Anil Gupta

Comprehensive Biochemistry for Dentistry

Textbook for Dental Students

Springer

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I dedicate my book to Almighty Shirdi Sai Baba.

Foreword

It gives me a great satisfaction to write a brief note on *Comprehensive Biochemistry for Dentistry* by Dr. Anil Gupta. In this book, the latest information has been incorporated to create a comprehensive text that is suitable for beginners.

Every effort has been made to update the text with the possible latest information. The information is clearly presented, logically arranged, and well-illustrated. References have been included to guide readers to the classical and current literature. I am confident that this textbook will prove to be a useful compendium for all students at the graduate and postgraduate levels, igniting their interest and enabling a greater involvement in the growing dental field.

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Foreword

It is my privilege to review and comment on the book *Comprehensive Biochemistry for Dentistry*. The 24 chapters of this book begin with cells and organelles—the fundamental units of life. The next two sections contain information on structural and molecular biology components and intermediary metabolism. The fourth section is dedicated to medical biochemistry, explaining the importance of acid–base balance, nutrition, and diagnostic enzymes. The final section focuses on dental biochemistry, which is of more clinical interest. This unique section examines the role of various molecules and macromolecules in the normal functioning of oral tissues and in the instigation of dental diseases. The index is quite good and easily steers the reader toward references of interest. Most chapters present information on applied biochemistry, including the biochemistry and treatment of specific diseases, making the book useful for both physicians and students. It also serves as a refresher on the fundamentals of biochemistry for students and physicians. The author presents up-to-date information on biochemistry and emphasizes relevant physiologic and pathophysiologic biochemical concepts. The book uses simple and clear language that can be easily understood by students, physicians, and researchers. I am sure this book will be welcomed by many undergraduate and postgraduate students, physicians, and researchers.

Rajesh Dabur
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Department of Biochemistry
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Rohtak, India

Foreword

I am glad to know about the publication of *Comprehensive Biochemistry for Dentistry*. This book covers the complete syllabus for undergraduate courses, as well as being a source of knowledge for professionals. I wish the author great success with this book.

S. P. S. Sodhi
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Executive Member
Dental Council of India
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Member–Academic Council
Member–Board of Studies
Member–Planning Board
Baba Farid University of Health Sciences
Faridkot, India

Foreword

It is a pleasure to write a foreword for *Comprehensive Biochemistry for Dentistry*, which was written by my younger brother, Dr. Anil Gupta. What impressed me most was his deep insight on the subject and his method of presenting even the most complex concepts in a simple, easily understandable, and convincing manner. With each chapter, he provides the details of biochemistry as applied to the understanding of dental disorders. The book is organized in a manner to help students. It is a book to be opened with expectation and closed with profit.

I have reviewed this book and appreciate the simple language, straightforward style, and clear presentation. This book will definitely prove to be very useful for all dental students and practitioners in India.

S. K. Singhal
MD, LLB
Medico Legal Consultant and Author of Seven Books
Medical Director
Professor, and Head of the Department of Forensic Medicine and Toxicology
A.C.P.M. Medical College
Dhule, India

Foreword

Biochemistry is a vast and challenging field for dental students. *Comprehensive Biochemistry for Dentistry* is a complete and student-friendly book. It offers the users an excellent opportunity to understand the basic fundamentals of biochemistry and its applications to the medical field. A dedicated effort has been made by Prof. (Dr.) Anil Gupta to systematically compile the book into six units covering the entire syllabus. I am sure that the textbook will be an informative read for undergraduate students, as well as clinicians. The author deserves appreciation and recognition for his efforts to carry out this commendable and arduous task.

Sanjay Bansal, MDS
Principal
EDCH
Kotputli, India

Foreword

I wish great success and my heartiest congratulations to my senior colleague, Dr. Anil Gupta, for publishing *Comprehensive Biochemistry for Dentistry.* This book fills a great need of students, especially those studying dentistry. I have known Dr. Anil for years; he is deeply loved and respected by our students for his skills in the subject, his teaching methodology, and his constant pursuit for excellence. He is a great academician, a great person, and above all, a kind human being. Dr. Anil has been continuously working on this title for years, trying to create the best possible textbook on biochemistry with up-to-date content and simple language, allowing its readers to understand the complexities of the biochemicals in the human body. It is a great fortune of mine to be associated with Dr. Anil Gupta. I believe this title will be a superb choice for students of biochemistry thanks to its comprehensive content, simplicity, and ease of understanding.

Nitul Jain, MDS
Professor and Head Department of Oral Pathology
Eklavya Dental College and Hospital
Kotputli, Rajasthan, India

Foreword

It gives me great pleasure to unveil yet another noteworthy work penned by the author.

Dr. Anil Gupta is a prolific writer and no stranger to the world of books. His exceptional style of writing, creativity, and groundbreaking ideas have only improved with time.

Biochemistry is one of the most important basic sciences in the preclinical years of medical and dental schools. For me personally, it was a daunting subject.

This book complements the classical textbooks of biochemistry. It blends the fundamental and dynamic concepts of biochemistry and provides exhaustive knowledge for dental students in a single, clearly presented volume. The chapters are skillfully written and easy to understand.

I recommend this book with enthusiasm and give my best wishes to Dr. Anil Gupta for undertaking this endeavor.

Prithvi Raj Singh
MD Pathology
Reader, Department of Pathology
EDCH, Kotputli, India

Foreword

Dr. Anil Gupta, the author of this book, deserves to be congratulated on presenting the speciality of biochemistry to medical and dental students at different levels of education, as well as to professionals of different specialists. This book provides a comprehensive and clear account of the current principles of biochemistry knowledge. The author has done this by drawing on his rich experience as a teacher of biochemistry for more than 10 years. This book defines all topics in a narrative format so that the information is palatable to students and professionals. In this book, Dr. Gupta has adopted a conventional approach to characterize food constituents, describing their formulae, properties, and place in human biological and chemical reactions. The language is simple and easily understandable. The chapters on the metabolism of carbohydrates, lipids, proteins, and nucleic acids are exhaustive and naturally presented. Students will benefit greatly from the descriptive account of vitamins, hormones, and enzymes, with special emphasis on dental topics. This book will be welcomed by teachers of biochemistry, dental students, medical students, and professionals for revising and refreshing one's knowledge in biochemistry. I am confident that this book will go through many editions in the coming years and the author will add more details on the topics herein.

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Foreword

This book, *Comprehensive Biochemistry for Dentistry*, is a good idea and great effort by the author. The book is very educative and informative for graduates. I wish Dr. Gupta good luck for this great endeavour.

Naveen Bansal
Head, Department of Orthodontics
Genesis Institute of Dental Sciences and Research
Ferozepur, India

Foreword

I sincerely thank the author for allowing me to be part of his precious book. The chapters within are unique and contain a plethora of information, not only for undergraduate studies but also for postgraduate entrance examinations. The genetics section may be especially helpful for this purpose. As a faculty member at a reputed coaching centre for postgraduate entrance examinations, I find that most undergraduate students lack a clear understanding of the concepts of biochemistry. Therefore, I think this book is very helpful for clarifying the concepts. It includes a section on dental biochemistry that is an additional benefit for students. To conclude, I want to quote Francis Bacon: "Some books are to be tasted, others swallowed, and some few to be chewed and digested." The content of this book should be chewed and absorbed properly for undergraduate and postgraduate entrance examinations.

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Foreword

I congratulate Dr. Anil Gupta for his extensive teaching and research experience, which were utilized to write this book, *Comprehensive Biochemistry for Dentistry.* I am absolutely sure that students of dentistry will find this book highly useful.

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Preface

Biochemistry is an essential subject in the medical, dental, nursing, paramedical, physiotherapy and homeopathy streams in various universities across the world. Knowledge of the fundamentals of biochemistry is necessary for the study of normal structure and functioning of organs and organ systems, as well as the pathogenesis of diseases.

A number of biochemistry books are available in the market. This book is unique in its approach to the vital concepts of biochemistry. It blends the fundamentals and dynamic concepts of biochemistry with the theory of dental sciences to provide valuable, coherent, and exhaustive knowledge for dental students and professionals.

Comprehensive Biochemistry for Dentistry is composed of 24 chapters on the structure, function, and metabolism of biomolecules. The information is presented in a simplified approach and enriched with diagrams, flow charts, tables,, and graphs. Important concepts, definitions, and clinical significance are provided in a summary format for easy understanding and recapitulation. Topics such as cell and organelles, vitamins, hormones, nucleic acids, biological oxidation, metabolism, nutrition, and serum enzymes have been prepared in such a way to provide exhaustive knowledge to students using clear and straightforward language. In particular, the information on dental biochemistry is unique to this book. Proteins, lipids, carbohydrates, vitamins, and hormones are discussed in relation to the normal structure and functioning of oral tissues, as well as their roles in dental diseases.

This book is a unique attempt to integrate the fundamentals of biochemistry with the science of dentistry for the purpose of imparting knowledge to dental students and professionals. I hope it will disseminate the knowledge of biochemistry to undergraduate students and serve as a reference book for professionals and academicians. I have made sincere and honest efforts to prepare and present a factually accurate book. However, I welcome criticisms, comments, and suggestions for improvements to forthcoming editions of this book.

Kotputli, India
27 March 2018

Anil Gupta

Acknowledgements

The Almighty Shri Shirdi Sai Baba bestowed upon me the knowledge and perseverance for writing the book. My father, Shri Ved Parkash Gupta, always inspires me to undertake great endeavours. I am highly indebted to my father for instilling the habit of learning in me since my school days.My wife persistently motivates me to achieve my goals and she stands by me in odd hours.

I owe my gratitude to Dr. Bhavik Sawhney, Associate Editor–Biomedicine, Springer (India) Pvt. Ltd, for his support, cooperation, and understanding, which he offered to me to complete the writing of this book. I am also thankful to Ms. Saanthi Shankhararaman, Project Coordinator (Books) and her production team for creating an attractive and appealing book design.

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Introduction to Biochemistry

1

Biochemistry is the study of chemical compounds that are structural and functional components of living organisms. These chemical compounds exist in organic and inorganic forms in the body of living organisms. Life is the highly organized form of biochemicals that exhibit proliferation, growth, development, irritation, and reproduction.

Biochemistry deals with study of basic structure of these biochemicals and proportions in which biochemicals aggregate to form a living cell. Study of biochemistry also emphasizes upon the transformation of biochemicals within the body in health and diseases. The subject of biochemistry also deals with molecular changes that are inherently associated with pathogenesis of diseases. Field of biochemistry is highly extensive. It also describes the role of biomolecules as biomarkers in the diagnosis and prognosis of diseases.

1.1 Definition

Biochemistry is a branch of life science (medical science) which deals with study of the structure, functions, and transformation of biomolecules within living organisms together with their role in diagnosis and pathogenesis of diseases.

The word biochemistry is derived from "bio" which means "living" and "chemistry" which means the study of chemicals. Biochemistry deals with the study of chemicals that are essential part of living matter.

1.2 Historical Development of Biochemistry

- Roots of modern biochemistry are traceable to the science of Indian medicine called as **Ayurveda**. Its origin coincides with the development of mankind. Ayurvedic science focuses on seven tissues of the body called as *DHATUS*. They

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are rasa, rakta, mamsa (muscles), meda (fats), asthi (skeletal system), majja (bone marrow), and shukra (semen). Ayurvedic principles strongly emphasize upon the positive interrelationship among *AHARA* (quality of diet), *VIHARA* (lifestyle), and *DHATUS*.

- **Charaka** was an Ayurvedic physician which dates back to 300 BC. He compiled a compendium of Ayurveda called as *Charak Samhita*. It describes types of foods, quality of food, and role of nutrition in health and diseases.
- **Modern medical science** relies on biochemical assaying of blood, urine, and cerebrospinal fluid to diagnose diseases.
- **Paracelsus** (1493–1541) introduced the chemicals in the field of medicine.
- **Carl Wilhelm Scheele** (1742–1786) studied organic compounds like tartaric acid, citric acid, and lactic acid.
- **Antoine Lavoisier** (1743–1794) was recognized as father of modern chemistry. He was pioneer in the study of oxidation of foods inside body cells.
- **J. von Liebig** (1803–1973) contributed to biological chemistry. In 1842, he wrote a book of organic chemistry with applications to physiology and pathology.
- **JJ Berzelius** (1779–1848) is considered as one of the founders of modern biochemistry. He coined the term protein. He wrote a book named as animal chemistry.
- **Friedrich Miescher** discovered nucleic acid in 1869.
- Kuhne used the term enzyme in 1877.
- **Emil Fischer** proposed lock and key theory to explain mechanism of enzyme action in 1998.
- **Carl Neuberg** was a German scientist. He is credited with title of **Father of Modern Biochemistry**. The term biochemistry was proposed by Carl Neuberg in 1903.
- **Embden-Meyerhof-Parnas** provided understanding about oxidation of glucose.
- **A. Szent-Gyorgyi** contributed to discovery of fumaric acid in 1930.
- **Kendell** was credited with isolation of thyroxine in 1914.
- **Hans A Krebs** described TCA cycle in 1937.
- **Watson and Crick** lead to pioneering research in molecular biology. They discovered double helical model of DNA in 1953.
- **Har Gobind Khorana** (1922–2011) led to remarkable research. He demonstrated significance of ribonucleotides (genetic codes) (UCUCUCU) in coding serine and leucine. He synthesized polyribonucleotides.
- **Herbert Boyer** in 1937 synthesized recombinant DNA by transducing DNA fragment into plasmid. Human insulin has been synthesized by DNA recombinant technology.
- Today, modern medicine is heavily relied on biochemistry in the diagnosis of diseases and in designing drugs.
- **In the future, mapping of human genome will lead to gene therapy.**

Part I

Cellular Biochemistry

Cell and Organelles

2

2.1 Cell

2.1.1 Definition

Cell can be defined as fundamental structural and functional unit of life bound by plasma membrane that can reproduce independently.

All living organisms are composed of basic structural and functional fundamental units, which are called as Cells. The body of living organisms like bacteria, protozoans and blue-green algae is unicellular. Single cell in these organisms performs all the functions. Plants, fungi, animals are multicellular organisms and their bodies are made up of millions of cells. The body of man is composed of nearly one trillion cells. The cell are highly specialized in their structure and functions in multicellular organisms.

2.2 Landmark Discoveries

In 1665, **Robert Hooke** investigated a piece of cork under microscope. He found that **cork** was made up of **small compartments; he called them as cells**.

In 1672, **Leeuwenhoek** was the first who observed sperms, bacteria, and red blood cells under microscope.

In 1831, **Robert Brown** postulated that all cells had a nucleus in the center.

In 1839, Schleiden and Schwann postulated cell theory.

2.3 Cell Theory Postulates

- Schleiden (1838) and Schwann (1839) together proposed Cell theory. All living organisms are made up of one or more than one cells.
- Cell is the fundamental unit of life.

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- Later on, Rudolph Virchow in 1885 described that "Omnis Cellula e Cellula". **The modified cell theory** is as follows:
  1. The body of all living organisms is made up of cells.
  2. The cell is the basic structural and functional unit of life.
  3. All cells arise from preexisting cells (Omnis Cellula e Cellula).

  Exception to Cell theory.
  - i. Viruses
  - ii. Viriods
  - iii. Prions

2.4 Modern Concept of Cell

- All living organisms are made up of one or more cells.
- All living cells arise from preexisting cells by division.
- The cell is the basic unit of structure and function among all living organisms.
- Biochemical reactions involving catabolism and anabolism in organism occur inside cells.
- Cells contain genetic material which is transferred from one cell to other cell.

2.5 Prokaryotic Cell

Pro- means "primitive," and karyon means "nucleus."

Features

- Prokaryotic cell has primitive nucleus. It is not enclosed by nuclear membrane.
- Cell has a single double-stranded circular DNA molecule in cytoplasm. It is called as nucleoid as in Fig. 2.1.
- Cell membrane is covered by cell wall.
- Cytoplasm lacks membrane-bound cytoplasmic organelles.
- Cell contains 70S ribosomes freely scattered in cytoplasm.
- Cell lacks internal cytoskeleton.
- Cell lacks mitochondria. Enzymes for respiration in prokaryotes are found within the infoldings of cell membrane and these infoldings are called as mesosomes.
- Cell division occurs by fission.

2.6 Eukaryotic Cell

The word Eu means "true" and karyon means "nucleus."

Features

- Eukaryotic cells have properly defined nucleus. It is surrounded by nuclear membrane.

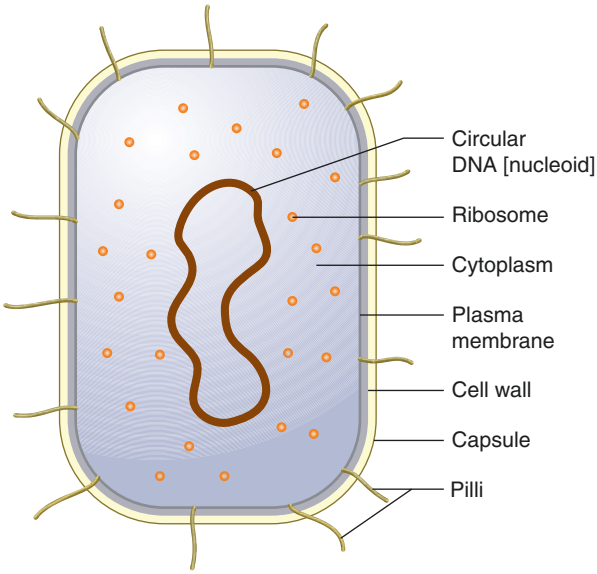

Fig. 2.1 Diagram of prokaryotic cell

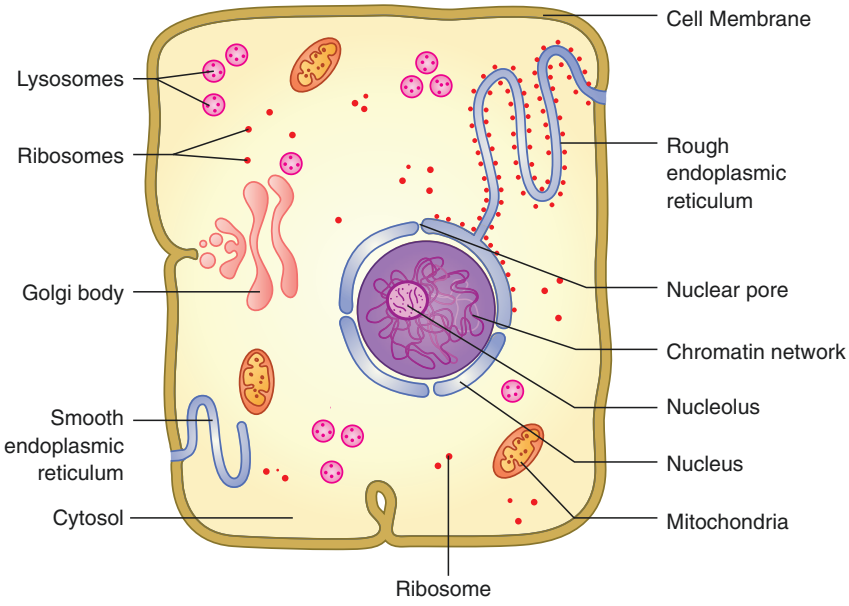

Fig. 2.2 Diagram of eukaryotic cell

- Cell contains single double-stranded helically coiled DNA which associates with histone proteins to form chromosomes as in Fig. 2.2.
- Cell membrane has phospholipid bilayer structure.
- Cytoplasm has membrane-bound organelles.
- Cell contains internal cytoskeleton.

- Cell contains 80S ribosomes attached to endoplasmic reticulum.
- Cell contains mitochondria containing enzymes for oxidative phosphorylation and energy production.
- Cells divide by mitosis.

2.7 Plasma Membrane

2.7.1 Definition

Plasma membrane is a lipoprotein aceous semipermeable structure that surrounds and supports protoplasm.

2.7.2 History

- In 1855, Nageli and Cramer proposed the term "cell membrane" for membrane surrounding protoplasm.
- In 1895, Charles Ernest Overton described lipid nature of plasma membrane.
- In 1917, Irving Langmuir proposed an orientation of hydrophilic heads and hydrophobic tails of phospholipid molecules in plasma membrane.
- In 1925, **Gorter and Grendel described lipid bilayer model** of plasma membrane without protein.
- In 1935, **Danielli and Davson proposed sandwich model** (protein-lipid-protein).
- In 1950, **Robertson proposed a unit membrane model** of plasma membrane.
- In 1972, **Singer and Nicholson proposed fluid mosaic model** of plasma membrane.

2.7.3 Chemical Composition

Plasma membrane is essentially composed of carbohydrates, lipids, and proteins in varying proportions. The relative proportion of macromolecules present in plasma membrane is dependent on type of cells.

In general, plasma membrane contains the following components:

- Example: Lipid contents vary between 20% and 75%
- [24% lipids in inner membrane of mitochondria and 74% in myelin sheath].
- Protein contents vary between 20% and 76%
- Example: [20% lipids in myelin sheath and 77% lipids in inner membrane of mitochondria].
- Carbohydrate contents vary between 1% and 10%
- Example: [1% carbohydrates in endoplasmic reticulum and 7% in plasma membrane].

Lipids in Plasma Membrane

Lipids constitute the essential component of plasma membrane. **Each lipid molecule is amphipathic in nature**. It is composed of a hydrophilic (polar) head and

hydrophobic (nonpolar) tail. Hydrophilic head is oriented outward towards the aquous medium and hydrophobic tail is directed inwardly.

Types of Lipids

- **Fatty acids**
  Fatty acids are the building blocks of phospholipids and glycolipids in plasma membrane. Nearly 50% of the total fatty acids in membranes are the saturated fatty acids like palmitic acid and steric acid. Remaining 50% of fatty acids are unsaturated fatty acids like are oleic acids, arachidonic acid, linoleic acid and linolenic acids. The number of fatty acids in lipids is variable.
- **Phospholipids**
  Phospholipids are the principal structural components of membrane lipids. Glycerophospholipids are important part of lipids in biomembranes. Lecithin and cephalin are common glycerophospholipids in biomembranes of animals.
- **Sphingolipids**
  Sphingolipids are important constituents of biomembranes of neurons in animals. Cerebrosides, gangliosides, and sphingomyelin are common sphingolipids.
- **Cholesterol**
  Cholesterol is an additional component of biological membranes in animals. Cholesterol is a sterol that is exclusively found in the biological membranes of animals. It is not found in plant tissues. Cholesterol forms about 20% of the total lipids of cell membrane.

Proteins in Plasma Membrane
Proteins constitute another essential structural part of biological membranes.

Types of Proteins

- **Integral membrane protein**
  They are deeply implanted in biological membrane. Integral membrane proteins are permanently attached to hydrophobic region of lipid layer by van der Waals forces. They are also called as **intrinsic proteins**.
- **Peripheral membrane proteins**
  They are weakly attached to hydrophilic regions of phospholipid layer by ionic bonds. These proteins are present on surface of membrane. They are also called as **extrinsic proteins**. They can be easily separated from membrane by denaturation and detergents.
- **Transmembrane proteins**
  Transmembrane proteins span across the membrane extending from its outer surface to inner surface. They are intrinsic proteins. They are linked by hydrophobic amino acid residues to nonpolar region of phospholipids. Transmembrane proteins serve as receptors for vast variety of drugs. These proteins also serve as ion channels for the transport of ions, solutes across the plasma membrane.

Carbohydrates in Plasma Membrane

Carbohydrates constitute a small fraction of biological membranes. Carbohydrates are covalently linked to membrane proteins. This process is called as glycosylation of proteins. Common monosaccharides are D-galactose, D-mannose, N-acetylglucosamine, and N-acetylneuraminic acid.

Glycosylation can be achieved through two types of glycosidic bonding as:

- **N-glycosidic linkage**
  It is a bonding between glycans and nitrogen of either asparagine or arginine residue. It occurs in lumen of endoplasmic reticulum in eukaryotic cells.
- **O-glycosidic linkage**
  It is a linkage between glycans to oxygen of hydroxyl group on serine, Hydroxyproline, hydroxylysine, tyrosine and threonine residues. It occurs in lumen of Golgi bodies in eukaryotic cells.

2.8 Models of Plasma Membrane Structure

2.8.1 Lipid Bilayer Model

Characteristics

- Lipid bilayer model of plasma membrane was proposed by Gorter and Grendel in 1925.
- Two workers studied the plasma membrane of RBCs.
- Plasma membrane is composed of two layers of lipid molecules.
- Each lipid molecule has hydrophilic head and hydrophobic tail. Heads of all lipid molecules are oriented toward aqueous medium, while tails of molecules are oriented inwardly as in Fig. 2.3.

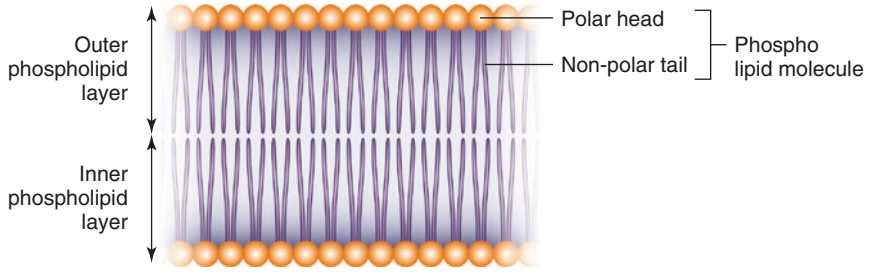

Fig. 2.3 Diagram Showing Lipid Bilayer Model

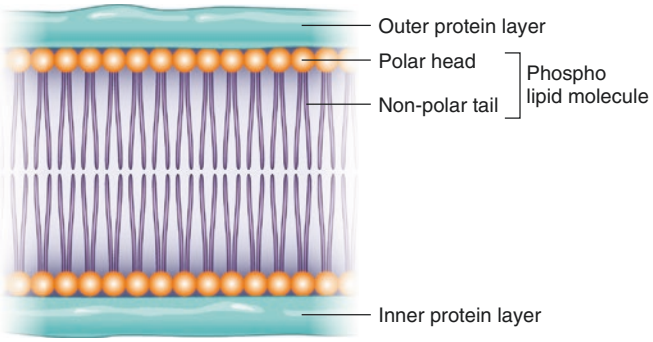

Fig. 2.4 Diagram of Sandwich Model

2.8.2 Sandwich Model

Characteristics

- Sandwich model was proposed by **Danielli and Davson in 1935**.
- Plasma membrane is made up of a phospholipid bilayer and two layers of proteins to form a **protein-lipid-protein** structure of plasma membrane.
- Lipid bilayer in Danielli and Davson model has the same structure as was proposed in lipid bilayer model.
- Lipid bilayer is surrounded (sandwiched) on either side by sheets of beta proteins as in Fig. 2.4.

2.8.3 Unit Membrane Model

Characteristics

- **Unit membrane model was proposed by Robertson in 1950**.
- All biological membranes have unit membrane structure.
- Unit membrane is made up of a central phospholipid bilayer, and it is sandwiched between two sheets of proteins. This arrangement of lipoprotein layers results in formation of a **trilaminar structure of plasma membrane** as in Fig. 2.5. The trilamella together constitute as a unit to surround and support cell and organelles.
- Thickness of unit membrane is 75 Å.
  - Thickness of lipid bilayer is 35 Å.
  - Thickness of each layer of protein is 20 Å.

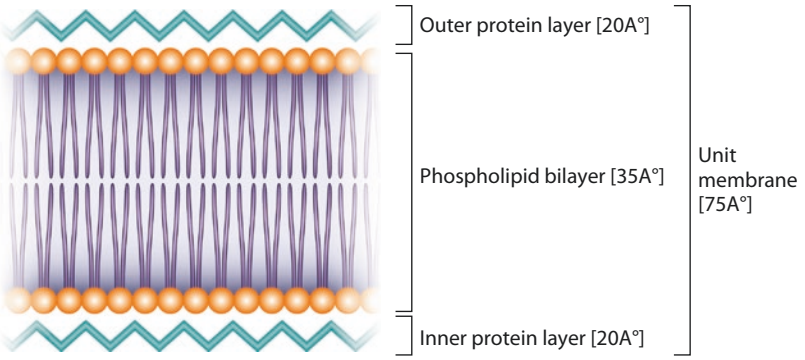

Fig. 2.5 Diagram of Unit Membrane Model

2.8.4 Fluid Mosaic Model

Features

- **It is a highly accepted model of plasma membrane.**
- Fluid mosaic model of plasma membrane structure was proposed by Singer and Nicolson in 1972. It is also called as **Singer and Nicolson model**.

Characteristics of Fluid Mosaic Model

- Plasma membrane has a **thickness of 75** Å.
- Plasma membrane is a **dynamic structure**. It has a feature of expansion, contraction, invagination, evagination, and repair.
- Plasma membrane has a **quasi-fluid nature**. It is partly solid as it surrounds and protects cell and organelles. It is partly liquid as it allows passage of substances through it.
- **Quasi-fluid nature of membrane allows lateral movement of protein molecules** through lipid bilayer as in Fig. 2.6.
- Plasma membrane structure represents a **mosaic of lipids and proteins**. The **protein molecules** like **icebergs** float in a **sea of lipid molecules**.
- On outer surface of plasma membrane, **oligosaccharides are linked to extrinsic proteins and phospholipid molecules** to form **glycoproteins and glycolipids**.

Nature of Lipids in Fluid Mosaic Model

- Lipid molecules have amphipathic nature. Lipid molecules are arranged into two layers forming a lipid bilayer.
- Each lipid molecule has a polar head (hydrophilic) and a nonpolar tail (hydrophobic). Polar heads of all lipid molecules are directed outward toward aqueous

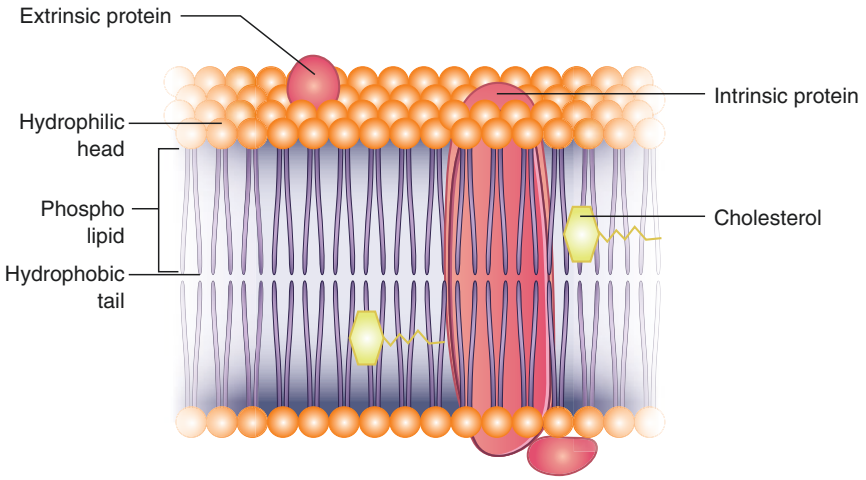

Fig. 2.6 Structure of cell membrane (Fluid Mosaic Model)

medium. Nonpolar tails of lipid molecules are oriented inward in such a way that tails of one lipid bilayer face tails of another lipid bilayer.

- **Lipid bilayer in membrane is quasi-fluid in nature**.

Nature of Proteins in Fluid Mosaic Model

- **Integral membrane protein**
  They are deeply implanted in biological membrane. Integral membrane proteins are permanently attached to hydrophobic region of lipid layer by Van der Waals forces.
- **Peripheral membrane proteins**
  They are weakly attached to hydrophilic regions of phospholipid layer by ionic bonds. These proteins are present on surface of membrane.
  A few extrinsic protein molecules are covalently attached to carbohydrate moieties to form glycoproteins.
  Protein molecules can translocate laterally due to quasi-fluid nature of lipid bilayer. Proteins provide structural and functional specificity to membrane.

2.8.5 Functions of Plasma Membrane

- Plasma membrane surrounds and protects cell.
- Plasma membrane permits exchange of substances between cytoplasm and extracellular compartment.
- Plasma membranes form different types of junctions that help communication among cells.

- Plasma membrane allows movement of selected molecules to pass through it (selective permeable), while other molecules cannot pass through membrane.
- Plasma membrane contains receptors for drugs and hormones.
- Plasma membrane contains carrier protein molecules for active transport of molecules.
- Plasma membrane of mitochondria carries ATPase for synthesis of ATP.
- Plasma membrane of enterocytes has fingerlike outgrowths and microvilli that increase absorptive area.
- Plasma membrane of neurons helps in nerve impulse generation and conduction. Plasma membrane of bacteria contains respiratory enzymes.

2.9 Cytoplasmic Organelles

2.9.1 Mitochondria

Definition
Mitochondria are filamentous, self-replicating, double-walled organelles located in cytoplasm of eukaryotic cells.

Mitochondria are termed as **powerhouse of cell**.

The term mitochondrion is derived from Greek words **mitos which means thread and chondros which means granule (owing to appearance of mitochondria in spermatogenesis)**.

History

- In 1880, Kolliker discovered mitochondria in insect flight muscles.
- In 1890, Altman described mitochondria in cells and called them as **bioblasts (living organelles inside cell)**.
- In 1898, Benda coined the term mitochondria.
- **In 1941, Claude separated mitochondria from other fractions** of cell.

Occurrence
Mitochondria are located in cytoplasm of eukaryotic cells.

Color
Mitochondria have brownish red color.

Size
Size of mitochondria is variable. Mitochondria may have **0.5–3 µm length and 0.1–0.5 µm diameter**.

Shape
Mitochondria have variable shapes. Under simple microscope, mitochondria appear as minute threadlike structures. They may have **sausage**, **spherical**, **or filament-like shape**.

Number
The number of mitochondria in a cell is dependent on metabolic activity.

- **Minimum number is one mitochondrion per cell**. Example: green algae belonging to genera *Micromonas*, *Trypanosoma*, and *Chlorella*, yeast
- **The highest number is 50,000 mitochondria/cell**. Example: insect flight muscles
- **Absence of mitochondria**. Example: human red blood cells

Generally, the number of mitochondria varies **between 100 and 2000 mitochondria per cell**.

Structure
Mitochondria structure can be described in three separate headings as:

Mitochondrial Membranes

Mitochondria are bounded by two successive membranes. Each one has unique biological functions.

Outer Mitochondrial Membrane

- Outer membrane has a thickness of about 60 Å.
- Its chemical composition is similar to that of plasma membrane of eukaryotic cell. It is composed of **phospholipids and proteins which are present in a 1:1 ratio**.
- **Outer membrane proteins**
  Outer membrane contains **integral membrane proteins** (transmembrane protein). These proteins act as channels and hence proteins are called as **porins**.
  – Porin proteins allow transport of molecules (7000 dalton mw) across the outer mitochondrial membrane.

Inner Mitochondrial Membrane

- Inner mitochondrial membrane has high protein contents than phospholipids. The ratio of proteins to phospholipids is 3:1.
- **Inner membrane phospholipid**
  Inner membrane contains a prominent phospholipid called as **cardiolipin** (exclusively found in inner membrane in eukaryotes, in bacterial cell wall).
- **Inner membrane proteins**
  Inner membrane contains more than 100 polypeptides. They act as ATP synthase enzyme, carrier proteins, and proteins for mitochondrial fission and fusion.
- **Inner membrane is impermeable to ionic and polar compounds.** These molecules require carrier proteins to pass across inner membrane as in Fig. 2.7.