Class: Four
Subject: Mechanics of Artificial Organs 2
Lecturer: Dr. Ameen M. Al-Juboori
E-mail: AmeenAL-Juboori@mustaqbal-college.edu.iq

Lecture # 1

Overview of Human System and Its Artificial Replacement

Human Body's Superfi cial Anatomy

The objective of this lecture is to briefly review the human system to refresh the reader's knowledge about 11 systems of the wonderful human machine from an engineer's point of view. The very basic anatomy of the system will be discussed.

Superficial, or surface, anatomy is important in human anatomy as the study of anatomical landmarks that can be readily identified from the contours or other reference points on the surface of the body. With knowledge of superficial anatomy, physicians gauge the position and anatomy of the associated deeper structures. Common names of well-known parts of the human body, from top to bottom, are listed below:

- Head—forehead—jaw—cheek—chin.
- Neck—shoulders.
- Arm—elbow—wrist—hand—fingers—thumb.
- Spine—chest—thorax.
- Abdomen—groin.
- Hip—buttocks—leg—thigh—knee—calf—heel—ankle—foot—toes.

The eye, ear, nose, mouth, teeth, tongue, throat, Adam's apple, breast, penis, scrotum, clitoris, vulva, and navel are also superficial structures. This section is about the human body as a whole.

A Brief Outline of the Organization of the Human System

The human body consists of the organ system, organs, tissue, and cells. Cells are the unit of living entity. Cells have their own activities in the body. Groups of cells working together form a tissue . There are four types of tissues:

- **Epithelial tissue** covers and protects underlying tissue. When we look at the surface of our skin, we see epithelial tissue.
- **Nerve tissue** sends electrical signals through the body. Nervous tissue is found in the brain, nerves, and sense organs. There is a total network of nerve tissue in the body, connecting and coordinating the activities of various organs and systems.
- **Muscle tissue** is made up of cells that can contract and relax to produce movement; muscle tissue covers the entire body.
- **Connective tissue** joins, supports, protects, insulates, nourishes, and cushions organs. It also keeps organs together in place.

Tissue + Tissue = Organ (Different Tissues Together Form an Organ)

Two or more type of tissues working together form an organ. One type of tissue alone cannot do all of the things that several types working together can do. Figure 1 shows the stomach organ, which is made up of all four types of tissue just described.

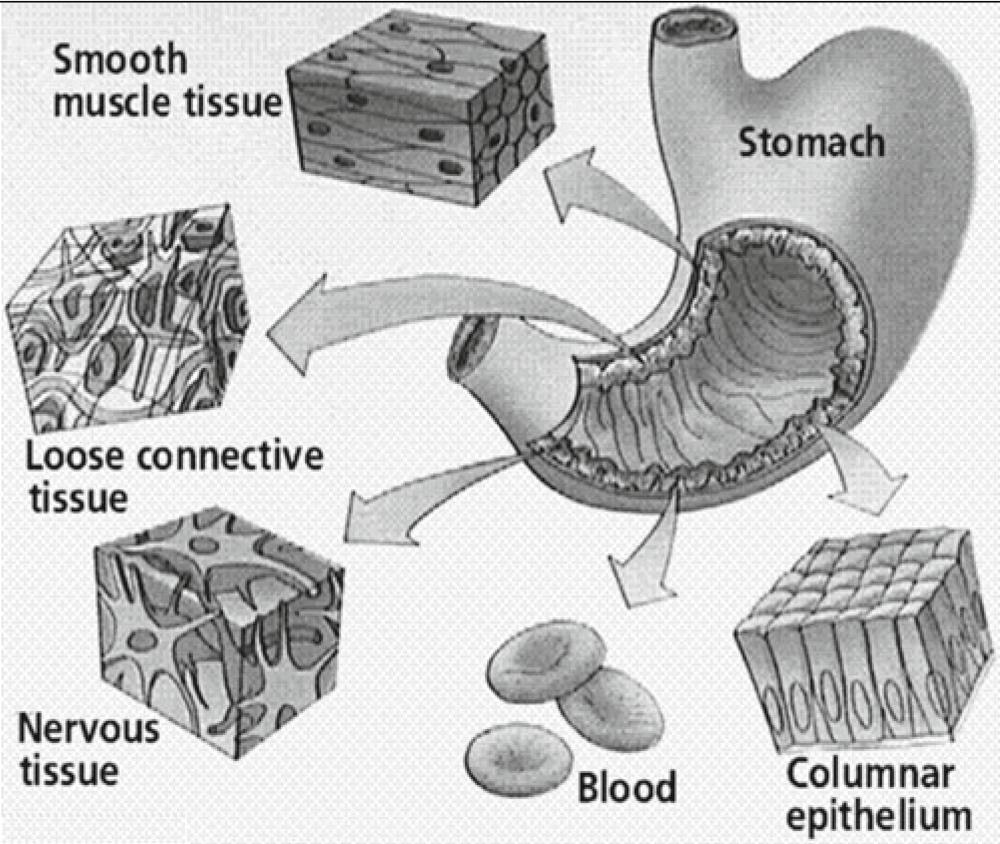

Fig. 1 : The stomach is an organ having all types of tissues

Organ + Organ = Organ System

Organs working together make up an organ system. A failure of one organ system affects others and may lead to the failure of others.

Major Organ Systems

The human body consists of the following major organ systems:

1. Integumentary system
2. Muscular system
3. Skeletal system
4. Cardiovascular system
5. Respiratory system

6. Urinary system
7. Reproductive system
8. Nervous system
9. Digestive system
10. Lymphatic system
11. Immune system

Integumentary System

The integumentary system is the largest organ system in the human body and is responsible for protecting the body from most physical and environmental factors. The largest organ in the body is the skin. The integument also includes appendages, primarily the sweat and sebaceous glands, hair, nails, and arrectores pili (tiny muscles at the root of each hair that cause goosebumps) (Fig. 2).

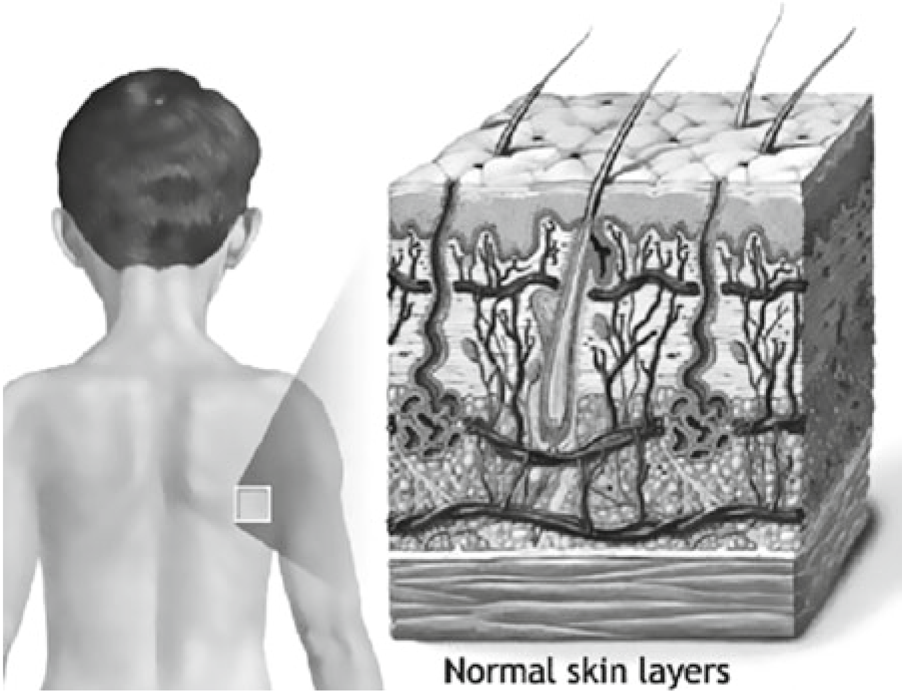

Fig. 2: Skin

Muscular System

This system moves our bones and helps us to walk, run, and perform all the movement- related activities of daily living. Muscles are connected to the bone through tendons, and bones are connected to another bone at the joints through ligaments (Fig. 3).

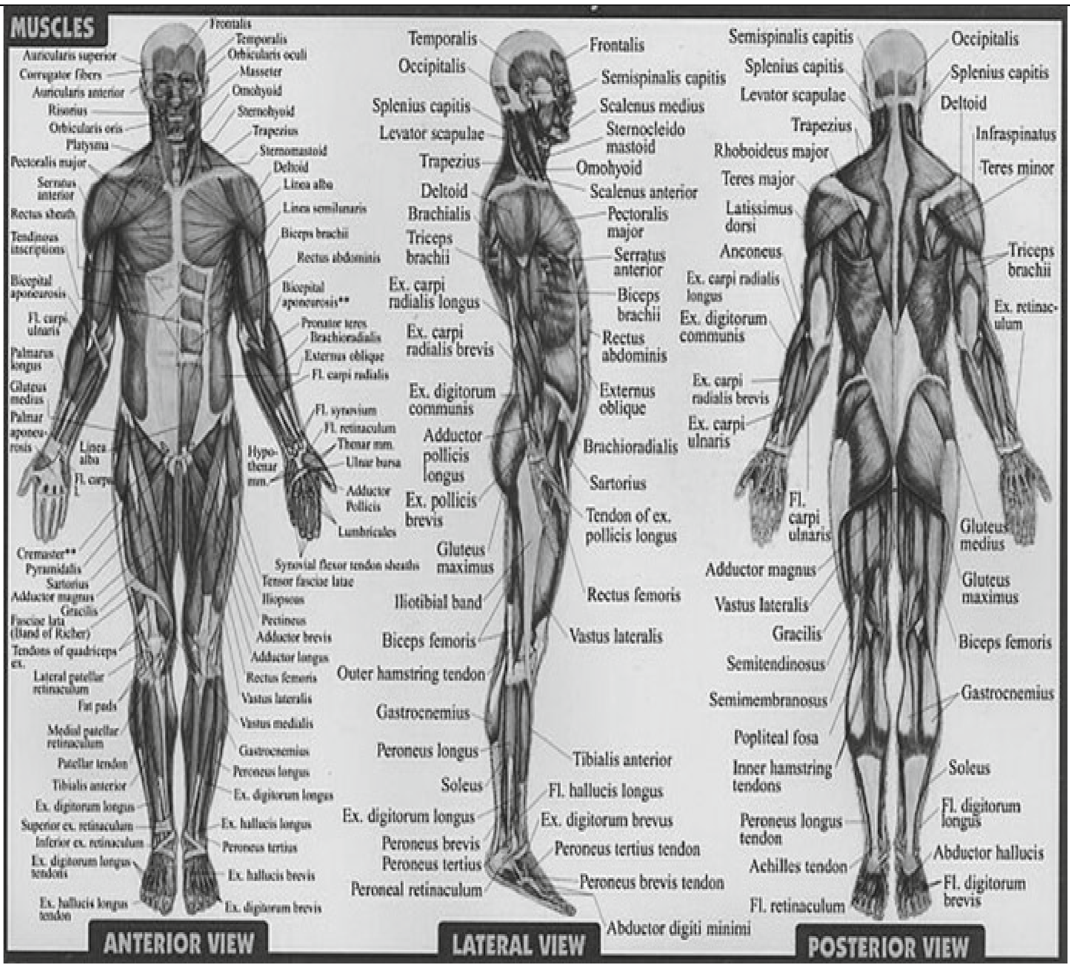

Fig. 3: Details of human muscular system

Skeletal System

The skeletal system consists of bones interconnected with ligaments and the muscle tendons. This system frames, houses, and protects body parts and organs. The human musculoskeletal system consists of the human skeleton, made by bones attached to other bones with joints, and skeletal muscle attached to the skeleton by tendons.

Bones: An adult human has approximately 206 distinct bones. A list of the number of bones in different body parts is given below; the nomenclature appears in Fig. 4.

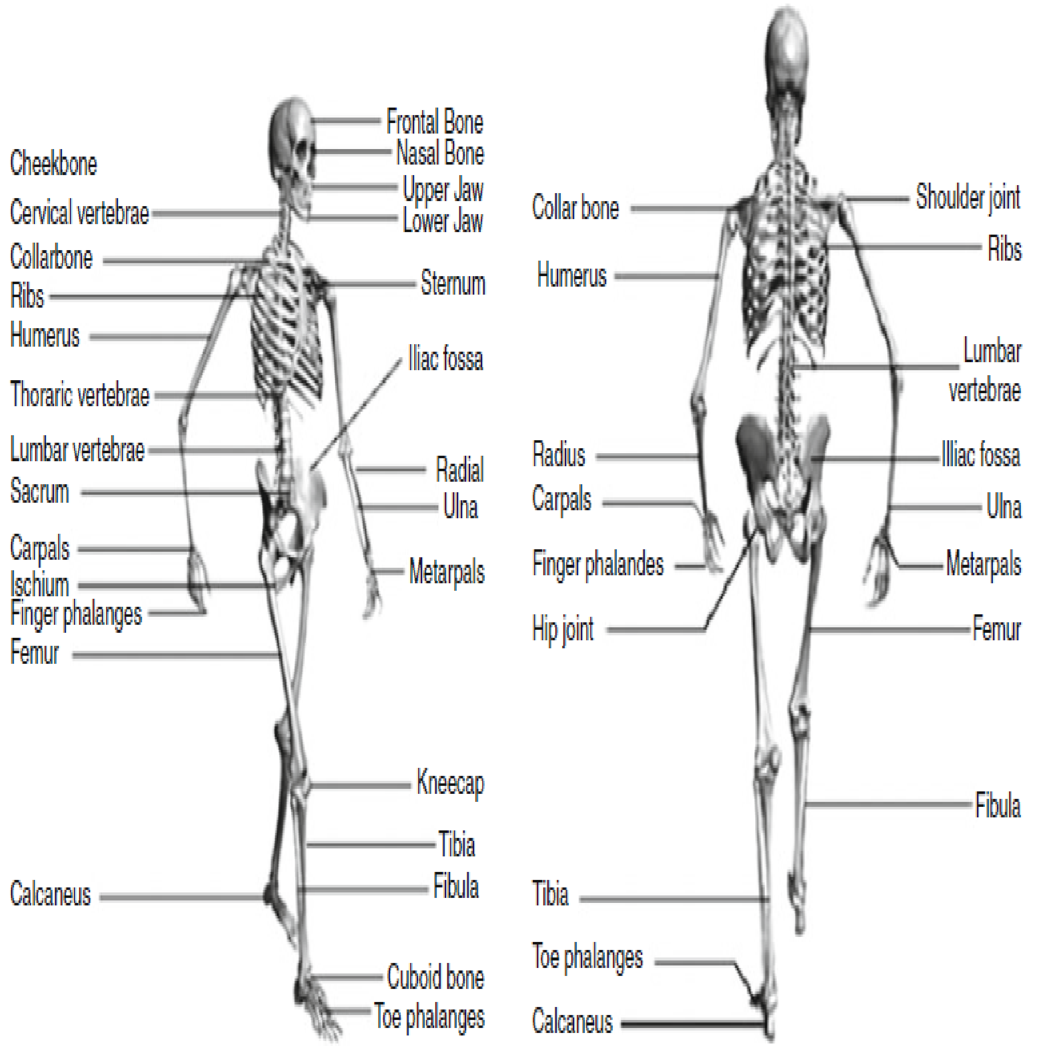

Fig. 4: Human skeletal system, anterior (front) and posterior (back side) views

Spine and vertebral column (26)

Cranium (8)

Face (14)

Hyoid bone, sternum, and ribs (26)

Upper extremities (64), lower extremities (62)

Long bones are bigger at the joints, with spongy bone inside filled with marrow, blood, and body fluid to absorb shock during walking and other activities. The middle part is narrower and cortical (dense bone), a tubular type filled with marrow, blood, and fluid. Blood is produced in this cavity.

Respiratory System

A regular supply of oxygen from air is vital to life. Air enters through the nose and mouth, where it is fi ltered. It then passes down the trachea to the lungs. The trachea has two main branches, the left and right bronchi, which divide into a network of smaller bronchioles. These lead into small air sacks called alveoli. The two lungs are shaped like inverted cones, with a wide base and a narrow top. The right lung has three lobes, while the left has only two to accommodate the heart. The lungs contain about 2,400 km of airways, and each lung has total surface area of 180 m 2 (Fig. 5).

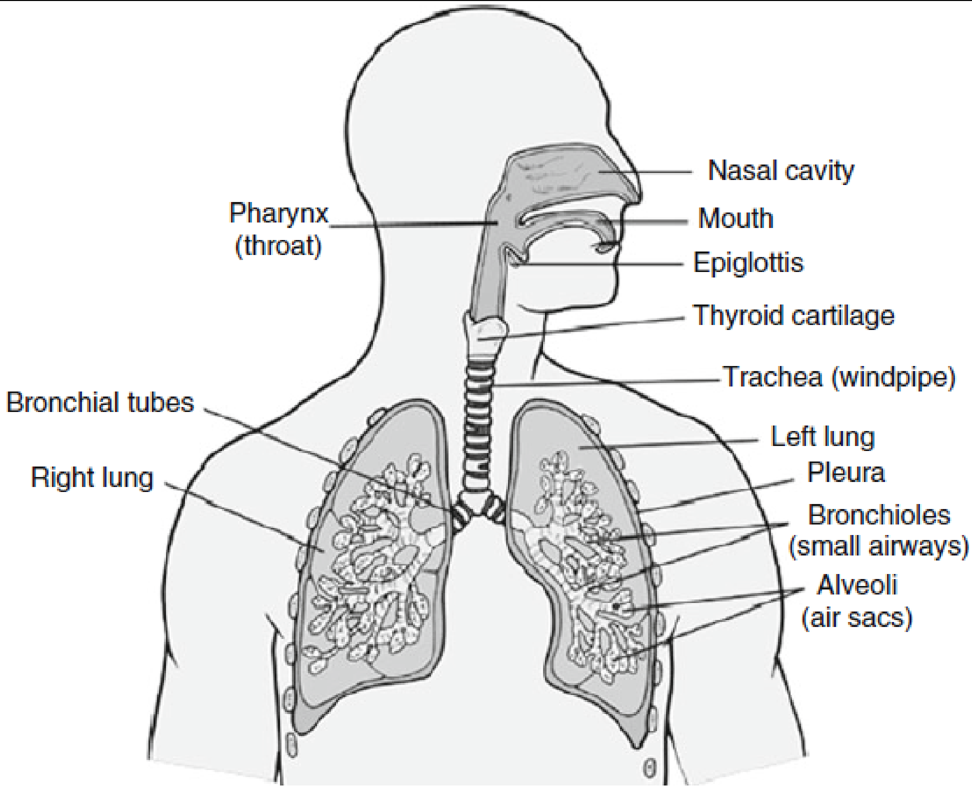

Fig. 5: Simplified respiratory system

Cardiovascular System

The cardiovascular system comprises the heart, veins, arteries, and capillaries. The primary function of the heart is to circulate the blood and, through the blood, oxygen and vital minerals to the tissues and organs that comprise the body. The left side of the main organ (left ventricle and left atrium) is responsible for pumping blood to all parts of the body, while the right side (right ventricle and right atrium) pumps only to the lungs. The heart itself is divided into three layers, called the endocardium, myocardium, and epicardium, which vary in thickness and function (Fig. 6).

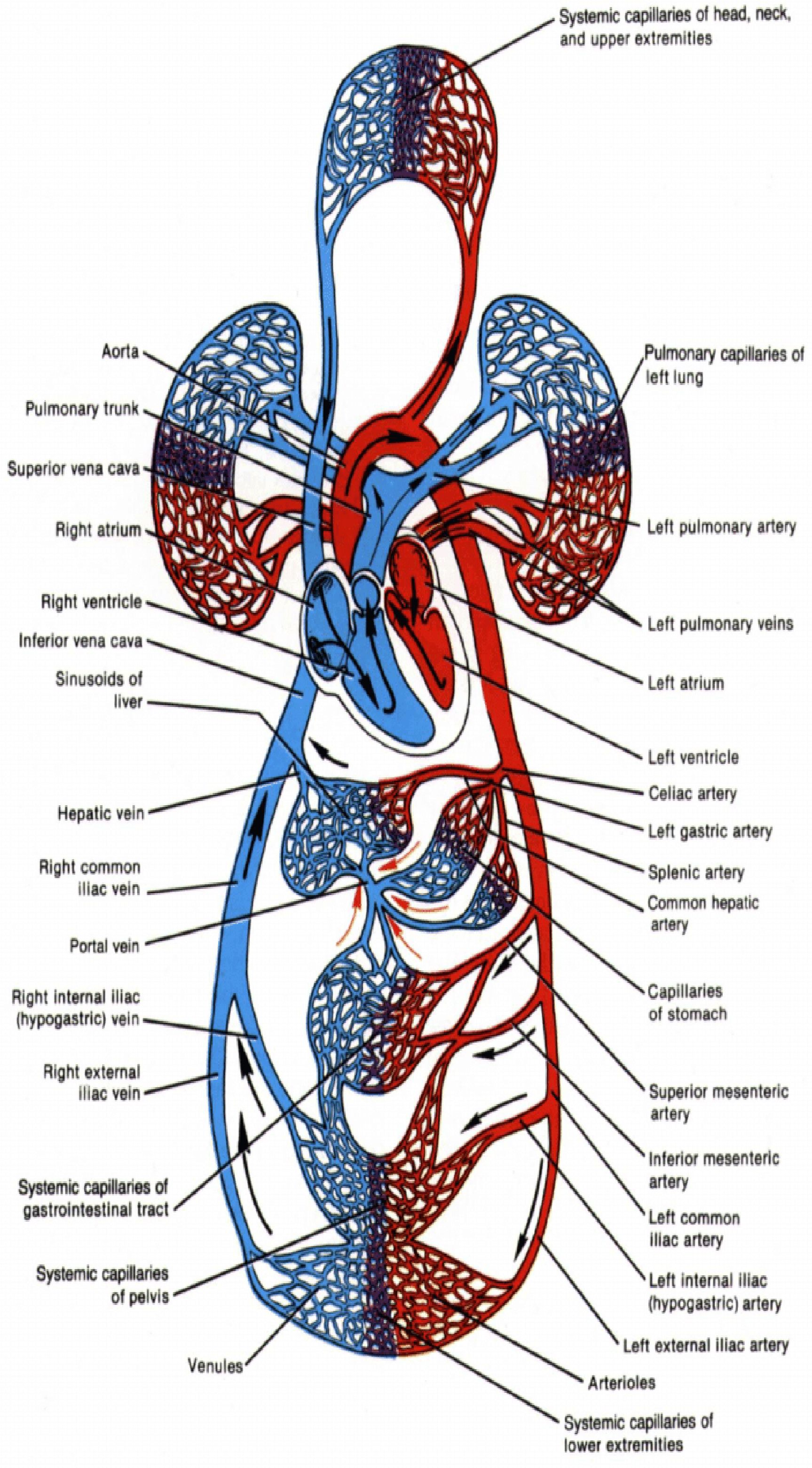

Fig. 5: A schematic diagram of the circulatory system

Urinary System

The urinary system removes excess fluid and soluble substances from blood circulation via the kidneys. Some fluids are reabsorbed back into the blood, while excess water and waste products are expelled from the body as urine. Each kidney is about 12 cm long and contains two layers of tissue: an outer cortex and an inner medulla. Urine continuously trickles down two tubes called ureters into the bladder, which is an elastic sac that stores urine until it can be expelled out. The bladder can hold up to 0.5 l of urine. The urinary tract consists of the organs, tubes, and muscles that work together to make, move, store, and release urine, the liquid waste of the human body. The upper urinary tract includes the kidneys, which filter wastes and extra fluid from the blood, and the ureters, which carry urine from the kidneys to the bladder. The lower urinary tract includes the bladder, a balloon-shaped muscle that stores urine, and the urethra, and a tube that carries urine from the bladder to the outside of the body during urination. Doctors who specialize in kidney problems are called nephrologists. Doctors who specialize in problems of the organs and tubes that transport urine from the kidneys to outside the body are called urologists. These problems may involve cancers or growths of these organs, including the kidneys, ureters, bladder, and testes, or may involve abnormalities in storing or releasing urine.

Nervous System

The nervous system and the human brain comprise a network of specialized cells that communicate information about the organism's surroundings and itself. They receive and send electrical messages through a network of nerves through the muscular system (Fig. 6).

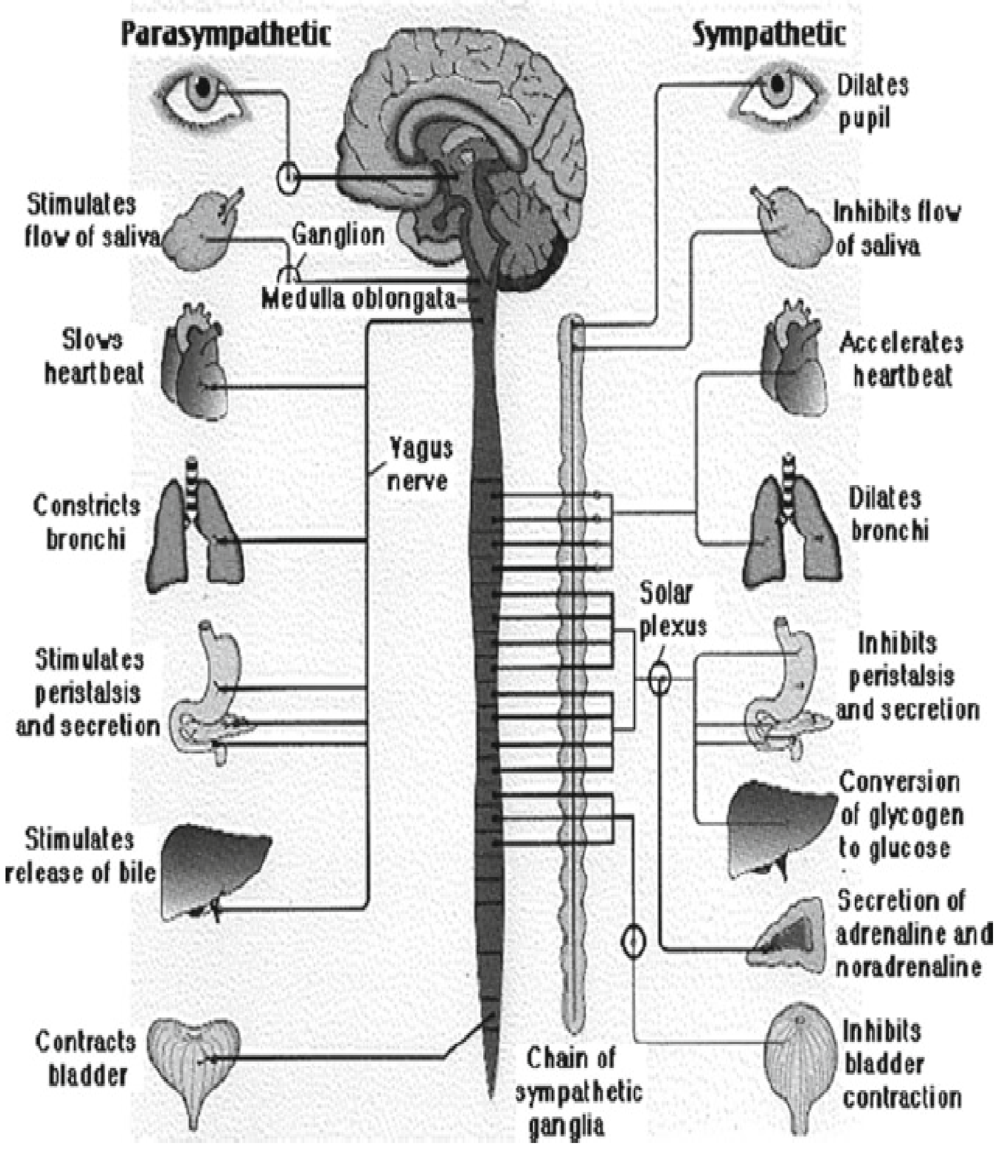

Fig. 6: The schema of the nervous system and its innervations with various organs. The organs are easily identifiable

Digestive System

The digestive system and the human gastrointestinal tract break down food into nutrients. The digestive system provides the body's means of processing food and transforming nutrients into energy. It consists of the organs marked in Fig. 7.

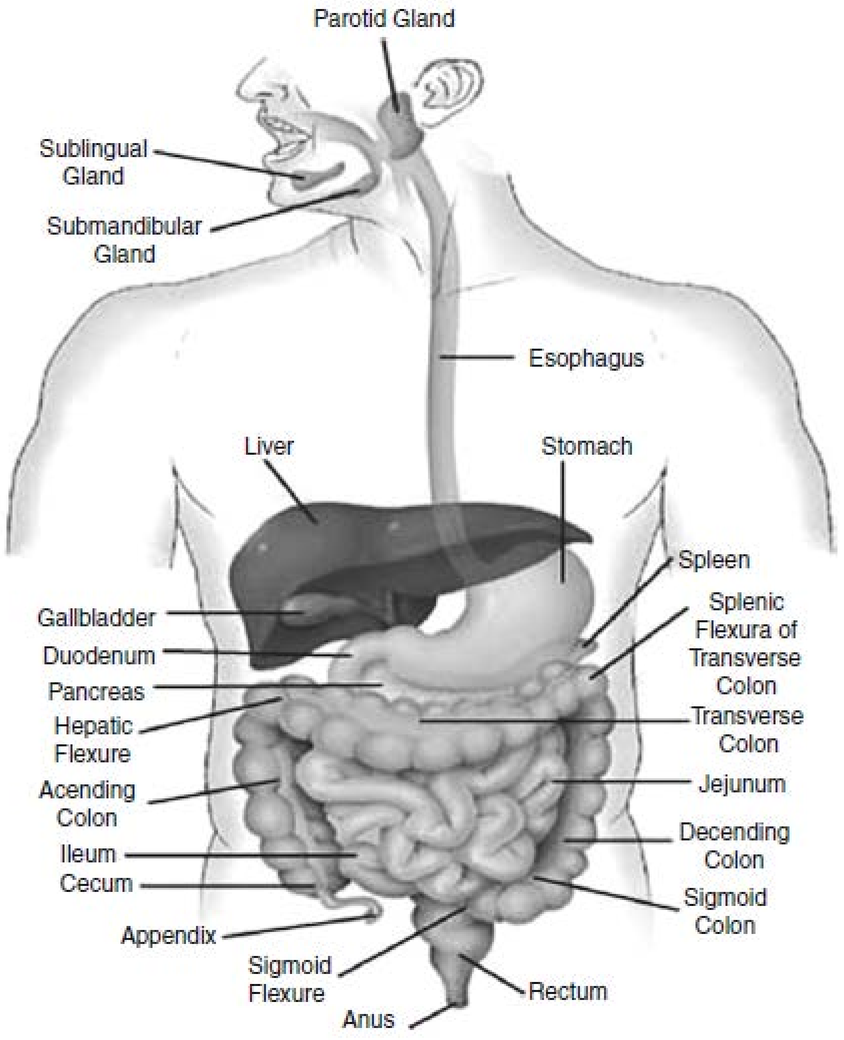

Fig. 7: Digestive system

Lymphatic System

The main function of the lymphatic system is to extract, transport, and metabolize lymph, the fluid found in between cells. The lymphatic system is very similar to the circulatory system in terms of both its structure and its most basic function is to carry body fluid (Fig. 8).

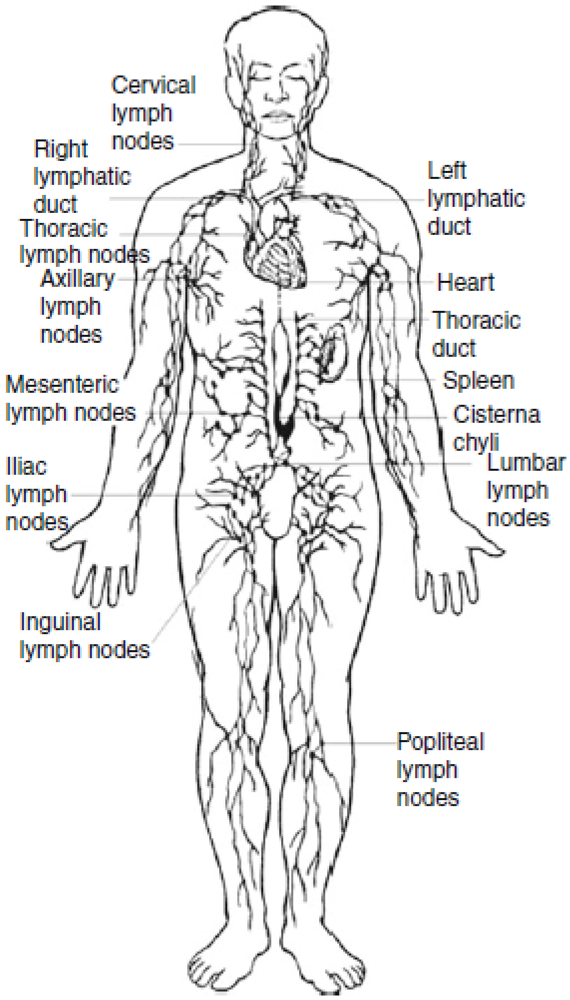

Fig. 8: Lymphatic system and the nodes

Immune System

The immune system is the body's defense against infectious organisms and other invaders. Through a series of steps called the immune response, the immune system attacks organisms and substances that invade body systems and cause disease. The immune system is made up of a network of cells, tissues, and organs that work together to protect the body. The cells involved are white blood cells, or leukocytes, which come in two basic types that combine to seek out and destroy disease-causing organisms or substances.

Leukocytes are produced or stored in many locations in the body, including the thymus, spleen, and bone marrow. For this reason, they are called the lymphoid organs. There are also clumps of lymphoid tissue throughout the body, primarily as lymph nodes, that house the leukocytes.

The leukocytes circulate through the body between the organs and nodes via lymphatic vessels and blood vessels. In this way, the immune system works in a coordinated manner to monitor the body for bacteria or viruses or substances that might cause problems, such as infection, fever, and pain.

Brief Idea of Artifi cial Organs

An artificial organ is a manmade device that is implanted, or integrated into, a human body to replace a natural organ with the purpose of restoring a specific function or a group of related functions so the patient may return to as normal a life as possible. The replaced function need not necessarily have to be related to life support, but often it is.

Implied by this definition is the fact that the device must not be continuously connected to a stationary power supply or other stationary resources, such as filters or chemical processing units. (Periodic rapid recharging of batteries, refilling of chemicals, and/or cleaning/replacing of filters would exclude a device from being called an artificial organ.) Thus, a dialysis machine, while a very successful and critically important life support device that completely replaces the functions of a kidney, is not an artificial organ. At this time, an efficient, self-contained artificial kidney has not become available.

Reasons to construct and install an artificial organ, an extremely expensive process initially, which may entail many years of ongoing maintenance services not needed by a natural organ, might include:

- Life support to prevent imminent death while awaiting a transplant (e.g., artificial heart, kidney).
- Considerable improvement of the patient's ability for self-care and ambulation (e.g., artificial joints, limb).
- Improvement of the patient's ability to interact socially (e.g., cochlear implant, IOL).
- Cosmetic restoration after cancer surgery or accident.

The use of any artificial organ by humans is almost always preceded by extensive experiments with animals. Initial testing in humans is frequently limited to those either already facing death or who have exhausted every other treatment possibility. (Rarely, testing may be done on healthy volunteers who are scheduled for judicial execution.)

Although they are not typically thought of as organs, one might also consider the replacement of bones and joints of the human body or other animals.

Different Types of Organs

There are now many artificial organs that have been implanted in humans, with varying degrees of success. In this section, we give a brief overview of the various types of artificial organs that have been developed over the years due to the tremendous efforts of various scientists worldwide.

Brain

Brain pacemakers, including deep brain stimulators, send electrical impulses to the brain in order to relieve depression, epilepsy, tremors from Parkinson’s disease, and other conditions such as increased bladder secretions. Rather than replacing existing neural networks to restore function, these devices often serve by disrupting the output of existing malfunctioning nerve centers to eliminate symptoms.

Cardia

Artificial cardia can be used to fight, among other diseases, esophageal cancer, achalasia, and gastroesophageal reflux disease. This pertains to gastric repairs, specifically of the valves at either end of the stomach.

Corpora Cavernosa

To treat erectile dysfunction of penis, both corpora cavernosa can be irreversibly surgically replaced with manually inflatable penile implants. This is a drastic therapeutic surgery meant only for men suffering from complete impotence that has resisted all other treatment modalities.

An implanted pump in the groin or scrotum can be manipulated by hand to fill these artificial cylinders, normally sized to be direct replacements for the natural corpus cavernosa, from an implanted reservoir in order to achieve an erection. Though technically novel, it may not be socially acceptable in everyday society.

Ear

Cochlear Implant

While natural hearing, to the level of musical quality, is not typically achieved with the use of cochlear implants, most recipients are pleased, with some finding it useful enough to return to their surgeon with a request to do implantation in the other ear.

Eye

Visual Prosthetic

The most successful function-replacing artificial eye so far is actually an external miniature digital camera with a remote unidirectional electronic interface implanted on the retina, optic nerve, or other related location inside the brain. The present state of the art yields only very partial functionality, such as recognizing levels of brightness, swatches of color, and/or basic geometric shapes, proving the concept's potential. While the living eye is indeed a camera, it is also much more than that.

Various researchers have demonstrated that the retina performs strategic image preprocessing for the brain. The problem of creating a 100% functional artificial electronic eye is even more complex than what is already obvious. The steadily increasing complexity of the advances in the artificial connection to the retina, optic nerve, or related brain areas, combined with ongoing advances in computer science, is expected to dramatically improve the performance of this technology.

For the person whose damaged or diseased living eye retains some function, other options superior to the electronic eye may be available.

Heart

The use of artificial hearts has been considered a success but still is limited to patients awaiting transplants whose death is imminent. The current state-of-the-art devices are unable to reliably sustain life beyond about 18 months.

Artificial pacemakers are electronic devices that can intermittently augment (defibrillator mode), continuously augment, or completely bypass the natural living cardiac pacemaker as needed. They are so successful that they have become very popular and easily implanted.

Ventricular assist devices are mechanical circulatory devices that partially or completely replace the function of a failing heart, without the removal of the heart itself.

Limbs

Artificial Limb

Artificial limbs include arms with semi functional hands, some even fitted with working opposable “thumbs” plus two “fingers,” and legs with shock-absorbing feet capable of allowing a trained patient to run. While the meaning of “full mobility” is debated, steady progress is being made. Energy consumption is an important criterion for determining the success of an implant.

Liver

Liver Dialysis and Devices

HepaLife, a U.S.-based company, is developing a bio artificial liver device intended for the treatment of liver failure using stem cells. The artificial liver, currently under development, is designed to serve as a supportive device, either to allow the liver to regenerate upon acute liver failure, or to bridge the patient's liver functions until a transplant is available. It is only made possible by the fact that it uses real liver cells, and even then, it is not a permanent substitute for a liver.

On the other hand, the researchers Dr. Colin McGucklin, professor of regenerative medicine at Newcastle University, and Dr. Nico Forraz, senior research associate and clinical sciences business manager at Newcastle University, say that pieces of artificial liver could be used to repair livers injured in the next five years. These artificial livers could also be used outside the body in a manner analogous to the dialysis process used to keep patients alive whose kidneys have failed.

Lungs

Some almost fully functional, artificial lungs promise to be a great success in the near future.

Pancreas

For the treatment of diabetes, numerous promising techniques that may be called an artificial pancreas are currently being tested, including some that incorporate donated living tissue housed in special materials to prevent the patient’s immune system from killing the foreign live components.

Bladder

Artificial bladders represent a unique success in that these are autologous laboratory grown living replacements, as opposed to most other artificial organs, which depend upon electromechanical contrivances and may or may not incorporate any living tissue.

Lecturer: Dr. Ameen M. Al-Juboori
E-mail: AmeenAL-Juboori@mustaqbal-college.edu.iq

Ovaries

Reproductive-age patients who develop cancer often receive chemotherapy or radiation therapy, which damages oocytes and leads to early menopause. An artificial human ovary has been developed at Brown University with self-assembled micro tissues created using novel 3D Petri dish technology. The artificial ovary will be used for the purpose of the in vitro maturation of immature oocytes and the development of a system to study the effect of environmental toxins on folliculogenesis.