The Biological Building Blocks

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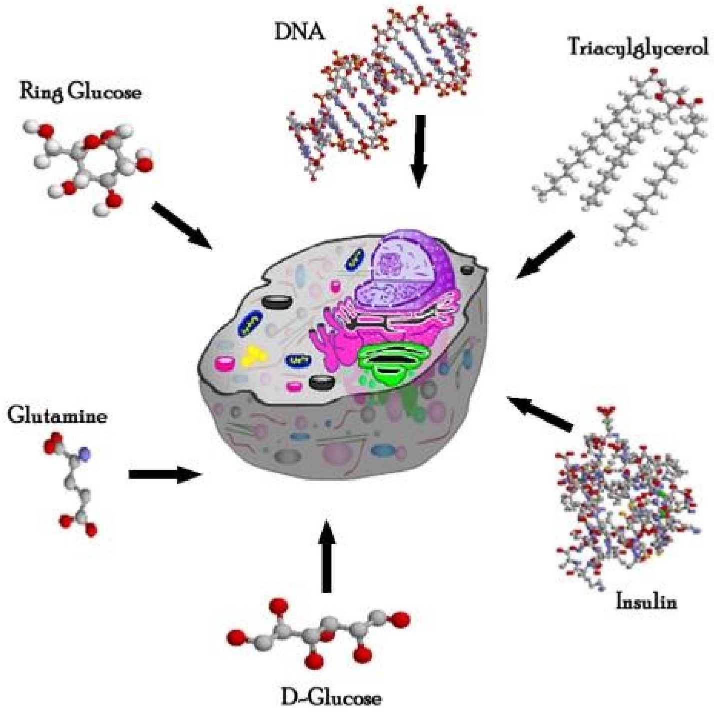

The cell is the basic unit of life. All organisms are composed of one or more cells. As will be discussed later, humans are made up of many millions of cells. In order to understand what goes wrong in cancer, it is important to understand how normal cells work. The first step is to discuss the structure and basic functions of cells.

First we will introduce the common building blocks of cells. All cells, regardless of their function or location in the body, share common features and processes. Amazingly, cells are comprised almost entirely of just four basic types of molecules. Shown above is a cell surrounded by examples of these building block molecules.

Since they are present in living things these building blocks are called biomolecules. The next sections describe the structures and functions of each of these basic building blocks. Further information on the topics on this page can also be found in most introductory Biology textbooks, we recommend Campbell Biology, 11th edition.[1]

- Carbohydrates
- Proteins
- Lipids
- Nucleic Acids
- Combinations

Carbohydrates

The first class of biomolecules we will discuss are the carbohydrates. These molecules are comprised of the elements carbon (C), hydrogen (H), and oxygen (O). Commonly, these molecules are known as *sugars*. Carbohydrates can range in size from very small to very large. Like all the other biomolecules, carbohydrates are often built into long chains by stringing together smaller units. This works like adding beads to a bracelet to make it longer. The general term for a single unit or bead is a *monomer*. The term for a long string of monomers is a *polymer*.

Examples of carbohydrates include the sugars found in milk (lactose) and table sugar (sucrose). Depicted below is the structure of the monomer sugar glucose, a major source of energy for our body.

Sphere Stick Surface Rotate

Carbohydrates have several functions in cells. They are an excellent source of energy for the many different activities going on in our cells. Some carbohydrates may have a structural function. For example, the material that makes plants stand tall and gives wood its tough properties is a polymer form of glucose known as cellulose. Other types of sugar polymers make up the stored forms of energy known as starch and glycogen. Starch is found in plant products such as potatoes and glycogen is found in animals. A short molecule of glycogen is shown below. You can manipulate the molecule yourself to take a good look.

Stick Line Space-Filling Rotate

Carbohydrates are essential for cells to communicate with each other. They also help cells adhere to each other and the material surrounding the cells in the body. The ability of the body to defend itself against invading microbes and the removal of foreign material from the body (such as the capture of dust and pollen by the mucus in our nose and throat) is also dependent on the properties of carbohydrates.

Learn more about how Dr. Michael Pierce is using carbohydrates to investigate cancer.

Proteins

Like the carbohydrates, proteins are composed of smaller units. The monomers that make up proteins are called *amino acids*. There are around twenty different amino acids. The structure of the simplest amino acid, glycine, is shown below.

Sphere Stick Rotate

Proteins have numerous functions within living things, including the following:

- They help form many of the structural features of the body including hair, nails and muscles. Proteins are a major structural component of cells and cell membranes.
- They aid in transporting materials across cellular membranes. An example would be the uptake of glucose into cells from the bloodstream. We will return to this important ability when we discuss the resistance of cancer cells to chemotherapy agents.
- They act as biological catalysts. A large group of proteins, known as enzymes, are able to speed up chemical reactions that are necessary for cells to work properly. For example, there are numerous enzymes that are involved in breaking down the food we eat and making the nutrients available.
- Interactions between cells are very important in maintaining the organization and function of cells and organs. Proteins are often responsible for maintaining contact between adjacent cells and between cells and their local environment. A good example would be the cell:cell interactions that keep the cells in our skin held closely together. These interactions are dependent on proteins from neighboring cells binding tightly to each other. As we will see, alterations in these interactions are required for the development of metastatic cancer.
- Proteins work to control the activity of cells, including decisions regarding cell division. Cancer cells invariably have defects in these types of proteins. We will return to these proteins in detail when we talk about the regulation of cell division.
- Many hormones, signals that travel through the body to change the behavior of cells and organs, are composed of protein. Shown below is insulin, a small protein hormone that regulates the uptake of glucose from the bloodstream.

Space Filling Ribbon Wire Frame Rotate

Lipids

The term lipid refers to a wide variety of biomolecules including fats, oils, waxes and steroid hormones. Regardless of their structure, location or function in a cell/body, all lipids share common features that enable them to be grouped together.

- They do not dissolve in water; they are hydrophobic.
- Like the carbohydrates, they are composed primarily of carbon, hydrogen and oxygen.

The hydrophobic nature of the lipids dictates many of their uses in biological systems. Fats are a good source of stored energy while oils and waxes are used to form protective layers on our skin, preventing infection. Some lipids, the steroid hormones, are important regulators of cell activity. We will revisit this during our discussion of the information flow in cells. The activities of steroid hormones such as estrogen have been implicated in cancers of the female reproductive system. Treatments based on this knowledge will be discussed in detail in the treatment section of the site.

Space-Filling Stick Wire Frame Rotate

Depicted above is an example of a triacylglycerol, or fat. The three long chains are composed only of carbon and hydrogen and this gives the molecule its hydrophobic properties. When you read about saturated and unsaturated fat content on a food label, they are referring to differences in these long hydrocarbon chains.

A main function of lipids is the formation of biological membranes. Cells are surrounded by a thin layer of lipids. The layer is made up of a special type of lipid that has both hydrophobic and hydrophilic properties. The hydrophilic ends of these molecules face the water-filled environment inside the cells and the watery environment outside the cells. A hydrophobic region exists inside the two layers. The membrane that surrounds the cells is rich in proteins and other lipids such as cholesterol.

Most chemicals can not cross the lipid bilayer. Water and some other small molecules can freely pass through the membrane while other molecules must be actively transported via protein channels embedded in the membrane. Membranes also contain a combination of the biomolecules that have been described so far. As seen above, proteins may be coupled to carbohydrates to form glycoproteins. Glycoproteins are important in the cell:cell interactions discussed previously, and changes in the amounts or types of these proteins are seen in cancer. Similarly, a combination of lipids and carbohydrates lead to the formation of glycolipids.

Nucleic Acids

All of the information needed to control and build cells is stored in these molecules.

There are two main types of nucleic acid, deoxyribonucleic acid (DNA) and ribonucleic acid (RNA). Both of these molecules are polymers. They are composed of monomer subunits like the carbohydrates and proteins described previously. The monomers used to build nucleic acids are called nucleotides. The nucleotides are often referred to by the single letter abbreviations A, C, G, T and U. Like all of the monomers described so far, the monomers used to build DNA are similar to each other but are not exactly alike. One of the differences between DNA and RNA is the subset of nucleotides used to build the polymers. DNA contains A, C, G and T while RNA contains A, C, G and U.

Deoxyribonucleic Acid (DNA)

DNA is composed of two long strings (polymers) of nucleotides twisted around each other to form the spiral or helical structure shown below. The twisted molecules are arranged in a particular manner, with specific nucleotides always found across from each other. The nucleotide containing adenine (A) always pairs with the nucleotide containing thymine (T). Likewise, guanine (G) always pairs with cytosine (C). If you look closely at the graphics below you can see the nucleotide pairs interacting in the middle of the helix. The polymers that form DNA can be extremely long, reaching millions of nucleotides per each individual DNA molecule. The following graphic depicts a short strand of double-stranded DNA. [2]

Sphere Stick Surface Rotate

DNA is located in the nucleus of cells, a structure that will be described in the next section of the site. All of the nucleated cells in the human body have the same DNA content regardless of their function. The difference is which parts of the DNA are being used in any given cell. For example, the cells that make up the liver contain the same DNA as the cells that make up muscles. The dramatically different activities of these two cell types is dependent on the portions of DNA that are active in the cells. DNA is the storage form of genetic information and acts as a blueprint for cells. As we shall see, changes in the sequence of DNA can lead to alterations in cell behavior. Unregulated growth, as well as many of the other changes seen in cancer, are ultimately the result of mutations, changes in the structure of DNA.

Ribonucleic acid

Ribonucleic acid (RNA) is similar in many ways to DNA. It is a polymer of nucleotides that carries the information present in genes. In addition to some chemical differences between RNA and DNA, there are important functional differences.

- RNA is copied from DNA in the nucleus and much of it is shipped out to the cytosol.
- RNA is the working form of the information stored in DNA.
- RNA is single stranded, not double-stranded

The information that resides in DNA works for cells much as an architect uses a blueprint. The specific production of RNA enables the cell to use only the pages of the "blueprint" that are required at any particular time. It is very important that the correct RNAs be produced at the correct time. In cancer, the production or regulation of particular RNAs does not occur properly. Just as an incorrect reading of a blueprint will cause a building to develop flaws, improper production of RNA causes changes in cell behavior that may lead to cancer. This important topic will be covered in depth in the section on Gene Function. First we will examine more complex forms of biomolecules, and then we will introduce some of the key functional components of eukaryotic cells.

Combinations

We have now been introduced to the major classes of biomolecules.

- carbohydrates
- lipids
- proteins
- nucleic acids

These biomolecules work together to perform specific functions and to build important structural features of cells. For example, in the section on lipids, we first saw the diagram below of a membrane.

In addition to the lipid bilayer, comprised of a special type of lipid, the membrane contains numerous proteins and sugars. As shown, proteins and sugars can be combined to form glycoproteins. Sugars can also be added to lipids to form glycolipids.

Many of the proteins that are important in the development and/or detection of cancer are glycoproteins. For example, diagnostic tests for prostate cancer involve testing blood samples for the presence of a glycoprotein called the prostate specific antigen or PSA. Ovarian cancers may be monitored by production of another glycoprotein called CA-125. CA stands for cancer associated.

More on the CA-125 test

Often many proteins and other biomolecules join together to form functional structures in cells. Next we will investigate some of these more complex structures, called organelles.

Summary

All living things, including the cells that make up a human body are comprised of a small subset of different biomolecules. There are four main classes, as described below:

1. **Carbohydrates**
    - Carbohydrates are comprised of the elements carbon (C), hydrogen (H), and oxygen (O).
    - Sugars are common carbohydrates.
    - Carbohydrates serve several functions inside cells:
        - Major energy source
        - Provide structure
        - Communication
        - Cell adhesion
        - Defense against and removal of foreign material
2. **Proteins**
    - Proteins are comprised of amino acids.
    - Proteins serve several functions inside living things:
        - Structure of hair, muscle, nails, cell components, and cell membranes
        - Cell transport
        - Biological catalysts or enzymes
        - Maintaining cell contact
        - Control cell activity

        - Signaling via hormones
3. **Lipids**
    - A wide variety of biomolecules including fats, oils, waxes and steroid hormones.
    - Lipids do not dissolve in water (they are hydrophobic) and are primarily comprised of carbon (C), hydrogen (H), and oxygen (O).
    - Lipids serve several functions in living things:
        - Form biological membranes
        - Fats may be stored as a source of energy
        - Oils and waxes provide protection by coating areas that could be invaded by microbes (i.e. skin or ears)
        - Steroid hormones regulate cell activity by altering gene expression
4. **Nucleic Acids**
    - All of the information needed to control and build cells is stored in these molecules.
    - Nucleic acids are comprised of nucleotides which are abbreviated A, C, G, T, and U.
    - There are two main types of nucleic acid, deoxyribonucleic acid (DNA) and ribonucleic acid (RNA):
        - DNA
            - DNA has a double helix structure comprised of nucleotides A, C, G, and T.
            - DNA is located in the nucleus of the cell.
            - DNA is the storage form of genetic information.
        - RNA
            - RNA is typically single stranded and comprised of nucleotides A, G, C, and U.
            - RNA is copied from DNA and is the working form of the information.
            - RNA is made in the nucleus and mRNA is exported to the cytosol.

Additional biomolecules can be made by combining these four types. As an example, many proteins are modified by the addition of carbohydrate chains. The end product is called a glycoprotein.

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1 Urry, L. A., Cain, M. L., Wasserman, S. A., Minorsky, P. V., & Reece, J. B. (2017). Campbell Biology (11th ed.). Pearson.
2 Kuszewski J,Schwieters C, Clore G.M. "Improving the accuracy of NMR structures of DNA by means of a database potential of mean force describing base-base positional interactions." Journal of the American Chemical Society (2001) 123:3903 [PUBMED]