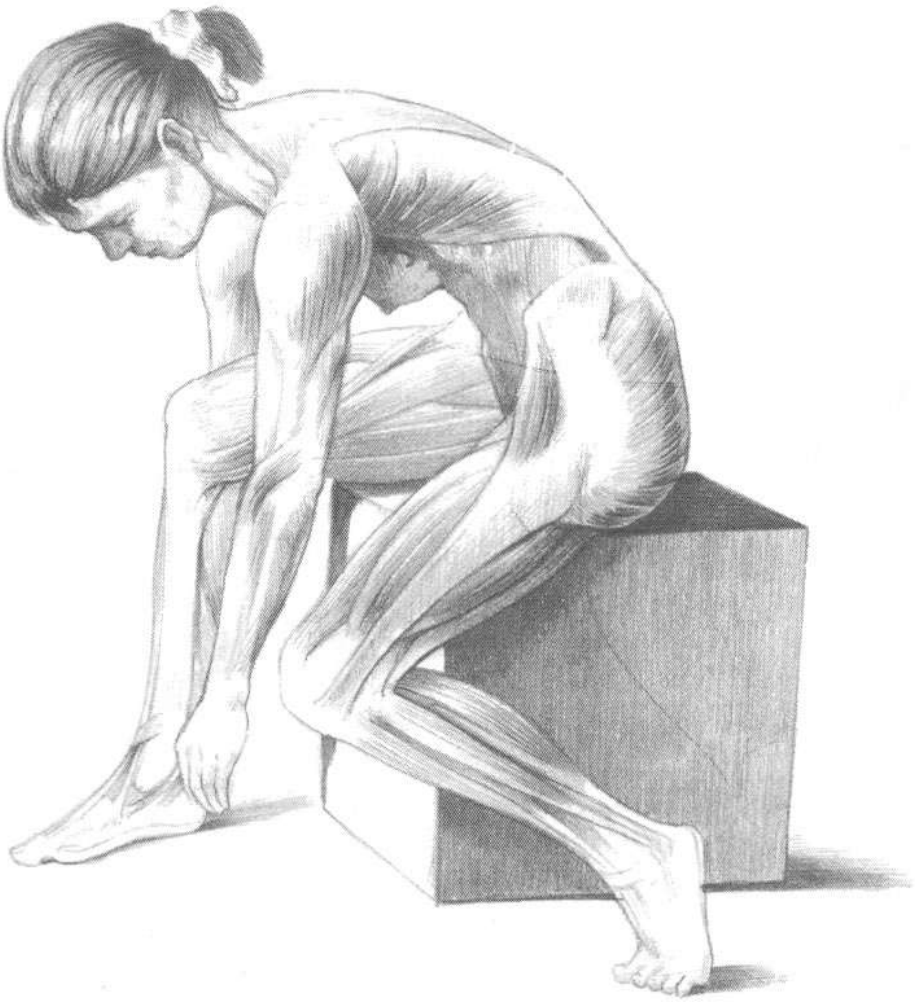
UNIVERSITY OF DEBRECEN
DEPARTMENT OF ANATOMY
HISTOLOGY AND EMBRYOLOGY

ANATOMY



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ANATOMY

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THE ANATOMICAL POSITION

The descriptions of the human body are always related to the anatomical position. The person is standing and looking forwards, the upper limbs are hanging by the sides of the body whereas the palms and toes are directed forwards.

THE ANATOMICAL PLANES, AXES AND DIRECTIONS

The anatomical planes are imaginary planes passing through the body in the anatomical position.

The **sagittal planes** are vertical planes that pass through the body from front to back and divide the body into right and left halves. The plane that passes along the midline of the body and divides the body into two equal parts is referred to as the median sagittal plane. Other sagittal planes that divide the body into unequal right and left portions are referred to as parasagittal planes.

The **frontal planes** are vertical planes passing through the body at right angles to the midsagittal plane and divide the body into front and back portions.

The **horizontal planes** are passing through the body at right angles to both the sagittal and frontal planes and are parallel to the surface on which the person is standing. These planes divide the body into upper and lower portions.

Various axes are used to describe the movements of different parts of the body. The **sagittal axis** is passing through the body from front to back; the **transverse axis** is passing through the body from right to left and the **vertical axis** which passes vertically from up to down.

Different terms are used to describe the relationship of different parts of the body in the anatomical position:

dexter	right
sinister	left,
median	located along the midline of the body,
medial	nearer to the median plane,

lateral farther from the median plane,
intermediate passing between a median and a lateral structure,
cranial nearer to the head,
caudal nearer to the feet,
superior nearer to upper part of the body,
inferior nearer to lower part of the body,
ventral nearer to the front,
dorsal nearer to the back,
anterior nearer to the forepart of the body,
posterior nearer to the back part of the body,
proximal nearer to the trunk,
distal farther from the trunk,
superficial nearer to the surface of the body,
deep farther from surface of the body,
external toward the exterior of an organ or body cavity
internal toward the inner part of an organ.

THE PARTS OF THE HUMAN BODY

The main parts of the human body are the head (caput), neck (collum), trunk (truncus) and the upper and lower limbs (extremitas). The skeleton of the head is composed of the skull which comprises the brain and the sensory organs. The skeleton of the trunk contains the vertebral column, the ribs and the sternum; they enclose the thoracic cavity which comprises the heart and the lungs. The lower part of the trunk is limited by muscles that encircle the abdominal cavity containing the digestive organs, the spleen, the kidneys and the suprarenal glands. The thoracic and abdominal cavities are separated by the diaphragm. The upper and lower limbs are connected to the trunk by the shoulder and the pelvic girdles. The pelvis and its ligaments and muscles encircle the urinary bladder, the rectum and the inner genital organs. The inferior outlet of the pelvis is closed by the perineum (pelvic diaphragm).

The internal organs of the human body are organised according to their functions into the following systems:

1. The skeletal system contains the bones and the joints
2. The muscular system is composed of skeletal muscles that move different parts of the body.
3. The cardiovascular system consists of the heart and the blood vessels that transport the blood.
4. The lymphatic system consists of the lymph organs that are involved in defence of the body against foreign organisms and substances and the network of lymphatic vessels return excess fluid to the blood.
5. The digestive system breaks down and absorbs nutrients for the body.
6. The respiratory system is concerned with exchange of gases between the air and the blood.
7. The reproductive system is responsible for reproduction of the human body.
8. The nervous system coordinates sensations and movements and controls the activities of the internal organs of the body.
9. The endocrine system is composed of glands that secrete hormones into the blood which regulate different functions of the body.

THE SKELETAL SYSTEM

The adult skeletal system consists of 206 individual bones which are united by joints (articulations). The bones and joints provide structural framework for the actions of skeletal muscles.

BONES

The bones are composed of specialized, rigid connective tissue with high amount of inorganic salts deposited into the intercellular space. The network of collagen fibers in the matrix is responsible for flexibility of the bones. In elder people the matrix contains more inorganic salts and the bones become less flexible and more breakable than in children.

The bone tissue is organized into the **hard compact shell** (substantia compacta) on the outer surface of the bones and a network of slender bony trabeculae, called **spongy bone** in the interior of the bone. The spaces of the spongy bone are filled with **bone marrow**. The surfaces of bones are covered by a fibrous, sensitive membrane (periosteum, endosteum) interwoven with blood vessels and nerves. The **periosteum** provides nutrients to the cells of the bone and is involved in fracture healing. On the articular surfaces the periosteum is replaced by the articular cartilage.

The bones are classified according their shapes as flat, long, short and irregular bones.

Flat bones consist of an inner and outer thin, curved plate of compact bone that encloses the narrow spongy bone with red bone marrow producing the formed elements of the blood. Flat bones include the bones of the skull, the thoracic cavity and the pelvis.

Short bones have about the same length and width. They present an outer thin compact layer that surrounds the central spongy bone filled with yellow bone marrow. They occur in the wrists and the ankles.

Long bones are typical bones of the arms and the legs. They could be divided into a central body or shaft (diaphysis) and two expanded, concave or convex end portions (epiphysis). The shaft consists of the cylindrical shell of compact bone which encircles the medullary cavity containing the yellow bone marrow. The medullary cavity is lined with the endosteum, whereas the outer surface of the shaft is covered with the periosteum. The epiphysis is composed of an organized network of spongy bony trabeculae filled with red

or yellow bone marrow. The articular surface of the epiphysis is covered with cartilage and is involved in joints.

The **irregular bones** have various shapes; the bones of the facial skeleton and the vertebrae belong to this group.

The bones in the human body disclose several mechanical and physiological functions. They give support for the weight of the body, encircle cavities (thorax, skull) and protect the internal organs. The bones provide attachments for the skeletal muscles and give the mechanical basis for movements. The bones are the main storehouse of calcium, magnesium and phosphate, the red bone marrow produces the formed elements of the blood.

JOINTS

The joints are those places of the body where two ore more bones meet. They can be divided into two main categories.

The **solid joints** lack the joint cavity and the articulating bones are united by connecting material which allows restricted movements. According to the connecting material solid joints are classified into fibrous and cartilaginous groups. In the **fibrous joints** (syndesmoses) the bones are connected by fibrous ligaments; the sutures between the bones of the skull are typical examples for this articulation. In the **cartilaginous joints** the bones are united by a plate of cartilage. Such articulations are found in the synchondroses of the ribs where hyaline cartilage plates connect the ribs to the sternum. In the symphysis the bony surfaces are covered by hyaline cartilages which are bridged by a disk of fibrocartilage (e.g. intervertebral discs between the vertebrae). In some places of the body the cartilaginous joints appear as temporary joints and are converted into bony tissue (e.g. sacrum).

In the **cavited ore synovial joints** the opposed surfaces of the bones are separated by a narrow space containing special fluid called synovia. In these joints, the bony surfaces are covered by hyaline cartilage and the convex articulating surface on one bone fits to the concave articulating surfaces of another bone. In some joints, where the opposing surfaces are not completely fit into each other a fibrocartilaginous disc or meniscus adjusts the unequal articular surfaces, or a fibrocartilaginous ring deepens the concave articular surface. The **articular capsule** surrounds the joint cavity and separates

the joint from other parts of the body. The outer part of the capsule is composed of bundles of collagen fibers connecting the articulating bones. The inner surface of the capsule is lined with a vascular, loose connective tissue producing the viscous **synovial fluid** which lubricates and nourishes the articular cartilages. The articular capsule is usually strengthened by numerous ligaments that limit the movements of the joints.

The synovial joints provide free movements between the bones. They are classified according to the shape of the articulating surfaces and the types of movements which are permitted by the surfaces. The movements of the joints are described in relation to the axes passing through the articulating surfaces. The axis of a movement is defined by the row imaginary points which remain stationary during the movement of the joints.

Uniaxial joints

In the **hinge joint** a cylindrical surface of one bone fits into an oval concave surface of another bone. In these articulations, movement is limited around one axis that passes at right angles to the longitudinal axis of the bone. The joint permits flexion and extension movements. **Flexion** means a bending motion in which the angle between the articulating bones decreases and the parts of the body shortens. **Extension** means straightening or increasing the angles between the bones and the body part lengthens. Hinge joints can be found in the finger, the knee and the elbow.

The other type of uniaxial joint is the **pivot or trochoid joint** where a central bony pivot rotates within a sleeve or ring. The axis of the **rotational movements** is passing along the long axis of bones. This type of movements occurs, for example, in the elbow when the radius is turning around the ulna.

Biaxial joints

In the **condyloid joint** an ellipsoid convex surface is moving against an oval shaped concave surface in two directions. The axes of these movements are at right angles to one another and they permit **flexion-extension** and **abduction-adduction** movements. Abduction means moving the part of the body away from the median plane, while adduction refers to a movement of the part of the body towards the median plane. Examples are the wrist joint and metacarpophalangeal joints.

The **saddle joint** is so named because the articular surfaces of the bones are shaped like a saddle. The carpometacarpal joint of the thumb is the best example for the saddle joint where the thumb is connected to the wrist. This joint permits **abduction** and

adduction along a frontal axis passing through the hand. Along an oblique axis, the thumb touches and opposes the palmar surface of other fingers, this movement is termed **opposition** and when the thumb moves back to the anatomical position is called **reposition**.

Multiaxial joint

The **ball-and-socket joints** are composed of a spherical head of on one bone that fits into a cuplike concave surface of another bone. These are the most freely movable joints in our body permitting movements around several axes. For descriptive purposes, the three axes which are passing in the anatomical planes are considered. The typical movements in these joints are **flexion** and **extension** around a sagittal axis, **abduction** and **adduction** around a frontal axis and **rotation** around a vertical axis. By combination of these movements a special circular movement called **circumduction** is accomplished where the distal end of the bone describes a circle while the proximal end of the bone remains in its original place. The shoulder and hip joints are typical ball-and-socket joints.

MUSCLES

Three basic types of muscular tissue exist in our body: the smooth muscle that forms the wall of the blood vessels and inner organs (viscera); the cardiac muscle constitutes the wall of the heart, and the skeletal muscle that produces movements of the skeleton of the body.

The skeletal muscle is composed of long, tubular multinucleated structures called **muscle fibers**. The bundles of muscle fibers are organized into fascicles. The fascicles are surrounded by a sheath of connective tissue (epimysium) that limits the fleshy portion of the muscle called **belly or venter**. Bellies of the skeletal muscle may be connected directly to the bones, but in most cases, the individual muscle fibers turn into connective tissue, called **tendon,** at the end portion of the muscle. On the limbs, the tendons form strong cords that attach the muscle to the bones. On the trunk, the tendons are broadening into sheets that are called aponeurosis. The medial or proximal attachments of muscles are regarded as the origin, whereas the lateral or distal attachments are defined as the insertion of the muscle. The skeletal muscles originate from one bone, pass one or more joints and are attached to another bone. Some muscles originate from several parts of the body and

have two, three or four bellies (biceps, triceps, and quadriceps) which unite and are inserted by a common tendon to the bone.

The fascicles (bundles of the muscle fibers) are organized in various patterns in different muscles. Each pattern determines the power of the muscle and the range of movements. In the **strap muscles**, the fascicles run parallel to the long axis of the muscle. These relatively week muscles are located, for example, on the neck. In the spindle-shaped belly of **fusiform muscle** the number of fascicles is greater and consequently the force generated by these muscles is also grater. This type of muscles is usually found on the upper and the lower limbs. In the **pennate muscle**, the fascicles are arranged obliquely on one or both sides of the tendon making the muscle look like a feather. The pennate muscles have the greatest power in our body. In the **circular muscle** the fibers are arranged circularly around the openings of the body.

The movements of the body involve the interaction of several skeletal muscles or groups of muscles. The **prime mover or agonist muscles** begin a certain movement and are active in maintaining the desired movement. The **antagonist muscles** counteract the prime mover and oppose the movement produced by the agonist muscles. For example: the biceps brachii and the brachialis muscles of the arm begin to flex the elbow and they are regarded as agonists at the elbow joint. The triceps muscle of the arm counteracts the flexion of the elbow and is the antagonist of the biceps and brachialis muscles.

The activation of skeletal muscles derives from the central nervous system (CNS). Nerve impulses from the brainstem and spinal cord are conducted to the muscles via the axons of motor neurons. The axons of motor neurons exit from the CNS and reach the muscles fibers by way of the spinal and cranial nerves. Nerve impulses are transmitted at the neuromuscular junction. The collection muscle fibers that are stimulated by axon terminals of one motor neuron constitute the functional unit of the skeletal muscle; it is called the **motor unit**. In the muscles of the trunk or tight the motor units are large and one motor neuron supplies several hundred muscle fibers. In small motor units of the eye muscles the motor unit contains only a few muscle fibers. When nerve impulses are passing along the axon of the motor neuron, all muscle fibers within the motor unit contract simultaneously. The force of muscle is improved by increasing the number of motor units being simultaneously in action. During maintenance of posture, some of our

motor neurons are continuously active and evoke a tonic contraction of muscle fibers. This is called muscle tone. During sleep, most of the motor neurons are silent and the muscle tone is decreased.

ANATOMY OF THE LIMBS

THE UPPER LIMB

The skeleton of the upper limb consists of four main parts: the shoulder girdle, the arm, the forearm and the hand. The shoulder girdle contains two bones the **clavicle** and the **scapula** which are connected to each other by joints and ligaments. The upper extremity is connected to the skeleton of the trunk by one joint which is formed by the medial end of the clavicle and the upper part of the sternum (sternoclavicular joint). The pyramidal shaped interval between the upper limb and chest wall is termed the **axilla;** it transmits the blood vessels and nerves to the upper limb. The skeleton of the arm contains one bone the **humerus** between the shoulder and the elbow. The forearm, located between the elbow and the wrist, includes two bones: **the ulna** on the lateral or thumb side and **the radius** on the medial or little finger side. The hand contains eight short bones in the wrist (**carpal bones**), five long bones make up the skeleton of the palm of the hand (**metacarpal bones**) and 14 small **phalanges** outline the skeleton of the fingers.

Bones of the upper limb

The **clavicle** or collar bone is a double-curved long bone. It can be palpated through the skin between the sternum and the scapula. The rounded medial end of the clavicle articulates with the sternum (sternoclavicular joint), the flattened lateral end is connected to the scapula (acromioclavicular joint).

The **scapula** or shoulder blade is a flat, triangular bone. On its dorsal surface the scapula presents a horizontal spine which ends laterally in the large acromion. Bellow the acromion, the lateral angle of the scapula has a shallow, piriform glenoid cavity for articulation with the humerus. Projecting forward above the glenoid cavity, the coracoid process serves as attachment for several ligaments and muscles.

The **humerus** is a typical long bone. The upper end of the bone presents the spheroid head articulating with the glenoid cavity of scapula. The distal end of the humerus includes the condyle presenting the medial pully-shaped trochlea and the lateral

spherical capitulum. On the sides of the condyle the medial and lateral epicondyles give origin to muscles of the forearm.

The **radius** is a long bone located on the lateral side of the forearm. At the proximal end the radius holds a disc-shaped head which articulates with the humerus and the ulna. The wide lower end of the radius articulates with the carpal bones; the head of the ulna fits into notch on the ulnar side.

The **ulna** is situated on the medial (little finger) side of the forearm. The large proximal end of the ulna (olecranon) constitutes the prominence on the back of the elbow. In front the olecranon presents the half-moon-shaped trochlear notch which articulates with the trochlea of the humerus. The lateral aspect of the olecranon (radial notch) is engaged with the head of the radius. The narrow distal end of the ulna terminates at a small head.

The **wrist** is composed of eight short bones which are arranged in two transverse rows. The proximal row is composed of the scaphoid, lunate, triquetrum and pisiform bones in the radio-ulnar direction; in the distal row the trapezium, trapezoid, capitate and hamate bones are found. The five metacarpal bones extend between the distal carpal bones and the phalanges, they form the skeleton of the palm of the hand. Three small phalanges constitute the skeleton of the fingers except the thumb which has only two phalanges.

Joints of the upper limb

In the **shoulder girdle** the medial end of the clavicle articulates with sternum (sternoclavicular joint) and lateral end of clavicle articulates with acromion of the scapula (acromioclavicular joint). The movements in shoulder girdle accompany the movements of shoulder joint. The large extent in the movements occur in the shoulder is due to the additional movements of scapula and clavicle including elevation, depression and rotation of these bones and gliding movements of the scapula on the chest wall.

In the **shoulder joint,** the spherical head of the humerus articulates with the shallow glenoid cavity of the scapula which is deepened by a fibrocartilaginous ring (glenoid labrum). The shoulder joint discloses larger extent in movements than any other joint in the body. It is a typical ball-and-socket joint with flexion and extension along the transverse axis through the head of the humerus, abduction and adduction along the

sagittal axis through the head of the humerus, medial and lateral rotation along the vertical axis and circumduction.

In the **elbow joint,** the trochlea of the humerus engages the trochlear notch of the ulna, the head of the radius articulates with the capitulum of the humerus and with the radial notch of the ulna. The elbow joint is a biaxial joint. Along the transverse axis (passing through the condyle of the humerus) flexion and extension occur. Along the vertical axis (passing between the head of the ulna and radius) the radius rotates medially around the ulna while crosses the ulna and the palm faces backward (pronation). Following lateral rotation the radius comes to lie parallel to the ulna and the palm faces forward (supination).

The **wrist joint** is a biaxial ellipsoid joint between the distal end of the radius and the proximal carpal bones (scaphoid, lunate and triquetrum). In this articulation, the hand is moving toward the radius or ulna along the sagittal axis (radial and ulnar abduction), or the hand moves forward and backward along the transverse axis (dorsalflexion and volarflexion). The carpal and metacarpal bones are connected to one another by plane joints which allow only limited gliding movements. The metecarpal bone of the thumb (first metacarpal bone) has a saddle-shaped surface which articulates with the similar articular surface of the scaphoid bone (carpometacarpal joint of thumb). In this biaxial joint, the tumb moves toward or away from the other fingers (adduction, abduction), and the thumb opposes the other fingers (opposition) and moves back to the anatomical position (reposition).

Muscles of the upper limb

The upper limb can be divided into the pectoral and shoulder regions, the arm, the forearm and the hand.

The **muscles of the pectoral region** (e. g. pectoralis major and minor) move the shoulder joint, or if the arm is fixed they elevate the ribs. The **muscles of the shoulder region** extend between the scapula and humerus; their function is important in the stabilization and in the movements of the shoulder joint. The typical example is the **deltoid muscle** which covers the shoulder joint and is responsible for the roundness of the shoulder.

The **muscles of the arm** are mainly responsible for the movements of the elbow joint and are divided into flexor and extensor groups. The flexor group is located on the anterior surface of the arm; it includes the **biceps brachii** muscle. As it name indicates, this muscle arises from the scapula with two heads which unite distally and insert to the radius by a common tendon. The extensor group is on the posterior side of the arm. It is formed by **triceps brachii** muscle which originates with three heads and is attached distally to the olecranon of the ulna.

The **muscles of the forearm** consist of the anterior flexor group and the posterior extensor group. The flexor muscles arise from the medial epicondyle of the humerus and form a superficial and a deep layer. The superficial muscles are the pronator of the elbow and the flexor of the wrist. The deep muscles are anchored the phalanges and are they are the flexors of the fingers. The muscles of the extensor group arise from the lateral epicondyle of the humerus and from the dorsal side of the radius and ulna. These muscles are the supinator of the elbow and the extensor of the wrist and the fingers.

The **intrinsic musles** of the hand are on the palmar side and can be divided into three groups. The short muscles that move the thumb produce the medial **thenar** eminence of the palm; the small muscles which are concerned with movements of the little finger form the lateral **hypothenar** eminence. The triangular area of the palm between the two eminences is the **central compartment** (mesothenar) containing the tendons of the flexor muscles, arteries, nerves and short muscles of the fingers (lumbricals and interossei).

Blood vessels and nerves of the upper limb

The blood supply for the upper limbs arises from the right and left subclavian arteries. The **sublcavian artery** forms an arch in the neck then enters the axillary fossa. Here it is termed **axillary artery** which gives branches to the pectoral and shoulder regions. From the axilla, the artery passes toward the arm where it is called brachial artery. The **brachial artery** descends on the medial side of biceps muscle where it can be compressed against the humerus and used for measurement of blood pressure. In front of the elbow, the brachial artery divides into ulnar and radial arteries. The **ulnar artery** runs among the flexor muscles of the forearm, it passes in front of the wrist and terminates in

the central compartment of the hand. Here it forms the **superficial palmar arch** which is completed by a branch from the radial artery. The **radial artery** is passing superficially and lies on the distal part of the radius where the pulsation of the artery can be easily felt. The terminal part of the radial artery winds around radius and after piercing the deep muscles of the hand enters the mesothenar of the palm. In the palm it joins with a branch from the ulnar artery to form the **deep palmar arch**. The fingers are supplied by branches arising from the superficial and deep palmar arches.

The blood from the upper limb is conveyed toward the heart by superficial and deep veins. The deep veins accompany the arteries usually in pairs except the axillary which is accompanied by a single vein. The superficial veins lie under the skin in the subcutaneous tissue. They begin as venous network on the dorsal side of the hand which is drained by the basilic and cephalic veins. The **cephalic vein** ascends on the lateral side of the forearm and arm and opens into the axillary vein. The **basilic vein** runs on the ulnar side of the forearm medial to the biceps and drains in the brachial vein. In front of the elbow, the cephalic and basilic veins are connected by the **median cubital vein** which is frequently used for taking blood samples or giving intravenous injections.

The motoneurons innervating the muscles of upper limb are situated in the cervical (C5-C8) and thoracic (Th1) segments of the spinal cord. The axons of these motoneurons are passing in the ventral rami of the spinal nerves which are recombined and form a complex network called **brachial plexus**. In the axilla, the brachial plexus gives rise to several nerves supplying the upper limb. The **musculocutaneous nerve** descends under the biceps muscle and supplies the flexor muscles of the arm. The **median nerve** traverses along the medial side of the biceps, it is located among the flexor muscles in the forearm, and terminates in the thenar compartment of the hand. It supplies most of the flexor muscles of the forearm and most of the short muscles of the thumb. The **ulnar nerve** descends medial to biceps in the arm, accompanies the ulnar artery among the flexor muscles of the forearm, then enters the hand where it innervates most of the muscles moving the fingers. The **radial nerve** is passing on the dorsal side of the arm and forearm and supplies the extensor muscles. The skin of the upper limb is innervated partly by direct branches from the brachial plexus or by cutaneous branches of the nerves of the brachial plexus.

THE LOWER LIMB

The lower limb is specialized for locomotion and supporting the body weight. It consists of four major parts: the pelvic girdle (hip), the thigh, the leg and the foot. The pelvic girdle is formed by the two **hip bones** which articulate with each other and with the **sacrum** and form a ring-like structure called the bony pelvis. The thigh contains the **femur** which extends between the hip and the knee. The leg connecting the knee and ankle includes two bones: the larger **tibia** or shin bone on the medial side and the slender **fibula** or split bone on the lateral side of the leg. The foot is divided into the **tarsus** containing seven short bones, the **metatarsus** with five long bones and 14 **phalanges** forming the skeleton of the toes.

Bones of the lower limb

The bony pelvis

The skeleton of the bony pelvis includes the two hip bones, the sacrum and os coccyx. They are connected to each other by the pubic symphysis and sacroiliac joints.

The irregular **hip bone** (os coxae) is formed by the fusion of three bones: the ilium, the ischium and the pubis. These bones are separated by a Y shaped cartilage before puberty, but are indistinguishably joined in the adult. The **ilium** is located on the upper and lateral part of the hip bone consists of a body and a wing. The upper border of the wing can be easily palpated on the lateral side of the hip and terminates in two spines in front and behind. These spines are important landmarks in measuring the size of the pelvis. The inner surface of the wing forms a fossa. The outer surface of the ilium presents an ear-shaped surface for articulation with the sacrum. The **ischium** is located posteriorly at the lower part of the hip bone. It consists of the body and the ramus extending forward from the body. On the lower end of the body, the ischial tuberosity bears the body weight in sitting position. The **pubic bone** forms the lower part of the hip bone in front. It has a body and superior and inferior rami extending from the body. The bodies if the ilium, ischium and pubis form a deep cup, called the acetabulum which articulates with the head of the femur. Bellow the acetabulum the rami of the pubis and the ischium surround a large round aperture, the obturator foramen.

The wedge-shaped and curved **sacrum** is composed of five fused vertebrae. In front and behind, the sacrum presents four pairs of foramina for the sacral spinal nerves. The enlarged anterior edge of the upper end of the sacrum is called promomtory; it is an important obstetrical landmark. On both sides the sacrum presents two ear-shaped auricular surfaces for articulation with the hip bones.

The **bony pelvis** is a ring-like structure formed by the hip bones and the sacrum which are bound by joints and ligaments. The auricular-shaped articular surfaces of the right and left hip bones form flat joints with the sacrum (sacroiliac joints). They are strengthened by strong ligaments which permit restricted movements. The bodies of the pubic bones are united anteriorly by a cartilaginous joint (pubic symphysis). The upper part of the bony pelvis between the wings the ilium is called the greater or false pelvis. It is the part of the abdominal cavity. The lower funnel-shape part of the bony pelvis is referred to as true or small pelvis containing the urinary bladder, the genital organs and the rectum.

Bones of the thigh, leg and foot

The **femur,** or thigh bone, is the longest bone of the human body; it is almost completely surrounded by muscles. On the upper end of the femur, the neck runs obliquely from the body and terminates in a spherical head which articulates with the acetabulum of the hip bone. At the junction between the neck and the body, two big projections (greater and lesser trochanter) give attachment for muscles and ligaments. The distal end of the femur is broadened into the lateral and medial condyles which are separated by a fossa behind and by a smooth patellar surface in front.

The **tibia,** or shin bone, is located on the medial side of the leg where it can be easily palpated. The proximal end of tibia form two condyles for articulation with the femur at the knee join. On the lower side of the lateral condyle a small spherical articular surface connects the tibia to the fibula. The lower end of the tibia articulates with the tarsus and forms an easily felt prominence on the medial side of the ankle (medial malleolus).

The **fibula,** or split bone, is a long slender bone on the lateral side of the leg. The head at its proximal end articulates with the lateral condyle of the tibia. The distal end of

the fibula constitutes the lateral malleolus which can be palpated on the lateral side of the ankle.

The **tarsus** is composed of seven short bones: talus, calcaneus, navicular, cuboid and three wedge-shaped cuneiform bones. The talus or ankle bone articulates with the tibia and fibula to form the ankle joint. The calcaneus, or heel bone, supports the body weight in standing position. The navicular is located in front of the talus and articulates with the three cuneiforms anteriorly. The cuboid is situated in front of the calcaneus on the lateral side of the tarsus. The five metatarsal bones form the skeleton of the sole of the foot, whereas the 14 phalanges constitutes the skeleton of the toes.

Joints of the lower limb

In the **hip joint** the spherical head of the femur articulates with acetabulum of the hip bone which is deepened by a fibrocartilaginous ring (acetabular labrum). The fibrous capsule is strengthened by strong ligaments which are taut in full extension of the hip joint and are important in stabilizing the body in standing position. The hip joint is a ball-and-socket joint with three main axes passing through the head of the femur. Along the transverse axis flexion and extension occur; along the sagittal axis the upper limb is moved toward or away from the midline (adduction, abduction) and along the vertical axis the thigh can be rotated medially and laterally. Combination of these movements results circumduction. A ligament passing within the joint cavity to the head (ligament of the head of the femur) carries a blood vessel to the head. Fractures of the neck of the femur may rupture this ligament resulting in avascular necrosis of the head.

The **knee joint** consists of articulations between the medial and lateral condyles of the femur and the tibia and an articulation between the femur and the patella. Two crescent-shaped fibrocartilaginous plates (medial and lateral menisci) deepen the tibial condyles and adjust the articular contact surfaces. The capsule of the joint is strengthened by collateral ligaments on both sides. The cruciate ligaments are strong cords crossing each other within the joint cavity. These ligaments are tight in the extended position of the joint and prevent dislocation of the condyles of the femur. The knee joint is the most complex and most vulnerable joint in the human body. Injury of the menisci or the cruciate ligaments occurs often. The knee joint is a modified hinge joint where the

principal movements are flexion and extension along the transverse axis through the head of the femur. Rotational movements also occur in a flexed position of the knee.

The **ankle joint** is a uniaxial hinge joint located between the distal end of the tibia and fibula (medial and lateral malleolus) and the dorsal surface of the talus. The bones are strongly connected by collateral ligaments on both sides which permit only movements of the foot along a transverse axis (dorsiflexion and plantarflexion).

The plane joints among the tarsal bones are tightly connected by ligaments and only slight movements are permitted between them. The joints between the talus, calcaneus and navicular bones are more movable and allow inner and outer rotational movements of the sole of the foot (eversion and inversion). The tarsal and metatarsal bones are joined by plane synovial joints; the phalanges of the foot form hinge joints with each other.

The bones of the foot are arranged in longitudinal and transverse arches. In standing position, the body weight is supported by the calcaneus and the heads of the metatarsal bones, the longitudinal arches extend between these weight bearing points. The transverse arch is formed by the tarsal bones and the proximal parts of the metatarsal bones. The arches of the foot transmit the body weight, absorb shakings during walking or jumping and provide protection for blood vessels and nerves of the sole.

Muscles of the lower limb

Based on their location and function, the muscles on the lower limb can be divided into muscles of the iliac and gluteal regions, muscles of the thigh, leg and foot.

The **iliac muscles** arise from the vertebral column and from the inner surface of the hip bone and are attached to upper part of the femur. These muscles move the hip joint. The largest muscle in this group, the iliopsas, can be seen on the anterior surface of the thigh. The **muscles of the gluteal region** consist of the three large gluteus muscles (gluteus maximus, medius and minimus) and a deeper group of smaller muscles. The gluteus muscles extend between the hip bone and femur and are important in stabilization of the hip joint in standing position. Intramuscular injections are usually given into the gluteus medius muscle in the upper and outer part of the buttock which is free of big blood vessels and nerves.

The **muscles of thigh** move the hip joint and the knee joint. According to their location and function they are organized into three groups. The muscles on the posterior aspect of the thigh are known as the **hamstrings** and are the main flexors of knee joint. The muscles on the medial aspect of the thigh are the chief **adductors** of the hip joint. The muscles on the anterior and lateral aspects of the thigh are the **extensors** of the knee joint. The **quadriceps femoris** in this group is the biggest muscle in the body. It arises from the hip bone and femur by four heads. The tendons of the four bellies unite, surround the patella and continue as the patellar ligament to the tibia.

The patella is embedded into the tendon of the quadriceps muscle. The knee jerk is elicited by tapping the patellar ligament which causes sudden contraction of quadriceps muscle.

The adductor canal - located between the adductor and extensor muscles in the lower one third on the medial side of the thigh - is a fibromuscular tunnel houses big blood vessels passing backward to the knee joint.

The **muscles of the leg** extend between the tibia, fibula and the bones of the leg; they move the ankle joint and the foot. The **extensor muscles** occupy the anterior part of the leg; the **peroneus muscles** are located on the lateral side of the fibula. The **flexor muscles** shape the posterior aspect the leg. The **triceps surae** muscle in this group forms the prominence of the calf and elevates the heel during walking. It arises by three heads which join and are attached to the calcaneus by the Achilles tendon (tendo calcaneus).

The **muscles of the foot** are mainly located on the sole and are considered in three groups: muscles in thenar move the big toe; muscles in the hypothenar move the little toe; and muscles located in the central portion of the sole.

Blood vessels and nerves of the lower limb

The big arteries from the pelvis enter the lower limbs as the right and left **external iliac arteries** which continue as femoral arteries. The **femoral artery** is located on the anterior side of the thigh, passes backward through the adductor canal, and changes its name to popliteal artery. Bellow the knee joint the **popliteal artery** divides into anterior and posterior tibial arteries. The **anterior tibial artery** passes among the extensor muscles of the leg and continues as the dorsalis pedis artery on the dorsal side of the foot. The **posterior tibial artery** descends in the flexor compartment of the leg and it divides behind the medial malleolus into medial and lateral plantar arteries.

Most of the blood from the lower limb returns to the heart by way of the deep veins that accompany the arteries. The femoral and popliteal veins are unpaired the other veins run in pairs. Similarly to the upper limb, there are two major superficial veins. The **great saphenous vein** arises from the dorsal venous arch of the foot, passes in front of the medial malleolus, ascends on the medial side of the leg and the thigh and opens into the femoral vein. The **small saphenous vein** winds behind the lateral malleolus, climbs up on the posterior aspect of the calf and opens into the popliteal vein.

The nerves supplying the muscles and the skin of the lower limb arise from the lumbar and sacral plexuses. The **lumbar plexus** is composed of the ventral rami of spinal nerves originating from the last thoracic and 1-4 lumbar segments of the spinal cord, gives off the femoral and obturator nerves to the lower limb. The **femoral nerve** is situated on the lateral side of the femoral artery and innervates the extensor muscles of the thigh. The **obturator nerve** gives branches to the adductor muscles of the thigh. The **sacral plexus** emerges from the fibers of the ventral rami of the last lumbar and 1-4 sacral spinal nerves. The **sciatic nerve** derives from this plexus, passes through the gluteal region, innervates the flexor muscles of the thigh and divides into tibial and common peroneal nerves. The **tibial nerve** runs deep to the gastocnemius muscle, supplies the flexor muscles of the leg then it passes behind the medial malleolus and innervates the muscles of the foot. The **common peroneal nerve** winds around the upper part of the fibula and divides into superficial and deep branches. The superficial peroneal nerve supplies the peroneus muscles; the deep peroneal nerve enters the extensor compartment of the leg and innervates the extensor muscles.

ANATOMY OF THE TRUNK

SKELETON OF THE TRUNK

The skeleton of trunk consists of the vertebral column, the ribs and the sternum.

Vertebral column

The vertebral column is composed of 33-35 vertebrae. The upper 24 vertebrae - termed true vertebrae - are individual movable bones, whereas the lower vertebrae are fused and form two bones: the sacrum and the coccyx. The movable vertebrae are divided into 7 cervical (neck), 12 thoracic (chest) and 5 lumbar vertebrae.

A typical **movable vertebra** is an irregularly shaped bone presenting a cylindrical **body** and an **arch** which is attached to the sides of the body. The body and the arch encircle the **vertebral foramen**. The sequence of vertebral foramina forms the vertebral canal which houses the spinal cord and its roots. The arch of the vertebra gives origin to several processes. The unpaired **spinous process** projects backward. The paired **transverse processes** pass laterally from the arch. The four **articular processes** project toward the upper and lower neighbouring vertebrae. At the root of the articular processes the superior and inferior notches can be seen. In the vertebral column the adjacent vertebral notches complete each other and form the **intervertebral foramina**. They serve for the exit of spinal nerves.

The vertebrae in different regions of the vertebral column show characteristic features which enable one to identify them. The **cervical vertebra** presents a small body and a relatively large triangular-shaped foramen. The distinctive feature of these vertebrae is the opening on the transverse process called transverse foramen. Their sequence in the cervical region forms a channel for the vertebral arteries. The first and second cervical vertebrae show some unique features. The first is called the **atlas;** It is a ring-like structure where the two lateral masses are connected by anterior and posterior arches. It has neither body nor spinous process. The second cervical vertebra (**axis**) emits a protrusion upward from the body which articulates with the anterior arch of the atlas. The typical **thoracic vertebra** presents a heart-shaped body and a circular vertebral foramen. The characteristic features of these vertebrae are the small articular facets on the sides of their bodies and the transverse processes for articulation with the ribs. The **lumbar vertebrae** with their

kidney-shaped bodies and relatively small triangular foramina are the largest. The **sacrum** is a wedge-shaped bone that is composed of five fused sacral vertebrae. The circular sacral foramina on the ventral and dorsal sides of the bone transmit the roots of the sacral spinal nerves. The sacrum shows two ear-shaped articular surfaces on each side of the bone for articulation with the right and left hip bones. The body of the first sacral vertebra protrudes anteriorly, it is the sacral promontory.

The vertebrae are united by synovial, fibrous and cartilaginous joints to form the vertebral column. The synovial joints are formed by the superior and inferior articular processes of the adjacent vertebrae. The arches and processes of the vertebrae are connected by different ligaments. The neighbouring vertebral bodies are connected to each other by fibrocartilagenous discs termed as the **intervertebral disc**. Each disc is composed of external concentric lamellae of fibrocartilage (annulus fibrosus) which surrounds the internal gelatinous core (nucleus pulposus). The nucleus pulposus may protrude the annulus fibrosus and compresses the adjacent spinal nerves.

In the adult vertebral column four curvatures are visible in the sagittal plane: the cervical and lumbar convexities, and the thoracic and sacral concavities. Although the movements between adjacent vertebrae are limited, the cumulative effects of these small movements allow considerable bending and rotation along the vertebral column. The mechanical stresses along the column are absorbed by the curvatures and the elastic deformation of the intervertebral discs.

Thorax

The skeleton of the thorax is formed by the ribs, the breastbone (sternum) and the thoracic vertebrae. The **ribs** (costae) are flat twisted bones that are connected to the sternum anteriorly and to the thoracic vertebrae posteriorly. The upper 7 pairs of ribs connect directly with the sternum by their costal cartilages (true ribs). The lower 3 pairs of ribs are attached to sternum indirectly, whereas the last two pairs of ribs freely terminate (floating ribs).

Each rib has an expanded head and a flat and curved shaft or body. The head have smooth surfaces which are connected to the bodies of the thoracic vertebrae. The body presents a tubercle which articulates with the transverse process of the corresponding thoracic vertebra. The joints between the ribs and vertebrae are plane joints allowing

gliding and rotational movements. During inspiration the ribs are elevated and the diameter of thorax is increased.

The sternum, the ribs and thoracic vertebrae are united to form a strong cage, the **bony thorax**. It protects the internal organs (e.g. heart, lungs, liver, and spleen) and provides a flexible framework for breathing. The cavity of the thorax is divided by the dome-shaped diaphragm into an upper part (thoracic cavity) and a lower part which is the part of the abdominal cavity.

MUSCLES OF THE TRUNK

The muscles of the trunk are divided into the muscles of the thorax, the muscles of abdominal wall and the muscles of the back.

The **muscles of thorax** include the intercostal muscles and the diaphragm. The **intercostal muscles** occupy the spaces between the adjacent ribs by forming outer and inner layers. The external intercostal muscles elevate the ribs to increase the diameter of thorax during inspiration. The internal intercostal muscles are involved in expiration. The **diaphragm** extends between the thoracic and abdominal cavities. Its muscular parts originate from the lumbar vertebrae, the ribs and the sternum. The muscular fibers converge radially to the central tendon. Contraction of the muscle fibres pulls the central tendon down and increases the vertical diameter of the thorax during inspiration.

The **muscles of the abdominal wall** support and protect the internal organs. The strap like **rectus abdominis** muscles extend between the sternum and the pelvis and complete the anterior abdominal wall. The lateral abdominal walls are strengthened by three layers of muscles (**external abdominal oblique, internal abdominal oblique and transversus abdominis**). Medially the fibers of these muscles are replaced by an aponeurosis that surrounds the rectus abdominis muscles as the rectus sheath. The lower part the lateral abdominal wall is pierced by an oblique passage; it is termed the inguinal canal. Before birth the testis descends from the abdominal cavity into the scrotum via this canal. In adult male it contains the spermatic cord. The inguinal canal is a relatively weaker area of the abdominal wall. Organs form the abdominal cavity may protrude the wall of the canal, or may pass through the canal into the scrotum (inguinal hernia).

The **muscles of the back** form superficial and deep layers. The muscles in the superficial group (e.g. trapezius) are involved in movements of the shoulder girdle and the

upper limb. The deep back muscles form bundles on both the sides of the spinous processes of the vertebrae. They keep the back erect.

ANATOMY OF THE HEAD AND NECK

THE SKULL

The skeleton of the head is formed by the skull. The skull can be divided into an upper and posterior **braincase** which protects the brain, and a lower and anterior **facial skeleton** which forms the framework of the orbits, the nasal cavity and the oral cavity.

Bones of the braincase

The braincase consists of seven bones, the unpaired frontal, sphenoid, occipital bones and the paired parietal and temporal bones.

The **frontal bone** is situated in the anterior part of the skull. It presents a squamous part which forms the forehead of the skull and two horizontal plates which constitute the roof of the orbits. The bone contains an air-filled cavity (frontal sinus) within the sqauma which are connected to the nasal cavity.

The **sphenoid bone** is located behind the frontal. It has a similarity to a bat and has two lesser wings, two grater wings which are attached to the cube-shaped body. The two pterygoid processes project downward from the body. The body contains two large air-filled cavities (sphenoidal sinuses) which open into the nasal cavity. On its superior surface, the body of the sphenoid presents a saddle-shaped depression (sella turcica) that houses the pituitary gland.

The **occipital bone** forms the back portion of the skull. It consists of a curved plate (squama), a basilar and two lateral parts that surround an oval opening called foramen magnum. The squamous part of the occipital forms the posterior wall of the skull. The basilar part of the bone is united with the body of the sphenoid. Two oval-shaped condyles are seen on the external surface of the bone that articulate with the atlas. In the foramen magnum the spinal cord forms junction with the brainstem and the two vertebral arteries enter the skull to supply the brain.

The **temporal bone** is located in the central part of braincase. The squamous portion of the bone forms the floor and the lateral wall of the skull. On the external surface the temporal bone presents an oval socket for the head of the mandible. The

petrous portion of the temporal bone is wedged between the sphenoid and occipital bones and shows three surfaces. The anterior and the posterior surfaces limit the anterior and the posterior cranial fossa respectively, the third surface contributes to the external cranial base. Enclosed within the petrous portion, the temporal bone contains the organs of hearing and equilibrium (tympanic cavity, inner ear). The facial nerve and the internal carotid artery run their own canals within the temporal bone. An elongated styloid process and a rounded mastoid process project downward to provide attachment sites for muscles.

The quadrilateral **parietal bone** forms the roof and the lateral wall of the skull.

The braincase

The braincase consists of the upper boxlike vault or **calvaria** and the lower irregular **cranial base**. The **calvaria** is composed of the parietal and the squamous parts of the frontal and the occipital bones. These bones are connected to each other by very tight junctions termed as **sutures** in which the saw-like edges of the adjacent bones are united by connective tissue. The sagittal suture is running between the two parietal bones along the midline of the calvaria. The coronal suture connects the frontal bone to the parietal bones, the lambdoid suture passes between the occipital and parietal bones. At birth the bones of the calvaria do not make full contact with each other. The large membranous areas between the bones are called **fontanelles** which allow the skull to expand during the first period of the postnatal life.

The **cranial base** presents internal and external surfaces. The **internal cranial base is** subdivided into anterior, middle and posterior depressions which are called **fossae.**

The **anterior cranial fossa** is formed by the frontal and the lesser wings of the sphenoid and contains the frontal lobes of the brain. The gap between the frontal and sphenoid bones is filled by the cribriform plate of the ethmoid bone.

The **middle cranial fossa** is deeper and bigger than the anterior one. Centrally, it contains the body of the sphenoid which presents the Turkish saddle (sella turcica) for the pituitary gland. On both sides of the Turkish saddle two big lateral fossae are formed by the greater wings of the sphenoid and the squamous and petrous parts of the temporal bones which support the temporal lobes of the brain.

The **posterior cranial fossa** consists of the petrous parts of the temporal bones and the occipital bone. In its central part, the foramen magnum gives wide communication between the fossa and the vertebral canal. The squama of the occipital lobe is depressed by the cerebellum bellow and by the occipital lobe of cerebrum above.

On the **external cranial base** the temporal bone presents an oval shaped depression (madibular fossa) which serves for the temporomandibular joint. In the posterior part the large foramen magnum and two condyles are found, they connect the skull to the vertebral column.

Bones of the facial skeleton

The facial skull is located anterior and inferior to the braincase. The bones of the facial skeleton are arranged around the four cavities of the face: the paired orbits, the nasal cavity and the oral cavity. The facial skeleton is composed of 14 irregular bones: the paired maxilla, zygomatic, lacrimal, nasal, palatine bones and the inferior nasal conchae; and the single vomer, mandible and ethmoid bones.

The **maxillae** are situated in the central part of the facial skeleton. Each maxilla has a pyramidal-shaped body containing a large air-filled cavity, the maxillary sinus. From the body, four processes extend into different directions. The frontal process passes upwards, the zygomatic process runs laterally. On the lower part of the body the palatine process extends horizontally and medially and separates the oral and nasal cavities. The arched alveolar process contains eight bony sockets for the upper teeth.

The **mandible** is a single bone that forms the skeleton of the lower jaw. It consists of a horseshoe-shaped body that presents the sockets for the lower teeth and two ascending perpendicular portions called rami. Each ramus terminates in two processes: a sharp anterior coronoid process and a rounded posterior condylar process. The condylar process has an oval head which fits into the mandibular fossa of the temporal bone.

The **zygomatic bones** are located on the lateral sides of the maxillae and form the prominences of the cheek. Posteriorly, they unite with the temporal bones and form the zygomatic arches.

The quadrilateral **nasal bones** form a supporting bridge for the upper part of the nose. Together with the nasal cartilages they determine the shape of nose.

The **ethmoid bone** shows a horizontal cribriform plate and a median perpendicular plate. The cribriform plate is situated in the anterior cranial fossa and forms the roof of the nasal cavity. The perpendicular plate forms the upper part of nasal septum. On both sides of the cribrifom plate the bone has the ethmoidal labyrinths containing the air-filled ethmoidal cells. From the medial wall of the ethmiodal labyrinth, the superior and the middle nasal conchae are hanging into the nasal cavity.

The **palatine bones** are L-shaped with a horizontal and a vertical plate. The horizontal plate forms the posterior part of the hard palate, the vertical plate contributes to the lateral wall of the nasal cavity.

The **inferior nasal conchae** are two thin curved plates on the lateral walls of the nasal cavity. The **vomer** forms the lower and posterior part of the nasal septum. The small rectangular **lacrimal bones** are located on the medial wall of the orbits.

Cavities of the facial skeleton

The **orbits** are two elongated pyramidal-shaped cavities that contain the eyes, the associated blood vessels, nerves, the lacrimal apparatus and the small eye moving skeletal muscles. The apex of each orbit presents the optic canal for the optic nerve which connects the eye with the brain and the ophthalmic artery which carries the blood to the eye. On the lateral sides of the optic canals two wide fissures transmit the nerves that supply the eye and its muscles.

The **nasal cavity** is an irregular space which is subdivided into two halves by the nasal septum. The roof is formed the cribriform plate of the ethmoid, its small foramina transmit the branches of the olfactory nerve. From the lateral wall of the nasal cavity, three curved laminae project: the superior, the middle and the inferior nasal conchae. Bellow each concha runs a passageway called superior, middle and inferior meatus. They receive the openings from the air-filled paranasal sinuses of the skull; they are the frontal sinus, the shpenoidal sinus, the maxillary sinus, and the ethmoidal labyrinth (ethmoidal air cells).

The **bony oral cavity** has a roof and two lateral walls. The roof is the bony palate and is composed of the palatine processes of the maxillae and the horizontal plates of the palatine bones. The lateral walls are formed by the alveolar processes of the maxillae with the upper teeth, and the body of the mandible with the lower teeth.

Joints of the skull

Except for the mandible, the bones of the skull are united by thin layer of fibrous tissue in special articulations called **sutures**. The **temporomandibular joint** is the only movable synovial joint of the head. The articular surfaces are the concave mandibular fossae on the temporal bone and the heads on the condylar processes of the mandible. Combinations of rotational and gliding movements are performed in both joints during opening and closing the mouth. The grinding action of the teeth is produced by alternating movements of the two sides of the mandible.

MUSCLES OF THE HEAD

According to their actions, the muscles on the head are classified into tow groups: the muscles of facial expression and the muscles of mastication.

The **muscles of facial expression** extend between the bones of the skull and the skin of the face. These muscles can express emotion. They are arranged around the orbits, the opening of the mouth and the nose. These are ring-like muscles and constrict the openings. The other muscles form the lateral wall of the mouth (buccinator) and raise or depress the angle of the mouth during smile. All facial muscles are supplied by the facial (VII) nerve.

The **masticatory muscles** arise from the bones of the skull and are attached to the mandible. These four pairs of muscles (masseter, temporalis, medial and lateral pterygoids) are involved in complex movements in the temporomandibular joints during chewing or biting. All muscles of mastication are innervated by the mandibular nerve, which is the third division of the trigeminal (V) nerve.

BONES OF THE NECK

The skeleton of neck is composed of seven cervical vertebrae and the hyoid bone. The U-shaped body of the hyoid bone could be palpated above the larynx in a living person.

The movements of the head are performed in the joints between the skull, the atlas and the axis. The **atlantooccipital joint** is formed by the condyles of the occipital bone

and the upper articular surfaces of the atlas. This ellipsoid joint enables lateral flexion (bending of the head) and flexion and extension of the head ("yes" movement of the head). In the **atlantoaxial joints** between the first and second cranial vertebrae the head is rotated around a vertical axis ("no" movement of the head).

MUSCLES OF THE NECK

The muscles are located on the anterior and lateral sides of the neck. Based on their locations, the muscles are divided into superficial, hyoid and deep groups.

The **superficial neck muscles** are located bellow the skin. The platysma is attached directly to the skin and tenses the skin of the neck. The sternocleidomastoids are broad straplike muscles run obliquely on each side of the neck.

The hyoid muscles are divided into suprahyoid and infrahyoid groups. The **suprahyoid muscles** are located between the skull and hyoid bone. They are involved in the depression of the mandible during opening of the mouth, and in the elevation the hyoid bone and larynx during swallowing. Bellow the mandible, the strap-like **infrahyoid muscles** are attached to hyoid bone, larynx, scapula and the sternum and depress the hyoid bone during swallowing and speaking.

The **deep muscles of the neck** pass on the anterior and lateral parts of cervical vertebrae. They move the head and the cervical part of the vertebral column. The scalenus muscles connect the cervical vertebrae to the ribs and they are able to elevate the ribs during forced inspiration.

BLOOD VESSELS AND NERVES OF THE HEAD AND THE NECK

The major arteries that give blood supply for the head and neck derive from the common carotid and the subclavian arteries. The **common carotid artery** enters the neck behind the sternoclavicular joint and passes upward to the superior margin of the thyroid cartilage where it divides into internal and external branches. The **internal carotid artery** climbs up along the neck without any branches. It passes through its own canal in the temporal bone (carotid canal) enter the cranial cavity and gives branches to the brain and the eyes. The **external carotid artery** supplies viscera and muscles of the neck. First it gives branches to the thyroid gland (superior thyroid) and to the tongue (lingual). Then it

gives off the **facial artery** which hooks around the mandible and passes obliquely on the face towards the medial angle of the orbit. The external carotid terminates within the parotid gland by dividing into superficial temporal and maxillary branches. The **maxillary artery** penetrates the deep regions of the face and supplies the teeth, the nasal and the oral cavities.

The **subclavian artery** enters the neck lateral side to the common carotid. It forms an arch in the lower part of the neck then it continues in the upper limb as the axillary artery. The **vertebral artery** originates in the subclavian, ascends through the transverse foramina of the cervical vertebrae, passes through the foramen magnum of the skull and supplies the brain.

The venous blood is drained from the head and the neck via the external jugular, the internal jugular and the subclavian veins. The **internal jugular vein** receives tributaries from the brain, the eyes, the nasal and oral cavities and the superficial regions of the face. It passes down on the neck together with the carotid artery in a common connective tissue sheath and unites with the subclavian vein. The **subclavian vein** is the continuation of the axillary which collects the blood from the upper limb. On the lower part of the neck, the subclavian vein and internal jugular vein unite and form the angulus venosus. It receives the largest lymphatic vessels of the body (the thoracic duct on the left side and the right lymphatic duct on the right side). The **external jugular vein** drains the superficial areas of the head and neck and opens usually into the internal jugular vein.

The muscles and the skin of the head are innervated by the cranial nerves or by the branches of cervical and brachial plexuses. The Vth cranial nerve (**trigeminal)** gives sensory branches to the skin of the face and motor branches to the masticatory muscles. The **facial nerve** (VII) supplies the muscles for facial expression and a few suprahyoid muscles. The nerves of the cervical plexus innervate the skin on the neck and the infrahyoid muscles; and the branches of the brachial plexus innervate the deep muscles of the neck.

VISCERA OF THE HEAD AND THE NECK

The **thyroid gland** consists of two lobes on each side of the larynx. It lies underneath the infrahyoid muscles and is surrounded by a thin fibrous capsule. Four small **parathyroid glands** are embedded in substance of thyroid lobes. These glands belong to the endocrine system and secrete hormones into the blood circulation.

The upper part of digestive system including the oral cavity, the salivary glands and the pharynx are located in the head and the neck but they will be written in the chapter "Anatomy of the Digestive System". The upper part of the respiratory tract, the nasal cavity and the larynx is written in the chapter "Anatomy of the Respiratory System".

ANATOMY OF THECARDIOVASCULAR SYSTEM

HEART

The heart is the central organ of the circulatory system. It is located within the thorax, in the anterior and inferior region of the medial compartment of the thoracic cavity, the **mediastinum**. The lungs and the parietal layer of the pleura are located on its lateral sides.

- The right lung covers much of the anterior surface of the heart. For this reason, two different sounds are perceived during medical examination of the thorax by tapping the chest wall with fingers (percussion). Change of the percussion note from resonant to dullness (**relative dullness**; the lung covers the heart here) defines the size of the heart in the thorax. Medial to this area the percussion note becomes even more dull (**absolute dullness**), since the cardiac musculature lies directly against the thoracic wall in this small area.

The heart lies on the tendinous part (central tendon) of the **diaphragm**. The heart is surrounded by a double-layered fibroserous membrane, the **pericardium**. Its external layer, the **fibrous pericardium**, is tough and dense. The internal **serous pericardium** is made of double layers of serous membrane (mesothelium). The outer layer of the serous pericardium (parietal layer) is fused to the internal surface of the fibrous pericardium, whereas the inner or visceral layer of it covers the surface of the heart. This layer can be considered as being the outer layer of the heart, the **epicardium**. The two layers of the serous pericardium are continuous with each other. The reflection between them occurs around the great vessels of the heart. This way a potential space, the pericardial cavity, is created between the opposing layers of the serous pericardium, containing a few millilitres of viscous fluid, which provides frictionless movement of the heart. The blood vessels of the heart are embedded in a loose areolar connective tissue, the subepicardial fat, located under the epicardium. Functionally the most important layer of the heart is the **myocardium**, which consists of cardiac muscle. The interior of the heart is lined by **endocardium**, a thin layer of connective

tissue and endothelium. The valves of the heart in the ostia are also derivatives of the endocardium.

External appearance of the heart

The heart is a cone shaped muscular organ. The **apex of the heart**, formed by the left ventricle faces anteriorly and laterally. The anterosuperior surface is mainly formed by the right ventricle and the inferior, or diaphragmatic, surface is formed mostly by the left ventricle. The atria are separated from the ventricles by a circumferentially running groove, the **coronary sulcus** (sulcus coronarius). The **base of the heart**, which mainly corresponds to the atria and the great vessels, is located superior to the coronary sulcus. The **anterior and posterior interventricular grooves** are slight longitudinal depressions on the anterior and posterior surfaces of the heart from the coronary sulcus to the apex indicating the position of the interventricular septum, the fibromuscular border between the ventricles.

Chambers of the heart

The heart has four chambers: **right** and **left atria** and **right** and **left ventricles**. These chambers are separated by interatrial and interventricular septa, respectively, and are communicating with each other by means of atrioventricular ostia (orifices) surrounded by bicuspid or tricuspid valves.

Atria

The atria are receiving chambers–they receive blood from the great veins of the heart.

The **right atrium** represents two morphologically and developmentally different portions. The rough portion has a thin myocardium composed of **pectinate muscles** on the inner surface and forms the earlike **right auricle**. The right auricle is separated

from the smooth walled region (**sinus venarum**) by the **crista terminalis** or terminal crest, a thicker cord of pectinate muscles. The sinus venarum receives the superior vena cava on its superior portion and the inferior vena cava opens in its inferior part. The **coronary sinus**, a venous trunk receiving most of the cardiac veins, opens to the posteroinferior part of the sinus venarum, close to the **interatrial septum**, which separates the right and left atria. On the right side it represents an oval shaped depression, the **oval fossa**, a remnant of the oval foramen connecting the two atria in foetal life.

The pacemakers of the impulse conducting system of the heart are also located in the wall of the right atrium. This system consists of modified cardiomyocytes which are hard to be distinguished in formalin-fixed specimens. The **sinuatrial node** (**SA node**), located at the junction of the superior vena cava and right atrium, close to the superior end of the crista terminalis, is the primary pacemaker of the heart. The **atrioventricular node** (**AV node**), the secondary rhythm generator of the heart, is located at the inferoposterior region of the interatrial septum close to the opening of the coronary sinus. Blood from the right atrium is pumped into the **right ventricle** through the **right atrioventricular orifice**, which is guarded by the **tricuspid valve** preventing backflow of blood during ventricular systole.

The tricuspid and bicuspid valves are composed of **cusps** with their bases attached to a fibrous ring around the orifice and **tendinous cords** (**chordate tendineae**) which originate from their free edges and attach to **papillary muscles**, conical projections of the ventricular musculature.

- Since the cords are attached to adjacent edges of two cusps and insert to papillary muscles, they allow for perfect closure of the valve during systole. Because the papillary muscles also contract along with the rest of the ventricular musculature, the cusps are prevented from prolapsing during ventricular systole.

The **left atrium** also consists of two different parts: the **left auricle** is similar to the right in both structure and position; the larger, **smooth-walled part** receives the four **pulmonary veins** (two on each side) carrying oxygenated blood from the lungs. Blood from the left atrium is discharged into the **left ventricle** through the **left**

atrioventricular orifice guarded by the **bicuspid (mitral) valve**. The adjective *mitral* refers to the resemblance of the valve to a miter of a bishop.

- The posterior surface of the left auricle is closely related to the esophagus–a fact that should be considered during clinical practice (*e.g.* esophagoscopy).

Ventricles

The ventricles receive blood from the atria and discharge it to the great arteries. The right atrium pumps venous blood from the superior and inferior venae cavae to the right ventricle, which in turn discharges blood through the pulmonary trunk to the lungs for oxygenation. The left atrium receives oxygenated blood from the lungs through the pulmonary veins and pumps it to the left ventricle, which discharges blood to the systemic circulation through the aorta.

The outflow orifices (*i.e.* aortic and pulmonary orifices) of the ventricles are guarded and closed by **semilunar valves** during diastole. Each cusp consists of a thick fibrous part **(pars tensa)** and a thin membranaceous part **(pars flaccida)**, the latter can be further divided into a demilune-shaped **lunula** and a thickened central part called **nodulus** (corpus Arantii).

The ventricles are separated from each other by the **interventricular septum**. Its greater and thicker part is formed by the wall of the left ventricle (**muscular part**), while its anterosuperior portion is thin (**membranous part**). The interior of the ventricles contains an irregular network of muscular elevations (**trabeculae carneae**).

Having relatively thin muscular wall, the **right ventricle** is a pocket-like chamber attached to the left ventricle. A superiorly located thick muscular ridge called the **supraventricular crest** incompletely separates its interior into a posterior inflow part and an anterior outflow part, giving the cavity of the ventricle a characteristic V-shape. The funnel-shaped outflow tract of the right ventricle is called **infundibulum** which, seen from the outside, can also be referred to as **conus arteriosus**. The inflow part receives the right atrioventricular orifice guarded by the tricuspid valve, and blood from the outflow part is discharged into the **pulmonary trunk** through the **pulmonary orifice**. It is worth to note that the pulmonary artery carries deoxygenated "venous" blood to the lungs for oxygenation.

Having the thickest wall, the cone-shaped **left ventricle** forms the **apex of the heart**. It receives oxygenated blood from the four pulmonary veins via the left atrium through the left atrioventricular orifice, guarded by the bicuspid valve. The left ventricle discharges blood through the aortic orifice to the aorta, the greatest artery in the human body. Seen from the outside as the **bulbus arteriosus**, the aortic sinuses are dilated parts of the root of the aorta containing the three cusps of the semilunar valve, which flanks the aortic orifice. The aortic sinuses also give origin to the **left and right coronary arteries** at the level of the upper free edge of the semilunar valve.

The fibrous skeleton of the heart

The myocardium of both the atria and the ventricles originate from the **anulus fibrosus**, a complex system of ostia and dense connective tissue. The plain of the anulus fibrosus is demarcated by the **sulcus coronarius** on the surface. The anulus fibrosus forms four thickened rings surrounding the ostia of the heart, to which the cusps of the bi- and tricuspid and the semilunar valves are attached. Being formed by dense connective tissue, the anulus fibrosus also acts as an insulator in separating the myocardium of the atria and the ventricles, so that the impulses generated in the right atrium can only reach the ventricular myocardium by means of the atrioventricular (AV) bundle (of His), the only bridge passing through the insulating fibrous skeleton of the heart. The AV bundle passes through the fibrous skeleton at its triangular-shaped central portion called trigonum fibrosum and continues in the membranous part of the interventricular septum.

Conducting system of the heart

The **SA node**, which initiates and regulates the impulses for contraction of the heart, is located in the right atrium. From here, impulses spread through specialised bundles consisting of nodal tissue to the left atrium and also to the **AV node**, which further propagates the signals through the atrioventricular bundle (of His) to the ventricular myocardium. As it approaches the muscular part of the interventricular

septum, the AV bundle divides into **left and right bundles (of Tawara)**. These, in turn, proceed on the respective sides of the septum to ramify into subendocardial branches (of Purkinje) supplying the walls of the ventricles.

- The SA node gives off a signal with 72 impulses per minute. The AV node also generates signals but with a lower frequency, so under physiological conditions it is the SA node which regulates the contraction of the heart. Interestingly, ventricular myocardium also has a potential to generate impulses with a rate of less than 50 per minute. Damage to the atrioventricular bundle results in heart block, because impulses generated in the atria do not reach the ventricular myocardium. In this case, the ventricular contraction rate is determined by the ventricular automacy, which cannot satisfy blood supply to the periphery. In such cases, insertion of a cardiac pacemaker is necessary.

Vasculature of the heart

The heart is supplied by the left and right coronary arteries, both arising from the respective aortic sinuses at the proximal part of the aorta. After their origin, they enter the coronary sulcus hidden by the two auricles. The **right coronary artery** turns to the right in the sulcus, where it gives off the **right marginal branch** at the right border of the heart formed by the right ventricle. The main trunk remains in the coronary sulcus until it reaches the posterior interventricular groove, where it continues as the **posterior interventricular branch**. The right coronary artery supplies most of the right ventricle and the posterior part of the interventricular septum. Via its nodal branch it also supplies the SA node. Damage to this artery results in temporary or permanent arrhythmias.

The proximal portion of the **left coronary artery** is located in the coronary sulcus, posterior to the origin of the pulmonary trunk. At the anterior interventricular groove it gives off the **anterior interventricular branch**, and the main trunk continues as the **circumflex branch** in the coronary sulcus. By the time it reaches the posterior interventricular artery it becomes very slender. The left coronary artery supplies the left atrium and ventricle, and also supplies the anterior part of the interventricular septum.

- Variations in the branching pattern and the area supplied by the coronary arteries are quite common. In each particular case it must be kept in mind that the actual pattern of blood supply

can be different from what has been described in anatomy textbooks. The actual distribution is usually determined by coronarography, when a contrast material is directly injected to the origin of the coronary arteries.

The branches of the coronary arteries enter and supply the myocardium from the outer surface, and upon entrance they usually give off three sets of branches. The first two generations form arcade-like anastomoses, therefore during occlusion of a branch blood supply can be still adequate via collateral routes. Blood vessels of the third generation (closest to the endocardium), however, are considered to be true end arteries, and occlusion here usually leads to myocardial infarcts. Therefore the subendocardial layer of the myocardium is considered to be the most vulnerable.

Venous drainage of the heart

The **great cardiac vein** begins near the apex in the anterior interventricular groove, which upon entrance to the coronary sulcus continues to the left as the **coronary sinus** after it receives the **oblique vein of the left atrium** (vein of Marshall), coming from the posterior surface of the left atrium. Being the main vein of the heart, the coronary sinus receives the **small cardiac vein** from the right originating on the right border of the heart, and the **middle cardiac vein** coming from the posterior interventricular groove also drains to it. The coronary sinus eventually opens to the right atrium. Besides the aforementioned veins there is usually a variety of other smaller veins on the surface of the heart.

Surface projections of the heart and auscultatory areas

Auscultation is one of the oldest methods in clinical practice–*i.e.* listening to the sounds produced by the closure of cardiac valves. For the bony components of the ribcage impair the auscultation, cardiac sounds are usually listened to in intercostals spaces. Because the valves of the heart are located behind the sternum, and since blood-filled cavities and vessels tend to conduct sounds in the direction of fluid flow, the sounds produced at any given valve are best listened to on those areas where the corresponding chamber or great vessel is located close to the anterior thoracic wall. Sounds of the aortic valve are best listened to in the 2nd right intercostals space, those of the pulmonary valve in the 2nd left intercostal space (note that these two arteries

cross each other), both at the edge of the sternum. The auscultatory area of the tricuspid valve is in the 5th right intercostal space close to the sternum, and that of the mitral valve is in the 5thintercostal space, 3–4 cm to the left from the sternum. The latter usually corresponds to the location of the apex beat. Normally the right outline of the heart does not exceed the edge of the sternum, while the left usually does not extend farther than the location of the apex beat.

Development of the heart

The **cardiogenic field**, which develops to form the primordium of the heart, appears on the 18th or 19th day of development. These structures, lacking lumen at their early stages of development, form two endocardial heart tubes surrounded by myoblasts. These myoblasts contribute to the formation of the myocardium, the pericardium and the primitive pericardial cavity. By the 21st day of development the two heart tubes fuse to form a single, slightly bent heart tube, which soon differentiates further. At the inferior part where blood enters the tube the **sinus venosus** is formed, which continues as the **common atrium**. Proceeding caudally, blood reaches the **common ventricles**, then the **bulbus cordis**, and finally the last part of the heart tube, the **truncus arteriosus**. Contraction of the cardiac myocytes also starts on day 22 of development. The final location of each part of the heart is a result a series of complex rotations and bending of the heart tube. First, the heart tube acquires an S-shape with all the portions mentioned above. The heart tube then continues to bend in a way that the atria are located superior and posterior to the ventricles. The right half of the sinus venosus is incorporated into the right atrium, and the left half regresses to form the coronary sinus. The right half of the primitive ventricle develops to form the inflow part of the right ventricle, while the outflow part, the conus arteriosus is formed by the bulbus cordis.

The primitive heart is divided by septa into left and right halves formed by the 45th day of development. The **interatrial septum** represents an oval shaped opening, the **oval foramen** for communication between the two sides, through which blood from the right atrium directly enters the left one. The truncus arteriosus is divided into aortic and pulmonary channels by the spiral **aorticopulmonary septum**. The muscular part

of the interventricular septum grows superiorly from the apex of the heart, the membranous portion is formed by outgrowth of the aorticopulmonary septum. The valves of the heart and great vessels are formed as blood flow hollows out mesenchymal condensations at respective areas.

BLOOD VESSELS

The circulatory system consists of two largely interdependent systems: the lymphatic and the cardiovascular systems, the former being unidirectional from the tissues toward the heart and the latter being bidirectional. Blood leaves the heart and distributed to the body by **arteries** and carried back to the heart by **veins**. Exchange of oxygen, nutrients and waste products, and movement of white blood cells occur through thin-walled **capillaries**. Arteries and veins, as well as bigger lymph vessels are impenetrable to substances carried by blood.

Arteries

The **aorta** carries oxygenated blood from the left ventricle of the heart toward the periphery. The aorta, after its initial wider part, the **bulbus aortae**, continues as the **ascending aorta** heading superiorly and slightly to the right. The ascending aorta then continues as the **arch of the aorta** curving first to the left, and then turns posteriorly and inferiorly as the **descending aorta**. As it reaches the posterior wall of the thoracic cavity, it descends slightly to the left from the midline and anterior to the oesophagus as the **thoracic aorta**. The arch of aorta gives rise to three great vessels; from the right to the left the first branch is the **brachiocephalic trunk** (innominate artery), which in turn bifurcates shortly to give rise to the **right subclavian** and **right common carotid** arteries. The second and third branches of the arch of the aorta are the **left common carotid** and **left subclavian arteries**.

The **common carotid arteries** ascend in the neck on the sides of the trachea with their pulsation palpable throughout their length. They bifurcate at the level of the superior edge of the thyroid cartilage to give rise to the **external carotid artery,** located more anteriorly and medially, and the **internal carotid artery,** posteriorly and more superficially. The internal carotid artery heads to the cranial base without giving any further branches and upon entrance it contributes to the arterial circle of Willis

supplying the brain and the sensory organs of the head. The external carotid artery supplies the cervical and facial viscera.

One of the first branches of the **subclavian artery** is the **vertebral artery,** heading toward the **foramen magnum** of the occipital bone in a canal formed by the transverse foramina of the cervical vertebrae. Upon entering the scull the two vertebral arteries unite to form the basilar artery at the posterior surface of the brain stem. All these arteries represent the major blood supply to the brain and the spinal cord. The subclavian artery gives further branches to supply the larynx and other cervical structures and passes under the clavicle to enter the axillary fossa. From here its name changes to **axillary artery**, which supplies the structures of the shoulder and axillary regions. After leaving the axillary fossa its name changes again to brachial artery, which divides into its two terminal branches, the **radial** and **ulnar arteries** in the cubital fossa. These arteries supply the forearm and the hand. The arterial pressure is usually measured in the brachial artery, and pulse is most frequently taken in the forearm over the radial artery.

- The arteries supplying the digits, which head toward the distal phalanges on the sides of the fingers, originate from two palmar arches. The deep arch allows for blood supply to the digits during compression of the superficial arch (*e.g.* during weightlifting).

The **thoracic aorta** supplies the posterior thoracic wall, the oesophagus, the trachea and the bronchus tree. It also supplies the pericardium and the mediastinum. As it pierces the diaphragm and enters the abdominal cavity it continues as the **abdominal aorta**, which has paired and unpaired visceral and parietal branches. The unpaired visceral branches supply the abdominal organs. The stomach, the liver, the pancreas, the spleen and the upper part of the duodenum are supplied by the **celiac trunk**. The rest of the duodenum, along with the small intestine and the ascending and the proximal two-thirds of the transverse colon are supplied by the **superior mesenteric artery**. The **inferior mesenteric artery** supplies the rest of the colon and the superior one-third of the rectum. The inferior two-thirds of the rectum is supplied by the internal iliac artery (by means of the middle rectal and internal pudendal arteries; the latter also supplies the external genitalia). The paired visceral branches of the abdominal aorta are the **renal arteries** supplying the kidneys and the gonadal arteries

supplying the gonads (in males it is known as the **testicular**, in females as the **ovarian artery**). Parietal branches supply the musculature of the abdominal wall.

The abdominal aorta bifurcates at the level of the 5th lumbar vertebra to give rise to the two **common iliac arteries**, which further bifurcate at the level of the sacroiliac joints to the **external** and **internal iliac arteries**. The internal iliac artery supplies the pelvic viscera, *e.g.* the uterus, and by the **internal pudendal artery**, its terminal branch, supplies the external genitalia and the inferior one-third of the rectum. The external iliac artery first gives off bigger posterior branches to supply the gluteal region, and after giving rise to some smaller branches it finally leaves the lesser pelvis and continues as the **femoral artery** supplying the lower limb. The femoral artery descends on the anterior surface of the thigh supplying its anterior and posterior regions and heads toward the medial aspect of the knee. In the popliteal fossa, posterior to the knee, it continues in the midline and is called as the **popliteal artery**. One of its important branches is the **anterior tibial artery,** which descends in the anterior compartment of the leg. It reaches the dorsum of the foot between the two malleoli as the dorsalis pedis artery, the pulsation of which is easily palpable here.

- Medical examination of the dorsalis pedis artery gives an overall impression of the condition of smaller blood vessels. Failure in palpation of its pulsation indicates inadequate blood supply to the lower limb.

Muscles in the lateral compartment of the leg are supplied by the peroneal artery, while the **posterior tibial artery** supplies those of the posterior compartment. The posterior tibial artery reaches the sole of the foot posterior to the medial malleolus to contribute to two arterial arches together with the perforating branches of the dorsalis pedis artery.

- Pulse is usually taken from the following areas: along the superficial temporal artery in the temporal region; over the facial artery as it crosses the base of the mandible; along the common carotid arteries in the neck; over the brachial artery in the cubital fossa; over the radial artery at the wrist; along the femoral artery in the proximal thigh; over the popliteal artery in the popliteal fossa; over the posterior tibial artery behind the medial malleolus; and over the dorsalis pedis artery in the dorsum of the foot.

Veins

Veins return blood from the organs and tissues to the heart. Their wall is generally thinner and contains relatively less smooth muscle elements. Valves of the veins allow blood to flow only toward the heart. The veins normally have the same name as the arteries they accompany (*e.g.* radial vein etc.) Such veins, especially those accompanying the arteries of the distal extremities, tend to be double or multiple. Superficial veins are also quite common within the subcutaneous tissue throughout the human body. Being aware of the fact that **the extremities have both a superficial and a deep venous drainage** is crucial in clinical practice. Superficial veins usually join the deep veins at well-defined points. **Perforating veins** connect the superficial veins to the deep veins, which allow blood to flow only toward the deep veins due to their valves. The **small saphenous vein** ascends at the posterior surface of the leg to enter the popliteal vein in the cubital fossa. The major superficial vein of the lower limb, the **great saphenous vein** arises anterior to the medial malleolus and ascends medially until it pierces the deep fascia of the proximal thigh to join the femoral vein. The **femoral veins** continue as the **external iliac veins**, which, after merging with the **internal iliac veins** draining the pelvic viscera, carry venous blood to the common iliac veins. The **common iliac veins** unite at the level of the lumbosacral joint to form the **inferior vena cava**, the major vein draining the lower half of the body.

- When the valves of the perforating veins usually preventing backflow of blood are insufficient due to overload (e.g. standing for a long time; a condition quite common among pharmaceutists), blood flows from the deep to the superficial veins causing varicose veins.
- The great saphenous vein is commonly used for coronary arterial bypasses during operations of atherosclerotic coronary arteries.

The basic principle of the venous drainage of the upper limb is quite similar to the lower extremity. The **cephalic vein** ascends subcutaneously on the radial side of the limb to join the subclavian vein inferior to the clavicle. The basilic vein, also running superficially, ascends on the ulnar side and pierces the brachial fascia at the lower one-third of the arm to enter the brachial vein. The cephalic and basilic veins are connected to each other through the **median cubital vein**, an obliquely running vein in the

cubital fossa. Because of the accessibility of this vein, it is commonly used for venipuncture and venous injections. The deep veins of the upper limb accompany the arteries and they share a common name.

The **internal jugular vein** drains the venous blood from the skull, which runs in a common sheath first with the internal and then the common carotid artery. The internal jugular vein merges with the subclavian vein draining venous blood from the upper limb at the **angulus venosus** behind the sternoclavicular joint. Venous blood from the superficial structures of the skull and the cranial viscera is drained mainly to the external **jugular vein**, which in turn empties into the internal jugular vein.

The angulus venosus continues as the **brachiocephalic vein**. The left vein, passing anterior to the structures of the superior mediastinum, fuses with its fellow at the right sternal end of the second rib to form the **superior vena cava**. The **azygos vein** drains venous blood from the body wall superior to the umbilicus; from the thoracic viscera (lungs, bronchi, pleurae, oesophagus, and pericardium) and from the intercostals spaces. The azygos vein, also draining venous blood from the body wall inferior to the umbilicus as it ascends at the posterior abdominal wall, pierces the diaphragm, enters the thoracic cavity and eventually empties into the superior vena cava superior to the root of the right lung. The superior vena cava, receiving venous blood from the head, the neck and the upper limbs, and also from the posterior body wall and the thoracic viscera, empties superiorly into the right atrium of the heart.

Venous blood from the paired abdominal viscera is carried to the inferior vena cava through veins having the same name as the respective organ. The unpaired abdominal viscera (gastrointestinal tract along with its associated organs and spleen), however, are drained by the **hepatic portal vein**, which opens into the liver sinusoids. Blood from the liver empties into the inferior vena cava by means of the **hepatic veins**. The inferior vena cava, upon entering the thoracic cavity, fuses with the right atrium.

It is worth to mention that though venous blood from the superior one-third of the rectum is drained to the hepatic portal system, the inferior two-thirds is directly connected to the inferior vena caval system. Rectal administration of suppositories allows for direct absorption of drugs into the inferior vena cava via the internal iliac

vein. Bypassing the metabolic function of the liver, lower doses are usually effective by rectal administration.

The blood supply to the internal organs is described in more details in the corresponding chapters.

Foetal circulation

The **placenta** is a special organ of pregnancy, whose most important functions include exchange of nutrients and metabolic and gaseous waste products between the foetus and the mother. Foetal blood in the placenta is separated by the lining of the chorionic villi from the maternal blood in the intervillous space, but it is the same layer which makes the transport processes possible. Oxygenated blood in the mother is carried to the placenta by the **uterine arteries** (branches of the internal iliac artery), and desaturated blood from the foetus is carried by the **umbilical arteries**. The umbilical arteries, originating from the proximal part of the internal iliac arteries, turn toward the umbilicus on the internal surface of the abdominal wall. Oxygenated, nutrient-rich and waste product-free blood from the placenta then returns to the foetus by way of the single **umbilical vein**. On entering the body, the umbilical vein heads first to the liver and bifurcates at the porta hepatis. Most of this blood directly enters the inferior vena cava by way of the **ductus venosus** (of Arantius) located on the ventral surface of the liver. The other branch communicates with the hepatic sinusoids supplying the parenchyma with oxygenated blood. This blood is also carried eventually to the interior vena cava by way of the hepatic veins. From the inferior vena cava blood enters the right atrium, where it is guided toward the **oval foramen** on the interatrial septum, connecting the two atria in foetal life. Most of the blood passes directly into the left atrium, and from here to the systemic circulation. Desaturated blood from the superior vena cava is prevented from entering the left atrium, so it flows to the right ventricle. Since the lungs are collapsed and are not involved in gas exchange during foetal life, and they only require a small amount of blood for nutrition, only a small portion of blood entering the pulmonary trunk actually reaches

the lungs. Most of the blood passes through the **ductus arteriosus** (of Botall) into the arch of the aorta, thus bypassing the lungs. *As a consequence, oxygen saturation of the foetal blood is less than in extrauterine life.* Therefore, foetal tissues generally have a higher tolerance for hypoxia, but a further decrease in oxygen saturation obviously results in necrosis.

The embryonic structures, which contribute to foetal circulation; namely, the two umbilical arteries, the single umbilical vein, the ductus venosus, the oval foramen and the ductus arteriosus, become at first temporarily, then permanently obliterated after birth. Failure of the closure of either the oval foramen or the ductus arteriosus results in severe circulatory disorders and needs to be surgically corrected. After birth the ductus venosus is preferably used for parenteral treatments or blood transfusions.

ANATOMY OF THE LYMPHATIC SYSTEM

Lymph is "surplus" fluid in the interstitium; filtration pressure at the arterial side is higher than colloidosmotic pressure at the venous side. The lymphatic system collects this surplus fluid and conveys it to the venous circulation. Lymph flow in unidirectional–from the periphery toward the centre. Lymph is a translucent, yellowish fluid, containing only white blood cells as cellular elements. Lymphatic capillaries, originating in most tissues, are uniting to form larger and larger lymph vessels, where lymph traverses one or more lymph nodes, which are secondary lymphatic organs filtering the lymph. Lymph nodes tend to aggregate and lymph from a region or a visceral organ traverses a series of lymph nodes (primary, secondary, tertiary etc.) before entering larger lymph vessels. Lymph nodes are protecting organs against lymph-borne pathogens.

Lipids from the small intestine are absorbed in the form of chylomicrons into the lymphatic capillaries. Lymph being rich in emulsified lipid droplets is referred to as **chyle**.

The wall of the lymphatics is thin consisting of an inner endothelium layer, some connective tissue and smooth muscle cells. Valves preventing backflow of lymph are quite ubiquitous; lymph flow is aided by contractions of ambient skeletal muscles.

Lymph from the lower limbs is collected in the **ascending lumbar trunks**, which unite with the **intestinal trunk** collecting lymph from the intestines at the level of the first lumbar vertebra to from the **cisterna chyli**. The largest lymphatic trunk, the **thoracic duct** originates here which, after piercing the diaphragm together with the aorta, ascends through the thorax in the posterior mediastinum. On leaving the thorax it curves posterior to the left cupula pleurae, and before entering the left angulus venosus it receives the **left subclavian trunk** draining lymph from the left upper limb, the **left jugular trunk** darining the left side of the head and neck, and the left bronchomediastinal trunk draining the left half of the thorax. Altogether, the thoracic duct drains the three-fourth of the lymph of the body to the left angulus venosus. The **right lymphatic duct** drains lymph from the right half of the thorax, the right upper

limb and the right half of the head and neck through the same named lymphatic trunks into the right angulus venosus.

ANATOMY OF LYMPHATIC ORGANS

Thymus

The thymus is a primary lymphatic organ housing the maturation of T lymphocytes. Being relatively large in childhood, it is the most superficial structure in the superior mediastinum. The thymus is a bilobed organ, in which lymphatic tissue is gradually becomes replaced by connective tissue and adipocytes after childhood. In adults it regresses and only a small mass of adipose tissue demarcates the position of the former lymphatic organ. Blood supply to the thymus is maintained through smaller branches from ambient structures.

Tonsils

Tonsils are secondary lymphatic organs embedded in the pharyngeal mucosa. **Tubal tonsils** are guarding the entrance of the auditory tubes in the nasopharynx. The **pharyngeal tonsil** is located at the pharyngeal fornix, the roof of the pharynx close to the basilar part of the occipital bone. The **palatine tonsils** are found on either side of the root of the tongue, in the faucial isthmus, connecting the oral cavity and the oropharynx. The **lingual tonsil** is under the mucosa lining the base of the tongue. The tonsils form a complete ring around the entrance of the pharynx called the **lymphatic ring of Waldeyer**.

Enlargement of the pharyngeal tonsil (adenoid) makes the passage of air from the nasal cavity into the nasopharynx almost impossible, making mouth breathing necessary. Impairment of hearing can also result from obstruction of the opening of the auditory tubes.

Spleen

The spleen, being an intraperitoneal organ, is located in the upper left quadrant of the abdominal cavity at the left side of the stomach and under the protection of the ribcage. Its parenchyma consists of two parts: the red pulp, which contributes to the elimination of damaged and old platelets and red blood cells; and the white pulp made of lymphatic tissue, which has an important protective role against blood-borne pathogens. At early foetal life the spleen also acts as an important organ of blood cell formation, a function which can be re-established in case of severe anaemia or leukaemia.

The spleen, having only a thin connective tissue capsule, can easily be ruptured caused by blunt trauma to the superior part of the abdomen. In such cases the spleen bleeds profoundly causing severe intraperitoneal haemorrhage. Its artery, the **splenic artery**, a branch of the celiac trunk, reaches the organ by curving superior to the pancreas. The **splenic vein** unites with the superior mesenteric vein, draining the small intestine, at the boundary between the neck and the body of the pancreas to form the **hepatic portal vein**.

Lymph nodes

Lymph nodes are bean shaped secondary lymphatic organs surrounded by a connective tissue capsule. They function against lymph-borne pathogens. Lymph nodes tend to aggregate at certain parts of the body to filter lymph from a given region. Afferent lymph vessels enter the lymph node on the convex surface, while efferent lymph vessels convey lymph from the hilum on the concave surface. It is the hilum where blood vessels enter and leave the organ.

Lymph nodes suddenly become swollen and painful when immune response is under way. On the contrary, when the swelling is slowly formed and painless, it can refer to malignant metastases.

ANATOMY OF THE RESPIRATORY SYSTEM

The respiratory system delivers air containing oxygen to the blood and removes gaseous waste products of metabolism. Air normally enters the respiratory tract through the nose. External nasal openings **(nares)** lead into the **nasal cavity** wherein the air warms and the wet surface of this area initiates the removal of the pollutants and increases the humidity of the air. From the nasal cavity, air streams to the nasal part of **pharynx** and then into the **larynx** where the vibration of the **vocal folds** provides the morphological basis of vocalization. The lower compartment of the laryngeal cavity is continuous with the windpipe **(trachea),** which divides into two main bronchi at the level of fourth thoracic vertebra (second rib anteriorly). The **main bronchi** enter the tissue of lungs **(pulmo)** at the **hilum** and divide into smaller and smaller tubes creating the bronchial tree, and allow the air to reach the bubble-shaped end part of airways called **alveoli,** wherein exchanges of respiratory gases between air and blood can occur.

The mucosal membrane of the airways is lined by pseudostratified columnar epithelium with cilia and goblet cells. The lamina propria of airways contains numerous lymphoid elements (BALT: bronchus associated lymphatic tissue) and the submucosa of larger components of the airways is rich in mixed salivary secretory units. The viscous secretory product of these acini plays an important role in the cleaning of the air and cilia can remove pollutants with the aid of this "glue". The rigidity of hyaline cartilage present in the wall of the airways keeps the lumen constantly open.

Smoking reduces the self-cleaning ability of airways, because nicotine paralyses the beating of cilia.

NASAL CAVITY

The nares open into the **nasal vestibule** which is covered by **skin** containing large hairs that form a mechanical filter for air. A deeper part of the nasal cavity is lined by a typical mucosal membrane, with pseudostratified columnar epithelium with cilia and goblet cells (**respiratory part** of the nasal mucosa). The submucosa of the respiratory mucosa is rich in mixed salivary glands and contains a very rich **superficial venous plexus**. Blood of these veins participates in warming of the inhaled air. Due to the wet surface and the presence of the above mentioned venous plexus in the respiratory mucosa, absorption of hydrophilic active ingredients of different aerosols is easy and quick, therefore medications which are applied as aerosols have a very effective local action and absorption. If these veins enlarge and dilate, they can be a source of severe nasal bleeding.

The floor of the nasal cavity is formed by the nasal surface of **hard and soft palates,** structures which separate the nasal cavity from the oral cavity.

A failure in the fusion process between the osseous parts of the hard palate during embryonic life causes cleft palate (oral and nasal cavities remain communicating). This developmental malformation is relatively frequent and needs special orofacial surgical interventions since such newborns cannot be fed in the natural way.

The roof of the nasal cavity is made by several bones listed in the following antero-posterior direction: nasal bone, frontal bone, cribriform plate of ethmoidal bone and lower aspect of the body of sphenoid bone.

The nasal surface of the cribriform plate is covered by **olfactory mucosa**. This tissue contains receptors involved in the sense of smell, which are primary sensory epithelial cells and function as chemoelectrical transducers. This means that the binding of odorants (molecules generating the sensation of smell) to cell surface receptors of sensory epithelial cells initiates a cascade of intracellular signal transduction events which ultimately lead to the generation of membrane depolarization of these cells. An action potential is conducted by the nerve processes of the cells towards the central nervous system. Nerve processes of olfactory epithelial cells are called **olfactory fila** and form the first cranial nerve, the **olfactory nerve**. Olfactory fila enter the anterior cranial fossa via tiny openings in the cribriform plate.

The nasal cavity is separated into two halves by the nasal septum. This septum has three parts: anteriorly it is **membraneous,** which is then stiffened by hyaline cartilage (**cartilagineous part**), and posteriorly the perpendicular plate of ethmoid bone and vomer form together the **osseous part**. The lateral compartment of the nasal cavity is subdivided by the superior, middle and inferior **nasal conchae** emerging from the lateral wall. The **sphenoethmoidal recess** it is situated above the superior nasal concha and each **nasal meatus** is located under their respective concha (*i.e.* superior nasal meatus is under the superior nasal concha). The **common nasal meatus** is the central compartment of the nasal cavity, is situated parallel to the nasal septum and it is medial to the nasal conchae (is not divided by them). The superior, middle and inferior nasal meatuses receive openings of different structures.

The squamous part of the frontal bone and labyrinth of the ethmoid bone, as well as the bodies of the maxilla and the sphenoid bone contain air-filled cavities which open into the nasal cavity. These cavities are lined by nasal mucosa that is continuous with that of the nasal cavity, therefore the name of these cavities is **paranasal sinuses.** We have the **frontal and maxillary** paranasal sinuses leading into the middle nasal meatus, and the **ethmoidal air cells** which open into both the superior and middle nasal meatuses. The s**phenoid sinuses** open on the anterior surface of the body of sphenoid bone and lead to the sphenoethmoidal recess.

Paranasal sinuses can become involved in the inflammatory reactions of the nasal cavity and their mucosal membrane may produce significant amounts of a highly viscous secretory product which may be infected by bacteria and thus lead to sinusitis. Some of physiological functions of these cavities include the warming of the air, providing resonating space during vocalization and reducing the weight of the skull.

The nasal cavity opens posteriorly into the **nasopharynx** via the two **choanae**. An important structure located on the lateral wall of the nasopharynx is the nasal opening of the **auditory tube** (Eustachian tube). This structure serves for ventilation of the tympanic cavity (cavity of middle ear) by connecting the cavity to the nasopharynx. An aggregation of lymphatic tissue in the mucosal membrane surrounding the **pharyngeal opening of the auditory tube** is the **tubarial tonsil**. Another tonsil of the nasopharynx is found in the mucosal membrane of the fornix of

the pharynx (on the lower surface of the clivus) and is called the **pharyngeal tonsil.** The enormous enlargement of this lymphatic organ (adenoid) may partly or entirely close the choanae and may cause difficulty of nasal breathing.

Tympanic cavity is separated from the external ear by the tympanic membrane (air drum) and its proper vibration requires continuous air refreshing of the middle ear.

LARYNX

The larynx (voice box) is the structure of the airways which receives air from the laryngeal part of pharynx and can be regarded as the organ of vocalization (speaking and singing). In addition, it is the landmark between the upper and lower airway compartments. The entire structure hangs down from the **hyoid bone** via the thyrohyoid membrane. The hyoid bone is held in its position by infrahyoid and suprahyoid groups of muscles that play a significant role in swallowing and speaking. This bone can be clearly palpated at the angle of the chin and the neck.

The larynx is supported by a rigid skeleton composed of several hyaline cartilages, of which the most prominent is the **thyroid cartilage**. The thyroid cartilage has two laminae which meet in a prominent anterior angle (Adam's apple), protruding forwardly at the middle of neck. The **cricoid cartilage** is situated under the thyroid cartilage and has a ring shape. Two smaller pyramid-shaped **arytenoid cartilages** sit on the posterior superior edge of the cricoid. The **epiglottis** is a flap of elastic cartilage that actively folds down over the opening into the larynx during swallowing, and swings back up when the act of swallowing ceases. The thyroid and cricoid cartilages as well as the two arytenoids and cricoid cartilages are interconnected by synovial joints and the action of several skeletal muscles allow to move the cartilages in these connections. Besides the joints and muscles, the cartilages are interconnected by elastic rich membranes which stretch the mucosal membrane of larynx.

The motor innervation of the laryngeal muscles and sensory innervation of the laryngeal mucosa are both provided by the superior and inferior (recurrent) laryngeal nerve branches of **the vagus nerve**.

The mucosal surface of larynx is very smooth due to the presence of a high ratio

of elastic fibers in the submucosal membraneous system. Two pairs of antero-posteriorly directed, more or less horizontal folds are visible within the cavity of the larynx: the **vestibular (false vocal) folds** are superior to the **true vocal folds**. The true vocal folds are elevated by vocal ligaments and are hardened by contraction of the vocalis muscles. The true vocal folds together form the **glottis** and the narrow slit between the true vocal folds is called the **rima glottidis**. Unlike the other regions of the larynx which are covered by typical respiratory mucosa with ciliated pseudostratified epithelium, the true vocal folds are lined by stratified squamous non-keratinized epithelium. Vibration of the true vocal folds occurs when the air streams through the rima glottidis during expiration if the cleft is narrowed by active function of the laryngeal muscles and consequently sounds can be produced. When the cleft is widely open –as it is during inspiration-, sounds are not formed.

The only muscle which can open the rima glottidis is the **posterior crycoarytenoid muscle**. Tight closure of the glottis after a deep inspiration is required when abdominal pressure must be increased (*e.g.* during weightlifting, defecation, vomiting or parturition). **Interarytenoid muscles** can pull the arytenoid cartilages closer to each other in such a way that the rima glottidis can be closed completely.

The larynx receives blood from two different directions: one is from the **superior laryngeal artery,** a branch of superior thyroid artery which comes from external carotid artery and a second from small arteries coming from the **subclavian artery**. Venous blood returns to the internal jugular vein. Lymphatic drainage of the larynx is mainly via the deep cervical lymph nodes situated along internal jugular vein.

The mucosal membrane of larynx is extremely rich in small vessels, and this includes the dense tissue of the true vocal folds which can become edematous easily. Laryngeal edema is a very frequent complication that occurs when a severe allergic reaction develops. The swelling of the glottis can become fatal, because it can block the airways completely. The patient can be rescued if the thickened anterior part of the cricothyroid membrane, called conic ligament is incised **(conicotomy).** The incision must be made under the thyroid and above the anterior part of cricoid cartilages. This area is easily palpable under the laryngeal prominence (Adam's apple).

The basic tone of the human voice is determined by the length of the vocal ligaments. The tone of the voice of men is deeper than that of females, because the distance between the thyroid cartilage and anterior process of arytenoid cartilages (insertion points and origin of vocal ligaments) is longer. (This is the reason why the Adam's apple of men is more prominent.)

The final quality of the voice is as individual as fingerprints, because shape and size of the

paranasal sinuses and larynx vary individually, as well as the fine tuning of the actions of laryngeal muscles, lip, soft palate and tongue all of which together modify the tone of our voice.

TRACHEA

The trachea or windpipe is an open tube about 2.5 cm in diameter and 10 to 12 cm in length. It extends from the lowermost part of the larynx until the level of the basis of the heart, containing the main vessels of the heart. This level is at the sternal angle anteriorly and 4th thoracic vertebra dorsally. Here, the trachea forks into two branches, the left and the right **main bronchi** (singular, **bronchus**). The trachea is kept open by 16 to 20 cartilaginous rings that are open on the posterior side (**cartilagineous part**). The C-shaped hyaline cartilages are connected by fibrous membranes containing smooth muscle fibers too. The posterior **membraneous part** of trachea is in contact with esophagus. The internal surface of the trachea is lined by typical respiratory mucosa, secreting a viscous secretory product and containing ciliated lining epithelium. Cilia beat upwardly and can support cleaning of the airways in this way.

The trachea is innervated by sympathetic fibers from the thoracic part of the sympathetic trunk and receives parasympathetic innervation via the vagus nerves. It receives fresh blood from the thoracic aorta via direct tracheal branches. Venous blood of the trachea is drained through the azygos system

LUNGS, PLEURA AND MEDIASTINUM

The lungs (**pulmo**) have conic shape and they occupy the majority of the thoracic cavity. Their base sits on the diaphragm, while their **apex** (tip) extends over the medial third of clavicle and is **localized at the root of the neck** in this way. Their medial surface is in contact with the organs of the thoracic cavity which are found in the central compartment (so called **mediastinum**) of the chest and these organs cause depressions on the soft material of lungs *e.g.* a cardiac impression is made by heart. The **hilum** (gate) of the lungs is also found on this mediastinal surface. This area transmits the lobar divisions of the bronchi, blood and lymph vessels of the lung, an

autonomic nerve plexus, as well as containing the hilar group of lymph nodes. These structures will be described later in detail, but note that they form the so called **root of the lungs**. Lungs are lobulated organs, the right lung has three (**superior, middle and inferior lobes**), while the left one has two lobes (**superior and inferior** ones). The lobes are separated by deep fissures which extend as deep as the hilum. The **oblique fissure** can be identified in both lungs, while the **horizontal fissure** is present only on the right lung. Lobes are further subdivided into **bronchopulmonary segments**, which are the surgical and anatomical units of lungs supplied individually by both blood and air. There are 10 segments in each of the lungs.

Each lung is surrounded by a double layer of serous membrane which is called the **pleura**. The two pleural sacs do not communicate with each other. The **visceral layer** of pleura follows tightly the surface of the lungs and extends even into the fissures, it reflects around the hilum and surrounds the structures of the root of the lung. The reflection is continuous in the **parietal layer** of the pleura. The parietal layer firmly adheres to the internal surface of the thoracic cavity and it therefore consists of the **costal, diaphragmatic and mediastinal parts**. The tip of the lungs reach into the so called **cupula** of the pleura.

> As it was mentioned before, the tip of lungs extends into the neck, thus the cupulae are also situated at the root of the neck where they are in contact with structures of vital importance *e.g.* blood vessels (subclavian artery and vein), nerves (brachial plexus) and large lymph vessels (thoracic duct on the left and the right lymphatic trunk).

The visceral and parietal layers of the pleura enclose the cavity of the **pleural sac**, which bordered by an epithelial layer, the so called **mesothelium**. Mesothelial cells form a simple squamous epithelium and secrete **pleural fluid,** which helps to develop a high surface tension keeping the two layers of pleura together and this fluid reduces the friction during respiratory movements. The volume of the pleural fluid is several milliliters under physiological conditions. Since the lung tissue is highly elastic, but does not contain muscular elements (only in the wall of bronchial tree and blood vessels), it passively follows the respiratory movements of thoracic cage and diaphragm, as the two layers of pleura normally are kept together via the pleural fluid.

The lungs are the organs responsible for the exchange of respiratory gases between blood and air. Atmospheric air enters into the lungs through the lumen of the branches

of the bronchial tree at the hilum of each lung. At the beginning of the bronchial tree, hyaline cartilage keeps the wall of bronchi continuously open. As the diameter of **bronchi** decreases, the proportion of smooth muscle in the tissue of the wall gradually increases. At the apex of each bronchopulmonary segment, a segmental bronchus enters and further splits into **bronchioles** which have only a 1-2 mm wide lumen, and do not contain any cartilage or glands in their wall. Bronchioles terminate as the **respiratory bronchiole** which is the first part of the bronchial tree belonging to the **respiratory part** of the airways. More proximal parts represent the so-called **conductive part** of the airways. Respiratory bronchioles open to **alveolar ducts** which finally lead into **alveolar sacs**. These alveolar sacs, which are bubble-like structures located at the most peripheral part of the tissue of the lungs, are the places where the majority of respiratory gas exchange takes place.

Carbon dioxide-rich venous blood is carried to the lungs via branches of the **pulmonary artery**. This big vessel starts from the right ventricle of heart and then gives right and left branches which enter into the lungs via the hilum. Branches of the pulmonary artery follow the arborization of the bronchial tree and ultimately form a meshwork of capillaries around the alveoli. Tissue layers of the **blood-air barrier** formed by the wall of alveoli and capillaries allow diffusion of respiratory gases guided by the partial pressure differences of oxygen and carbon dioxide between the air and the blood. Arterial blood has a high oxygen saturation and is carried away from the lungs by branches of **pulmonary veins.** Larger branches of the pulmonary vein run independently from the bronchial tree and can be found in the intersegmental connective tissue septa (between adjacent bronchopulmonary segments). Two left and two right pulmonary veins finally leave the lungs via the hilum and open into the left atrium of heart. As it is easily understandable from the facts described above, the **pulmonary circulation** serves to refresh our blood and it exists between the heart and lungs. It **begins from the right ventricle with the pulmonary artery and terminates at the left atrium with the pulmonary veins**. Note, that the pulmonary artery carries venous blood, with a high CO_2 saturation, while pulmonary veins carry arterial blood, with a high O_2 saturation. Since the pulmonary circulation does not provide nutrients for the tissue of lung itself, there is therefore a need for a "private" circulation to

satisfy this function. This kind of blood supply is called the **bronchial circulation**. Bronchial arteries arise from the **thoracic aorta** and follow the bronchial tree to supply their respective tissues. Venous blood from the tissue of the bronchial tree drains to the **azygos system** on right side and to the pulmonary veins on left side.

The **autonomic innervation** of the bronchial tree is provided by the thoracic sympathetic chain and parasympathetic fibers carried by the vagus nerve. These fibers control the production of mucous by the glands of the wall of bronchi and the diameter of the bronchioles via the innervation of the smooth muscle in them. Note, that sympathetic fibers cause DILATION of the lumen of bronhi and bronchioli!

DEVELOPMENT OF AIRWAYS AND LUNGS

Tissues of the larynx originate in the pharyngeal gut; mesenchyme of the **4th to 6th pharyngeal arches** contributes to the formation of the connective tissue, cartilage and muscle elements, whereas the epithelium and glands differentiate from the endoderm of the pharyngeal gut.

More distal parts of the airways start to develop from the foregut immediately under the primordium of larynx; it buldges out from the wall ventrally and is referred to as the **tracheobronchial pouch** on the 4th embryonic week. The primordium of the esophagus develops from the same but dorsal part of the foregut. At a later stage in the formation of the trachea and esophagus, the two organs are separated by a frontal **esophagotracheal septum**, consequently the esophagus is situated dorsal to the trachea.

In case of the incomplete separation of the two organs, the lumen of esophagus and trachea may communicate to a variable degree, or the lumen of esophagus may be obliterated (proximal and distal parts do not communicate). These malformations are not too rare and require urgent surgical intervention on the newborn.

The primordium of the bronchial tree undergoes rapid proliferation, when the endodermal epithelial tissue branches in a dichotomic fashion (each new division is Y-shape) and grows into the tissue of further pleura. The epithelium and glands of the bronchial tree as well as the alveolar epithelium are of endodermal origin, the connective tissue, cartilage and muscle elements of the organ differentiate from the mesenchymal tissue of the splanchnopleura of the intrembryonic mesoderm.

The maturation process of the lung tissues can be subdivided into phases and this fact has a crucial importance in the viability of the premature newborns, therefore we give a detailed description of this process here:

1. **pseudoglandular phase** (5th-16th weeks)
   - tissue of lung is made by solid cords of epithelial tissue (no lumen yet) and the surrounding mesenchyme.
2. **canalicular phase** (16th-26th weeks)

- solid epithelial cords gain a lumen, primitive bronchi are lined by a simple

cuboidal epithelium. Cartilage and muscle elements start to differentiate, pulmonary vessels grow into the tissue.

3. **terminal sac phase** (26th-36th weeks)

- distal end of the bronchi gradually flattens out and a simple squamous epithelium will line it, thus the formation of terminal sacs initiates; terminal sacs establish contacts with pulmonary capillaries. Type II pneumocytes appear first on the 28th intrauterine week and their number rapidly increases.

Production of surfactant starts at the 32nd week and a premature newborn has a better and better chance to survive beginning with this period of the pregnancy. Production of surfactant by type II pneumocytes can be stimulated by corticosteroids given to the mother if premature delivery is a real danger.

4. **alveolar phase** (from 36th intrauterine week during entire childhood (!)

- number of alveoli increases and gas exchange of lungs becomes more and more effective

As surfactant is responsible for keeping the lumen of alveoli open during expiration, and the lung tissue does not satisfy the criteria for a successful respiratory gas exchange prior to the formation of terminal sacs, a premature newborn before the 28th intrauterine week of gestation has a very poor prognosis to stay alive without hypoxic central nervous system damage.

ANATOMY OF THE DIGESTIVE SYSTEM

The organs of the digestive system are devoted to ingestion, digestion and absorption of nutrients. The alimentary canal is about 8 metres long and can be divided into different compartments according to their specific functions.

The parts of the digestive system:

I. ORAL CAVITIY

- Teeth
- Tongue
- Salivary glands
  - Parotid
  - Submandibular
  - Sublingual
- Throat

II. PHARYNX

III. ESOPHAGUS

IV. STOMACH

V. SMALL INTESTINE

- Duodenum
- Jejunum
- Ileum

VI. LARGE INTESTINE

- Cecum
  - Appendix
- Ascending colon
- Transverse colon
- Descending colon
- Sigmoid colon
- Rectum

VII. LIVER

- Gallbladder

VIII. PANCREAS

ORAL CAVITIY

The alimentary canal begins with the mouth or oral cavity. The opening of the mouth is surrounded by the upper and the lower lips. The skeleton of the lips contains the **orbicularis oris muscle** which is covered by the skin on its external surface and is lined by the mucous membrane on the internal surface. The lateral walls of the oral cavity are formed by the cheeks presenting similar structures like the lips. The main components of the cheeks are skeletal muscles (buccinator) which are coated by skin externally by mucous membrane internally. The roof of the oral cavity consists of the hard and the soft palate. The bony anterior **hard palate** is formed by the palatine processes of maxillae and the horizontal plates of palatine bones. The mobile posterior **soft palate** is composed of skeletal muscles. The floor of the oral cavity is formed by **mylohyiod muscle**. Posteriorly, the oral cavity communicates with the pharynx by way of the **throat (**faucal isthmus**)**.

The teeth divide the oral cavity into a horse-shoe shaped slit (vestibule**)** which is located between the lips, cheeks and the teeth and the oral cavity proper which is bonded by the inner surfaces of the teeth.

Teeth

The teeth are arranged in two arches, 16 teeth in the upper jaw (maxilla) and 16 teeth in the lower jaw (mandible). Each jaw holds 4 **incisors** (cutting teeth), 2 **canines** (cuspid, with one cusp on its crown), 4 **premolars** (bicuspids with two cusps) and 6 **molars** (millstone teeth). The incisors, canine and premolars have single roots, whereas the molars have two or three flattened or conical roots.

All teeth consist of three parts: the **root** which is embedded into the socket of the jaw, the **crown** which projects upward into the oral cavity, and a narrow **neck** between the root and the crown which is surrounded by the gum. The teeth are fixed in their sockets (alveoli) of the jaw by bundles of connective tissue called periodontal ligaments. Each tooth is composed of the **dentin**; it is covered by the extremely hard enamel over the crown and of a bonelike tissue called **cement** in the root. The **cavity** within the dentin contains the pulp; it consists of connecting tissue, blood vessels and nerves. The blood

vessels of the teeth derive from the maxillary artery; the nerves are the branches of the trigeminal.

Tongue

The tongue consists of three parts: the posterior **root**, the middle **body** and the anterior **tip**. The root and the body are separated by a V-shaped sulcus terminalis on the dorsal side of the tongue; taste buds are aligned along this sulcus.

The tongue is a highly movable organ which is composed of striated muscle fibers running in three different planes. These **intrinsic muscles** alter the shapes of the tongue and assist in swallowing. The group of **extrinsic muscles** of the tongue originates from the bones of the skull and the hyoid bone, they protrude and withdraw the tongue. The muscular core of the tongue is covered by a mucous membrane. The mucous membrane on the dorsal side of the tongue is divided into two parts. In the anterior oral part, corresponding to the body and tip of the tongue, the mucous membrane presents numerous elevations called **papillae** for taste sensation. In the pharyngeal part, corresponding to the root of the tongue, the mucous membrane contains aggregation of lymphatic nodules which constitutes the **lingual tonsil**.

The skeletal muscles of the tongue are innervated by the XII. (hypoglossal) nerve. The sensory innervation of the tongue is provided by the V. (trigeminal) nerve, the taste sensation is mediated by the VII. (facial) and IX. (glossopharyngeal) nerves.

Salivary glands

The mucous membrane of the oral cavity contains many smaller and larger salivary glands but the three large pairs of glands (parotid, submandibular and sublingual) produce the bulk of the saliva.

The **parotid gland** is the largest and lies in front of the ears. It is composed of exclusively serous units that secrete clear and watery saliva. The saliva is conveyed from the gland by the parotid duct that passes bellow the zygomatic arch then pierces the buccinator muscle of the cheek and opens into the oral cavity.

The **submandibular gland** is located bellow the body of the mandible. It is composed of mixed secretory units producing both serous and mucous saliva. Its duct hooks around the mylohyoid muscle and opens bellow the tip of tongue.

The **sublingual gland** is found in the floor of the mouth under the tongue. This gland is composed chiefly of mucous units that produce thick and viscous saliva. Numerous small ducts transmit the saliva from the gland and open into the floor of the mouth.

Faucal isthmus

The faucal isthmus connects the oral cavity with the pharynx. It is bounded above by the soft palate with the uvula in the midline. On the sides, two arches are visible that connect the soft palate to the tongue (palatoglossal arch) and to the wall of the pharynx (palatopharyngeal arch). The **palatine tonsils** sit in the triangular depressions between the two palatine arches on either side. Bellow, the faucial isthmus is bounded b the root of tongue which contains the **lingual tonsil**.

PHARYNX

The pharynx is a muscular tube behind the nasal cavity, oral cavity and larynx and in front of the vertebral column. It conducts the food from the oral cavity into the esophagus, and the air from the nasal cavity into the larynx. The framework of the pharynx is composed of skeletal muscles that could be divided into two groups. The **constrictor muscles** comprise overlapping circular layers in the wall of the pharynx. Their actions constrict the pharynx during swallowing and propel the food into the esophagus. The **longitudinal muscles** connect the pharynx to the skull and the soft palate. They raise the pharynx during swallowing. The muscles are lined by mucous membrane on the inner aspect and covered by fascia on the outer surface of the pharynx.

The cavity of the pharynx is divided into three parts: the nasopharynx behind the nose, the oropharynx behind the mouth and the laryngopharynx at the level of the larynx.

The **nasopharynx** receives the large openings of the nasal cavity (choanae) and the opening of the auditory tube which is guarded by lymphatic tissue called tubal tonsil. In the roof of the nasopharynx another collection of lymphoid tissue is known the **pharyngeal tonsil**.

The **oropharynx** receives the oral cavity through the faucial isthmus. It extends from the soft palate to the epiglottis and shows the **palatine tonsil** between the palatoglossal and palatopharyngeal arches.

The **laryngopharynx** is situated behind the larynx. It communicates with the esophagus through pear-shaped depressions (piriform recesses) on each side of the larynx.

ESOPHAGUS

The esophagus is about 25-30 cm long muscular tube extending between the pharynx and the stomach. The first (cervical) part of the esophagus lies on the cervical vertebrae behind the trachea. The middle portion of the esophagus descends in the posterior part of thoracic cavity (posterior mediastinum) in front of the vertebral column and behind the left atrium of the heart. The short abdominal part of the esophagus enters the cardiac part of the stomach where the esophagus is guarded by a sphincter muscle.

STOMACH

The stomach is an expanded portion of the alimentary canal located on the left upper part of the abdominal cavity bellow the diaphragm. The **cardia** of the stomach receives the opening of the esophagus. The **fundus** - the rounded upper part of the stomach above the cardia - lies in the dome of the diaphragm. The **body** is the largest central portion of the stomach which narrows and forms the **pyloric part**. The opening between the stomach and duodenum is the pyloric canal which is guarded by the pyloric sphincter controlling the discharge of the stomach content into the small intestine. The empty stomach presents a J-shaped outline defined by the concave **lesser and greater curvatures**.

The stomach is completely covered by the peritoneum (intraperitoneal organ). Two important peritoneal ligaments are related to the stomach: the lesser omentum which connects the lesser curvature to the liver, and the greater omentum which is hangs down from the greater curvature into the abdominal cavity.

SMALL INTESTINE

The small intestine constitutes the longest (5-6 metres long) segment of the alimentary canal. It forms greatly coiled loops in the central portion of the abdominal cavity. The small intestine is subdivided into three parts: duodenum, jejunum and ileum.

The **duodenum** presents a C-shaped course. The superior part passes right and horizontally under the liver. The descending part turns downward around the head of the pancreas. The horizontal part runs horizontally to the left. The short ascending part appears in front of the second lumbar vertebra where it continues to the jejunum at the duodenojejunal junction. The descending part receives three ducts: the common bile duct and the major pancreatic duct open at the **major duodenal papilla** (Vater's papilla); the accessory pancreatic duct opens little above the former papilla.

The **jejunum** begins at the duodenojejunal junction and forms horizontal loops in the left upper part of the abdominal cavity. The mucous membrane of the jejunum presents large and well developed **circulars folds** (valve of Kerkring) which increase the internal surface for absorption.

The **ileum** forms vertical folds in the right lower parts of the abdominal cavity and opens into the large intestine at the iliocecal junction in the right iliac fossa. The circular folds are low and spars, or absent in the ileum. The distinctive feature of the ileum is the presence of aggregated lymph follicles (**Peyer's patches**) in its wall.

The jejunum and the ileum are connected to the posterior abdominal wall by double layer of the peritoneum called mesentery. The blood vessels, lymph vessels and nerves that supply the intestine are passing and reach the wall of the intestine between the two layers of the mesentery.

LARGE INTESTINE

The large intestine is about 1.5 m long part of the alimentary canal. It begins in the right iliac fossa, frames the loops of the small intestine and terminates in the pelvic cavity. The large intestine presents some characteristic features: the **teniae** which are longitudinal bands of the smooth muscle layer along the length of the intestine, and the **haustrae** which are blind sacs of the wall of the intestine. Based on these distinctive structural differences, the large intestine can be easily distinguished from the small intestine. The first part of the large intestine is the **cecum** which is located in the right iliac fossa. On its superior part the ilium enters and invaginates the cecum by forming the iliocecal valves which prevent the reflux of the intestinal content back to the ileum. The **vermiform appendix** is the worm-shaped protrusion of the cecum which contains an abundance of lymphoid tissue in its wall. It originates from the lower part of the cecum and reaches variable length (about 8-10 cm). The next part of the large intestine is the **ascending colon,** it extends upward and turns right under the liver. Here it continues to the **transverse colon** which passes from right to left then it turns downward bellow the spleen and runs to the right iliac fossa as the **descending colon**. The next section is the **sigmoid colon** which forms an S-shaped loop and descends into the pelvic cavity where it continues to the rectum. The **rectum** passes in front of the sacrum and become the anal canal which terminates in the gluteal region at the anus. The **anal canal** and anus are closed by the involuntary circular smooth muscle ring called internal anal sphincter and the voluntary striated external anal sphincter which are opened during defecation.

LIVER

The liver is located in the right upper part of the abdominal cavity underneath the diaphragm. It presents a convex upper **diaphragmatic surface** which matches the dome of the diaphragm, and a lower **visceral surface** which is related to the abdominal viscera. On the diaphragmatic surface the liver is divided into the **right and left lobes** which are separated by a peritoneal ligament (falciform ligament). On the visceral surface, an H-shaped fissure separates four lobes: right, left, caudate and quadrate lobes. The fissures

contain remnants of embryonic blood vessels, the inferior vena cava and the gallbladder. The crossbar of the H-shaped fissures between the caudate and quadrate lobes is called **porta hepatis**. It contains the **hepatic artery proper** which supplies the liver with oxygenated blood, the **portal vein** which transmits venous blood from the alimentary canal to the liver, and the **hepatic duct** which drains the bile from the liver.

The histological units of the liver are the six-sided polygons which are called lobules. In the middle portion, each lobule carries the central vein. The hepatocytes within the lobule are arranged in one-cell thick plates that radiate from the central vein to the edge of the lobule. The spaces between adjacent radiating hepatocytes are lined with endothelial cells and called hepatic sinusoids. The terminal branches of the hepatic artery and the portal vein run among the lobules of the liver. The blood from these branches enters the lobules and flows through the sinusoids to the central veins of the lobules. The convergence of the central veins transports the blood into the **hepatic veins** which drain the venous blood from the liver into the inferior vena cava. The characteristic feature of the circulation of the liver is called **portal circulation**. The name derives from the special branching structure of the portal vein that enters the liver and forms a secondary capillary network (hepatic sinusoids) that unites again to form veins.

Another function of the liver is to secrete the bile. The bile is synthesised in the hepatocytes and is secreted into the **bile canaliculi** running between the adjacent hepatocytes. From the canaliculi, the bile is transported into the **interlobular hepatic ducts** which unite into the right and left **hepatic ducts** that leave the liver and join to form the **common hepatic duct.** The common hepatic duct joins the **cystic duct** which extends from the gallbladder; they unite into the **common bile duct** that leads into the descending part of the duodenum. When the stomach is empty, a sphincter muscle keeps the outlet of the common bile duct closed and the bile is stored and concentrated in the gallbladder. Whenever the content of the stomach enters the duodenum, the sphincter muscle relaxes, the wall of gallbladder contracts and the bile is released into the duodenum.

The liver - as an intraperitoneal organ - is surrounded by the visceral layer of the peritoneum (except the bare area on the right lobe where it is attached to the diaphragm). It is fixed to the diaphragm and to the abdominal wall by peritoneal ligaments. The **lesser omentum** is a double layer of peritoneum extending between the liver, the stomach and

the duodenum. The free margin of the lesser omentum ensheathes the hepatic artery proper, the portal vein and the common bile duct.

PANCREAS

The pancreas lies horizontally against the posterior abdominal wall behind the peritoneum. It consists of three main parts: the broad **head** on the right side which fits into the concavity of the duodenum, the large **body** which is behind the stomach, and the narrow **tail** which extends left toward the spleen.

The pancreas is composed of both exocrine and endocrine parts. The **exocrine part** contains groups of secretory units that produce digestive enzymes. This pancreatic juice is carried from the pancreas by two big ducts. The **main pancreatic duct** joins the common bile duct and opens on the major duodenal papilla in the descending part of the duodenum. The **accessory pancreatic duct** collects a small amount of the pancreatic juice and opens into the duodenum above the main duct. The endocrine part of the pancreas form spherical areas within the gland called **pancreatic islets of Langerhans**. The cells of the islets secrete hormones (insulin, glucagon) into the bloodstream.

BLOOD SUPPLY AND INNERVATION OF THE ABDOMINAL PART OF THE DIGESTIVE SYSTEM

The arteries of the alimentary canal originate from the **unpaired visceral branches of the abdominal aorta**: the celiac trunk, the superior mesenteric artery and the inferior mesenteric artery. The **celiac trunk** arises from the aorta below the diaphragm. It divides into three main branches that supply the stomach, the pancreas, the liver, the spleen and the proximal part of the duodenum. The **superior mesenteric artery** arises close to the celiac trunk. Its branches run in the mesentery and provide blood supply to the small intestine (except the proximal part of the duodenum). The adjacent arteries anastomose and form arterial arcades from which the terminal branches reach the

intestinal wall. The arteries to the large intestine derive from the **superior and inferior mesenteric arteries**, whereas the lower part of the rectum is supplied by branches of the **internal iliac artery**.

The veins from the alimentary canal, liver, pancreas and spleen are drained by three veins: the slpenic vein, the superior mesenteric vein and the inferior mesenteric vein. The **splenic vein** is formed by union of several veins that emerge from the spleen. It runs horizontally and receives the **inferior mesenteric vein**. Behind the neck of the by pancreas, the splenic vein unites with **superior mesenteric vein** to form the **portal vein** which transports the venous blood from the digestive system into the liver.
The blood from the upper part of the rectum flows through the inferior mesenteric vein into the portal vein and the liver. The lower part of the rectum is drained to the **inferior vena cava**. The veins in the upper and lower parts of the rectum are connected in the wall of the rectum which establishes +the anatomical basis of communication between the portal and systemic venous circulations of the body.

The parasympathetic innervation of the digestive organs derives mostly from the X. (vagus) nerve. The terminal part of the large intestine is supplied from branches of the sacral spinal cord. The sympathetic nerves originate from the thoracic spinal cord and innervate the abdominal organs via the prevertebral ganglia that are located in front of the abdominal aorta.

PERITONEUM

Most of the organs in the abdominal cavity are enveloped by a serous membrane called peritoneum. It is composed of two layers: the **parietal peritoneum** that lines the walls of the abdominal cavity and the **visceral peritoneum** that covers the abdominal viscera. The narrow space between the parietal and visceral membranes is called **peritoneal cavity** that contains a small amount of fluid which reduces the friction during the movements of the abdominal organs. The viscera that are completely surrounded by the visceral peritoneum are called **intraperitoneal organs**. The organs lie behind or bellow the peritoneal cavity are not surrounded by the peritoneum, they are the **retroperitoneal and infraperitoneal organs**.

Intraperitoneal organs

The abdominal organs that are surrounded by the visceral peritoneum are the liver, the stomach, the small intestine (except the duodenum) the transverse colon and the sigmoid colon. The rounded diaphragmatic surface of the liver is connected to the anterior abdominal wall by double layers of the peritoneum called falciform ligament. From the visceral surface of the liver, the **lesser omentum** of the peritoneum extends to the lesser curvature of the stomach and to the superior part of the duodenum. The right free margin of the lesser omentum encloses the hepatic artery, the portal vein and the bile duct. Behind these structures the epiploic foramen is found. It leads into a pouch of the peritoneal cavity. This is the **lesser sac or omental bursa** that is located behind the stomach and in front of the pancreas. The **greater omentum** is an apron-like fold of the peritoneum that hangs down from the grater curvature of the stomach and covers the intestine.

Several peritoneal ligaments connect the abdominal organs to the posterior abdominal wall. Blood vessels and nerves run within these ligaments and supply the intraperitoneal organs. The jejunum and the ileum are suspended from the posterior abdominal wall by the **mesentery** which originates at the duodenojejunal flexure and extends obliquely on the posterior abdominal wall toward the iliocecal junction. The peritoneal ligament of the transverse and sigmoid colons are called **transverse and sigmoid mesocolon,** respectively.

The retroperitoneum

The retroperitoneum is a vertical space between the parietal peritoneum and the posterior abdominal wall. It contains several organs including the duodenum, the pancreas, the ascending and descending colons, the kidneys and the suprarenal glands. The retroperitoneum also houses the big blood vessels of the abdominal cavity; the abdominal aorta and the inferior vena cava. The **abdominal aorta** descends in front of the vertebral column and gives off parietal and visceral branches. The parietal branches supply the diaphragm and the abdominal wall. The visceral branches can be divided into unpaired and paired arteries. The **unpaired visceral branches - celiac trunk, superior and inferior mesenteric arteries** - arise from the anterior surface of the aorta and supply

the digestive organs. The **paired visceral branches** arise from the lateral aspect of the aorta and supply the kidneys (**renal arteries**) and the gonads (**testicular arteries** in male and **ovarian arteries** in female). In front of the body of L4 vertebra, the abdominal aorta divides into the right and left common iliac arteries.

The **inferior vena cava** is the largest vein of our body. It begins in front of the L5 vertebra by the union of the right and left common iliac veins that returns the blood from the lower limbs and the pelvis. The inferior vena cava ascends on the right side of the abdominal aorta; it collects the blood from the kidneys via the **renal veins** and the veins from the gonads (**testicular** or **ovarian veins**). The distal part of the inferior vena cava lies in the fossa of the liver between the caudate and right lobes where it drains the venous blood from the liver through the **hepatic veins**. Then it pierces the diaphragm and enters the right atrium of the heart.

Infraperitoneal organs

The infraperitoneal organs are located in the pelvic cavity underneath the peritoneal sac. In the male, the parietal peritoneum reflects from the anterior abdominal wall to the superior surface of the urinary bladder, then covers the upper part of the rectum. In the female, the parietal peritoneum is reflected from the anterior abdominal wall to the superior surface of the urinary bladder then it envelopes the uterus and covers the upper part of the rectum. Between the rectum and uterus the peritoneum forms a deep hollow (**rectouterine pouch or Douglas pouch**) which is the lowest part of the peritoneal cavity.

DEVELOPMENT OF THE DIGESTIVE SYSTEM

The epithelial lining and the glands of the gastrointestinal tract derive from the **endodermal germ layer**, whereas the connective tissue and muscular layers of the wall of the gut originate from the **visceral layer of the mesoderm**. Initially the endoderm develops as a flat disc. As a result of the rapid growth, the flat embryo folds into the amnionic cavity and the endoderm will be incorporated into the body of the embryo constituting the primitive gut. This tubular structure can be divided into three main regions: the foregut, the midgut and the hindgut. The foregut opens into the primary oral cavity (stomodeum).

The **primary oral cavity** is bounded by the unpaired **frontal prominence** above, the paired **maxillary prominences** laterally and the paired **mandibular prominences** bellow. Two depressions appear on the frontal prominence. They invaginate and form the nasal pits which become surrounded by horseshoe-shaped elevations, the medial and the lateral nasal prominences. The maxillary and the two medial nasal prominences fuse and form the upper lip, the two mandibular prominences unite and gives rise to the lower lip and jaw. Two horizontal plates appear on the maxillary prominences between the oral and nasal cavities. They fuse and form the hard plate which separates the nasal and oral cavities. The teeth derive from C-shaped upper and lower thickenings of the ectodermal lining of the oral cavity called dental lamina. They invaginate into the underlying mesenchyme and form the dental buds. The ectoderm layer of the buds gives origin to the **ameloblasts** which produce the enamel of the teeth. The mesenchyme within the dental buds forms the dental pulp, and the **ondontoblasts** which are responsible for production of the dentin for the teeth.

The **proximal part of the foregut** presents four swellings called **pharyngeal arches** which are separated by deep grooves known as **pharyngeal grooves** outside and **pharyngeal poutches** inside. The arches are covered by the ectoderm outside and lined by the endoderm inside. Each pharyngeal arch consists of a mesenchymal tissue from which a cartilagenous core, a nerve and an artery differentiate. The mesenchyme of the arches gives rise to the bones of the skull, the hyoid bone, the cartilages of the larynx and the muscles of the head, neck and larynx. The nerves of the pharyngeal arches develop into the V, VII, IX and X cranial nerves. The endodermal lining of the pharyngeal pouches

gives origin to the thymus, the thyroid and parathyroid glands. Caudal to the pharyngeal pouches, the epithelium on the ventral wall of the foregut bulges anteriorly and forms a diverticulum that gives origin to the **respiratory system**. During development, the ventral and the dorsal parts of the foregut are separated by a vertical septum and the dorsal part elongates to from the **esophagus**.

The **middle portion of the foregut** dilates and forms the **stomach**. The **terminal part of the foregut** forms a C-shaped loop which gives rise to the **duodenum**. In the duodenal loop, the endoderm is thickened and protrudes as a dorsal and a ventral bud. The **ventral bud** divides into the liver bud, the gallbladder and the ventral pancreatic bud. The **dorsal bud** fuses with ventral pancreatic bud to form the **pancreas**. The **liver bud** forms epithelial cords that grow into the surrounding mesoderm and differentiate into the lobes of the liver. During further development the stomach and duodenum rotate around their axes. As a result of these movements the stomach, the liver, the pancreas and the spleen occupy their final positions in the abdominal cavity.

The **midgut** forms the long primary intestinal loop that elongates and rotates to form the **jejunum, ileum, cecum, ascending and transverse colons**. During the 6^{th} week, the elongated intestinal loop protrudes into the umbilical cord (physiological herniation) but in the 10^{th} week it returns into the abdominal cavity.

The **hindgut** differentiates into the **descending and sigmoid colons and the upper part of the rectum**. The terminal part of the hindgut is divided by a vertical urorectal septum into a ventral part (**urogenital sinus**) and a dorsal part. The ventral part gives rise to the urinary and the genital organs, whereas the dorsal part of the hindgut forms the **lower part of the rectum**.

ANATOMY OF THE URINARY SYSTEM

The urinary apparatus consists of the **kidneys**, which secrete the urine, the **ureters**, which transport the urine into the reservoir, the **urinary bladder** and the **urethra**, which discharges the urine from the body.

KIDNEY

The kidneys are bean-shaped organs located in the posterior part of the abdominal cavity behind the peritoneum They are extended between the 12^{th} thoracic and 2^{nd} lumbar vertebrae on both sides of the vertebral column. Due to the size of the liver, the right kidney is located lower by a length of a half vertebra than the left kidney. The medial or concave margin of the kidney shows toward the midline. The central part of the medial margin is the **hilum**, which transmits vessels, nerves, lymphatics and the ureter into the **renal sinus**. The kidney is enclosed in three layers. The innermost layer is the **fibrous capsule**, which is attached firmly to the surface of the organ. The middle layer is the **adipose capsule**, encloses the suprarenal gland and it has a crucial role in the fixation of kidney. The outermost layer, the **renal fascia**, is a sac of fibrous connective tissue ensheathing the kidneys, the ureters, the suprarenal glands, the aorta and the inferior vena cava.

In a vertical section of the kidney, the **parenchyma** surrounds the renal sinus. The renal sinus contains the calices, the pelvis, blood vessels, lymphatics and nerves of the kidney embedded into an adipose tissue. The parenchyma is composed of an external cortical and an internal medullary substance. The **medulla** of kidney exhibits a triangle-shaped structure, termed as **renal pyramid.** There are 27-30 pyramids in each kidney. The **cortex** surrounds the medulla; its part between the pyramids is the **renal column**. The extension of the medulla into the cortex shows striated appearance known the **medullary rays**. Each renal pyramid and the surrounding cortex comprise the **renal lobe.** The lobar organization of the kidney is recognizable during its development of the kidney. The lobes of kidneys consist of the renal lobules which have a central **medullary ray** surrounded by the **cortical labyrinth**. The border of the

renal lobule is the interlobular artery. The renal lobule contains the **nephron**s, the morphological and functional units of the kidney, as well as the first part of the collecting tubules.

The apex of the pyramid is the **renal papilla**, its cribriform appearance is due to the openings of the collecting ducts that excrete the urine into the **minor calyces**. The minor calices unite and form the three **major calices** which, in turn, join in the **renal pelvis**. The renal pelvis continues into the ureter.

The blood supply of kidneys is provided by the renal arteries that originate from the abdominal aorta. Upon entering the renal sinus, the **renal artery** divides into the **interlobar arteries** and continues as the **arcuate arteries** between the medulla and cortex. The branches of the arcuate arteries are the **interlobular arteries** located at the border of renal lobule. The interlobular arteries give off the **afferent arterioles** that enter the Malpighian body and produce the innumerable **glomerular capillaries**. The glomerular capillaries reunite and continue into the **efferent arterioles**. The further course of the efferent arterioles depends on the position of glomeruli. The superficial efferent arterioles give rise to a second capillary network, the **peritubular capillaries** and supply the tissue of kidney. The efferent arterioles of the juxtamedullary glomeruli descend into the medulla as **arteriolae rectae**, breaks up into capillaries which descend and with a hairpin loop turn back to the base of the pyramid. The venous return follows the course of the arterial flow and the renal vein opens to the inferior vena cava.

URETER

The ureters are tubes, 28-30 cm in length, in the continuation of the renal pelvis. They are running downward in the retroperitoneal space within the adipose capsule of the kidney. The inner surface of the ureter is lined by mucosa. The ureters pierce the wall of urinary bladder in an oblique course that acts as a valve and prevents the backflow of urine into the ureter. In the female pelvic cavity, the ureter crosses the uterine artery which is located in front of the ureter. In the caudal direction the ureters

are related to the lateral fornix of the vagina; and in male they are crossed by the ductus deferens.

URINARY BLADDER

The urinary bladder is located in the pelvic cavity behind the pubic symphisis. It is a reservoir for the urine and is able to distend up to 300 ml. The urinary bladder has three openings, the upper two for the ureters and the lower one is for the **urethra**. Inside the bladder, the three openings define the **trigone** of the urinary bladder. It has a relatively smooth surface and it is different form the folded appearance of the rest of bladder. The lower part of bladder is the **fundus** attached firmly to the prostate in male. In female the fundus of bladder is connected with loose connective tissue to the anterior fornix of vagina. The bladder is an infraperitoneal organ, its superior and posterior parts are covered by the peritoneum that is reflected to the uterus in female (vesicouterine pouch) and to the rectum in male (rectovesical pouch).

URETHRA

The internal orifice of the urethra is located at the lower angle of the trigone of urinary bladder. The **female** urethra is short, measuring 3-4 cm in length and opens into the vestibule of vagina. The first part of the wall contains a circular smooth muscle layer, the **musculus sphincter vesicae**. Along its course, the urethra pierces the pelvic and the urogenital diaphragm and attached firmly to the anterior wall of the vagina. It opens into the vestibule of vagina immediately behind the clitoris. At the level of urogenital diaphragm, the circularly running skeletal muscle fibers form the **musculus sphincter urethrae.**

The **male urethra**, as the duct of the urinary and genital system, is described with the male genital organs.

DEVELOPMENT OF THE URINARY SYSTEM

The urinary organs develop from the **intermediate mesoderm**. The formation of permanent kidneys is preceded by a set of embryonic structures that appear in a cranial to caudal sequence as the **pronephros**, the **mesonephros** and the **metanephros**.

The **pronephros** develops in the cervical and upper thoracic segments. The primitive renal corpuscles are formed by branches of the dorsal aorta. They protrude into the celomic epithelium and into the intermediate mesoderm and bring about ptimitive "tubules". The pronephroi are non-functional and disappear by the end of first month. Parallel to the formation of the pronephros, the dorsal part of the intermediate mesoderm thickens and evaginates. This compact cell mass grows downward, and caudalward fuses successively with the lower counterparts. Finally the cell mass opens to the cloaca and after acquiring a lumen it is called the mesonephric, or Wolffian duct. The mesonephric duct is involved in the development of exctertory system of permanent kidney and the male genital system.

The **mesonephros** consists of renal corpuscles that open into the Wolffian duct. The mesonephric glomeruli degenerate and disappear by the end of the second month. In male the caudal tubules of the mesonephric duct persist and participate in the formation of the genital system; in female they are present in rudimentary form.

The permanent kidney **(metanephros)** develops in the lumbar segments. First, the metanephric tissue forms a cap above the **ureteric bud**, which is an outgrowth on the dorsal wall of the Wolffian duct. The metanephric tissue develops into nephrons whereas the ureteric bud gives rise to the collecting ducts of the kidney, the minor and major calices, the renal pelvis, the ureter and the trigone of urinary bladder. The formation of the permanent kidney is completed by the union of the distal part of the nephron and the collecting duct. The urinary bladder develops from the urogenital sinus of cloaca except the trigone which originates from the Wolffian duct.

ANATOMY OF THE GENITAL ORGANS

MALE GENITAL ORGANS

TESTIS

The testis is the male gonad which has two interrelated functions: (1) the production of spermatozoa and (2) the production of sex steroids, primarily testosteron. It is a paired, plum-shaped and sized, slightly flattened organ, weighing 15-20 g, that is located in the perineal region within the scrotum, a sac-like swelling of the abdominal wall. It has medial and lateral surfaces, blunt anterior and posterior margins, and superior and inferior poles at the connection of the margins. The axis of the testis connecting the two poles slopes slightly forward and laterally, in such a way that the upper pole is somewhat anterior and lateral to the lower pole. Its surface is covered by a dense and stretched connective tissue capsule (tunica albuginea). A serous sac, the tunica vaginalis testis is attached to the outer surface of the tunica albuginea. On the dorsal aspect of the testis which is not covered with tunica vaginalis, blood and lymph vessels, as well as nerve fibers enter and leave the testis.

The cut surface of the testis is straw-yellow, its substance is soft and easily torn, from which fine filaments can be drawn, these are the tortuous tubules of the testis (see at the microscopic structure).

EPIDIDYMIS

The epididymis is an elongated organ attaching to the dorsal margin of the testis, and embracing its posterior aspect in the shape of a crescent. The upper, thicker, and spherical end of the epididymis, which is fixed to the superior pole of the testis, is called head, its middle portion is named body, and the lower, narrowing end portion is the tail. Its parenchyme is formed by the proximal portion of the genital duct system. The tail region bends backwards like a hook behind the lower pole of the testis, and continues into the deferent duct. Surface of the epididymis is covered by a connective tissue capsule which, however, is thiner than the tunica albuginea of the testis. The

head and tail of the epididymis is attached to the testis by ligaments (superior and inferior ligament of epididymis).

DUCTUS DEFERENS

The ductus deferens (deferent duct; vas deferens) is a 2-3 mm-thick, hard to the touch, about 45 cm long duct, which has a narrow lumen like a pin-prick surrounded by thick muscular wall. As it was mentioned above, it arises from the tail of the epididymis bending backwards like a hook, and then ascends along the posterior margin of the testis (pars testicularis). Leaving the testis and epididymis, it ascends to the superficial opening (anulus superficialis) of the inguinal canal (canalis inguinalis) as one of the constituents of the **spermatic cord** (funiculus spermaticus). It enters the inguinal canal together with other components of the spermatic cord, and passes the canal. Emerging from the inguinal canal, it enters the lesser pelvis and elevates a peritoneal fold, while it crosses the external iliac artery and vein, and then the ureter. Thereafter it turns to the dorsal aspect of the uninary bladder (vesica urinaria), where it goes downwards and medially. The ductus deferens enlarges here (**ampulla ductus deferentis**). The ampulla on both sides going downwards and medially converges considerably. Approaching each other, the two deferent ducts become slender again and join with the excretory duct of the seminal vesicle (vesicula seminalis), that lies just lateral to it, to form the ejaculatory duct (**ductus ejaculatorius**). The two ejaculatory ducts, approaching each other and the urethra within the prostate, run anteriorly and downwards, and then enter the urethra at the central part of the prostate.

SEMINAL VESICLE

The seminal vesicle (vesicula seminalis) is about 5 cm long, flat, oval-shaped, bulging paired sac. It consists of a single, strongly convoluted tube which is about 10-15 cm long and 3-4 mm wide, and is covered by a connective tissue capsule. Concerning its function, the seminal vesicle is an independent gland. It lies on the dorsal wall of the urinary bladder close to the opening of the ureter, lateral to the ampulla of the ductus deferens. Its lower medial end continues into a straight

excretory duct (ductus excretorius) which joins with the ductus deferens in a sharp angle (see at description of the ductus deferens). It is connected to the dorsal wall of the urinary bladder by a thin connective tissue layer, through which it is in contact with the rectum posteriorly. The seminal vesicle is an infraperitoneal organ, only its upper pole is covered by peritoneum that comes from the posterior wall of the bladder, and bends backwards to the rectum.

PROSTATE GLAND

The prostate gland (prostata) is an unpaired compact gland. It is about the size of a horse chesnut and weighs about 20-25 g. The diameter of the prostate is 2.5-4.0 cm and it lies below the urinary bladder in the lesser pelvis. Its larger **base** (basis prostatae) is closely connected to the fundus of the urinary bladder, and its **apex** (apex prostatae), facing downwards, rests on the pelvic fundus. The gland is perforated downwards by the urethra near to its anterior surface. Two other ducts, the paired **ejaculatory ducts** invade its substance, which are formed by the fusion of the ductus deferens and the excretory duct (ductus excretorius) of the seminal vesicle. The two ejaculatory ducts approaching each other, and the urethra within the prostate, go downwards and anteriorly, then reach the urethra and enter it in the middle of the prostate. The wedge-shaped area between the urethra and the two ejaculatory ducts becoms broader posteriorly and upwards, and may be slightly separated from the other parts of the prostate, as the isthmus prostatae. Posterior aspect of the prostate is in contact with the rectum, from which only a thin connective tissue layer separates it. Therefore, the posterior and two lateral surfaces of the prostate can be easily palpated from the direction of the rectum.

BULBOURETHRAL GLAND

The bulbourethral gland (glandula bulbourethralis; Cowper's gland) is a paired gland, about 1 cm in diameter, embedding in the urogenital diaphragm. This is the smallest accessory sex gland. Its excretory duct perforates the lower sheet of the urogenital diaphragm and enters the urethra through the bulbus penis.

SPERMATIC CORD

The ductus deferens, which ascends from the epididymis to the inguinal canal, and then passes through the inguinal canal, is accompanied throughout its course by blood vessels, nerves and other structures runing to and from the testis and epididymis, to form together a rounded cord of a little finger's breadth. This cord, running from the upper pole of the testis and the head of the epididymis to the inner opening of the inguinal canal (deep inguinal ring), is called spermatic cord (funiculus spermaticus). The following structures run within the spermatic cord:

- **ductus deferens** accompanying by a little artery (a. ductus deferentis) and a nerve plexus (plexus deferentialis);
- **testicular artery**, that supplies the testis and epididymis;
- **pampiniform plexus**, that drains the venouos blood from the testis and epididymis, and emerging from the inguinal canal it forms the testicular vein in the abdominal cavity;
- **spermatic nerve plexus**, that innervates the testis and epididymis;
- **vestigium processus vaginalis peritonei**, which is an occluded remnant of the peritoneal process that descends to the testis and epididymis in the embryonic life.

These structures are connected to each other by loose connective tissue, and constitute the spermatic cord. On its outer surface, the spermatic cord is accompanied by two nerves: a branch of the genitofemoral nerve (genital branch) that innervates the cremaster muscle, and the ilioinguinal nerve that supplies the skin of the scrotum with sensory fibers.

Entering the abdominal cavity, at the inner opening of the inguinal canal (deep inguinal ring), the spermatic cord disintegrates to its constituents, and the structures separating from each other run in different directions.

Coverings of the testis and the spermatic cord

The testes begin to develop at the level of the future abdominal cavity, behind the peritoneum, and migrate from here downwards into a swelling called scrotum. The scrotum is located on the antero-medial lower portion of the abdominal wall. The testes pull the peritoneum attached on their anterior surface with them during their descent. At the end of the migration, the testes, together with their excretory duct (ductus deferens), blood vessels (testicular artery, pampiniform plexus), and the peritoneum, pulled with them (processus vaginalis peritonei), migrate into the scrotum completely. The opening of the swelling narrows later into a narrow canal (inguinal canal). The swellings of the abdominal wall on the two sides finally stick closely together, but they never open into each other; the sacs on the two sides are always separated by a tough connective tissue septum. Considering the above mentioned process of descent of the testis, it is easy to imagine that the testis, epididymis, and the spermatic cord (funiculus spermaticus) containing structures runing to or coming from them, are covered with an envelop formed by outpouching layers of the abdominal wall. These are named coverings of the testis and spermatic cord which are from outside to inside as follows:

1. **Skin** of the scrotum which is thin, and considerably pigmented. It contains scattered hair follicles and sebaceous glands. The scrotum of the two sides are joined together by a suture-like line (raphe scroti).
2. **Tunica dartos**, is the continuation of the subcutaneous connective tissue and the superficial abdominal fascia (fascia superficialis abdominis). In addition to connective tissue elements, it contains numerous smooth muscle bundles (musculus dartos). The tunica dartos on the two sides unites in the midline, and forms a sagittal septum which insures separated spaces for the testes and their inner coverings. Contraction of smooth muscle bundles of the tunica dartos wrinkles the skin of the scrotum.
3. **External spermatic fascia**, a thin connective tissue layer that is the continuation of the aponeurosis of the external oblique abdominal muscle (m.

obliquus abdominis externus). It begins at the external opening of the inguinal canal where the aponeurosis continues into a thin layer of fascia.

4. **Cremaster muscle**, a net-like muscular sheet which is formed by the continuing fibers of the inner oblique abdominal muscle (m. obliquus abdominis internus) and of the transverse abdominal muscle (m. transversus abdominis). Contraction of the cremaster muscle considerably elevates the testis within the scrotum.
5. **Internal spermatic fascia**, a thin connective tissue layer which is a protrusion of the transversalis fascia. As the processus vaginalis peritonei pushes the transversalis fascia outwards at the inner opening of the inguinal canal, it carries a thin layer of the fascia in front of, and this becomes internal spermatic fascia, a filmy inner layer.
6. **Tunica vaginalis testis**, a process of the peritoneum (processus vaginalis peritonei) that is pulled by the testis during its descent. That is why the tunica vaginalis does not surround the testis completely, as the other coverings do it, but the lower end of the processus vaginalis laps over only the anterior and lateral surfaces of the testis, becoming fixed to the testis in this way. The cavity of the tunica vaginalis is open and communicates with the peritoneal cavity until the last fetal month. Thereafter, however, its upper part closes and remains as a connective tissue bundle (vestigium processus vaginalis peritonei). Its lower end connecting to the testis does not close, but remains as a small serous sac which covers the anterior and lateral surfaces of the testis. Consequently, the testis finally is invaginated into its own serous sac (tunica vaginalis), and occupies thus a retroperitoneal position.

PENIS

The penis is a cylindrical body, covered by skin, protruding from the anterior part of the perineal region (perineum) just below the pubic symphysis. Its posterior portion near the pubic symphysis is called root of the penis (radix penis), the middle portion is the shaft (corpus penis), and the anterior enlarging part is the glans penis.

Erectile bodies of the penis. The penis is formed by three sponge-like erectile bodies: the paired **cavernous bodies** (corpora cavernosa) that are attached to each other on their medial aspect, and the unpaired **spongious body** (corpus spongiosum) located behinde and between the cavernous bodies.The end of the spongious body constitutes the erectile substance of the glans penis anteriorly. The erectile bodies expand backwards onto the perineal region.

The cavernous body (corpus cavernosum penis) arises with a tapered portion at the meeting of the stems of the sciatic and pubic bones (ramus ossis ischii and ramus inferior ossis pubis), and then passes along the inferior ramus of the pubic bone attaching to its inferior surface. The cavernous bodies of the two sides meet in front of the pubic symphysis at an acute angle and enter the penis. Their medial aspects attache with each other so that the two cavernous bodies are separated only by a net-like connective tissue septum (septum penis). The two cavernous bodies are surrounded by a firm connective tissue covering (tunica albuginea) separately at the region of crus penis, and collectively within the shaft of penis. The cavernous bodies end at the posterior margin of the glans penis forming a blunt tip and protruding into the glans.

The spongy body (corpus spongiosum penis) begins in the middle portion of the perineum, attaching to the lower surface of the urogenital diaphragm, with an onion-shaped thickening (**bulbus penis**), 1-1.5 cm in front of the anus. Anterior to the bulbus penis, the spongy body becomes slender and extends forwards in the midline. The urethra enters the corpus spongiosum in this portion, just anterior to the bulbus penis. In front of the pubic symphysis, the spongy body is attached to the lower surface of the cavernous bodies within the penis, and extends until the tip of the cavernous bodies in this position. Here it conoidally enlarges (**glans penis**) and laps over the end of the cavernous bodies like an eccentrical head of a mushroom. The posterior rim of the glans penis is more voluminous than the two cavernous bodies, therefore it rises concentrically (corona glandis). The corpus spongiosum is covered outside by a connective tissue capsule which is much thiner and elastic than the tunica albuginea that covers the corpus cavernosum.

Skin and subcutaneous connective tissue of the penis. The three erectile bodies of the penis are covered by skin which overreaches the tip of the glans. Here

the skin bends backwards as a fold and adheres behind the coronary groove of the glans (sulcus coronarius glandis). This is a cylindrical fold of skin (foreskin; prepuce; preputium) which is retractable from the glans penis. The entire glans of little boys is covered by the prepuce in general; but in adulthood depending on the state of the penis, the anterior portion of the glans may be covered by prepuce to variant extent.

Fine structure of the erectile bodies. The erectile bodies are composed of a network of trabecules crossing very often in every direction of the space. The trabecules are formed by collagen and elastic fibres and smooth muscle bundles, and their surface is covered by endothelial cells which completely line the wall of the spaces (caverns; cavernae) between the trabecules. The caverns are largest in the central region of the erectile bodies, becom gradually narrower in the peripheral region, and flatten parallel to the outer connective tissue capsule. Blood circulates within the caverns. This structure is characteristic for both the cavernous bodies and the spongy body, but as it is indicated by the term, substance of the corpus spongiosum is a more fine spongy tissue than that of the corpus cavernosum. This difference derives from the fact that the trabecules are thiner and the caverns are narrower in the corpus spongiosum. Tissue of the glans penis is less cavernous, rather a fine network of tortuous veins predominates its substance.

Blood vessels and nerves of the penis:

Arteries. The deep artery of the penis (a. profunda penis) supplies the corpus cavernosum penis. Its main trunk runs forwards in the axis of the corpus cavernosum. The corpus spongiosum is supplied usually by three pairs of arteries. The a. bulbi penis enters the bulbus penis. In front of the bulbus penis, the a. urethralis enters the narrower part of the corpus spongiosum, and runs along the urethra until the glans penis. The glans penis has a private artery (a. dorsalis penis) which reaches the glans runing on the dorsal aspect of the penis.

The arterial side branches are undulating in their downward courses, therefore they are called helical arteries (aa. helicinae). After a short course, the helical arteries enter directly the central veins of the erectile bodies. Another very important characteristic feature of the penil arteries is the longish, crest-like intima-swellings

(Ebner's pads) which protrude into the lumen. In consequence of the protrusions, the arterial lumens taper and become crescent-shaped.

Veins. Veins of the penis are collected from the peripheral caverns of the erectile bodies, they exit the erectile bodies at the entering site of the arteries, and are collected into the internal pudendal vein.

Nerves. The penis possesses rich sensory and autonomic innervation. Its sensory nerve is the paired dorsal nerve of penis which is an endbranch of the pudendal nerve arising from the sacral segments (S_{2-4}) of the spinal cord. The prepuce and the glans receive especially rich sensory innervation from the nerve.

Autonomic innervation of the penis is dual, like in other viscera, partly sympathetic and partly parasympathetic. The sympathetic preganglionic fibers arise from the Th_1-L_2 segments of the spinal cord. After separating from spinal nerves, they pass through the paravertebral ganglia and terminate partly in the prevertebral ganglia (primarily in the inferior mesenteric ganglion), and partly in the pelvic autonomic plexus (hypogastric plexus). The sympathetic postganglionic fibers conjoin with the parasympathetic fibers arising from S_{2-4} spinal segments, to form the autonomic nerve plexus of the penis. The so called nn. erigentes collecting sympathetic and parasympathetic postganglionic fibers then pass through the urogenital hiatus at the pelvic fundus, perforate the urogenital diaphragm and enter the penis, where they innervate glands and smooth muscles of the arteries of the penis.

Mechanism of the erection

In flaccid stade, only a small amount of blood circulates in the erectile bodies of the penis, because the strong musculature in the tunica media of the arteries closes the blood vessels almost completely.

During sexual stimulation, the tone of the arterial smooth muscle decreses in consequence of which the crescentic lumen of vessels becomes many times larger. Therefore, large volume of the blood streams into the erectile bodies and fills up the caverns. The central caverns become first filled up, and they compress the peripheral veins to the inner surface of the tunica albuginea. This makes more difficult the outflow of blood from the erectile bodies. The blood keeps streaming into the erectile

bodies, and the penis grows both in its thickness and length. Although the cavernous bodies and the spongy body become filled up with blood equally during erection, the bloodstream differs in the two erectile bodies. In the two corpora cavernosa, the peripheral caverns are compressed nearly completely, and the outflow of blood decreases to the minimum. The cavernous bodies remain completely rigid. Although, the spongy body becomes also swolen, its peripheral caverns are never compressed as much as in the cavernous bodies, since it is covered by a significantly thiner connective tissue capsule than the tunica albuginea. Thus, the venous outflow in the spongy body is always guaranteed to some extent, and the spongy body remains compressible at the height of the erection as well. This compressibility guarantees the permeability of the urethra at the height of the erection as well, and renders possible the ejaculation of the sperm throuh the urethra.

At the end of sexual stimulation, tone of smooth musculature of arteries supplying erectile bodies returns at the normal level, their crescentic lumen tapers considerably, and the normal circulation becomes gradually restored.

FEMALE GENITAL ORGANS

The female genital organs are divided into the internal and external organs. The internal organs comprise the **ovaries**, the **oviducts**, the **uterus** and the **vagina**.

OVARY

The ovary is an almond-shaped and sized organ. The anterior margin of the ovary is attached to the posterior layer of the broad ligament with a double layer of the peritoneum, the **mesovary.** The posterior margin of the ovary is free and directed toward the ureter separated by the peritoneum. The surface of the ovary is covered by a simple cuboidal epithelium, the embryonic remnant of celoma. In childhood, the surface of the ovary is smooth, and it becomes scarred due to the repeated ruptures of the follicles. After the menopause the ovary decrease in size. The blood supply is provided by the ovarian artery, a branch of the abdominal aorta and the veins flow back to the inferior vena cava.

The role of the ovary is the production of female germ cells and femal sexual hormons. Primordial germ cells migrate from the yolk sac into the body of the embryo. In a genetic female, they differentiate into oogonia that will be surrounded by the follicular epithelial cells. The oogonium with the surrounding epithelial cells is known the primordial follicle. After repeated mitoses, the oogonia differentiate into primary oocytes that enter the first meiotic division and remain arrested in the prophase for years. The maturation of the follicle is continues at the onset of puberty in a 28-day period, known the ovarian cycle. The completion of first meiotic division occurs just before the ovulation, on the 14^{th} day of the ovarian cycle. The ovulation is the rupture of the follicle resulting in the release of the oocyte to the peritoneum-free surface of the ovary. Following ovulation, the oocyte enters the uterine tube and migrates toward the cavity of uterus. Parallel to the follicular maturation, the production of the estrogen commences and it promotes the proliferation of the endometrium of uterus. The estrogen is also responsible for the development of the secondary sexual characters. The wall of the ruptured follicle gives rise to the corpus luteum, the yellow body, which produces the progesterone hormone. The progesterone causes the secretory stage of the mucosa in preparation for the pregnancy. If fertilization does not occur, the corpus luteum degenerates and a scar tissue, the corpus albicans is formed. In case of fertilization, the corpus luteum continues to grow and after the fourth embryonic month it regresses and the hormonal

production continues in the placenta. The ovarian cycle, including the production of the oocye, is continued from the puberty till the menopause. The hypothalamo-hypophyseal system controls the regulation of hormonal production of the ovary.

OVIDUCT, UTERINE TUBE

The paired oviducts, or uteine tubes or Fallopian tubes, are thin-walled tubes lined by mucous membrane. The medial end of the tube is very narrow and it opens into the cavity of the uterus. In the lateral direction it gradually dilates and the ampulla ends in the funnel-shaped infundibulum. The infundibulum opens into the abdominal cavity and with its processes, the fimbriae, overlaps the surface of the ovary. When the oocyte is released from the ovary, it is swept into the infundibulum by the motion of the fimbriae. Upon entering the oviduct, the oocyte migrates toward the uterus. The oocyte is fertilized in the ampulla of the oviduct, and the fertilized ovum, the zygote, by the movement of ciliae of lining epithelium and by peristaltic contraction of the muscular coat is transported to the uterus. The uterine tube lies in the upper part of the broad ligament. The blood supply of the oviduct is provided by the branches of the uterine and ovarian arteries.

Since the abdominal end of the uterine tube is open, the peritoneal cavity in female communicates with the exterior. It explains the relatively large incidence of the inflammatory processes in the pelvic cavity of female. Pelvic inflammation may result in the adhesion of the wall of uterine tube and prevents the transport of germ cells causeing infertility. Another possible consequence of the adhesion is that the zygote is not able to pass along the tube to the uterus and it is implanted into the mucosa of the uterine tube. The ectopic tubal pregnancy may result in rupture of the uterine tube and the subsequent hemorrhage threatens the mother's life.

UTERUS

The uterus is a pear-shaped, hollow muscular organ, lined by mucous membrane, the endometrium. It is located in the center of the pelvic cavity and its length measures appr. 7-8 cm.

> Under the influence of ovarian hormones the endometrium of uterus undegoes cyclic changes. If fertilization does not occur, the functional layer of the endometrium is shedding off during the menstruation. The length of the menstrual cycle is 28 days and the first day of menstruation is regardede as the first day of cycle.

The upper, wider part of the uterus is the **body** and it is continued downward into the narrower neck or **cervix**. The uppermost part of the body is the **fundus** located between the attachments of the uterine tubes. The cervix is continued directly into the wall of the vagina. The part of the cervix above the vagina is the supravaginal portion of the cervix, whereas its intravaginal part is called as the vaginal protion of the uterus or briefly the portio.

The cavity of the uterus is a flattened, triangle-shaped slit in an anteroposterior direction. It is divided into three parts: **cavity of body, isthmus** and **cervical canal**. The base of the triangle is bordered by the openings of the uterine tubes, the apex is continued into the isthmus of uterus. The upper part of the isthmus is bordered by the **internal anatomical os (orifice)** whereas the lower border is the **internal histological os (orifice)**. The spindle-shaped cervical canal is continued into the vagina through the **external os (orifice)**. During parturition the external os of uterus is ruptured and its round –shaped form is changing into a narrow slit. The implantation of the embryo occurs into the endometrium near to the fundus. Parallel to the growing of the embryo, the cavity of the uterus is expanding and from the third month of pregnancy the isthmus is also involved in the cavity of pregnant uterus. After parturition, the involution of uterus results in the restoration of the uterus almost to its original size. The cervical canal is closed during the pregnancy and it is dilated relatively during parturition.

The uterus is located in the pelvic cavity behind the urinary bladder, in front of the rectum and above the vagina. The position of the uterus is defined as **anteversion-anteflexion**. The **anteversion** is defined as a 70-degree bending of the axis of cervix

in relation to the axis of the vagina. The axis of the vagina is bended posteriorly with a 30-40-degree in relation to the vertical line. At the isthmus, the axis of the body of the uterus is bended with a 70-80-degree in relation to the axis of the cervical canal, called as the **anteflexion**. Thus, the body of the uterus is found in an almost horizontal plane above the urinary bladder, and its position is varied with the fullness of the bladder. The vaginal portion of the uterus is indirectly related to the rectum through the wall of vagina.

The uterus is an infraperitoneal organ. The peritoneum covers the entire body of the uterus and reflects to the urinary bladder forming the **vesicouterine pouch**. At the posterior surface of the uterus the peritoneum continues from the body to the supravaginal portion of the cervix and after covering the posterior fornix of vagina it reflects to the rectum and gives rise to the **rectouterine,** or **Douglas pouch**. Laterally to the uterus, the peritoneum continues as the **broad ligament**. The two layers of the broad ligaments are directed to the lateral wall of the true pelvis. Blood vessels, lymphatics and nerves of the uterus are found between the layers of the broad ligament together with remnants of embryonic structures that may develop into malignant tumors.

> The Douglas pouch is the deepest point of the pelvic cavity in female. Consequently, the blood or any fluid deriving from inflammation or other diseases, such as exudates, transsudates, is accumulated in the Douglas pouch. The Douglas pouch is easily accessed, through the posterior fornix of vagina, to obtaining a sample of fluid for further analysis.

The **attachment of the uterus** is provided by the **suspending** and **supporting** structures. The suspending structures are the broad ligament, the round ligament of the uterus and the pelvic visceral fascia. The round ligament is followed into the labium major through the inguinal canal. Principal components of the supporting structures are the thickenings of the pelvic visceral fascia that contain smooth muscle cells and connective tissue. The pelvic visceral fascia is condensed either into ligaments, or thickenings around the pelvic organs. The most important component of the pelvic visceral fascia is the **parametrium** located between the two layers of the broad ligament extending from the supravaginal portion of the uterus to the lateral wall of the pelvis. The supporting structures of the uterus are the fasciae and muscles of the perineum. The **pelvic diaphragm** forms a funnel-shaped fibromuscular sheet at the

floor of the pelvis and attached to the parametrium. In the anterior part of the perineum, the **urogenital diaphragm** contributes to the support of the uterus by inserting in the wall of the vagina.

VAGINA

The vagina is a fibromuscular tube, its length measures 7-9 cm. During sexual intercourse it receives the penis and the ejaculatum and it forms the birth canal during parturition. The upper part of vagina is attached to the cervix with a recess, the **vaginal fornix** or pouch. The posterior part of the fornix shows toward the rectum and the Douglas pouch, the lateral fornices are in contact with the ureters. The anterior fornix is attached to the urinary bladder with loose connective tissue, whereas the anterior wall of the vagina is fused with the urethra. The external opening of vagina is in the **vestibule of vagina**, a cleft between the labia minora. In the external opening of vagina, a tiny fold of mucous membrane forms the hymen that is ruptured and causes minor bleeding at the first sexual intercourse.

FEMALE EXTERNAL GENITAL ORGANS

The external genital organs are located in the perineal region. Anatomically, the perineum is a rhomboid-shaped area bordered by the pubic symphisis, the ischial tuberosities and the coccyx. The outlet of the pelvis is closed by the pelvic and urogenital diaphragms consisting of perineal muscles and their upper and lower fasciae. The urethra and vagina pierce both the pelvic and urogenital diaphragm, whereas the rectum is passing through the pelvic diaphragm. The pelvic and urogenital diaphragm play an important role in supporting of the urterus.

Clinically, the perineum is located between the vaginal and anal orifices. In order to help the delivery of the infant and prevent the tearing of perineal structures during parturition, a surgical incision of the perineum, episiotomy, is performed starting from the posterior wall of vagina in a posterolateral direction.

Labia majora are folds of fatty skin that border the pudendal cleft. The labia majora are continued posteriorly to the perineum, and anteriorly to the **mons pubis**. After puberty, the mons pubis is covered with pubic hair. The labia majora cover the folds of **labia minora** that surround the vestibule of vagina. The vestibule of vagina receives the opening of urethra, vagina and the **greater (Bartholini)** and **lesser vestibular glands**. These glands produce a mucous secretion which moistens the vestibule of vagina. The erectile tissue of the **bulbs of vestibule** is located along the sides of the vagina under cover of the labia majora. Another erectile tissue, the **clitoris**, is located in front of the urethral opening. The structure of erectile tissues is similar to the erectile bodies of penis, and their blood vessels are dilated and filled with blood during the sexual stimulation.

DEVELOPMENT OF THE GENITAL ORGANS

Although the sex of the embryo is determined at the time of fertilization, no morphological differences are recognizable in the male and the femal until the seventh week of development. The indifferent gonads appear as **genital ridges** medially to the mesonephric ridge as the proliferation of the celoma epithelium at the posterior abdominal wall. The **primordial germ cells** migrate from the yolk sac into the genital ridges become by aggregations of penetrating celomic epithelium, the **primitive sex cords**.

In male, under the influence of the Y chromosome, the primitive sex cords continue to proliferate and give rise to the **testicular cords**. The testicular cords develop into sequence of the seminiferous tubules, the straight tubules and the rete testis. The Leydig cells originate from the mesenchyme of the genital ridge. The testis begins to descend at the end of the second month and remains in the abdominal cavity until the seventh month when it moves to the inguinal region. Parallel to the beginning of the descent of the testis, the peritoneum evaginates as the processus vaginalis and with the layers of the abdominal wall they descend into the scrotal swelling by way of the inguinal canal. By the end of the ninth month the testis reaches the scrotum. All along its route to the scrotum, the testis maintains its retroperitoneal position.

In female, the primitive sex cords break into spherical clusters containing the primordial gem cells that develop into the **oogonia**. The surface epithelium continues to proliferate and gives rise to a second generation of sex cords that penetrate into the underlying mesenchyma and ensheath the oogonia as the **follicular epithelium**. The ovary descends into the pelvic cavity.

In both sexes, two pairs of genital ducts, the **mesonephric** or **Wolffian duct** and, laterally to it, the **paramesonephric** or **Mullerian** duct develop during the early embryonic period. The Mullerian ducts cross the caudal part of the Wolffian duct and fuse to form the **uterine canal**. The Wolffian ducts and the uterine canal opens into the posterior part of urogenital sinus which is the anterior derivative of the cloaca. **In female**, the cranial part of the **Mullerian ducts** develop into the uterine tubes, whereas the uterine canal forms the uterus and a smaller part of the vagina. The larger part of

the vagina develops from the urogenital sinus. **In male**, the Mullerian duct degenerates and remain as embryonic remnants. The **Wollfian duct** develops into the ductuli efferentes testis, the ductus epididymis, the ductus deferens, the seminal vesicle and the ejaculatory duct. The prostate develops from the urogenital sinus. **In female**, the Wolffian ducts degenerate and their remnants are found between the layers of the broad ligament.

The **external genital organs** develop from the same primordial structures in both sexes. At the early indifferent stage, the paired **urethral folds** and **genital swellings** and the unpaired **genital tubercle** are recognizable around the urogenital membrane. By the rupture of the urogenital membrane, the cavity of the urogenital sinus opens into the amniotic cavity. **In male**, the genital tubercle develops into the corpora cavernosa of penis, whereas the fusion of urethral folds gives rise to the corpus spongiosum of the penis and the urethra. The fusion of the genital swelling results in the formation of the scrotum. **In female**, the genital tubercle forms the clitoris. The urethral folds develop into the labia minora and the labia majora which are the derivatives of the genital swellings.