Cover Story 3

Chemistry in Medicine

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Chemistry plays a huge part in medicine, with biochemistry concerning normal structure, function and nutrition of the body, pharmaceutical chemistry involving in treatment of diseases, and laboratory chemistry helping in diagnostic testing. Chemistry can also account for diseases in the body, for example abnormalities in metabolic processes in the body can give rise to diseases such as diabetes, and various chemicals and metals also can harm in the body by causing toxicity. In this article, the main ways how chemistry affects the human body is discussed under 5 main headings.

Biochemistry
Pharmaceutical chemistry
Diagnostic chemistry
Metals in health and diseases
Toxicological chemistry

Biochemistry

Biochemistry is the study of chemical processes in living organisms, and it is one of the main subjects that medical students have to study when they enter the Medical Faculty. Biochemistry governs all living organisms and living processes. Much of biochemistry deals with the structures and functions of cellular components such as proteins, carbohydrates, lipids, nucleic acids and other biomolecules, which are the main components of a human cell. Today the main focus of pure biochemistry is in understanding how biological molecules give rise to the various chemical and other processes that occur within living cells which in turn relates greatly to the study and understanding of whole organisms. The most important biochemical cellular components which are also the main nutrients in the body are discussed below.

Carbohydrates

Carbohydrates are a major components of our diet giving 40-45% of dietary calories. Starchy foods such as rice, bread, potatoes and their products consist of mostly carbohydrates. The functions of carbohydrates includes energy storage and providing cellular structure. Sugars are carbohydrates, but not all carbohydrates are sugars. There are more carbohydrates on earth than any other known type of biomolecule. They are used to store energy and genetic information, as well as play important roles in cell to cell interactions and communications. Abnormalities in carbohydrate regulation and metabolism in the body results in elevation of blood glucose giving rise to common diseases such as diabetes mellitus which is now a global problem.

The simplest type of carbohydrate is a monosaccharide, which contains carbon, hydrogen, and oxygen, mostly in a ratio of 1:2:1. (generalized formula $C_nH_{2n}O_n$, where n is at least 3). Some of these monosaccharides include glucose ($C_6H_{12}O_6$), fructose ($C_6H_{12}O_6$), the sugar commonly found in fruits and deoxyribose ($C_5H_{10}O_4$). Combination of monosaccharides, glucose and fructose gives a disaccharide, sucrose, the ordinary table sugar, probably the most familiar carbohydrate.

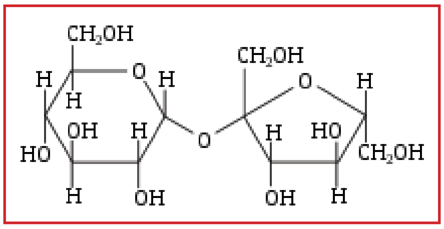


Figure 1 Sucrose: ordinary table sugar

Lipids

The term lipid comprises a diverse range of molecules of biological origin, including waxes and fatty acids and fatty-acid derived compounds. Lipids are also an integral part of our daily diet. Most oils and milk products that we use for cooking and eating like butter, cheese, ghee etc are composed of fats. Vegetable oils are rich in various polyunsaturated fatty acids. Lipid-containing foods undergo digestion within the body and are broken into fatty acids and glycerol, which are the final degradation products of fats and lipids.

Lipids are usually made from one molecule of glycerol combined with other molecules. In triglycerides, the main group of bulk lipids, there is one molecule of glycerol and three fatty acids.

Blood lipids (or blood fats) are lipids in the blood, either free or bound to other molecules. They are mostly transported along with proteins called lipoproteins. The concentration of blood lipids depends on intake in diet, excretion from the intestine, and uptake and secretion from cells. Blood lipids consist of mainly fatty acids and cholesterol. Hyperlipidemia is the presence of elevated or abnormal levels of lipids, lipoproteins and cholesterol in the blood, and is a major risk factor for heart diseases and strokes by getting deposited in the blood vessels known as arteries.

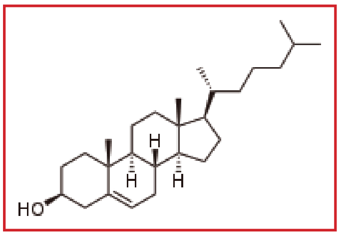


Figure 2 Cholesterol molecule

Proteins

Like carbohydrates, some proteins perform largely structural roles in the body. For instance, movements of the proteins actin and myosin ultimately are responsible for the contraction of skeletal muscle. One common property that many proteins have is that they specifically bind to a certain molecule or class of molecules that is extremely selective in what they bind. Antibodies are an example of proteins that attach to one specific type of molecule. Receptors found on cell membranes which are also protein molecules bind various hormones or neurotransmitters in the body or drugs which show highly selective action in binding. Other most important proteins in the body are the enzymes. These molecules recognize specific reactant molecules called substrates; they then catalyze the reaction between them. Using various medicines as modifiers, the activity of the enzyme can be controlled, enabling control of the biochemistry of the cell as a whole, resulting in the desired therapeutic effects. For example drugs such as paracetamol and aspirin give pain relief by inhibiting the activity of an enzyme called cyclo-oxygenase in the body which reduces the production of pain and fever producing substances called prostaglandins..

Proteins are chains of amino acids. An amino acid consists of a carbon atom bound to four groups. One is an amino group, —NH_2, and one is a carboxylic acid group, —COOH. The third is a simple hydrogen atom. The fourth is commonly denoted "—R" and is different for each amino acid.

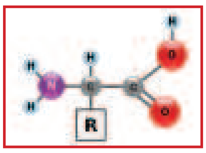


Figure 3 The general structure of an α-amino acid

There are twenty standard amino acids. Humans and other mammal, however, can synthesize only half of them. Since these are the essential amino acids, those that cannot be synthesized, must be ingested (eg. isoleucine, leucine, lysine, methionine, phenylalanine, threonine, tryptophan, and valine). The others are the nonessential amino acids, where mammals possess the enzymes to synthesize (eg. alanine, asparagine, aspartate, cysteine, glutamate, glutamine, glycine, proline,serine, and tyrosine). While they can synthesize arginine and histidine, they cannot produce it in sufficient amounts for young growing animals, and so these are also often considered essential amino acids. Some of these have functions by themselves or in a modified form; for instance, glutamate functions as an important neurotransmitter, which is involved in chemical communication between nerve cells.

Nucleic acids

Nucleic acids are the molecules that make up deoxyribonucleic acid (DNA), an extremely important substance which all cellular organisms use to store their genetic information. The most common nucleic acids are DNA and ribonucleic acid (RNA). Their monomers are called nucleotides. The most common nucleotides are adenine, cytosine, guanine, thymine, and uracil. Adenine binds with thymine and uracil; Thymine only binds with adenine; and cytosine and guanine can only bind with each other.

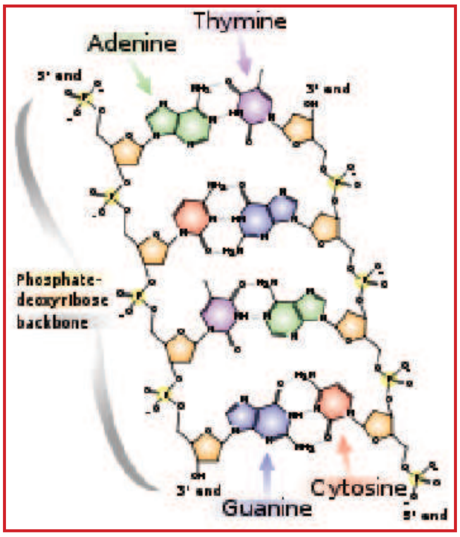
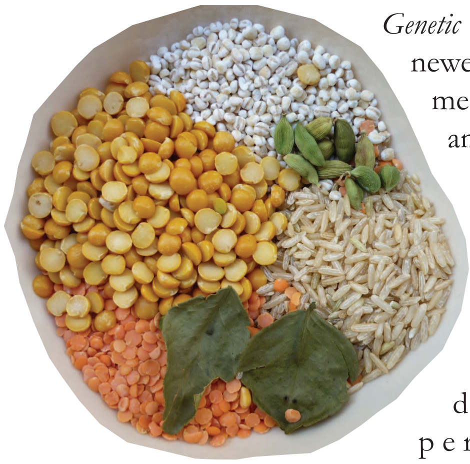


Figure 4 The structure of DNA, the picture shows the monomers being put together

A **gene** is a unit of heredity in a living organism. It normally resides on a stretch of DNA that codes for a type of protein or for an RNA chain that has a function in the organism. All living things depend on genes, as they specify all proteins and functional RNA chains. Genes hold the information to build and maintain an organism's cells and pass genetic traits to offspring. A **genetic disorder** is an illness caused by abnormalities in genes or chromosomes. Such abnormalities in genes results in diseases that are inherited from parents which are also known as hereditary disorders (eg Haemophilia, sickle cell anaemia). While some diseases, such as cancer, diabetes, are due in part to genetic disorders, they can also be caused by environmental factors.



Genetic medicine is a newer term for medical genetics and incorporates areas such as gene therapy where genes are used as treatments to correct genetic disorders, personalized medicine, where drugs are synthesized to treat, based on that person's genetic make up and the rapidly emerging new medical specialty, predictive medicine where based on genetic information of a person, diseases that can occur is predicted.

Pharmaceutical chemistry

Medicinal chemistry or **pharmaceutical chemistry** is a discipline at the intersection of chemistry and pharmacology, involved with designing, synthesizing and developing pharmaceutical drugs. Medicinal chemistry involves the identification, synthesis and development of new chemical entities suitable for therapeutic use. It also includes the study of existing drugs and their biological properties. Pharmaceutical chemistry is focused on quality aspects of medicines and aims to assure quality of medicinal products. Medications are manufactured via chemical processes and compounding. Without chemistry, there would be no medication.

Compounds used as medicines are overwhelmingly organic compounds including small organic molecules and biopolymers. However, inorganic compounds and metal-containing compounds have been found to be useful as drugs. For example, the cis-platin series of platinum-containing complexes have found use as anti-cancer agents.

Without chemistry, we would not know anything about plants and herbs, which resulted in the development of medications, and we would not be able to study the chemistry of blood , not be able to use anesthesia during surgery, not understand how chemotherapy works or develop any chemical forms of cancer treatment.

Most medications are involved with inhibiting a specific enzyme, a receptor or expression of a gene, naturally found in the body. Blocking an enzyme's active site or binding site of a receptor requires a specifically designed "blocker" to disable the enzyme's or receptors function. Since enzymes and receptors are proteins, their functions differ based on shape, and inhibitor drugs must be customized for each target enzyme. This requires chemistry.

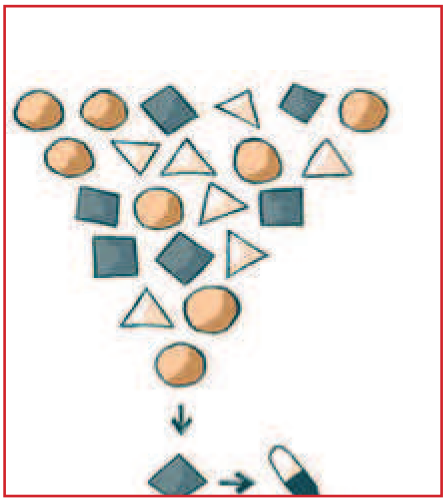


Figure 5 Combinatorial chemistry; a technique that helps narrow the search for new drugs by combining various types of chemicals

As the name suggests, medicinal chemistry is an area of research that focuses on designing and making drugs of all sorts. The first step in this process is identifying new molecules.

Years ago, medi-cinal chemists spent most of their time isolating interesting mole-cules from living organisms, mainly plants. Today, however, chemists working in this area are equally concerned with finding good ways to make these molecules in the laboratory. Medicinal chemists also work out the best way to deliver the new drug, eg. as a capsule, tablet, aerosol or injection.

Identifying a molecule with a specific medicinal effect like lowering cholesterol or killing only tuberculosis bacteria takes time and patience. But a strategy called combinatorial chemistry can help a lot. In this process, chemists create and then sift through immense collections, or "libraries," of molecules. The newly identified molecules are then tested for their usefulness in treating disease in animals and people.

Just like an online catalog helps you find books in the library or in a bookstore, combinatorial chemistry helps find molecules in a chemical library. It also usually involves computers to help a chemist find molecular matches that meet defined criteria.

Chemical libraries consist of a diverse matrix of thousands or even millions of different molecules made from just a few starting chemical building blocks. Each chemical has associated information about its chemical structure, purity or other characteristics stored in some kind of database. Using computers it is possible to identify the most suitable molecules having a chemical structure that will have most of the desired properties of the new drug.

All drugs have a chemical structure and often the name is derived from its chemical structure. For example the well known pain and fever relieving drug paracetamol, also known as acetaminophen in some countries, derives these medical names from its chemical name para-acetylaminophenol.

Although one of the most commonly consumed drugs all over the world, and safe for use at recommended

Table 1 Metals in Health and Disease

METAL(Chemical Symbol)	WHERE IS IT?	WHAT DOES IT DO?	HOW DO I GET IT?
"Healthy" Metals			
Iron (Fe)	Binds to enzymes throughout the body (e.g., hemoglobin, nitric oxide synthase)	Helps body transport oxygen and certain chemical messengers	Meats (highest in beef, pork, liver), baked or lima beans, molasses, spinach
Copper (Cu)	Binds to enzymes throughout the body (e.g., superoxide dismutase)	Defends body against damage from free radicals	Shellfish (crab, lobster), dried beans, nuts
Zinc (Zn)	Binds to enzymes throughout the body, to DNA, and to some hormones (e.g., insulin)	Plays role in sexual maturation and regulation of hormones, helps some proteins stick tightly to DNA	Shellfish (oysters), chick peas, baked beans, whole grains, nuts
Sodium (Na) Potassium (K)	Throughout the body (Na outside cells, K inside cells)	Helps communicate electrical signals in nerves, heart	Na: Table salt and baking soda K: Bananas, oranges, avocados
Calcium (Ca)	Bones, muscle	Muscle and nerve function; blood clotting	Dairy products, broccoli, figs, sardines
Cobalt (Co)	Forms the core of vitamin B12	Necessary ingredient for making red blood cells	Meats, dairy products, leafy green vegetables
"Unhealthy" Metals			
Arsenic (As)	Rocks, soil	Can cause cancer, death	Toxic
Lead (Pb)	Old paint (before 1973)	Can cause cancer, neurological damage, death	Toxic
Mercury (Hg)	Contaminated fish (especially from the Great Lakes region of the United States)	Binds to sulfur-containing molecules in organelles; can cause neurological damage, death	Toxic

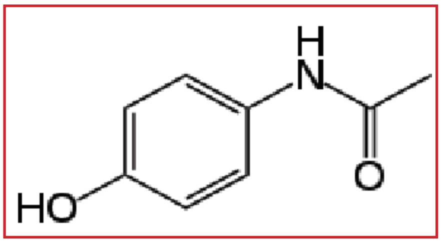


Figure 6 Chemical structure of paracetamol (chemical name for the compound: para-acetylaminophenol)

doses, acute overdoses or accidental intake of increased daily doses of paracetamol for few days can cause potentially fatal liver damage

Paracetamol toxicity is the foremost cause of acute liver failure in the western world, and accounts for most drug overdoses in the United States, the United Kingdom, and now even in Sri Lanka. Therefore all medicines need to be used carefully as all these chemicals used as drugs can cause toxicity if not taken according to recommendations.

Diagnostic chemistry

Chemistry departments in hospital medical laboratories analyze blood, urine, etc. for proteins, sugars (glucose in the urine is a sign of diabetes), and other metabolic and inorganic substances. Electrolyte tests are a routine blood analysis, testing elements like potassium and sodium. The enzyme-linked immunosorbent assay (ELISA), which uses antibodies, is currently one of the most sensitive tests that modern medicine uses to detect various biomolecules. The blood glucose tests, blood lipid profile tests are used to diagnose diseases such as diabetes mellitus and high cholesterol and also to monitor effect of treatment. Without laboratory chemistry we would not be able to diagnose and manage most diseases that are treated using modern medicines.

Metals in health and diseases

Some chemists study the role of metal-containing molecules in biological systems. Many processes in our bodies like respiration and reproduction depend on metals like iron, zinc and copper.

Iron, for instance, helps the protein hemoglobin transport oxygen to organs throughout the body. Many metals act to stabilize the shapes of enzymes. Our bodies take great care to make sure metals go only where they need to go, and in exactly the proper amount as metals can be toxic. In many cases that means one or two atoms in an individual cell. That is in contrast to thousands to millions of proteins or other molecules.

Some toxic metals are not good in any amount. They can poison important enzymes, preventing them from doing their jobs of keeping the body healthy. Lead from the environment for instance, can mess up the body's synthesis of a vital component of hemoglobin called heme, disabling the blood's oxygen transport system.

Certain forms of mercury can be deadly, causing irreversible damage in the brain. Other dangerous metals, such as arsenic, cause cancer in the skin and lungs.

Medical Toxicology

Medical researchers who study the harmful effects of chemicals on living organisms are called toxicologists. Some chemists help solve crimes. Some scientists in this field focus on forensics, combining toxicology, chemistry, pharmacology and medicine to help criminal investigations of death, poisoning and drug use. These researchers record symptoms reported by a victim as well as any evidence collected that could narrow the search for a perpetrator. This evidence could include pill bottles, powders and trace residues of chemicals. Since it is rare for a chemical to remain in its original form after being ingested, toxicologists rely on a solid understanding of metabolism and of chemical reactions in the body to identify the toxic molecules formed in the body.

Conclusion

Modern medicine involving human health, diseases, their diagnosis and treatment needs a good understanding of chemistry and chemical processes. Therefore chemistry plays a huge role in medicine as discussed in detail in this article.

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