears lusterless and rough, sometimes with fine lines or patches. This stage of xerophthalmia is reversible with timely Vitamin A supplementation, underscoring the importance of early detection and intervention to prevent progression to more severe forms of eye damage, such as Bitot's spots or corneal xerosis.

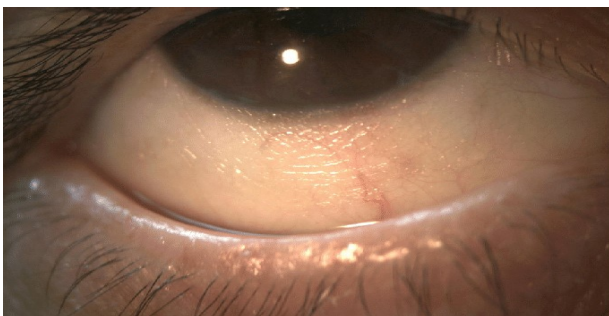


Figure 5 : **Conjunctival xerosis**

- **Bitot's spots:** **Bitot's spots** are one of the hallmark signs of Vitamin A deficiency and represent an advanced stage of xerophthalmia. They are characterized by white, grayish, or foamy patches on the conjunctiva, typically located on the temporal side of the eye. These spots result from the buildup of keratinized epithelial debris and are a consequence of chronic dryness and epithelial changes in the conjunctiva due to insufficient Vitamin A.
- Vitamin A plays a crucial role in maintaining healthy mucosal surfaces, and its deficiency leads to keratinization of epithelial cells and the loss of normal lubrication by the tear film. Bitot's spots are often accompanied by other symptoms of xerophthalmia, such as conjunctival xerosis and night blindness. While not directly vision-threatening, these spots indicate a significant deficiency and the need for urgent intervention. Prompt administration of Vitamin A can reverse Bitot's spots and prevent progression to more severe conditions like corneal xerosis and blindness.
- **Corneal xerosis:** **Corneal xerosis** is a serious stage of Vitamin A deficiency-related xerophthalmia, characterized by dryness and clouding of the corneal surface. It occurs due to the keratinization of the corneal epithelium, which results from prolonged Vitamin A deficiency. Vitamin A is essential for maintaining the health and function of epithelial tissues, including those in the cornea. Without adequate Vitamin A, the cornea loses its ability to retain moisture and protect itself from environmental damage, leading to desiccation. In corneal xerosis, the cornea appears dull, hazy, and rough, with a significant loss of its normal transparency. Patients may experience symptoms such as discomfort, pain, blurred vision, and increased sensitivity to light (photophobia). If left untreated, this condition can progress to more severe complications, including corneal ulceration, keratomalacia (softening of the cornea), and eventual blindness. Early detection and treatment are critical to prevent permanent damage and restore ocular health. High-dose Vitamin A supplementation is the primary treatment to halt progression, and supportive measures like lubricants or antibiotics may be used to prevent secondary infections.

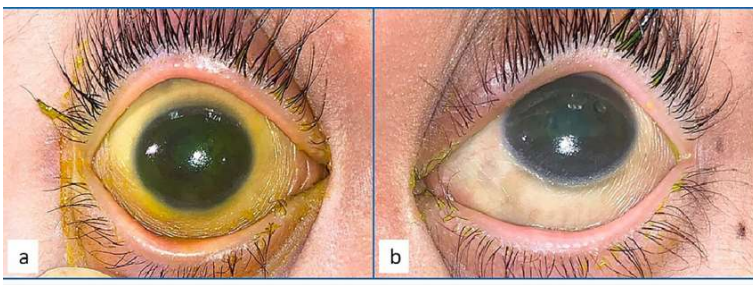


Figure 6 : corneal xerosis

Reference: ResearchGate

- **Keratomalacia:** Keratomalacia is the softening and liquefaction of the corneal tissue, a direct result of prolonged Vitamin A deficiency. It signifies an extreme stage of malnutrition where the structural integrity of the cornea is compromised. The cornea may appear cloudy, swollen, or even perforate, leading to the collapse of the eye structure. Patients with keratomalacia experience severe discomfort and vision loss. This stage often progresses rapidly and requires urgent medical intervention. It is irreversible stage and often results in permanent blindness.

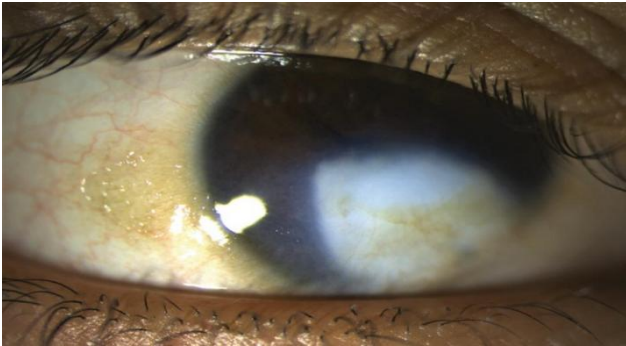


Figure 7 : **Keratomalacia**

- **Skin and Mucosal Changes:** Skin and mucosal changes are common signs of Vitamin A deficiency, as the vitamin plays a crucial role in maintaining the health and integrity of epithelial tissues. One of the earliest manifestations is **dry, scaly skin (xerosis)**, which occurs due to the keratinization of skin cells, making the skin appear rough and less elastic. Another characteristic sign is **follicular hyperkeratosis**, where hair follicles become clogged with keratin, leading to small, raised bumps on the arms, thighs, and buttocks. Vitamin A deficiency also affects the mucous membranes lining the respiratory, gastrointestinal, and urinary tracts, causing them to become dry and less effective at trapping and removing pathogens. This dryness increases the risk of infections, as the mucosal barriers become weaker and less protective. These skin and mucosal changes are often among the first visible signs of Vitamin A deficiency and serve as early indicators that the body's epithelial health is compromised.
- **Immune dysfunction:** Immune dysfunction is a significant consequence of Vitamin A deficiency. It is essential for the development and differentiation of immune cells, particularly T cells, which are crucial for the body's defense against infections. Both the innate and adaptive immune systems are compromised by deficiencies, making a person more vulnerable to infections. Low vitamin A levels make it harder for the body to generate a strong immune response, which makes people more vulnerable to gastrointestinal and respiratory infections. Moreover, Vitamin A deficiency can result in delayed wound healing and longer recovery times from illnesses, as the repair and regeneration of epithelial tissues, which are essential for immune defense, are also compromised. This immune dysfunction

underscores the importance of adequate Vitamin A intake for maintaining a strong and responsive immune system.

Vitamin A deficiency can have profound effects on both growth and reproductive health. In children, insufficient Vitamin A can lead to **stunted growth**, as the vitamin is essential for cell differentiation and the development of bones and tissues. Without adequate Vitamin A, growth processes are impaired, leading to developmental delays and failure to reach optimal height and weight. For adults, Vitamin A plays a critical role in **reproductive health**. In women, a deficiency may contribute to menstrual irregularities and complications during pregnancy, including a higher risk of maternal and fetal health issues. In men, low levels of Vitamin A can affect sperm production, leading to reduced fertility. The vitamin's role in maintaining the health of reproductive tissues and regulating hormones is vital, and its deficiency can disrupt both fertility and normal reproductive functions. Thus, Vitamin A deficiency can significantly impact both physical growth and reproductive capacity, underlining the importance of adequate intake for overall health.

Toxicity

The accumulation of excessive levels of vitamin A in the body is known as vitamin A toxicity, or hypervitaminosis A. It often occurs due to prolonged intake of high-dose supplements or excessive consumption of Vitamin A-rich foods, particularly liver. Acute toxicity results from consuming a large dose of Vitamin A in a short period, leading to symptoms such as nausea, dizziness, headache, and vomiting. Chronic toxicity develops gradually with the continuous intake of excess Vitamin A over time, causing more severe symptoms, including liver damage, bone abnormalities, and in extreme cases, intracranial pressure increase, leading to headaches and blurred vision. In addition to physical symptoms, chronic toxicity can also affect the skin, causing peeling, hair loss, and dryness.

Vitamin D

Vitamin D is unique because it functions both as a vitamin (a nutrient that must be obtained from food or supplements) and as a hormone (a chemical messenger that regulates specific bodily functions); yet it is often overlooked or misunderstood. Unlike most vitamins, the body can produce it on its own through exposure to sunlight. Despite this capacity, vitamin D insufficiency affects a large number of individuals worldwide and can result in a variety of health issues. Maintaining optimum health requires an understanding of the significance of vitamin D and making sure that one gets enough of it from food, sunlight, or supplements. In the body, it undergoes conversion in the liver and kidneys into its active form, **calcitriol**, which regulates calcium and phosphate metabolism. This active form is crucial for several physiological processes, especially bone mineralization and maintaining normal blood calcium levels.

In addition to its role in bone health, Vitamin D is involved in biological activities and exhibit disease preventing properties. In this section we explore the each aspect of vitamin D from history to sources,function , related diseases and many more.

History of Vitamin D:

In the early 1900s, researchers observed that children living in industrialized cities with limited sunlight exposure developed **rickets**, characterized by weakened bones and skeletal deformities. The connection between rickets and a lack of exposure to sunlight led to the discovery that a specific nutrient was essential for bone health.

In 1922, **Elmer McCollum** and colleagues identified a factor in cod liver oil that could cure rickets, which was later recognized as **Vitamin D**. This discovery was pivotal in understanding the role of Vitamin D in calcium metabolism and bone health. In 1936, scientists discovered that **Vitamin D** is a **prohormone** rather than a vitamin, as the body is capable of synthesizing it when exposed to sunlight. This discovery fundamentally changed the understanding of Vitamin D's biological role, and its importance in other physiological processes.

Chemistry of Vitamin D

Chemically, it is a secosteroid, which have the same basic structure of a steroid molecule.It consist of **steroid structure with four fused carbon rings**, similar to other steroid structures. The difference with vitamin D is that it has a **side chain** at one end (on the D ring) and a **hydroxyl group (-OH)** at the other **location, which is crucial for its biological activity**.The steroid nucleus remains intact, and the side chain and hydroxyl group contribute to vitamin D's specific properties. The presence of the hydroxyl group is important for the conversion of vitamin D into its active form, calcitriol, and the side chain plays a role in the compound's solubility and absorption.

There are two primary forms of vitamin D: Vitamin D2 (ergocalciferol) and Vitamin D3 (cholecalciferol). Both forms are chemically similar as they belong to the same sterol family, with a structure based on a four-ring steroid nucleus. However, they differ in their side chains. Vitamin D3 (Cholecalciferol). Let's discuss it in detail:

The chemical structure of **Vitamin D3** consists of a steroid nucleus with a broken ring at the B-ring position, a feature that distinguishes it as a secosteroid. The synthesis of Vitamin D3 begins with the

conversion of 7-dehydrocholesterol, a compound found in the skin, into cholecalciferol (Vitamin D₃) under UVB radiation. This process breaks the B-ring of the sterol nucleus, resulting in the formation of previtamin D₃, which is then converted into the active form, Vitamin D₃, through heat or isomerization.

Vitamin D₂ has a similar structure to Vitamin D₃ but differs in the side chain. It is derived from the ergosterol found in fungi and yeasts, which undergoes UVB irradiation to form Vitamin D₂. The side chain of Vitamin D₂ contains a double bond and a methyl group, which makes it structurally different from Vitamin D₃, though both are biologically active.

Sources of Vitamin D

Vitamin D, often known as the "sunshine vitamin," can be obtained through several sources: sunlight exposure, dietary intake, and supplementation. Here's an overview of these different sources:

- **Sunlight (Ultraviolet B Radiation):** The sun is a natural source of Vitamin D. When your skin is exposed to sunlight, it can produce Vitamin D. This is because your skin contains a compound called **7-dehydrocholesterol**, which is converted into **pre-vitamin D₃** and then into **Vitamin D₃ (cholecalciferol)** by ultraviolet B (UVB) radiation. However, factors like skin pigmentation, sunscreen use, time of day, season, and geographical location can affect how much Vitamin D your skin produces. For most people, 10 to 30 minutes of sun exposure a few times a week is enough to meet their vitamin D needs. People with darker skin, older adults, or those living in regions with limited sunlight may have reduced Vitamin D synthesis and may require additional sources of Vitamin D.
- **Dietary Sources of Vitamin D:** Vitamin D is naturally present in a limited number of foods, mainly animal-based products such as fish, cod liver oil, egg yolk, liver. However, certain foods are also fortified with Vitamin D, meaning that Vitamin D is added to them during production. Many foods such as fortified dairy products, fortified cereals are fortified with Vitamin D to help individuals meet their daily needs, especially for those who do not consume animal products.

Absorption of Vitamin D

The absorption of Vitamin D involves several processes, primarily occurring in the small intestine, with the subsequent transport and conversion to its active form. Here's a detailed look at how Vitamin

D is absorbed, starting from its intake through food or sunlight exposure to its entry into the bloodstream:

Absorption: The absorption of vitamin D occurs primarily in the **small intestine**, particularly in the **duodenum and jejunum**, following its intake from dietary sources or synthesis in the skin. When vitamin D is consumed through food or supplements, it is absorbed along with dietary fats. It is incorporated into **micelles**, which are small lipid aggregates that help fat-soluble vitamins, like vitamin D, cross the intestinal wall. Once in the enterocytes (intestinal cells), vitamin D is incorporated into **chylomicrons**, which are lipoproteins that transport fat-soluble vitamins through the lymphatic system into the bloodstream. If vitamin D is synthesized in the skin, it directly enters the bloodstream. The absorption process is facilitated by the presence of bile, which emulsifies fats and fat-soluble vitamins, and requires adequate dietary fat for optimal uptake. Once in the circulation, vitamin D is bound to **vitamin D-binding protein (DBP)**, which transports it to the liver and other tissues for further metabolism and utilization.

Transport: After vitamin D is absorbed in the intestines, it is transported to the liver via the bloodstream. In the circulation, vitamin D is carried by **chylomicrons** (in the case of dietary vitamin D) or by **vitamin D-binding protein (DBP)**, which is responsible for binding both vitamin D₂ and vitamin D₃, protecting them from degradation, and facilitating their transport to the liver. Once in the liver, vitamin D undergoes its first hydroxylation step, converting it into **25-hydroxyvitamin D** (also called calcidiol), the major circulating form of vitamin D. This conversion is catalyzed by the enzyme **25-hydroxylase**. The 25-hydroxyvitamin D produced is then released into the bloodstream, where it can be further converted into its active form, **calcitriol**, in the kidneys. This process ensures that vitamin D is metabolized efficiently and is made available for other physiological function.

In summary, Vitamin D is absorbed through the intestines when consumed with dietary fat, or synthesized in the skin upon UVB exposure. The absorbed or synthesized Vitamin D is then transported to the liver for conversion to its inactive form and further processed in the kidneys into its active form, calcitriol. This process allows Vitamin D to fulfill its essential roles in calcium and phosphate regulation, bone health, immune function, and more.

Storage of Vitamin D: The body also stores Vitamin D to maintain an adequate supply during times of insufficient dietary intake or limited sun exposure. It is stored primarily in **fat cells** and to a lesser extent in the liver. This storage is particularly important during winter months or in regions with

limited sunlight, as the body can rely on Vit D-fat reserves. However, this stored vitamin D is less readily available than the circulating form. Individuals with higher body fat may have more vitamin D stored in fat tissue, but this form is less bioavailable for the body, which can lead to vitamin D deficiency despite having adequate fat stores.

In addition, the **liver** stores Vitamin D, particularly in its inactive form, **25-hydroxyvitamin D** (calcidiol). and released into the bloodstream as needed for conversion into its active form(**1,25-dihydroxyvitamin D**) in the kidneys. It is important to note that Vit D circulate majorly in form of calcidiol, although**1,25-dihydroxyvitamin D is a most active and potent form.**

The regulation of vitamin D levels in the body is a highly controlled process. Feedback mechanisms govern the conversion of 25-hydroxyvitamin D to 1,25-dihydroxyvitamin D in the kidneys, depending on calcium and phosphate levels in the blood. When calcium levels are low, the kidneys increase conversion to the active form of vitamin D (calcitriol), enhancing calcium absorption in the intestines. Conversely, when calcium levels are high, the conversion is reduced to prevent excess calcium in the blood.

Biochemical Function of Vitamin D

Vitamin D plays a crucial role in maintaining variety of metabolic processes. Below is a detailed explanation of its biochemical functions:

Regulation of Calcium and Phosphate Homeostasis: Vitamin D is the regulation of **calcium** and **phosphate** levels in the blood, which are necessary for strong bones, teeth, and cellular processes. Vitamin D increases the intestinal absorption of calcium and phosphorus by binding to the **Vitamin D receptor (VDR), present** in the intestinal cells. In addition to its role in intestinal absorption, vitamin D also influences bone health by regulating bone resorption. When blood calcium levels are low, calcitriol acts on **osteoclasts** (bone-resorbing cells) to increase bone resorption, releasing calcium and phosphate into the circulation. This process helps maintain optimal blood calcium levels, ensuring that they remain within the range necessary for various physiological functions, including nerve signaling, muscle contraction, and enzyme activity. Further, calcitriol enhances the reabsorption of calcium and phosphate in the distal tubules of kidneys as promotes the

expression of proteins that facilitate the retention of calcium and phosphate, preventing their loss in urine.

Bone Health and Mineralization: Its active form, **calcitriol**, facilitates the absorption of calcium and phosphate from the intestines, ensuring these minerals are readily available in the bloodstream. These minerals are then deposited into the bone matrix, contributing to bone strength and density. Additionally, vitamin D promotes the synthesis of bone proteins, such as **osteocalcin**, which helps bind calcium in the bone matrix.

When blood calcium levels are low, vitamin D stimulates **bone resorption** by activating **osteoclasts**—cells that break down bone tissue—to release calcium and phosphate into the bloodstream, maintaining optimal levels necessary for critical physiological functions. This dual role in promoting bone formation and mobilizing calcium during periods of deficiency highlights vitamin D's importance in preventing bone-related disorders, such as **rickets** in children and **osteomalacia** in adults. Adequate vitamin D levels are also crucial in reducing the risk of osteoporosis, as it supports bone remodeling and maintains skeletal integrity throughout life.

Immune System Modulation: The immune system plays a critical role in defending the body against infections, diseases, and foreign invaders, and its modulation is essential for maintaining health and preventing disorders. Vitamin D regulates the differentiation of both immune cells - T cells and B cells; thereby influencing both innate and adaptive immunity. It also helps promote the production of **antimicrobial peptides** and enhancing the body's ability to fight infections.

Gene Expression and Cell Growth: Calcitriol has been shown to affect the growth, differentiation, and apoptosis of various cell types, including those in the **epithelial**, **bone**, **muscle**, and **immune** systems. This has implications for the development of certain diseases, such as cancer, where Vitamin D may help inhibit the uncontrolled proliferation of cells.

Cardiovascular Function: Recent research indicates that vitamin D may play a pivotal role in cardiovascular health, primarily by influencing calcium regulation and modulating the renin-angiotensin system (RAS). Through its effects on RAS, vitamin D reduces the production of renin, thereby lowering the risk of hypertension and its associated cardiovascular complications. Vitamin D helps regulate calcium levels, which is essential for proper vascular and cardiac function. Additionally,

it directly impacts calcium handling within cardiac cells, contributing to optimal heart muscle contraction and electrical stability.

Insulin Secretion and Glucose Metabolism: In pancreatic beta cells, vitamin D enhances insulin secretion by regulating calcium influx, a critical factor in insulin exocytosis. It also exerts anti-inflammatory effects, reducing systemic inflammation that can impair insulin action.

In insulin-sensitive tissues like muscle and adipose tissue, vitamin D improves glucose uptake by promoting the expression and activity of glucose transporters. Furthermore, it modulates the renin-angiotensin system and reduces oxidative stress, factors that can contribute to insulin resistance when dysregulated. Vitamin D deficiency has been associated with impaired insulin secretion, increased insulin resistance, and a higher risk of developing type 2 diabetes.

Vitamin D is essential for numerous biochemical functions and acts as a key regulator of health. Adequate Vitamin D levels are necessary to prevent diseases such as rickets, osteomalacia, osteoporosis, and may also play a protective role in immune function and chronic diseases. Let's discuss it in detail in next section.

Vitamin D Deficiency

Vitamin D deficiency occurs when the body does not produce enough of the vitamin, leading to disturbances in calcium and phosphate metabolism. This deficiency can have significant effects on bone health, immune function, and various other physiological processes. Below is a detailed explanation of Vitamin D deficiency, including its causes, symptoms, and potential consequences.

Causes of Vitamin D Deficiency

There are various factors, responsible for this which can be broadly classified into **inadequate intake**, **impaired absorption**, **reduced synthesis**, and **increased requirements**:

Inadequate Sunlight Exposure: Since The individuals who have limited sunlight exposure are at a higher risk of deficiency. This can be due to:

Living in northern latitudes where sunlight is limited, especially during the winter months.

Spending most time indoors.

Wearing clothing that covers most of the skin.

Using sunscreen with a high SPF, which blocks UVB rays.

Dietary Insufficiency: Vitamin D deficiency is more prevalent in vegetarian individual as for them, the primary source of vitamin D is typically sunlight contain very little natural vitamin D.

Malabsorption Disorders: individuals with malabsorption disorders, such as celiac disease, Crohn's disease, or cystic fibrosis, the ability to absorb fat-soluble vitamins like vitamin D from the digestive tract is impaired. This leads to reduced bioavailability of vitamin D, even if dietary intake or sunlight exposure is adequate. Malabsorption can cause deficiencies in not only vitamin D but also other essential nutrients, contributing to a range of health issues including bone weakness, weakened immune function, and an increased risk of cardiovascular disease.

Liver or Kidney Diseases: Since, Vitamin D converted into its active form in liver and kidney. Liver diseases (e.g., cirrhosis) or kidney dysfunction (e.g., chronic kidney disease) can impair this conversion, leading to deficiency even if dietary intake is sufficient.

- Vitamin D Deficiency

Common and initial sign of Vitamin D deficiency is pain in the bones and muscles, especially in the lower back and legs. This can also manifest as **muscle weakness**, making it difficult to stand up or walk. In children, Vitamin D deficiency leads Rickets characterized by **softening and weakening of bones**. While in adult, it causes a disease called osteomalacia Lets delve in detail:

Rickets is a skeletal disorder that results from a **deficiency** of Vitamin D, calcium, or phosphate. It primarily affects children during their growing years, leading to weakened bones and abnormal bone development. The condition is most commonly seen in children under the age of 5, but it can also affect older children and, in some rare cases, adults. Without adequate Vitamin D or calcium, bones become soft, which can lead to deformities and growth problems.

The symptoms of rickets include:

Bone Deformities:

Bow-leggedness: The most common sign of rickets is the outward bowing of the legs, which occurs because the bones are too weak to support the weight of the body.

Knock-knees: In some cases, the legs may turn inward, causing the knees to touch while the feet are apart.

Rachitic Rosary: A characteristic sign of rickets is the appearance of **bony lumps** at the junctions of the ribs and the cartilage, forming a "rosary" pattern along the chest.

Flat or Abnormal Feet: Rickets may cause the bones in the feet to flatten, which can lead to difficulty walking.

Delayed Growth:

Children with rickets may experience **short stature** and **delayed growth**, as the bones become weak and less capable of supporting normal growth.

Bone Pain:

Children with rickets often experience tenderness or pain in their bones, especially in the legs, spine, and pelvis.

Muscle Weakness:

Muscle weakness is common in rickets, particularly in the legs and back, which can affect a child's ability to walk or perform other physical activities.

Dental Issues:

Children with rickets may have delayed tooth development, enamel hypoplasia (weakened tooth enamel), or other dental abnormalities due to impaired calcium metabolism.

Hypocalcemia Symptoms:

In severe cases of rickets, low levels of calcium can cause symptoms like **seizures**, irritability, and muscle spasms (tetany).

Osteomalacia (in adults):

In adults, a prolonged deficiency of Vitamin D can lead to osteomalacia, a condition characterized by **softening of the bones** due to insufficient mineralization. This can lead to bone pain, muscle weakness, and an increased risk of fractures.

Osteomalacia is a condition characterized by the weakening of bones that have already completed their growth in adult. Pain, muscle weakness, and an elevated risk of fractures can result from osteomalacia. The condition is often underdiagnosed because its symptoms can be vague and easily attributed to other conditions. The symptoms of osteomalacia generally include bone pain and deformities, difficulty walking, muscle weakness and an increased risk of fractures. **Bone pain is one** of the hallmark symptoms of osteomalacia especially in the lower back, hips, pelvis, and legs. The pain may worsen with activity or pressure on the affected bones.

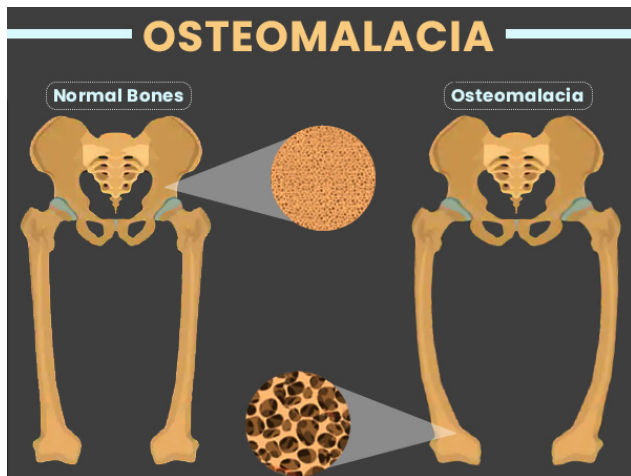


Figure 8 : Osteomalacia

- Diagnosis

Osteomalacia is diagnosed through a combination of **clinical evaluation, laboratory tests, and imaging studies**:

Blood Tests:

Serum Calcium: In osteomalacia, calcium levels may be low or normal.

Phosphate Levels: Low phosphate levels can indicate osteomalacia, especially when related to mineralization defects.

Alkaline Phosphatase (ALP): High levels of alkaline phosphatase can indicate bone turnover and the presence of osteomalacia, as the body compensates for poor bone mineralization.

25-Hydroxyvitamin D: Low levels of this form of Vitamin D are indicative of a deficiency.

Parathyroid Hormone (PTH): Elevated levels of PTH are often seen in Vitamin D deficiency as a compensatory response to low calcium levels.

X-ray Imaging:

Bone X-rays may reveal characteristic signs of osteomalacia, such as **looser zones** (radiolucent areas) and **bone softening**, which are seen as irregularities or deformities in the bone structure.

Bone Biopsy:

In rare cases, a bone biopsy may be performed to confirm the diagnosis of osteomalacia and assess the degree of mineralization defect.

Treatment

The primary treatment for osteomalacia is to correct the underlying deficiency of Vitamin D, calcium, and phosphate. Treatment may involve:

Vitamin D Supplementation: The first line of treatment is to **increase Vitamin D intake**, either through **oral supplements** or through **increased sunlight exposure**. High-dose Vitamin D may be given initially, followed by maintenance doses to ensure adequate levels.

Calcium and Phosphate Supplements: Calcium and phosphate supplements may be prescribed to improve bone mineralization, especially in cases where dietary intake is insufficient or there is a metabolic issue affecting their absorption.

Dietary Changes: **Vitamin D-rich foods** (such as fatty fish, fortified dairy products, and eggs) and **calcium-rich foods** (such as dairy products, leafy green vegetables, and fortified foods) should be incorporated into the diet.

Management of Underlying Conditions: If osteomalacia is caused by an underlying condition, such as **kidney disease** or **malabsorption**, treatment will also focus on managing that condition to improve overall bone health.

Physical Therapy: In cases with muscle weakness or pain, physical therapy may be beneficial to improve strength, mobility, and reduce the risk of falls.

Surgical Intervention: In severe cases with significant bone deformities or fractures, surgery may be required to correct deformities or stabilize bones.

- Prevention

Osteomalacia is largely preventable through:

- **Adequate Sunlight Exposure:** Ensuring regular exposure to sunlight helps the body produce Vitamin D naturally.
- **Balanced Diet:** Consuming foods rich in Vitamin D and calcium can help prevent deficiencies that lead to osteomalacia.
- **Vitamin D Supplementation:** Supplementing Vitamin D, especially in individuals at risk (e.g., elderly, those with limited sunlight exposure, or individuals with malabsorption conditions), can prevent osteomalacia.
- **Monitoring and Managing Health Conditions:** Conditions that affect Vitamin D metabolism or calcium absorption should be managed with the help of healthcare providers.

Osteomalacia is a condition that results from impaired bone mineralization, primarily due to Vitamin D deficiency. It can lead to bone pain, muscle weakness, and an increased risk of fractures. Early diagnosis and treatment are essential to restore bone health and prevent long-term complications. Adequate Vitamin D, calcium, and phosphate intake, along with appropriate medical management, can effectively treat and prevent osteomalacia.

- **TOXICITY**

Vitamin D toxicity, also known as **hypervitaminosis D**, is a condition that occurs when there are excessively high levels of **Vitamin D** in the body. Unlike other vitamins, Vitamin D toxicity does not arise from excessive sun exposure or from eating foods rich in Vitamin D but is typically the result of

over-supplementation or very high doses of Vitamin D, especially in the form of supplements. However, toxicity is rare and usually occurs when individuals take extremely high doses of Vitamin D for extended periods.

The most common cause of Vitamin D toxicity is the **overuse of Vitamin D supplements**. Taking very high doses (more than 10,000 IU/day) over a long period can lead to toxicity. The **tolerable upper intake level** for Vitamin D for most adults is about 4,000 IU/day. Doses significantly higher than this, especially when taken for months or years, can result in toxicity.

Some medical conditions, such as **sarcoidosis**, **tuberculosis**, or certain types of **lymphoma**, can lead to increased production of Vitamin D in the body, causing an accumulation of calcium in the blood and resulting in toxicity.

VITAMIN E

It is a fat-soluble vitamin with strong antioxidant qualities, and is essential for shielding cells from oxidative harm. Its significance was first recognized in the early 20th century, and it has since become an essential nutrient for maintaining overall health. Let's delve into the history of its discovery in next section.

- **History of Vitamin E**

The discovery of Vitamin E dates back to **1922** when researchers at the University of California, led by **E.V. McCollum**, identified a fat-soluble compound in the diet that was essential for reproduction in rats. This compound was later named **Vitamin E**. The name "Vitamin E" was derived from the word "reproduction," as the nutrient was initially thought to be crucial for fertility and reproduction. The initial studies focused on the importance of Vitamin E in preventing reproductive failure in animals, leading to its characterization as a vital nutrient.

In the following years, research expanded to uncover the full scope of Vitamin E's functions, including its potent antioxidant properties. The main biologically active form of Vitamin E, **alpha-tocopherol**, was isolated and its role in protecting cells from oxidative stress and preventing cell membrane damage was recognized.

- **CHEMISTRY**

The **core structure** of Vitamin E compounds, both tocopherols and tocotrienols, consists of a **chromanol ring** with a **hydrophobic tail** that is responsible for its fat-solubility. The chromanol ring is a six-membered oxygen-containing aromatic ring, which is the key to Vitamin E's **antioxidant activity**. This structure allows Vitamin E to **scavenge free radicals**, neutralizing them before they can damage cells.

The specific form of vitamin E is determined by the number and type of methyl groups (-CH₃) attached to the chromanol ring of its structure. Vitamin E exists in eight different forms, which are divided into two main categories: **tocopherols** and **tocotrienols**. Both categories contain four distinct compounds, but the key difference lies in the structure of the chromanol ring and the methyl groups attached to it.

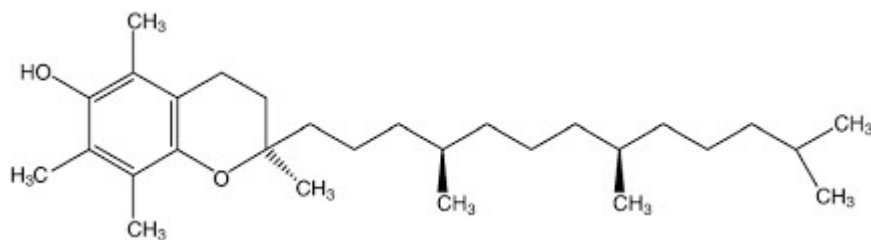


Figure 9 : Tocopherol

Reference: ResearchGate

Tocopherols:

Tocopherols are characterized by a saturated tail attached to the chromanol ring, which contains a benzene ring with varying numbers of methyl groups. The most well-known form of tocopherol is **alpha-tocopherol**, which has three methyl groups attached to the chromanol ring at positions 5, 7, and 8. The presence of these methyl groups significantly affects the antioxidant activity of tocopherols.

There are four types of tocopherols, classified by the position and number of methyl groups on the chromanol ring:

Alpha-tocopherol – Three methyl groups at positions 5, 7, and 8.

Beta-tocopherol – Two methyl groups at positions 5 and 8.

Gamma-tocopherol – One methyl group at position 7.

Delta-tocopherol – No methyl groups at positions 5, 7, or 8.

Among these, **alpha-tocopherol** is the most biologically active form of vitamin E in humans, primarily due to its strong antioxidant properties, which help protect cells from oxidative damage.

Tocotrienols:

Tocotrienols have a similar structure to tocopherols but differ in having an unsaturated tail (three double bonds in the isoprenoid side chain) instead of a saturated one. This structural difference makes tocotrienols more flexible and more easily able to penetrate cell membranes. There are also four types of tocotrienols:

Alpha-tocotrienol – Similar to alpha-tocopherol but with an unsaturated tail.

Beta-tocotrienol – Similar to beta-tocopherol but with an unsaturated tail.

Gamma-tocotrienol – Similar to gamma-tocopherol but with an unsaturated tail.

Delta-tocotrienol – Similar to delta-tocopherol but with an unsaturated tail.

Tocotrienols are also potent antioxidants but are thought to have additional biological activities, including anti-inflammatory, cholesterol-lowering, and anti-cancer effects, potentially due to their ability to interact with different cellular pathways. However, tocotrienols are less well-known than tocopherols and are less abundant in the typical diet.

• SOURCES

Vitamin E is found in a variety of foods, particularly plant-based oils, nuts, seeds, and green leafy vegetables. The richest sources include **vegetable oils** such as wheat germ oil, sunflower oil, safflower oil, olive oil, and canola oil. Nuts and seeds, especially **almonds**, **sunflower seeds**, **hazelnuts**, and **pine nuts**, are also excellent sources of Vitamin E. **Green leafy vegetables** like spinach, Swiss chard, kale, and collard greens provide a substantial amount of Vitamin E. **Fruits**, particularly **avocados**, are

notable sources, offering Vitamin E along with healthy fats that enhance absorption. **Fortified foods**, including breakfast cereals, margarine, and fruit juices, often contain added Vitamin E. **Whole grains** such as oats, barley, and brown rice contribute moderate amounts of Vitamin E. Although **animal products** like eggs and liver contain trace amounts, plant-based sources are the most significant contributors to dietary Vitamin E. Additionally, **tomato paste** and **red bell peppers** offer small but useful amounts of Vitamin E. By incorporating a range of these foods into the diet, individuals can effectively meet their Vitamin E needs, supporting cellular protection and overall health.

- **Biochemical Functions of Vitamin E**

Vitamin E primarily functions as an **antioxidant** in the body, protecting cells and tissues from damage caused by **oxidative stress**. Its biochemical roles are fundamental to various physiological processes, particularly in cellular protection, immune function, and regulation of gene expression. The following are key biochemical functions of Vitamin E:

1. **Antioxidant Activity**

The most well-known and important biochemical function of Vitamin E is its role as an **antioxidant**. The body is constantly exposed to reactive oxygen species (ROS) and free radicals, which can cause **oxidative damage** to cells and tissues. Vitamin E, particularly in its active form of **alpha-tocopherol**, acts as a **free radical scavenger** by donating an electron to neutralize these reactive molecules, thus preventing damage to cellular components, such as:

2. **Lipids:** Lipid peroxidation can lead to the breakdown of cell membranes, affecting their integrity and function. Vitamin E prevents this by stabilizing the cell membrane lipids.
3. **Proteins and DNA:** Oxidative damage to proteins and DNA can disrupt cell function and lead to mutations. By neutralizing free radicals, Vitamin E helps to protect these macromolecules from damage.
4. The antioxidant action of Vitamin E is particularly important in tissues with high lipid content, such as the **brain, liver, lungs**, and **heart**, where it plays a crucial role in maintaining cellular integrity and preventing diseases related to oxidative stress.

Immune System Support

5. Vitamin E plays a significant role in supporting the **immune system**. It enhances immune responses by protecting immune cells from oxidative damage and maintaining the integrity of cell membranes, allowing immune cells to function optimally. Vitamin E also helps in the **activation** and **proliferation** of immune cells such as **T lymphocytes**, which are important for defense against infections. Additionally, it modulates the activity of other immune system components, such as **cytokines**, which are involved in inflammation and immune signaling.

Anti-Inflammatory Effects

6. Vitamin E exerts **anti-inflammatory** effects by modulating the expression of certain proteins involved in inflammation. It helps reduce the levels of **pro-inflammatory cytokines** and **reactive oxygen species (ROS)**, which are often involved in chronic inflammatory diseases, such as **cardiovascular disease**, **arthritis**, and **diabetes**. This function is particularly linked to its ability to modulate the activity of various enzymes and proteins, including **NF-kB** (nuclear factor-kappa B), which plays a key role in inflammation.

Gene Expression Regulation

7. Vitamin E also plays a role in regulating **gene expression**, particularly genes involved in **antioxidant defense**, **inflammation**, and **cellular growth**. It interacts with the **nuclear receptors** and **transcription factors** in the cell to regulate the expression of specific genes. For example, Vitamin E can activate **NRF2** (nuclear factor erythroid 2-related factor 2), a transcription factor that regulates the expression of antioxidant genes, which are critical for cellular defense against oxidative stress.

Neurological Function

8. Vitamin E supports **neural health** by protecting neurons from oxidative damage, which is crucial for maintaining cognitive function and preventing neurodegenerative diseases. Its antioxidant properties are vital for protecting brain tissues, particularly in regions like the **hippocampus**, which is involved in memory and learning. Some studies suggest that Vitamin E may play a role in protecting against **Alzheimer's disease** and **Parkinson's disease**, both of which are characterized by oxidative damage to brain cells.

Skin Health

9. Vitamin E is involved in maintaining **skin health** by protecting skin cells from damage caused by **UV radiation** and environmental toxins. As an antioxidant, Vitamin E helps prevent the formation of free radicals that can damage skin cells, causing **premature aging** and increasing the risk of **skin cancer**. Vitamin E also contributes to the healing process of skin wounds and burns by promoting **collagen synthesis** and **tissue repair**.

Cardiovascular Health

10. Vitamin E plays a role in **cardiovascular health** by protecting the **endothelial cells** that line the blood vessels from oxidative damage. By preventing the oxidation of **low-density lipoproteins (LDL)**, Vitamin E helps reduce the risk of **atherosclerosis**, a condition where plaque builds up in the arteries, leading to heart disease. Additionally, Vitamin E has been shown to **dilate blood vessels**, improving blood flow and reducing blood pressure.

Cellular Signaling

11. Vitamin E influences cellular signaling pathways by interacting with enzymes and receptors that regulate various cellular processes. It has been shown to affect **protein kinase C (PKC)**, an enzyme involved in cell signaling, which in turn affects processes like **cell proliferation** and **apoptosis** (programmed cell death). By modulating these pathways, Vitamin E can influence cell growth, differentiation, and survival.
12. The absorption of **Vitamin E**, primarily in the form of **tocopherols** and **tocotrienols**, is a complex process that occurs primarily in the **small intestine**, particularly in the **duodenum** and **jejunum**. Since Vitamin E is a fat-soluble vitamin, its absorption is closely linked to dietary fat and requires the presence of **bile acids** for efficient uptake.

Process of Absorption:

13. **Ingestion and Digestion:** Vitamin E is typically consumed in its esterified form in food, such as in vegetable oils, nuts, seeds, and green leafy vegetables. Upon consumption, Vitamin E is released from its esterified form in the stomach, aided by **gastric lipases**.

14. **Incorporation into Micelles:** After release in the stomach, Vitamin E is incorporated into **micelles** in the small intestine. Micelles are tiny fat droplets that help transport fat-soluble vitamins and other lipids through the aqueous environment of the intestine. **Bile salts**, secreted by the liver and stored in the gallbladder, help in the formation of these micelles by emulsifying fats, making the absorption of Vitamin E more efficient.
 15. **Absorption into Enterocytes:** The micelles move to the surface of the intestinal cells (enterocytes), where Vitamin E is absorbed into the cells through **passive diffusion**. This process does not require energy and is facilitated by the micellar structure.
 16. **Incorporation into Chylomicrons:** Once inside the enterocytes, Vitamin E is incorporated into **chylomicrons**, which are large lipoproteins responsible for transporting fat-soluble nutrients. Chylomicrons are then released into the **lymphatic system**, bypassing the liver initially.
 17. **Transport to the Liver:** Chylomicrons eventually enter the bloodstream via the **thoracic duct** and transport Vitamin E to the liver, where it is repackaged into other lipoproteins like **very low-density lipoproteins (VLDL)** for distribution to various tissues in the body.
- **Factors Affecting Absorption:**
 - **Dietary Fat:** Adequate fat intake is necessary for efficient Vitamin E absorption, as fat helps to form micelles that aid in transporting Vitamin E through the intestinal lining.
 - **Bile Production:** Adequate bile production is essential for the emulsification of fat and the formation of micelles. Any impairment in bile production or secretion can lead to reduced Vitamin E absorption.
 - **Intestinal Health:** Conditions that affect intestinal health, such as **celiac disease** or **Crohn's disease**, can impair the absorption of Vitamin E.

In conclusion, the absorption of Vitamin E is a fat-soluble process that requires dietary fat, bile, and healthy intestinal function. The vitamin is absorbed into the bloodstream via chylomicrons and transported to tissues where it plays a key role as an antioxidant and in maintaining cellular health.

The transport and storage of **Vitamin E** are critical for its effective utilization in the body, as it is a fat-soluble vitamin. Its transport and storage processes are closely linked to lipids and lipoproteins, ensuring it reaches the tissues where it is needed and is preserved for future use.

Transport of Vitamin E:

Incorporation into Chylomicrons: After Vitamin E is absorbed from the small intestine, it is incorporated into **chylomicrons**, which are lipoproteins responsible for transporting fat-soluble vitamins and lipids. These chylomicrons are then released into the **lymphatic system** before entering the bloodstream.

Circulation in Blood: Once in the bloodstream, Vitamin E is transported via lipoproteins, primarily **very low-density lipoproteins (VLDL)** and **low-density lipoproteins (LDL)**. These lipoproteins are produced by the liver and transport Vitamin E to various tissues throughout the body. VLDL and LDL are essential for distributing Vitamin E to cells where it plays antioxidant roles, particularly in cell membranes and tissues rich in polyunsaturated fatty acids.

Tissue Uptake: The uptake of Vitamin E by tissues occurs via specific **lipoprotein receptors** present on the surface of target cells. The liver is a primary site for initial Vitamin E processing and distribution to the rest of the body.

Storage of Vitamin E:

Liver: The liver plays a central role in storing Vitamin E, although it is not stored in large amounts. After being absorbed and transported via chylomicrons and VLDL, Vitamin E is either used by the liver for immediate needs or stored in small amounts for later use. The liver releases Vitamin E into the bloodstream as needed, particularly when there is a deficit in dietary intake or increased antioxidant demand.

Adipose Tissue: Vitamin E is also stored in **adipose tissue** (fat cells) in the body. Since Vitamin E is fat-soluble, it can accumulate in fat reserves, providing a storage depot for the vitamin. However, its storage in adipose tissue is not as efficient as in the liver, and the release of Vitamin E from fat stores is slower than from the liver.

Slow Release: Vitamin E is not stored in large amounts, and its turnover in the body is relatively slow compared to other vitamins. When the body has an adequate supply of Vitamin E, it can maintain a balance between what is stored and what is circulating in the bloodstream. Excess Vitamin E is primarily excreted through the bile, although some may be eliminated in urine.

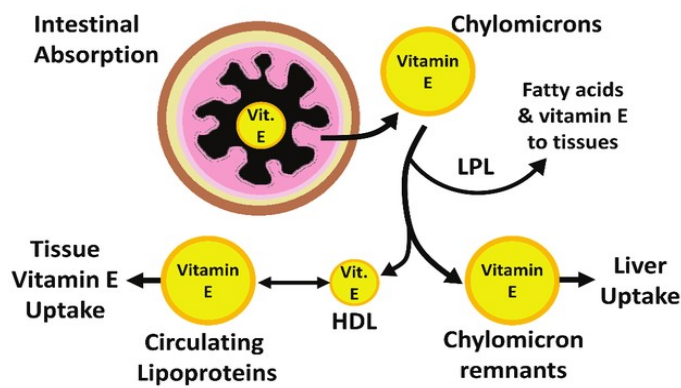


Figure 10 : Transportation and storage of Vitamin E

Reference: ResaerchGate

- **Summary:**

Vitamin E is transported through the bloodstream by lipoproteins, primarily chylomicrons, VLDL, and LDL, ensuring its delivery to tissues. The liver serves as the main storage site, while adipose tissue also holds small amounts of Vitamin E. Since it is fat-soluble, Vitamin E can be stored in these tissues and released gradually to meet the body's needs. Regular intake is important to maintain sufficient circulating levels of this essential antioxidant.

- **DEFICIENCY**

Vitamin E deficiency, although rare in developed countries, can occur under certain conditions and lead to a range of health issues. The deficiency typically results from inadequate dietary intake, fat malabsorption disorders, or genetic conditions affecting the metabolism of Vitamin E.

- **Symptoms and Effects:**

Neurological Impairment: One of the most prominent effects of Vitamin E deficiency is **neurological problems**, such as **ataxia** (lack of coordination), muscle weakness, and **dysarthria**

(difficulty speaking). These occur because Vitamin E plays a crucial role in protecting the nervous system from oxidative damage.

Hemolytic Anemia: Vitamin E is essential for protecting red blood cells from oxidative damage. In its absence, **hemolysis** (destruction of red blood cells) can occur, leading to **anemia**. This is particularly common in infants with low birth weight or those with malabsorption syndromes.

Immune System Dysfunction: A deficiency in Vitamin E can impair the immune response, leading to increased susceptibility to infections. Vitamin E helps maintain the function of immune cells and supports immune defense mechanisms by neutralizing free radicals that could damage immune cells.

Retinal Degeneration: Vitamin E deficiency can cause damage to the **retina**, leading to **vision problems**. This is due to its antioxidant role in protecting cells in the eye from oxidative stress, which can result in conditions like **retinopathy**.

Skin and Hair Issues: The skin may become dry and flaky, and hair loss may occur due to the essential role of Vitamin E in maintaining skin and scalp health.

Reproductive Problems: Vitamin E deficiency can impair fertility, especially in males, as it plays a role in sperm health and motility.

- **Causes of Deficiency:**

- **Malabsorption Disorders:** Conditions like **cystic fibrosis**, **Crohn's disease**, and **celiac disease** can impair the absorption of fat, leading to reduced Vitamin E uptake.
- **Genetic Disorders:** Certain genetic conditions, such as **abetalipoproteinemia**, affect the transport of Vitamin E in the body, leading to deficiency despite adequate intake.
- **Low Dietary Intake:** Inadequate consumption of Vitamin E-rich foods, especially in individuals with limited access to varied diets, can contribute to deficiency.

In severe cases, Vitamin E deficiency can lead to significant health complications, but it is often treatable through dietary adjustments or supplementation.

- **TOXICITY**

Vitamin E toxicity, also known as **hypervitaminosis E**, occurs primarily due to excessive intake of **supplements** rather than food sources, as the body can usually regulate Vitamin E absorption from dietary sources. Since Vitamin E is a fat-soluble vitamin, it is stored in the body's fat tissues and liver, which increases the risk of toxicity if consumed in high doses over extended periods.

- **Symptoms of Vitamin E Toxicity:**

Hemorrhagic Effects: One of the most concerning effects of excessive Vitamin E intake is its impact on blood clotting. High doses of Vitamin E can interfere with Vitamin K, which is essential for blood clotting. This can lead to an increased risk of **bleeding**, including **hemorrhages**, bruising, and gastrointestinal bleeding.

Gastrointestinal Disturbances: High doses of Vitamin E can cause digestive issues, including **nausea**, **diarrhea**, and **abdominal cramping**.

Fatigue and Weakness: Some individuals may experience **fatigue**, **weakness**, and **dizziness** as a result of Vitamin E toxicity.

Increased Risk of Stroke: Excessive Vitamin E intake has been linked to an elevated risk of hemorrhagic stroke, as the excess vitamin can interfere with the normal clotting process, making bleeding in the brain more likely.

Muscle Weakness and Impaired Vision: In extreme cases, prolonged high doses of Vitamin E may cause **muscle weakness**, **fatigue**, and potential **vision disturbances**, as the vitamin disrupts normal cellular processes.

- **Causes of Toxicity:**

Vitamin E toxicity is typically the result of **high-dose supplementation**, not from food sources, as it is difficult to reach toxic levels through diet alone. The **upper tolerable intake level (UL)** for Vitamin E established by health authorities is **1,000 mg (1,500 IU) per day** for adults, which is much higher than what is typically consumed through food.

Management:

If Vitamin E toxicity occurs, discontinuing the supplementation is the primary course of action. Treatment may also involve **vitamin K supplementation** to help counteract the effects on blood clotting. It is important to consult with a healthcare provider before taking Vitamin E supplements, especially at high doses, to avoid the risk of toxicity.

- **Conclusion:**

While Vitamin E is essential for health, excessive intake, particularly from supplements, can lead to toxicity and adverse health effects, particularly related to blood clotting and cardiovascular health. It is crucial to balance Vitamin E intake, ensuring it is sufficient for antioxidant protection without exceeding safe limits.

CHECK YOUR PROGRESS EXERCISE 1

1. Explain the process of absorption of fat soluble vitamin.

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2. Give the classification of Xerophthalmia and their prominent sign and symptoms

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3. Explain the role of vitamin D in calcium and phosphorus Homeostasis

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4. Discuss the sign and symptoms of Vit E deficiency

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Water soluble vitamins

VITAMIN C

Vitamin C, also known as **ascorbic acid**, is one of the most essential nutrients for humans, playing a crucial role in many physiological processes. Vitamin C plays a wide range of vital biochemical roles, including acting as an antioxidant, supporting collagen synthesis, enhancing iron absorption, promoting immune function, and assisting in neurotransmitter production. These functions highlight the importance of adequate Vitamin C intake for overall health, especially in maintaining the integrity of connective tissues, the immune system, and energy metabolism. Its discovery and understanding of its significance in human health have evolved over time.

- Historical Background:

Early Observations: The importance of Vitamin C became apparent in the 18th century when **James Lind**, a British naval surgeon, conducted experiments on sailors. He observed that sailors who consumed citrus fruits were less likely to develop **scurvy**, a disease caused by Vitamin C deficiency. This discovery led to the widespread use of citrus fruits like lemons and limes to prevent scurvy in sailors, though the exact nutrient responsible remained unknown for some time.

Isolation of Vitamin C: In the early 20th century, scientists were able to isolate and identify the substance responsible for preventing scurvy. In **1928**, the Hungarian chemist **Albert Szent-Györgyi** isolated Vitamin C from **citrus fruits** and subsequently identified its chemical structure, earning the Nobel Prize in Physiology or Medicine in 1937 for his work. This discovery was instrumental in understanding the role of Vitamin C in health and nutrition.

Synthetic Vitamin C: The synthesis of Vitamin C was achieved in **1933** by **Tadeus Reichstein** and colleagues, further expanding its availability and leading to the development of synthetic Vitamin C supplements. This was a significant breakthrough, making Vitamin C available for public use, especially in areas where fresh fruits and vegetables were scarce.

- **Chemistry of Vitamin C (Ascorbic Acid)**

Vitamin C, also known as **ascorbic acid**, is a water-soluble vitamin with the chemical formula **C₆H₈O₆**. It is a naturally occurring compound found in various fruits and vegetables, and its structure is based on a six-membered lactone ring, which is essential for its biological activity.

- **Molecular Structure:**

The **chemical structure** of Vitamin C consists of a six-carbon chain with hydroxyl (-OH) groups attached to carbon atoms. Its key structural features include:

- A **lactone ring** (a cyclic ester) at the core, formed by a reaction between the hydroxyl and carbonyl group.
- The hydroxyl group at **position 3** in the ring is vital for Vitamin C's antioxidant activity, as it can donate electrons to neutralize free radicals.
- A **double bond** between carbons **2 and 3**, which is important for its stability and reactivity.
- **Hydroxy and carbonyl groups** at other positions on the ring structure are important for its solubility in water and its ability to participate in biochemical reactions.

- **Oxidation and Reduction:**

Vitamin C exists in two main forms:

Ascorbic Acid (Reduced Form): This is the active form of Vitamin C that acts as an electron donor in various biochemical reactions. It is a potent **antioxidant**, neutralizing free radicals by donating electrons.

Dehydroascorbic Acid (Oxidized Form): When Vitamin C donates electrons, it gets oxidized into **dehydroascorbic acid**. This form is biologically active but is less stable and may eventually degrade into other metabolites if not reduced back to ascorbic acid.

The interconversion between these two forms (ascorbic acid and dehydroascorbic acid) is important for its function as a **cofactor** in enzymatic reactions and for its antioxidant properties.

- **Functional Groups:**
- **Hydroxyl Groups:** The two hydroxyl groups (-OH) attached to the carbon chain of ascorbic acid are key to its biochemical function. These groups allow Vitamin C to act as a **reducing agent**, which helps in **free radical scavenging** and also contributes to its role in collagen synthesis and iron absorption.
- **Lactone Ring:** The lactone structure is central to Vitamin C's ability to stabilize the molecule, making it effective in biochemical reactions, particularly those involving collagen formation and neurotransmitter synthesis.
- **Stability and Degradation:**

Vitamin C is highly sensitive to **heat**, **light**, and **oxygen**, which can cause degradation and oxidation of the molecule. In the oxidized state (dehydroascorbic acid), Vitamin C is less effective as an antioxidant. This sensitivity is why Vitamin C-rich foods should be stored and cooked carefully to preserve their nutritional value.

- **Sources of Vitamin C**

Vitamin C, also known as **ascorbic acid**, is abundant in a variety of fruits and vegetables. Regular consumption of these foods is essential, as the human body cannot synthesize or store Vitamin C efficiently. Incorporating a variety of fresh fruits and vegetables into the diet is the best way to ensure adequate Vitamin C intake. Foods such as citrus fruits, berries, and bell peppers are among the richest natural sources, while fortified foods can provide an additional dietary boost.

- **Rich Dietary Sources:**

Fruits:

Citrus Fruits: Oranges, lemons, limes, and grapefruits are among the richest sources.

Berries: Strawberries, raspberries, blackberries, and blueberries are packed with Vitamin C.

Tropical Fruits: Kiwi, guava, papaya, pineapple, and mango are excellent sources.

Others: Melons such as cantaloupe and watermelon also contain significant amounts.

Vegetables:

Leafy Greens: Spinach, kale, and other dark leafy greens are good sources.

Cruciferous Vegetables: Broccoli, Brussels sprouts, and cauliflower are rich in Vitamin C.

Peppers: Bell peppers (red, green, and yellow) are exceptionally high in Vitamin C.

Other Vegetables: Tomatoes, potatoes (especially new potatoes), and peas provide moderate amounts.

Fortified Foods:

Some breakfast cereals, fruit juices, and other processed foods are fortified with Vitamin C to help increase intake, especially in populations at risk of deficiency.

- **Cooking and Storage Tips:**

Vitamin C is sensitive to heat, light, and oxygen, which can reduce its content in foods. To maximize Vitamin C intake:

- Eat fruits and vegetables raw whenever possible.
- Use minimal cooking times (e.g., steaming instead of boiling).
- Store produce in a cool, dark place or refrigerate to preserve its Vitamin C content.

- **ABSORPTION**

Vitamin C is absorbed primarily in the **small intestine**, specifically in the **duodenum** and **jejunum**, through an active transport mechanism. The absorption process is influenced by the **concentration** of Vitamin C in the intestinal lumen. At lower concentrations, Vitamin C is absorbed efficiently via **sodium-dependent Vitamin C transporters (SVCTs)**, which actively transport ascorbate (the reduced form of Vitamin C) into enterocytes (intestinal cells). These transporters are critical for the uptake of Vitamin C from the intestinal lumen into the bloodstream.

- At higher concentrations of Vitamin C, absorption becomes less efficient, and passive diffusion can also occur. The absorption efficiency can be reduced when intake exceeds the body's requirement, as the transport mechanisms become saturated.
- Once absorbed, Vitamin C enters the bloodstream and is transported to various tissues throughout the body, including the liver, kidneys, and other organs that require it for biochemical functions. The bioavailability of Vitamin C can be affected by factors such as age, diet, and the presence of other nutrients. Additionally, certain conditions, such as gastrointestinal disorders, can impair Vitamin C absorption, making supplementation necessary for individuals with poor absorption capacity.
- In conclusion, Vitamin C absorption is a complex process that depends on both the body's needs and the amount of Vitamin C available in the intestines. Efficient absorption occurs at low concentrations, and excess amounts are typically excreted through urine.

- **TRANSPORT AND STORAGE**

Vitamin C is transported in the bloodstream primarily in its **ascorbate** (reduced) form. After absorption in the small intestine, it enters the bloodstream and is distributed to tissues, where it is needed for various biochemical functions. The transport of Vitamin C is facilitated by specialized **sodium-dependent Vitamin C transporters (SVCTs)**, which actively carry ascorbate into cells. In addition, Vitamin C can be transported in its **dehydroascorbic acid (oxidized)** form, but this requires a different set of transporters called **glucose transporters (GLUTs)**. Once inside the cells, Vitamin C is primarily stored in the **cytosol** and **organelles**, such as the **mitochondria** and **endoplasmic reticulum**, where it functions as an antioxidant and a cofactor for enzymatic reactions.

Regarding **storage**, Vitamin C is not stored in significant amounts in the body, as it is water-soluble and is rapidly excreted in the urine when consumed in excess. The body has a limited capacity to retain Vitamin C, and it must be replenished regularly through dietary sources. The **liver** plays a role in

maintaining circulating levels of Vitamin C by regulating its release into the bloodstream and excreting excess amounts. Due to its water-solubility and lack of storage capability, consistent intake from food sources is necessary to maintain adequate levels of Vitamin C for the body's various functions.

In summary, Vitamin C is transported through the bloodstream via specialized transporters, and while it is not stored in large amounts, it is readily available in tissues where it performs essential biochemical roles. Since the body does not store significant amounts of Vitamin C, regular dietary intake is crucial to meet the body's needs.

- **BIOCHEMICAL FUNCTION**

Vitamin C, or **ascorbic acid**, is involved in several important biochemical functions that are essential for maintaining health. Below are the key roles of Vitamin C in the body:

Antioxidant Activity:

Vitamin C is a potent **antioxidant**, meaning it helps protect cells from **oxidative stress** caused by free radicals. Free radicals are unstable molecules that can damage cellular components like DNA, proteins, and lipids, leading to inflammation and contributing to the development of chronic diseases such as heart disease, cancer, and aging. Vitamin C neutralizes free radicals, reducing oxidative damage.

Collagen Synthesis:

One of the most critical functions of Vitamin C is its role in **collagen synthesis**. Collagen is a structural protein found in connective tissues, such as skin, blood vessels, tendons, ligaments, and cartilage. Vitamin C acts as a cofactor for enzymes **prolyl hydroxylase** and **lysyl hydroxylase**, which are required for the proper formation of collagen. This function is crucial for wound healing, tissue repair, and maintaining skin elasticity. Without sufficient Vitamin C, the body cannot produce stable collagen, leading to conditions like **scurvy**.

Iron Absorption:

Vitamin C enhances the absorption of **non-heme iron** (the type of iron found in plant-based foods) from the digestive tract. It reduces iron from its ferric (Fe^{3+}) form to the ferrous (Fe^{2+}) form, which is

more easily absorbed by the intestines. This is especially important for individuals following plant-based diets, as non-heme iron is less readily absorbed compared to heme iron from animal products. By improving iron absorption, Vitamin C helps prevent **iron deficiency anemia**.

Immune System Support:

Vitamin C is essential for the proper functioning of the immune system. It supports the production and function of **white blood cells** (such as **phagocytes** and **lymphocytes**), which help fight infections. It enhances the activity of **T-cells**, which are important for adaptive immunity, and helps in the synthesis of **interferons**, proteins that protect cells from viral infections. Additionally, Vitamin C has a role in the **clearance of pathogens** and supports the skin's barrier function to prevent microbial invasion.

Neurotransmitter Synthesis:

Vitamin C is involved in the synthesis of several **neurotransmitters**, including **dopamine**, which is important for brain function and mood regulation. Vitamin C acts as a cofactor for the enzyme **dopamine β -hydroxylase**, which is responsible for converting dopamine to **norepinephrine**, a key neurotransmitter involved in alertness, concentration, and stress responses.

Detoxification:

Vitamin C plays a role in **detoxification** processes in the liver, where it helps neutralize toxic substances, such as heavy metals and pollutants, through its antioxidant properties. By reducing oxidative damage, Vitamin C also aids in the overall detoxification process, protecting the liver and other organs from harmful substances.

Enzyme Activation:

Vitamin C is involved in the activation of several enzymes in the body. For example, it acts as a cofactor for enzymes involved in the **synthesis of carnitine**, a molecule that is essential for the transport of fatty acids into mitochondria, where they are burned for energy. This process is particularly important for energy metabolism.

Gene Expression and Cellular Signaling:

Vitamin C has an impact on **gene expression** and regulates various signaling pathways in cells. It affects the activity of several transcription factors that influence the production of proteins involved in immune function, wound healing, and antioxidant defense.

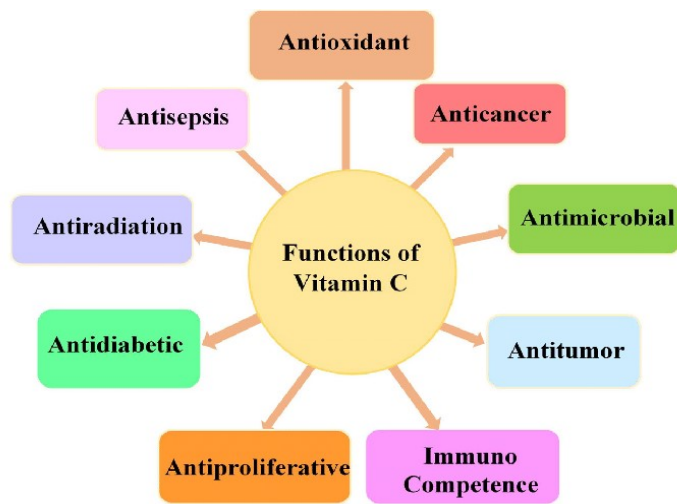


Figure 11 : Biochemical Function

- **DEFICIENCY**

Vitamin C deficiency can lead to **scurvy**, a disease characterized by various symptoms due to the vital role of Vitamin C in collagen synthesis and its antioxidant properties. When the body does not receive enough Vitamin C, it is unable to properly synthesize collagen, which is necessary for the health of skin, blood vessels, bones, and connective tissues.

- Symptoms of Scurvy:

Fatigue and Weakness: One of the early signs of Vitamin C deficiency is fatigue, which occurs due to weakened collagen structures, leading to poor tissue repair and compromised energy metabolism.

Bleeding Gums: The most characteristic symptom of scurvy is swollen, bleeding gums, as Vitamin C is crucial for the health of blood vessels and gums. Collagen deficiency weakens the gums, making them prone to infection and bleeding.

Joint Pain and Swelling: The inability to produce collagen also affects the joints, leading to pain, swelling, and discomfort. This can cause difficulty in movement and affect mobility.

Bruising: Due to weakened blood vessels, individuals with Vitamin C deficiency may bruise easily. Small capillaries in the skin become fragile and rupture easily, even with minimal pressure.

Anemia: Vitamin C is important for the absorption of non-heme iron from plant-based foods. A deficiency in Vitamin C can therefore contribute to **iron deficiency anemia**, which can lead to symptoms like weakness, paleness, and shortness of breath.

Dry and Scaly Skin: Collagen is a key structural component of the skin, and a lack of Vitamin C can result in rough, dry, and flaky skin. The skin may also become more susceptible to infections.

Wound Healing Problems: Since Vitamin C is essential for collagen formation, wound healing is delayed or impaired in individuals with a deficiency. Cuts and bruises may take longer to heal, and surgical wounds may show signs of poor recovery.

Depression and Irritability: Vitamin C is involved in the synthesis of neurotransmitters like dopamine. A deficiency can contribute to mood disturbances, such as irritability, depression, and apathy.

- **Severe Complications:**

If left untreated, scurvy can lead to more serious complications, including:

- **Internal Bleeding:** The blood vessels become so fragile that bleeding can occur in the internal organs.
- **Organ Dysfunction:** In severe cases, scurvy can affect the function of vital organs like the heart, kidneys, and liver.
- **Death:** In extreme cases, if not treated, scurvy can lead to death due to severe internal bleeding and infection.

- **Prevention and Treatment:**

Scurvy is rare in developed countries due to the availability of Vitamin C-rich foods, but it can still occur in individuals with limited access to fresh fruits and vegetables or those with certain medical conditions (such as malabsorption syndromes or poor dietary habits).

- **Dietary Sources:** To prevent Vitamin C deficiency, individuals should consume a diet rich in fruits and vegetables, especially **citrus fruits** (oranges, lemons), **kiwi**, **strawberries**, **broccoli**, **bell peppers**, and **tomatoes**.
- **Supplementation:** For those with insufficient dietary intake, Vitamin C supplements can help prevent or treat scurvy. Treatment typically involves oral supplementation of Vitamin C, which can rapidly improve symptoms within days.

In conclusion, Vitamin C deficiency leads to scurvy, a condition that affects collagen production, leading to a variety of symptoms, including bleeding gums, joint pain, bruising, and impaired wound healing. Early detection and treatment with Vitamin C can reverse these symptoms and prevent serious health complications.

Vitamin C toxicity is rare, as the body typically excretes excess amounts through urine due to its water-soluble nature. However, excessive intake of Vitamin C, usually through supplementation, can lead to **adverse effects**. The **tolerable upper intake level (UL)** for adults is set at **2,000 milligrams per day**, and consuming amounts significantly higher than this can cause **toxicity**.

- Symptoms of Vitamin C Toxicity:
 1. **Gastrointestinal Distress:** One of the most common side effects of high Vitamin C intake is gastrointestinal discomfort, which can include nausea, diarrhea, abdominal cramps, and bloating. This is due to the unabsorbed Vitamin C in the gastrointestinal tract.
 2. **Kidney Stones:** Excessive Vitamin C can be metabolized into **oxalate**, which can combine with calcium to form kidney stones. This risk is particularly high for individuals with a history of kidney stones or those who are prone to developing them.
 3. **Iron Overload:** Since Vitamin C enhances the absorption of **non-heme iron** (the type of iron found in plant-based foods), excessive intake of Vitamin C can lead to an overload of iron, especially in individuals with **hemochromatosis** (a genetic condition that causes iron accumulation).

4. **Hemolysis:** In some cases, excessive Vitamin C may contribute to the destruction of red blood cells, particularly in individuals with **G6PD deficiency**, leading to **hemolytic anemia**.
- **Other Effects:**
 - **Interference with Medical Tests:** High doses of Vitamin C may interfere with certain diagnostic tests, such as those measuring blood glucose levels, leading to inaccurate results.
 - **Potential for Disrupting Normal Metabolism:** Chronic excessive intake could disrupt normal metabolic pathways due to the body's inability to store Vitamin C and the potential for altering the balance of other essential nutrients.

Conclusion:

While Vitamin C is generally safe and beneficial in appropriate amounts, excessive intake can lead to toxicity, primarily causing gastrointestinal issues, kidney stones, and iron overload. It is essential to adhere to the recommended daily intake levels and avoid unnecessary supplementation unless prescribed by a healthcare professional.

Vitamin B1:

Vitamin B1, also known as **thiamine**, was the first vitamin to be discovered in the early 20th century. In 1897, **Christiaan Eijkman**, a Dutch physician and researcher, made the groundbreaking discovery that a diet deficient in a certain component of rice caused **beriberi**, a disease characterized by neurological and cardiovascular symptoms. This discovery led to the identification of thiamine as the essential nutrient preventing beriberi.

Thiamine was officially isolated in 1926 by **Robert R. Williams**, who later coined the term "vitamin B1." This marked a significant milestone in understanding the role of vitamins in human health. It was the first vitamin to be chemically synthesized in 1936, opening up the possibility of fortifying foods with thiamine to prevent deficiency diseases.

- **Chemistry of Vitamin B1:**

Thiamine is a water-soluble vitamin that consists of a **pyrimidine ring** and a **thiazole ring** connected by a methylene bridge. The active form of thiamine, **thiamine pyrophosphate (TPP)**, is formed by

the addition of two phosphate groups to the molecule. Thiamine is stable in acidic conditions but can be destroyed by prolonged exposure to alkaline environments, heat, or ultraviolet light.

The chemical structure of thiamine allows it to participate in various biochemical reactions as a coenzyme. The thiazole ring in the structure is critical for its function, as it allows thiamine to be involved in decarboxylation reactions.

Biochemical Functions of Vitamin B1:

Energy Metabolism: Thiamine, in its active form as **thiamine pyrophosphate (TPP)**, functions as a coenzyme for enzymes involved in carbohydrate metabolism. The key enzymes that require TPP are:

Pyruvate dehydrogenase: This enzyme plays a vital role in converting pyruvate (derived from glucose) into acetyl-CoA, which enters the citric acid cycle (Krebs cycle) for energy production.

Alpha-ketoglutarate dehydrogenase: It is involved in the citric acid cycle and aids in the conversion of alpha-ketoglutarate to succinyl-CoA.

Transketolase: This enzyme participates in the pentose phosphate pathway, which is essential for generating nucleotides and other molecules required for cell growth and repair.

Nervous System Function: Thiamine is critical for the proper function of the nervous system. TPP is involved in the synthesis of neurotransmitters and the maintenance of myelin sheaths that insulate nerve fibers. Thiamine deficiency can lead to neurological disorders, including **Wernicke-Korsakoff syndrome**, which is associated with chronic alcohol abuse and is characterized by memory loss, confusion, and motor difficulties.

Metabolism of Amino Acids and Lipids: In addition to carbohydrate metabolism, thiamine also plays a role in the metabolism of amino acids and lipids. It helps in the conversion of certain amino acids and lipids into energy, contributing to overall metabolic function.

Antioxidant Role: Thiamine has antioxidant properties and helps protect cells from oxidative stress by participating in redox reactions. This is particularly important in high-energy tissues like the brain and muscles, where metabolic activity is high.

Absorption of Vitamin B1:

Vitamin B1 is absorbed primarily in the **small intestine**, specifically in the **duodenum** and the **proximal jejunum**. The absorption process is facilitated by both **passive diffusion** and **active transport mechanisms**.

Active Transport: At low concentrations of thiamine, active transport mechanisms are employed. **Thiamine transporters (THTR-1 and THTR-2)** located in the intestinal epithelial cells facilitate the uptake of thiamine. This process requires energy and involves the transport of thiamine against a concentration gradient.

Passive Diffusion: At higher concentrations of thiamine, absorption occurs through passive diffusion, where thiamine moves from an area of higher concentration in the lumen of the intestine to the bloodstream.

Once absorbed, thiamine enters the bloodstream, where it is transported to various tissues for further utilization.

Transport of Vitamin B1:

After absorption, thiamine is transported through the **bloodstream** primarily in its **free (unphosphorylated)** form. However, in tissues, thiamine is mostly converted into its active form, **thiamine pyrophosphate (TPP)**, by the enzyme **thiamine pyrophosphokinase**.

Plasma Transport: In the blood, a small portion of thiamine is bound to **plasma proteins**, such as **albumin**, to ensure its stability during circulation. The majority of the thiamine is transported in its free form to various tissues, especially the liver, heart, kidneys, and muscles, where it is needed for energy production and other biochemical functions.

Uptake by Cells: The uptake of thiamine into cells is facilitated by thiamine transporters. Once inside the cells, thiamine is phosphorylated to form **thiamine pyrophosphate (TPP)**, which acts as a coenzyme for several key enzymes involved in carbohydrate metabolism and other metabolic pathways.

Intracellular Distribution: The liver plays a central role in maintaining thiamine homeostasis, distributing it to other tissues based on need. It can store small amounts of thiamine, particularly in the form of TPP, and releases it as required.

Storage of Vitamin B1:

Vitamin B1 is not stored in large quantities in the body, as it is a **water-soluble vitamin** and is readily excreted in urine when consumed in excess. The storage of thiamine is limited to the **liver, kidneys,** and **muscle tissues**, but in relatively small amounts.

1. **Liver:** The liver is the primary storage site for thiamine, where it is stored in its active form, **thiamine pyrophosphate (TPP)**. However, the body's storage capacity is limited, and there is only a small reservoir of thiamine available in the liver.
 2. **Muscle and Other Tissues:** While the liver is the major storage site, thiamine is also present in **muscles**, where it supports energy metabolism and is involved in the function of **pyruvate dehydrogenase** and other key enzymes.
 3. **Excretion:** Excess thiamine that is not utilized is excreted in the **urine**. The kidneys actively filter thiamine and reabsorb the majority of it to maintain plasma levels, with only small amounts lost in urine.
- Conclusion:

Vitamin B1 (thiamine) is absorbed in the small intestine through active and passive transport mechanisms. It is transported through the bloodstream in its free form and taken up by tissues, particularly the liver, where it is stored in small amounts. Thiamine is primarily used in its active form, thiamine pyrophosphate (TPP), to facilitate energy production and other biochemical processes. Due to its water-solubility, thiamine is not stored in large quantities and is excreted through urine when excess amounts are consumed. The body relies on a continuous supply of thiamine from the diet to support its essential functions.

Thiamine deficiency can lead to serious and sometimes fatal diseases like **beriberi** and **Wernicke-Korsakoff syndrome**. Both conditions primarily affect the **nervous** and **cardiovascular systems**. Beriberi presents as either a neurological or cardiovascular disease, while Wernicke-Korsakoff syndrome primarily impacts the brain and memory. Adequate dietary intake of thiamine is essential to prevent these conditions, and treatment typically involves thiamine supplementation, especially in individuals at high risk, such as those with poor diets or alcohol dependence.

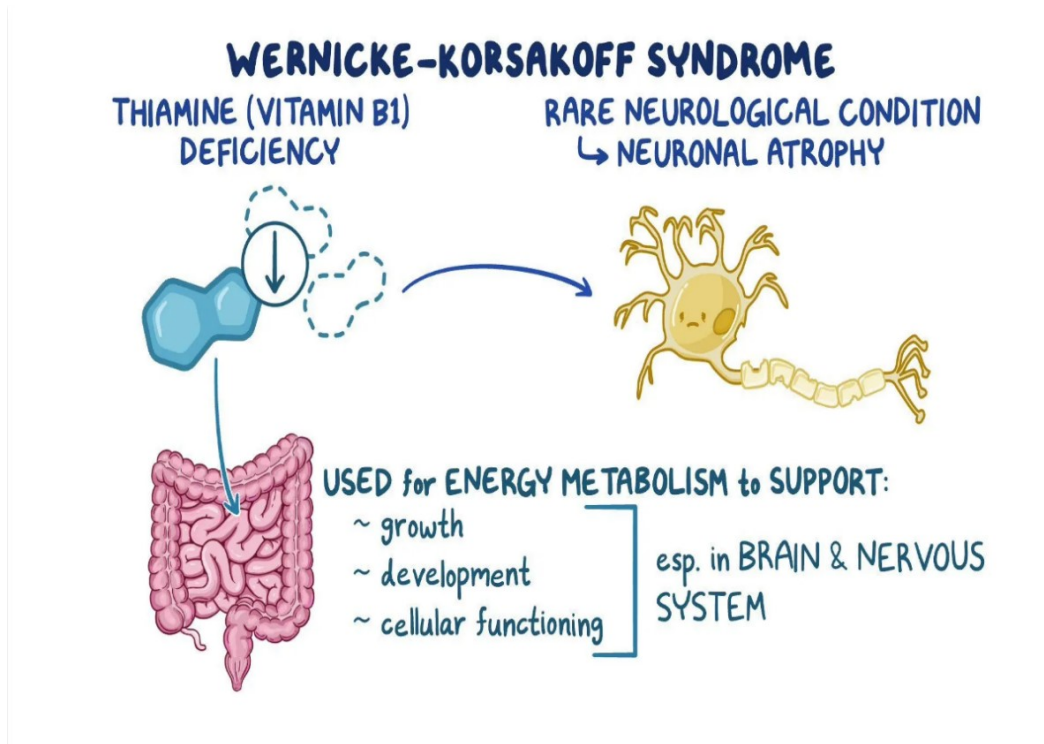


Figure 12 : Wernicke-Korsakoff syndrome

- **TOXICITY**

Vitamin B1 (thiamine) is a **water-soluble vitamin**, and the body does not store it in significant amounts. As a result, excess intake is typically excreted through urine, making the risk of **toxicity** from high thiamine consumption extremely rare. The body has mechanisms to regulate thiamine levels, and even at high doses, there is generally no toxicity.

However, **acute thiamine toxicity** is very unusual, and no established **tolerable upper intake level (UL)** has been set for thiamine. Most people can tolerate high doses of thiamine without adverse effects. In some cases, excessive intravenous or intramuscular injections of thiamine, especially in people with kidney problems or other health conditions, might cause side effects

Vitamin B2 (Riboflavin)

- History of Vitamin B2:

Vitamin B2, also known as **riboflavin**, was first identified in the early 20th century. The discovery of riboflavin followed the identification of other B vitamins and was essential for understanding the role of vitamins in human health.

- In **1920**, **Richard Kuhn**, a German chemist, isolated and identified riboflavin. His work was crucial in understanding the chemical structure of riboflavin and its role in human nutrition. Kuhn was later awarded the **Nobel Prize in Chemistry** in 1938 for his contributions to biochemistry, including his research on vitamins.
 - The term "riboflavin" is derived from **ribose** (a sugar) and **flavin** (referring to its yellow color, as riboflavin has a bright yellow hue). The discovery of riboflavin and its importance in preventing **aribo flavinosis**, a condition caused by riboflavin deficiency, helped highlight the essential role of vitamins in metabolic processes.
- Chemistry of Vitamin B2:

Riboflavin is a water-soluble vitamin that belongs to the **flavonoid group** of compounds. Its chemical structure includes a **flavin ring** (a type of heterocyclic aromatic ring structure) attached to a **ribose sugar** molecule.

- **Chemical structure:** Riboflavin consists of a **isoalloxazine ring** (a nitrogen-containing heterocyclic ring) and a **ribitol** (a type of sugar alcohol) side chain. The flavin ring is responsible for the vitamin's yellow color and is crucial for its function as an electron carrier in various biochemical reactions.
 - The active coenzyme forms of riboflavin are **flavin mononucleotide (FMN)** and **flavin adenine dinucleotide (FAD)**. These derivatives are formed by the attachment of a **phosphate group** (FMN) or an **adenosine monophosphate (AMP) group** (FAD) to the riboflavin molecule.
- Biochemical Functions of Vitamin B2:

Vitamin B2 plays a crucial role in **energy metabolism** and is essential for various enzymatic reactions in the body. As the coenzyme for several important enzymes, riboflavin is involved in a wide range of metabolic processes:

Energy Production:

FMN and **FAD** serve as **coenzymes** for enzymes involved in oxidation-reduction reactions. They are critical in the **electron transport chain**, a series of reactions that generate energy (ATP) in the mitochondria.

Riboflavin is involved in the metabolism of **carbohydrates**, **proteins**, and **fats**, helping to convert these macronutrients into energy. For example, **FAD** is a coenzyme for the enzyme **succinate dehydrogenase**, a key enzyme in the **citric acid cycle (Krebs cycle)**, which plays a vital role in cellular respiration and energy production.

Redox Reactions: Riboflavin derivatives (FMN and FAD) are essential for **redox reactions** (reduction-oxidation reactions) in the body, which involve the transfer of electrons. These reactions are fundamental to many cellular processes, including the breakdown of fatty acids, the conversion of amino acids, and the production of ATP.

Metabolism of Amino Acids: Riboflavin is involved in the **metabolism of amino acids** and helps in the synthesis and breakdown of **amino acid derivatives**, including neurotransmitters such as **dopamine**.

Antioxidant Role: Riboflavin has an indirect role in protecting cells from oxidative stress. It helps regenerate **glutathione**, a potent antioxidant, by aiding in the conversion of **glutathione reductase** from its oxidized to reduced form. This helps prevent damage to cells and tissues caused by free radicals.

Synthesis of Other Vitamins: Riboflavin is involved in the **activation** of other vitamins, particularly **vitamin B6 (pyridoxine)** and **folic acid**. Riboflavin helps convert **pyridoxine** into its active form, **pyridoxal phosphate**, which is necessary for protein metabolism and the synthesis of neurotransmitters.

Skin, Eyes, and Mucous Membranes: Riboflavin is essential for the **maintenance of healthy skin, eyes, and mucous membranes**. It is involved in the formation of **collagen**, which is essential for skin and connective tissue structure. Additionally, riboflavin plays a role in the **formation of visual pigments** in the retina, essential for proper vision.

- Conclusion:

Vitamin B2 (riboflavin) is a water-soluble vitamin that plays an essential role in energy production, redox reactions, amino acid metabolism, and maintaining healthy skin and eyes. Its active forms, **FMN** and **FAD**, serve as coenzymes in key biochemical reactions, including the citric acid cycle and electron transport chain, which are crucial for cellular respiration and energy generation. Riboflavin also supports the function of other vitamins, such as vitamin B6 and folate, and contributes to the antioxidant defense system. Deficiency in riboflavin can lead to symptoms such as skin disorders, eye problems, and anemia, highlighting its vital role in human health.

- Vitamin B2 (Riboflavin) Deficiency Diseases

Deficiency in **Vitamin B2** (riboflavin) can lead to a variety of health issues, most notably affecting the skin, eyes, and mucous membranes. The disease associated with riboflavin deficiency is called **ariboflavinosis**. This condition is often characterized by several distinct symptoms and can become severe if left untreated.

The symptoms of riboflavin deficiency are often grouped by the areas of the body most affected:

- **Skin problems:** One of the hallmark signs of riboflavin deficiency is the development of **dermatitis**, which manifests as **red, inflamed skin**. The areas most commonly affected are those exposed to sunlight, such as the face, neck, and hands. The skin may become cracked, dry, and irritated, particularly in the **nasolabial folds** (the lines from the nose to the corners of the mouth) and the **scrotum** (in men).
- **Eye problems:** Riboflavin deficiency can lead to **photophobia** (sensitivity to light), **conjunctivitis** (inflammation of the outer layer of the eye), and **corneal vascularization** (growth of blood vessels in the cornea). In severe cases, it can contribute to **cataracts** and damage to the cornea, impairing vision.
- **Mucosal issues:** A deficiency in riboflavin can cause inflammation and sores on the mucous membranes, especially in the **mouth** and **tongue**. The tongue may become smooth, swollen, and sore, a condition known as **glossitis**. **Cheilosis**, or cracking at the corners of the mouth (angular cheilitis), is another common symptom.

- **Nervous system effects:** Although not as common, riboflavin deficiency may also cause **neurological symptoms**, such as **numbness**, **tingling** in the hands and feet, and **muscle weakness**. This occurs because riboflavin plays a role in maintaining healthy nerves.

Symptoms of Vitamin B2 Deficiency

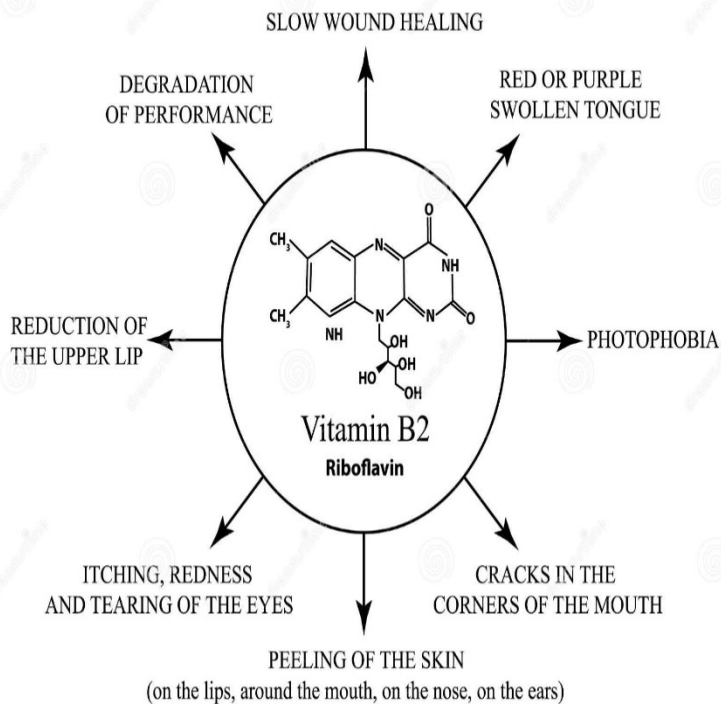


Figure 13 : Symptoms of deficiency

Specific Symptoms of Riboflavin Deficiency:

Cracked lips (cheilosis) and cracks at the corners of the mouth

Glossitis (swollen, smooth, and inflamed tongue)

Seborrheic dermatitis (skin rash with scaling and redness, often on the face, nose, and ears)

Photophobia (light sensitivity)

Eye problems (including conjunctivitis and corneal damage)

Fatigue and weakness

Anemia due to impaired iron metabolism

Sore throat and **difficulty swallowing** due to inflammation of the mucous membranes

- Vitamin B3 (Niacin) - History, Chemistry, and Biochemical Function
 - History of Vitamin B3:

Vitamin B3, also known as **niacin**, was discovered in the early 20th century. It was recognized for its role in preventing **pellagra**, a disease caused by niacin deficiency. Pellagra was a significant health issue, especially in populations with diets primarily based on **corn** (maize), which is low in niacin and its precursor **tryptophan**.

- **1873**: The first clinical descriptions of **pellagra** were made by Spanish physician **Gaspar Casal**, who documented symptoms including diarrhea, dermatitis, and dementia. However, the nutritional deficiency leading to these symptoms was not understood at that time.
- **1913**: The connection between niacin and **pellagra** was first recognized by **Goldberger**, an American physician, who proved that the disease could be prevented and treated by supplementing the diet with niacin or tryptophan.
- **1937**: The chemical structure of niacin was identified, and its essential role in human nutrition became clearer. Researchers established that niacin is synthesized in the body from the amino acid **tryptophan**.
- **1940s**: Niacin was further studied for its **biochemical role**, leading to the discovery that it functions as a **precursor for coenzymes** involved in metabolism, namely **NAD⁺** (Nicotinamide adenine dinucleotide) and **NADP⁺** (Nicotinamide adenine dinucleotide phosphate).
- Chemistry of Vitamin B3:

Niacin is a **water-soluble vitamin** with two main forms:

1. **Nicotinic acid** (also known as **niacin**)
2. **Nicotinamide** (also called **niacinamide**)

Both forms of niacin can be converted into the biologically active coenzymes, **NAD⁺** and **NADP⁺**, which are involved in critical metabolic pathways.

- **Chemical structure:** Niacin is a **pyridine derivative**, consisting of a **pyridine ring** (a six-membered aromatic ring with a nitrogen atom) attached to a **carboxyl group** (-COOH) in nicotinic acid, or to an **amide group** (-CONH₂) in nicotinamide. Both compounds are converted into their coenzyme forms, **NAD⁺** and **NADP⁺**, in the body.
 - **Coenzyme forms:** Niacin functions primarily as a precursor for **NAD⁺** and **NADP⁺**, which are involved in oxidation-reduction (redox) reactions. **NAD⁺** is crucial for energy metabolism, while **NADP⁺** plays a role in **biosynthetic reactions**, such as lipid and nucleic acid synthesis.
- Biochemical Functions of Vitamin B3:

Vitamin B3 plays an essential role in various biochemical functions within the body, primarily due to its involvement in **redox reactions** as part of the **NAD⁺/NADH** and **NADP⁺/NADPH** coenzymes. These coenzymes are involved in a wide variety of metabolic processes.

Energy Metabolism:

NAD⁺ is crucial for **glycolysis**, the **citric acid cycle**, and **oxidative phosphorylation**, all of which are key pathways in **cellular respiration**. **NAD⁺** acts as an electron carrier, accepting electrons during metabolic reactions and passing them to the electron transport chain for ATP (energy) production.

NAD⁺ is also involved in the **beta-oxidation** of fatty acids and the **catabolism** of carbohydrates and proteins.

DNA Repair and Synthesis:

NAD⁺ is essential for maintaining the **integrity of DNA** by participating in the **repair of DNA**. It is used by enzymes known as **poly(ADP-ribose) polymerases (PARPs)**, which help repair damaged DNA and are involved in cell signaling.

NAD⁺ also plays a role in the **synthesis of nucleotides**, which are the building blocks of DNA and RNA.

Antioxidant Defense:

NADPH, derived from **NADP⁺**, is used in **reducing oxidative stress** by donating electrons to **antioxidant enzymes** such as **glutathione reductase**. This helps protect cells from damage caused by free radicals and reactive oxygen species (ROS).

NADPH is also important in the **synthesis of fatty acids, cholesterol, and steroid hormones**.

Cellular Signaling:

NAD⁺ plays a role in regulating **cellular signaling pathways**. It activates enzymes such as **sirtuins**, which are involved in regulating **gene expression, cell survival, and aging**. Sirtuins help regulate **metabolism, stress responses, and the cell cycle**.

Metabolism of Lipids, Carbohydrates, and Proteins:

NAD⁺ and **NADP⁺** are involved in **lipid metabolism**, including the breakdown of fatty acids and the **synthesis of triglycerides** and phospholipids.

Niacin also plays a role in **protein metabolism**, including the conversion of **amino acids** and the production of **glutamine**.

Neurotransmitter Synthesis:

NAD⁺ is required for the synthesis of neurotransmitters such as **dopamine** and **serotonin**, which are critical for **mood regulation and cognitive function**.

○ Conclusion:

Vitamin B3 (niacin) is a water-soluble vitamin that plays a crucial role in energy production, DNA repair, antioxidant defense, and cellular signaling. Its active coenzymes, **NAD⁺** and **NADP⁺**, are involved in numerous biochemical processes, including glycolysis, fatty acid oxidation, and DNA repair. Niacin is essential for maintaining cellular metabolism and protecting cells from oxidative damage. Deficiency in niacin can lead to **pellagra**, a condition characterized by **dermatitis, diarrhea, and dementia**. Additionally, niacin plays a key role in preventing metabolic disorders and supporting cognitive function and overall cellular health.

Vitamin B3 (Niacin) Deficiency Disease

The primary disease associated with **Vitamin B3 (niacin)** deficiency is **pellagra**, which is characterized by the **3 D's: Dermatitis, Diarrhea, and Dementia**. Pellagra occurs when there is an insufficient intake of niacin or its precursor **tryptophan** (an amino acid), which can be converted into niacin in the body.

- Symptoms of Pellagra:

Dermatitis:

One of the first symptoms of niacin deficiency is **dermatitis**, which typically appears as a **symmetric rash**. This rash is most commonly found on sun-exposed areas of the body, such as the face, neck, hands, and feet. The skin may become red, inflamed, and cracked, with a characteristic "**Casal's necklace**" pattern (a necklace-like rash around the neck).

The affected skin may also become thickened, rough, and pigmented over time, resembling a condition called **hyperkeratosis**.

Diarrhea:

Niacin deficiency can also lead to gastrointestinal disturbances, including **diarrhea**. The lining of the digestive tract becomes inflamed, which may result in **bloody stools** or **abdominal pain**. Diarrhea can lead to dehydration and further nutritional imbalances if left untreated.

Dementia:

Cognitive decline, confusion, **delirium**, and **psychosis** are neurological symptoms associated with severe niacin deficiency. This phase of pellagra can lead to **dementia**, characterized by memory loss, difficulty concentrating, and disorientation. In extreme cases, untreated deficiency can cause **hallucinations** and **permanent mental impairment**.

Other Symptoms:

Glossitis: Inflammation of the tongue, making it swollen, red, and painful.

Stomatitis: Inflammation of the mouth and lips, often leading to **cheilosis** (cracks at the corners of the mouth).

Fatigue and **weakness** due to impaired cellular energy metabolism.

- Risk Factors for Niacin Deficiency:

Certain groups of people are more susceptible to niacin deficiency:

- **Alcoholics:** Chronic alcohol consumption interferes with niacin absorption and the conversion of tryptophan into niacin.
- **Individuals with poor dietary intake:** Diets based primarily on **corn** or **maize** (which contains very little niacin or tryptophan) are particularly prone to niacin deficiency.
- **Malabsorption disorders:** Conditions like **Crohn's disease**, **Celiac disease**, or **short bowel syndrome** can impair nutrient absorption, including niacin.
- **People with high metabolic demands:** Pregnant or breastfeeding women, as well as those undergoing **extreme physical stress**, may need increased amounts of niacin.

- Treatment of Pellagra:

Pellagra can be treated effectively with niacin supplementation or increased dietary intake of niacin-rich foods such as meat, poultry, fish, legumes, and enriched grains. Early diagnosis and treatment are crucial to preventing long-term neurological damage or death. If left untreated, **pellagra** can be fatal due to severe complications affecting organ systems such as the heart and liver.

- Conclusion:

Niacin deficiency, manifested as **pellagra**, can have severe health consequences if not addressed. It primarily affects the skin, gastrointestinal tract, and nervous system, leading to dermatitis, diarrhea, and dementia. Ensuring adequate intake of niacin and its precursor, tryptophan, through a balanced diet is essential in preventing this deficiency. With proper treatment, individuals can recover fully from pellagra, but if left untreated, it can lead to long-term complications and even death.

Absorption of Vitamin B3:

Vitamin B3, in the form of **nicotinic acid** or **nicotinamide**, is absorbed in the small intestine.

Passive Transport: The absorption of niacin occurs through **passive diffusion**. Both **nicotinic acid** and **nicotinamide** are readily absorbed from the gastrointestinal tract, particularly in the **jejunum** and **ileum**.

Efficiency of Absorption: The absorption efficiency is high, with approximately **60-80%** of the niacin ingested being absorbed under normal conditions. Absorption can be affected by various factors such as the presence of other nutrients and gastrointestinal health.

Dietary Sources: Niacin is found in foods as either the **preformed vitamin** (nicotinic acid or nicotinamide) or as **tryptophan**, which can be converted to niacin in the body. Tryptophan conversion to niacin occurs through the **kynurenine pathway**, but only about 60 mg of tryptophan is required to make 1 mg of niacin.

Transport of Vitamin B3:

After absorption, niacin is transported in the bloodstream to various tissues:

In the Bloodstream: Vitamin B3, primarily in the form of **nicotinamide**, enters the bloodstream and is transported to the liver and other tissues. In the blood, niacin is typically bound to **albumin**, a plasma protein, which helps in its transport.

Transport to the Liver: Once in the liver, nicotinic acid and nicotinamide are further metabolized to their active forms, **NAD⁺** (nicotinamide adenine dinucleotide) and **NADP⁺** (nicotinamide adenine dinucleotide phosphate), which are essential coenzymes in many metabolic reactions.

Cellular Uptake: Niacin is taken up by various tissues via **SLC22A** transporters, specifically the **organic cation transporter (OCT)**, which facilitates the entry of niacin into cells where it is converted into its active coenzyme forms (NAD⁺ and NADP⁺).

- Storage of Vitamin B3:

Unlike fat-soluble vitamins, **niacin is water-soluble**, and therefore, it is not stored in significant amounts in the body.

Minimal Storage: There is no extensive **storage pool** for niacin. Instead, it is rapidly utilized or excreted in the urine. The body maintains niacin in a continuous cycle of synthesis and breakdown. The primary storage form of niacin in the body is as **NAD⁺** and **NADP⁺**, the active coenzyme forms involved in various metabolic processes.

Excretion: Excess niacin that is not immediately needed by the body is converted into metabolites such as **niacinamide** or **N-methylniacinamide** and excreted through the urine. Therefore, maintaining a consistent intake of niacin is important to ensure that the body has enough of the vitamin for its metabolic needs.

Regulation: The liver plays a key role in regulating niacin levels in the body. If there is insufficient dietary intake of niacin, the liver can increase the conversion of **tryptophan** into niacin, ensuring that the body has enough of the vitamin to maintain essential biochemical functions. However, the efficiency of this conversion can be affected by other factors, such as **tryptophan availability**, **B6 status**, and the **overall protein intake** in the diet.

- Conclusion:

Vitamin B3 (niacin) is absorbed efficiently from the gastrointestinal tract and is transported throughout the body via the bloodstream, primarily in its form of **nicotinamide**. The body does not store niacin to any significant extent but maintains adequate levels by continuously converting it into its active coenzymes, **NAD⁺** and **NADP⁺**, which are critical for various metabolic functions. Excess niacin is excreted in the urine, highlighting the importance of regular intake of niacin to meet the body's ongoing metabolic needs.

- Deficiency of Vitamin B3 (Niacin)

A deficiency in **Vitamin B3 (niacin)** can lead to a condition known as **pellagra**, which is characterized by the classic symptoms of the **3 D's**: **dermatitis**, **diarrhea**, and **dementia**. Pellagra primarily arises due to inadequate dietary intake of niacin or its precursor **tryptophan**, an amino acid that the body can convert into niacin.

- Causes of Niacin Deficiency:

Inadequate Dietary Intake: Diets that are primarily composed of **corn** or **maize**, which are low in niacin and tryptophan, can lead to niacin deficiency. Niacin in corn is poorly bioavailable, and if not properly processed (such as by **lime treatment**), it cannot be adequately absorbed.

Malabsorption Disorders: Conditions that impair nutrient absorption in the intestines, such as **Celiac disease**, **Crohn's disease**, or **short bowel syndrome**, can reduce the absorption of niacin and its precursors.

Alcoholism: Chronic alcohol consumption is a significant risk factor for niacin deficiency because it impairs both the absorption and the conversion of tryptophan to niacin. Additionally, alcohol-related liver damage can hinder niacin metabolism.

Increased Metabolic Demands: Conditions that increase the body's need for niacin, such as **pregnancy**, **lactation**, or **fever**, can lead to deficiency if the increased requirements are not met through diet.

Genetic Factors: Some genetic disorders affect the metabolism of tryptophan into niacin, leading to a deficiency even with adequate dietary intake.

- Symptoms of Niacin Deficiency (Pellagra):

Dermatitis:

Skin lesions are often the first signs of niacin deficiency. The dermatitis usually appears in sun-exposed areas of the skin, such as the face, neck, hands, and feet. The rash typically presents as **rough, red, and inflamed** patches of skin that may become thickened or hyperpigmented. A hallmark of the rash is its symmetry.

This condition is also known as **Casal's necklace**, which describes a necklace-like rash around the neck.

Diarrhea:

Diarrhea occurs due to the inflammation of the gastrointestinal tract. It can range from mild to severe, with symptoms such as **abdominal pain**, **nausea**, and **bloody stools**. Chronic diarrhea can lead to dehydration, malnutrition, and further depletion of essential nutrients.

Dementia:

The nervous system is severely affected by niacin deficiency, resulting in symptoms such as **mental confusion, memory loss, delirium, and hallucinations**. In severe cases, untreated niacin deficiency can lead to irreversible **neurological damage**, manifesting as **dementia** or permanent cognitive impairment.

Other Symptoms:

Glossitis: Inflammation of the tongue, which may appear red and swollen.

Stomatitis: Inflammation of the mouth and lips, often presenting as cracks in the corners of the mouth (cheilosis).

Fatigue and general **weakness** due to impaired energy production in the body.

Depression and irritability, as niacin plays a role in neurotransmitter synthesis.

○ Risk Groups for Niacin Deficiency:

Certain populations are more vulnerable to niacin deficiency:

- **Alcoholics:** Chronic alcohol consumption impairs both the absorption and the metabolic conversion of tryptophan to niacin.
- **Poor Diets:** Diets lacking in niacin-rich foods (such as meat, fish, and fortified cereals) or tryptophan-rich foods can contribute to deficiency.
- **Malnourished Individuals:** Particularly those with **protein deficiencies** or conditions like **anorexia nervosa**.
- **Individuals with Malabsorption Syndromes:** Conditions such as **Celiac disease, Crohn's disease, or inflammatory bowel disease** hinder nutrient absorption.
- **People with High Metabolic Stress:** Pregnant women, those under physical stress, or those with fever may require more niacin than they consume, making them susceptible to deficiency.

○ Treatment of Niacin Deficiency:

The treatment of niacin deficiency typically involves **niacin supplementation** (nicotinic acid or nicotinamide) and **dietary improvements**. Foods rich in niacin, such as **meat, poultry, fish, whole**

grains, and **fortified cereals**, should be incorporated into the diet. In severe cases, intravenous niacin may be necessary. If treated early, niacin deficiency is reversible, and the symptoms of pellagra, including dermatitis, diarrhea, and dementia, can significantly improve.

- Conclusion:

Niacin deficiency, leading to **pellagra**, is a serious condition with a range of symptoms affecting the skin, digestive system, and nervous system. Ensuring adequate dietary intake of niacin or tryptophan is key in preventing deficiency. If left untreated, niacin deficiency can lead to severe health complications, but with appropriate supplementation and dietary adjustments, recovery is possible.

Pyridoxine (Vitamin B6) - History, Chemistry, and Biochemical Function

- History of Pyridoxine (Vitamin B6):

The history of pyridoxine, commonly known as **Vitamin B6**, is rooted in research related to various metabolic disorders and deficiencies. The discovery of Vitamin B6 as a vital nutrient occurred over several decades:

1900s – Early Research: In the early 20th century, scientists observed that certain diseases such as **peripheral neuropathy** (nerve damage) and **dermatitis** could be prevented or treated by diet, but the exact nutritional factor responsible was unclear. It was also noted that these conditions were often associated with **inadequate protein intake**.

1934 – Discovery: In 1934, **Paul György**, a Hungarian biochemist, identified Vitamin B6 and its importance in preventing **dermatitis** and other related diseases. He initially isolated the compound and named it "**antidermatitis factor**."

1938 – Isolation of Pyridoxine: The compound **pyridoxine**, one of the forms of Vitamin B6, was isolated by **A. J. Smith** and **E. A. L. McCollum**. This led to the eventual understanding that Vitamin B6 encompassed several related compounds, including pyridoxine, **pyridoxal**, and **pyridoxamine**, all of which contribute to its biological activity.

1940s – Recognition as Vitamin B6: In the 1940s, it was established that Vitamin B6 was essential for various enzymatic processes, and it was officially classified as **Vitamin B6**.

- **Chemistry of Pyridoxine (Vitamin B6):**

Pyridoxine is part of the Vitamin B complex and exists in several chemical forms, all of which are collectively referred to as **Vitamin B6**:

Pyridoxine (PN): The alcohol form of Vitamin B6, which is found in plant sources. It is the precursor of the active coenzyme form of Vitamin B6, **pyridoxal phosphate (PLP)**.

Pyridoxal (PL): The aldehyde form, which is found in animal sources and is also a direct precursor of the active coenzyme form, **pyridoxal phosphate**.

Pyridoxamine (PM): The amine form, which also serves as a precursor to the active coenzyme.

Pyridoxal Phosphate (PLP): The active coenzyme form of Vitamin B6, responsible for its biochemical activities. It is essential for a variety of enzymatic reactions, particularly in amino acid metabolism.

The structure of pyridoxine includes a **pyridine ring** attached to a **hydroxymethyl group**. This structure is common to all forms of Vitamin B6. Pyridoxal phosphate, the active form, has a **phosphate group** attached to the hydroxymethyl side chain, enabling it to participate in enzymatic reactions.

- **Biochemical Function of Pyridoxine (Vitamin B6):**

Pyridoxine (as pyridoxal phosphate, PLP) plays a crucial role in numerous biochemical functions, primarily related to **amino acid metabolism** and **neurotransmitter synthesis**. Some of the key functions include:

Amino Acid Metabolism:

Vitamin B6 is involved in **transamination**, a process where amino acids are transferred from one molecule to another. This is crucial for the synthesis of non-essential amino acids and the metabolism of **glutamate**, a key neurotransmitter.

It also participates in **decarboxylation reactions**, essential for producing **neurotransmitters** such as **serotonin**, **dopamine**, and **gamma-aminobutyric acid (GABA)**, all of which play roles in mood regulation, nerve function, and brain activity.

Synthesis of Hemoglobin:

Vitamin B6 is involved in **heme synthesis**, a crucial component of hemoglobin, the molecule responsible for transporting oxygen in the blood. A deficiency in Vitamin B6 can lead to **microcytic anemia**, a type of anemia characterized by small red blood cells.

Synthesis of Neurotransmitters:

Pyridoxine is vital for the production of several key neurotransmitters, including:

Serotonin (from tryptophan)

Dopamine (from tyrosine)

GABA (from glutamate)

These neurotransmitters are important for mood regulation, behavior, and nerve function.

Cognitive Function:

Due to its role in neurotransmitter synthesis, Vitamin B6 is also important for cognitive functions such as memory, learning, and concentration. It helps regulate brain function, and a deficiency may contribute to symptoms of **depression**, **confusion**, and **irritability**.

Immune System Function:

Vitamin B6 supports the production of **interleukin-2**, a protein that helps in immune response. It is essential for maintaining a healthy immune system, and deficiency can impair immune function.

Glycogen Metabolism:

Vitamin B6, in the form of PLP, is required for the breakdown of **glycogen** into glucose, providing energy during periods of physical activity or fasting.

○ Conclusion:

Pyridoxine (Vitamin B6) is an essential nutrient involved in a wide variety of physiological processes. From amino acid metabolism to the synthesis of neurotransmitters and heme, Vitamin B6 plays a fundamental role in maintaining cellular function, brain health, and overall metabolic processes. Its deficiency can lead to various symptoms, including irritability, depression, anemia, and peripheral neuropathy, underscoring its importance in daily nutrition.

Absorption of Vitamin B6:

Vitamin B6, primarily in the form of **pyridoxine** (PN), is absorbed in the small intestine. The process occurs in the following steps:

Absorption in the Small Intestine:

Vitamin B6 is absorbed mainly in the **jejunum** and **ileum** (the middle and lower parts of the small intestine).

It enters the enterocytes (intestinal cells) via **passive diffusion** and **active transport**, especially when intake is low.

Conversion to Active Forms:

Once inside the enterocyte, pyridoxine (the inactive form of Vitamin B6) is converted into its active coenzyme form, **pyridoxal phosphate (PLP)**, by the action of specific enzymes.

Pyridoxamine (PM) and pyridoxal (PL), other forms of Vitamin B6, are also converted into PLP in the liver and tissues.

Efficient Absorption:

The absorption of Vitamin B6 can be affected by various factors, such as the amount of Vitamin B6 present in the diet and the efficiency of the **sodium-dependent active transport mechanisms**.

Transport of Vitamin B6:

After absorption, Vitamin B6 is transported through the bloodstream and distributed to tissues and organs in the following ways:

Binding to Plasma Proteins:

In the blood, **pyridoxal phosphate (PLP)** is primarily transported bound to **albumin**, a plasma protein. Only a small amount of Vitamin B6 is found in its free form.

Delivery to Tissues:

Vitamin B6 is delivered to tissues where it is required for various biochemical functions, particularly the liver, muscles, and brain.

In the liver, PLP is stored or further processed to meet the body's needs.

Conversion in Target Tissues:

In target tissues, pyridoxine and other forms of Vitamin B6 are converted to **pyridoxal phosphate (PLP)**, the active coenzyme form of the vitamin, which is critical for enzyme catalysis in amino acid metabolism, neurotransmitter synthesis, and other vital processes.

Storage of Vitamin B6:

Vitamin B6 is primarily stored in the **liver** but is also found in smaller amounts in other tissues such as the **muscles**. The storage and distribution of Vitamin B6 are as follows:

Liver Storage:

The liver is the main storage organ for Vitamin B6, holding around **70-80%** of the body's total stores in the form of pyridoxal phosphate (PLP).

The liver can convert excess pyridoxine (PN) into its active form, PLP, and release it into the bloodstream as needed to maintain appropriate levels in tissues.

Muscle Storage:

Muscle tissues also store a small amount of Vitamin B6 in the form of pyridoxal phosphate (PLP). However, muscle storage is much less significant than that in the liver.

Limited Storage:

Vitamin B6 is not stored in large amounts compared to some other vitamins, so it must be regularly replenished through dietary intake. **Deficiency** can develop within **2-3 months** of inadequate intake, as stores in the liver are depleted relatively quickly.

Excretion:

Vitamin B6, especially in its active form (PLP), is excreted in the **urine**. Excess amounts that are not utilized by the body are filtered by the kidneys and excreted as **pyridoxic acid**, the primary metabolite of Vitamin B6 in urine.

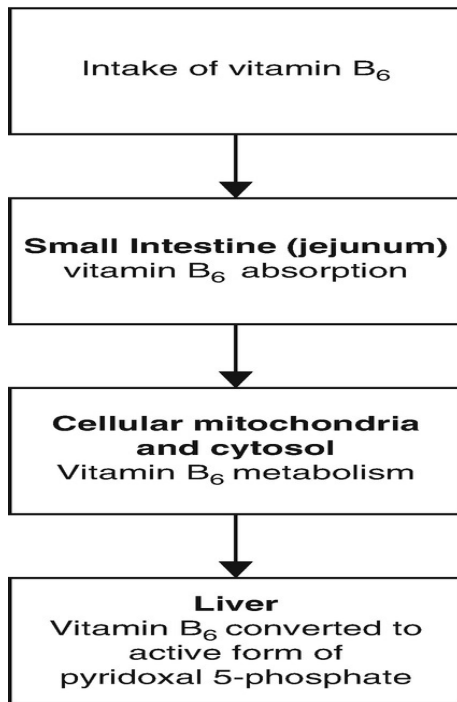


Figure 14 : Absorption, Transport, and Storage of Vitamin B6 (Pyridoxine)

Reference: Springer

- Conclusion:

Vitamin B6 is absorbed through the small intestine, primarily in its inactive form (pyridoxine), which is converted to its active form, pyridoxal phosphate (PLP). It is transported in the bloodstream bound to albumin and delivered to various tissues, especially the liver, where it is stored. The liver plays a central role in maintaining Vitamin B6 levels, converting excess pyridoxine into the active form and ensuring its availability for critical metabolic functions.

- Deficiency Diseases of Vitamin B6 (Pyridoxine)

Vitamin B6 deficiency can result in a variety of health issues, as this vitamin plays a critical role in amino acid metabolism, neurotransmitter synthesis, immune function, and many other biochemical processes. The symptoms of Vitamin B6 deficiency can affect the skin, nerves, blood, and overall metabolism. The deficiency diseases and associated symptoms include:

Pyridoxine Deficiency Symptoms:

Peripheral Neuropathy: A common symptom of Vitamin B6 deficiency is **peripheral neuropathy**, which manifests as **tingling**, **numbness**, and sometimes **pain** in the extremities (hands and feet). This occurs due to the impaired functioning of **nerve cells** and **neurotransmitter imbalance**.

Dermatitis: A deficiency of Vitamin B6 can cause **seborrheic dermatitis**, which results in red, inflamed, scaly skin, especially around the eyes, mouth, and nose. It may also lead to **cheilosis** (cracking at the corners of the mouth) and **stomatitis** (inflammation inside the mouth).

Microcytic Anemia: Vitamin B6 is involved in the production of **hemoglobin**; hence, a deficiency can cause **microcytic hypochromic anemia**, where red blood cells are smaller than normal and have reduced hemoglobin content.

Depression and Irritability: Due to its role in neurotransmitter synthesis (including serotonin and dopamine), a lack of Vitamin B6 can contribute to **mood disorders** such as **depression**, irritability, and even confusion.

Impaired Cognitive Function: Chronic deficiency may lead to issues with **memory**, concentration, and learning, due to its involvement in brain functions and neurotransmitter production.

Convulsions: In severe cases of deficiency, especially in infants, **seizures** or **convulsions** may occur due to the role of Vitamin B6 in stabilizing neuronal activity and supporting GABA production.

Weakened Immune System: Vitamin B6 is essential for the proper functioning of the immune system. A deficiency can result in **weakened immune responses**, leading to increased susceptibility to infections.

Glossitis: Inflammation of the tongue (glossitis) can occur, causing the tongue to become sore, swollen, and red.

Sideroblastic Anemia:

This is a specific type of anemia associated with Vitamin B6 deficiency. It is characterized by the presence of **sideroblasts** (abnormal red blood cell precursors) in the bone marrow. This form of anemia is often unresponsive to iron supplementation but can be corrected with Vitamin B6.

Carpal Tunnel Syndrome:

Although not a classical deficiency disease, some studies suggest that **Vitamin B6 deficiency** may contribute to **carpal tunnel syndrome**, a condition that causes **pain, numbness, and tingling** in the hands due to compression of the median nerve.

Deficiency in Infants:

In infants, Vitamin B6 deficiency can lead to severe conditions such as **seizures** and **irritability**. These symptoms are particularly common in babies who are fed **inadequate formula** or have impaired absorption of the vitamin.

Risk Factors for Deficiency:

Individuals at risk for Vitamin B6 deficiency include:

Alcoholics, who often have poor dietary intake and impaired absorption.

Elderly individuals, who may have reduced absorption efficiency.

Individuals with malabsorption disorders like **celiac disease** or **Crohn's disease**.

Pregnant or breastfeeding women, who may require increased amounts of Vitamin B6.

People with kidney diseases who undergo **dialysis** may lose Vitamin B6 in the process.

○ Conclusion:

Vitamin B6 deficiency can lead to a wide range of symptoms, including **neurological, dermatological, hematological, and cognitive** issues. Ensuring adequate intake of this essential vitamin through diet or supplementation is vital for maintaining metabolic functions, nerve health, and overall well-being.

Biotin: History, Chemistry, and Biochemical Function

- History of Biotin:

Biotin, also known as Vitamin H or B7, was discovered in the 1930s. The name "biotin" is derived from the Greek word "bios," meaning "life," due to its essential role in various metabolic processes.

1. Early Discovery (1930s):

- Biotin was first isolated in 1931 by two researchers, **Paul Gyorgy** and **Vera K. Kitt**, who studied a substance that was essential for preventing **dermatitis** in chickens.
- In 1936, **Gyorgy** showed that biotin could cure the condition of **egg-white injury** (biotin deficiency caused by prolonged consumption of raw egg whites) in rats.

2. Identification as Vitamin B7:

- Biotin was identified as part of the **B-complex vitamins** and was later officially named **Vitamin B7**. Over the years, it has gained attention due to its role in maintaining skin, hair, and overall metabolic health.

- Chemistry of Biotin:

Biotin is a water-soluble B-vitamin with a complex chemical structure. It is a **heterocyclic compound** composed of a **thiophene ring** fused to an **imidazolidine ring**. The structure includes several functional groups that make it capable of binding to enzymes and playing a critical role in **carboxylation reactions**.

Chemical Structure:

The **biotin molecule** consists of a **cyclohexene ring** and a **valeric acid side chain** (C₅H₉NO₂S).

The structure of biotin includes a **ureido ring** (a sulfur-containing heterocyclic ring) attached to the bicyclic structure, which helps biotin bind to the active site of enzymes involved in various biochemical pathways.

Forms of Biotin:

Free Biotin: This is the form of biotin that is absorbed in the body and is found in foods and supplements.

Biotinylated Proteins: In the body, biotin is primarily found attached to proteins, forming **biotinylated enzymes**, such as **acetyl-CoA carboxylase** and **pyruvate carboxylase**, which are involved in important metabolic processes.

- **Biochemical Function of Biotin:**

Biotin plays a vital role in various metabolic functions, particularly in **carboxylation reactions**, where it serves as a coenzyme for certain **carboxylase enzymes**. These enzymes are essential for **fatty acid synthesis**, **gluconeogenesis**, and **amino acid metabolism**. Biotin's role in **gene expression** and **DNA repair** has also been recognized in recent years.

Carboxylation Reactions:

Biotin acts as a **coenzyme** for enzymes known as **carboxylases**, which catalyze the transfer of a carboxyl group (CO₂) to substrates. These enzymes include:

Acetyl-CoA carboxylase: Involved in **fatty acid biosynthesis**.

Pyruvate carboxylase: Involved in **gluconeogenesis** (the production of glucose from non-carbohydrate precursors).

Propionyl-CoA carboxylase: Involved in the breakdown of **propionyl-CoA** into **succinyl-CoA** for energy production.

Methylcrotonyl-CoA carboxylase: Important in **amino acid metabolism**, specifically for the breakdown of leucine.

Fatty Acid Synthesis:

Biotin is crucial for the **synthesis of fatty acids**. As a coenzyme for acetyl-CoA carboxylase, biotin facilitates the conversion of **acetyl-CoA** to **malonyl-CoA**, a key step in fatty acid synthesis.

Gluconeogenesis:

Biotin helps in the production of glucose from non-carbohydrate sources. As a coenzyme for pyruvate carboxylase, it helps convert **pyruvate** into **oxaloacetate**, which can then be used in the synthesis of glucose.

Amino Acid Metabolism:

Biotin participates in the metabolism of amino acids such as **leucine**, which is involved in protein synthesis and energy production. Biotinylated enzymes assist in breaking down specific amino acids for energy.

Gene Expression and DNA Repair:

Biotin is involved in the regulation of **gene expression** by modifying histones (proteins around which DNA is wrapped), which can impact **DNA replication** and **repair**.

Biotin also plays a role in **cell division**, and its deficiency has been linked to **impaired cell growth** and **increased risk of certain genetic disorders**.

Health Functions Beyond Metabolism:

Biotin is essential for the health of **skin, hair, and nails**. It is often associated with **hair growth** and the prevention of **brittle nails**. Biotin deficiency can lead to **dermatitis, alopecia**, and other skin conditions.

○ Conclusion:

Biotin, or Vitamin B7, is a crucial B-vitamin with important roles in **metabolism, cellular health, gene expression, and enzyme regulation**. Its primary biochemical functions revolve around serving as a coenzyme in **carboxylation reactions**, supporting fatty acid synthesis, gluconeogenesis, and amino acid metabolism. Given its widespread impact on metabolic pathways and cell growth, biotin is vital for maintaining health, particularly for the **nervous system, skin, and hair**.

○ Absorption:

Biotin is primarily absorbed in the **small intestine**, particularly in the **duodenum** and **jejunum**. The absorption process occurs in both its **free** and **protein-bound** forms, although the absorption of biotin bound to protein requires an additional step.

Free Biotin:

Free biotin from food sources is absorbed via **sodium-dependent carrier-mediated transporters**, specifically the **SMVT (Sodium-Dependent Multivitamin Transporter)**. This transporter facilitates the entry of biotin into the enterocyte (intestinal cell) lining.

Protein-Bound Biotin:

A significant portion of biotin in food is bound to proteins, such as in egg whites, liver, and certain vegetables. In the gastrointestinal tract, **biotinidase enzymes** in the stomach and small intestine hydrolyze these biotin-protein complexes, releasing free biotin, which is then absorbed by enterocytes via SMVT transporters.

Efficiency:

The absorption of biotin from the diet is typically **efficient**, with studies suggesting that around **80% of dietary biotin** is absorbed in healthy individuals.

- Transport:

Once biotin is absorbed, it enters the bloodstream and is transported to various tissues in the body. This transport occurs via specific **plasma proteins**.

Plasma Transport:

Biotin is carried in the blood in its free form and is also bound to **biotin-binding proteins**, such as **albumin** and **biotinidase**. The plasma transport ensures biotin is delivered to tissues where it is needed for enzyme function, particularly for **carboxylase enzymes** involved in metabolic pathways.

Cellular Uptake:

Biotin enters cells through **biotin transporters**, which are also **Sodium-Dependent Multivitamin Transporters (SMVT)**, similar to the transport mechanisms in the intestines. These transporters are expressed on the cell membranes of many tissues, including those in the liver, kidney, and brain.

- Storage:

Biotin is **not stored in large quantities** within the body, as it is water-soluble. However, some biotin is stored in **liver tissue**, where it is primarily used to support metabolic processes.

Liver Storage:

The **liver** serves as a central hub for biotin, although only small amounts are stored there. The body's ability to store biotin is limited, and any excess biotin is typically excreted in the urine.

Excretion:

Biotin is excreted from the body primarily through the **urine** in its free form, which is why biotin deficiencies can develop if dietary intake is insufficient over time.

○ **Conclusion:**

Biotin is efficiently absorbed in the small intestine through **SMVT transporters**, whether free or protein-bound. Once in the bloodstream, biotin is transported to tissues where it is used in essential biochemical processes. The body has limited biotin storage, primarily in the **liver**, and any excess is excreted in the urine. This necessitates regular dietary intake to meet the body's needs, as biotin is essential for numerous metabolic pathways.

○ **Biotin Deficiency Disease**

Biotin deficiency, though rare, can lead to a range of symptoms due to its critical role in metabolic processes, especially those involving energy production and cellular function. The deficiency can result from inadequate dietary intake, impaired absorption, or disorders that affect biotin metabolism.

○ **Causes of Biotin Deficiency:**

Inadequate Dietary Intake:

Biotin deficiency is uncommon in healthy individuals because biotin is widely available in food sources such as eggs, liver, nuts, seeds, and certain vegetables. However, people with a poor or unbalanced diet may be at risk.

Impaired Biotin Absorption:

Conditions such as **inflammatory bowel disease (IBD)**, **malabsorption syndromes**, or **chronic alcohol consumption** can impair biotin absorption in the intestines.

Biotinidase Deficiency:

A genetic disorder known as **biotinidase deficiency** can prevent the body from recycling biotin. This results in **inadequate availability** of biotin in the body, even if it is present in the diet.

Consumption of Raw Egg Whites:

Eating large amounts of **raw egg whites** over a prolonged period can lead to biotin deficiency. **Avidin**, a protein in egg whites, binds to biotin and prevents its absorption. Cooking egg whites destroys avidin, so this issue is generally avoided if egg whites are cooked.

Prolonged Use of Certain Medications:

Medications like **anticonvulsants** and certain antibiotics can interfere with biotin metabolism, leading to a deficiency over time.

○ Symptoms of Biotin Deficiency:

Biotin deficiency can manifest through various physical, neurological, and dermatological symptoms due to its role in metabolic functions and cellular health.

Dermatological Symptoms:

Alopecia (hair loss) is one of the most common and early signs of biotin deficiency.

Seborrheic dermatitis, characterized by scaly, red patches on the skin, is another key symptom.

Rashes and **eczema** on the face, neck, and scalp can occur.

Neurological Symptoms:

Biotin deficiency can lead to **neurological symptoms** such as **depression**, **lethargy**, **confusion**, and **hallucinations**.

It may also cause **muscle pain, weakness**, and in severe cases, **seizures**.

Metabolic Symptoms:

Biotin is essential for various metabolic pathways, so deficiency can lead to disruptions in energy production. Symptoms include **fatigue, anorexia**, and **nausea**.

Developmental Issues in Infants:

In infants, biotin deficiency can result in **developmental delays, growth retardation**, and **irritability**.

Congenital Biotinidase Deficiency:

This genetic condition leads to a **severe form of biotin deficiency** in infants, presenting with neurological and dermatological symptoms shortly after birth. If untreated, it can lead to **severe developmental delays** and **neurological damage**.

○ Conclusion:

Biotin deficiency is rare but can have significant health impacts, primarily affecting skin, hair, and neurological function. It is typically caused by inadequate dietary intake, impaired absorption, or genetic disorders such as biotinidase deficiency. The symptoms range from skin rashes and hair loss to neurological issues like depression and confusion. Early diagnosis and treatment with biotin supplementation can effectively resolve most symptoms.

Vitamin B12

History of Vitamin B12:

Vitamin B12, also known as **cobalamin**, was discovered in the early 20th century, after scientists identified its essential role in the treatment of pernicious anemia.

Discovery:

In **1926**, **George Richards Minot** and **William Murphy** discovered that a substance found in liver could cure **pernicious anemia**, a condition characterized by a deficiency of red blood cells due to impaired absorption of vitamin B12. Their work led to the identification of the factor responsible, which was later named vitamin B12.

Isolation:

In **1948**, **Carl and Herbert A. A. Johnson** successfully isolated vitamin B12 from liver, paving the way for the development of vitamin B12 supplementation.

Structural Elucidation:

The structure of vitamin B12 was determined in **1956** by **R. B. Woodward** and his team, which was a groundbreaking achievement in biochemistry. The structure includes a **corrin ring**, a complex molecular arrangement that distinguishes it from other vitamins.

Nobel Prize:

The discovery of the structure and function of vitamin B12 earned **Dorothy Crowfoot Hodgkin** the **Nobel Prize in Chemistry in 1964** for her work in X-ray crystallography that helped clarify the structure of B12.

○ Chemistry of Vitamin B12:

Vitamin B12 is a water-soluble vitamin that is structurally unique due to its **cobalt atom** at the center of a **corrin ring** structure, which is similar to a porphyrin ring but with slight differences.

Structure:

The core of vitamin B12 consists of a **corrin ring**, which contains a **cobalt ion** coordinated to a **dimethylbenzimidazole** group. This structure is unique because it forms a highly stable and functional complex.

The vitamin's bioactive form contains a **cyano** (cyanide) group or, in the body, can be converted into **methyl** or **adenosyl** groups (the two most common active forms of vitamin B12 in the body).

Types of Vitamin B12:

There are several forms of vitamin B12, but the two primary active forms are:

Methylcobalamin: Involved in **methylation reactions** (important for DNA synthesis and amino acid metabolism).

Adenosylcobalamin: Involved in the **conversion of methylmalonyl-CoA** to succinyl-CoA during the citric acid cycle (important for energy metabolism).

Stability:

Vitamin B12 is sensitive to **light** and **oxygen**, but it is stable under normal conditions if stored properly.

Biochemical Function of Vitamin B12:

Vitamin B12 plays several crucial roles in cellular metabolism, particularly in **DNA synthesis**, **red blood cell formation**, and **nerve function**.

Coenzyme in Metabolic Pathways:

Vitamin B12 is required as a coenzyme for two key enzymatic reactions:

Methionine Synthase: Converts **homocysteine** to **methionine**, a process critical for **protein synthesis**, **DNA methylation**, and the production of **S-adenosylmethionine (SAM)**, which is vital for various biochemical processes including gene expression regulation.

Methylmalonyl-CoA Mutase: Catalyzes the conversion of **methylmalonyl-CoA** to **succinyl-CoA**, which is an essential step in the **citric acid cycle** (Krebs cycle), involved in energy production in the body.

Nerve Health:

Vitamin B12 is essential for the **synthesis of myelin**, the protective sheath around nerves. Deficiency can lead to **neurological damage**, including symptoms like **numbness, tingling**, and **memory loss**.

Red Blood Cell Formation:

Vitamin B12 is essential for **proper red blood cell formation**. It aids in the **synthesis of DNA** during the production of red blood cells in the bone marrow. A deficiency in vitamin B12 can lead to **megaloblastic anemia**, where the red blood cells are larger than normal and less effective in oxygen transport.

Homocysteine Metabolism:

Vitamin B12 works in conjunction with **folate (vitamin B9)** to reduce levels of **homocysteine** in the body. Elevated homocysteine is a risk factor for cardiovascular diseases, as it can damage blood vessel walls and contribute to clot formation.

Conclusion:

Vitamin B12 is an essential nutrient with a unique structure centered around a cobalt ion. Discovered in the early 20th century, its importance for **red blood cell production, DNA synthesis**, and **nervous system function** is well-established. The active forms, **methylcobalamin** and **adenosylcobalamin**, participate in critical enzymatic reactions. Deficiency of vitamin B12 can lead to serious health issues, including **anemia, neurological disorders**, and **elevated homocysteine levels**.

Absorption of Vitamin B12:

The absorption of vitamin B12 is a complex, multi-step process that primarily occurs in the **small intestine** and involves several key proteins and receptors.

Gastric Phase:

Dietary vitamin B12 in food is typically bound to **proteins**, and it first needs to be released in the **stomach** by the action of **gastric acid** and **pepsin**.

After being freed, vitamin B12 binds to a protein called **haptocorrin** (also known as **R-protein**) in the stomach to protect it from digestive enzymes.

Small Intestinal Phase:

Once the vitamin B12 reaches the **duodenum**, **pancreatic enzymes** break down the haptocorrin, allowing vitamin B12 to bind to another protein called **intrinsic factor (IF)**, which is produced by the parietal cells of the stomach.

The vitamin B12-IF complex is essential for the subsequent absorption in the **ileum** of the small intestine. Specific receptors, such as **cubam**, are located on the surface of enterocytes (intestinal cells) in the ileum, where the complex binds, allowing the absorption of vitamin B12 into the bloodstream.

Transport of Vitamin B12:

Once absorbed, vitamin B12 enters the bloodstream and is transported to various tissues and organs.

Binding to Transcobalamin II:

In the bloodstream, vitamin B12 is bound to a transport protein called **transcobalamin II (TCII)**. This complex facilitates the transport of vitamin B12 across cell membranes to tissues that require it.

Tissue Distribution:

The **liver** is the main organ that stores vitamin B12 and releases it into the bloodstream as needed. Vitamin B12 is also transported to other tissues, including the **bone marrow** (for red blood cell production) and the **brain and nervous system** (for myelin synthesis and nerve function).

Storage of Vitamin B12:

Vitamin B12 is stored primarily in the **liver** and to a lesser extent in other tissues such as the **kidneys** and **muscles**.

Liver Storage:

The liver holds significant reserves of vitamin B12, which can last for **several years** in healthy individuals. This storage allows the body to maintain vitamin B12 levels even during periods of inadequate intake.

Mobilization of Vitamin B12:

The liver releases vitamin B12 into the bloodstream in response to the body's needs. The vitamin B12 bound to **transcobalamin II** is then delivered to tissues where it is utilized in various metabolic processes.

Excretion of Vitamin B12:

Vitamin B12 is **not excreted** to a large extent in the urine or feces. However, small amounts of vitamin B12 are excreted, particularly when **vitamin B12 is in excess** or when the body has adequate reserves.

Biliary Excretion:

A small amount of vitamin B12 is excreted via the **bile** into the intestines. In the intestines, vitamin B12 can be reabsorbed in a process known as the **enterohepatic circulation**, where it is recycled and returned to the bloodstream.

Urinary Excretion:

Minimal amounts of vitamin B12 can also be excreted in the urine. However, since the body stores significant reserves of vitamin B12, urinary excretion typically remains low unless there is an excess or an underlying health condition.

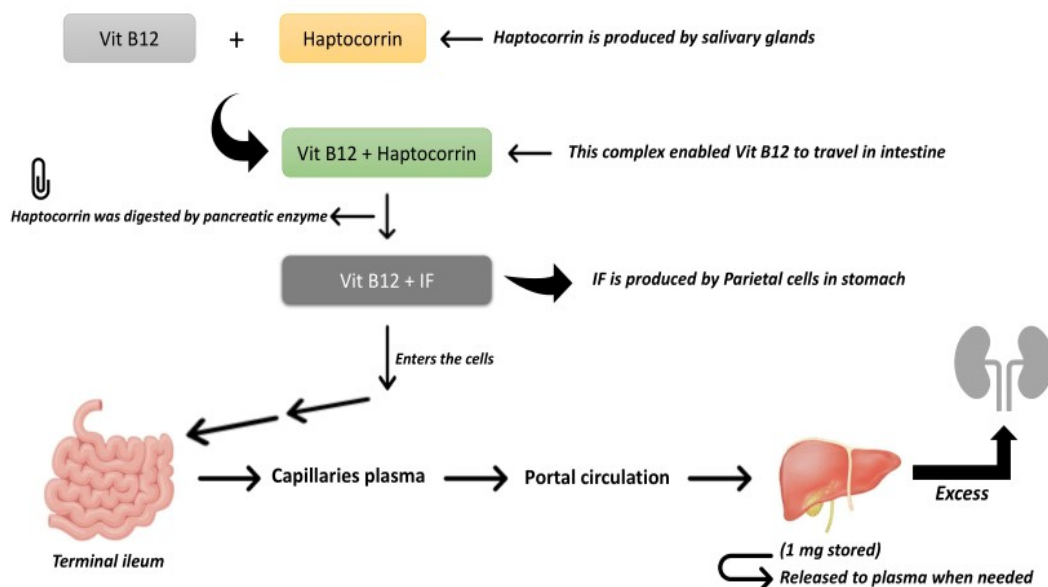


Figure 15 : Absorption transport and storage of vitamin b12

Reference: ResearchGate

○ Conclusion:

The absorption of vitamin B12 is a multi-step process involving the release of vitamin B12 from food proteins, binding to intrinsic factor, and absorption in the ileum. Once absorbed, it is transported through the bloodstream bound to transcobalamin II, with major storage in the liver. Vitamin B12 is excreted in small amounts via bile and urine, but due to its extensive storage capacity, the body can maintain adequate levels over time. This intricate system ensures that vitamin B12 is efficiently absorbed, stored, and utilized for essential physiological functions.

○ Deficiency Disease of Vitamin B12

Vitamin B12 deficiency can lead to a variety of serious health conditions due to its critical roles in **red blood cell production, nervous system function, and DNA synthesis**. The most common deficiency diseases associated with a lack of vitamin B12 are **pernicious anemia, megaloblastic anemia, and neurological disorders**. Below are the key deficiency diseases and symptoms:

Pernicious Anemia:

Cause: Pernicious anemia is an autoimmune condition that leads to **vitamin B12 deficiency** due to the inability to produce **intrinsic factor (IF)**. Without intrinsic factor, vitamin B12 cannot be absorbed in the ileum of the small intestine, leading to low vitamin B12 levels.

Symptoms:

Fatigue

Weakness

Pale skin

Sore tongue

Shortness of breath

Heart palpitations

Cognitive impairments (memory loss, confusion)

Pathophysiology: The lack of vitamin B12 impairs red blood cell production, resulting in large, immature red blood cells (megaloblasts). This can lead to anemia and reduced oxygen delivery throughout the body.

Megaloblastic Anemia:

Cause: A vitamin B12 deficiency leads to impaired **DNA synthesis** during the maturation of red blood cells in the bone marrow. This results in the formation of abnormally large and immature red blood cells called **megaloblasts**.

Symptoms:

Fatigue

Weakness

Pale skin

Shortness of breath

Lightheadedness

Pathophysiology: The inability to produce mature red blood cells leads to anemia, which is characterized by a reduced number of functioning red blood cells and impaired oxygen delivery.

Neurological Disorders:

Cause: A deficiency in vitamin B12 affects the **myelin sheath** of nerves, leading to neurological symptoms.

Symptoms:

Tingling and numbness (usually in the hands and feet)

Weakness

Balance problems

Cognitive decline (memory loss, confusion, difficulty concentrating)

Depression

Psychiatric disturbances (paranoia, hallucinations)

Pathophysiology: Vitamin B12 is essential for the maintenance of **myelin** (the protective coating around nerves). A deficiency impairs the formation of myelin, leading to nerve damage and neurological symptoms. This can cause irreversible damage if not treated.

Homocysteine Elevation and Cardiovascular Risk:

Cause: Vitamin B12 is involved in the metabolism of **homocysteine**. A deficiency leads to elevated levels of homocysteine, which is associated with an increased risk of cardiovascular diseases.

Symptoms: While elevated homocysteine itself may not cause immediate symptoms, it increases the risk for:

Heart disease

Stroke

Blood clot formation

Pathophysiology: Elevated homocysteine can damage the walls of blood vessels, leading to atherosclerosis (hardening of the arteries), which increases the risk of cardiovascular events.

Glossitis and Mouth Ulcers:

Cause: A deficiency of vitamin B12 can lead to inflammation of the **tongue** (glossitis) and the formation of mouth ulcers.

Symptoms:

Sore, swollen, and red tongue

Mouth sores and ulcers

Pathophysiology: Vitamin B12 plays a role in cell regeneration and mucosal integrity. Its deficiency can lead to impaired tissue repair, causing oral mucosal lesions.

Cognitive Impairment and Psychiatric Symptoms:

Cause: A prolonged deficiency of vitamin B12 may affect **brain function** and lead to cognitive decline and psychiatric disturbances.

Symptoms:

- **Memory loss**
- **Difficulty concentrating**
- **Confusion**
- **Depression**
- **Delirium and hallucinations** in severe cases
- **Pathophysiology:** Deficiency of vitamin B12 affects the production of key neurotransmitters and the health of brain cells. This can lead to cognitive and psychiatric issues, especially in the elderly.
- **Risk Factors for Vitamin B12 Deficiency:**
 - **Age:** Older adults are at higher risk due to reduced stomach acid and the ability to absorb B12.
 - **Diet:** **Vegetarians** and **vegans** are at risk because vitamin B12 is primarily found in animal products.

- **Gastrointestinal Issues:** Conditions like **Crohn's disease**, **celiac disease**, or **gastric bypass surgery** can impair vitamin B12 absorption.
- **Medications:** Long-term use of certain medications like **proton pump inhibitors (PPIs)** or **metformin** can reduce vitamin B12 absorption.
- **Autoimmune conditions:** Individuals with conditions like **pernicious anemia** or **autoimmune gastritis** are at higher risk.

CHECK YOUR PROGRESS

Exercise 2

1. Give symptoms of Pyridoxine deficiency disease.

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2. Write the function of Vitamin C.

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3. Write few sources of riboflavin and discuss its role in energy metabolism.

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4. What do you understand by term of beri beri

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ANSWER TO CHECK YOUR PROGRESS

EXERCISE 1

1. Fat-soluble vitamins (A, D, E, and K) are absorbed in the small intestine with dietary fats. Bile salts emulsify dietary fats, forming micelles that transport vitamins to the intestinal lining. Here, they are absorbed into enterocytes, packaged into chylomicrons, and transported via the lymphatic system to the bloodstream. Proper absorption requires adequate fat intake and functioning bile and pancreatic enzymes.

2 Classification of Xerophthalmia and their prominent signs and symptoms

1. **Night Blindness:** Poor vision in low light due to impaired rhodopsin production.
2. **Conjunctival Xerosis:** Dry, dull conjunctiva from reduced tear production.
3. **Bitot's Spots:** Foamy, white spots on the conjunctiva caused by keratin accumulation.
4. **Corneal Xerosis:** Hazy, rough cornea due to severe dryness.
5. **Corneal Ulceration/Keratomalacia:** Ulcers or softening of the cornea, risking perforation.
6. **Corneal Scarring/Blindness:** Permanent damage leading to vision loss.

3. Vitamin D regulates calcium and phosphorus levels by enhancing their absorption in the intestines, promoting reabsorption in the kidneys, and mobilizing calcium from bones when blood levels are low. It helps maintain optimal mineral levels for bone strength and other physiological functions.

4. Vitamin E deficiency can cause:

- **Neuromuscular Issues:** Muscle weakness, ataxia, and loss of reflexes due to oxidative damage to nerves.
- **Hemolytic Anemia:** Fragile red blood cells due to oxidative damage to membranes.
- **Retinopathy:** Vision problems from retinal cell damage.
- **Impaired Immunity:** Reduced ability to fight infections.

EXERCISE 2

1. Symptoms of Pyridoxine (Vitamin B6) Deficiency Disease

- Irritability, depression, and confusion.
- Peripheral neuropathy (tingling or numbness in extremities).
- Seborrheic dermatitis (scaly skin rash).
- Glossitis (swollen, inflamed tongue).
- Microcytic anemia (small red blood cells).

2. Function of Vitamin C

- Acts as an antioxidant, protecting cells from damage.
- Promotes collagen synthesis for healthy skin, bones, and connective tissue.
- Enhances iron absorption from plant-based foods.
- Supports immune function and wound healing.
- Helps regenerate other antioxidants, like vitamin E.

3. Sources-Milk, eggs, almonds, spinach, and fortified cereals.

Role: Riboflavin (Vitamin B2) plays a critical role in energy metabolism by serving as a precursor for two essential coenzymes: flavin mononucleotide (FMN) and flavin adenine dinucleotide (FAD). These coenzymes are vital for various biochemical reactions involved in energy production. FAD and FMN are involved in the citric acid cycle (Krebs cycle) and the electron transport chain, both

of which are crucial processes for generating ATP, the body's primary energy source. Riboflavin also aids in the metabolism of carbohydrates, fats, and proteins by facilitating the enzymatic reactions that break down these macronutrients into usable energy.

4. **Beriberi** is a disease caused by a deficiency of **thiamine** (Vitamin B1), which is essential for carbohydrate metabolism and energy production. Thiamine is a coenzyme that helps convert carbohydrates into glucose, which the body uses for energy.

There are two main types of beriberi: **Wet Beriberi**: and Dry Beri Beri

LET US SUM UP

The chapter on vitamins highlights their crucial role in maintaining health, classifying them into **fat-soluble** (A, D, E, K) and **water-soluble** (B-complex and C) groups. Vitamins are essential nutrients that regulate various physiological processes, including metabolism, immunity, and tissue repair. **Vitamin A** is vital for vision, immune function, and skin health. Its deficiency leads to xerophthalmia and night blindness, while excess can cause toxicity. **Vitamin D** is key to calcium and phosphorus homeostasis, supporting bone health and preventing rickets or osteomalacia. Its synthesis depends on sunlight, making deficiency common in low-sunlight regions. **Vitamin E** acts as an antioxidant, protecting cells from oxidative stress and supporting skin and nerve health. Deficiency results in neuromuscular disorders and weakened immunity. **Vitamin K** is essential for blood clotting and bone metabolism.

Water-soluble vitamins, like B-complex, support energy metabolism and nerve function, while vitamin C boosts immunity and acts as an antioxidant. Their deficiency leads to diseases such as scurvy (vitamin C) and beriberi (vitamin B1). Overall, the chapter emphasizes balanced nutrition to prevent deficiencies or toxicities and highlights how vitamins interact with body systems to sustain life and health.

GLOSSARY

1. **Antioxidant:** A substance that prevents or slows damage caused by free radicals in the body.
2. **Beriberi:** A disease caused by a deficiency of vitamin B1 (thiamine), leading to neurological and cardiovascular symptoms.
3. **Fat-Soluble Vitamins:** Vitamins (A, D, E, K) that dissolve in fats and oils and are stored in the liver and fatty tissues.
4. **Free Radicals:** Unstable molecules that can damage cells, leading to oxidative stress.
5. **Homeostasis:** The body's ability to maintain a stable internal environment, such as calcium and phosphorus balance regulated by vitamin D.
6. **Lipid Peroxidation:** A process where free radicals damage cell membranes by targeting lipids.
7. **Micelles:** Tiny fat molecules formed in the intestines that aid in the absorption of fat-soluble vitamins.
8. **Nyctalopia:** Night blindness caused by vitamin A deficiency.
9. **Rickets:** A bone disease in children caused by vitamin D deficiency, leading to soft, weak bones.
10. **Scurvy:** A disease caused by vitamin C deficiency, characterized by bleeding gums and poor wound healing.
11. **Water-Soluble Vitamins:** Vitamins (B-complex and C) that dissolve in water, are not stored in the body, and require regular replenishment through diet

STRUCTURE

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8.1 INTRODUCTION

When we think about food and nutrition, concentrate on the vital elements that are required for human development and well-being, such as proteins, lipids, carbs, and vitamins and minerals. However, there's an interesting aspect of food that often goes unnoticed: **non-nutritive food components**. These are the compounds found in food that do not directly provide calories or essential nutrients but may still have significant health benefits or effects. They play critical roles in maintaining overall health, preventing disease, and enhancing bodily functions. Non-nutritive food components include a wide range of substances like **phytochemicals, polyphenols, flavonoids, terpenes, fiber, and antioxidants**, among others. Unlike vitamins and minerals, these components don't provide the body with energy or nutritional value in the traditional sense. Instead, they play other vital roles in the body, especially when it comes to **preventing disease, promoting general health**, and enhancing **well-being**. They are frequently present in whole grains, herbs, fruits, vegetables, and other plant-based diets.

Among the most known groups of non-nutritive food components are **antioxidants**. These compounds, such as **vitamin C, vitamin E**, and various polyphenols found in foods like berries, nuts, and green tea, protect our cells from the oxidative harm that free radicals produce. While, phytochemicals are naturally occurring chemicals found in plants that have beneficial effects on human health. For example, **carotenoids, flavanoids**. Later, in this unit we will discuss different class of Non-nutritive food components, its source, importance and biosynthetic pathway in detail. Generally, the health benefits of non-nutritive food components often come from their ability to interact with **biological pathways** in the body. Incorporating a range of plant-based foods that are high in antioxidants, fibre, polyphenols, and other bioactive compounds is the greatest method to include non-nutritive components in your diet. As a result so, you can lower your risk of developing chronic diseases and enhance your quality of life. Ultimately, these non-nutritive substances work synergistically with other nutrients to create a well-balanced and health-promoting diet.

Expected Outcomes:

Here the students will be able to:

- Describe the concept of different types of **Non-Nutritive Food Components**
- Explain health Benefits of Non-Nutritive Food Components
- Describe nutritional role in regulation in gene expression

8.2 HEALTH BENEFITS OF NON-NUTRITIVE FOOD COMPONENTS

While, they do not provide essential calories or nutrients like protein, fats, or vitamins, they are far from being insignificant as they play critical roles in maintaining overall health, preventing disease, and enhancing bodily functions.

Non-nutritive food components are beneficial for several reasons, primarily due to their ability to enhance health and prevent disease without directly providing energy or essential nutrients like vitamins, minerals, or proteins. These components, though not essential for basic survival, offer a variety of health-promoting effects that contribute significantly to long-term well-being. Here's why non-nutritive food components are beneficial:

1. Antioxidant Properties: Many non-nutritive components, such as polyphenols, flavonoids, and vitamin E, act as antioxidants in the body. Antioxidants work by neutralizing free radicals, donating an electron without becoming unstable themselves, thereby stopping the chain reaction of oxidative damage. Antioxidants aid in preventing damage to cells, tissues, and organs by neutralising these dangerous chemicals, which promotes healthier ageing and lowers the risk of chronic illnesses.

2. Anti-Inflammatory Effects: Numerous illnesses, including as diabetes, cancer, heart disease, and arthritis, are significantly influenced by inflammation. It has been demonstrated that non-nutritive elements including terpenes, polyphenols, and certain phytochemicals included in foods like berries, garlic, and turmeric might lessen inflammation in the body. Eating foods with anti-inflammatory qualities can help control and avoid chronic inflammation, which is a major cause of disease.

3. Heart Health: The health of the heart can be significantly impacted by non-nutritive food ingredients. Examples of foods that include flavonoids include dark chocolate, apples, and citrus fruits.

These foods can help lower blood pressure, increase blood circulation, and lower the risk of atherosclerosis, or the hardening of the arteries. In addition, elements like fibre from whole grains and legumes and omega-3 fatty acids from seeds and nuts provide blood sugar regulation and cholesterol reduction, all of which are essential for preventing heart disease.

4. Cancer Prevention: Some non-nutritive ingredients have been connected to preventing cancer, including sulforaphane (found in cruciferous foods like broccoli) and lignans (found in flaxseeds). These drugs can lower the risk of cancer by regulating cell growth, assisting in the detoxification of toxic substances, and shielding cells from DNA damage. Antioxidants also aid in the defence against free radicals, which can result in cellular alterations that give rise to cancer.

5. Gut Health and Digestion: A healthy digestive tract depends on non-nutritive elements like fibre, which is present in fruits, vegetables, and whole grains. By providing food for good bacteria, fibre helps maintain a healthy gut microbiota, encourages regular bowel movements, and avoids constipation. In turn, a healthy gut microbiota promotes immune system performance and may lower the risk of gastrointestinal disorders like inflammatory bowel disease (IBD) and irritable bowel syndrome (IBS).

6. Weight Management: Numerous non-nutritive factors aid in weight control. Fibre, for instance, promotes satiety, which makes you feel fuller for longer and less likely to overeat. Similar to this, substances like capsaicin found in chilli peppers have been demonstrated to boost metabolism and encourage fat burning, both of which can aid in weight loss. These elements support the maintenance of a healthy weight by controlling metabolism and appetite.

7. Brain Health: Some non-nutritive components, particularly polyphenols found in foods like berries, tea, and dark chocolate, are beneficial for brain health. These compounds have been shown to improve cognitive function, protect against neurodegenerative diseases like Alzheimer's, and support memory and learning abilities. Additionally, some non-nutritive compounds have neuroprotective effects, reducing the risk of inflammation and oxidative damage in the brain.

8. Immune System Support: Vitamin D and flavonoids are examples of non-nutritive substances that can strengthen the immune system's capacity to fight off infections and diseases by modifying it. Also regarded as non-nutritive elements, probiotics and prebiotics support a healthy gut microbiota, which

is intimately related to immunological function. The body needs a balanced immune system to fend off infections and avoid autoimmune reactions or excessive inflammation.

9. Detoxification: Some non-nutritive ingredients aid in the body's detoxification by encouraging the removal of toxic chemicals. For instance, cruciferous vegetables include sulforaphane, which has been demonstrated to increase the activity of liver detoxification enzymes, assisting the body's capacity to neutralise and get rid of toxins. This aids in defence against toxins, pollutants, and other dangerous materials.

10. Support for Mental Health: Some non-nutritive ingredients, including those in dark chocolate, turmeric, and omega-3 fatty acids (found in nuts and seeds), may have antidepressant and mood-enhancing properties, according to new research. These substances may boost brain function, lessen stress and anxiety, and elevate mood, all of which could improve mental health in general.

8.3 CLASSIFICATION OF NON-NUTRITIVE FOOD COMPONENTS

Compounds found in non-nutritive dietary components are substances that don't contribute directly to caloric or essential nutrient needs but can influence physiological and biochemical processes in the body. These compounds may have **health-promoting effects** or **antinutritional properties**, depending on the type and context of consumption.

Here is the classification of non-nutritive food components based on their origin, function, and effects:

8.3.1 Phytochemicals (Plant-Derived Components)

Plants naturally contain chemical substances called phytochemicals that primarily produced as a defense mechanism against environmental stressors, pests, and diseases. They are not essential nutrients but exert powerful effects on health effects on humans when included in a plant-based diet.

Phytochemicals are classified based on their chemical structures and biological functions, ranging from antioxidants to hormone modulators. This classification includes polyphenols, carotenoids,

glucosinolates, saponins, alkaloids, phytoestrogens, and more. Below is an in-depth exploration of the major classes of phytochemicals, their sources, mechanisms of action, and health benefits.

2. Polyphenols

Polyphenols are plant-derived compounds characterized by their multiple phenolic structures, found abundantly in fruits, vegetables, tea, wine, and spices. Known for their antioxidant properties, they significantly lower the risk of chronic illnesses like cancer and cardiovascular conditions, as well as oxidative stress and inflammation. The two main categories of polyphenols are flavonoids (such as quercetin, catechins, and anthocyanins) and non-flavonoids (such as phenolic acids, stilbenes, and lignans), each contributing uniquely to plant defense and human health. They are also of interest in pharmaceutical and nutritional sciences for their potential therapeutic applications. Later, in this unit we learn more about this.

3. Terpenoids

This enormous and complex group of naturally occurring organic compounds, sometimes referred to as isoprenoids, is made up of five-carbon isoprene units (C_5H_8). They are produced in microbes, plants, and mammals via the methylerythritol phosphate (MEP) or mevalonate pathways. Terpenoids are characterized by their vast structural diversity and play essential roles in plant growth, development, and defense. They are also important in human health due to their biological and pharmacological activities.

Terpenoids have diverse biological functions and significant applications in both natural ecosystems and human industries. In plants, they act as pigments, such as carotenoids, aiding in photosynthesis and imparting vibrant colors. Aromatic monoterpenoids attract pollinators, while sesquiterpenoids and diterpenoids defend against herbivores and pathogens. Additionally, gibberellins, a class of diterpenoids, regulate plant growth and development. In humans, terpenoids exhibit remarkable pharmacological properties, including antioxidant, anti-inflammatory, anticancer, antimalarial, and antimicrobial effects. A notable example is Taxol, a diterpenoid extensively used as a chemotherapy drug. Economically, terpenoids are indispensable in pharmaceuticals, perfumery, food flavoring, and agriculture. Essential oils rich in monoterpenoids and sesquiterpenoids are popular in aromatherapy and cosmetics, while carotenoids are used as natural food colorants and dietary

supplements. In summary, terpenoids are versatile compounds with critical roles in ecological functions, human health, and industrial applications, driven by their structural and functional diversity.

Terpenoids are characterized by their vast structural diversity and play essential roles in plant growth, development, and defense. Based on the number of isoprene units in their structure, they can be classified as Monoterpenoids (Limonene: Found in citrus fruits)(C₁₀), Sesquiterpenoids (Farnesol: Found in essential oils), Diterpenoids (Retinol: Essential for vision), Triterpenoids (Lupeol: Found in fruits like mango), Tetraterpenoids (Carotenoids found in orange-yellow vegetables and fruits), Polyterpenoids (Natural Rubber)

4. Glycosides

A class of naturally occurring substances known as glycosides can be found in a variety of plants, such as fruits, vegetables, herbs, and medicinal plants. They are formed when a sugar molecule (such as glucose) is bonded to a non-sugar component, which is often a biologically active molecule (aglycone). The sugar component is typically glucose, rhamnose, or other monosaccharides, while the aglycone can be a variety of chemical structures, including phenolic compounds, terpenoids, alkaloids, or flavonoids.

Glycosides have been studied for their wide array of health benefits, which vary depending on the type of glycoside and the plant source. The non-sugar component of the glycoside typically has a pharmacological or therapeutic effect on the body, while the sugar component helps to stabilize the compound and aid its absorption.

Health Benefits of Glycosides

A. Cardiovascular Health Some glycosides, particularly **cardiac glycosides** found in plants like **foxglove** (*Digitalis* species), have been used for centuries to treat **heart failure** and **arrhythmias**. These glycosides help to:

- 20 Increase the force of heart contractions (positive inotropic effect).
- 21 Slow down the heart rate, allowing for better heart function and improved circulation.
- 22 Some well-known examples include **digoxin** and **ouabain**, which are used in modern medicine under medical supervision to treat heart conditions.

B. Antioxidant Effects Many glycosides have potent **antioxidant properties**. These glycosides, which are often found in fruits and vegetables, can aid in lowering oxidative stress and shielding the body from damage caused by free radicals, which is connected to cancer, ageing, and other long-term illnesses. For example, glycosides in **berries** and **grapes**, such as **anthocyanin glycosides**, are known to have antioxidant effects that support cellular health.

C. Anti-inflammatory Benefits Inflammatory illnesses like asthma, arthritis, and others can be lessened by some glycosides' demonstrated anti-inflammatory properties. For instance, **saponins** (a type of glycoside found in legumes and some herbs) can reduce inflammation by modulating immune response and inhibiting inflammatory cytokines.

D. Anti-cancer Properties Some glycosides, such as those found in **ginseng** (ginsenosides) and **soy** (isoflavone glycosides), have been shown to exhibit anti-cancer effects. They help by:

- 23 Preventing cancer cells from growing.
- 24 Inducing apoptosis (programmed cell death) in abnormal cells.
- 25 Preventing the cancer cells from spreading to other bodily regions. These glycosides are under investigation for their potential as complementary treatments in cancer therapy.

E. Immune System Support Glycosides can improve the body's defences against infections by modifying the immune system. **Flavonoid glycosides** found in citrus fruits, onions, and apples have been shown to support immune function by stimulating the activity of immune cells like macrophages and lymphocytes.

F. Digestive Health Some glycosides, such as those found in **bitter herbs** (e.g., **gentian**), have been used traditionally to stimulate appetite and improve digestion. They can help by:

- 26 Increasing bile production, aiding in the digestion of fats.
- 27 Enhancing the secretion of digestive enzymes, which improves overall digestion and nutrient absorption.
- 28 Supporting gut health through encouraging a balanced gut microbiome.

G. Antimicrobial Properties Several plant glycosides possess **antimicrobial effects**, meaning they can help combat bacteria, viruses, and fungi. For example:

- 29 **Ginger** contains **gingerol glycosides**, which have shown antibacterial and antiviral activity.
- 30 **Garlic** contains **allicin glycosides**, which have been shown to reduce bacterial growth and act as a natural antibiotic.

H. Blood Sugar Regulation Certain glycosides, especially those found in **bitter melon** and **fenugreek**, have been found to help **regulate blood sugar levels**. These glycosides can:

- 31 Increased insulin sensitivity lowers the risk of type 2 diabetes.
- 32 Reduce blood sugar spikes after meals.

I. Liver Protection Glycosides found in herbs such as **milk thistle** (silymarin) have been used to protect and detoxify the liver. **Silymarin**, a flavonolignan glycoside, has been shown to:

- 33 Support liver regeneration.
- 34 Protect liver cells from toxins and oxidative damage.
- 35 Aid in the treatment of liver diseases such as hepatitis and cirrhosis.

5. Glucosinolates:

Glucosinolates are sulfur-containing phytochemicals predominantly found in cruciferous vegetables such as broccoli, brussels sprouts, kale, cauliflower, and cabbage. These compounds are responsible for the distinctive pungent aroma and slightly bitter taste of these vegetables. When glucosinolates are broken down by plant enzymes during chopping, chewing, or digestion, they produce bioactive metabolites such as indoles and isothiocyanates, which support their anti-inflammatory, anti-tumor, antioxidant, and hypochloestermic health benefits.

Health Benefits of Glucosinolates

- i. **Cancer Prevention** One of the most well-known health benefits of glucosinolates is their potential role in **cancer prevention**. When glucosinolates are broken down in the body, they form compounds like **sulforaphane** (from broccoli) and **indole-3-carbinol** (from cabbage). These compounds have been shown to:
 - ii. **Induce detoxification enzymes:** These enzymes help the body neutralize and eliminate carcinogens, reducing the risk of cancer.

iii. **Inhibit cancer cell growth:** Isothiocyanates such as sulforaphane can stop the growth of cancer cells and promote apoptosis (programmed cell death) in abnormal cells.

iv. **Prevent DNA damage:** By enhancing antioxidant defense mechanisms, glucosinolates help protect cells from oxidative damage that could lead to cancer.

v. **Anti-Inflammatory Effects** Glucosinolates and their breakdown products, such as sulforaphane, exhibit potent **anti-inflammatory effects**. Chronic inflammation is associated with many diseases, including heart disease, arthritis, and certain cancers. Sulforaphane helps reduce the activity of pro-inflammatory proteins and pathways, thereby lowering inflammation levels in the body.

vi. **Detoxification and Antioxidant Activity** Glucosinolates promote the activation of the body's natural **detoxification processes** by boosting the production of phase II detoxification enzymes, which help neutralize harmful substances. Their breakdown products, like sulforaphane, also exhibit **antioxidant properties**, scavenging free radicals and preventing oxidative damage to cells, which is important for preventing aging and chronic diseases.

vii. **Support for Cardiovascular Health** The consumption of glucosinolate-rich vegetables may support **heart health**. These compounds help reduce blood pressure and lower cholesterol levels, both of which are important for preventing cardiovascular diseases. The antioxidant and anti-inflammatory effects of glucosinolates also contribute to reducing the risk of heart disease.

viii. **Improved Gut Health** Glucosinolates have been shown to positively influence gut health by promoting a healthy gut microbiome. The breakdown products of glucosinolates can help maintain a balanced gut flora and potentially improve digestion. Some studies suggest that these compounds may have a protective effect against colon cancer by supporting the growth of beneficial gut bacteria and enhancing the gut's ability to fight off harmful pathogens.

ix. **Hormonal Balance** The breakdown product **indole-3-carbinol** has been found to influence estrogen metabolism in a way that may reduce the risk of hormone-related cancers, such as breast cancer. It promotes the formation of a safer estrogen metabolite, which can reduce estrogen's cancer-promoting effects.

5. **Phytoestrogens:** Naturally occurring substances derived from plants that physically and functionally resemble the hormone oestrogen are known as phytoestrogens. These non-nutritive

substances, which are present in foods including soy, flaxseeds, sesame seeds, legumes, and whole grains, have structural similarities to 17-beta-estradiol, the main type of human oestrogen, and can attach to the body's oestrogen receptors.

The two main classes of phytoestrogens are **isoflavones** (found in soy and other legumes) and **lignans** (abundant in flaxseeds and whole grains). Isoflavones, such as genistein and daidzein, are particularly well-studied for their health benefits.

Phytoestrogens have both oestrogenic and anti-estrogenic properties as selective oestrogen receptor modulators (SERMs) depending on the hormonal environment. For instance, in premenopausal women, they may block excess estrogen activity, while in postmenopausal women, they can compensate for declining estrogen levels, offering relief from symptoms like hot flashes and bone density loss.

These compounds have been linked to various health benefits, including::

- Supporting women during menopause and reducing the risk of hormone-related conditions like breast and prostate cancer.
- Promoting bone density and reducing the risk of osteoporosis.
- : Improving lipid profiles and reducing cholesterol levels.
- Protecting against chronic inflammation and oxidative stress.

While phytoestrogens are generally considered safe and beneficial, their effects can vary based on individual hormonal levels and genetic factors. Consuming phytoestrogen-rich foods as part of a balanced diet can support overall health and provide protective benefits, particularly in aging populations.

6. Alkaloids: Alkaloids are substances with nitrogen that have pharmacological effects. Found in plants like coffee, tea, and cocoa, they include caffeine, which boosts alertness, and theobromine, which has mood-enhancing properties. Alkaloids also possess anti-inflammatory and antimicrobial effects.

The consumption of these phytochemicals is diversified when a range of plant-based foods are included in the diet, which promotes general health and lowers the risk of chronic illnesses.

8.2. Dietary Fiber (Indigestible Carbohydrates)

The form of carbohydrate that is present in plant-based foods but takes some effort for the human digestive system to digest is called dietary fibre. Unlike other nutrients, it passes through the stomach and intestines largely intact, playing a pivotal role in maintaining digestive health. Plant-based foods like fruits, vegetables, grains, legumes, and nuts contain it. There are two main types of dietary fiber: **soluble fiber**, and **insoluble fiber**

- **Soluble Fiber:** This form of fibre, which is present in foods including oats, beans, lentils, apples, and citrus fruits, turns into a gel-like substance when dissolved in water. It is advantageous for managing diabetes and cardiovascular health since it lowers blood cholesterol and stabilises blood sugar levels.
- **Insoluble Fiber:** It is present in whole grains, nuts, seeds, and vegetables. It gives stool volume, which encourages regular bowel movements and keeps constipation at bay.

Health Benefits of Dietary Fiber: The two forms offer significant health advantages, promoting general health and preventing a number of chronic illnesses. Let's discuss in detail:

· **Improved Digestive Health** A healthy digestive tract depends on dietary fibre. **Insoluble fiber** prevents constipation by giving stool more volume and facilitating its passage through the intestines. This type of fiber promotes regular bowel movements and prevents conditions like **irritable bowel syndrome (IBS)** and **diverticulosis**. **Soluble fiber** has the ability to absorb water and form a gel-like substance that slows down bowel motions, which can also help treat diarrhoea.

· **Weight Management** Foods high in fibre tend to be low in calories but high in volume, which promotes satiety, the sense of fullness. Because fewer calories are consumed overall, this can help with weight management. Soluble fibre also helps regulate appetite and avoid overeating by slowing the absorption of nutrients, especially lipids. High-fiber foods take longer to chew, contributing to a slower eating pace and greater satisfaction after meals.

· **Blood Sugar Regulation** Soluble fibre can help control blood sugar levels by slowing down the bloodstream's absorption of glucose. Those who already have type 2 diabetes or are at risk of getting it would especially benefit from this. By improving insulin sensitivity and reducing blood sugar spikes after meals, fiber helps control glucose levels, promoting stable energy levels throughout the day.

·**Cholesterol Reduction** LDL cholesterol (the "bad" cholesterol) can be lowered with the help of soluble fibre, which is especially present in foods like oats, beans, apples, and carrots. It lowers the total amount of cholesterol in the blood by binding with and eliminating cholesterol particles from the body. This is beneficial for heart health, as high cholesterol is a major risk factor for **heart disease** and **stroke**.

·**Heart Health** Fiber's cholesterol-lowering properties support heart health in general. Additionally, fibre lowers blood pressure, which is another critical cardiovascular health component. A lower incidence of heart disease, stroke, and high blood pressure has been linked to diets high in fibre. Regular fiber intake has also been shown to reduce inflammation, which plays a role in many cardiovascular conditions.

·**Colon Health and Cancer Prevention** Dietary fibre, particularly insoluble fibre, helps the colon stay healthy by accelerating the movement of food and waste products through the digestive tract and minimising the amount of time the colon is exposed to potentially hazardous chemicals. High intake of fibre, especially from vegetables and whole grains, has been shown to lower the risk of colon cancer. Fiber also helps to maintain a healthy gut microbiota, which plays a role in reducing inflammation and promoting digestive health.

·**Gut Health and Microbiome Support** Fibre provides nourishment for the gut's good bacteria. Fibre supports the development and activity of these "good" bacteria, which aids in preserving a microbiome in balance. Overall health, immunological response, and digestion all depend on a healthy gut microbiota. **Prebiotics**, a type of fiber found in foods like **bananas**, **onions**, and **garlic**, help stimulate the growth of healthy gut bacteria, enhancing overall gut health.

·**Reduced Risk of Chronic Diseases** Adequate fibre consumption has been associated with a decreased risk of heart disease, type 2 diabetes, and several cancers, particularly colorectal cancer. Together, fiber's capacity to lower cholesterol, control blood sugar, and promote a healthy digestive system helps to stave off many chronic illnesses.

·**Detoxification** Fibre helps the body rid itself of waste and poisons. It aids in the absorption and removal of toxic chemicals and heavy metals that build up in the digestive tract. Foods high in fibre also aid the liver's detoxifying functions, which improves general health.

Adults are recommended to consume 25–38 grams of fiber daily, but many fall short of this goal. Incorporating a variety of fiber-rich foods, such as fruits, vegetables, whole grains, legumes, nuts, and seeds, into daily meals ensures adequate intake. This simple dietary adjustment can significantly improve overall health and quality of life.

8.3. Anti-Nutritional Factors

Anti-nutritional factors (ANFs) are naturally occurring substances in food that can interfere with the digestion, absorption, or utilization of nutrients. Found primarily in plant-based foods, these compounds serve as defense mechanisms for plants but can impact human nutrition when consumed in excess. Despite their potential drawbacks, some ANFs also have health-promoting properties, highlighting the complexity of their role in nutrition.

- **Phytates (Phytic Acid):** Phytates are substances that are naturally present in whole grains, legumes, and seeds. They serve as a storage form of phosphorus in plants but are considered an anti-nutritional factor due to their ability to chelate minerals like calcium, iron, magnesium, and zinc, reducing their bioavailability. This binding can lead to nutrient deficiencies if phytate-rich foods are consumed excessively, particularly in populations with low mineral intake. However, phytates are not entirely negative; they exhibit antioxidant properties and may reduce the risk of certain chronic diseases, including cancer and cardiovascular conditions. Soaking, fermenting, and sprouting grains and legumes are effective ways to break down phytates, enhancing mineral absorption while retaining their health-promoting benefits.
- **Oxalates:** Oxalates are organic compounds found in foods such as spinach, rhubarb, beets, and nuts. They form insoluble complexes with calcium and other minerals, which can impair their absorption and potentially contribute to kidney stone formation in susceptible individuals. Despite their role as an anti-nutritional factor, oxalates may help bind and excrete excess metal ions, providing detoxifying benefits in moderation. Cooking, boiling, or pairing oxalate-rich foods with calcium sources (like dairy) can mitigate their adverse effects and reduce the risk of kidney stone development.
- **Lectins:** Lectins are carbohydrate-binding proteins present in legumes, grains, and certain vegetables. In raw or undercooked foods, lectins can bind to the intestinal lining, interfering with

nutrient absorption and causing gastrointestinal discomfort. In some cases, excessive consumption of lectins may damage the gut barrier. However, when properly processed through cooking, lectins lose their anti-nutritional properties and may even exhibit health benefits, such as immune modulation and anti-cancer effects. This highlights the importance of proper food preparation, particularly for lectin-rich foods like beans and lentils.

- **Tannins:** Tannins are polyphenolic compounds found in foods like tea, coffee, wine, and certain fruits and legumes. They can inhibit the absorption of proteins and minerals, particularly non-heme iron, leading to potential deficiencies if consumed excessively. However, tannins also possess strong antioxidant and anti-inflammatory properties, which contribute to their role in reducing the risk of chronic diseases such as cardiovascular disease and cancer. Pairing tannin-rich foods with vitamin C can enhance iron absorption, offsetting the inhibitory effects of tannins while retaining their health benefits.
- i. **Saponins:** A type of naturally occurring glycosides called saponins is widely distributed in plants such as legumes (e.g., soybeans, chickpeas), quinoa, spinach, and ginseng. They are named for their soap-like properties, as they produce a foamy lather when mixed with water. Structurally, saponins consist of a hydrophobic sapogenin (steroidal or triterpenoid) core attached to one or more hydrophilic sugar chains, giving them both water- and fat-soluble properties. However, saponins can reduce the bioavailability of certain nutrients, such as iron, due to their chelating properties. Proper preparation methods, such as cooking or fermentation, can minimize these effects, allowing for the safe and beneficial inclusion of saponin-rich foods in a balanced diet.
- vi **Goitrogens:** Compounds called goitrogens are present in cruciferous vegetables like broccoli, cabbage, kale, and Brussels sprouts. They can interfere with iodine uptake by the thyroid gland, potentially leading to hypothyroidism or goiter in iodine-deficient individuals. However, their impact is generally minimal for individuals with adequate iodine intake. Cooking or steaming these vegetables significantly reduces goitrogenic activity while retaining their numerous health benefits, including cancer prevention and cardiovascular support.
- vii **Trypsin Inhibitors:** Trypsin inhibitors are proteins found in raw legumes and soybeans that interfere with the enzyme trypsin, a key player in protein digestion. This can reduce protein availability and potentially lead to malnutrition if consumed in large amounts. Heat treatment, such as cooking or roasting, effectively inactivates trypsin inhibitors, ensuring that protein in legumes and soy

is fully digestible. When properly processed, these foods are excellent sources of high-quality plant protein.

Anti-nutritional factors are not purely harmful; they often have health benefits when consumed as part of a varied diet and prepared properly. Their dual nature—both as inhibitors of nutrient absorption and as providers of bioactive compounds—underscores the importance of informed food preparation and dietary diversity to optimize health outcomes.

8.4. Bioactive Peptides

The short chains of amino acids that form bioactive peptides are obtained from dietary proteins that exert specific biological effects on the body beyond basic nutrition. These peptides are typically inactive within the parent protein but are released during digestion, fermentation, or enzymatic hydrolysis. Found in a variety of food sources, including milk, eggs, soy, fish, and meat. These peptides can influence various physiological processes, such as improving immune function, reducing blood pressure, enhancing gut health, and acting as antioxidants. An example of bioactive peptides formed through enzymatic hydrolysis is the production of *lactotripeptides* through fermentation from milk proteins. Bioactive peptides are found in various food sources, including dairy products, meat, fish, eggs, soy, and certain grains.

Health Benefits of Bioactive Peptides

Antioxidant Effects Bioactive peptides often have powerful **antioxidant** properties, which help protect cells from oxidative stress and damage caused by free radicals. Oxidative stress is linked to aging and many chronic diseases, such as cardiovascular diseases and neurodegenerative disorders like Alzheimer's disease. Peptides derived from milk proteins (like **lactoferrin** and **casein-derived peptides**) and fish proteins have been shown to exhibit strong antioxidant effects, reducing oxidative damage and supporting overall health.

Anti-Inflammatory Effects Chronic inflammation is a key contributor to various diseases, including **arthritis**, **heart disease**, and **diabetes**. Certain bioactive peptides, such as those derived from **whey protein**, have been found to exert anti-inflammatory effects by modulating inflammatory pathways and cytokine production. For example, peptides like **lactokinins** from

milk proteins have demonstrated the ability to reduce inflammatory markers, promoting better immune health and reducing inflammation in conditions like **rheumatoid arthritis**.

Blood Pressure Regulation (Antihypertensive Effects) One of the most well-known benefits of bioactive peptides is their ability to **lower blood pressure**. These peptides, commonly known as **angiotensin-converting enzyme (ACE) inhibitors**, work by inhibiting the activity of the enzyme that constricts blood vessels, thereby promoting vasodilation and reducing blood pressure. Peptides derived from sources like **milk proteins** (such as **lactotripeptides**), **soy protein**, and **fish proteins** have been shown to be effective in reducing both systolic and diastolic blood pressure, making them beneficial for individuals with **hypertension** or those at risk of developing high blood pressure.

Improved Immune Function Bioactive peptides can enhance immune function by stimulating the production of immune cells and cytokines, which are involved in the body's defense mechanisms. For example, **lactoferrin**, a peptide found in **milk**, has antimicrobial properties and plays a key role in regulating the immune response. Some bioactive peptides also have the ability to modulate **T-cells**, promoting better immune surveillance and protection against infections.

Antimicrobial and Antiviral Properties Certain bioactive peptides, such as **defensins** and **lactoferrin**, possess **antimicrobial** and **antiviral** properties. These peptides can help fight off a wide range of pathogens, including bacteria, fungi, and viruses, by disrupting microbial membranes or interfering with viral replication. For instance, **lactoferrin** has been found to inhibit the growth of pathogenic bacteria like **E. coli** and **Salmonella**, as well as viruses like the **HIV** virus. This makes bioactive peptides a potential source of natural antimicrobial agents.

Gut Health and Digestive Health Bioactive peptides derived from **milk**, **soy**, and **wheat** proteins have beneficial effects on **gut health**. Some peptides promote the growth of beneficial gut bacteria, enhancing the balance of the gut microbiome. Others support the integrity of the intestinal barrier, reducing intestinal permeability (often referred to as **leaky gut**) and improving nutrient absorption. Bioactive peptides like **glutamine** have also been studied for their role in maintaining a healthy digestive tract, supporting conditions such as **irritable bowel syndrome (IBS)** and **inflammatory bowel disease (IBD)**.

Muscle Health and Recovery Bioactive peptides, especially those derived from **whey protein**, have been found to support **muscle health** and promote **muscle recovery** after exercise. These peptides can stimulate muscle protein synthesis, help prevent muscle breakdown, and support recovery from intense physical activity. For athletes and individuals engaging in regular physical activity, peptides like **whey peptides** and **collagen peptides** are often included in supplements to support muscle repair and growth.

Weight Management Some bioactive peptides, such as those found in **casein** and **whey proteins**, may aid in **weight management** by promoting satiety and reducing appetite. These peptides help regulate hormones such as **ghrelin** (the hunger hormone) and **leptin** (the satiety hormone). By influencing appetite-regulating hormones, bioactive peptides can help control food intake, potentially contributing to effective weight loss or weight maintenance.

Bone Health Certain bioactive peptides derived from **collagen** and **milk proteins** have demonstrated the ability to support **bone health**. These peptides help stimulate the production of collagen in bones, contributing to bone strength and density. Studies suggest that peptides derived from collagen, such as **collagen hydrolysates**, can enhance bone formation, reduce bone loss, and help prevent conditions like **osteoporosis**.

Skin Health Bioactive peptides, particularly those derived from **collagen**, are widely used in the skincare industry. Collagen peptides support skin elasticity and hydration, reducing the appearance of wrinkles and promoting a more youthful complexion. These peptides are often incorporated into skincare products, as well as in oral supplements, to improve skin appearance and health.

8.5 Functional Lipids

Functional lipids are lipids that contribute significantly to the maintenance and enhancement of general health in addition to their fundamental nutritional purpose. Monounsaturated and polyunsaturated fats, omega-3 and omega-6 fatty acids, linolenic acid, and linoleic acid (LA) are examples of functional lipids. These bioactive substances, which improve heart health by lowering blood pressure and inflammation, include omega-3 fatty acids (EPA and DHA), which are present in flaxseeds and fatty fish. Phospholipids, such as phosphatidylserine, are crucial for maintaining cellular

structure and function, particularly in brain health and cognitive performance. Conjugated linoleic acid (CLA), present in meat and dairy, is linked to fat reduction and improved insulin sensitivity, aiding in weight management and metabolic health. Additionally, plant sterols and stanols, found in seeds and vegetable oils, help reduce cholesterol levels by inhibiting its absorption. These functional lipids are incorporated into foods and supplements to enhance health, particularly in areas like cardiovascular health, brain function, and metabolic balance.

Health Benefits of Functional Lipids

Heart Health One of the most well-known benefits of functional lipids, especially **omega-3 fatty acids**, is their positive impact on **cardiovascular health**. Omega-3s, found in **fatty fish**, **flaxseeds**, and **walnuts**, help lower **triglycerides**, reduce **blood pressure**, and improve **cholesterol profiles** by increasing **HDL (good) cholesterol** and decreasing **LDL (bad) cholesterol**. They also have anti-inflammatory effects, reducing the risk of **atherosclerosis** (plaque buildup in arteries), and decreasing the risk of **heart attack** and **stroke**.

Brain Function and Mental Health Functional lipids, particularly omega-3 fatty acids such as **EPA (eicosapentaenoic acid)** and **DHA (docosahexaenoic acid)**, are essential for brain function. These fats are important for the development and maintenance of the brain and central nervous system. Omega-3s are known to improve cognitive function, memory, and mood regulation. They have been linked to a lower risk of **depression**, **anxiety**, and **Alzheimer's disease**. DHA, in particular, is a key structural component of brain cells and is involved in neurotransmission.

Anti-Inflammatory Effects Functional lipids such as **omega-3 fatty acids** and **monounsaturated fats** (found in **olive oil** and **avocados**) have powerful **anti-inflammatory** properties. Chronic inflammation is a contributing factor in many diseases, including **arthritis**, **cardiovascular disease**, and **cancer**. Omega-3s, especially **EPA** and **DHA**, help reduce inflammation by modifying the production of pro-inflammatory molecules called **eicosanoids**. This can help alleviate symptoms of inflammatory conditions like **rheumatoid arthritis** and **inflammatory bowel disease (IBD)**.

Weight Management and Metabolic Health Some functional lipids, such as **conjugated linoleic acid (CLA)**, have been shown to aid in **weight management**. CLA, found in **grass-fed beef** and **dairy products**, has been linked to a reduction in body fat and an increase in lean muscle mass. Additionally, functional lipids such as **medium-chain triglycerides (MCTs)**, found in coconut oil and palm kernel oil, are more easily metabolized by the body, providing a quick source of energy and potentially promoting **fat loss**. These lipids help improve **insulin sensitivity**, regulate **blood sugar** levels, and reduce the risk of **type 2 diabetes**.

Skin Health Functional lipids, particularly **omega-3 fatty acids** and **phospholipids**, play a crucial role in maintaining **skin health**. Omega-3s contribute to skin hydration, elasticity, and the prevention of **dry skin** and **eczema**. They also help protect against the harmful effects of UV radiation and reduce the appearance of wrinkles. **Phospholipids**, found in **egg yolks** and **soybeans**, are key components of cell membranes and help maintain the integrity of skin cells, promoting a healthy skin barrier and preventing **skin aging**.

Liver Health Omega-3 fatty acids and other functional lipids can support **liver health** by reducing the accumulation of fat in the liver and improving fat metabolism. Omega-3s have been shown to reduce the risk of **non-alcoholic fatty liver disease (NAFLD)** and improve liver function. They help reduce **inflammation** in the liver and may assist in lowering liver enzyme levels in individuals with fatty liver disease.

Hormonal Balance Certain functional lipids, such as **omega-3 fatty acids** and **monounsaturated fats**, help regulate **hormonal balance** in the body. These lipids are involved in the synthesis of **hormones** such as **prostaglandins**, which help manage inflammation and pain, and **estrogen** and **testosterone**. Omega-3 fatty acids, in particular, have been linked to improved **menstrual health** and may help alleviate symptoms of **PMS (premenstrual syndrome)** and **menopausal** discomfort.

Bone Health Omega-3 fatty acids, particularly **DHA**, play a role in maintaining **bone health** by enhancing calcium absorption and bone mineralization. Omega-3s have been shown to improve bone density and reduce the risk of **osteoporosis** and **fractures**. Studies suggest that omega-3s work synergistically with **vitamin D** and other nutrients to promote bone strength and prevent bone loss with age.

Gut Health Functional lipids such as **omega-3 fatty acids** and **phospholipids** contribute to the health of the **gut microbiota**, supporting the growth of beneficial bacteria and the integrity of the gut lining. Omega-3s, for example, help reduce gut inflammation and improve gut barrier function, which is important for preventing conditions like **leaky gut syndrome** and **inflammatory bowel diseases** like **Crohn's disease**.

Cancer Prevention Omega-3 fatty acids and other functional lipids have been studied for their potential role in **cancer prevention**. These lipids can inhibit the growth of cancer cells, reduce inflammation, and promote apoptosis (programmed cell death) in tumors. Omega-3s may particularly help reduce the risk of **breast, prostate, and colorectal cancer** by interfering with cancer cell signaling pathways and enhancing the effectiveness of cancer treatments.

6 Phytosterols

Natural substances called phytosterols, sometimes referred to as plant sterols, can be found in plant-based meals such fruits, vegetables, nuts, seeds, and vegetable oils. It has been demonstrated that phytosterols, which share structural similarities with cholesterol, lower cholesterol levels by competing with cholesterol for intestinal absorption. Less cholesterol enters the bloodstream as a result, which can help lower LDL (bad) cholesterol levels and minimise the risk of heart disease. Functional foods including margarine, dairy products, and beverages frequently contain phytosterols to improve cardiovascular health. Apart from reducing cholesterol, phytosterols may also have immune-modulating, anti-inflammatory, and antioxidant benefits. Small amounts are usually taken in fortified goods or as part of a balanced diet.

7. Probiotics (Live Microorganisms): Probiotics are live microorganisms, usually yeast or bacteria, that, when taken in sufficient quantities, have health advantages. By preserving a balanced gut microbiota, these "good" bacteria promote digestive health and general wellbeing. Probiotics can be found in dietary supplements and fermented foods including kefir, yoghurt, miso, kimchi, and sauerkraut. By restoring or preserving a healthy balance of good bacteria, which can be upset by things like disease, antibiotics, or an unhealthful diet, they are known to improve gut health. Probiotics also have potential benefits beyond digestion, including improving immune function, reducing inflammation, and enhancing nutrient absorption. Specific strains of probiotics, such as *Lactobacillus*

and *Bifidobacterium*, have been extensively studied for their ability to support gut health and prevent or alleviate gastrointestinal disorders like irritable bowel syndrome (IBS) and diarrhea.

Examples: Bacteria *Lactobacillus* and *Bifidobacterium*, found in fermented foods like yogurt, kefir, and sauerkraut, these bacteria support gut health. Enhance digestion, improve gut flora balance, and support immune function.

8. Other Bioactive Compounds

Other bioactive compounds, such as resistant starch, chitosan, and lignans, provide additional health benefits and play crucial roles in promoting overall well-being:

- **Resistant Starch:** A form of carbohydrate known as resistant starch evades digestion in the small intestine and enters the colon, where it functions as a prebiotic and promotes the development of good gut flora. Resistant starch, which is present in foods including whole grains, cooked and cooled potatoes, legumes, and unripe bananas, supports gut flora, improves blood sugar regulation, and promotes digestive health. It also aids in weight management by increasing feelings of fullness and reducing appetite.
- **Chitosan:** A naturally occurring polymer, chitosan is extracted from the shells of crustaceans, such as crabs and prawns. It is frequently used as a weight-management supplement and has been researched for its potential to decrease the absorption of fat in the digestive tract. Additionally, chitosan may help lower cholesterol, improve gastrointestinal health, and function as an antibacterial.
- **Lignans:** Plant substances called lignans can be found in whole grains, seeds (especially flaxseeds), and some fruits and vegetables. They are classified as phytoestrogens, which means they can imitate or alter the body's oestrogen activity, and they have anti-inflammatory and antioxidant qualities. By reducing cholesterol and enhancing blood vessel function, lignans promote cardiovascular health and are linked to a lower risk of hormone-related malignancies, including breast and prostate cancer.

These bioactive compounds contribute to better digestive health, weight management, hormonal balance, and the prevention of chronic diseases such as cancer and heart disease.

Summary Table

Category	Examples	Functions
Phytochemicals	Polyphenols, carotenoids, saponins	Antioxidant, anti-inflammatory, anticancer.
Dietary Fiber	Soluble, insoluble fiber	Digestive health, cholesterol reduction.
Anti-Nutritional Factors	Phytates, oxalates, tannins	May inhibit nutrient absorption.
Secondary Metabolites	Alkaloids, terpenoids	Bioactive effects (e.g., stimulant, analgesic).
Prebiotics	Inulin, FOS	Promote gut microbiota growth.
Bioactive Peptides	Casein-derived peptides	Antihypertensive, antimicrobial.
Functional Lipids	Omega-3s, phytosterols	Heart health, anti-inflammatory.
Probiotics	Lactobacillus, Bifidobacterium	Gut health and immunity.
Resistant Starch	Green bananas, cooled potatoes	Blood sugar control, gut health.

8.4 POLYPHENOLS

The presence of numerous phenolic structures characterises the broad group of naturally occurring chemicals known as polyphenols. Rich in fruits, vegetables, tea, wine, chocolate, and spices, they are well-known for their strong antioxidant qualities and array of health advantages, such as lowering the risk of chronic diseases like diabetes and cancer, preventing cardiovascular disease, and reducing inflammation. Polyphenols are classified into two main groups: **flavonoids** and **non-flavonoids**, each with distinct structures and biological activities.

3. Flavonoids

A wide variety of polyphenolic chemicals, flavonoids are present in large quantities in tea, wine, cereals, fruits, and vegetables. Their vivid pigments are well-known for giving many plant-based meals their red, blue, and yellow hues. The distinctive flavan structure of flavonoids is formed by the structural joining of two aromatic rings by a three-carbon bridge. These substances are divided into several subclasses, each with unique characteristics and health advantages: flavonols, flavones, flavanones, flavan-3-ols, anthocyanins, and isoflavones. Flavonoids are potent antioxidants that prevent oxidative stress and shield cells from harm by scavenging free radicals. They boost immunity, have anti-inflammatory, cardioprotective, and neuroprotective qualities, and may lower the chance of developing long-term conditions like diabetes, cancer, and heart disease. Additionally, flavonoids improve vascular health by enhancing endothelial function and reducing blood pressure. Examples include quercetin (found in onions), catechins (in green tea), and anthocyanins (in berries), making flavonoids essential components of a healthy, plant-based diet.

The most abundant and most researched class of polyphenols are flavonoids, which are distinguished by their core structure consisting of two aromatic rings joined by a three-carbon bridge. According to their particular structural distinctions, they are further separated into subclasses. Flavonols, such as quercetin and kaempferol, are present in tea, apples, and onions and are well-known for their anti-inflammatory and antioxidant qualities. The flavones found in celery, parsley, and chamomile (such as apigenin and luteolin) have been associated with anti-cancer properties. There are a lot of isoflavones in soy products, such as genistein and daidzein, which function as phytoestrogens and mimic oestrogen in the body. Citrus fruits contain flavanones, which benefit heart health (e.g., naringenin, hesperidin). **Anthocyanins**, responsible for red, purple, and blue colors in berries and grapes, are powerful antioxidants that support vascular health. **Flavanols** (e.g., catechins in green tea and epicatechin in cocoa) are notable for improving brain and cardiovascular function.

B.Non-Flavonoids

Non-flavonoid polyphenols represent a variety of polyphenolic substances that are not members of the flavonoid family. These substances have numerous health advantages for people and are crucial to

plant defence systems. Non-flavonoids can be broadly divided into several subclasses, including **phenolic acids**, **stilbenes**, **lignans**, **tannins**, and others. Below is a detailed explanation of each subclass:

1. Phenolic Acids

The simple structure of a hydroxyl group joined to an aromatic ring defines phenolic acids, a subclass of polyphenols. These substances can be found in a variety of plant-based foods, including whole grains, seeds, coffee, fruits, and vegetables.

Common phenolic acids include caffeic acid, ferulic acid, gallic acid, and chlorogenic acid, each contributing to the nutritional and therapeutic value of the foods in which they are found. Phenolic acids exhibit potent antioxidant properties, anti-inflammatory effects, anticancer properties, reducing blood pressure, enhancing lipid metabolism, and protecting blood vessels through their vasodilatory and anti-inflammatory effects. Chlorogenic acid, for instance, found in coffee, is known to help regulate blood glucose levels and may lower the risk of type 2 diabetes. These compounds act synergistically with other bioactive phytochemicals, contributing to the health-promoting effects of a diet rich in fruits, vegetables, and whole grains, reinforcing the importance of plant-based nutrition for disease prevention and overall wellness.

The wide variety of non-flavonoid polyphenols known as phenolic acids is further subdivided into hydroxybenzoic and hydroxycinnamic acids. They are commonly found in fruits, vegetables, whole grains, and seeds.

- **Hydroxybenzoic acids** include **gallic acid** (found in berries and tea) and **ellagic acid** (found in pomegranates and raspberries). These compounds have antioxidant, anti-inflammatory, and anticancer properties.
- **Hydroxycinnamic acids** include **caffeic acid** (found in coffee, apples, and artichokes), **ferulic acid** (found in whole grains and rice), and **sinapic acid**. These acids have potent antioxidant effects and may contribute to heart health and cancer prevention.

2. Stilbenes

Stilbenes are aromatic compounds that have a fundamental structure made up of two phenyl groups joined by an ethylene bridge with two carbons. Tree bark, seeds, and certain fruits are the main sources of these substances. Red wine, grapes, and berries contain resveratrol, one of the most well-known stilbenes. Its anti-inflammatory, anti-cancer, antioxidant, and cardiovascular protective properties have all been extensively researched. The possible health advantages of moderate wine intake are frequently connected to resveratrol. Similar to resveratrol, pterostilbene is a stilbene that is also present in blueberries and grapes. It is thought to have stronger anticancer and antioxidant effects and to be more bioavailable.

3. Lignans

Lignans are plant compounds found primarily in seeds, particularly flaxseeds, sesame seeds, and whole grains. They are precursors to important hormones, especially in the regulation of estrogen activity. They are classified as **phytoestrogens** due to their structural similarity to estrogen, a hormone in the human body. Lignans are a type of polyphenol, and their primary function in plants is to act as a defense mechanism against pathogens and herbivores. When consumed by humans, lignans have been associated with a range of health benefits, particularly in relation to hormone balance and cardiovascular health. Lignans are most commonly found in plant-based foods, particularly: flaxseeds (the richest source), sesame seeds, whole grains such as oats, barley, and rye, legumes and fruits like strawberries, apricots, and citrus fruits.

Mechanism of Action

Lignans exert their effects primarily by acting as **phytoestrogens**. They bind to estrogen receptors in the body, though they are much weaker than the body's natural estrogen. By interacting with these receptors, lignans can regulate the balance of estrogenic activity in the body. This impact is especially helpful for people with estrogen-sensitive diseases or those going through menopause. Further supporting general health are the anti-inflammatory and antioxidant properties of lignans.

Health Benefits of Lignans

- **Hormone Regulation:** Lignans are phytoestrogens, meaning they can mimic estrogen in the body. Their ability to assist balance hormone levels has been connected to their possible advantages after menopause. Because they compete with oestrogen for binding to hormone receptors in the body,

they may also lower the total oestrogenic activity and lower the risk of hormone-related malignancies, including breast cancer.

- **Cardiovascular Health:** When they help lower cholesterol and enhance blood pressure, lignans have been demonstrated to have positive benefits on heart health. Their antioxidant properties also contribute to reducing inflammation, a key factor in the development of cardiovascular diseases.
- **Cancer Prevention:** Lignans may have anti-cancer properties, according to some research. Because they serve as antioxidants and modulate oestrogen metabolism, which shields cells from oxidative damage that can cause cancer, they are thought to help lower the risk of colorectal, breast, and prostate cancers.
- **Antioxidant Properties:** Lignans have antioxidant properties, just like other polyphenols. They aid in scavenging free radicals, which are unstable chemicals that can harm cells and lead to chronic illnesses and ageing.
- **Gut Health:** Gut health may benefit from lignans as well. It is believed that enterolignans, such as enterodiols and enterolactone, which are produced by the gut microbiota from lignans, support a healthy gut flora and have other positive health effects.

4. Tannins

A type of naturally occurring polyphenolic compounds, tannins can be found in berries, nuts, tea, coffee, red wine, and other plant-based meals and drinks. Tannins, which have an astringent flavour, help plants stay safe by keeping pests and diseases off. Tannins offer a variety of health benefits, including antioxidant properties that combat oxidative stress, anti-inflammatory effects that reduce the risk of chronic conditions, and antimicrobial activity that supports immune health. They also aid in digestive health by managing gastrointestinal issues and promoting gut microbiota balance. Furthermore, condensed tannins, such as those found in red wine, contribute to cardiovascular health by improving blood vessel function and lowering LDL cholesterol. However, excessive intake can hinder nutrient absorption, particularly iron, highlighting the importance of consuming tannin-rich foods in moderation within a balanced diet.

Structurally, they are categorized into **hydrolyzable tannins** or **condensed tannins**. They are abundant in tea, wine, fruits, nuts, and seeds and are known for their astringency.

- **Hydrolyzable tannins**, such as **gallotannins** and **ellagitannins**, are found in pomegranates and oak trees and can be broken down into smaller molecules like gallic acid. These tannins are known for their antioxidant and antimicrobial properties.
- **Condensed tannins** (also known as **proanthocyanidins**) are found in foods like dark chocolate, berries, and grapes. They are potent antioxidants and have been observed to to benefits for cardiovascular health, such as lowering inflammation and enhancing blood vessel function.

5. Other Non-Flavonoids

- **Coumarins**: These are aromatic compounds found in fruits, herbs, and spices like cinnamon and parsley. Coumarins have anticoagulant and anti-inflammatory properties and are often used in traditional medicine.
- **Xanthones**: Found in the fruit rind of **mangosteen**, xanthones have been studied for their anti-inflammatory, antimicrobial, and antioxidant properties.
- **Alicin**: A sulfur-containing compound found in garlic, allicin has well-documented antimicrobial, anticancer, and heart-health benefits.

CHECK YOUR PROGRESS EXERCISE 1

What are phytoestrogens, and how do they work in the body?

What are common food sources of phytoestrogens?

8.5 PHYTOESTROGENS

Phytoestrogens are naturally occurring plant substances that function similarly to the human hormone oestrogen. These substances can attach to oestrogen receptors and affect hormonal activity because they share structural similarities with oestrogen. Depending on the situation, phytoestrogens can bind to oestrogen receptors and have either oestrogenic or anti-estrogenic effects, although not having the same potency as oestrogen. Particularly for disorders involving hormone balance, such menopause, osteoporosis, and breast cancer, phytoestrogens are thought to offer health advantages. Many plant-based foods, such as flaxseeds, soy, and some fruits and vegetables, contain them.

Phytoestrogens can be broadly categorized into four types:

1. Isoflavones

Isoflavones are the most well-known and studied class of phytoestrogens. They are primarily found in soybeans and soy-based products but are also present in legumes like chickpeas, lentils, and peanuts. Isoflavones are considered the most potent phytoestrogens due to their ability to bind to estrogen receptors in the human body.

- **Genistein:** This is of the most prevalent and well researched isoflavones. Anti-inflammatory, antioxidant, and anti-cancer properties are thought to be associated with genistein. It may help reduce the risk of hormone-related cancers, such as breast and prostate cancer, by regulating estrogen signaling.
- **Daidzein:** Another major isoflavone, daidzein is converted into equol by certain gut bacteria. Equol has a stronger affinity for estrogen receptors, and its presence may be associated with improved menopausal symptoms and lower risks of breast cancer.

2. Lignans

Lignans are a type of phytoestrogen found in a variety of plant-based foods, particularly seeds (especially flaxseeds), grains, fruits, and vegetables. Lignans are converted by gut bacteria into enterolignans, which have weak estrogenic effects.

- **Secoisolariciresinol** and **matairesinol** are two common lignans found in foods. These lignans may have protective effects against hormone-related cancers, heart disease, and osteoporosis. Lignans also have antioxidant and anti-inflammatory properties.
- Flaxseeds are one of the richest sources of lignans, and they are also high in omega-3 fatty acids, contributing to heart health.

3. Coumestans

Some plants, especially legumes like soybeans, alfalfa, and clover, contain coumestans, a lesser-known kind of phytoestrogen. Despite having a lower dietary abundance than isoflavones and lignans, coumestans nevertheless have effects similar to those of oestrogen.

- **Coumestrol** is the most studied coumestan. It has been found to bind to estrogen receptors and may exhibit estrogenic effects, particularly in postmenopausal women. Research has shown that coumestrol may help alleviate symptoms of menopause, such as hot flashes and night sweats.
- Although less common in the diet, coumestans are found in various sprouts and beans, including clover sprouts.

4. Flavonoids

- A variety of plant molecules known as flavonoids can be found in a variety of fruits, vegetables, and drinks including wine and tea. Some flavonoids are classified as phytoestrogens because they have mild oestrogenic activity.
- **Kaempferol** and **quercetin** are two examples of flavonoids with estrogenic properties. These compounds are found in foods such as apples, onions, grapes, and broccoli. Kaempferol and quercetin may help modulate estrogen activity in the body and may reduce the risk of certain cancers, heart disease, and menopausal symptoms.
- **Apigenin**, found in chamomile, parsley, and celery, is another flavonoid with weak estrogenic effects. It has also shown potential in reducing the risk of hormone-related cancers, such as breast cancer.

8.5.1 How Phytoestrogens Work

Phytoestrogens work by mimicking the action of estrogen, the primary female sex hormone, in the body. They are structurally similar to estrogen, which allows them to bind to estrogen receptors on cells. However, their effect is typically weaker than that of natural estrogen. Phytoestrogens can exert both estrogenic (estrogen-like) and anti-estrogenic effects depending on the concentration of estrogen in the body. When estrogen levels are low, such as during menopause, phytoestrogens can bind to estrogen receptors and produce estrogen-like effects, helping to alleviate symptoms like hot flashes and bone loss. Conversely, when estrogen levels are high, phytoestrogens can block the estrogen receptors, potentially reducing the risk of estrogen-related conditions, such as breast cancer. In this way, phytoestrogens act as a natural "balancer" of estrogen levels, providing a modulating effect on hormonal activity. This mechanism is especially beneficial in conditions like menopause, osteoporosis, and hormone-related cancers. However, the overall impact of phytoestrogens on human health can

vary based on factors like the type of phytoestrogen, individual hormonal levels, and the gut microbiome's ability to metabolize these compounds.

8.5.2 Health Benefits of Phytoestrogens

Phytoestrogens offer a variety of health benefits, primarily due to their ability to mimic the effects of estrogen in the body. These plant compounds can support hormonal balance and contribute to overall well-being, particularly in conditions where estrogen plays a key role. Here are some of the main health benefits of phytoestrogens:

1. Alleviating Menopausal Symptoms: The capacity of phytoestrogens to lessen menopausal symptoms like mood swings, hot flashes, and night sweats is one of its best-known advantages. These discomforts are caused by the natural decrease in oestrogen levels that occurs throughout menopause. By binding to oestrogen receptors and helping to offset the drop in oestrogen, phytoestrogens—such as those in soy, such as isoflavones like genistein and daidzein—relieve these symptoms. Studies have shown that regular consumption of phytoestrogen-rich foods can significantly reduce hot flashes and improve quality of life for women during menopause.

2. Bone Health and Osteoporosis Prevention: Osteoporosis is largely caused by the decline of oestrogen during menopause, which is essential for preserving bone density. Because they imitate the protective effects of oestrogen on bone metabolism, phytoestrogens—in particular, isoflavones—may help maintain bone health. Phytoestrogens may decrease bone resorption and boost bone mineral density, which could lessen postmenopausal women's risk of fractures, according to research.

3. Cardiovascular Health: Cardiovascular health has been associated with phytoestrogens. Blood vessel function, blood pressure, and cholesterol levels may all be improved by them. Better heart health may result from isoflavones, which are included in soy, having the ability to raise HDL (good cholesterol) and decrease LDL (bad cholesterol). Furthermore, oxidative stress, a component in cardiovascular disorders, can be lessened by phytoestrogens' antioxidant qualities.

4. Cancer Prevention: The potential of a specific phytoestrogens, such as those in soy and flaxseeds, to lower the incidence of hormone-related malignancies, especially breast and prostate cancer, has been investigated. For instance, lignans and isoflavones may aid in controlling oestrogen levels and preventing the action of excess oestrogen, which can promote the development of hormone-sensitive

malignancies. According to research, phytoestrogens may reduce the risk of breast cancer by preventing the formation of cancer cells and modifying oestrogen receptor activation.

5. Improved Skin Health: By encouraging collagen synthesis and delaying the ageing process, phytoestrogens may improve skin health. Oestrogen helps keep skin hydrated and elastic, and as we age, our oestrogen levels might drop, making our skin thinner and more prone to wrinkles. In addition to improving skin texture, phytoestrogens can assist increase skin suppleness and moisture retention, which may lessen the obvious symptoms of ageing.

6. Hormonal Balance: Natural regulators of oestrogen action are phytoestrogens. When oestrogen levels in women are low (during menopause, for example), they can have estrogen-like effects; when oestrogen levels are high (during premenopausal women), they can have anti-estrogenic effects. For diseases like endometriosis or polycystic ovarian syndrome (PCOS), where hormone imbalances can cause symptoms like irregular periods and infertility, this balancing effect might be helpful.

7. Antioxidant and Anti-inflammatory Properties: Numerous phytoestrogens have anti-inflammatory and antioxidant qualities that can improve general health. Phytoestrogens can prevent chronic diseases like diabetes, heart disease, and neurological disorders by lowering inflammation and scavenging free radicals. Because they can help slow down the process of cellular damage and degeneration, these antioxidant benefits are particularly significant as people age.

8. Mental Health and Cognitive Function: According to recent studies, phytoestrogens might benefit brain function. It is possible that they can enhance mood, memory, and cognitive performance via altering oestrogen receptors in the brain. By having neuroprotective properties, phytoestrogens may help prevent age-related cognitive decline, including Alzheimer's disease, according to some research. Additionally, the capacity of phytoestrogens to stabilise oestrogen levels may help lower the risk of mood disorders like depression, especially in women who are perimenopausal or postmenopausal.

9. Weight Management: Maintaining a healthy may be aided by phytoestrogens, especially during menopause. According to certain research, phytoestrogens may help control fat metabolism and lower the chance of weight gain around the abdomen, which is frequently seen during the menopause transition. By influencing the distribution of fat in the body and improving metabolic function, phytoestrogens may assist in maintaining a healthy weight as women age.

8.5.3 Food Sources of Phytoestrogens: To include phytoestrogens in your diet, focus on these foods:

- **Soy and Soy Products:** Tofu, tempeh, soy milk, and edamame are rich in isoflavones.
- **Flaxseeds:** The highest dietary source of lignans, flaxseeds are easy to incorporate into smoothies, cereals, and baked goods.
- **Legumes:** Chickpeas, lentils, and beans are good sources of phytoestrogens.
- **Whole Grains:** Rye, oats, and barley contain lignans.
- **Fruits and Vegetables:** Apples, carrots, pomegranates, and berries provide small amounts of phytoestrogens.

8.5.4 Considerations and Precautions

As phytoestrogens have a lot of advantages, it's crucial to use them sparingly. Hormonal balance may be impacted by excessive consumption, notably of soy-based products, especially in patients with thyroid conditions or those receiving hormone-sensitive medications.

Further, individual characteristics such as genetic predisposition, hormonal status, and gut microbiota composition might affect how phytoestrogens affect a person. Before making major dietary changes, always get medical advice, especially if you have hormone-related disorders.

In conclusion, phytoestrogens offer a natural way to support hormonal balance, protect against chronic diseases, and enhance overall health. Incorporating a variety of phytoestrogen-rich foods, such as soy, flaxseeds, and legumes, into a balanced diet can provide these benefits. While they are not a replacement for medical treatment, phytoestrogens are a valuable addition to a healthy lifestyle, especially for women experiencing hormonal changes. By embracing these plant-based compounds, you can take a proactive step toward improved health and well-being.

8.6 JENNER'S SY COMPOUNDS

Jenner's SY compounds, often referred to as SY compounds, are a group of synthetic chemical structures primarily studied for their biological activities. These compounds are designed with specific molecular frameworks to target particular biological pathways or systems.

In **pharmacology**, SY compounds, sometimes referred to as "SY-numbered" compounds, typically denote a series of **synthetic molecules** that are identified by a systematic naming convention used

during drug discovery or research. These compounds are often designed to explore their potential **therapeutic effects**, **mechanisms of action**, or **biological interactions** in a preclinical or clinical setting.

SY compounds are often synthesized to mimic, enhance, or inhibit biological pathways. They may be designed based on computational modeling, screening of chemical libraries, or structural analogs of bioactive molecules.

The purpose of these compounds ranges from acting as **enzyme inhibitors**, **receptor agonists/antagonists**, or **modulators of metabolic pathways**. They are often used to study disease mechanisms or develop treatments for conditions such as cancer, inflammation, neurological disorders, or infections.

8.6.1 Applications of SY Compounds in Pharmacology

Let's explore the applications of **SY compounds** in pharmacology, highlighting some notable examples. These compounds, derived from various natural sources, have demonstrated a wide range of pharmacological properties, making them valuable in treating and preventing various diseases.

1. Anticancer Properties

Many SY compounds possess powerful anticancer effects, often by interfering with the growth and spread of cancer cells. For example:

- **Taxol** (a diterpenoid) is a popular anticancer medication used to treat ovarian and breast cancer, among other malignancies. It works by inhibiting cell division, effectively stopping the proliferation of cancer cells.
- **Berberine**, an alkaloid compound found in plants like **Berberis**, has shown potential in inhibiting tumour growth and causing apoptosis in cancer cells.

2. Anti-inflammatory and Antioxidant Effects

SY compounds also exhibit anti-inflammatory and antioxidant activities, which are beneficial in the treatment of inflammatory diseases like arthritis, cardiovascular diseases, and neurodegenerative conditions.

- **Curcumin**, produced from the spice turmeric, is a thoroughly studied substance that possesses strong antioxidant and anti-inflammatory qualities. Cardiovascular disorders, arthritis, and even some forms of cancer have been treated with it.
- **Resveratrol**, a stilbene, which is present in red wine and grapes, has antioxidant and anti-inflammatory qualities that help prevent oxidative stress and inflammation, which are connected to ageing and conditions including heart disease and Alzheimer's.

3. Cardiovascular Health

Certain SY compounds help regulate heart function and protect against cardiovascular diseases.

- **Flavonoids**, found in foods like tea and citrus fruits, all of which contribute to improved cardiovascular health by lowering cholesterol, enhancing blood vessel function, and lowering blood pressure.
- **Omega-3 fatty acids**, present in fish oils, have anti-inflammatory properties that may lower the risk of stroke and heart disease.

4. Antimicrobial and Antiviral Effects

SY compounds have been traditionally used in herbal medicine for their antimicrobial properties, and modern research has validated many of these applications.

- **Allicin**, derived from garlic, has antibacterial, antifungal, and antiviral effects. It has been used to combat infections caused by bacteria like *E. coli* and viruses like the flu.
- **Quercetin**, a flavonoid found in apples and onions, shows antiviral properties and is being studied for its potential in managing viral infections such as the common cold and influenza.

5. Neuroprotective Benefits

SY compounds may also provide neuroprotective effects, aiding in the treatment or prevention of neurological conditions including Parkinson's and Alzheimer's diseases.

- **Ginkgolides**, from the Ginkgo biloba plant, are well-known for enhancing cognitive performance and preventing cognitive loss brought on by ageing. Alzheimer's disease and other types of dementia have been treated with them.
- **L-theanine**, found in tea, is another compound with neuroprotective effects, promoting relaxation and enhancing brain function without causing drowsiness.

6. Antidiabetic Effects

A variety of SY compounds have shown promise in the treatment of diabetes by enhancing insulin sensitivity and controlling blood sugar levels.

- **Berberine**, It has been shown to aid individuals with type 2 diabetes reduce blood sugar and improve insulin resistance in addition to its anticancer effects.
- **Cinnamon**, which contains compounds like **cinnamaldehyde**, can improve blood sugar regulation and insulin sensitivity.

Some Examples:

SY-1365:

1. A **CDK7 (cyclin-dependent kinase 7) inhibitor** developed for cancer treatment.
2. It works by inhibiting transcriptional regulation in cancer cells, leading to apoptosis (cell death), particularly in cancers dependent on overactive transcription, such as ovarian and breast cancers.

SY-5609:

1. A selective **CDK7 inhibitor** under investigation for its anti-tumor effects.
2. It has shown promise in preclinical and early clinical trials for targeting transcription-driven cancers, particularly solid tumors and hematologic malignancies.

SY Compounds in Neurology:

1. Certain SY compounds have been synthesized to modulate **neurotransmitter pathways** or act on **ion channels** to explore treatments for neurodegenerative diseases, epilepsy, or pain management.
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8.6.2 Pharmacological Significance

- **Target Specificity:** SY compounds are often developed to target specific enzymes, receptors, or signaling pathways with high specificity, minimizing off-target effects.
 - **Mechanism Exploration:** They are valuable in understanding the biological mechanisms underlying diseases and how molecular inhibition or activation impacts these pathways.
 - **Therapeutic Potential:** Some SY compounds progress through preclinical and clinical phases, potentially becoming viable drugs for diseases with unmet therapeutic needs.
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8.6.3 Challenges in SY Compound Development

- **Safety and Efficacy:** Ensuring that the compound is safe and effective in vivo is a critical challenge, as many fail due to toxicity or lack of efficacy.
 - **Optimization:** Ensuring therapeutic benefit by striking a balance between pharmacokinetics (absorption, distribution, metabolism, and excretion) and pharmacodynamics (mechanism of action).
 - **Cost and Time:** Synthesizing, testing, and optimizing SY compounds for clinical use can be resource-intensive and time-consuming.
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8.7 CARBOHYDRATE-BINDING PROTEINS

Carbohydrate-binding proteins are molecules with the ability to recognize and bind to specific sugar structures. They do not provide calories or essential nutrients but play **functional roles** in biological

systems, including cellular communication, pathogen defense, and nutrient transport. Carbohydrate-binding proteins (CBPs), such as **lectins**, are a class of **non-nutritive food components** that interact specifically with carbohydrate molecules on the surfaces of cells and glycoproteins. These proteins are naturally found in many plant and animal foods and have unique biological activities that can influence health and nutrition.

8.7.1 Sources of CBPs in Foods

- **Plants:** Lectins are the most well-known carbohydrate-binding proteins in plant-based foods. They are especially abundant in legumes (e.g., beans, lentils, soybeans), grains (e.g., wheat, barley), and some fruits and vegetables (e.g., tomatoes, bananas, and potatoes).
 - **Animals:** Some CBPs are found in animal-derived foods, such as milk or eggs, but their biological effects are less studied compared to plant-based lectins.
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8.7.2 Potential Benefits of CBPs

While they do not contribute to caloric intake or provide essential vitamins or minerals, carbohydrate-binding proteins can impact health in both **beneficial** and **adverse** ways.

- **Immune Modulation:** CBPs can influence immune system function by interacting with glycoproteins on immune cells, potentially enhancing the body's defense against pathogens.
- **Anti-Cancer Activity:** Certain CBPs have shown promise in targeting cancer cells. They may inhibit tumor growth by recognizing specific sugar molecules expressed on cancer cell surfaces.
- **Gut Microbiota Interaction:** CBPs may selectively interact with gut microbiota, influencing the composition and activity of the microbial population. This can impact digestion, nutrient absorption, and immune responses.
- **Potential for Therapeutics:** CBPs are being investigated for their ability to block bacterial or viral infections by binding to pathogen surfaces and preventing their adhesion to human cells. In addition, Cancer research explores CBPs for their ability to identify and bind to unique sugar molecules on tumor cells, paving the way for novel therapies.

8.7.3. Risks and Challenges of CBPs

- **Antinutritional Effects:**Some CBPs, like lectins, bind to carbohydrates in the gut lining, potentially interfering with nutrient absorption (e.g., minerals like iron and zinc) and causing nutrient deficiencies.
 - **Digestive Issues:**In their active form, CBPs can disrupt intestinal cells, leading to symptoms like bloating, diarrhea, and nausea. For example, raw kidney beans contain high levels of active lectins that can cause severe digestive distress if not cooked properly.
 - **Toxicity:**High concentrations of certain CBPs can be toxic. For example, **phytohemagglutinin** in raw or undercooked beans can cause poisoning, characterized by gastrointestinal symptoms.
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8.7.4 Reducing Risks of CBPs in Food

The potentially harmful effects of CBPs, particularly those in plant-based foods, can be mitigated through proper food preparation methods:

- **Cooking:**High temperatures denature most CBPs, making them inactive and safe to consume. Boiling or pressure cooking legumes is especially effective.
 - **Soaking:**Soaking beans, grains, and seeds before cooking can help reduce CBP content by leaching them into water.
 - **Fermentation and Sprouting:**Fermenting or sprouting lectin-containing foods reduces their activity while enhancing the bioavailability of other nutrients.
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8.8 LECTINS

Lectins are **naturally occurring carbohydrate-binding proteins** found in a wide variety of plants and animals. They are classified as **non-nutritive food components** because they do not provide calories or essential nutrients but can exert significant biological effects. Lectins play critical roles in biological systems, including cell-cell communication, immune responses, and pathogen defense.. Although, lectins are part of a plant's **defense mechanism** against pests and pathogens. By binding to

carbohydrates in the digestive systems of predators, lectins can inhibit nutrient absorption or cause digestive discomfort, deterring consumption.

In the context of foods and human health can have either positive or negative consequences, depending on the type, concentration, and mode of consumption.

8.8.1 Characteristics of Lectins

- **Carbohydrate-Binding Ability:** Lectins specifically bind to carbohydrate molecules on the surface of cells. This property allows them to influence cellular interactions and immune functions.
- **Heat Sensitivity:** Most lectins are **heat-labile**, meaning they are destroyed by cooking. However, some lectins, such as those in undercooked legumes, remain active and can cause adverse effects.

8.8.2 Sources in Food

Lectins are abundant in certain plant-based foods, particularly:

1. **Legumes:** Kidney beans, lentils, chickpeas, and soybeans.
2. **Grains:** Wheat and barley.
3. **Vegetables:** Potatoes, tomatoes, and eggplants (from the nightshade family).
4. **Fruits:** Bananas and avocados.

8.8.3 Effects of Lectins on Human Health

A. Health Benefits

- i. **Immune Modulation:** Lectins interact with immune cells, potentially enhancing immune responses. For example, they may stimulate macrophages, which help combat infections.
- ii. **Cancer Research:** Some lectins have demonstrated anti-cancer effects by causing apoptosis (programmed cell death) or preventing the development of tumour cells. Lectins are being investigated for their possible use in cancer treatment and diagnosis.
- iii. **Blood Sugar Regulation:** Some studies suggest that lectins may help regulate glucose levels by influencing carbohydrate metabolism.
- iv. **Gut Health:** Properly processed lectin-containing foods (like beans and lentils) are rich in fiber and bioactive compounds, promoting healthy gut microbiota.

4. Negative Effect on Health

- i. **Antinutritional Effects:** Lectins can interfere with the absorption of essential nutrients by binding to carbohydrates in the gut lining. This may lead to deficiencies in minerals like iron, calcium, and zinc.
 - ii. **Digestive Issues:** Consuming large amounts of raw or undercooked lectin-containing foods (e.g., raw kidney beans) can cause symptoms such as nausea, vomiting, bloating, and diarrhea.
 - iii. **Gut Barrier Disruption:** Lectins can bind to the intestinal lining, potentially increasing gut permeability (commonly known as "leaky gut"). This may lead to immune activation or inflammation.
25. **Toxicity:** Some lectins, such as **phytohemagglutinin** in raw red kidney beans, are toxic in high amounts and can cause severe gastrointestinal symptoms.

8.8.4 Reducing Risks of Lectins

26. **Cooking and Processing:** Most lectins are heat-sensitive and become inactive when foods are cooked thoroughly. For example- boiling, pressure cooking, soaking, and fermenting significantly reduce lectin content.
27. **Fermentation and Sprouting:** Fermenting or sprouting lectin-rich foods can decrease their lectin levels while enhancing nutrient bioavailability.
28. **Balanced Diet:** Consuming a variety of foods ensures that the benefits of lectin-containing foods, such as fiber, protein, and antioxidants, outweigh potential risks.

8.9 Saponins

Saponins are a group of substances that occur naturally in many different types of plants, particularly in beans, legumes, and some herbs. These compounds are known for their distinct foaming properties when mixed with water, which is why they are named "saponins" (from the Latin word *sapo*, meaning soap). They are glycosides meaning they consist of a sugar molecule linked to a non-sugar component, usually a steroid or triterpene. The sugar part is hydrophilic (water-soluble), while the aglycone (the non-sugar part) is lipophilic (fat-soluble), allowing saponins to interact with both water and fats.

Saponins are widely studied for their dual roles in nutrition and pharmacology, offering both health benefits and potential risks.

8.9.1 Types of Saponins

Saponins are classified into two main types based on their chemical structure:

- xiii. **Steroidal Saponins:** These saponins have a steroid structure as their aglycone. They are commonly found in plants like **ginseng**, **alfalfa**, and **yucca**.
- xiv. **Triterpenoid Saponins:** These saponins have a triterpene structure and are commonly found in plants like **soybeans**, **quinoa**, and **ginseng**.

8.9.2 Sources of Saponins

Saponins are present in a variety of plant-based foods, herbs, and legumes, including:

- **Legumes:** Soybeans, chickpeas, lentils, and kidney beans.
- **Grains:** Oats, quinoa, and amaranth.
- **Vegetables:** Spinach, garlic, and asparagus.
- **Herbs and Medicinal Plants:** Ginseng, licorice, and fenugreek.

They are particularly abundant in the outer layers of seeds and roots.

8.9.3 Biological Functions and Health Benefits

- i. **Antioxidant and Anti-inflammatory Effects** Saponins exhibit potent antioxidant and anti-inflammatory properties. They help neutralize free radicals in the body, which can reduce oxidative stress and the risk of chronic diseases such as cancer, heart disease, and neurodegenerative disorders. Their anti-inflammatory effects may help alleviate conditions like arthritis and inflammatory bowel disease.
- ii. **Immune System Modulation** Saponins have been shown to enhance immune responses by stimulating the production of white blood cells, improving the body's ability to fight infections.

They also have antimicrobial properties, which can help protect against bacterial, viral, and fungal infections.

- iii. **Cholesterol-Lowering Effects** One of the most well-known benefits of saponins is their ability to lower cholesterol levels. Saponins can reduce the absorption of cholesterol in the intestines and increase the excretion of bile acids. This can help lower total cholesterol and LDL ("bad") cholesterol levels, reducing the risk of cardiovascular diseases.
- iv. **Anticancer Properties** Some saponins have been found to have anticancer properties. They can induce apoptosis (programmed cell death) in cancer cells and inhibit the growth and spread of tumors. For instance, saponins from plants like **ginseng** and **Quillaja saponaria** have been studied for their potential to fight cancer.
- v. **Blood Sugar Regulation** Saponins may also help in regulating blood sugar levels by improving insulin sensitivity and reducing blood glucose. This makes them potentially beneficial for managing type 2 diabetes. Some studies have suggested that saponins can enhance glucose uptake by cells and reduce insulin resistance.
- vi. **Liver Health** Some saponins are believed to protect liver cells from damage caused by toxins or diseases like fatty liver. They help by promoting detoxification processes and supporting liver regeneration.

8.9.4 Potential Side Effects and Considerations

While saponins have many health benefits, they also have some possible adverse effects, particularly if taken in excessive amounts:

- **Toxicity:** Some saponins can be toxic when consumed in large amounts, leading to symptoms like nausea, vomiting, and diarrhea. They can also be toxic to red blood cells, causing hemolysis (destruction of red blood cells).
- **Digestive Issues:** Saponins can interfere with nutrient absorption in the intestines and cause gastrointestinal discomfort in sensitive individuals.
- **Foaming and Bitter Taste:** The foaming property of saponins can cause them to have a bitter taste, which may reduce the palatability of foods containing them.

8.10 NUTRITIONAL REGULATION OF GENE EXPRESSION

The relationship between nutrition and gene expression is a cornerstone of nutrigenomics, a field that explores how nutrients and dietary components influence molecular and cellular processes. Nutritional regulation of gene expression refers to the mechanisms by which nutrients or bioactive food compounds modulate the activity of specific genes, ultimately affecting physiological functions and health outcomes.

8.10.1 Mechanisms of Nutritional Regulation of Gene Expression

Nutritional influence on gene expression refers to the way in which the nutrients we consume can modulate the activity of our genes. This concept lies at the intersection of nutrition, epigenetics, and molecular biology, and highlights how dietary components can directly or indirectly affect gene expression, potentially influencing health outcomes. The field is particularly relevant in understanding how food can influence chronic diseases, aging, and overall well-being at a genetic level.

1. Epigenetic Modifications

Nutrients can induce changes in **epigenetic marks**, such as DNA methylation and histone modification, which control the accessibility of genes for transcription. These modifications can either activate or silence genes without altering the underlying DNA sequence.

- **DNA Methylation:** The process to incorporate an amino group to DNA, which usually suppresses gene expression, can be influenced by specific nutrients. For example, folate and B vitamins, particularly B12, are involved in the methylation of DNA, which can alter the expression of genes related to metabolism, immune function, and cancer.
- **Histone Modification:** Histones, which are proteins that encircle DNA, can also be impacted by nutrients. Histone alterations like acetylation or methylation can either increase or decrease gene expression. For instance, compounds like resveratrol (found in grapes) and curcumin (found in turmeric) have been shown to influence histone acetylation, potentially activating genes involved in anti-inflammatory responses and cancer prevention.

- **Non-coding RNA:** Certain dietary components can influence the activity of non-coding RNAs, such as microRNAs, which regulate the expression of genes. For example, omega-3 fatty acids found in fish may modulate microRNA expression, influencing genes related to inflammation and cardiovascular health.

2. Transcription Factors Activation:

Proteins known as transcription factors aid in controlling the initial stage of gene expression, the transcription of DNA into RNA. Certain transcription factors, which are proteins that control gene expression, can be activated by dietary substances. Nutrients can affect genes linked to immunity, metabolism, and stress responses by either activating or inhibiting these transcription factors. Vitamin D, for instance, stimulates transcription factors that control genes involved in immunological function, bone health, calcium absorption, and the avoidance of autoimmune illnesses. Furthermore, Nrf2, a transcription factor involved in antioxidant defence, can be activated by polyphenols found in foods like berries, tea, and dark chocolate. This helps shield cells from oxidative damage, which can cause ageing and cancer.

3. Signaling Pathways:

Nutrients can activate various signaling pathways that influence gene expression. For instance:

- **Insulin signaling:** Consuming carbohydrates triggers insulin release, which can influence the expression of genes involved in glucose metabolism and storage. Chronic consumption of high-glycemic foods can lead to altered insulin signaling and gene expression related to obesity and diabetes.
- **AMPK pathway:** AMP-activated protein kinase (AMPK), a regulator of energy balance that can affect gene expression linked to fat storage, energy expenditure, and ageing, can be activated by nutrients like polyphenols, which are present in foods like berries and red wine.
- **PPARs (Peroxisome Proliferator-Activated Receptors):** These nuclear receptors control when genes related to fat metabolism are expressed. By affecting the expression of genes that regulate lipid metabolism, omega-3 fatty acids and certain lipids can activate PPARs, lowering inflammation and enhancing insulin sensitivity.

- **Nutrient-Specific Gene Expression**
- **Polyphenols:** It has been shown these plant-based substances, which are present in fruits, vegetables, tea, and red wine, affect the expression of genes related to oxidative stress, inflammation, and cancer prevention. Resveratrol, for instance, stimulates genes involved in cellular repair and antioxidant defence.
- **Fatty Acids:** Commonly present in walnuts, flaxseeds, and fatty fish, omega-3 fatty acids have the ability to control genes related to lipid metabolism and inflammation. These fatty acids have the ability to activate transcription factors such as PPARs and NF-kB, which can affect the expression of genes linked to inflammation, fat accumulation, and heart health.
- **Vitamins and Minerals:** Minerals like zinc and selenium, as well as micronutrients like vitamins A, D, and E, can control gene expression by triggering particular enzymes and receptors. Vitamin D, for instance, affects genes related to immune system performance, bone health, and cancer prevention, whereas zinc is necessary for DNA synthesis and repair.
- **Amino Acids:** Essential amino acids found in diets high in protein can affect the expression of genes linked to metabolism and muscular building. For instance, leucine promotes muscle protein synthesis and growth and repair-related gene expression via activating the mTOR pathway.
- **Diet and Chronic Diseases:** Chronic disorders like obesity, diabetes, cardiovascular disease, and cancer can be significantly impacted by dietary modifications in gene expression. For example, diets that are low in fruits and vegetables and high in processed foods might activate genes linked to inflammation, which can lead to the development of chronic diseases.

Conversely, a diet rich in whole foods, antioxidants, and anti-inflammatory compounds can influence gene expression in ways that protect against these diseases. For example, the Mediterranean diet, rich in olive oil, fruits, vegetables, and fish, has been shown to modulate gene expression related to inflammation, oxidative stress, and cardiovascular health.

Examples of Nutritional Influence on Gene Expression

Macronutrients:

- **Carbohydrates:** Regulate insulin signaling, which influences genes involved in glucose metabolism.
- **Proteins and Amino Acids:** Branched-chain amino acids like leucine activate mTOR signaling, modulating protein synthesis.

Micronutrients:

- **Vitamin A:** Retinoic acid (active form) regulates genes involved in vision, immune function, and cell differentiation.
- **Zinc:** Acts as a cofactor for transcription factors like zinc finger proteins.

Bioactive Compounds:

- **Polyphenols:** Found in tea and berries, polyphenols like resveratrol modulate genes involved in oxidative stress and inflammation through pathways like NF- κ B.
- **Omega-3 Fatty Acids:** Regulate genes involved in inflammation and lipid metabolism via PPAR activation.

8.10.2 Health Implications

Nutritional regulation of gene expression has profound effects on health and disease prevention:

- **Chronic Diseases:** Dietary components regulate genes involved in inflammation, oxidative stress, and lipid metabolism, influencing the risk of conditions like diabetes, cardiovascular diseases, and cancer. Therefore, nutritional regulation of gene expression has a direct impact on the prevention of chronic diseases:
 - A diet heavy in refined carbohydrates and saturated fats can cause protective genes to be suppressed and inflammatory genes to be activated, which can lead to disorders including

obesity, diabetes, and cardiovascular disease. Long-term changes in gene expression can also result from epigenetic modifications brought on by these diets.

- In contrast, a diet rich in **antioxidants** (e.g., vitamins C and E, polyphenols) and **fiber** has protective effects on gene expression, promoting the activation of genes that reduce oxidative stress and inflammation, thereby reducing the risk of chronic diseases.

ii. Gut Microbiota : The regulation of gene expression by diet is significantly influenced by the gut flora. Dietary factors affect the gut microbiome, which can then affect the expression of genes linked to inflammation, metabolism, and immunity. Positive gene expression patterns that enhance immune function and lower the risk of metabolic and autoimmune illnesses are associated with a healthy, balanced microbiome.

iii. Cancer Prevention: The control of gene expression by nutrition is particularly important for preventing cancer. Numerous plant-based meals, including whole grains, fruits, and vegetables, include substances that can affect gene expression in ways that can stop cancer from developing.

For instance:

- **Sulforaphane**, a compound found in cruciferous vegetables like broccoli, activates genes that enhance detoxification processes and protect against carcinogens.
- **Resveratrol**, a polyphenol found in grapes and red wine, has been shown to modulate gene expression by inhibiting pathways involved in cancer cell proliferation and metastasis.

iv. Development: Foetal gene expression is regulated by proper maternal nutrition, which affects growth and long-term health (for example, by the developmental roots of health and disease concept).

V Aging: Nutrients like antioxidants influence genes associated with aging and cellular repair.

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9.6.2 Nutritional Challenges in Submarine Environments

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9.7 Let Us Sum Up

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9.9 Answer to Check Your Progress

9.1 INTRODUCTION

Extreme environments such as space, high-altitude terrains, low-temperature regions, and submarines pose unique challenges to human physiology. Nutrition plays a pivotal role in supporting these adaptations, ensuring the maintenance of health and performance despite the stressors of these settings. The demands of these conditions necessitate tailored nutrition management to maintain health, optimize performance, and ensure survival.

Extreme environments present unique challenges that significantly alter the body's nutritional needs. One key factor is altered energy requirements, which vary depending on the environment. For instance, energy demands increase in cold climates or high altitudes due to the body's need to generate heat and adapt to reduced oxygen availability. In contrast, microgravity in space often reduces energy needs due to decreased physical activity. **Physiological stress** is another challenge, as conditions like hypoxia (low oxygen levels), hypothermia (prolonged exposure to cold), or the effects of microgravity can disrupt metabolic processes, weaken muscle and bone health, and impact overall well-being. Additionally, access to **limited food resources** in remote or controlled environments, such as submarines or space missions, makes it difficult to provide fresh and diverse food options, potentially leading to nutrient deficiencies. Finally, the **psychological impact** of extreme environments, including stress, isolation, and monotony, can alter appetite and eating behaviors, contributing to either undernutrition or overconsumption of less nutritious foods. These challenges necessitate precise nutritional planning to ensure health and performance in such demanding settings.

This essay explores advances in nutrition have been driven by modern science and technology for extreme conditions, leading to the development of specialized dietary strategies and innovative food systems. As humans continue to push the boundaries of exploration and operate in increasingly challenging environments, the role of nutrition management becomes even more critical. Tailored nutritional strategies ensure survival and optimize physical performance, cognitive function, and overall well-being, making it possible to thrive in the most demanding conditions. This understanding forms the basis for designing specific nutritional plans for diverse extreme settings, including space travel, high-altitude expeditions, low-temperature survival, and submarine missions.

Expected Outcomes:

Students shall able to:

- Understand the nutritional and health problems in extreme conditions.
- Gain knowledge about advances in nutrition for extreme conditions.
- Design specific nutritional plans for diverse extreme settings.

Let's delve into the advances in Nutrition for development of specialized dietary strategies and innovative food systems for coping extreme conditions

9.2 ADVANCES IN NUTRITION FOR EXTREME CONDITIONS

Advances in nutrition for extreme conditions have been driven by modern science and technology, leading to the development of specialized dietary strategies and innovative food systems. One notable advancement is the creation of **compact, high-nutrient foods**, such as freeze-dried, vacuum-sealed, and energy-dense meals. These options are designed to deliver essential nutrients while minimizing weight and storage requirements, making them ideal for environments where space and resources are limited. Another breakthrough is the use of **fortified and functional foods**, which are enriched with specific nutrients to address common deficiencies in extreme settings, such as vitamin D for submarine crews or antioxidants for astronauts exposed to radiation. Additionally, **hydroponic and closed-loop systems** have revolutionized food production in isolated environments. These systems enable the cultivation of fresh produce without soil, using minimal water and space, and are particularly valuable in settings like space missions or long-term submarine deployments. Together, these advancements

ensure that individuals in extreme conditions receive balanced nutrition to maintain health and optimize performance.

9.3 SPACE TRAVEL

In this section you will learn about unique challenges faced by Space travel and maintaining health and nutrition becomes critical for the success of long-term missions. Making proper nutrition a critical component of astronaut health and performance. Space presents an environment of microgravity, where Muscle atrophy, bone density loss, and changes in fluid distribution are significant concerns. Nutrition management in space is not just about maintaining caloric intake; it is about addressing the physiological changes that occur in microgravity, radiation exposure, and the limited resources available in a spacecraft or space station. The primary objective of nutrition in space travel is to ensure that astronauts are healthy, perform optimally, and maintain long-term well-being despite the stresses of a space environment.

First let's discuss the nutritional challenges faced by space travelers

9.3.1 Nutritional Challenges in Space

- i. **Microgravity:** One of the most significant challenges in space is the absence of gravity. Microgravity reduces appetite and alters taste perception, leading to insufficient nutrient intake. Microgravity leads to muscle atrophy and bone demineralization. The loss of muscle mass and strength, particularly in weight-bearing muscles, occurs because muscles are no longer needed to counteract gravity. Additionally, calcium is lost from bones, leading to a condition known as spaceflight osteopenia, which increases the risk of fractures upon return to Earth.
- ii. **Fluid Redistribution:** In microgravity, body fluids shift from the lower extremities to the upper body, leading to puffiness in the face and potential dehydration.
- iii. **Radiation Exposure:** Space radiation poses a significant risk to astronauts, potentially damaging DNA and increasing the risk of cancer. Antioxidant-rich foods and supplements are important to mitigate the damage caused by radiation. Proper nutrition can help repair cellular damage and maintain immune function.

- iv. **Energy Requirements:** The energy demands of space missions can vary depending on the duration, physical activities, and psychological stressors experienced by astronauts. Caloric intake must be carefully monitored to prevent muscle loss, fatigue, and energy imbalances.
- v. **Fluid Shifts:** In microgravity, fluids in the body shift towards the upper part of the body, leading to facial puffiness, increased intracranial pressure, and changes in fluid distribution. This affects hydration, electrolyte balance, and overall cardiovascular health.
- vi. **Limited Food Storage and Preparation:** Space missions have limited space for food storage, strict weight restrictions, and no possibility of refrigeration. Food must be lightweight, compact, shelf-stable, and nutritious. Therefore, food selection and preparation are crucial to meeting nutritional requirements without adding excess weight to the spacecraft.
- vii. **Radiation Exposure:** Space radiation increases oxidative stress and risks for cancer, cardiovascular disease, and neurodegeneration, necessitating antioxidant-rich diets.
- viii. **Psychological Stress:** Isolation and confined spaces can lead to mood disorders, stress, and reduced appetite, which directly impact nutritional intake.

9.3.2 Nutrition Management in Space Travel

Space travel presents unique challenges to human health and nutrition due to the microgravity environment, isolation, limited food supply, and exposure to radiation. Proper nutrition management is critical for maintaining the health, performance, and well-being of astronauts during short-term missions and especially for long-duration missions such as trips to Mars. This section explores the intricacies of nutrition management in space, covering physiological changes, dietary requirements, food preservation, and future challenges.

Certain nutrients play a vital role in addressing the unique challenges of space travel. Let's discuss the key nutrients for space travel:

- i. **Calcium and Vitamin D:** These are critical for bone health. In microgravity, bone demineralization leads to the loss of calcium, increasing the risk of osteoporosis: Supplementation of calcium and vitamin D, combined with resistance exercise, helps minimize bone loss. Vitamin D is especially crucial as sunlight exposure is limited in space, affecting vitamin D synthesis.
- ii. **Protein:** Protein is necessary for maintaining muscle mass and strength. Microgravity leads to muscle atrophy, making adequate protein intake essential. High-quality proteins with essential

amino acids are included in astronauts' diets. Protein-rich foods like meats, fish, nuts, and legumes are carefully chosen to maintain lean body mass.

- iii. **Antioxidants (Vitamins A, C, E, Selenium):** Antioxidants combat oxidative stress caused by radiation exposure in space. They help neutralize free radicals that can damage cells. A diet rich in fruits, vegetables, and antioxidant supplements is necessary to provide adequate protection against radiation.
- iv. **Iron:** Iron is crucial for oxygen transport in the body. However, in space, iron metabolism changes, and astronauts may be at risk of iron overload rather than deficiency due to decreased red blood cell mass (space anemia). Iron intake is closely monitored, and iron-rich foods are limited to avoid potential health risks. Regular blood tests help adjust iron intake according to individual needs.
- v. **Omega-3 Fatty Acids:** Omega-3 fatty acids have anti-inflammatory properties that help counteract the effects of muscle and bone loss, as well as immune function dysregulation. Sources like fish oil supplements are provided to maintain adequate levels of omega-3 fatty acids.
- vi. **Folic Acid and B Vitamins:** These are essential for DNA synthesis, red blood cell formation, and neurological health. They also help mitigate the risk of radiation-induced DNA damage: Adequate intake is ensured through fortified foods and supplements, especially for long-duration missions.
- vii. **Potassium and Sodium:** Electrolyte balance is essential to counteract fluid shifts and prevent dehydration.
- viii. **Water:** Hydration is critical, and water must be recycled and monitored efficiently. Systems like the Water Recovery System (WRS) ensure a sustainable supply.

9.3.3 Criteria for Space Food:

- 5. Develop space-friendly, nutrient-dense meals that are easy to consume.
- 6. Supplement astronauts with calcium, vitamin D, and other essential nutrients.
- 7. Include antioxidant-rich foods and supplements to counteract increased oxidative damage.
- 8. **Shelf Stability:** Foods must have a long shelf life to remain safe and nutritious throughout the mission.
- 9. **Nutritional Density:** High nutrient content in compact forms is essential to save space and reduce payload weight.

10. **Palatability and Variety:** To maintain appetite and morale, foods must taste good and offer variety.
11. Food packaging is designed to be lightweight, durable, and compatible with microgravity. Packages often include Velcro or magnetic features to keep them stable during use.

9.3.4 Innovations in Space Nutrition and Sustainability

Long-duration space missions, such as those to Mars, require sustainable food production systems:

14. **Hydroponics and Aquaponics:** **Hydroponics** and **Aquaponics** are innovative methods for growing plants without soil, each with distinct systems. **Hydroponics is a** method where plants are grown directly in a nutrient-rich water solution. On otherside, Aquaponics is technique which combines hydroponics with aquaculture (fish farming).Fish waste provides natural nutrients for plants, while plants help filter and clean the water for the fish. Creates a self-sustaining ecosystem ideal for food production.

These systems allow astronauts to grow fresh fruits, vegetables, and herbs in space. Plants can provide essential nutrients, improve diet quality, and offer psychological benefits. Plants like lettuce, radishes, and wheat are being studied for their growth potential in space-based agriculture.

15. **Bioregenerative Life Support Systems:** NASA and other space agencies are researching closed-loop systems where plants, microorganisms, and humans coexist. Plants can help regenerate oxygen, remove carbon dioxide, and provide food, creating a sustainable ecosystem.
 16. **Lab-Grown Foods:** Efforts are being made to produce lab-grown meat and other protein sources for future missions. This technology could help reduce the dependence on pre-packaged foods.
7. **Personalized Nutrition:** With advances in technology, personalized nutrition plans based on genetic, metabolic, and health data are becoming feasible. Tailoring diets to individual needs can optimize health and performance in space.
 8. **Nutrient Delivery Systems:** Innovative nutrient delivery systems like pills, gels, and nutrient-rich drinks are being explored to ensure astronauts get the essential nutrients needed without consuming large amounts of food.

9. Microbiome Considerations: Research is focusing on maintaining a healthy gut microbiome, which plays a crucial role in immune function, nutrient absorption, and overall health. Probiotics and prebiotics are being included in space diets to support gut health.

Nutrition management in space is a complex yet vital aspect of space missions. Ensuring that astronauts receive the right nutrients in the right amounts helps combat the unique physiological challenges posed by space environments. As space exploration continues to evolve, innovative solutions for food production, nutrient delivery, and personalized nutrition will be essential. Addressing the nutritional needs of astronauts is not only crucial for their health and well-being but also for the success of future long-duration missions, paving the way for sustainable human presence beyond Earth.

CHECK YOUR PROGRESS EXERCISE 1

1. What are the nutritional challenges in space?

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2. What are the nutritional requirements in space ?

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3. What are the innovations in space nutrition and sustainability?

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9.4 HIGH ALTITUDE

High-altitude environments, defined as areas above 2,400 meters (8,000 feet), pose significant physiological and nutritional challenges due to reduced oxygen availability, cold temperatures, and increased energy demands. Proper nutrition is essential to maintain physical and mental performance and prevent altitude-related illnesses. This essay explores innovations, nutritional requirements, and the challenges associated with high-altitude nutrition.

9.4.1 Nutritional Requirements at High Altitudes

1. **Energy Demands:** The body expends more energy at high altitudes due to elevated basal metabolic rate (BMR) and physical exertion in low oxygen conditions. Energy requirements may increase by 10-50%, depending on altitude and activity level.
 2. **Carbohydrates:** Preferred energy source due to their higher oxygen efficiency compared to fats. Recommended to comprise 60-70% of total caloric intake.
 3. **Proteins:** Essential for muscle repair and recovery but should not exceed moderate levels to avoid excessive nitrogen waste, which burdens the kidneys.
 4. **Fats:** Provide a concentrated energy source but are less efficiently metabolized in hypoxic (low oxygen) conditions.
 5. **Iron:** Critical for oxygen transport and red blood cell production. Altitude exposure increases erythropoiesis, raising iron demands.
 6. **Antioxidants (Vitamins C, E, and Selenium):** Counteract oxidative stress caused by increased free radical production at high altitudes.
 7. **Vitamin D:** Necessary for bone health, particularly when exposure to sunlight is limited in cold, high-altitude regions.
 8. **Sodium and Potassium:** Electrolyte balance is crucial to prevent dehydration and maintain proper muscle and nerve function.
 9. **Hydration:** Dehydration is a common issue due to increased respiratory water loss in cold, dry air. Fluid intake should be increased to compensate for these losses.
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9.4.2 Challenges in High-Altitude Nutrition

High-altitude nutrition presents several unique challenges due to the lower oxygen levels, reduced air pressure, and colder temperatures. At higher elevations, the body's metabolic rate increases as it works harder to obtain oxygen, which can lead to a higher caloric requirement. However, appetite often decreases at high altitudes, making it difficult for individuals to meet these increased energy demands. Additionally, dehydration is a concern because the body loses more water due to increased respiration rates and dry air, yet thirst is often suppressed in high-altitude conditions. Nutrient absorption can also be impaired due to lower oxygen levels, affecting digestion and overall health. Furthermore, high-

altitude conditions can lead to a higher risk of malnutrition if not properly addressed, especially among individuals engaged in prolonged physical activity or those unaccustomed to the environment. To overcome these challenges, a balanced diet rich in easily digestible, high-calorie foods, adequate hydration, and specific nutrients like iron, which is critical for oxygen transport, is essential for maintaining optimal health and performance at high altitudes.

9.4.3 Innovations in High-Altitude Nutrition

High-Energy, Lightweight Foods: Development of calorie-dense, compact foods to meet increased energy needs while reducing transport burdens. Examples include energy bars, freeze-dried meals, and high-fat nuts and seeds.

Fortified Foods and Supplements: Foods enriched with iron, vitamins, and antioxidants are tailored to prevent deficiencies. Supplements like multivitamins and iron tablets are widely used to address specific nutritional needs.

Antioxidant-Rich Diets: Research supports incorporating natural antioxidants, such as flavonoids and carotenoids, into high-altitude diets. Functional foods like fortified teas and herbal extracts are designed to combat oxidative stress.

Portable Cooking and Preservation Technologies: Lightweight stoves and solar-powered cookers enhance the ability to prepare warm, nutrient-rich meals. Vacuum-sealed and freeze-dried food packaging ensures long-term preservation without nutrient loss.

Hydration Solutions: Advanced hydration systems, such as insulated water bottles and electrolyte-enriched fluids, help maintain hydration levels in cold conditions. Portable water purification devices ensure access to clean drinking water in remote areas.

Personalized Nutrition Plans: Advances in genetic and metabolic profiling allow for tailored diets that match individual physiological responses to high-altitude conditions.

CHECK YOUR PROGRESS EXERCISE 1

1. How does microgravity affect nutrient absorption and metabolism in space?

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2. What role does food packaging and preservation play in space nutrition?

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3. What are the main challenges in providing proper nutrition for individuals at high altitudes?

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4. What recent innovations in nutrition have been developed to address challenges at high altitudes?

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9.5 LOW TEMPERATURE

In cold environments, the body faces significant nutritional challenges, as maintaining body temperature and ensuring adequate energy reserves becomes essential for survival and performance. Exposure to low temperatures increases the body's basal metabolic rate (BMR) because the body works harder to generate heat. To keep the core temperature stable, the body requires more energy, often from food sources that provide high-calorie content, such as fats and carbohydrates. This increased energy demand can raise caloric needs by up to 50-100%, depending on the severity of the cold environment and the individual's activity level.

9.5.1 Nutritional Requirements in Low Temperature

- xv. **Calories:** Cold temperatures significantly increase the caloric requirements, particularly for individuals involved in physical labor or outdoor activities. The body burns more calories to maintain warmth, which means that an individual in a cold climate may need to consume up to 4,000-5,000 calories per day, depending on the level of exertion.
- xvi. **Fats and Carbohydrates:** High-fat foods provide a dense source of energy, as fats contain more than twice the calories per gram compared to proteins or carbohydrates. Fats are also essential for long-term energy reserves during periods of prolonged cold exposure. Carbohydrates, particularly complex carbs, provide a quick source of energy and are important for maintaining glycogen stores, which are needed to fuel muscles and maintain physical performance in cold conditions.
- xvii. **Proteins:** Protein is necessary for tissue repair and muscle maintenance. While protein requirements are generally stable in cold environments, higher protein intake may be needed if the individual is exposed to extreme cold for long periods, as it helps prevent muscle breakdown and supports the immune system.
- xviii. **Vitamins and Minerals:** Micronutrients like vitamin C, vitamin D, calcium, and iron are vital in cold environments. Vitamin D helps with calcium absorption and supports immune function, which is particularly important when the body is exposed to stress. Iron is crucial for hemoglobin production, which ensures adequate oxygen supply to tissues and supports metabolism during physical activity. Vitamin C is needed to maintain healthy connective tissues and reduce the risk of injuries, especially when the body is under stress.

9.5.2 Challenges in Low Temperature

- i. **Appetite Suppression:** Cold temperatures can suppress appetite, making it harder to meet increased calorie requirements. This is partly due to the body's focus on preserving heat, which redirects blood flow away from the digestive organs, slowing down the digestive process. This can lead to a decreased desire to eat and poor nutrient absorption.
- ii. **Dehydration:** Cold air is often dry, and although individuals may not feel thirsty, dehydration is a significant risk in cold environments. The body loses fluids through increased respiratory rate, where moisture is lost with each breath. Additionally, cold temperatures can cause the kidneys to increase fluid excretion in an effort to balance fluid levels. Since individuals tend to drink less water in cold conditions, it is essential to consume enough fluids, ideally in the form of warm liquids, to prevent dehydration.
- iii. **Impaired Digestion and Nutrient Absorption:** Exposure to extreme cold can reduce blood flow to the digestive system, slowing down the digestive process and impairing nutrient absorption. This can affect the body's ability to utilize the food it consumes, leaving the person at risk of nutritional deficiencies despite adequate caloric intake. Additionally, cold temperatures can increase the risk of gastrointestinal problems, such as bloating or constipation, as blood flow is diverted to vital organs and muscles rather than to the gut.
- iv. **Fatigue and Hypothermia:** If calorie and fluid intake are insufficient in cold conditions, the body becomes more susceptible to fatigue, frostbite, and hypothermia. As the body's energy stores deplete, its ability to generate heat diminishes, leading to a drop in core body temperature, reduced physical performance, and an increased risk of hypothermic conditions.

9.5.3 Addressing Nutritional Challenges

To overcome these challenges and ensure adequate nutrition in cold environments:

- **Eat energy-dense foods:** Focus on high-fat, high-calorie foods that can provide sustained energy. Examples include nuts, seeds, dried fruits, fatty fish, and meat.
- **Regular, small meals:** Since appetite may decrease in the cold, it is beneficial to consume smaller, more frequent meals throughout the day, which can help maintain a steady supply of energy and prevent fatigue.

- **Hydrate properly:** Even in cold environments, it's crucial to stay hydrated. Warm beverages like herbal teas or broths can provide hydration as well as additional warmth.
- **Consume warm, easy-to-digest meals:** Eating meals that are easy on the digestive system, such as soups or stews, helps prevent discomfort and allows for better nutrient absorption.
- **Include micronutrient-rich foods:** Ensure adequate intake of vitamins and minerals through foods like leafy greens, fruits, and fortified cereals, especially for vitamins D and C and minerals like iron and calcium.

By addressing these nutritional needs, individuals can better adapt to cold climates, maintain energy levels, and reduce the risk of cold-induced illnesses like frostbite or hypothermia.

9.6 SUBMARINE ENVIRONMENTS

Living and working aboard a submarine presents unique nutritional challenges due to confined spaces, limited resources, and the need for long-term sustenance in an isolated environment. Submarines, especially during extended missions, have restricted storage for food and limited opportunities for resupply, making careful attention to nutrition essential. The environment also presents challenges related to physical activity, water conservation, and mental health, all of which require specialized dietary considerations.

9.6.1 Nutritional Requirements in Submarine Environments

- Caloric Intake:** Submarine crews often work in physically demanding conditions, with tasks such as operating equipment, standing watch, and managing the vessel's systems. Despite this, the space limitations and lack of exercise may lead to a decrease in appetite. As a result, it is essential to provide a higher caloric intake (around 2,500–3,500 kcal/day) to ensure that the crew has the energy needed to meet the physical and mental demands of their duties. High-calorie, nutrient-dense foods, particularly those rich in fats and carbohydrates, are essential to maintain energy balance during long missions.
- Proteins:** Protein intake is vital for muscle maintenance and repair, especially for submarine crews who are performing physically strenuous tasks in tight, often uncomfortable spaces. Protein helps maintain muscle mass and supports the immune system. It is crucial that a variety of protein-

rich foods, such as meat, fish, legumes, and dairy products, be included in the submarine's diet to ensure adequate intake for the crew.

- iii. **Vitamins and Minerals:** In the closed environment of a submarine, fresh fruits and vegetables are often limited or unavailable, which can lead to deficiencies in key vitamins like vitamin C, vitamin D, and folate. Vitamin C is essential for immune function and preventing scurvy, while vitamin D supports bone health, particularly important when natural sunlight exposure is minimal. Minerals like calcium and iron are also essential, as the lack of fresh produce can result in deficiencies that negatively impact bone health and oxygen transport, respectively. Fortified foods and supplements are often necessary to meet these nutritional needs.
- iv. **Hydration:** Access to fresh water on a submarine is often limited, with many submarines relying on desalination processes to convert seawater into potable water. This process requires careful management to avoid water shortages. Maintaining hydration is critical, as dehydration can lead to fatigue, poor cognitive function, and increased susceptibility to illness. Submarine crews must be vigilant about water consumption and may be required to ration their water intake to ensure adequate supplies for the duration of their missions.

9.6.2 Nutritional Challenges in Submarine Environments

- **Limited Food Storage and Variety:** The confined space aboard submarines limits the ability to store large quantities of fresh food. Most submarine meals are freeze-dried, canned, or packaged, which can affect taste and nutrient retention. The lack of variety in meals can lead to “menu fatigue,” where crew members become disinterested in the available food options, potentially reducing their caloric intake and overall nutrition.
- **Reduced Appetite and Mental Health:** Extended periods of confinement, limited natural light, and isolation can lead to stress, depression, and anxiety among submarine crew members. Mental health issues can affect appetite and food intake, potentially leading to undernutrition or fatigue. To combat this, it is important to provide a variety of meal options and incorporate comfort foods that can improve morale and enhance the overall dining experience.
- **Food Spoilage and Safety:** While submarines are equipped with refrigeration units to preserve food, the limited storage capacity and potential for equipment malfunction can lead to issues with food spoilage. Proper storage and monitoring of food quality are essential to prevent foodborne

illnesses, which could have serious consequences in an isolated environment where medical support is limited.

- **Nutrient Absorption and Digestion:** Submarine crews may face challenges in nutrient absorption due to the stress of a demanding environment. Poor digestion and absorption can lead to gastrointestinal discomfort and malnutrition. To minimize this, it is important to provide easily digestible, high-quality foods that promote healthy digestion.

9.6.3 Strategies to Address Nutritional Challenges in Submarine Environments

To ensure the crew's health and performance, several strategies can be employed:

29. **Caloric Density and Nutrient-Rich Meals:** Meals should be designed to provide sufficient calories and a wide array of nutrients to meet the energy demands and prevent deficiencies. Nutrient-dense foods, such as fortified cereals, energy bars, and high-quality protein sources, are essential.
30. **Supplementation:** Given the limited availability of fresh fruits and vegetables, vitamin and mineral supplements, especially those containing vitamin C, D, and calcium, can help ensure that the crew is receiving adequate nutrition and prevent deficiencies.
31. **Hydration Management:** Submarine crews must manage water use efficiently, consuming enough fluids to stay hydrated without depleting the available water supply. Regular monitoring of water intake and ensuring adequate hydration with water, tea, and other low-calorie beverages is necessary.
32. **Meal Variety and Morale:** To maintain appetite and improve morale, a variety of foods should be offered, including comfort foods and those with different flavors and textures. This variety can help prevent menu fatigue and keep the crew engaged in maintaining a healthy diet.

By carefully addressing these nutritional requirements and challenges, submarines can support the health and well-being of their crew members during long, isolated missions, ensuring they have the energy and nutrients needed for optimal performance.

1. How do nutritional needs change in cold environments to prevent hypothermia and maintain energy levels?

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2. What role do fats and carbohydrates play in nutrition at low temperatures?

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3. What are the main challenges in ensuring adequate nutrition in a submarine environment?

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9.7 LET US SUM UP

In extreme environments, such as space, high altitudes, low temperatures, and submarine settings, the challenges of maintaining proper nutrition are significant. Each of these environments presents unique conditions that affect the body’s nutritional needs, metabolism, and food consumption. In space, microgravity alters nutrient absorption, requiring specialized food packaging and management strategies to ensure astronauts get the necessary nutrients. Innovations like sustainable space food production are critical for long-term missions. At high altitudes, reduced oxygen levels increase energy demands, and special attention is needed to ensure adequate calorie intake, hydration, and the balance of essential nutrients like iron. Nutrition at high altitudes must also address appetite suppression and digestive changes. In low-temperature environments, the body requires more energy, particularly from fats and carbohydrates, to combat cold stress and maintain body heat. Nutritional strategies in such

conditions focus on providing high-energy foods and ensuring adequate hydration. Similarly, in submarines, space constraints and the need for long-term food preservation create challenges, requiring careful planning and innovative storage methods. Overall, advances in nutrition for extreme conditions are essential for the health, performance, and safety of individuals in these environments, and continued research is necessary to optimize food systems and address these challenges effectively.

9.8 GLOSSARY:

Space Travel: The act of traveling beyond Earth's atmosphere, where unique conditions like microgravity affect physiological processes, including nutrition.

Microgravity: A condition in which the force of gravity is significantly weaker than on Earth, such as in space, affecting bodily functions like digestion and fluid balance.

Hydration: The process of providing adequate fluids to the body to maintain normal physiological functions.

Space Food: Specially designed food that meets the nutritional needs of astronauts while being stable, lightweight, and easy to prepare in space.

Space Adaptation Syndrome: A collection of symptoms experienced by astronauts due to prolonged exposure to microgravity, including changes in fluid balance and appetite.

Altitude Sickness: A condition that can occur at high altitudes, causing symptoms such as dizziness and nausea due to reduced oxygen levels and changes in the body's fluid balance.

Cold Stress: The physiological strain on the body caused by exposure to cold temperatures, increasing energy and nutritional needs.

Submarine Nutrition: The specific nutritional planning and challenges related to feeding individuals living in confined, isolated environments like submarines for extended periods.

9.9 ANSWER TO CHECKYOUR PROGRESS

EXERCISE 1

1. Microgravity in space affects nutrient absorption and metabolism by altering the way the body processes food and nutrients. In microgravity, the digestive system may experience slower gastric emptying and reduced blood flow to the intestines, which can affect nutrient absorption. Additionally, changes in fluid distribution and muscle mass in space can impact metabolism, leading to a decrease in energy expenditure. These factors necessitate adjustments in space food design and nutrient delivery to ensure astronauts receive adequate nutrition for maintaining health and performance during long-duration missions.
2. Food packaging and preservation play a crucial role in space nutrition by ensuring that food remains safe, nutritious, and stable during long-duration space missions. Packaging must protect food from contamination, spoilage, and degradation while being lightweight and compact. Preservation methods, such as freeze-drying or vacuum-sealing, help maintain the food's nutritional value and extend shelf life without the need for refrigeration. Effective packaging and preservation are essential to meet astronauts' nutritional needs and minimize waste in the limited space available on spacecraft.
3. The main challenges in providing proper nutrition at high altitudes include reduced oxygen levels, which increase energy demands and affect appetite. Individuals may experience decreased appetite, digestion issues, and dehydration, making it harder to consume sufficient calories and fluids. Additionally, higher altitudes can lead to an increased need for nutrients like iron, which supports oxygen transport, and electrolytes, to maintain fluid balance.
4. Recent innovations in nutrition for high altitudes include the development of high-calorie, easy-to-digest foods that help overcome reduced appetite and energy needs. Freeze-dried meals and nutrient-dense snack bars are designed to be lightweight, compact, and provide essential nutrients like iron, protein, and electrolytes. Additionally, research has led to the creation of supplements that support hydration and prevent altitude sickness, such as those containing vitamin B12, folate, and iron.

EXERCISE 2

1. In cold environments, nutritional needs increase to prevent hypothermia and maintain energy levels. The body requires more calories, particularly from fats and carbohydrates, to generate heat and maintain body temperature. Fats provide a long-lasting energy source and help insulate the body, while carbohydrates offer quick energy to support physical activity. Additionally, adequate hydration is crucial, as cold temperatures can lead to dehydration despite lower thirst signals. Proper intake of vitamins and minerals, especially those that support metabolism and immune function, is also important to prevent cold stress and maintain overall health in such conditions.

2. At low temperatures, fats and carbohydrates play a critical role in maintaining energy and body heat. Fats provide a concentrated source of energy, which is essential for sustaining body temperature and preventing cold stress. They also help to protect vital organs by providing insulation. Carbohydrates, on the other hand, offer a quick-release source of energy to support metabolism and physical activity in cold environments. The body relies on both fats and carbohydrates to generate heat through thermogenesis and to maintain energy levels, especially in environments where energy expenditure is high due to cold exposure.

3. The main challenges in ensuring adequate nutrition in a submarine environment include limited space for food storage, restricted access to fresh foods, and the need for long-term food preservation. Additionally, the confined environment may lead to monotony in the diet, making it harder to meet all nutritional needs. The lack of sunlight and fresh air can affect vitamin D synthesis and overall well-being.

**BLOCK-IV: INTRODUCTION OF FOOD AND FUNCTIONS, NUTRIENT FUNCTIONS,
AND ADAPTATION OF NORMAL DIET**

INTRODUCTION

Block-IV serves as a foundational yet comprehensive exploration of food, its multifaceted roles, and the principles of diet adaptation, providing M.Sc. students with essential knowledge to understand the relationship between food, nutrition, and health. This block is structured into three interconnected units that bridge basic concepts of food science with the applied aspects of diet planning and nutrient management, emphasizing both theoretical and practical dimensions of nutrition education.

UNIT 10: INTRODUCTION OF FOOD AND FUNCTIONS OF FOOD

This unit provides an essential foundation for understanding the interrelationship between food, nutrition, and health. It begins with the basic concepts in food and nutrition, emphasizing their role in human well-being. The functions of food are explored in depth, categorized into physiological (e.g., energy provision, tissue repair, and maintenance of metabolic functions), psychological (e.g., comfort, satisfaction), and social (e.g., cultural and communal bonding) aspects. The unit introduces students to the classification of food into groups, the concept of a balanced diet, and the use of tools like the food pyramid for dietary planning. Additionally, it defines key terms used in food science and nutrition, such as health, food, nutrition, and nutrients, establishing a shared vocabulary for advanced discussions.

UNIT 11: NUTRIENT FUNCTIONS

This unit dives into the core functions of nutrients, their classification, and their critical role in maintaining health and preventing disease. It provides a detailed overview of the dietary sources, biochemical functions, and physiological roles of macronutrients, including carbohydrates, lipids, and proteins. Students will explore recommended dietary allowances (RDA) for these nutrients and learn to identify clinical signs and symptoms of their deficiency or excess. This unit equips students with the knowledge to analyze nutrient intake critically and assess the impact of imbalances on health, offering a deeper understanding of how energy-yielding nutrients contribute to the body's structure, function, and metabolism.

UNIT 12: ADAPTATION OF NORMAL DIET

This unit introduces the principles and practices involved in adapting a normal diet to meet varying qualitative and quantitative nutritional needs. It covers the types of diets and their modifications based

on individual health conditions, cultural preferences, and specific life stages. The unit also explores the various modes of feeding, including oral, enteral, and parenteral nutrition, as applied in clinical and community settings. By the end of this unit, students will develop the skills to design and evaluate dietary plans tailored to individual or group needs, ensuring that nutritional requirements are met effectively under diverse circumstances.

These units collectively provide M.Sc. students with a well-rounded understanding of the fundamental and applied aspects of food and nutrition, laying the groundwork for more specialized studies in nutrition science and dietetics.

UNIT-10 INTRODUCTION OF FOOD AND FUNCTIONS OF FOOD

You will learn the definitions of nutrients, food science, food and nutrition in the current unit. You will additionally learn about the way we feel towards food are affected by societal and physiological variables.

Structure

10.0 SCOPE

10.1 OVERVIEW

10.2 INTRODUCTION OF FOOD

10.2.1 BASIC CONCEPTS IN FOOD AND NUTRITION

10.2.2 Learning about the relation between Nutrition, Diet and Health

10.3. FUNCTIONS OF FOOD

10.3.1 Physiological, Psychological and Social

10.3.2 Food Groups

10.3.3 Food Pyramid

10.3.4 Definitions and terms used in Food Science and Nutrition Health, Food, Nutrition and Nutrients

10.4 LET US SUMMERISE

10.5 GLOSSARY

10.6 EXERCISES TO CHECK YOUR PROGRESS ANSWERS

10.0 SCOPE

You will be able to do the following after studying this unit:

- Discuss Basic concepts in food and nutrition
- Describe Understanding relationship between food Nutrition and Health
- Explain Functions of Food, food groups, food pyramid
- Definitions and terms used in Food Science and Nutrition Health, Food, Nutrition and Nutrients

10.1 OVERVIEW

Every living thing needs food. Food is what we consume to maintain our health, growth, and ability to work, play, and grow. Foods can be viewed as a composite mixture of different chemical components that, when consumed, satisfy both hunger and taste. One of our fundamental needs is food. Our existence has always depended on Nourishment. As you learn more about the science behind foods and nutrition, you must carefully evaluate your beliefs about food and choose either to accept or reject them. You should use whatever you study in the course in daily life.

10.1 INTRODUCTION OF FOOD

All of the food that is present in nature is not consumed by civilized people. Before eating, they chop, smashes, cools, prepares, and changes in a number of ways to provide diversity to the diet. You can determine the nutritional value of foods by studying dietary composition. You may have heard that some meals are essential for sustaining good health. We now have a plethora of knowledge about how to utilize food to guarantee kids and young people grow, in order to stay healthy throughout life, to meet the unique demands of nursing and motherhood, as well as for usage in using it to heal from illness.

10.2.1 BASIC CONCEPTS IN FOOD AND NUTRITION

Nutritional science investigates how food interacts with a person to maintain and improve health. All bodily parts obtain and utilize the nutrients necessary for their tasks, as well as for the growth and regeneration of every component (rejuvenation), through a series of processes known as nutrition. Food may be a substance which is consumed for the nutritional, growth, and reproductive purpose. The definition of optimal nutrition involves getting and using vital nutrients in the right amounts as needed by the body, but also maintaining a "reserve."

“State of complete physical, mental and social wellbeing and not merely the absence of disease and infirmity” definition given by WHO (World Health Organization)

The following are some of the main requirements (or qualities) of "health":

- Obtaining optimal growth and development while fully expressing one's hereditary ability.
- Maintaining the structural uprightness and functional productivity of the body tissue required for a healthy and constructive life. The capacity to age with minimum disability and impairment in function, and

- The capacity to fight illness, including
 - (a) The ability to fend off infections (immune competence),
 - (b) The ability to halt the progression of cancer and degenerative diseases, and
 - (c) The capacity to fend off the effects of environmental poisons and pollutants.
- Mental Health
- Happiness in society is the capacity to coexist peacefully with other people.

Vital nutrients are the component in food which might be provided to the physique in sufficient quantity such as Carbs, Fats, Proteins, Vitamins, and minerals as well as Water.

A person's nutritional status is their state of health as it relates to how well they use their nutrients. It can only be established by comparing the data gathered through a rigorous medical and nutritional history, a thorough physical examination, and the right scientific analysis.



Fig10.1 Essential Nutrients

10.2.2 LEARNING ABOUT THE RELATION BETWEEN NUTRITION, DIET, AND HEALTH

The foods we eat affect our health. Consuming a diet rich in the right nutrients in the right levels is crucial for maintaining good health. A balanced diet comprises various kinds of food in enough

amounts as well as proportion which are requirement for energy, fats, proteins, vitamins and minerals is sufficiently supplied, and a small amount of supplements prevent short-term weight gain.

In promoting health, diet has always had a vital role to play. The general welfare of human beings is strongly influenced by the quality of nutrition. The foods we eat have an influence on our state of health and wellness. Malnutrition occurs when there is a deficiency in the intake and use of nutrients. Lack of nutrition may have an impact on energy levels, alertness, mobility, stability, and healing. An imbalance in nutritional intake due to large quantities of one or more food types leading to obesity, protein energy malnutrition etc. or specific, i.e. excess nutrients that are possibly caused by poor eating habits or underlying disease such as vitamin C deficiency, iron deficiency anemia etc.

The deficiency in nutrients caused by the lack of food intake is called undernutrition. This has a major effect on how much of the nutrients in your body are balanced. Serious health and nutritional problems, like weakened immunity, recurrent infections, hormone changes, decreased body fat index, reduced efficiency of work, lower growth in children, higher costs for medical treatment or even a decline in quality of life can result from the absence of adequate nutrition when combined with an unhealthy diet.

Overnutrition is the opposite of undernutrition, which is caused by the frequent or habitual consumption of nutrients by eating too much food that is dangerous to health. Even if most nutrients are harmful in excess, the risk of overnutrition is mainly due to carbohydrates and fats. Obesity, which occurs because of the accumulation of an excessive amount of body fat, is a serious form of malnutrition.

Obesity increases the chance of developing chronic diseases that include high blood pressure Type 2 diabetes, cancer, stroke, coronary artery disease, joint pain, problems with the liver, breathing problems, and restricted movement. The health effects of these disorders vary from premature mortality to disability.

Consequently, correct eating choices that result in excellent nutrition might provide the following benefits:

- Promotion of children's optimum prospective growth and development
- The risk of developing chronic diseases like Heart disease, Cancer, Diabetes, Obesity, Osteoporosis, Iron deficiency, and Dental Caries (Cavities) has decreased.
- Have healthy, productive life.

ASSESS THE PROGRESS OF YOUR SESSIONS 1

1) What do you understand by basic principles in Nutrition?

2) What are the basic relationships between Food, Nutrition and Health?

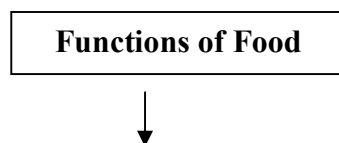
3) How do you understand the term “Under nutrition” and “over nutrition”?

PHYSICAL ACTIVITY 1

1) Create a poster illustrating the signs and measures to prevent obesity.

10.3. FUNCTIONS OF FOOD

All living things require food to survive. Food may be categorized based on its functions in the body.



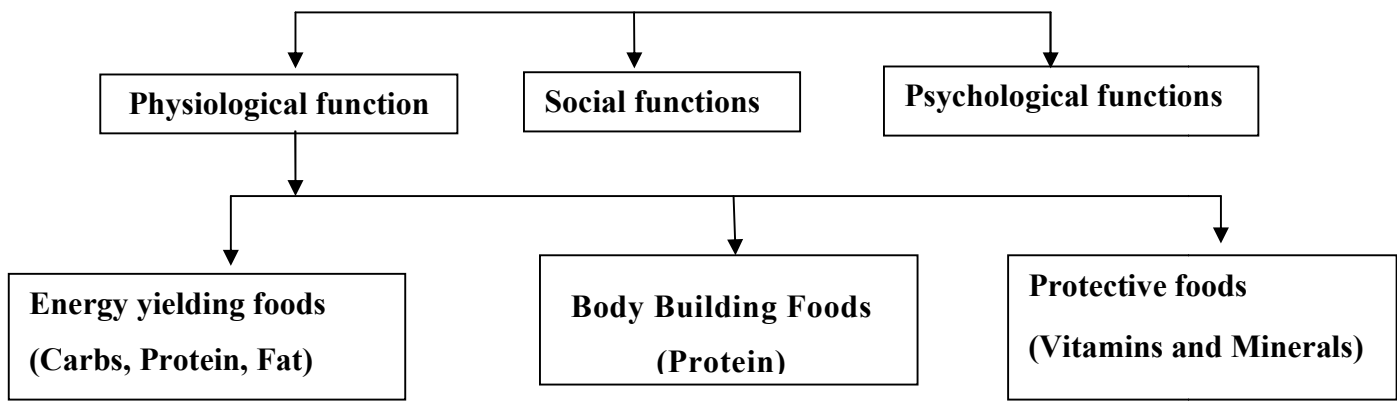


Fig 10.2 Functions of Food

What we consume, which nourishes our bodies, is referred to as "food." It consists of solids, semi-solids, and liquids. It should be palatable, or 'edible' and nourish our body also. The food we consume needs to be harmless and include all of the nutrients our bodies require. We must consume a broad range of meals and do so on a regular basis, throughout the day. Keep in mind that the food we eat must taste good and look, odor, and be enjoyable. Inadequate nutrition, kids as well as teenagers may not reach their full potential, and elderly struggle to perform at their best.

i. Energy yielding foods

That category contains foods overwhelming in carbohydrate, fats as well as protein. 1gram of carbohydrate has 4 calories. 1 gram of protein has 4 calories. 1 gram of fat has 9 calories. These could be classified into two different categories such as:

- Cereals, Pulses, Roots, and tubers
- Carbohydrate like sugars, Oils and Fats fondness and safety
Growth and regeneration Energy Regulation

Food Party

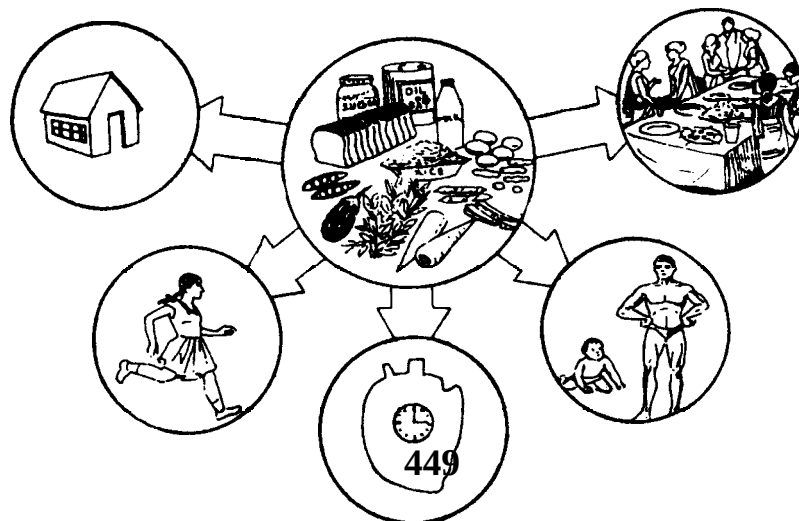


Fig 10.3 Various functions of Food

Grains of cereals contribute good quantities of proteins, minerals, and vitamins to the food along with energy. Along with providing energy for the body, pulses also include protein and B vitamins. Despite the fact that roots and tubers primarily give energy, which is also contribute less amount of minerals and vitamins. Simple carbohydrates, such as sugar, solely contain energy (i.e., empty calories) but fats also include concentrated energy sources.

ii) Body Building Foods

Protein-rich diets are known as "body building foods." These are divided into two categories.

- Milk, meat, eggs and seafood:

They include a lot of proteins with significant biological importance. These kinds of proteins contain all of the necessary proteins needed in the appropriate amounts towards the formation of body tissues.

- Pulses, nuts, and oil seeds:

Despite having high protein content, they are unable to supply the entire range of amino acids needed for the body of a person to function properly.

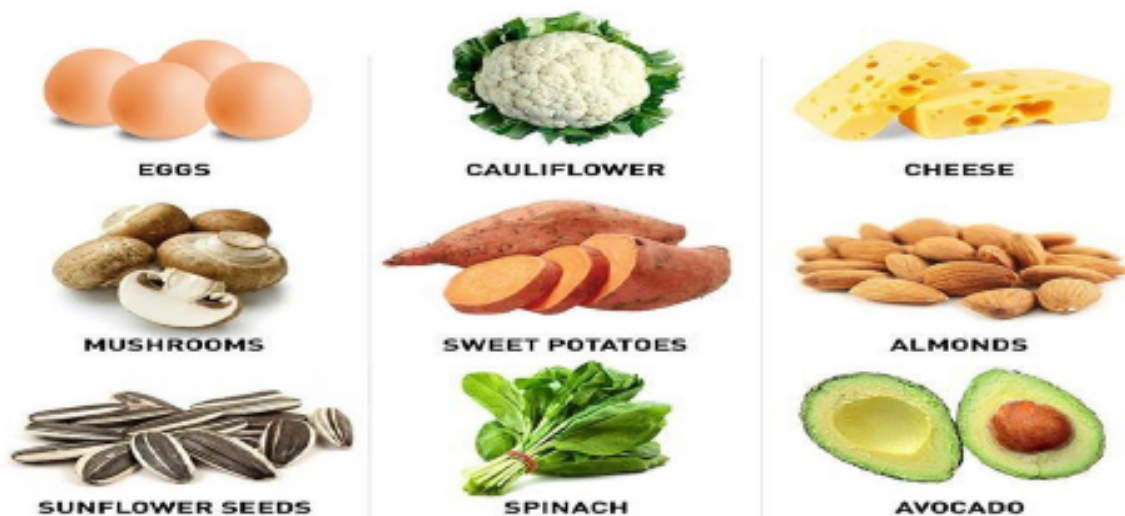


Fig
10.4

Energy giving foods

ASSESS THE PROGRESS OF YOUR SESSIONS 2

1) Fill in the blanks.

- a) Body building foods are those that are high in _____.
- b) _____ are good in protein of high biological value.
- c) 1 gram of carbohydrate provide _____ calories.
- d) 1 gram fat provide _____ calories.
- e) Nuts and oilseeds are rich in _____.



Fig 10.5 Body building foods

iii) Protective foods

Food that contains vitamins, protein as well as minerals serve as regulators in the body as keep the body's temperature, water balance, and heartbeat are roughly divided into two categories.

- Vitamin and high in minerals foods, as well as high-biological-value proteins, such as milk, eggs, salmon, and liver.
- Foods those are particularly high in a certain vitamin or mineral, such as some fruits and green leafy vegetables.

Table 10.1 Function of foods

Food Groups	Food sources
Energy Giving Foods	Wheat, Rice, Millets, Potatoes, Yam, Sweet Potatoes
Body building foods	Lentils, Beans, Peas, Green grams, Meat, Eggs, Ground Nuts, Fish, Milk
Protective foods	Vegetables and fruits

ASSESS THE PROGRESS OF YOUR SESSIONS 3

1) Give the names of five foods that help us stay healthy.

- a) _____
- b) _____
- c) _____
- d) _____
- e) _____

2) List five foods that give us energy.

- a) _____
- b) _____
- c) _____

10.3.1 PHYSIOLOGICAL, SOCIAL AND PSYCHOLOGICAL FUNCTIONS

- **Physiological functions of food.**

The body's initial purpose is to give you energy. The body requires energy to support the natural functions required for life to continue, to perform professional, home, and leisure activities, to transform food taken into useable nutrients in the body, to develop, and to remain warm. The process of oxidation of the nutrients ingested provides the required energy. What we eat becomes a part of us. Thus, one of the more significant roles of eating is body formation. If the proper types and quantities of food are consumed from birth until adulthood, a newborn infant weighing 2.7-3.2 kg

may grow to its full adult size of 50-60 kg. Daily dietary intake contributes to the maintenance of the adult body's composition and the replacement of the body's worn-out cells.

The key role of food is to control bodily activity. It governs a wide range of activities, including:

- Heart beating
- Keeping the body temperature stable
- contraction of muscle
- water balance controls
- blood clotting
- Elimination of waste through the body
- The 4th purpose of eating is to increase our body's ability to fight against illness.

• **Social Functions of Food**

Our social existence consistently been focused on food. Our community's social, cultural, and religious lifestyle has included it. At religious events held in homes, temples, and churches, special delicacies are given out as *prasad* or a blessing. Celebrations are held at particular life's stages, including birth, naming ceremony, anniversaries, marriages, etc. The majority of religious occasions require that certain groups of people be fed at feasts. Most of these feasts are connected with specific cuisine in each location.

Food has long been used to communicate affection, camaraderie, and acceptance by society. *Pedha* are given out for a successful exam or the birth of a child, *laddus* are connected with Deepawali festivals and weddings, desserts are mostly served in birthdays parties, and *tilgul* is linked to with the occasion of happiness. *Sankranti* is also celebrating with friendship and happiness.

Because food is such a crucial component of our societal existence and its role is essential in routine lifestyle. A comfortable mood is produced by the provision of refreshments during gatherings. The food for such a gathering should draw people together rather than separate them. This fundamental component must be addressed while creating menus for such events.

• **Psychological Functions of Food**

Foods help people with their emotional demands in addition to their bodily and social needs. They consist of acceptance, affection, and a feeling of security. Making delectable meals for family members, for instance, is a sign of care as well as affection.

Each of us has emotional needs, such as the desire for safety and love. Food can be crucial in satisfying these demands. Making the child's favorite food is one way a mother may show her child how much she cares. Giving food away as a kind of punishment for bad behavior is also an option. When given food they are accustomed to eating, people feel confident and at ease. Many people utilize food as a way to relieve stress and irritation, whereas others who are sad and lonely may eat less or refuse meals. Sago *kheer* and *Khichdi* are two dishes that may be connected to illness, whereas *Pedha* is connected to good news. As a result, eating is closely related to feeling and mood.

ASSESS THE PROGRESS OF YOUR SESSIONS 4

- 1) Explain the body-building function of food.

- 2) Mention the societal significance of food.

PHYSICAL ACTIVITY 1

- 1) Which foods are commonly linked with the following types of events/situations that are made in your family's house?
- a) Birthday party
 - b) Marriage
 - c) Holi, Deepawali, Makar Sankranti

10.3.2 FOOD GROUPS

Because they contain equivalent amounts of the necessary nutrients, foods are arranged together in order to meet your body's dietary needs for optimum health, you must eat a variety of foods through each of the five categories of food each day in the given quantities.

For the convenience of preparing meals, foods have been divided into distinct groups based on their nutritional content. Meals can be planned according to convenience using food groupings like "Basic Four," "Basic Five," or "Basic Seven."



Fig 10.6 Five Basic Food Groups

- BASIC FOUR**

S.No.	Group	Nutrients

1.	Cereals, Millets and Pulses	Energy, Protein, B-Vitamins
2.	Vegetables and Fruits	Vitamins, Minerals and Fibre
3.	Milk, Milk products, and animal foods	Protein, Calcium B-vitamins
4.	Oils, Fats, Nuts and Oilseeds	Energy, Protein (Nuts and oil seeds)

II Basic Five: ICMR

Group	Nutrients
Cereals, Grains and Products: Rice, Wheat, Ragi, Maize, Bajra, Jowar, Rice flakes, puffed rice	Energy, Protein, Invisible Fat, Thiamine, Folic Acid, Riboflavin, Iron and Fibre
Pulses and Legumes: Bengal gram, Black gram, Cow pea, peas(dry) Rajma, Soya, Beans	Energy, Protein, Invisible Fat, Thiamine, Folic Acid, Riboflavin, Calcium, Iron and Fibre
Milk and Meat Products i) Milk, Curd, Skimmed Milk, Cheese ii) Chicken, Liver, Fish, Egg and Meat	Protein, Fat, Riboflavin, Calcium, Protein, Fat, Riboflavin
Fruits and Vegetables: Fruits:	

Mango, Guava, Tomato Ripe, Papaya, Orange. Sweet Lime, Watermelon. Vegetables (Green Leafy): Amaranth, Spinach, Gogu, Drumstick leaves, Coriander leaves, Mustard leaves, Fenugreek leaves. Other Vegetables: Carrots, Brinjal, Ladies finger, Capsicum, Beans, Onion, Drumstick, Cauliflower.	Carotenoids, Vitamin –C, Riboflavin, Folic Acid, Iron, Fibre. Riboflavin, Folic Acid, Calcium, Fiber, Iron, Carotenoids, Carotenoids, Folic Acid, Calcium and Fibre
Fats and Sugars: Fats: Butter, Ghee, Hydrogenated Oils, Cooking Oils like Groundnut, Mustard, Coconut. Sugars: Sugar, Jaggery	Energy, Fat, Essential fatty Acids and Fat-Soluble Vitamins Energy, Iron (From Jaggery)

III. BASIC SEVEN

Groups	Nutrients
Green and Yellow Vegetables	Carotenoids, Ascorbic acid, and Iron
Oranges, Grape Fruit, Tomatoes or Raw Cabbage	Ascorbic acid
Potatoes, Other Vegetables And Fruits	Vitamins and Minerals in general and Fibre of Cellulose
Milk and Milk Products	Calcium, Phosphorus, Protein and Vitamins
Meat, Poultry, Fish and Eggs	Proteins, Phosphorus, Iron and B Vitamins
Bread, Flour and Cereals	Thiamine, Niacin, Riboflavin, Iron, Carbohydrate and Fibre
Butter or Fortified Margarine	Vitamin A and Fat

While planning a balanced diet, include dishes from each category in sufficient amounts. You should consume enough grains and pulses, various fruits and vegetables, good amounts of animal products, and little to no oils and sweets.

PRACTICAL ACTIVITY 2

- 1) You group foods and discuss about their nutritional value.

ASSESS THE PROGRESS OF YOUR SESSIONS 5

- 2) Which nutrients do cereals, millets, and pulses give us when we eat them?

10.3.2 Nutrient Density

It is the amount of a variety of nutrients provided by a food in relation to its actual amount of calories. When comparing the proteins content of isocaloric servings of dhal, bread, and dairy products, you will find that dhal has the greatest nutritional density for protein, followed by milk, while bread has the lowest. Therefore, nutritional density should be taken into account while choosing foods that are suitable for the diets of youngsters, pregnant women, nursing mothers, and patients on diets for therapeutic purposes.

10.3.3 Function of Nutrients

We consume a variety of foods on a regular basis, including grains such as wheat and rice, dal, fruits and vegetables, eggs, dairy products, meat, fish, sugar, fat, and oils. These various foods include a various types of chemical substances referred as nutrients. These nutrients are categorized referring to their chemical constituents. Although every component category serves a distinct purpose, every

nutrient requires cooperation together to be successful. Carbohydrates, proteins, lipids, mineral, vitamins as well as water are the nutrients that are present in food. Another crucial element of our daily meals is fibre.

Carbohydrates: Foods that include carbs include the starch from grains and sugar from sugarcane and fruits. The major function of carbohydrates' is give energy to our body. Those which are not used immediately for this reason are retained as glycogen or converted to fat and preserved, to be used for supply of energy whenever required.

Fat: Examples of fats that may be present in diet include lard by beef, cream from milk as well as the oils contained in seeds. In addition to serving as transporters for vitamins that are fat-soluble and being a supplier of important fatty acids, fats constitute significant as suppliers of energy. Excessive fats in foods are retained as fat accumulated within the body. Extra energy consumed than the body requires becomes deposited as fat.

Protein: Casein from dairy products, albumin from eggs, globulins from legumes, while gluten from wheat is all kind of proteins that are present in the diet. Proteins are mostly used in the growth novel tissues in addition to maintaining and making repairs of previously established tissues. Additionally, the manufacture of regulatory and defence-related molecules including enzymes, hormone and antibodies involves the use of dietary proteins. Ten percent of the total amount of energy utilized by the diet comes from proteins. Protein that is taken in surplus of what the body needs is converted into fats and carbohydrates and retained as fat in the body.

Minerals: Minerals such as phosphorus, iron, calcium, iodine, salt, potassium, and many more can be identified in a range of foods that include both inorganic and organic ingredients. Minerals are necessary for the development of the muscles, bones, teeth, and structural elements of tissues that are soft. It also help to regulate a variety of biological processes, such as blood clotting, neuron activation, contractions of muscles, and several more.

Vitamins: Diet includes both water-soluble vitamins C and B group and fat-soluble vitamins A, D, E, and K. These are essential for development, healthy bodily operation, and regular bodily functions.

Water: We obtain water via the meals and drinks we consume, as well as from the water we drink directly. Our bodies are mostly made up of water, which makes up around 60% of our total body weight. Water is required for the body to utilize nutrients as well as to eliminate wasted food. It regulates biological activities such as controlling temperatures.

Everyone needs similar nutrients to live a life of wellness. The sole difference is the amount of every nutrient required based on characteristics such as age, size, activity level, and so on. Everyone needs energy for work, although a man who carries goods may need more than a man who sits at a desk in a work environment. You probably already know that we get our nutrients from the food and drinks that we consume. The majority of diets contain the nutrients at various levels.

ASSESS THE PROGRESS OF YOUR SESSIONS 6

- 1) Why nutrients are crucial to maintaining our health?

10.3.3 FOOD PYRAMID

The food pyramid is designed to be used by the majority of healthy people as a reference for the kinds of foods and their proportions to be present in a routine diet. The food pyramid has been created to help for choosing foods from each dietary group. To maintain excellent health, the food pyramid makes it very explicit that we should eat something from all five food categories. In addition, it advises us to take fewer of the foods at the high of the food pyramid, like as sugars and lipids, in comparison to the cereals and pulses at the base of the pyramid. The food pyramid may be used to design a balanced diet and make it easier to choose substitute foods. It also promotes optimum health.

The US Department of Agriculture produced the Food Guide Pyramid in 1992. It has six food categories and was created to reflect changing consumer eating patterns and to provide the department's official advice on what is healthy for humans. The pattern gradually becomes narrower as it ascends from a wide base. The six food categories are arranged in the pyramid according to their daily portions and importance:

1. 6to11serving of bread, cereal and pasta
2. 3to5portionofvegetables
3. 2to4servingsoffruits
4. 2to3 servings of milk, yogurt, and cheese
5. 2to3servingsofmeat,poultry,fish,beans,eggsandnuts
6. Oils, fats, and sugars are at the top of the pyramid and take up the least amount of space.

The "my pyramid" version, which was revised in 2005, helped people pick the proper foods and servings to balance their physical activity. Any healthy person over the age of two is intended to use it.

10.3.4 DEFINITIONS AND TERMS USED IN FOOD SCIENCE AND NUTRITIONHEALTH, FOOD, NUTRITION AND NUTRIENTS

Food Science: Food science is a synthesis of several distinct chemical substances. Food science is the study of the changes that present in these nutrients while preparing food which are organic or produced through handling processes. When food is prepared, numerous physical and chemical reactions take place. Understanding the nutritional content of various foods and how to preserve them during cooking are also important aspects of food science studies.

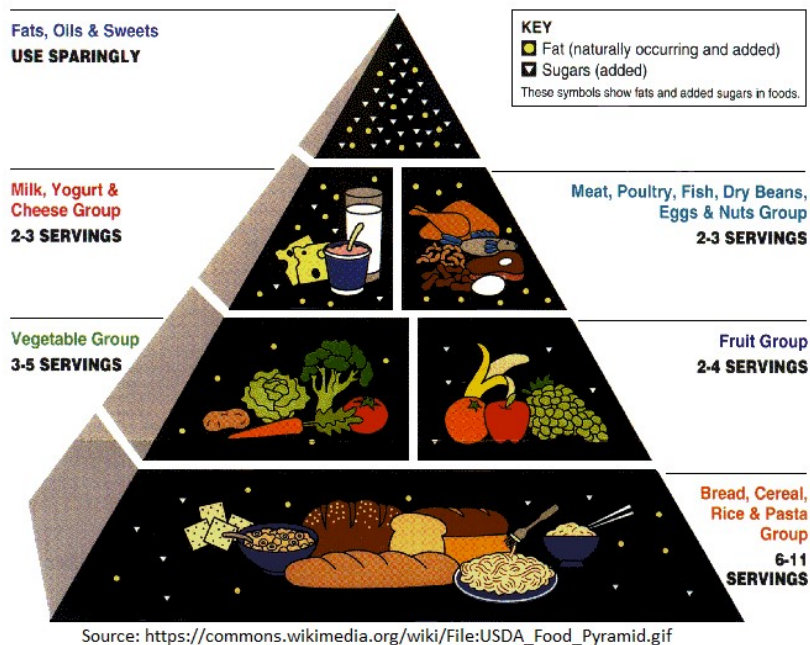


Fig 10.7 Food Pyramid (Source: Food guide pyramid, USD)

Nutrition: The process through which living beings obtain the nourishment they need to be healthy is known as nutrition. The study of all bodily functions that depend on the breakdown and assimilation of food, as well as the analysis of that food, is known as nutrition.

Health: The WHO defines health as "a state of complete physical, mental, and social well-being, rather than merely the absence of disease or infirmity."

Food: The substance consumed through food helps the body satisfy its demands for growth, energy, maintenance of health, and reproduction.

Nutrients: Nutrients are essential for the body to grow, reproduce and live a healthy life. Nutrients are dietary ingredients. Proteins, water, lipids, carbs, vitamins and minerals comprise the nutrients.

Food Technology: Food technology refers to the science and engineering of processing and preserving large quantities of food using food science principles.

ASSESS THE PROGRESS OF YOUR SESSIONS 7

1) What do you understand by the term nutrients?

2) What is food pyramid?

3) How do you apply your understanding of nutrition?

10.4 LET US SUMMRISE

The most fundamental requirement for existence is food. Everyone eats, and the majority of people prefer it. Today, nutrition plays a crucial role in our daily lives. We now understand that how well the cells in our bodies are nourished determines the quality of our health. Many people eat what they want or because it is the norm or out of habit. The fact that they are aware of a food's nutritional content has no impact on their choice of food. Few individuals are aware of how the body uses food. It's also important to understand that tasty food doesn't always mean this is healthy.

Having a healthy diet is a goal that every person can achieve. The secret to success is to adopt moderation in all we consume. It is important to make accurate choices while choosing among the many meals on the market. Convenience meals come in a wide range and are designed to make life easier for modern housewives who might also be using them. They can only be used to supplement the daily diet. Never forget that no single meal can supply all the nutrients needed for a healthy lifestyle. Choose natural meals and eat things that will meet your dietary requirements.

10.5 GLOSSARY

Food: Foods are materials that are ingested by humans for food, sustenance, and enjoyment in their naturally occurring, processed, or prepared forms.

Nutrition: People get the nutrients they need to develop and maintain their health through the processes that occur when they eat certain foods.

Culture: A community-accepted activity

Fruits: Fruits represents the part of plants delicious soft and eatable component.

Cereals: Any kind of grain which may be consumed or turned into flour

Legumes: Any plant that produces elongated seed pods. Beans and peas

Meat: The edible portions of animals or birds that are consumed by humans.

Bajra: Pearl millet is a variety of millet that is widely cultivated in the north western region of India and can be processed into flour.

10.6 EXERCISES TO CHECK YOUR PROGRESS ANSWERS

Assess the progress of Your Sessions 1

1. The following information should be in your response:

- Fundamental requirements (or qualities) of "health"
- Basic concepts in food and nutrition

2. The following information should be in your response:

- Understanding relationship between food, Nutrition and Health

3. The following information should be in your response:

- Under nutrition and over nutrition

Assess the progress of Your Sessions 2

- a) Protein
- b) Milk, Egg, Meat
- c) 4 calories
- d) 9 calories
- e) Energy

Assess the progress of Your Sessions 3

- 1) Milk, egg, Cereals, and millets
- 2) Rice, Potatoes, Wheat

Assess the progress of Your Sessions 4

- Protein-rich food is referred to as "body building foods. "High-quality proteins are abundant in dairy products, meat, eggs, and seafood. Considering the fact that nuts and pulses are rich in protein while the protein is of inferior quality. That foods support growth and support life. They also provide the energy.
- Social Functions of Food

Assess the progress of Your Sessions 5

- 1) Energy, Protein, B-Vitamins, fiber, carbohydrates

Assess the progress of Your Sessions 6

All humans need the same nutrients for their bodies to function properly. The amount of each nutrient required based on variables like age, size, activity level, etc. is the sole variation. Everyone requires energy for work, but men who move heavy objects may need more than men who sit at desks all day.

Assess the progress of Your Sessions 7

- 1) Nutrients are essential for the body to develop, reproduce and live an active life. Nutrients are dietary ingredients. Proteins, water, lipids, carbs, vitamins and minerals comprise the nutrients.
- 2) The food pyramid is designed to be used by the majority of healthy people as a reference for the kinds of meals and their proportions to be present in a routine diet.
- 3) The metabolic reactions that occur when people consume certain foods provide them with the nutrients they require to grow and sustain their health.

UNIT 11: NUTRIENT FUNCTIONS

Structure

- 11.1 INTRODUCTION
- 11.2 CLASSIFICATION
 - 11.2.1 MACRONUTRIENTS
 - 11.2.2 MICRONUTRIENTS
 - 11.2.3 ENERGY GIVING NUTRIENTS
 - 11.2.4 BODY BUILDING NUTRIENTS
 - 11.2.5 PROTECTIVE NUTRIENTS
- 11.3 BASAL METABOLIC RATE
- 11.4 BODY MASS INDEX
- 11.5 DIETARY REFERENCE INTAKE

- 11.6 RECOMMENDED DIETARY ALLOWANCE
- 11.7 ENERGY METABOLISM
- 11.8 CARBOHYDRATE
- 11.9 LIPID
- 11.10 PROTEIN

11.1 INTRODUCTION:

Nutrition is the one of the streams of science which deals with foods, the nutrients and other components they contain, their action, metabolism, absorption and interrelation with health and disease. It is the collaboration of science and art wherein, we study the different processes by which all organism ingests, digests, absorbs, transports & utilizes nutrients & disposes of their end products.

In addition, nutrition can be influenced by different aspects of food and eating behaviors like for eg. Social, Economic, Cultural and Psychological. In short, nutrition science is the area of knowledge regarding the role of food in the maintenance of health.

FOOD: Any eatable substance that we can consume or drink is called Food. Food provides us nourishment, take care of wear and tear, heals our body and protects us from infections and diseases. Thus, food helps us to maintain good health. The major function of foods is the life support function. In addition to that foods satisfy hunger& create pleasure & happiness, when we consume foods of our choice.

The primary functions of food are to take care of physiological function & maintain health by providing body building & regulatory functions. It also provides psychological satisfaction by relieving hunger when we relish food made by our loved ones.

With these aspects we shall study nutrients & their functions under the following subtopics •

NUTRIENT: Nutrients are the chemical substances which are obtained from the food we eat and they are used in our body to provide energy, to support our growth & development, maintenance & repair of the body's tissues. Some of these nutrients are meant for reducing the risks of degenerative diseases and deficiency disorders.

ESSENTIAL NUTRIENT: An essential nutrient is a nutrient that our body cannot synthesize on its own or also not to an adequate amount & must be provided by the dietary sources. These nutrients are

necessary for the body to function properly. The six essential nutrients include carbohydrates, protein, fat, vitamins, minerals and water.

11.2 CLASSIFICATION: The nutrients are classified on the specific basis, based on which they have been grouped under different terminologies.

1. Classification based on the need and requirements in our body:
 - a) Macronutrients
 - b) Micronutrients
2. Classification based on the function they perform in our body:
 - a) Energy giving nutrients (GO Nutrients)
 - b) Body building nutrients (GROW Nutrients)
 - c) Protective nutrients (GLOW Nutrients)

Let us know more about them.

11.2.1 MACRONUTRIENTS: Macronutrients provides the bulk to the diet and they are needed in large quantities by our body. They supply energy as well as the essential nutrients needed for growth, maintenance, & activity. They include carbohydrates, proteins and fats. Water is also included in macronutrient.

11.2.2 MICRONUTRIENTS: Nutrients which are just essential in small quantities for the proper functioning of our body are referred as micronutrients. Minerals and vitamins are grouped under micronutrient category.

11.2.3 ENERGY GIVING NUTRIENTS: Those nutrients which provide energy to the body are called Energy giving nutrients. For Eg., Carbohydrate, Fats

11.2.4 BODY BUILDING NUTRIENTS: Those nutrients which help to build up muscle and tissues, help in growth and development of the body and maintain repair are called Body building nutrients. For Eg., Protein.

11.2.5 PROTECTIVE NUTRIENTS: Those nutrients which are effective in providing protection to the body from various infections are called Protective nutrients. For Eg., Vitamins and Minerals.

Water is considered as a regulatory nutrient which does not provide above mentioned functions, still is very vital for life. One cannot survive without water for more than few days.

11.3 BASAL METABOLIC RATE (BMR)

The amount of energy required to carry on the involuntary work of the body is known as basal metabolic rate. It includes the functional activities of the various vital organs such as brain, heart, liver, kidney & lungs & also the secretory activities of glands, peristaltic movements of gastro intestinal tract, oxidation occurring in resting tissue, maintenance of muscle tone & body temperature. In general terms, it is amount of the energy expenditure required when the body is at rest and no physical movements are taking place. For Eg., When we are lying on bed or at sleep.

Determinants of BMR

Many factors affect the BMR of an individual, they are as follows;

1) **Body composition**

2) **Gender:** males have higher muscle mass & lower body weight therefore they have high BMR. Females have higher fat mass & thus have lower BMR.

3) **Age:** BMR decreases with advancing age.

4) **Hereditary factors:** some people are born with faster metabolism & some with slower metabolism.

5) **Body surface area:** surface area depends on height & weight. Greater the surface area higher the BMR & vice versa.

6) **Hormones:** some of the endocrine hormones like thyroid, catecholamine, adrenaline, growth hormone all of them increases.

7) **Pregnancy:** BMR increases by 5% during the first & second trimesters. During the last trimester it increases by 12%.

8) **State of nutrition:** BMR is lowered during starvation, malnutrition & wasting diseases.

11.4 BODY MASS INDEX (BMI)

Body mass index (BMI) is a measure of relative size based on the mass and height of an individual. BMI is defined as the ratio of weight (kgs) to height² (meter) of an individual (Fig: 11.1).

BMI is used as a screening tool to indicate whether a person is underweight, overweight, and obese or a healthy weight for their height. It is a simple, inexpensive and non invasive measure of body fat. BMI values are age-independent and the same for both genders. However, BMI may not correspond to the same degree of fatness in different populations due to different body proportions. BMI Range: (Table 11.2) gives the range of BMI. Fig.11.2 (BMI ranges for men & women)

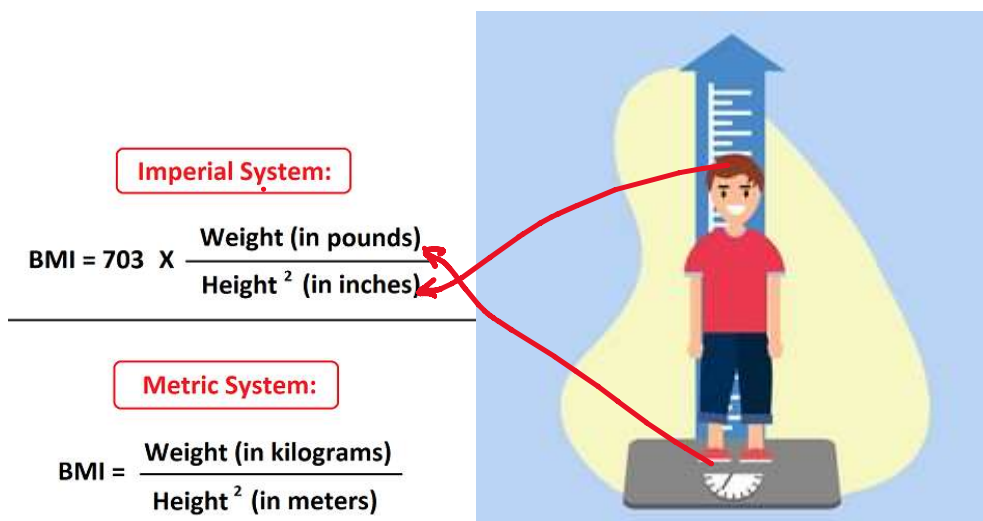


Fig.11.1: Formula for calculation of Body Mass Index (BMI)

Table 11.1: BMI standard ranges, their relationship to the nutritional status & obesity.

BMI (kg/m ²)	Nutritional status
Below 18.5	Underweight
18.5–24.9	Normal weight
25.0–29.9	Pre-obesity
30.0–34.9	Obesity class I
35.0–39.9	Obesity class II
Above 40	Obesity class III

Raised BMI is a major risk factor for non-communicable diseases such as- cardiovascular diseases (mainly heart disease and stroke), which were the leading cause of death all round the world; Type II Diabetes Mellitus; Musculoskeletal disorders (especially osteoarthritis – a highly disabling degenerative disease of the joints); Some cancers (including endometrial, breast, ovarian, prostate,

liver, gallbladder, kidney, and colon). The risk for these non-communicable diseases increases, with increases in BMI. As the high BMI is the sign of higher level of adiposity and obesity which the root cause of various deadly lifestyle disorders.



Fig.11.2: BMI ranges for the men and women.

11.5 DIETARY REFERENCE INTAKES

The results of research studies in the field of nutrition are used by Scientists/Researchers to derive standards. These standards explain the amounts of individual nutrients required by healthy individuals of all age groups for supporting health. Such standards are collectively called as '*Dietary Reference Intakes*' which is an umbrella term for the following individual values:

1. Estimated average requirements (EAR)

The estimated nutrient requirement that is adequate in 50% of the population studied and is used to develop the recommended dietary allowances.

2. Recommended dietary allowances (RDA)

RDAs are estimates of nutrients to be consumed daily to ensure the requirements of all individuals in a given population. RDA is adequate for 97-98% of the healthy population and is separate for physiological groups such as infants, preschoolers, children, adolescents, pregnant women, lactating mothers, and adult men and women, taking into account their physical activity. RDA also includes a margin of safety to cover variation between individuals, dietary traditions and practices.

3. Adequate intakes (AI)

For some nutrients, there is insufficient knowledge to determine an Estimated Average Requirement (which is needed to set an RDA). In these cases, an AI is used which reflects the average amount of a nutrient that a group of healthy people consume.

4. Tolerable upper intake levels (UL)

It is the maximum intake of a nutrient that is not associated with adverse side effects in most individuals of the healthy population. Overall, these recommendations apply to healthy people and may not be appropriate for people with diseases who have altered nutrient needs. Care should be taken to consider country specific recommendations while deciding the nutrient requirements

Let us study RDA in details.

11.6 RECOMMENDED DIETARY ALLOWANCES (RDA)

RDA is defined as “the average daily dietary intake level that is sufficient to meet the nutrient requirement of nearly all healthy individuals (97-98%) in a particular life stage & gender group”. RDA is revised periodically by Expert Group of Indian Council of Medical Research (ICMR)& updated with newer concepts & emerging knowledge concerning human nutrient requirements. RDA is based on Indian reference man & reference woman.

Reference Man and Reference Woman

For the purpose of computing the total nutrient needs of population at the national level, the concept of reference man and woman is used.

- ❖ Reference man and woman are defined on the basis of body weight of well-nourished healthy adults in each country, who have satisfactory growth during their childhood and are currently leading a healthy and active life.
- ❖ **Reference man** is between 18-29 years of age, and weight 60 kg with a height of 1.73m with a BMI of 20.3. He is free from disease and physically fit for active work. On each working day, he is employed for 8 hours in occupation that usually involves moderate activity. While not a work, he spend 8 hours in bed, 4-6 hours in sitting and moving about and 2-4 hours in walking and in active recreation or household duties.

- ❖ **Reference woman** is between 18-29 years of age, non- pregnant, non-lactating and weighs 55 kg with a height of 1.61 m and a BMI of 21.1 is free from disease and physically fit for active work; on each working day, she is engaged in 8 hours of occupation which usually involves moderate activity, while when not at work she spends 8 hours in walking or active recreation or household chores.

RDA can also be defined as follows:

Recommended Dietary Allowances- *The Recommended Dietary Allowances (RDA) are the levels of intake of the essential nutrients that are judged to be adequate or sufficient to meet the nutrient requirement of nearly all (97 to 98 percent) healthy individuals in a particular life stage and gender group.*

A safety factor is considered while deciding the RDA for all nutrients except for energy. Thus, RDAs provide safe and adequate levels of nutrients needed by different age groups. A diet composed of a variety of foods from diverse food groups will be adequate in meeting the RDA for all nutrients.



Fig.11.3: Simplification of RDA definition.

The latest RDA was revised in 2020 & recommendations for different age groups with nutrient requirement are shown below:

Age Group	Category of work	Body Wt (kg)	Protein (g/d)	CHO (g/d)	Cal cium (mg/d)	Magne sium (mg/d)	Iron (mg/d)	Zinc (mg/d)	Iodine (µg/day)	Thiamine (mg/d)	Ribo flavin (mg/d)	Niacin (mg/d)	Vit B6 (mg/d)	Folate (µg/d)	Vit B12 (µg/d)	Vit C (mg/d)	Vit A (µg/d)	Vit D (IU/d)
Men	Sedentary	65	54.0	130	1000	385	19	17	150	1.4	2.0	14	1.9	300	2.5	80	1000	600
	Moderate									1.8	2.5	18	2.4					
	Heavy									2.3	3.2	23	3.1					
Women	Sedentary	55	45.7	130	1000	325	29	13.2	150	1.4	1.9	11	1.9	220	2.5	65	840	600
	Moderate									1.7	2.4	14	1.9					
	Heavy									2.2	3.1	18	2.4					
	Pregnant woman	55 + 10	+9.5 (2 nd trimester) +22.0 (3 rd trimester)	175	1000	385	40	14.5	250	2.0	2.7	+2.5	2.3	570	+0.25	+15	900	600
	Lactation 0-6m		+16.9	200	1200	325	23	14	280	2.1	3.0	+5	+0.26	330	+1.0	+50	950	600
	7-12m		+13.2	200						2.1	2.9	+5	+0.17	330				
Infants	0-6 m*	5.8	8.1	55	300	30	-	-	100	0.2	0.4	2	0.1	25	1.2	20	350	400
	6-12m	8.5	10.5	95	300	75	3	2.5	130	0.4	0.6	5	0.6	85	1.2	27	350	400
Children	1-3y	11.7	11.3	130	500	135	8	3.0	90	0.7	0.9	7	0.9	110	1.2	27	390	
	4-6y	18.3	15.9	130	550	155	11	4.5	120	0.9	1.3	9	1.2	135	1.2	32	510	600
	7-9 y	25.3	23.3	130	650	215	15	5.9	120	1.1	1.6	11	1.5	170	2.5	43	630	
Boys	10-12y	34.9	31.8	130	850	270	16	8.5	150	1.5	2.1	15	2.0	220	2.5	54	770	600
Girls	10-12y	36.4	32.8	130	850	255	28	8.5	150	1.4	1.9	14	1.9	225	2.5	52	790	600
Boys	13-15y	50.5	44.9	130	1000	355	22	14.3	150	1.9	2.7	19	2.6	285	2.5	72	930	600
Girls	13-15y	49.6	43.2	130	1000	325	30	12.8	150	1.6	2.2	16	2.2	245	2.5	66	890	600
Boys	16-18y	64.4	55.4	130	1050	405	26	17.6	150	2.2	3.1	22	3.0	340	2.5	82	1000	600
Girls	16-18y	55.7	46.2	130	1050	335	32	14.2	150	1.7	2.3	17	2.3	270	2.5	68	860	600

* AI

(Source: Summary Of Recommendations, Recommended Dietary Allowances & Estimated Average Requirements For Indians – 2020, A Short Report Of Expert Group, ICMR-NIN.)

Fig.11.4: SUMMARY OF R.D.A. FOR INDIANS-2020.

The various applications of RDA include:

- Comparison of individual intakes to the RDA allows an estimate to be made about the probable risk of deficiency among individuals.
- Modifying nutrient requirements in clinical management of diseases,
- To help public health nutritionists to compose diets for schools, hospitals, prisons etc.
- For health care policy makers and public health nutritionists to design, develop nutrition intervention programmes and policies,
- For planning and procuring food supplies for population groups,
- For evaluating the adequacy of food supplies in meeting national nutritional needs.
- For interpreting food consumption records of individuals and populations,
- For establishing Standards for the national feeding programmes implemented by the Governments for its vulnerable population,
- For designing nutrition education programmes for the masses,
- For developing new food products and dietary supplements by the industry,

- Establishing guidelines for the national labelling of packaged foods (by Food Standards Safety Authority of India (FSSAI).

Factors on which RDA depends:

- I. Age of the individual:** RDAs increases with age in young children and after adulthood during old age they gradually decreases.
- II. Physical activity:** On the basis of physical activity, individuals have been classified as follows:
 - Sedentary worker – with least physical activity like lawyer, teacher, doctor
 - Moderate worker – with moderate physical activity like carpenter, tailor, plumber
 - Heavy worker- with vigorous physical activity like coal miner, steel worker, army man.
- III. Sex:** Male has higher values than females
- IV. Body Composition**
- V. Vulnerable:** pregnant and lactating mothers, infants and elderly people.

Why Is RDA Important?

- Maintenance of a state of positive health and optimal performance in populations at large by maintaining ideal body weight.
- Ensuring adequate nutritional status for pregnant women and lactating mothers.
- Improvement of birth weights and promotion of growth of infants, children and adolescents to achieve their full genetic potential.
- Achievement of adequacy in all nutrients and prevention of deficiency diseases.
- Prevention of chronic diet-related disorders.
- Maintenance of the health of the elderly and increasing the life expectancy.

General Principles of Deriving RDA

Numbers of methods have been employed for determining the human nutrient requirements.

- I. Dietary intake:** This approach has been used in arriving at the energy requirements of children. Energy intakes of normally growing healthy children are utilized for this purpose.
- II. Growth:** The requirements of any particular nutrient or the breast milk intake, for satisfactory growth have been utilized for defining requirements in early infancy.

III. **Nutrient balance:** The minimum intake of nutrient for equilibrium (intake=output) in adults and nutrient retention consistent with satisfactory growth in children have been used widely for arriving at the protein requirement.

IV. **Obligatory loss of nutrients:** The minimal loss of any nutrient or of its metabolic products (namely nitrogenous end products in the case of proteins) through normal routes of elimination- urine, faeces and sweat- is determined on a diet devoid of or very low in the nutrient. This information is used to determine the amount of nutrient to be consumed daily through the diet to replace the obligatory loss.

V. **Factorial approach:** In this approach, the requirements for different functions are assessed separately and added to arrive at the total daily requirements.

VI. **Nutrient turnover:** Data from turnover of nutrients in healthy persons, using isotopically labelled nutrients have been employed in arriving at requirements of certain nutrients. Requirements of Vitamin A and Vitamin C, iron and Vitamin B₁₂ have been determined on this basis.

Practical Application of RDA

- To assess the adequacy of national food supplies and to plan for food production both in terms of quantity and quality e.g., agriculture planning
- To provide dietary guidelines for healthy living individual and groups and to formulate balanced diets.
- RDA can also be used for judging the adequacy of intake of individuals or groups in a preliminary way. In the case of adult individuals, RDA has to be adjusted for the actual body weight while assessing the adequacy of intake.
- RDA are used for formulating diet plan for patient in various illnesses and nutrient deficiency diseases after specific modifications related to the subject.

11.7 ENERGY METABOLISM

Energy is the ability to do work. The energy contained within the chemical constituents of food can be either trapped within the chemical constituents of the body or used to produce heat. Energy is defined property of chemical compounds & other physical systems. Carbohydrates, fats, proteins in the diet are

responsible for its energy content & are made available to the body when these compounds are oxidized in the energy releasing reaction of respiration.

Units of energy

All forms of energy are inter-convertible. The energy value of food is expressed in “**kilocalories**” which have been used in nutrition for a long time. One kilocalorie is defined as “*the amount of heat energy required to raise the temperature of 1 kg of water by 1°C at normal atmospheric pressure*”.

However, recently the International Union of Science & the International Union of Nutritional Science (IUNS) has adopted ‘Joule’ as the unit of energy instead of kcal.

A joule is defined as “*the energy required to move 1 kg mass by 1 meter by force of 1 Newton acting on it*”.

$$1 \text{ kcal} = 4.184 \text{ kJ}$$

$$1 \text{ kJ} = 0.239 \text{ kcal}$$

$$1000 \text{ kcal} = 4184 \text{ kJ}$$

$$1 \text{ mJ} = 239 \text{ kcal}$$

Energy value of food

The energy value of a food indicates its value to the body as a fuel. After a food is ingested, some of its energy may be 'lost' during digestion and metabolism. Only three food classes release energy & they are carbohydrates, proteins & lipids. Carbohydrates gives 4calories/g, proteins 4calories/g & fat 9calories/g calories (Fig:11.5) the energy released from food is measured in calories.

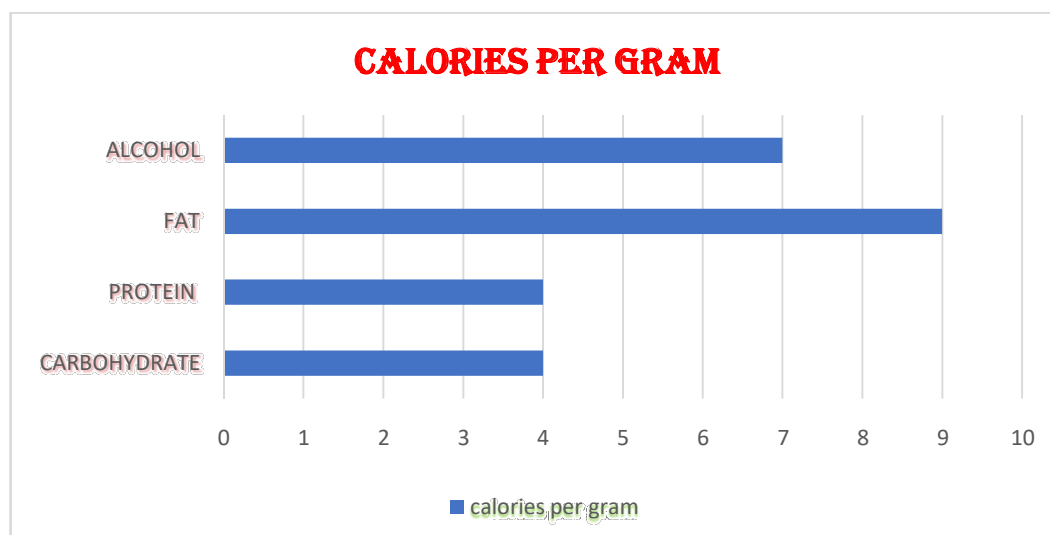


Fig. 11.5: Calorie content of molecules

Determination of energy value of foods

The first system for giving energy values to the macronutrients was described by Dr. W. O. Atwater in 1899. The amount of energy released from foods & the amount of energy expended by an individual can be obtained by direct & indirect calorimetry.

The principle of direct calorimetry includes the chemical changes that occur when carbohydrates or fat are oxidized during respiration in the body & the chemicals are burnt in the air. The amount of energy released or expended is measured by the heat produced.

Indirect calorimetry is based on the principle that when an organic substance is completely combusted either in calorimetry or in the human body. Oxygen consumed in amounts is directly related to the energy liberated as heat.

Although the energy value of some foods has been found by combustion in a bomb calorimeter, the amounts of the macronutrients - fat, protein, carbohydrate - in a food are taken into account when assessing the total energy value of the food.

Physiological fuel value

The amount of energy available to the body from a given amount of nutrient is called physiological fuel value. In the human body the process of digestion does not proceed with 100% efficiency as carbohydrates, fats & proteins are not completely oxidized.

Therefore, the entire amount of any ingested nutrient does not eventually become available to the body. The efficiency with which nutrient is digested must be taken into account. The coefficient of digestibility is used to express the proportion of an ingested nutrient that ultimately becomes available to the body's cells.

Table 11. 2: Equipment used & purpose in direct & indirect calorimetry

Principle	Equipment	Purpose
Direct calorimetry	Bomb calorimeter	Energy value of food
	At water Rose respiration calorimeter	Energy expenditure during BMR/RMR
Indirect calorimetry	Benedicts oxy calorimeter	Energy value of food
	Eenedict-Roth respiration	Determination of BMR

	Douglas bag	Energy expenditure respirometer during work
	Max Plank	

The coefficient of digestibility for carbohydrate, fat & protein are 0.98, 0.95 & 0.92 respectively. There is no loss in metabolism of carbohydrate & fat. But in case of protein, a part of energy is lost as urea due to incomplete oxidation. The loss has been estimated to be 1.3 kcal/g of protein oxidized. The physiological energy values of carbohydrates, fats & proteins are 4, 9 & 4 respectively after making changes for losses of food energy in digestion & metabolism. These values are called Atwater Bryant factors or physiological fuel values.

Energy requirement

The energy requirement of an individual is based on the level of energy intake from food that will balance energy expenditure. The human body's total energy needs can be divided into three important components as follows- (Fig. 11.6)

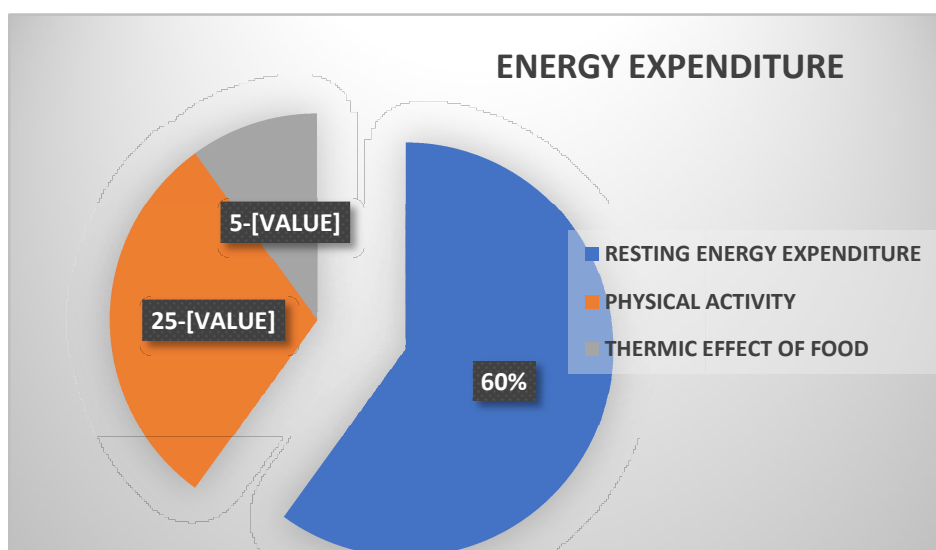


Fig. 11.6: Components of energy expenditure

- 1) Energy required to maintain basal metabolism (60%)
- 2) Energy required for the muscle movements or physical activity (25-30%)
- 3) The energy that is released as a result of the thermic effect of food (5-10%).

RDAs for Energy: The total energy requirement or the total energy expenditure (TEE) is calculated based on amultiplication of basal metabolic rate (BMR) to physical activity level(PAL): $TEE = BMR \times PAL$.

Now, in this unit we will study our macronutrients (Carbohydrates, Lipids and Proteins) in details under the sub-heading of Definition, Classification, Dietary Sources, Functions, Recommended Dietary Allowances, Clinical signs and symptoms of Deficiency diseases and Excess.

11.8 CARBOHYDRATES:

Carbohydrates are a major source of energy for humans, providing approximately 45 percent to 80 percent of the total caloric intake in different income groups. They are mainly present in food in the form of sugars, starches, and fibres.

Definition: Carbohydrates may be defined as polyhydroxy aldehydes or ketones or compound which produces them on hydrolysis. Carbohydrates are primarily composed of carbon, hydrogen and oxygen. They have a general empirical formula- $C_nH_{2n}O_n$

Table 11.3a. Summary of recommended energy requirement for Indians

Age group	Category	ICMR 2020	ICMR 2010	Difference
		Kcal/d		
Adult Men	Sedentary work	2110	2320	-210
	Moderate work	2710	2730	-20
	Heavy work	3470	3490	-20
Adult Women	Sedentary work	1660	1900	-240
	Moderate work	2130	2230	-100
	Heavy work	2720	2850	-130
	Pregnant	+ 350	+ 350	--
	Lactating (0-6m)	+600	+600	--
	Lactating (7-12m)	+520	+520	--
Infants	0-6 months	530	520	+10
	6-12 months	660	670	-10
Children*	1-3 y	1070	1060	+10
	4-6 y	1360	1350	+10
	7-9 y	1700	1690	+10
Boys	10-12 y	2220	2190	+30
Girls	10-12 y	2060	2010	+50
Boys	13-15 y	2860	2750	+110
Girls	13-15 y	2400	2330	+70
Boys	16-18 y	3320	3020	+300
Girls	16-18 y	2500	2440	+60

*For children 1% increase over the previous recommendations.

Table 11.3b. Energy Requirement*

Age Group	Category	Body weights	(kcal/d) ^a	(kcal/kg/day)
Men	Sedentary work	65.0	2110	32
	Moderate work	65.0	2710	42
	Heavy work	65.0	3470	53
Women	Sedentary work	55.0	1660	30
	Moderate work	55.0	2130	39
	Heavy work	55.0	2720	49
	Pregnant	55.0 + GWG ^b	+ 350	
	Lactating	55.0+	+600 +520	
Infants	0-6 m	5.8	530	90
	6-12m	8.5	660	80
Children^c	1-3y	12.9	1110	83
	4-6y	18.3	1360	74
	7-9 y	25.3	1700	67
Boys	10-12y	34.9	2220	64
Girls	10-12y	36.4	2060	57
Boys	13-15y	50.5	2860	57
Girls	13-15y	49.6	2400	49
Boys	16-18y	64.4	3320	52
Girls	16-18y	55.7	2500	45

^a Rounded off to the nearest 10 kcal/d

^b GWG: Energy need in pregnancy should be adjusted for actual bodyweight, observed weight gain and activity pattern for the population

^c Energy needs of children and adolescents have been computed for reference children and adolescents; with a moderate daily physical activity level.

*The actual requirement in specific population groups should be adjusted for the actual weight and physical activity of that population

(Source: A Brief Note on Nutrient Requirements for Indians, the Recommended Dietary Allowances (RDA) and the Estimated Average Requirements (EAR), ICMR - NIN, 2020)

Classification:

Carbohydrates, which are of immense importance in the diet, are classified on the basis of the sugar units present in them as simple carbohydrates and complex carbohydrates.

Monosaccharides and disaccharides make up simple carbohydrates, called simple sugars, which contain one and two sugar units, respectively. **Polysaccharides**, called complex carbohydrates, are structurally larger and more complex than simple sugars. They include starch, dietary fiber, and glycogen. There are two main classes of monosaccharides based on the carbonyl group present in them. They are aldoses and ketoses, aldoses (e.g., glucose) containing the aldehyde group (CHO) and ketoses (e.g., fructose) containing the ketone group (C=O).

Aldoses are further divided into trioses, tetroses, pentoses, and hexoses based on the number of carbon atoms.

The common disaccharides are maltose, lactose, and sucrose, which, upon hydrolysis, yield two monosaccharide units.

Polysaccharides have a high molecular weight and are insoluble in water. They are in the form of long chains, either branched or unbranched. The polysaccharides are further classified into groups

depending upon the products they yield on hydrolysis. Homopolysaccharides yield only one type of monosaccharide unit on hydrolysis, e.g., starch, dextrin, cellulose, and glycogen.

Heteropolysaccharides yield more than one type of monosaccharide unit on hydrolysis, e.g., heparin and hyaluronic acid. Heparin is an anticoagulant found in the liver, spleen, lungs, and blood. Hyaluronic acid is found in the umbilical cord, synovial fluid, and vitreous humor. It has a lubricating action. In tissues, it forms an important part of the cementing ground substance.

The sugars are also classified as reducing and nonreducing sugars. The reducing property is attributed to the free aldehyde or keto group. They may also be classified as available and unavailable carbohydrates.

Available carbohydrates: carbohydrates that can be digested in the human body and yield energy when they are oxidized in the body.

Unavailable carbohydrates: carbohydrates that cannot be digested because the human body does not contain the enzymes necessary for their breakdown. Unavailable carbohydrates do not provide any energy to the body but are necessary as they perform some important functions in the body, such as the elimination of fecal waste.

Dietary Sources:

Daily diet should provide up to 50–70 percent kcal of energy from carbohydrate. Carbohydrates are not only an economical source of energy but are also readily available and easy to store as they have a long shelf life. The important sources of carbohydrates in the diets of Indians are cereals and millets, roots, tubers, pulses, sugar and jaggery. All sugars provide 4 kcal/g of energy. The carbohydrate and calorie content of a food can be reduced by using sugars which are sweeter than sucrose so that the quantity of sugar required will be less.

Functions:

- The chief function of carbohydrate is to provide energy to the body so that it can carry out day to day work to maintain body temperature. All carbohydrates except fibre provide 4 kcal/g of energy. It is the cheapest source of energy available.
- Glucose is the only form of energy used by the central nervous system. When blood glucose levels fall, the brain does not receive energy and convulsions may occur.

- Carbohydrates spare proteins from being broken down for energy and are used for body building and repair. In carbohydrate deficient diets, proteins meant for body building and repair are oxidised to meet the most important and primary need of the body, i.e., energy.
- They are required for complete oxidation of fat. In the deficiency, fats are broken down rapidly for energy and intermediate product such as ketones are formed in large amounts resulting in a condition called ketosis.
- Carbohydrates can be converted into non-essential amino acids, provided a source of nitrogen is available.
- The sugar lactose helps in the absorption of minerals calcium and phosphorus.
- Lactose helps certain bacteria to grow in the intestine. This bacterial flora is capable of synthesizing B complex vitamins in the gut
- Dietary fibre plays an important role of increasing faecal mass by absorbing and holding water, stimulating peristalsis, and eliminating faecal waste.
- Fibre also helps in lowering blood cholesterol levels by binding bile acids and cholesterol.

RDAs:

Table 11.4: RDA (2020) for Carbohydrate

Age Group	Category Of Work	Body Weight (kg)	Carbohydrate (g/d)
Men	Sedentary	65	130
	Moderate		
	Heavy		
Women	Sedentary	55	130
	Moderate		
	Heavy		
	Pregnant	55+10	175
	Lactation (0-6m)		200

	Lactation (7-12m)		200
Infant	0-6m	5.8	55
	6-12m	8.5	95
Children	1-3y	11.7	130
	4-6y	18.3	130
	7-9y	25.3	130
Boys	10-12y	34.9	130
Girls	10-12y	36.4	130
Boys	13-15y	50.5	130
Girls	13-15y	49.6	130
Boys	16-18y	64.4	130
Girls	16-18y	55.7	130

*AI

Deficiency:

The daily diet should not contain less than 100gram of carbohydrate. A deficiency of carbohydrate in the diet results in utilization of fat for energy. In severe deficiency, incomplete oxidation of fats causes ketone bodies to accumulate in the blood.

Excess:

- Excessive consumption of refined sugars could be one of the causes of dental caries or tooth decay.
- Excessive sugar depresses the appetite, provides hollow calories, and could result in malnutrition.
- High intake of sugar and refined carbohydrates increase the blood triglyceride levels leading to heart diseases.

- When excessive carbohydrates are consumed, they are converted into fat and deposited in the adipose tissue, which could lead to obesity, i.e., body weight of 20 per cent or more than the desirable weight.
- Excessive fibre could irritate the intestinal lining, causing cramps or bloating due to gas formation.
- Excessive fibre interferes with the absorption and availability of minerals elements such as iron and calcium

11.9 LIPIDS:

Definition: Lipids consists of group of compounds containing fats and oils, which are insoluble in water but soluble in fat solvents. Similar to carbohydrates, they are mainly made up of carbon, hydrogen and oxygen. They contain much smaller proportions of oxygen than carbohydrates and larger proportions of carbon and hydrogen. They are more concentrated source of energy, providing two and a quarter time more energy than carbohydrates and proteins. The lipids of importance to our health are fatty acid, fats, oil, phospholipids, lipoproteins, and sterols.

Classification:

- A. **Classification Based On Structure:** Based on their structure lipids are classified into simple lipids, compound lipids, derived lipids, sterols
 - i. **Simple lipids:** They constitute more than 98 per cent of food and body fats. Simple lipids are made up of three fatty acids attached to glycerol. They are mixed triglycerides which mean that more than one type of fatty acid is present in the fat, e.g., cooking oils and butter.
 - ii. **Compound lipids:** They are fats in which at least one fatty acids is replaced by carbohydrates, protein, or phosphorous, i.e., they are fats + non fat molecules, e.g., phospholipids, glycolipids, and lipoprotein.
 - iv. **Derived lipids:** They are the breakdown products of fats and include diglycerides, monoglycerides, glycerol and fatty acids.
 - v. **Sterols:** They are not made up of fatty acids and glycerol but have a benzene ring structure. These fat-like substances include cholesterol and fat soluble vitamin A, D, E, K.

Fatty Acids: Fatty acids consist of chain of carbon atoms with a methyl (CH₃) group at one end and a carboxyl (COOH) group at the other end. Fatty acids may have short chains or they may have long

chains (12-22 carbon chains). They may be saturated or unsaturated. Saturated fats have single bonds between carbon atoms, while unsaturated fats have one or more double bonds between the carbon atoms. Fatty acids with two or more double bonds are called polyunsaturated.

Fatty acids are classified as saturated fatty acids and unsaturated fatty acids. Unsaturated fatty acids are further classified as monounsaturated fatty acids and polyunsaturated fatty acids.

Monounsaturated Fatty Acid: Oleic acid is a monounsaturated fatty acid and has one double bond. It is found in groundnut, olive oil, corn oil, etc. It may help lower blood cholesterol levels. It is an omega-9 fatty acid.

Polyunsaturated Fatty Acid: The polyunsaturated fatty acids are those with two or more double bonds. They include linoleic acid (two double bonds) linolenic acid (three double bonds), and arachidonic acid (four double bonds). They help in lowering blood cholesterol levels and prevent atherosclerosis and coronary heart disease.

Essential Fatty Acids: Two of the PUFA cannot be synthesized by the body. They have to be provided in the required amount by our diet and are called essential fatty acids. They are linoleic acid (an omega-6 fatty acid), and linolenic acid (an omega-3 fatty acid). Omega is the last letter of the Greek alphabet used by scientist for naming fatty acids.

Omega-6 Fatty Acids: Omega-6 fatty acids have the last double bond located on the sixth carbon from the methyl or omega end. Essential fatty acid linoleic acid (18:2 omega 6) and arachidonic acid (20:4 omega 6) are omega-6 fatty acids. And are present in number of foods. Omega-6 rich oils include safflower, sunflower, cottonseed, corn, sesame, and groundnut. When consumption of omega-6 goes up, need for omega-3 increases. Omega-3 and omega-6 in the correct ratio helps in reducing blood cholesterol levels.

Saturated Fatty Acids: These are found in animal food such as meat, butter, cheese, and egg yolk and in plant food such as coconut oil, palm oil, and cocoa butter. Hydrogenated fats used in bakery products and confectionaries have high percentage of saturated fatty acids. Stearic acid, palmitic acid, myristic acid and butyric acid are some of the saturated fatty acids. A maximum 10 percent of our total calories should come from saturated fats

Phospholipids: They are composed of fats, phosphoric acid, and a nitrogenous base, e.g., lecithin and cephalins. They are required for cell permeability and for the formation of brain and nervous tissue. They help in transporting fats throughout the body as they form a part of the lipoproteins.

Glycolipids: They contain glucose or galactose in place of one of the fatty acids in the triglyceride.

Lipoproteins: They include chylomicrons, very low-density lipoproteins (VLDL), low density lipoproteins (LDL), and high-density lipoprotein (HDL). They are composed of lipids (triglycerides, cholesterol, and phospholipids) and proteins in varying proportions with percentage of proteins being least in chylomicrons and most in HDL. Lipoproteins are required for transporting triglycerides to various tissues in the body via blood circulation. Triglycerides are encased by a covering of water-soluble proteins which help them to circulate in water-based blood. These lipid protein complexes are called lipoproteins. Since LDL are the main carriers of cholesterol, and increase in LDL increases the risk of heart disease. High density lipoproteins help in lowering cholesterol levels. An LDL/HDL ratio of less than 3 is desirable.

Cholesterol: It is a fatlike substance present in food. It is different in structure from triglycerides, as it has a ring structure. It is present in all cells of the body and in large amounts in brain and nerve tissue. Cholesterol if consumed in excess is responsible for disease of the cardiovascular system. The normal blood cholesterol level for adults should be below 200mg/100ml blood. If the diet is deficient in cholesterol, the body can synthesize the required cholesterol. The human gets cholesterol from two sources:

1. Synthesis in the liver
2. Food rich in cholesterol

Dietary Sources:

- A. **Plant Sources:** All oils and oilseeds, such as groundnut, sesame, soya bean, rice bran, coconut, almond, cashew nut, corn, safflower, sunflower, and all hydrogenated fats and margarine are sources of lipids.
- B. **Animal Sources:** Mutton, pork, fish, poultry, milk and milk products (butter, cream, yoghurt, cheese), eggs. And organ meats are rich sources of lipids.
- C. **Invisible Sources:** Invisible sources of fats are nuts, salad dressings, flesh food, desserts, cookies, cakes, milk, eggs, milk based sweets etc., which are rich in fat, but fat is not visible.

Table 11.5a- Fatty acid and their food sources.

Fatty Acid	Number Of Carbon Atoms	Number Of Double Bonds	Food Sources
Oleic Acid	18	1	Groundnuts, Sesame, Olives, Butter, Cocoa Butter, Cashew Nuts, Avocado.
Linoleic Acid	18	2	Safflower, Sunflower, Cottonseed, Corn, Soyabean, Groundnut, Salmon, Tuna.
Linolenic Acid	18	3	Soya Bean, Rapeseed, Sesame, Butter.
Arachidonic Acid	20	4	Animal Fats, Groundnut.
Eicosapentaenoic Acid	20	5	Fish Oils.
Erucic Acid	22	1	Rapeseed Oil/ Mustard Oil.

Table 11.5b- Fatty acid and their food sources.

Fatty Acid	Number Of Carbon Atoms	Food Source
Acetic Acid	2	Vinegar
Butyric Acid	4	Butter
Caproic Acid	6	Butter
Caprylic Acid	8	Coconut, Palm Kernel
Lauric Acid	12	Palm Kernel, Coconut
Myristic Acid	14	Coconut, Butter
Palmitic Acid	16	Palm, Soya, Sesame, Butter, Lard, Cotton Seed
Stearic Acid	18	Beef Tallow. Cocoa Butter, Lard

Table11. 5c- Cholesterol content in different food sources.

Food	Cholesterol (Mg)	Food	Cholesterol (Mg)
Beef	109	Mutton	70
Lard	95	Beef	70
Butter	250	Pork	70
Processed Cheese	150	Chicken With Skin	80
Paneer	19	Liver	300
Ice Cream	40	Brain	2000
Whole Milk	14	Fish	60
Skimmed Milk	2	Shellfish	150
Mawa Based Sweets	65	Vanaspati	0
Egg White (1 Egg)	0	Margarine (Veg Fat)	0
Egg Yolk (1 Egg)	252	All Plant Foods	0

Cholesterol is present in animal body only. Whole milk, butter, ghee, cream, egg yolk, organ meat, and shellfish are rich sources. Cholesterol is also synthesized by the body independent of the dietary intake. It is a precursor of all steroid hormones, e.g., sex hormones. A precursor of vitamin D, 7-dehydrocholesterol is present in the skin which is irradiated by ultraviolet (UV) rays of sunlight to form vitamin D. It is required for formation of bile and is an essential constituent of cell membrane.

Functions:

1. **Energy:** Fats are concentrated source of energy in our diet. One gram of fat/oil gives 9kcal when it is oxidized in the body. All tissues, except those of the central nervous system and brain, can utilize fat as a source of energy.
2. **Protein Sparing Action:** The kilocalories from fat spare dietary proteins from being oxidized for energy. An adequate intake of fat in the diet allows protein to perform their main function of growth and maintenance.
3. **Thermal Insulation:** Subcutaneous fats act as insulation and helps in retaining body heat.
4. **Absorption of Fat-Soluble Vitamins:** Fat is necessary for the absorption of fat-soluble vitamins A, D, E, and K.
5. **Protection of Vital Organs:** Fat provides a protective padding to vital organs from mechanical shock and keeps them in place.
6. **Essential Fatty Acids:** An adequate intake of fats /oils is necessary to meet the body's requirement for linoleic and linolenic acids.
7. **Satiety Value:** Fats slow down the secretion of gastric juice and speed of digestion. Food is more flavoursome because of volatile essential oils naturally present in fats used for cooking. A well-cooked meal containing fats is more satisfying than a meal devoid of fats.
8. **Synthesis of Cell Membrane:** Fats are an important constituent of all cell membranes.
9. **Synthesis of Hormones:** The lipid cholesterol is necessary for the synthesis of some hormones, e.g., sex hormones.

Fat should contribute not more than 30 per cent of the total kilocalories. Kilocalories from the saturated fat should not exceed 10 percent of the total calories and at least 10 percent calories should be provided by PUFA to ensure an adequate intake of essential fatty acid. The correct ratio of omega-3 to omega-6 fatty acids should be maintained.

The cholesterol intake should not exceed 200 mg/day. A variety of cooking oils should be used every day to ensure consumption of all essential fatty acids. Non vegetarians should eat groundnut, corn, soya, and olive oil throughout the year, while for fish eaters a mixture of safflower and sunflower oil is adequate. Rice bran oil and corn oil is recommended for vegetarians.

RDAs:

Table 11.6: EAR values for Indians of Fats-(2020)

Age Group	Category Of Work	Body Weight (kg)	Fats/Oils (visible)(g/d) (#)
Men	Sedentary	65	25
	Moderate		30
	Heavy		40
Women	Sedentary	55	20
	Moderate		25
	Heavy		30
	Pregnant	55+10	30
	Lactation (0-6m)		30
	Lactation (7-12m)		30
Infant	0-6m	5.8	-
	6-12m	8.5	25
Children	1-3y	11.7	25
	4-6y	18.3	25
	7-9y	25.3	30
Boys	10-12y	34.9	35
Girls	10-12y	36.4	45
Boys	13-15y	50.5	50
Girls	13-15y	49.6	35
Boys	16-18y	64.4	40
Girls	16-18y	55.7	35

#: Visible fat requirement is in proportion to EER

Deficiency:

- ❖ A deficiency of fat causes a deficiency of essential fatty acids, linoleic and linolenic acids and subsequently a deficiency of arachidonic acid.
- ❖ These (PUFA) are required for healthy cell membranes and their permeability. A deficiency results in characteristic eczema and skin lesions. It is seen in infants as dry scaly lesions on the skin. Toad skin or dry papules are seen on upper limbs.
- ❖ A deficiency of fat may result in a deficiency of fat-soluble vitamins, and growth and weight may be affected in children.
- ❖ Fat is present in minute quantities in almost all foods including cereals and pulses, a deficiency in adults are unlikely because these foods are consumed in large quantities.

Excess:

- ❖ The percentage consumption of fat varies widely in different regions and in different income groups. The percentage consumption increases directly with incomes, and today it is a major problem faced in urban areas and changing lifestyles.
- ❖ Excess intake of fat causes obesity because more kilocalories are consumed than required by the body. Excess fat is stored in the adipose tissue.
- ❖ Excessive consumption of saturated fats can elevate blood cholesterol levels. A high intake of saturated fats and cholesterol are predisposing factors for cardiovascular diseases, while foods rich in omega-3 fatty acids have a protective effect.

11.10 PROTEINS:

Definition: Proteins are large, complex, organic compounds made up of carbon hydrogen, oxygen and nitrogen. Apart from nitrogen, elements such as sulphur, phosphorus, copper, and iron are also found in some proteins.

The basic units from which proteins are built are the amino acids. Each amino acid contains a carboxyl group (COOH) or acid group and an amino group (NH₂) or basic group. Proteins consist of chain of amino acids that are linked to each other by a peptide linkage (-CO-NH-)

Amino Acids: Twenty-two different amino acids are widely distributed in nature.

Essential Amino Acids: Those amino acids which cannot be synthesized in sufficient amounts by the body and must be provided by the diet are called essential amino acids. The human adult requires eight essential amino acids, while growing children require ten essential amino acids. Essential amino acids are indispensable to life.

Non-Essential Amino Acids: All amino acids are required by the body for tissue synthesis and repair. Non-essential amino acids do not mean that these amino acids are not required by the body. They are termed non-essential because they are not dietary essentials. If they are lacking in the diet, they can be synthesized by the body from other amino acids. Innumerable proteins can be formed by using the 22 amino acids in varying sequences and quantities.

Classification:

Proteins may be classified on the basis of their structure or on the basis of their quality, i.e., the amino acids present in them.

1. Classification by Structure

- ❖ **Simple Proteins:** These proteins are made up of amino acids only, e.g., zein in corn, albumin in egg white, and gliadin in wheat consist of amino acids only
- ❖ **Conjugated Proteins:** These proteins have a non-protein molecule attached to the protein, e.g., blood protein haemoglobin, which contains a haem (iron) group attached to protein and milk protein casein, which has a phosphate group attached.
- ❖ **Derived Protein:** These result from a partial breakdown of a native protein. Proteoses, peptones, and polypeptides are formed when digestive enzymes bring their action on proteins.

2. Classification by Quality: Proteins are classified into three groups on the basis of their quality.

- ❖ **Complete Proteins:** These proteins contain all essential amino acids in sufficient proportions and amounts to meet the body's need for growth and repair of tissue cells.
A complete protein food has a high biological value. Eggs, Milk, Meat, fish, and poultry are complete protein foods. They are found in animal foods
- ❖ **Partially Complete Proteins:** These are proteins in which one or more essential amino acids are present in inadequate amounts. They cannot synthesize tissues without the help of other proteins. The value of each is increased when it is consumed in combination with another complete protein at the same meal. Cereals, pulses, nut, and oilseeds are partially complete

protein foods. Cereals contain inadequate amounts of essential amino acid lysine, and pulses are deficient in essential amino acid methionine.

- ❖ **Incomplete Proteins:** These proteins are incapable of growth and repair of body cells. One or more essential amino acids may be completely lacking in these proteins, e.g., gelatin and zein in corn. Gelatin lacks three essential amino acids and is the only animal protein which is incomplete.

Dietary Sources: Proteins are present in both plant and animal foods

Animal Food Sources: Animal food sources provide the highest quality or complete proteins such as eggs, milk and milk products (cheese, paneer, mawa, milk powder, curds, and condensed milk), meat, fish, shellfish, poultry, and organ meat.

Plant Food Sources: Pulses especially, soya bean (43% protein) and its products such as soya milk, tofu, textured vegetable proteins; nuts, and oilseeds- groundnut and gingelly seeds are important sources of protein in the Indian diet.

Cereal contains 6-12 % partially complete proteins and as they form the bulk of the diet, they contribute significantly to the protein content. Vegetables, with the exception of peas and beans, are poor sources of proteins. Green leafy vegetables contain a small percentage of good quality protein (1-3%). Fruits do not contribute towards the protein content of the diet

Special Protein Supplements:

1. Special protein supplements in the form of premix powders or ready to consume health drinks are available in a variety of popular flavours and different nutrient composition.
2. They are used by sportspersons for minimizing muscle catabolism, boosting energy and muscle growth and stimulating greater fat loss.
3. Protein supplements are available in the form of pure protein isolates, weight gainers or as meal replacements.
4. The protein, carbohydrate and fat content varies in these supplements depending on what they are being recommended for.
5. The following proteins are used:
 - Whey protein concentrate
 - Complete milk protein
 - Micellar casein
 - Soya protein isolate

Functions: Proteins perform three main functions: structural function, regulatory function, and energy.

1. Structural Functions:

A. **Growth:** The primary function of food protein is the synthesis of body cells. All body tissue and fluids, except urine and bile, are made up of protein. Protein are the major constituent of muscles, organs, endocrine glands, and collagen. Collagen is the main structural protein of bones, tendons, ligaments, skin, blood vessels, and connective tissue. All enzymes and some hormones, e.g., insulin are made up of proteins. Proteins are required for the formation and growth of all these substances. During periods of rapid growth, additional proteins are needed for synthesis of body components.

B. **Maintenance Or Wear and Tear:** Protein is required by all age groups for continuous maintenance of all the cells in the body. Cells have a varying lifespan and proteins are needed to replace the old or worn out cell.

2. Regulatory Functions:

- ❖ All amino acids from food protein are used for growth and maintenance. Certain amino acids and protein have highly specialized functions in the regulation of body processes and protection against disease. Some of the regulatory functions are as follows:
- ❖ Haemoglobin, an iron containing protein in the red blood cells, performs an important role by transporting oxygen to the tissue cells.
- ❖ Plasma proteins maintain water balance and regulate the osmotic pressure in the body.
- ❖ Antibiotics that are protein in nature perform a protective function by increasing the body's resistance to disease.
- ❖ The hormone insulin regulates blood sugar levels. Enzymes act as specific catalyst to metabolic processes in the body.
- ❖ Some amino acids have specific functions, e.g., tryptophan serves as a precursor for niacin, a B complex vitamin. The amino acid tyrosine in combination with iodine forms the hormone thyroxine.

3. Providing Energy:

- ❖ Like carbohydrates, proteins too provide 4 kcal/g when broken down in the body. The basic need of the body is energy and takes priority over protein synthesis.
- ❖ If the diet does not supply adequate calories from carbohydrates and fats, the proteins from the diet will be oxidized to meet the energy needs of the body.

- ❖ If the diet is deficient in calories, the body uses up its protein and fat stores. Using protein as a source of energy is not advisable as it puts an extra burden on the body and the pocket.
- ❖ Protein is used by the body as a source of energy only when no other source of energy is available.

RDA:

Table 11.7: Summary of recommended protein requirements for Indians 2020.

		Body weight (kg)	EAR (g/kg/d)	RDA (g/kg/d)	EAR (g/d)	RDA (g/d)
Adult Men	Sedentary	65	0.66	0.83	42.9	54.0
	Moderate					
	Heavy Work					
Adult Women	Sedentary	55	0.66	0.83	36.3	45.7
	Moderate					
	Heavy Work					
Pregnant Women	2nd Trimester				+7.6	+9.5
	3rd Trimester				+17.6	+22.0
Lactating Women	0-6 months				+13.6	+16.9
	6-12 months				+10.6	+13.2
Infants	0-6 months	5.8	1.16	1.40	6.7	8.1
	6-12 months	8.5	1.04	1.23	8.8	10.5
Children	1-3y	12.9	0.79	0.97	10.2	12.5
	4-6y	18.3	0.70	0.87	12.8	15.9
	7-9y	25.3	0.75	0.92	19.0	23.3
Boys	10-12y	34.9	0.75	0.91	26.2	31.8
Girls	10-12y	36.4	0.73	0.90	26.6	32.8
Boys	13-15y	50.5	0.72	0.89	36.4	44.9
Girls	13-15y	49.6	0.70	0.87	34.7	43.2
Boys	16-18y	64.4	0.70	0.86	45.1	55.4
Girls	16-18y	55.7	0.67	0.83	37.3	46.2

For people consuming cereal-based diet with low quality protein, the protein requirements are 1 g/kg per day

Note: The cereal-legume-milk composition of the diet should be 3:1:2.5 for good protein quality.

Deficiency:

- ❖ A reduced intake of protein over a prolonged period of time leads to loss of weight, fatigue, anaemia, nutritional oedema, lowered resistance to infection, and poor healing of wounds.
- ❖ Protein deficiency is more marked during periods when protein needs are more, e.g., during infancy, childhood, pregnancy and lactation.
- ❖ The deficiency occurs when an individual does not eat enough proteins or obtains insufficient calories.
- ❖ Protein calorie malnutrition (PCM) is common in preschool children in developing countries and manifest itself in the form of kwashiorkor, a deficiency of protein or marasmus, a deficiency of calories as well as protein, which is equal to starvation in adults.

- ❖ Protein deficiency is also seen in people who follow a crash diet for weight loss. It can be prevented by including correct mixture of inexpensive protein rich foods in the diet.

Excess:

- ❖ An excessive intake of protein is not beneficial for health. When the diet provides more protein than what is necessary for body building, repair, and regulatory functions, the excess protein is used as energy or converted to fat and stored in the adipose tissue in the body.
- ❖ A high protein intake has many disadvantages:
 1. Once the body needs have been taken care of, the excess protein is determined by the liver and urea is synthesized. The kidneys have to work more to excrete the additional amount of urea. A high protein intake is an unnecessary burden on two vital organs, i.e. the liver and the kidneys. If these organs are diseased, toxic waste tend to accumulate in the body.
 2. When animal proteins, such as meat, poultry, and whole milk products, forma substantial part of the high protein diet, there is risk of high blood levels of cholesterol.
 3. A high intake of protein increases the loss of calcium through the urine.
 4. Protein rich foods are much costlier, are in short supply and are not an economical source.

UNIT 12: ADAPTATION OF NORMAL DIET

Content:

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12.5. LET US SUM UP

12.1. INTRODUCTION

Normal nutrition is the basis of therapeutic reforms. The main principle of diet therapy/nutrition therapy is that it is based on the patient's natural nutritional needs. Any therapeutic regimen is simply a modification of a person's normal nutritional needs to match the needs of that person's particular condition. A person's "diet" is defined as that person's food and drink intake.

All detailed dietary changes should be accompanied by supporting information about options, clear instructions, menu guides and possible substitutions. Patients should be encouraged to understand the important relationship between food and diet. The value of a food is determined by the amount of nutrients it contains and how often it is consumed. If people are provided with clear explanations and simple instructions as to why they are needed, they are more likely to follow through on the necessary dietary changes. The Recommended Dietary Allowance (RDA) is often used as a basis for assessing the adequacy of diets. When planning your diet, you should consider the specific nutritional needs of your particular disease or disorder. As a nutritionist, you must remember that a person's diet is influenced by various factors such as lifestyle, income, knowledge, taste preferences, religious beliefs

and various other socio-cultural factors. Not considering these things can make the planning of treatment regimen unrealistic.

12.2. QUALITATIVE AND QUANTITATIVE ADAPTATION

Adaptation of the usual diet can be done using quantitative or qualitative methods. In some cases, a combination of both may be required. What do these methods mean? How are they done? Read the next section to find out. Let's start with a qualitative method.

a) ***Qualitative Methods:*** Here we provide support information such as individual selections, clear instructions, menu guides and advice on suitable manufactured products. Patients should understand the important relationship between food and diet. The value of food is determined by the amount of nutrients in it and how often it is consumed. Different qualitative methods are:

- Publication of healthy eating guidelines
- Food guide pyramid
- A list of preferred food options, and
- Elimination diet

b) ***Quantitative Methods:*** These are often necessary to create treatment regimens. There are two ways to do this:

i) Use an exchange system that provides a constant amount of nutrients for each food item. An example of this is carbohydrate exchange systems used in meal planning for insulin-dependent diabetics. The desired amount of consumption is determined and a meal is created from the exchange list.

ii) Determine the amount of food and its frequency of consumption. The diet includes portions of normal-sized foods, but foods with the highest content of a specific nutrient per serving are excluded from the diet. We also learned about this aspect earlier and learned about diets limited in fat, Na and K. We also reviewed foods that are allowed and excluded based on their nutrient content.

12.3. TYPES OF DIET

A person's diet is the total amount of food and drink they normally consume. A diet is an attempt to achieve or maintain a certain weight by restricting food intake. People's food choices are often influenced by various factors, including moral and religious beliefs, clinical needs, and the desire to control weight.

Not all meals are healthy. Some people continue to eat unhealthy foods out of habit rather than consciously choosing unhealthy foods. The terms of this type of diet include "junk diet" and "western diet". Many diets have serious health risks, but doctors believe the long-term benefits are minimal. This is especially true of "crash" or "fad" diets, which are short-term weight loss programs that involve significant changes in a person's normal eating habits.

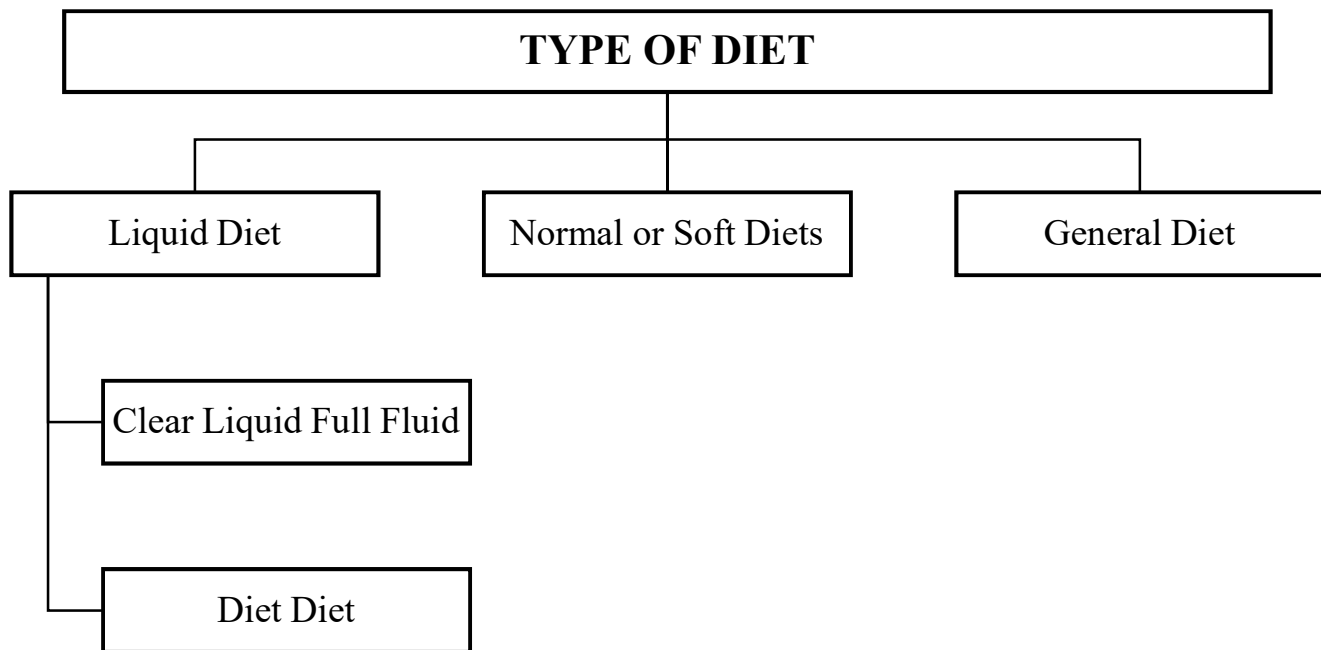


Figure 12.1: Type of Diet

12.3.1 Normal or General Diet

This diet is planned to meet Recommended Dietary Allowances (RDAs) for nutrients and is based on food groups. It is usually based on periodic menus planned according to the region, type of hospital

and customers. Adequacy of nutrition is determined by the patient's choice of food and the amount of food received by the patient. The role of the clinical dietitian is to monitor food selection and consumption to ensure adequate nutrition. General diets are intended for hospitalized patients whose medical conditions do not require therapeutic changes. A sample meal plan for reference is shown in Table 3.1.

Table 12.1: A Day's Normal Diet for an Adult

Foods	Quantity (g)	Energy (g)	Protein (g)	Carbohydrates (g)	Fats
Cereals and cereal products	370	1386.62	37	277.5	9.25
Milk and milk products (3% fat)	300	174	9	14.4	9
Pulses and legumes	75	250	17.48	42.48	2.25
Roots and Tubers	200	100	3	20	0.6
Green Leafy vegetables	100	30	3	2.5	0.5
Other vegetables	200	60	4	7	0.6
Fruits	100	45	1	10	-
Fat	25	225	-	-	25
Sugar	20	80	-	20	-
Total		~2350	~75	~394	~47

Source: Dietary Guidelines for Indians, 2011, National Institute of Nutrition, Hyderabad, India

Approximate amount of food: calories = 2350 kcal. Carbohydrates = 394 grams, protein = 75 grams, fat = 47 grams.

For non-vegetarians: 1 egg = 1/2 cup milk. 75 grams of lamb/chicken = 1 bowl of beans
+ Card bowl

This diet is used for all patients who do not need a special diet.

12.3.2 Liquid Diets

A Liquid diet includes foods that can be prepared in liquid or strained form at room temperature. These are usually prescribed after certain types of surgery. The two main types of liquid diets are clear liquid and complete liquid.

12.3.3 Clear Liquid Diet

Clear Liquid Diet includes low-residue foods that minimize the food load that must be digested in the intestines. Clear liquid diets provide foods and liquids that are clear and liquid at room temperature. The type of fluid provided will vary depending on the patient's clinical condition, the test or diagnostic procedure, or the specific surgery the patient is undergoing. The goal of the clear liquid diet is to provide fluids and electrolytes to prevent dehydration. The diet is insufficient in terms of calories and essential nutrients. Do not use clear liquid diets as your sole source of nutrition for more than 1 to 3 days without supplemental protein, calories, vitamins, and minerals. A clear liquid diet leaves the least amount in the digestive tract. It also minimizes gastrointestinal irritation.

The diet is used as an initial feeding progression between intravenous feeding and a full liquid or solid diet that follows surgery. It could be used as a dietary preparation for bowel examination or for surgery. It is also useful at times of acute disturbance of gastrointestinal function. It has application in many illnesses characterized by a high fever.

Recommended food items include:

- Clear and fat-free soup/broth.
- Coffee, light tea (without milk or cream)
- Strained fruit juice
- Soft coconut water, whey, oat water
- Gelatin, fruit ice cream, ice cream
- Sugar and salt added to liquids.
- Carbonated drinks are acceptable.
- Commercial supplements with high protein and high calories (dissolved in drinks or water).
- Honey.
- Ice
- Do not use other foods.

Small amounts of fluids are given at frequent intervals (50 to 100 mL every 1 to 2 hours). The nutritional composition of clear liquid diets varies depending on the type and amount of liquid provided and consumed by the patient. Do not use solid foods.

12.3.4 Full Liquid Diet

This diet provides liquid or semi-liquid foods and liquids at room temperature. Depending on the clinical condition of the patient, the type of meals provided may be different. It is used as a step between a clear liquid diet and a regular diet.

The purpose of diet therapy is to provide oral hydration to people who are unable to chew, swallow and digest solid foods. It is used in parenteral nutrition or in combination with parenteral nutrition as an intermediate step for solid food after surgery.

If you have trouble chewing or swallowing, or if you have certain procedures such as jaw wiring. It is also used in cases of esophageal or digestive tract narrowing, during moderate inflammation of the digestive tract, and in patients with acute illness. Do not use solid foods.

Recommended food items include:

- Soup and soup
- Cereal porridge (refined cereals)
- Milk and milk drinks, yogurt
- Coffee, tea, fruit juice, carbonated drinks
- Butter, cream and oil are added to food
- Simple pudding, custard, ice cream, jelly,
- Sugar, honey, salt, mild taste.

The food composition of the diet depends on the type and amount of liquids available to the patient. This diet is deficient in iron, vitamin B12, vitamin A and thiamine. With careful planning, you can meet your maintenance needs with the exception of dietary fiber. You can also add liquid nutritional supplements or mixed foods to improve nutritional adequacy. Breastfeeding is usually done 2 to 4 hours apart. This diet is generally low in fiber and can lead to constipation if used for a long time. If long-term use is required, vitamins, iron or liquid nutritional supplements should be added.

12.3.5 Soft Diets

Soft meals offer soft, whole foods that are lightly seasoned and relatively low in fiber. This food has a soft texture and is easily digested. Small meals are offered until the patient's tolerance to solid foods is established.

Soft foods provide a transition between liquid and regular foods. It may be prescribed for post-operative cases, acute infections, digestive disorders or patients with chewing disorders.

Soft diets should be individualized based on clinical diagnosis, surgery, patient appetite, food tolerance, previous nutritional status, and ability to chew and swallow. If the patient is able to consume adequate amounts of food, soft food can be nutritionally adequate. Supplements and feeding between meals can also be used to increase nutrient intake.

Foods allowed in soft diet include:

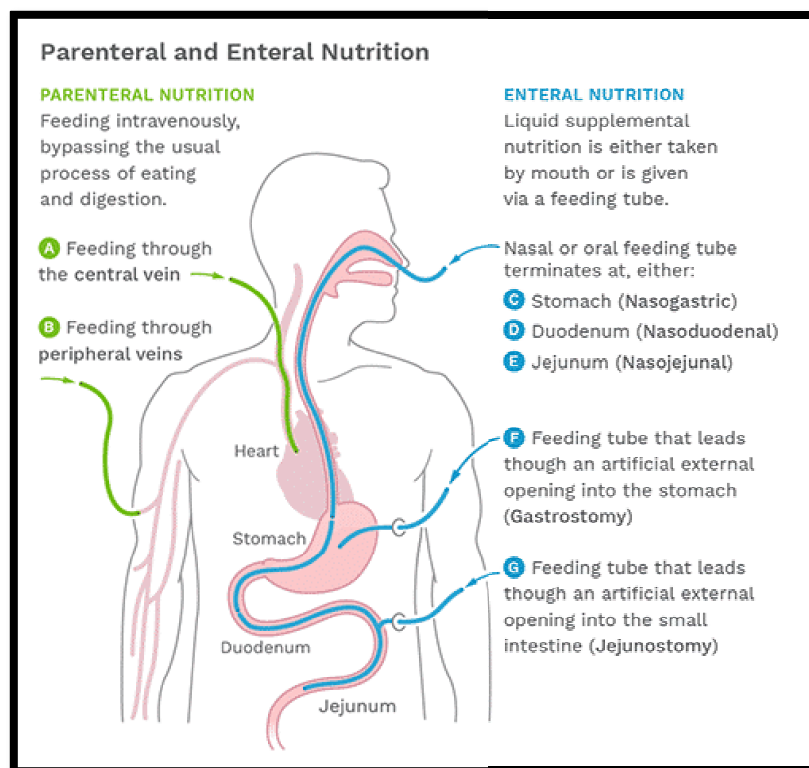
- Soups – mildly flavored soups and creamy soups.
- Drinks - everything
- Meat - moist, soft meat, fish or chicken, cottage cheese, eggs (except) fried in oil)
- Fats – butter, cream, oils, salad dressings.
- Milk – milk, milk drinks, yogurt.
- Cereals – soft cooked refined grains – rice, pasta, bread, porridge.
- Vegetables – cooked soft vegetables.
- Fruits - soft cooked fruits, juices
- Dessert - custard, ice cream, jelly, cake (sponge), pudding without nuts.
- Sweets - sugar, honey, plain candy

Foods to avoid include:

- Fried foods and nuts.
- A wide selection of sweets and desserts.
- raw vegetables,
- Spicy foods;
- Vegetables that produce gas.
- Skin and seeds of vegetables and fruits.

Avoid heavy sauces, dressings, pickles, fried foods, rich cakes and nuts. Mechanical soft food is a regular food, only the texture has been changed to make it easier to chew. This method is used when patients are unable to chew or use their facial muscles due to a variety of dental, medical and surgical conditions. Foods in the diet can be liquid, crushed, pureed or regular foods with a very soft consistency. Now that we've covered the different hospital foods, we'll finally look at the different feeding methods used for therapeutic purposes.

12.4. MODE OF FEEDING



12.4.1 Enteral

The term "enteral" refers to nutrition that takes place through the digestive system. It may be administered orally or by oral gavage.

a) Oral

Oral nutritional supplements (ONS) are nutritional support products that provide an effective and non-invasive way for people to meet their nutritional needs or increase their food intake. People taking ONS can eat a normal diet, but their regular diet alone cannot meet all their nutritional needs, so they

need nutritional supplements. Also, patients requiring a fluid-based diet may benefit from ONS. ONS products are often prescribed or recommended by a physician or registered dietitian. In some cases, people rely on ONS as their only source of power.

b) Tube Feeding

If you have a condition or disease that limits or prevents oral intake, enteral nutrition (EN) therapy can be administered directly into your digestive tract as a tube feed. Tube feeding is a stable form of feeding and is often needed. If your dog cannot eat solid food or has a digestive disorder, this is the first feeding method. EN treatment consists of specialized liquid nutritional supplements containing proteins, carbohydrates, fats, vitamins, minerals and other nutrients necessary for survival. These nutritional support products are formulated to meet individual needs for a variety of medical conditions and symptoms.

12.4.2 Parenteral

Parenteral nutrition (PN) is the intravenous injection (intravenous delivery) of nutrients directly into the systemic circulation, bypassing the digestive tract. A special liquid mixture containing proteins, carbohydrates, fats, vitamins, minerals and other essential nutrients. for life. PN represents an alternative or additional approach to nutritional intervention when oral or enteral routes alone cannot meet nutritional needs or are contraindicated.

12.5. LET US SUM UP

Therapeutic nutrition refers to the role of food and nutrition in the treatment of various diseases. Illness or disability In this section, you will learn about diet therapy and its types of food treatments. Types of dietary modifications that are made in the patient's usual diet to meet the patient's medical needs. You also learned that all therapeutic diets are modifications of normal diets.

Then we discussed the purpose of diet modification and different types of diets. Treatment is possible. These include liquid foods, soft foods, and other types of meals. Feeding modes such as oral feeding, tube feeding, peripheral injection feeding and complete feeding parenteral nutrition. Nutritional support is an essential part of medical treatment. As Careful awareness and sensitivity are essential for clinical nutritionists to translate nutrition Translate knowledge into languages appropriate to customer

needs. Enough Achieving or maintaining favorable conditions requires knowledge, skills and correct attitude nutritional status.

CHECK YOUR PROGRESS:

Write Short Notes on:

1. Qualitative and Quantitative Adaptation
2. Normal or General Diet
3. Clear Liquid Diet
4. Full Liquid Diet
5. Enteral and Parenteral Feeding

Questions:

1. What is the difference between qualitative and quantitative adaptation in therapeutic nutrition?
2. When would a clear liquid diet be recommended, and what does it consist of?
3. How does a full liquid diet differ from a clear liquid diet?
4. What are the key differences between enteral and parenteral modes of feeding, and when is each used?

Note