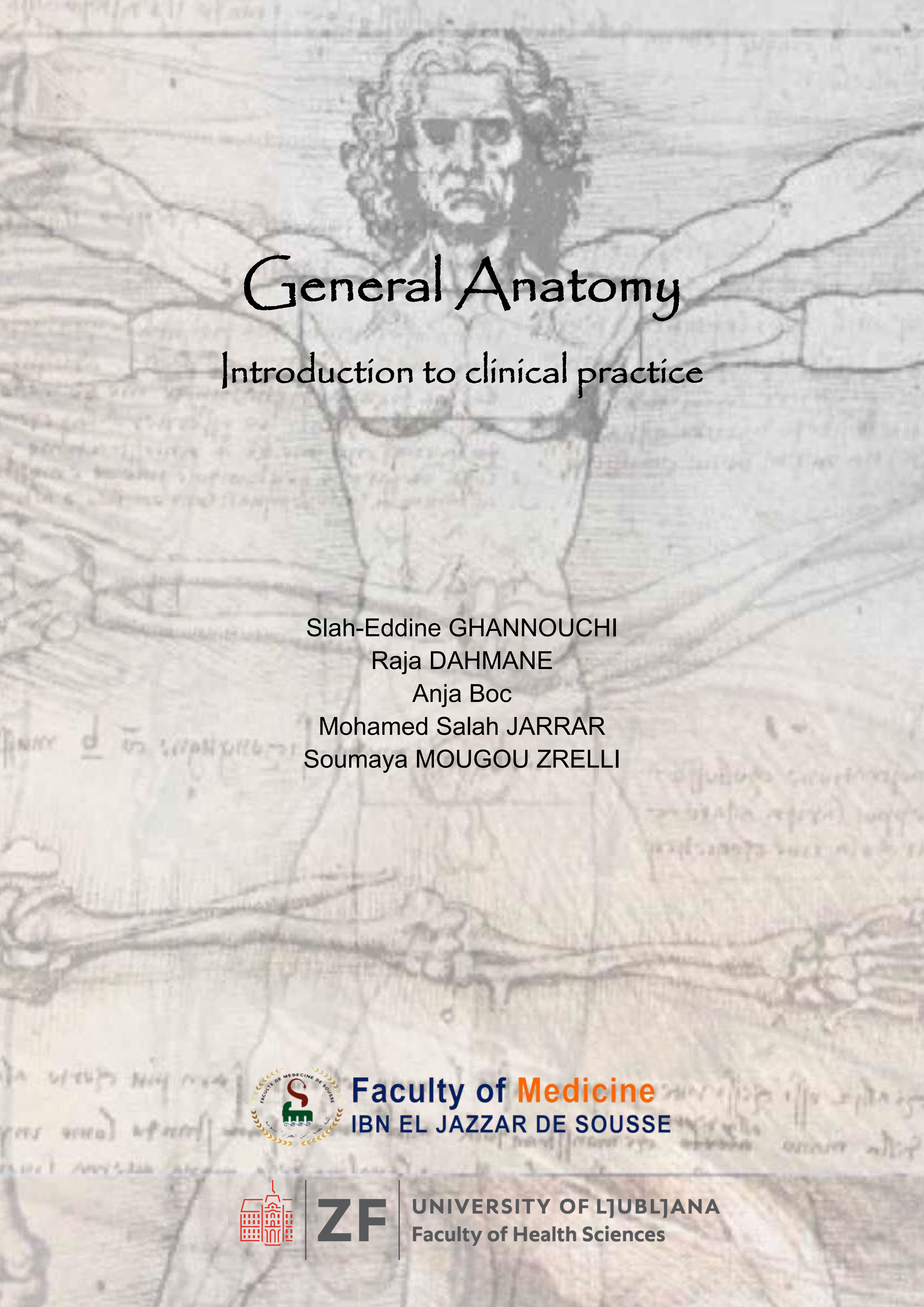


# General Anatomy

## Introduction to clinical practice

Slah-Eddine GHANNOUCHI
Raja DAHMANE
Anja Boc
Mohamed Salah JARRAR
Soumaya MOUGOU ZRELLI

Faculty of Medicine
IBN EL JAZZAR DE SOUSSE

ZF
UNIVERSITY OF LJUBLJANA
Faculty of Health Sciences

University of Ljubljana Press
Faculty of Medicine, Sousse

# General Anatomy

## Introduction to clinical practice

**Professor Slah-Eddine GHANNOUCHI**
**Professor Raja DAHMANE**
**Assistant Professor Anja BOC**
**Professor Mohamed Salah JARRAR**
**Professor Soumaya MOUGOU ZRELLI**

**Design and management**
**Doctor Sihem KHELIFI**
**Mr. Robert SOTLER**

**General Anatomy: Introduction to clinical practice**

**Authors:** Slah-Eddine Ghannouchi, Raja Dahmane, Anja Boc, Mohamed Salah Jarrar, Soumaya Mougou Zrelli
**Reviewers:** Marija Hribernik, Vita Čebašek, Tina Levec

**Published by:** Faculty of Medicine of Sousse and University of Ljubljana Press
**For the publisher:** Mohamed Ben Dhiab, dean of the Faculty of Medicine of Sousse and Gregor Majdič, rector of University of Ljubljana
**Issued by:** Faculty of Health Sciences, University of Ljubljana
**For the issuer:** Martina Oder, dean of the Faculty of Health Sciences, University of Ljubljana

**Design and management:** Doctor Sihem Khelifi, Mr. Robert Sotler
**Authors of photographies and figures:** Lassaad Ben Regaya, Nader Naouar, Nadia Mama Larbi, Khaled Maaref, Amira Berrich Amara, Mounir Landolsi, Wejdi Chermiti, Yasser Bechikh, Amel Amamou, Jalel Dahmane, Sabri Youssef, Vili Gošnak, Khaldoun Ghannouchi, Molka Zlitni and all the students of the Anatomy Club (Associa-Med de Sousse), Rihab Boularès, Inès Hachfi Bechedli, Lotfi Fennani

Sousse and Ljubljana, 2024
First digital edition.
Publication is free of charge.
Publication is available at: http://ebooks.uni-lj.si/ and https://www.zf.uni-lj.si/images/stories/datoteke/Zalozba/General.pdf
DOI: 10.55295/9789612973971



Kataložni zapis o publikaciji (CIP) pripravili v Narodni in univerzitetni knjižnici v Ljubljani
**COBISS.SI**-ID **207717635**
ISBN 978-961-297-397-1 (PDF, Založba Univerze v Ljubljani)

# Preface

The first questions we ask ourselves while leafing through a new anatomy book are: “What is new in it? Is it useful? Is not anatomy set in stone ... especially general anatomy, designed to reel off new concepts for a beginner in medical disciplines, making it a daunting discipline?”
Since anatomy is based on a morphological description of organs, their position in the body and their relationships to each other, it has been revolutionised by the development of new imaging technologies, which naturally affects the methods of examination. We have therefore made use of them.
In this way, the literary description of an organ, its location, vascularity, innervation, and relationships is no longer necessary. Video eliminates the need for it. Videos are easily and directly accessible, as is “YouTube”. This technology has been used in online education. Video clips, called capsules, are organised into teaching modules such as MOOCs (Massive Open Online Courses) and provide flexible ways to take courses.
However, for a beginner, it is important to be guided in the first steps and have a clear idea of what he already knows and what he still needs to learn. This can be provided by teaching platforms such as Moodle. We have made use of this by depositing courses at the Université Virtuelle de Tunis and also by monitoring our students' questions.
We have expanded the use of virtual teaching through social media, in this case Facebook, which provides great flexibility in communication. Our experience with this virtual instruction has been compelling, and we are working to expand it further.
The fact remains that paper is a physical medium that is reassuring for both the student and the teacher. It allows us to follow and develop different phases of the lesson. This is the goal we have set for this work, which is the fruit of decades of experience.

**Review of the Textbook "General Anatomy – Introduction to Clinical Practice"**

Publisher: Faculty of Medicine, Sousse and University of Ljubljana.

The textbook "General Anatomy – Introduction to Clinical Practice" is designed for students of medicine, health sciences, pharmacy, and dental surgery as they embark on their first encounter with anatomy, a fundamental medical science. The book covers the normal macroscopic morphology of the human body by organ systems.

This comprehensive textbook spans 299 pages and is divided into 10 chapters. The first chapter, "Introduction," explains basic anatomical terms used to describe anatomical structures, anatomical planes, anatomical positions, and the division of the body into regions. Chapters 2 to 10 describe individual organ systems. Each chapter is systematically and logically divided into several subsections, making it easier to understand the specific anatomy of a particular organ system.

The descriptions of anatomical structures are brief and concise, covering only the main characteristics without delving into details, which is very sensible for an initial encounter with the study of anatomy. Some chapters include basic histological and/or physiological features of the organ system, as well as common pathological changes. This makes the text more interesting, comprehensible, and meaningful for the study of anatomy.

The descriptions of anatomical structures are well complemented by visual material, which significantly aids in understanding the anatomy of a specific body part. A total of 314 images include simple and clear sketches, X-ray and CT images, photographs of organs during surgical procedures, and photographs of anatomical preparations.

The textbook "General Anatomy – Introduction to Clinical Practice" encompasses the anatomy of the entire human body. Students can acquire all the necessary knowledge for further studies where understanding the body's structure is a mandatory foundation. Due to the short and clear descriptions, as well as the illustrative and simple sketches and other visual materials, this textbook can serve anyone who wishes to refresh or newly acquire basic knowledge about the structure of the human body.

Assist. prof. Vita Čebašek, PhD, M.D.

Prof. Marija Hribernik, PhD, M.D.

Ljubljana, July 2024

## Acknowledgement

The authors would like to thank:

Associate Professor Lassaad Ben Regaya
Professor Nader Naouar
Professor Nadia Mama Larbi
Professor Khaled Maaref
Doctor Amira Berrich Amara
Professor Mounir Landolsi
Professor Wejdi Chermiti
Professor Yasser Bechikh
Doctor Amel Amamou
Professor Jalel Dahmane
Professor Sabri Youssef
Mr. Vili Gošnak
Doctor Khaldoun Ghannouchi
Doctor Molka Zlitni and all the students of the Anatomy Club
(Associa-Med de Sousse)
Mrs. Rihab Boularès
Mrs. Inès Hachfi Bechedli
Mr. Lotfi Fennani

Reviewers list:

Prof. Marija Hribernik

Assist. Prof. Vita Čebašek

Lect. Tina Levec

## Table of contents

# Chapter 1 - Introduction

**The objectives of this chapter are to:**

1. Define types of human anatomy: systemic, regional, radiological, functional.
2. Define biological levels of organisation: cell, tissue, organ, organ system.
3. Define vegetative life and name the systems involved.
4. Define relational life and name the systems involved.
5. Define the genital system.
6. Name the main parts of the human body.
7. Name different regions of the human body.
8. Define the standard anatomical position.
9. Define the anatomical planes: sagittal, frontal, transverse.
10. Define the anatomical axes.

## 1 - Introduction

Human anatomy is a morphological science which studies the forms and structures of the human body. Anatomical knowledge is essential and therefore obligatory part of health sciences. Anatomy unjustly bears a reputation of a difficult subject at the level of understanding, but especially at the level of memorising concepts that are new to young students beginning their study.

Anatomy can be associated with several adjectives. One speaks of general, descriptive, topographical, artistic, functional anatomy, etc. The goal is always the same; namely, a good knowledge of the human body structure. The difference is only in the approach, depending on the objective.

Besides mastering the insight into the human body structure, anatomy begins to teach the future doctors the art of description which will be useful in their daily practice.

In this book, the general human anatomy is introduced through the description of all the elements that compose the human body, and alongside, of course, it introduces the basic medical vocabulary for all other medical and healthcare disciplines. The practical applications illustrate the importance of a perfect knowledge of anatomy.

# 2 - Anatomy Definitions

In this chapter, we present different definitions of anatomy, based on different approaches.

Two major types of anatomy are gross and microscopic anatomy.

- Gross anatomy refers to the macroscopic structure of the body and describes the structures visible with the naked eye.
- Microscopic anatomy, also known as histology, describes the structures that can be examined through a microscope.

Gross anatomy can be approached through two main principles:

- Systemic anatomy describes the body by defined organ systems.
- Regional anatomy describes body by defined body parts and deals with the relationships between various organs of the same anatomical region and their projections onto the skeleton and body surface.

According to the point of interest, there are several subtypes of anatomy:

- Descriptive anatomy describes the structure of body parts, describing their location, orientation, shape, dimensions, weight, colour, texture, internal structure, etc.
- General anatomy describes the body in its entirety, with all the consisting organs grouped according to their functions.

Organs that perform the same function form an organ system.

- Radiological anatomy describes images produced by various imaging modalities, i.e. conventional radiography (plain X-ray), computed tomography (CT), magnetic resonance imaging (MRI), ultrasonography (US), and nuclear medicine imaging.
- Surgical anatomy is the anatomy applied to surgery, describing the approaches to various organs and the obstacles a surgeon must avoid.
- Functional anatomy addresses the changes in position, orientation and morphology of an organ or group of organs during their function. It differs from biomechanics, which attempts to apply the laws of mechanics of solid and fluid materials to the human body.
- Superficial or palpatory anatomy is the study of the external forms and reliefs of the body. It is the basis for clinical observation by palpation, and for artistic anatomy.
- Anthropological anatomy studies the differences between individuals and races.
- Organogenesis studies the formation and development of organs. It differs from embryology, which deals with the development of the embryo (the first two months of intrauterine life), and the foetus (from the third month of intrauterine life until birth).
- Paediatric anatomy studies human development and growth from birth to late adolescence.
- Teratology studies congenital anomalies, malformations, and monstrosities.
- Ontogenesis studies the origination and development of an organism, usually from the time of fertilization of the egg to adulthood.
- Phylogenesis studies the evolution of the species.

# 3 - General organisation of the human body

The human body is a composite of cells. Each type of cells has its specialisation.

Cells with the same specialisation form tissue. There are four basic tissue types in human body: epithelial tissue, connective tissue, muscular tissue, and nervous tissue.

Different tissues form organs. An organ is a group of tissues that performs a specific function (e.g. stomach, kidney, etc.).

Organs are grouped into organ systems. There are 11 organ systems in human body: integumentary system (skin), skeletal system, (bones and joints), muscular system, nervous system, endocrine system, cardiovascular system (heart and vessels), lymphatic system, respiratory system, digestive system, urinary system, and reproductive systems.

To help you understand the anatomy, we will introduce the human body according to the three main functional groups.

- The apparatuses of relational life: they sum up all the apparatuses that put the human body in contact with its environment.
- The apparatuses of vegetative life, which ensure the self-regulation of the human body and which are autonomously managed.
- The reproductive apparatus, which enables the continuation of the human species.

# 4 - Landmarks and plans

For each description, a marker or origin position is mandatory. The human reference position, known as the standard anatomical position, is defined as a person standing erect, with upper limbs extended by the side of the trunk with the palms facing forward (thumbs outward), lower limbs extended with the feet parallel and together, and the head facing forward, the gaze directed toward the horizon. The position of organs is described relative to this reference position.

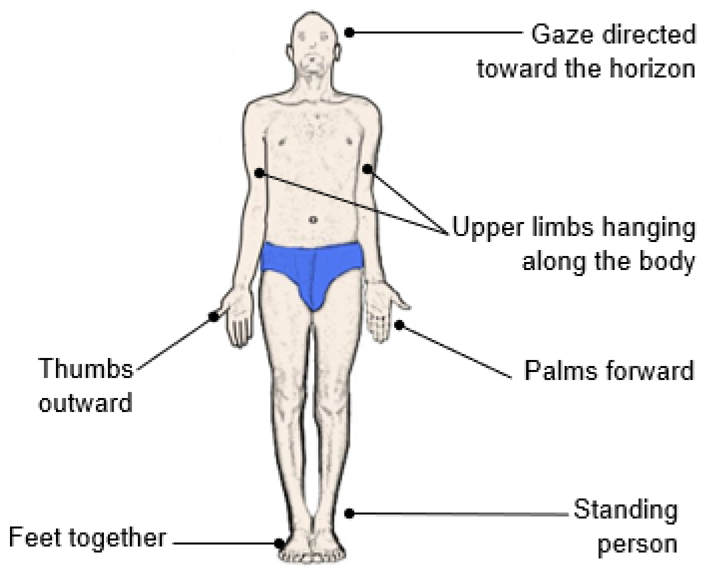



***Figure 1: The standard anatomical position.***

At this point we will also define the anatomical planes. Three reference groups of planes are distinguished, which are perpendicular to each other. Each group contains multiple parallel planes.

- The coronal (frontal) planes are vertical planes that are parallel to the forehead.
- The transverse (horizontal) planes are parallel to the horizon.
- The sagittal planes are vertical antero-posterior planes. The sagittal plane that passes through the midline of the body and divides the body into right and left halves is called the median plane.

Based on these scales, we will define adjectives which describe the position of two structures relative to each other:

- Cranial or superior to denote what is above.
- Caudal or inferior to denote what is below.
- Ventral or anterior to denote what is in front.
- Dorsal or posterior to denote what is behind.
- Lateral to denote what is further away from the median plane of the body.
- Medial to denote what is nearer to the median plane of the body.
- Proximal to define what is nearer to the point of attachment to the body (on the limbs).
- Distal to define what is further away from the point of attachment to the body (on the limbs).

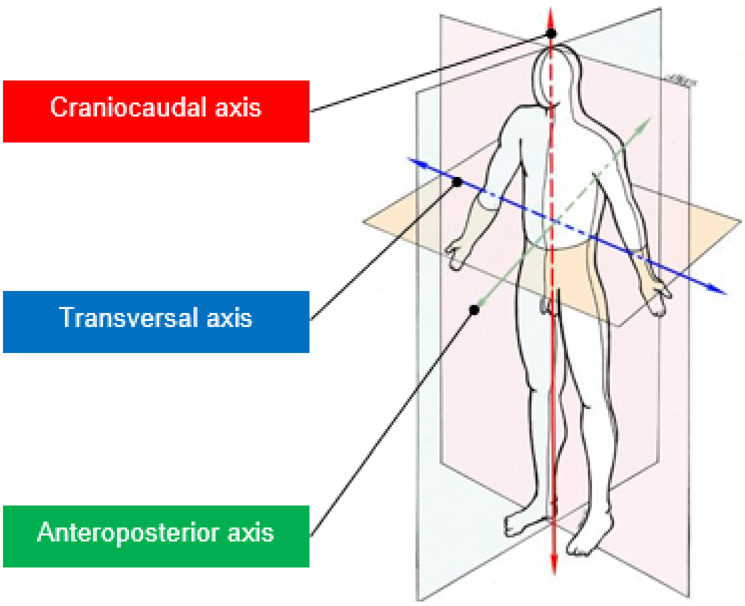



***Figure 2: The reference planes and axes.***

In addition to these standard planes and axes, specific planes and axes can be defined for each organ in order to obtain an easily interpretable section that facilitates understanding. An example is a plane passing through the four chambers of the heart and the longitudinal axis of the heart.

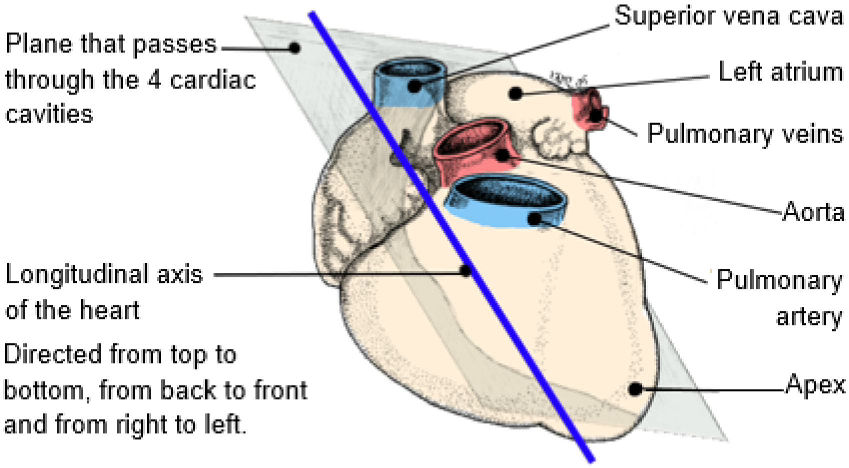



***Figure 3: The longitudinal axis of the heart. Anterior view.***

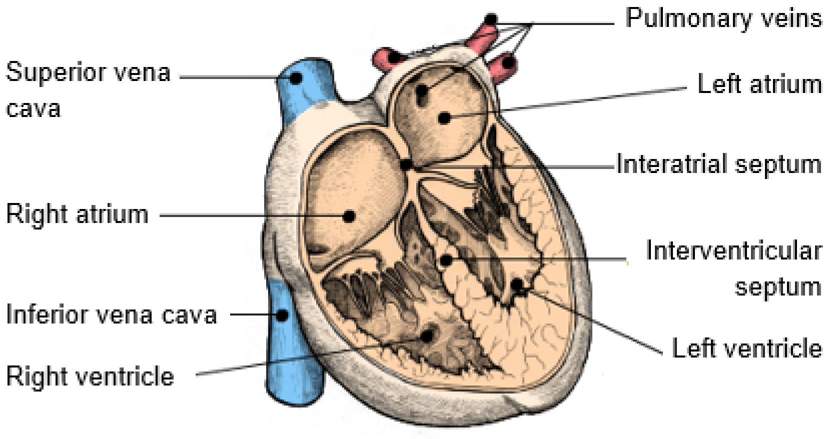



***Figure 4: Frontal section through the four cardiac cavities. Anterior view.***

A second example: axes can be used to study positions of the bones in relation to orthonormal landmarks, in relation to the reference position or joint amplitudes of the human body. For example, the diaphyseal axis of femur is oblique. If we want to study walking, we need to represent a mechanical axis of femur which allows us to study the transmission of forces from the femoral head to the centre of the femoral condyles.

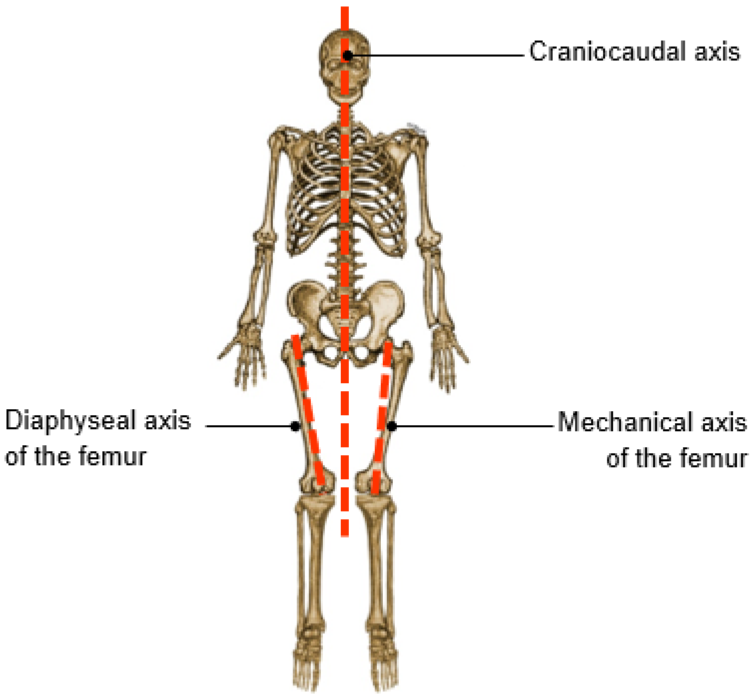



***Figure 5: The diaphyseal and mechanical axes of femur.***

# 5 - Main parts and regions of the human body

The human body can be divided into different parts and regions. The trunk supports the head over the neck. The four limbs are connected to the trunk by the girdles.

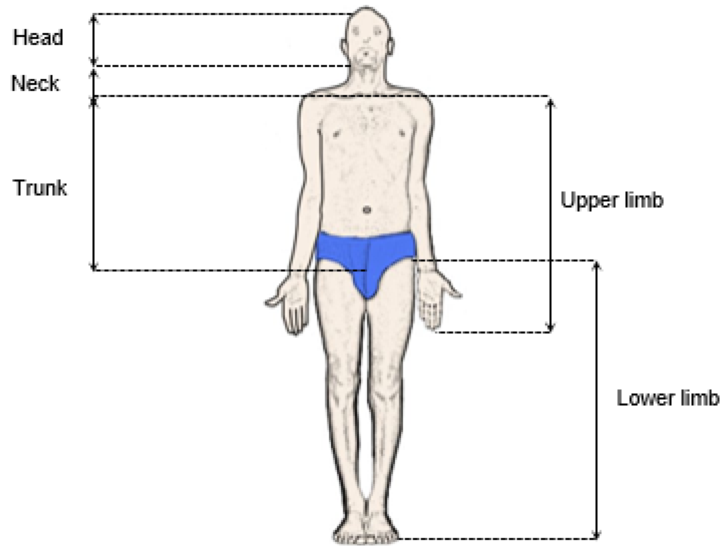



***Figure 6: The main parts of the body.***

## 5.1 - Head

The head is divided into the neurocranial part and the face. The skeleton of the head is formed by the skull or cranium, and the mandible.

**Neurocranial part of the head**

The neurocranial part of the head includes the forehead, occiput, temple, and auricle. Inside the neurocranial part is the cranial cavity.

**Face**

The face is the lower anterior part of the head, in front of the cervical spine. On the face, we describe the eyes, cheeks, external nose, mouth, and chin.

## 5.2 - Neck

The neck can be divided into two parts:

- A dorsal or nuchal region consists of a mass of muscles that hold the head in a vertical position.
- A prevertebral region contains the oesophagus, trachea, thyroid gland, and vessels and nerves leading to or from the head. It also contains muscles.

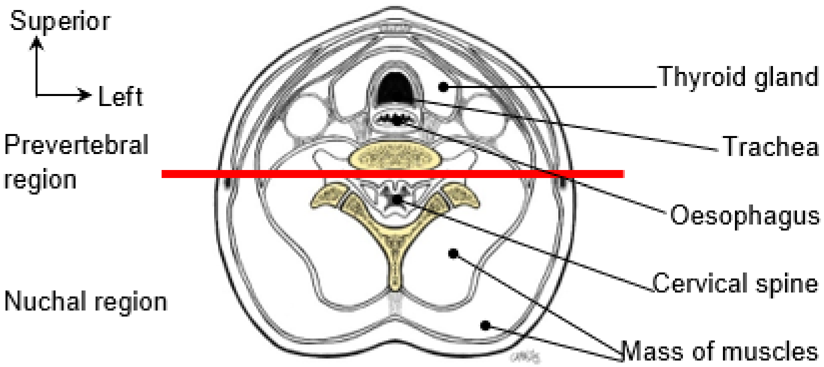



***Figure 7: Cross-section of the neck. Inferior view.***

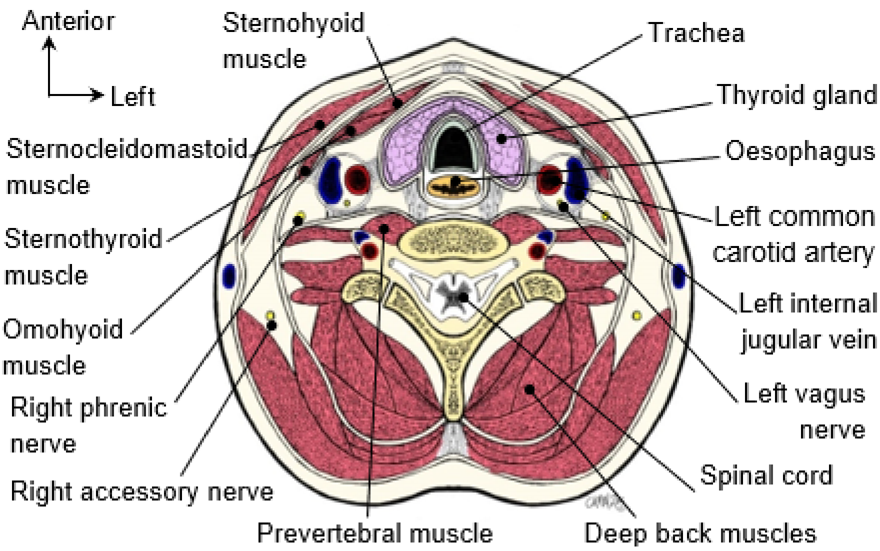



***Figure 8: Cross-section of the neck passing through the vertebra C7. Inferior view.***

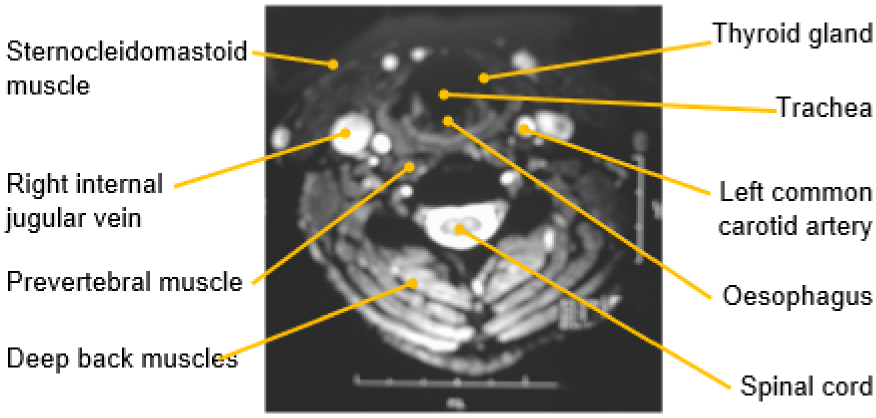



***Figure 9: MRI, cross-section of the neck passing through the vertebra C7. Inferior view.***

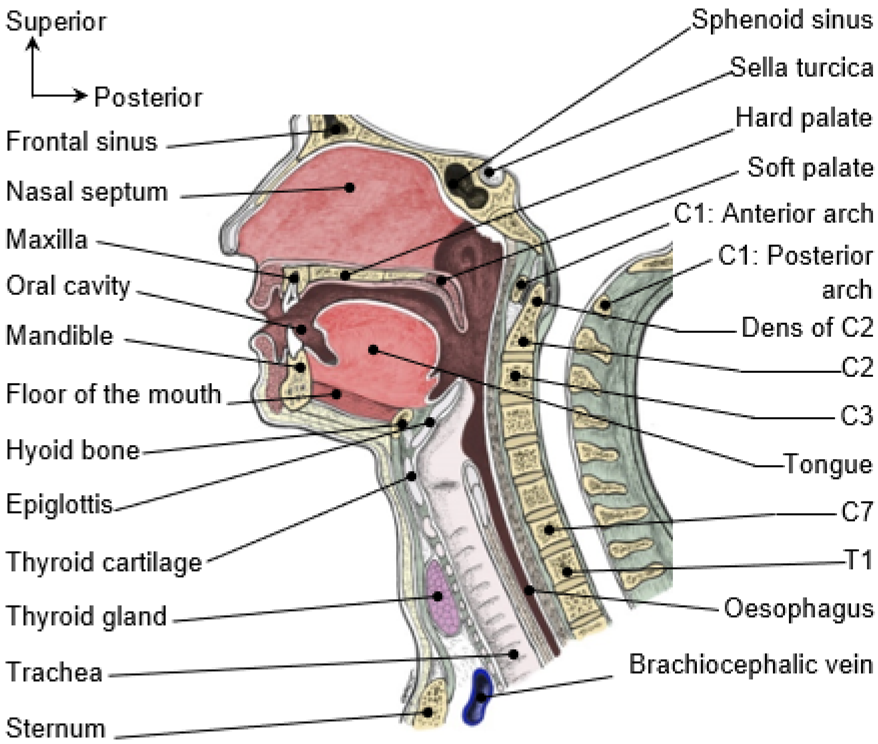



***Figure 10: Median section of the face and neck. View from the left.***

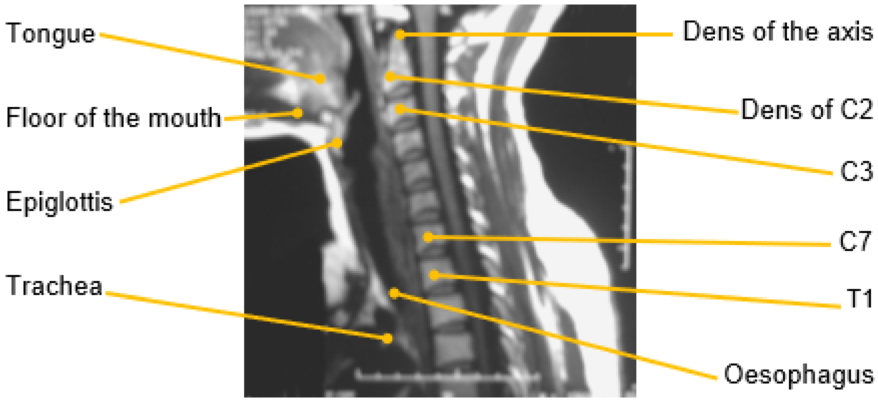



***Figure 11: MRI, median section of the neck. View from the left.***

## 5.3 - Trunk

The trunk is composed of the anterior trunk and the back. The anterior tunk is divided in three parts – thorax, abdomen and pelvis.

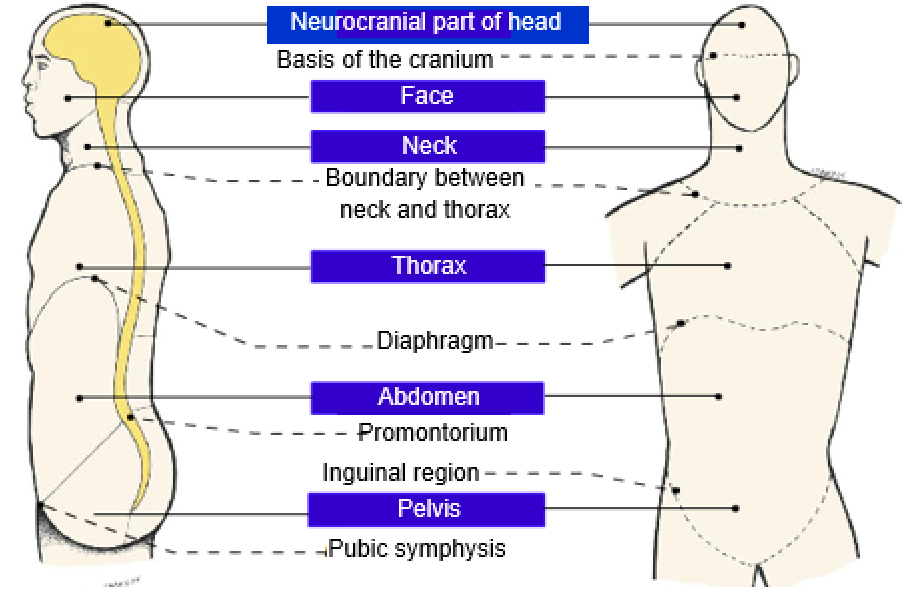



***Figure 12: Parts of the head and trunk.***

### Thorax

The thorax is the uppermost part of the trunk. Its upper boundary is a fictitious plane at the level of superior thoracic aperture, separating thorax from the base of the neck. Its lower boundary is formed by the inferior thoracic aperture and the diaphragm, separating the thoracic cavity from the abdominal cavity. The dorsal boundary is the thoracic spine, and the ventral boundary the sternum.
The walls of the thorax enclose the thoracic cavity.

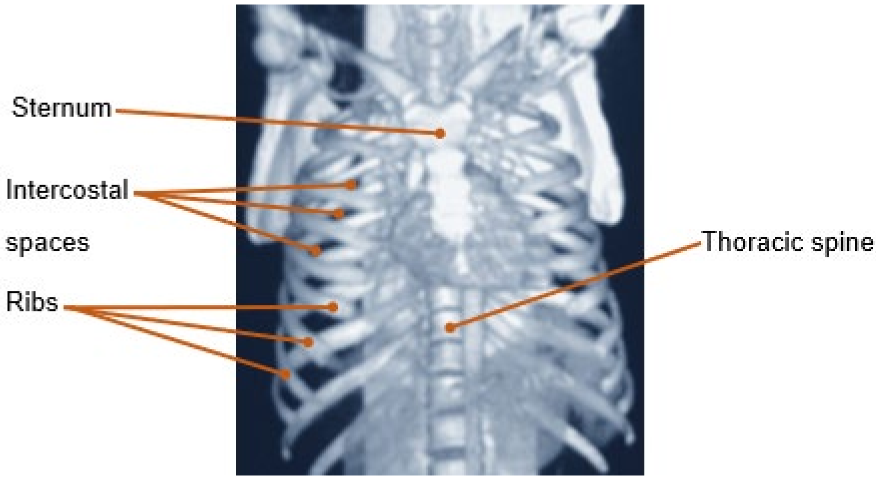



***Figure 13: 3D reconstruction of the thorax skeleton. Anterior view.***

### Thoracic cavity

The thoracic cavity is divided into paired pleuro-pulmonary compartments and the mediastinum.

The mediastinum is bounded by the superior thoracic aperture above, by the diaphragm below, and by the mediastinal pleura laterally.

Mediastinum is further divided (Figure 19) in the superior and inferior mediastinum. The superior mediastinum lies above the pericardial sac. The inferior is divided into three parts: the anterior mediastinum, located in front of the pericardial sac, middle mediastinum, which includes the pericardial sac with heart, and posterior mediastinum, located behind the pericardial sac.

Some structures are found only at one level of the mediastinum (e.g. the heart), while others cross different parts of the mediastinum (e.g. the oesophagus).

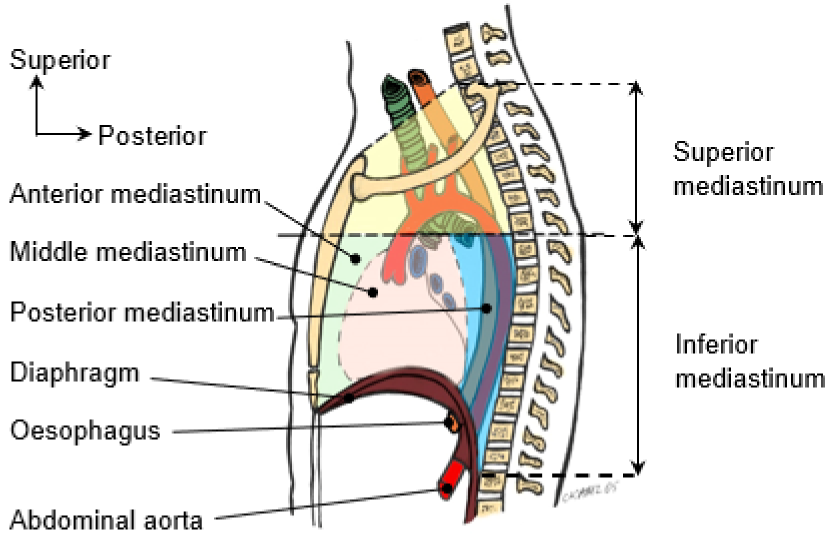



***Figure 14: The regions of mediastinum. Left lateral view.***

The left and right pleuro-pulmonary compartment include the lungs enveloped in a double layer of a serous membrane named pleura. Both pleural layers enclose the pleural cavity.

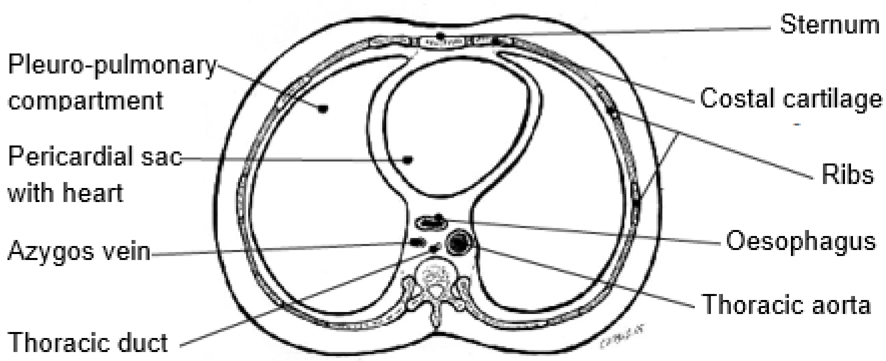



***Figure 15: The regions of thorax. Cross-section, inferior view.***

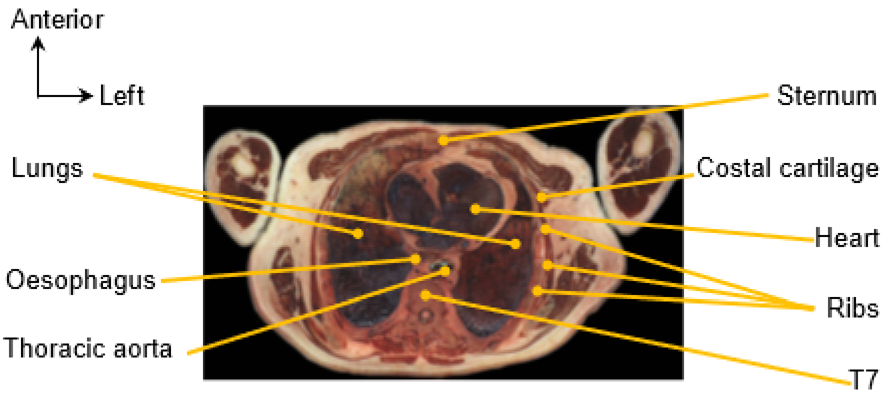



***Figure 16: Cross-section of thorax through the vertebra T7. Inferior view.***

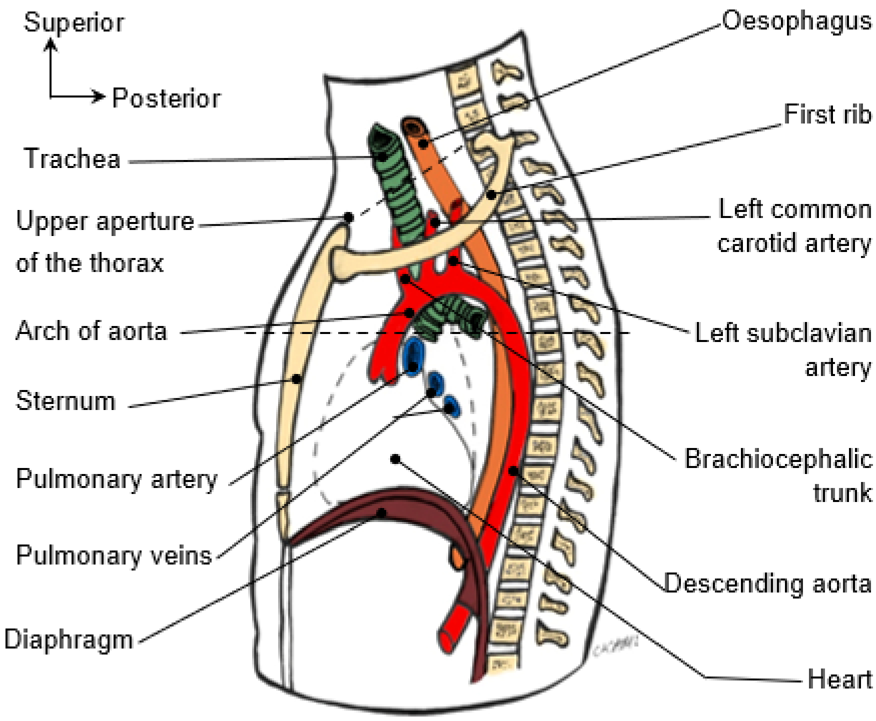



***Figure 17: The structures of mediastinum. Left lateral view.***

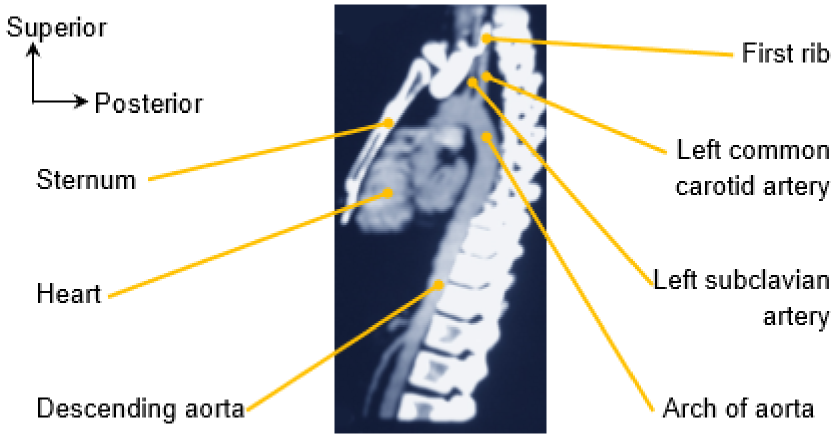



***Figure 18: CT reconstruction of the mediastinal organs. Left lateral view.***

### Abdomen

The abdomen is the middle part of the trunk. Its upper boundary is formed by the inferior thoracic aperture and the diaphragm. Its lower boundary is a fictitious plane at the level of pelvic inlet (linea terminalis), separating the abdominal cavity and the pelvic cavity. The dorsal boundary is formed by the lumbar spine and the quadratus lumborum muscle.

The walls of the abdomen enclose the abdominal cavity.

### Abdominal cavity

The abdominal cavity is divided into two major regions, the peritoneal cavity anteriorly and the retroperitoneal space posteriorly.

The peritoneal cavity is enveloped in a serous membrane named peritoneum. Various peritoneal structures divide the peritoneal cavity into compartments. The peritoneal structure that connects the transverse colon to the posterior abdominal wall (the transverse mesocolon) divides the cavity into upper and lower part. The upper part (supracolic compartment) contains the abdominal part of the oesophagus, stomach, and two solid organs, liver and spleen. The lower part (infracolic compartment) contains the rest of the digestive tract.

The retroperitoneal space contains the abdominal aorta, inferior vena cava, kidneys, ureters, adrenal glands, duodenum, pancreas, etc.

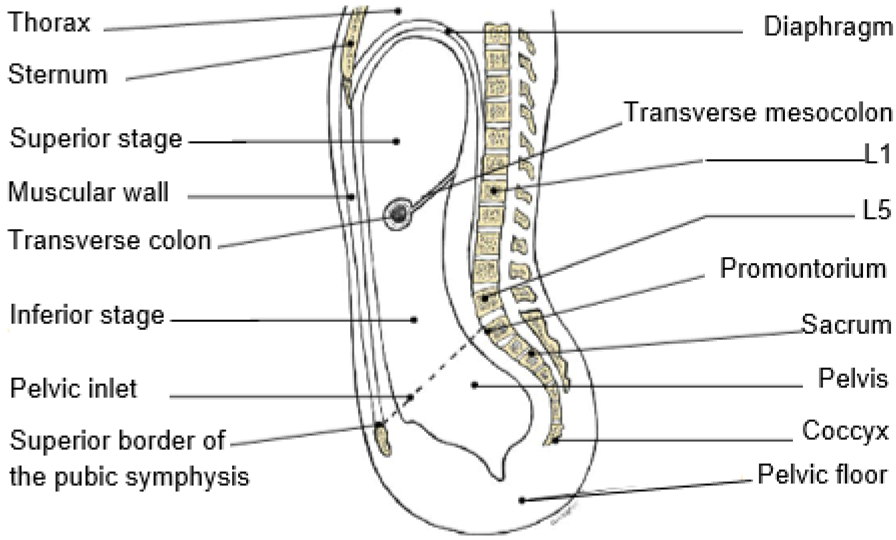



***Figure 19: The compartments of the abdominal cavity. Median section, view from the left.***

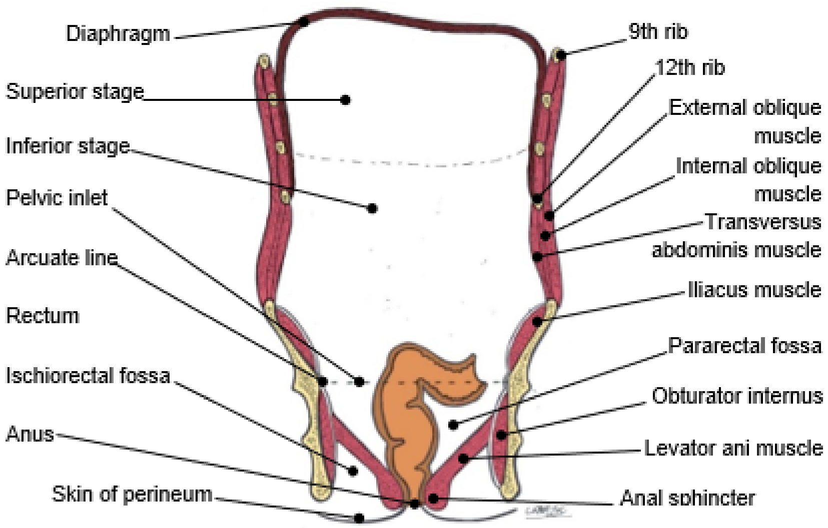



***Figure 20: The walls of the abdominal cavity. Frontal section, anterior view.***

## Regions of abdomen

The abdomen can be divided into nine regions by two vertical midclavicular planes, and two horizontal planes: one at the level of the lower edge of the 10th ribs, and the other at the level of the iliac crests. The abdominal organs project into these regions. For example:

- The right hypochondrium: the liver.
- The left hypochondrium: the spleen.
- The epigastric region: the stomach.
- The right iliac fossa: the appendix, the right ovary.
- The left iliac fossa: the sigmoid colon, the left ovary.
- The hypogastrium: the urinary bladder, the uterus.
- The umbilical region: the small intestine.
- The left and right lumbar region: the kidney.

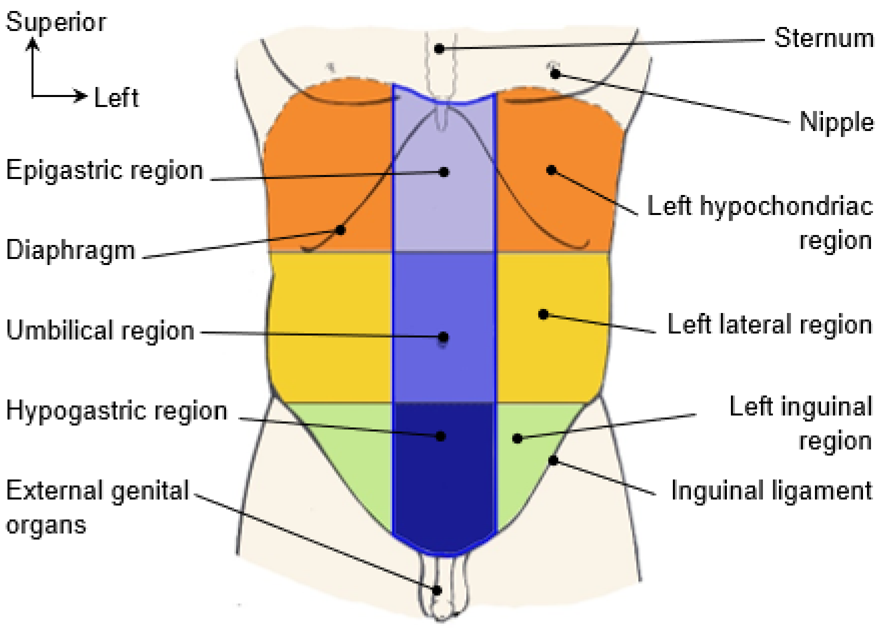



***Figure 21: The regions of the abdomen.***

**Pelvis**

The pelvis is the lowermost part of the trunk. Its upper boundary is the pelvic inlet. Its lower boundary is the skin covering the perineum. The dorsal boundary is formed by the sacrum and the coccygeal bone.
The pelvic inlet is a fictitious plane at the level of the terminal line separating the abdomen from the pelvis. The terminal line runs across the promontory of sacrum, arcuate line of ilium, pectineal line of pubis, and upper margin of the pubic symphysis.

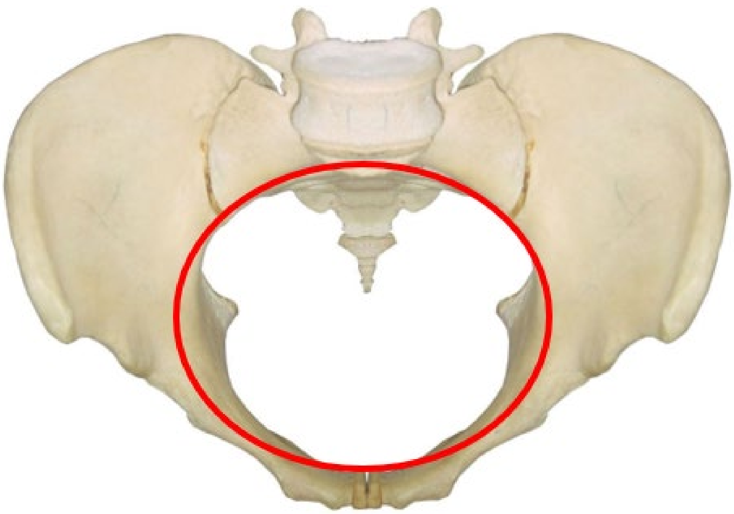


***Figure 22: The pelvis and the terminal line (in red). Anterosuperior view.***

The pelvic diaphragm forms a boundary between the pelvic cavity and the perineum. In women, the pelvic diaphragm can be weakened by childbirth.

The contents of the pelvic cavity are parts of the urinary system, genital system and parts of digestive system.

The perineum is the lowest part of the trunk, below the pelvic diaphragm. It includes the external orifice of the urethra and anus in both men and women, plus the vaginal orifice in women.

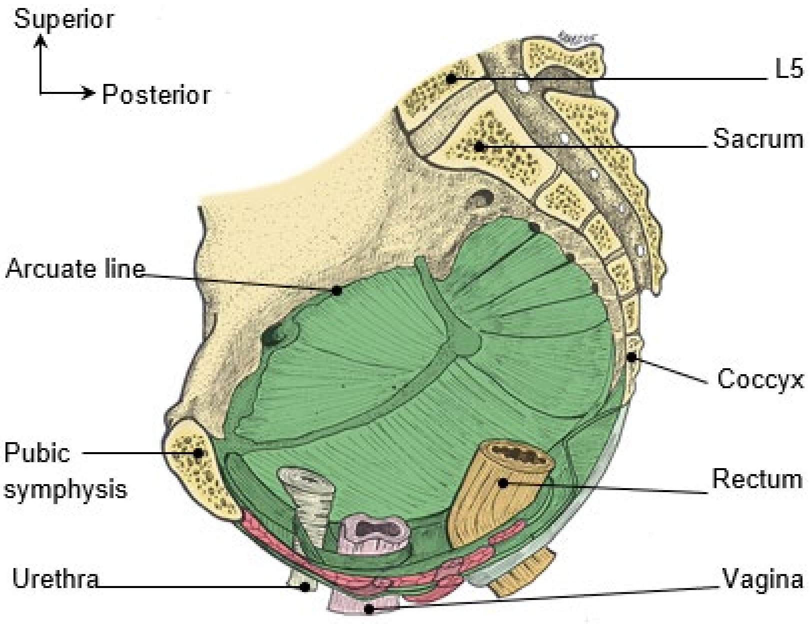



***Figure 23: The walls of the pelvis in women.***

## 5.4 - Upper limb

The upper limb is anchored to the trunk by its root, represented by the shoulder girdle. It consists of two major parts: the shoulder and the free part. The latter is divided into the arm, the elbow, the forearm, the wrist, and the hand.


***Figure 24: The right upper limb. Anterior view.***

## 5.5 - Lower limb

The lower limb is anchored to the trunk by its root, the pelvic girdle. It consists of three major parts: the buttock, the hip, and the free part. The latter is divided in the thigh, the knee, the leg, the ankle, and the foot.

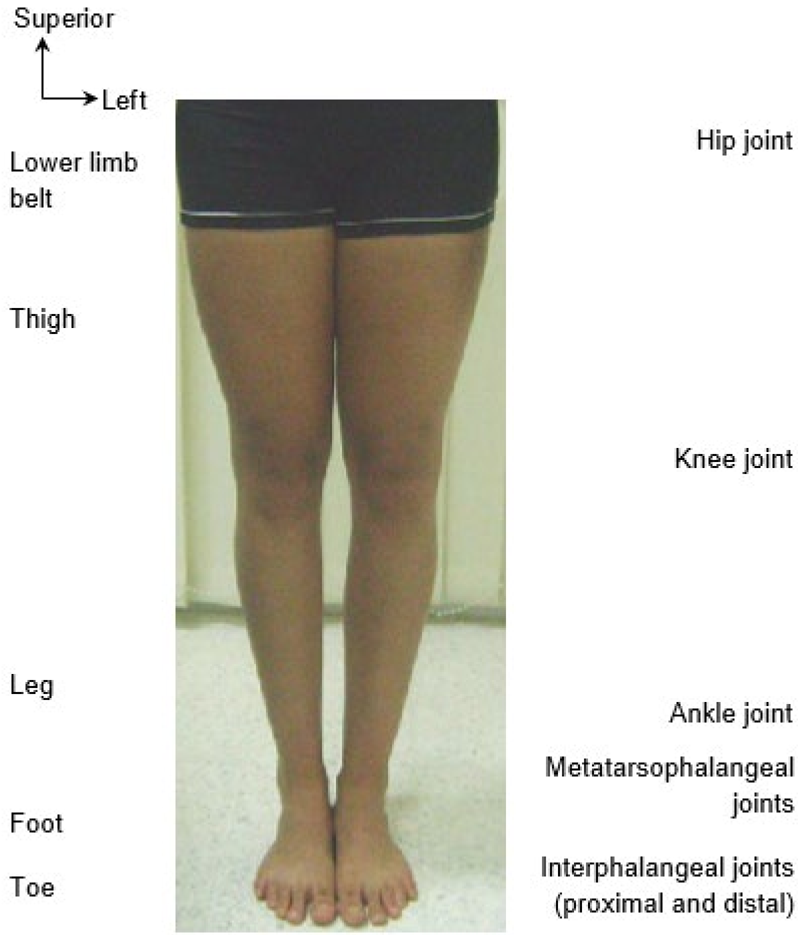



***Figure 25: The lower limbs. Anterior view.***

# 6 - Organisation of the human body in apparatuses

The human body is controlled by the nervous system, which provides the control of relational life (ascending or sensory pathways, descending or motor pathways) and of vegetative life (the vegetative nerve centres and pathways).

Morphologically, a distinction is made between the central nervous system (brain and spinal cord) and the peripheral nervous system (cranial nerves and spinal nerves).

The nerve networks and cords that connect the central nervous system to the various organs are called nerves and constitute the peripheral nervous system.

We will present the organisation of the human body according to the apparatuses:

- The apparatus of relational life.
- The apparatus of vegetative life.
- The apparatus of sexual reproduction.

## 6.1 - Apparatus of relational life

The apparatus of relational life is concerned with the life of the body in relation to its environment. The maintenance of posture and movements are the result of the locomotor system. The sensory organs and the nervous system are closely connected and provide for the reception of information from the environment, its integration and the corresponding reactions. The phonatory apparatus enables precise and rapid communication in humans.

**Musculoskeletal systems**

The musculoskeletal systems encompass the skeletal and the muscular system.

- The skeletal system includes the bones and the joints that form the framework of the body, i.e. the skeleton.

  Osteology is the study of bones, and arthrology is the study of joints.

- The muscular system includes the skeletal muscles, fasciae, synovial bursae, and tendon sheaths.

**Sensory apparatus**

The sensory apparatus consists of the sense organs, which are specialised in receiving information and are connected to the central nervous system by ascending pathways.
There are four sense organs: olfactory organ, eye, ear, and gustatory organ. They inform the nervous system about the body's environment.

## 6.2 - The apparatus of vegetative life

The apparatus of vegetative life enables the regulation of the human body homeostasis by all the vital phenomena of animal existence.

**The cardiovascular and the lymphatic systems**

The cardiovascular system enables the transport of blood and lymph through the body, supplies the tissues with oxygen and nutrients, and removes the waste products of metabolism from the tissues.

- The blood system includes the heart and the vessels: arteries, veins, and blood capillaries.
- The lymphatic system and the hematopoietic organs: the lymph nodes and lymph vessels, the red bone marrow, the spleen, and the thymus.

**The respiratory system**

The respiratory system enables the exchange of oxygen and carbon-dioxide between the body and air, maintenance of the acid-base balance, and phonation.

**The digestive system**

The digestive system enables the mechanical and chemical degradation of food:

- the dental system: the teeth;
- the tubular system: the digestive tract;
- the glands: the liver, the pancreas and the salivary glands.

**The urinary system**

The urinary system enables filtration of blood and elimination of the waste products and unnecessary compounds:

- the kidneys: filtration system;
- the tubular system: the ureters, the urinary bladder and the urethra.

**The endocrine system**

The endocrine system regulates a wide variety of bodily functions through the production of hormones. It includes the endocrine glands.

## 6.3 - The apparatus of sexual reproduction

The genital systems enable the reproduction.

- the male genital system;
- the female genital system.

# Chapter 2 - Musculoskeletal system

**The objectives of this chapter are to:**

1. Name the organs that constitute the musculoskeletal system.
2. Define a long - short - flat - elongated - irregular bone and give an example of each.
3. Name the bones of the skeleton.
4. Define a joint.
5. Name different anatomical types of joints and give an example for each joint type.
6. Define a muscle.
7. Name different types of muscles.

## 1 - Skeleton

The skeleton is a framework of the human body. It consists of the bones, the cartilages and the joints. The skeleton can be subdivided into two major divisions, the axial skeleton, and the appendicular skeleton.

The skeleton is examined by utilizing medical imaging: plain X-ray, CT or MRI. Reconstructions can be made on the basis of the skeleton sections. Other procedures are also possible, such as bone scintigraphy, in which the injected radioactive product binds electively to the bones.

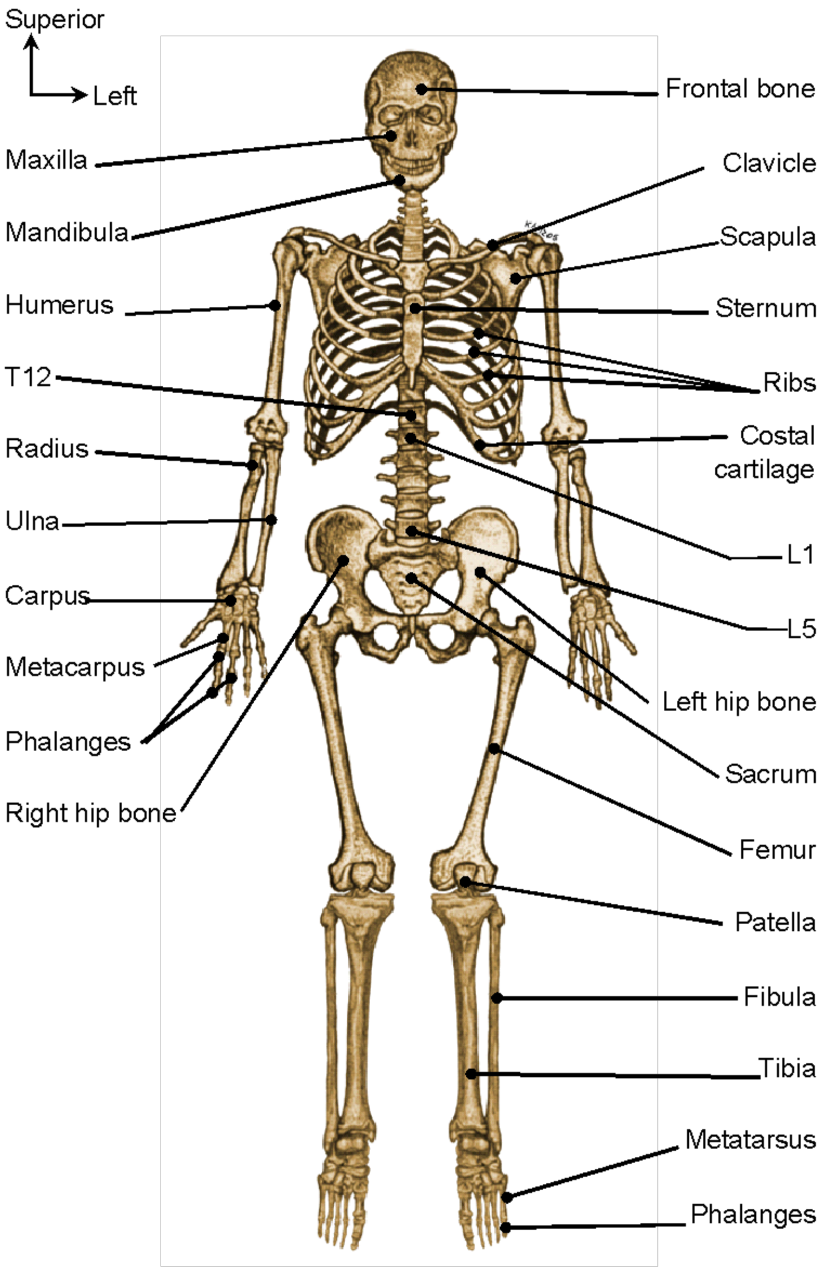



***Figure 26: The human skeleton. Anterior view.***

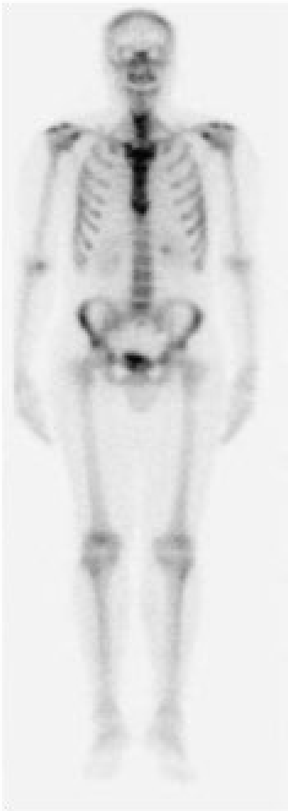


***Figure 27: Bone scan. Anterior view.***

## 1.1 - Bones of axial skeleton

The axial skeleton consists of the skeleton of the head, neck and trunk.

### *Bones of the head*

The skeleton of the head is formed by the skull, also called cranium, and two extracranial bones.

**Cranium**

The cranium is divided into neurocranium and viscerocranium.

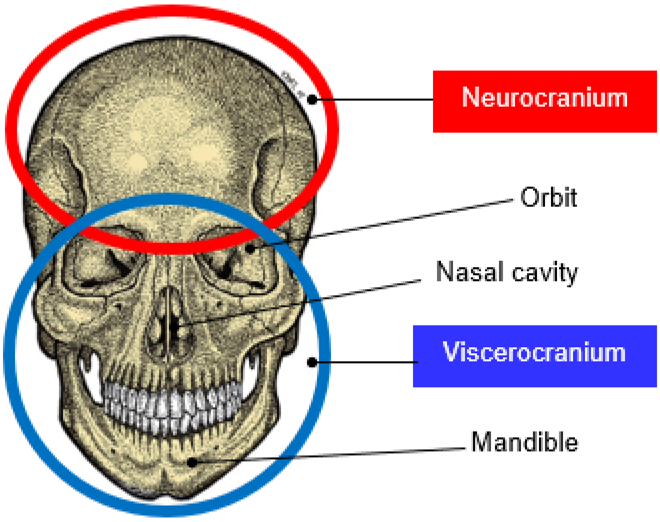



***Figure 28: The cranium. Anterior view.***

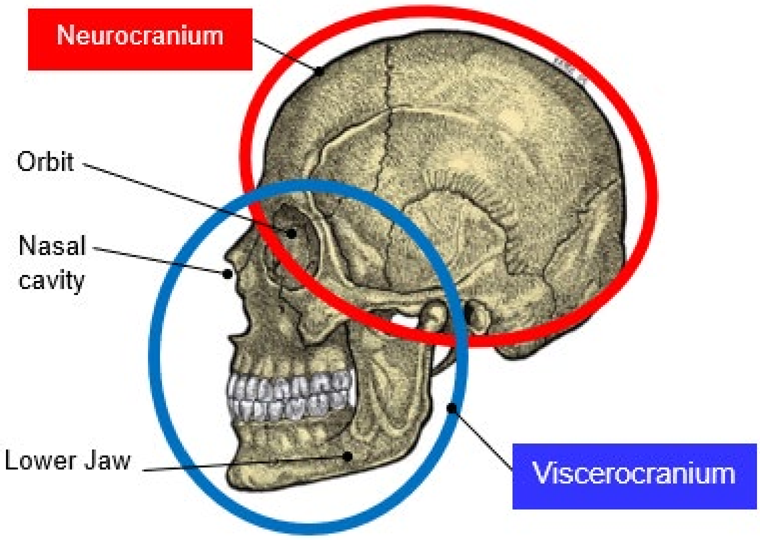



***Figure 29: The cranium. Left lateral view.***

The skeleton of the neurocranium is composed of:

- frontal bone,
- ethmoid bone,

- occipital bone,
- temporal bone (2),
- parietal bone (2).

The neurocranium encloses the cranial cavity. It can be divided in the calvaria and the cranial base.

The calvaria is "a covering" which is not penetrated by anatomical elements. It protects the brain.

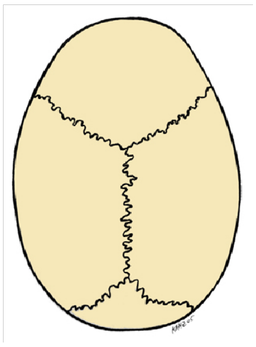


***Figure 30: External surface of the calvaria.***

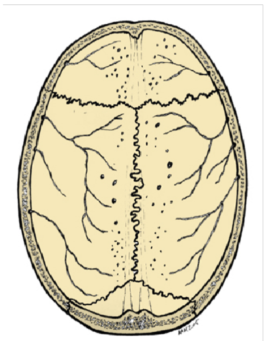
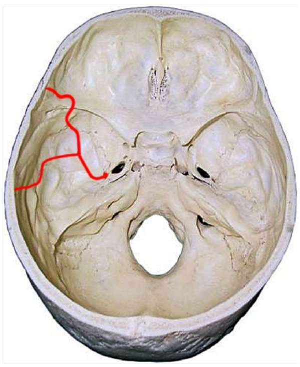


***Figure 31: Internal surface of the calvaria.***

The cranial base is divided into three cranial fossae and has several communication holes that allow the passage of anatomical elements.

***Figure 32: Intracranial view of the cranial base.***



The skeleton of the viscerocranium is composed of:
- vomer,
- maxilla (2),
- palatine bone (2),
- lacrimal bone (2),
- inferior nasal turbinate (2),
- nasal bone (2),
- zygomatic bone (2).

On the anterior aspect of the cranium, there are cavities:

- The left and right orbits house the eyeballs and the eye appendages.
- The bony nasal cavity houses the sense of smell and provide for the passage of air.

**Extracranial bones**

The extracranial bones are:
- mandible,
- hyoid bone.

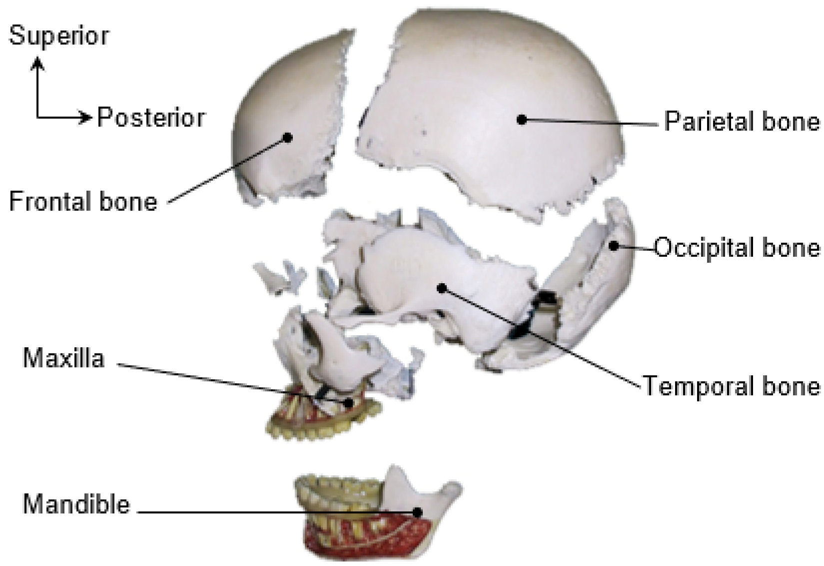



Figure 33: The bones of the head. Left lateral view.

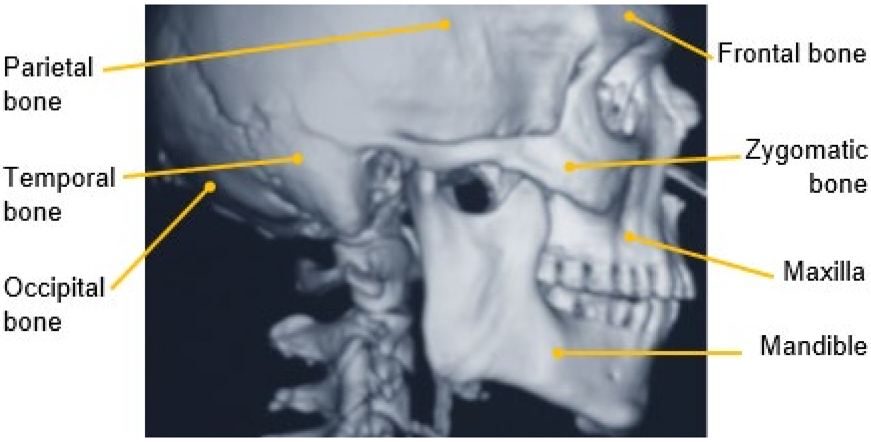



***Figure 34: CT reconstruction of the skull. Right lateral view.***

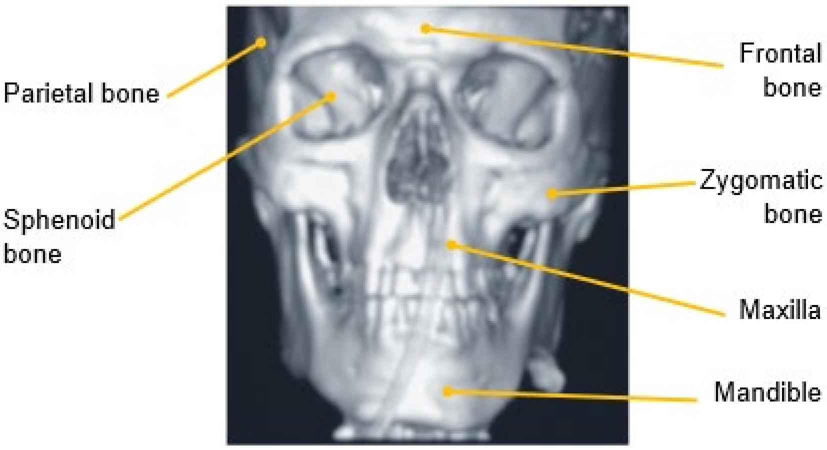



***Figure 35: CT reconstruction of the skull. Anterior view.***

## *Bones of vertebral column*

The vertebral column (spine) consists of 33 vertebrae:

- 7 cervical vertebrae (vertebrae C1-C7),
- 12 thoracic vertebrae (vertebrae T1-T12),
- 5 lumbar vertebrae (vertebrae L1-L5),

- 5 sacral vertebrae fused into sacrum,
- 4 coccygeal vertebrae fused into coccyx.

Viewed from the front, the spine appears to be straight. In profile, it shows curvatures. These curvatures increase the resistance of the spine and have different values. They can be reduced or increased, depending largely on a genetic component.

The curvature of the spine with the concavity directed backwards is called lordosis. In adult, there are cervical and lumbar lordoses.

The curvature of the spine with the concavity directed forwards is called kyphosis. In adult, there are thoracic and sacral kyphoses).

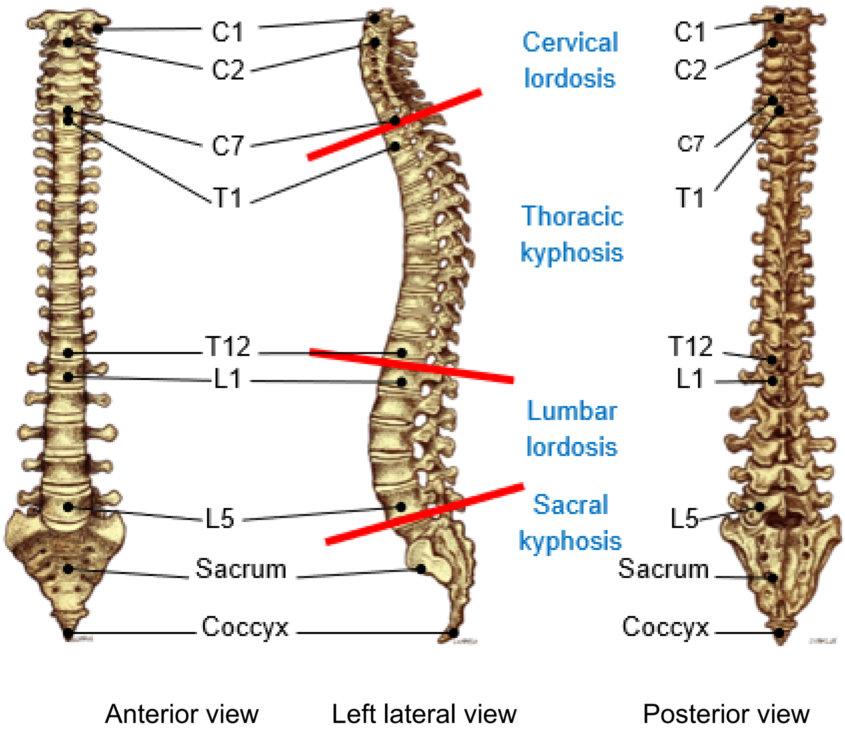



***Figure 36: The spine.***

The curvature in the frontal plane is called scoliosis and is pathological. In most cases, the cause cannot be determined (idiopathic scoliosis). It may be due to an unequal length of the lower limbs or paralysis of the trunk muscles.

***Figure 37: Photo of a patient's back showing scoliosis.***

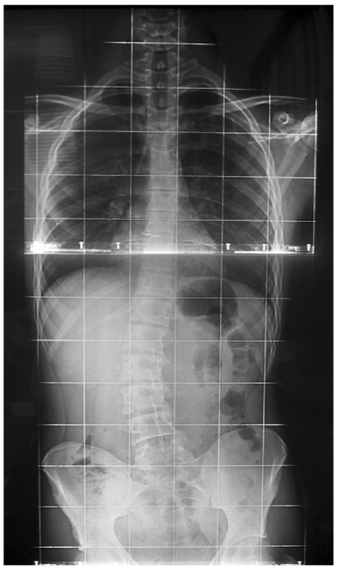


***Figure 38: X-ray of the spine showing scoliosis.***

## *Bones of thorax*

The bones of thorax are sternum and 12 pairs of ribs.

The sternum is a flat bone in the centre of the anterior wall of the chest.

The ribs are paired bones. Posteriorly, thy are connected to the thoracic vertebrae. Anteriorly, the upper ribs are connected to the sternum. According to their connection with sternum, the ribs are divided into two groups.

- The ribs 1 to 7 are connected to the sternum by a costal cartilage. They are called the true ribs.

- The ribs 8 to 12 are not in connection with sternum. They are called the false ribs. The costal cartilages of ribs 8, 9, and 10 are connected to the costal cartilage of the rib above them. The ribs 11 and 12 end freely in the muscles of abdominal wall and are called the floating ribs.

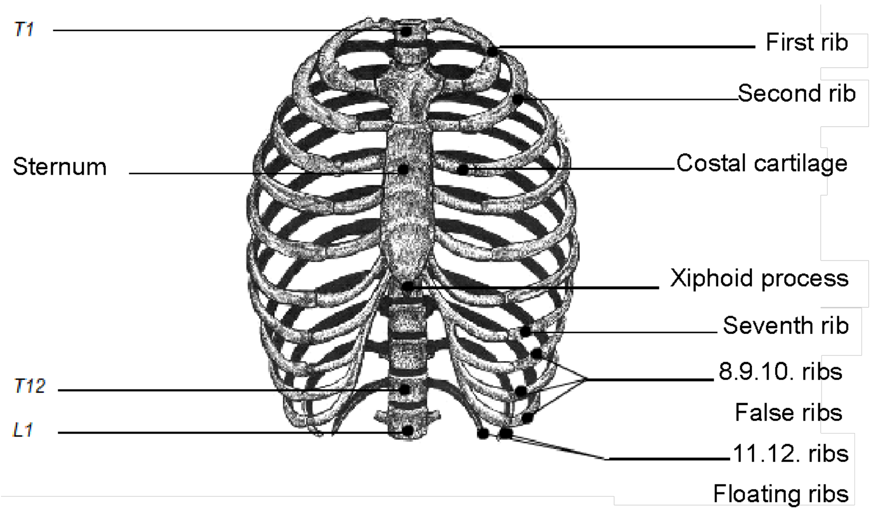



***Figure 39: Skeleton of the thorax. Anterior view.***

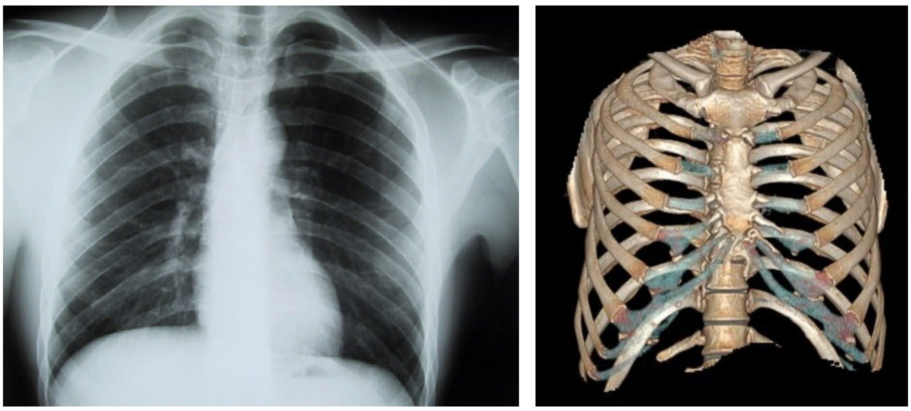


***Figure 40: X-ray of the thoracic skeleton.***

### Bones protecting the abdominal cavity

The bones protecting the organs in the human cavity are the lower ribs, the lumbar spine, and superior part of pelvis above the terminal line called the greater pelvis. Pelvis is formed by the sacrum and pelvic girdle. The bones of pelvic girdle are classified among the bones of lower limb.

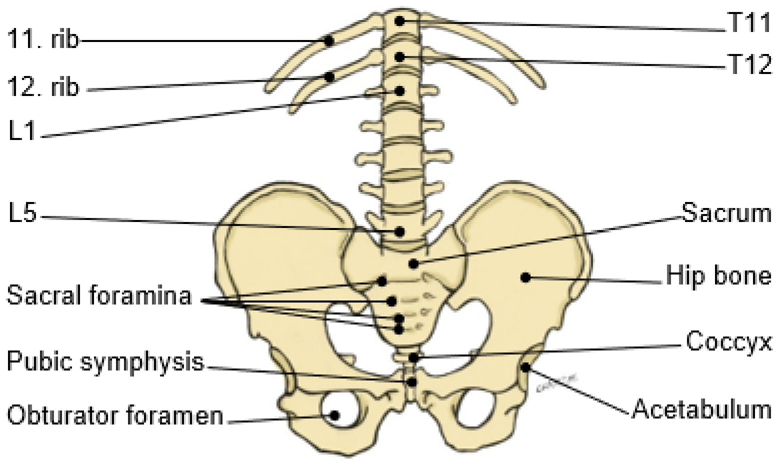



***Figure 41: Bones protecting the abdominal cavity. Anterior view.***

## 1.2 - Bones of appendicular skeleton

The appendicular skeleton is the skeleton of the upper and lower limbs.

### Bones of upper limb

The bones of upper limb are divided into the bones of pelvic girdl and the bones of free part of upper limb.

**Bones of pectoral girdle:**

- scapula, clavicle.

**Bones of free part of upper limb:**

Arm: humerus.

Forearm: radius, ulna.

Hand:

- Carpus: 8 bones, arranged in 2 rows (listed from the thumb side to the little finger side):

  proximal row: scaphoid bone, lunate bone, triquetrum bone, pisiform bone;

  distal row: trapezium bone, trapezoid bone, capitate bone, hamate bone.

- Metacarpus: 5 metacarpal bones I to V, numbered from the thumb side to the little finger side.
- Fingers: 3 phalanges in the 2nd to 5th finger: proximal middle, and distal phalanx; 2 phalanges in the thumb: proximal and distal phalange.

***Figure 42: Drawing of metacarpal bones and phalanges of hand.***

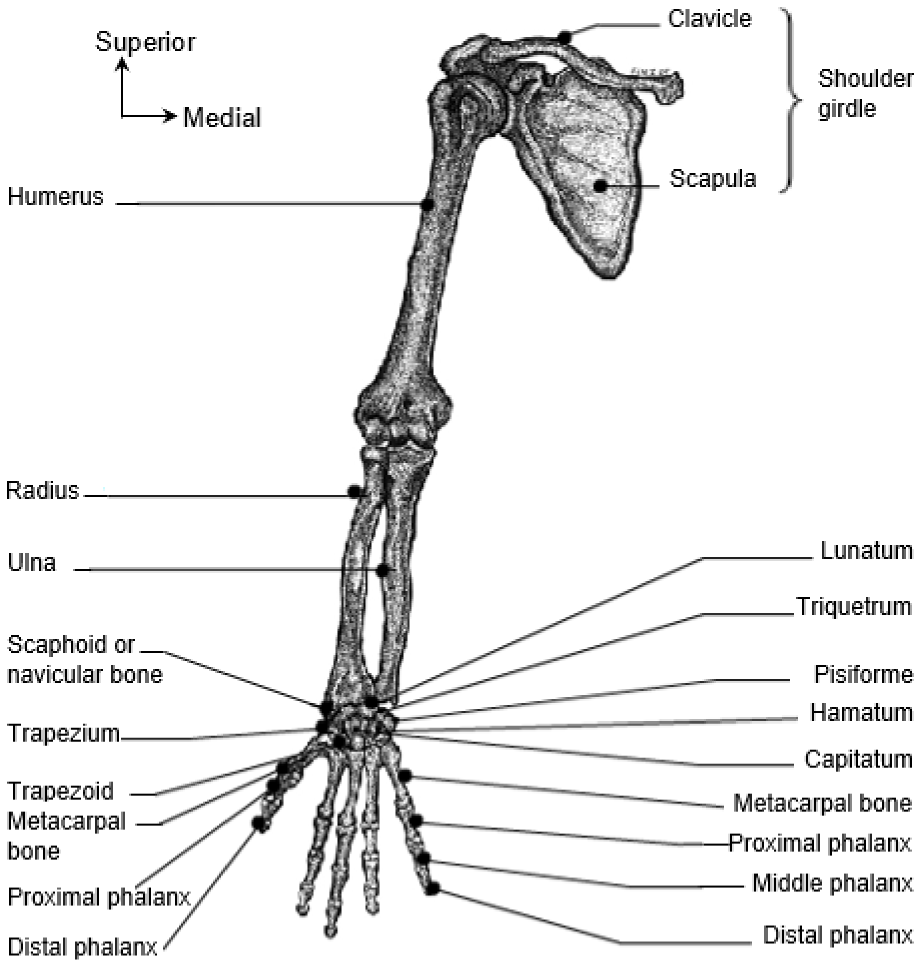



***Figure 43: Skeleton of the right upper limb. Anterior view.***

## *Bones of the lower limb*

The bones of upper limb are divided into the bones of pelvic girdl and the bones of free part of upper limb.

**Bones of pelvic girdle:**

- hip bone: ilium, ischium, and pubis.

**Bones of free part of lower limb:**

Thigh: femur, patella.

Leg: tibia, fibula.

Foot:

- Tarsus: 7 bones: talus, calcaneus, navicular bone, cuboid bone, medial cuneiform bone, intermediate cuneiform bone, lateral cuneiform bone.
- Metatarsus: 5 metatarsal bones I to V, numbered from the great toe side to the little toe side.
- Toes: 3 phalanges in the $2^{nd}$ to $5^{th}$ toe: proximal middle, and distal phalanx; 2 phalanges in the thumb: proximal and distal phalanx.

Both lower limbs should be of equal length. Inequality in length causes lameness. Telemetry examinations are performed to investigate a possible axial deviation.

Figure 44: ***X-ray of lower limb skeleton (Telemetry).***

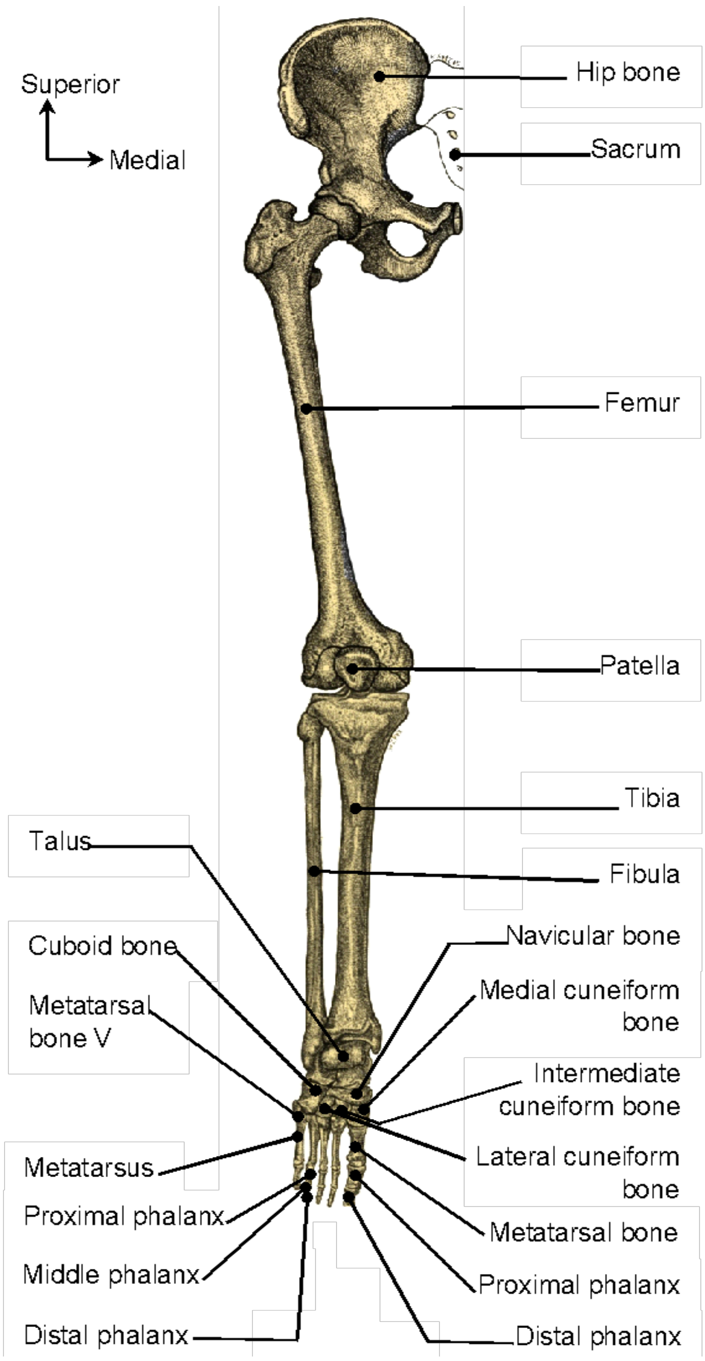



***Figure 45: Skeleton of the right lower limb. Anterior view.***

## 1.3 - Classification of bones

According to their form, bones can be classified into four main groups: long, flat, short, and irregular bones.

**Long bones**

In long bones, one dimension usually predominates over the other two. They have two extremities or epiphyses and one body (shaft) or diaphysis. The epiphysis and diaphysis are connected by a zone called the metaphysis.

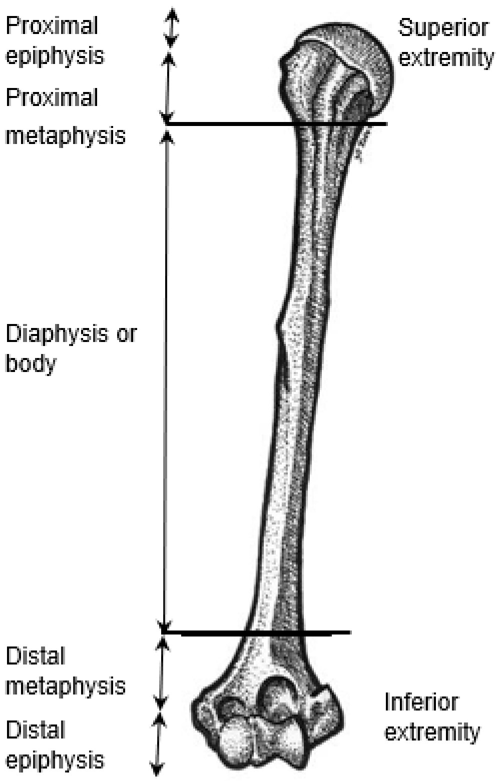



*Figure 46: Drawing of the right humerus. Anterior view.*

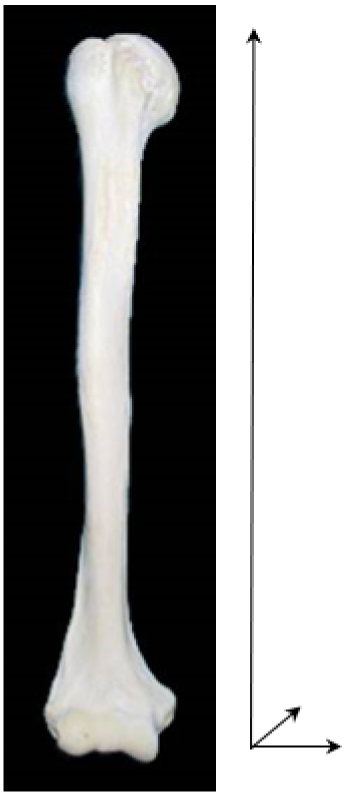


*Figure 47: Photo of the right humerus. Anterior view.*

## Flat bones

In flat bones, the thickness is small or even zero, resulting in a hole in the bone. The periphery of these bones has thickenings on certain sides that form a zone of resistance (for example, the lateral edge of the scapula, the so-called scapular pillar).

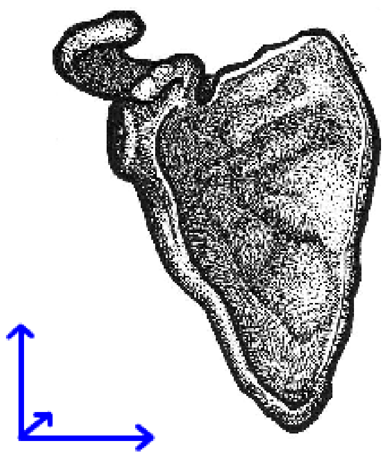


***Figure 48: Drawing of the right scapula. Anterior view.***

***Figure 49: Photo of the right scapula. Anterior view.***

***Figure 50: X-ray showing a fracture of the pillar of left scapula. Anterior view.***

**Short bones**

In short bones, the three dimensions are equivalent.

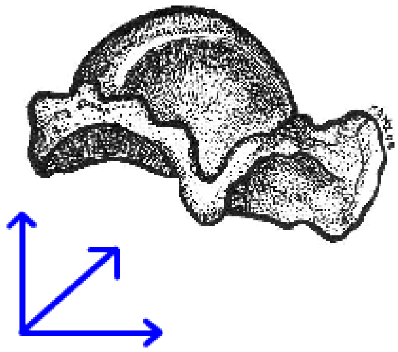


*Figure 51: Drawing of the right talus. Lateral view-*

*Figure 52: Photo of the right talus. Lateral view.*

## 1.4 - Architecture of the bone

According to the density and organisation of bone tissue, we distinguish the compact bone and the spongy bone.

**Cortical bone (compact bone)**

The cortical bone forms the surface of the bone and is thick. Its thickness varies depending on the type of bone.

At the level of the diaphysis of long bone, it is very thick and tubular in structure, surrounding the medullary cavity in which is the bone marrow. It is very strong and only breaks when subjected to very high energy.

At the level of the epiphysis of long bone and in short and flat bones, the compact bone surrounds the spongy bone which forms the inner part of the bone.

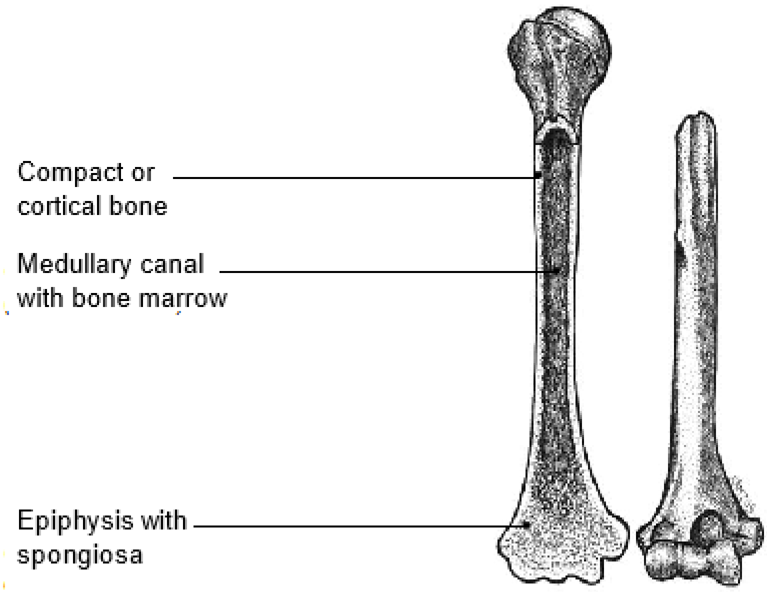



***Figure 53: Frontal section of the right humerus. Anterior view.***

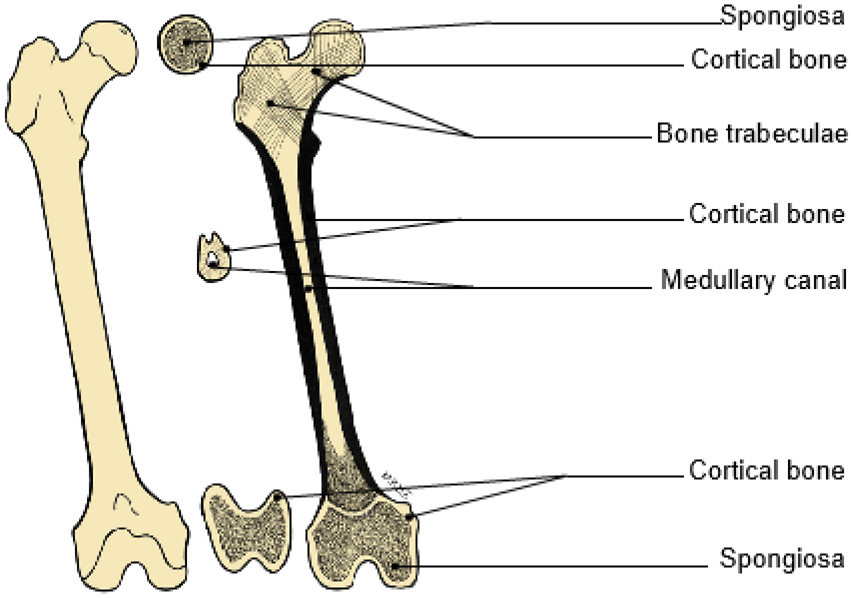



***Figure 54: Frontal and transverse section of the right femur. Anterior view.***

**Spongy bone (cancellous bone)**

The spongy bone forms large and complex parts of the bone. It is located at the level of the epiphyses of the long bones and in the flat and short bones. It can be compared to a honeycomb. It consists of a network of bony trabeculae, between which the red bone marrow is located.

The bony trabeculae represent lines of force that connect two parts of cortical bone. They can be organized in bundles and give the bone the necessary strength.

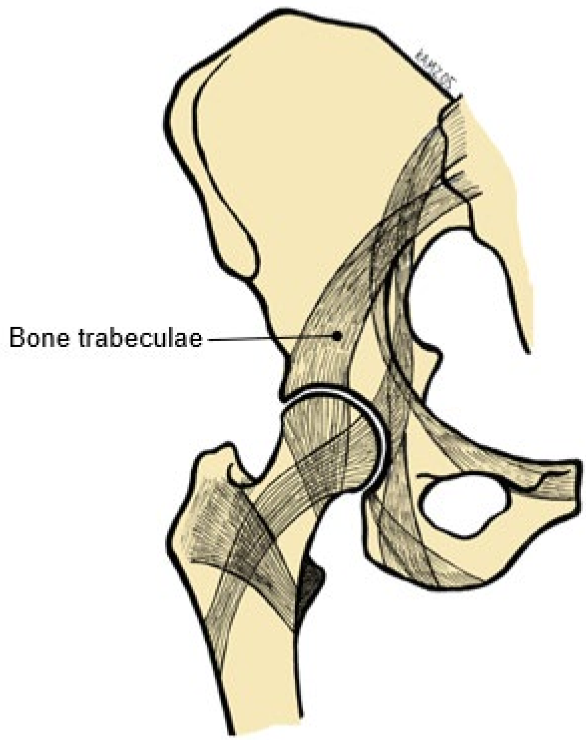



***Figure 55: The direction of bony trabeculae in the right hip. Anterior view.***

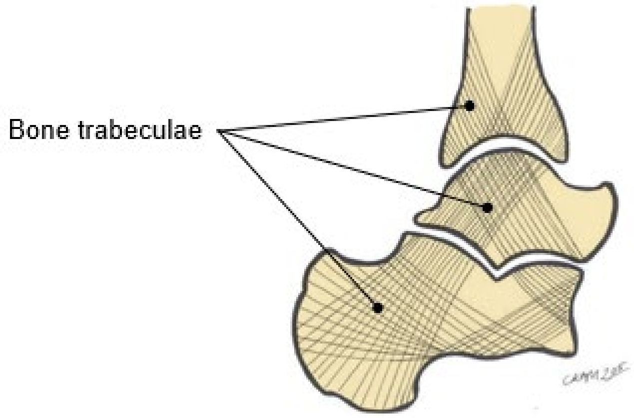



***Figure 56: The direction of bony trabeculae in the ankle. Lateral view.***


***Figure 57: X-ray of the ankle showing the bony trabeculae. Lateral view.***

### Bone marrow

The bone marrow is located in the cavities of the spongy bone and in the medullary cavity of the long bones. In adult, the medullary cavity contains the yellow bone marrow, while the cavities of the spongy bone contain the red bone marrow with blood stem cells.

**Periosteum**

The bone is covered by a protective and nourishing fibrous membrane, the periosteum.

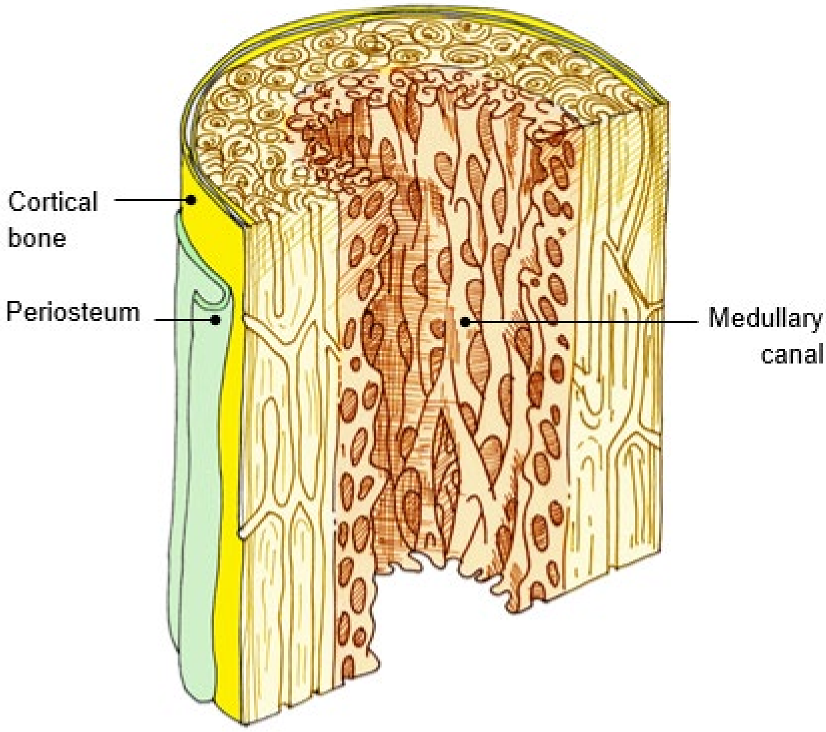



***Figure 58: Section through a diaphysis wrapped in the periosteum.***

## 1.5 - Growth of the long bone

Growth of the long bone occurs through two phenomena:

- Epiphyseal plates allow the bone to grow in length.
- Periosteum enables the appositional growth of the bone (the increase in diameter). The periosteum is the main element in fracture healing and forming of the periosteal callus.

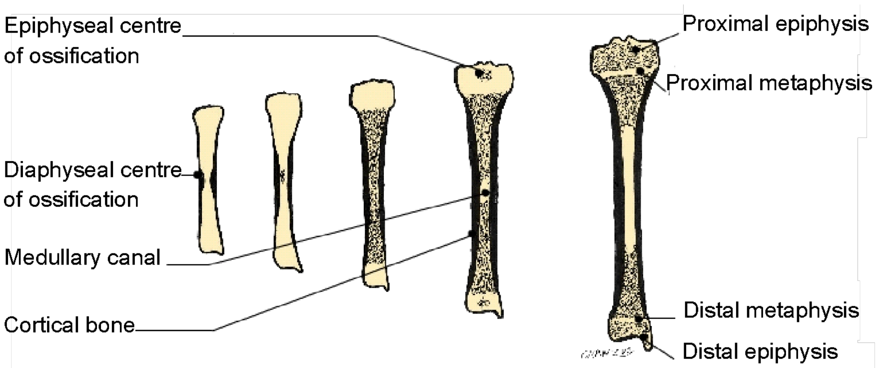



***Figure 59: Growth of the long bone.***

The long bone develops from hyaline cartilage. The ossification progresses from three main ossification centres: one primary centre in the diaphysis (it usually occurs during prenatal development) and two secondary centres, one in each epiphysis (they usually occur during postnatal development). The centres of different bones appear at the certain age according to the development, and therefore allow us to determine the age. Premature or delayed ossification is pathological.

Hyaline cartilage persists at the epiphyseal plate which is located between the diaphysis and epiphysis. The epiphyseal plate is responsible for the lengthwise growth of long bones and is therefore also called growth plate or growth cartilage.

It should be noted that ossification centres develop in a cartilage with a fixed morphology. They are capable of forming complex shapes with protrusions and grooves.

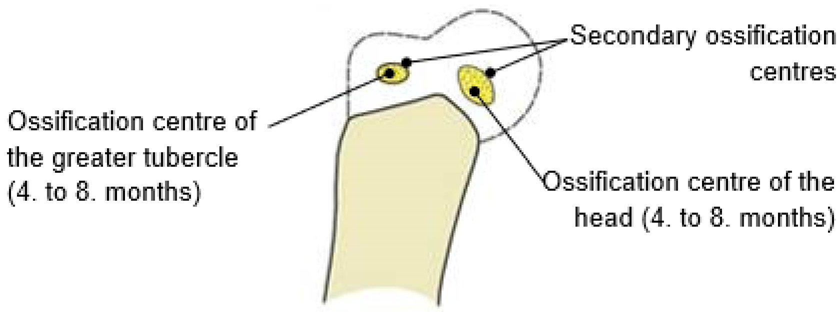



***Figure 60: Ossification centres in the proximal epiphysis of humerus.***

Next x-rays show the epiphyseal plates – growth cartilage.


***Figure 61: X-ray of the left knee (anterior view).***


***Figure 62: X-ray of the right wrist (anterior view).***

## 1.6 - Bone vascularisation

The bone is a living organ that is constantly renewing itself. Its blood supply is rich. Oxygenated blood is supplied by a nutrient artery that runs in the periosteum and enters the bone through the nutrient foramen. Deoxygenated blood flows via the veins. It should be noted that the growth cartilage is not vascularised.

There are venous lakes in which the blood stagnates, which enables bone development. The disadvantage of this venous stagnation is that it can be a source of infection which is then referred to as osteomyelitis.

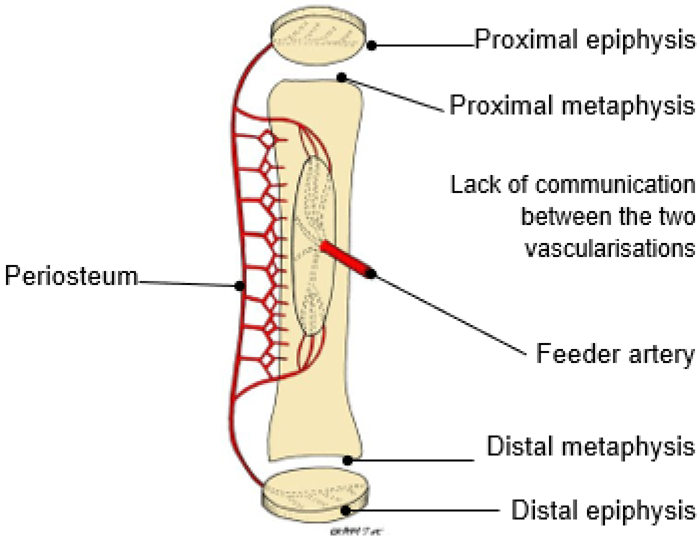



***Figure 63: Bone vascularisation.***

# 2 - Joints

A joint (articulation) is any connection by which two or more bones are joined together.

## 2.1 - Classification of joints

Joints are divided into three main groups: the fibrous joints, the cartilaginous joints, and the synovial joints.

### *Fibrous joints*

In a fibrous joint, bones are joined by fibrous tissue. The degree of mobility is minimal, usually practically zero.

**Syndesmosis**

An example of syndesmosis is the inferior tibiofibular joint (tibiofibular syndesmosis): a fibrous tissue is inserted between the two bones. This allows for a stable mortise in which talus is inserted.

A gap between these two bones (diastasis) leads to instability.

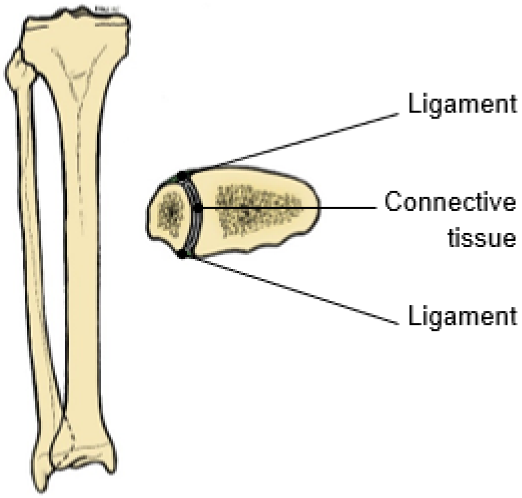



***Figure 64: Inferior tibiofibular joint. Syndesmosis.***

### Suture

Sutures connect the flat bones of the skull. In adults, sutures ossificate and the volume of the cranial cavity is fixed. A premature ossification of the sutures is called craniosynostosis (craniostenosis) and can lead to skull deformities or even compression of the brain.

In new-borns, the bones are not fully ossified yet; the soft membranous spaces separating the bones are called fontanelles.

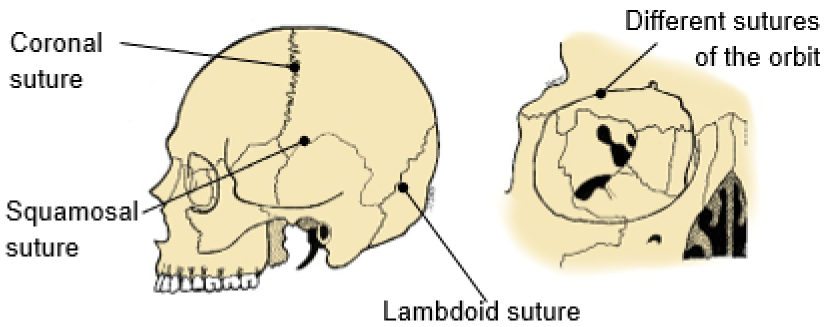



***Figure 65: Sutures of skull.***

### Gomphosis

Gomphosis is a special type of syndesmosis that connects a tooth to the tooth socket. These joints are stable but can move a little. This can be achieved by wearing braces.

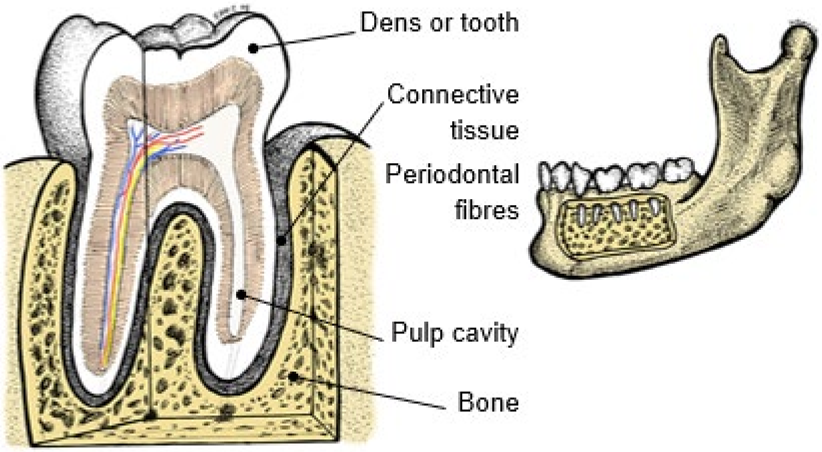



***Figure 66: Gomphosis.***

## *Cartilaginous joints*

In a cartilaginous joint, bones are joined by cartilaginous tissue. A degree of mobility is insignificant.

### Synchondrosis

Synchondrosis is a connection of bones by hyaline cartilage. Example: the first sternocostal joint.

### Symphysis

Symphysis is a connection of bones by fibrous cartilage. Compressibility of the fibrocartilage tissue allows for small movements. Example: the intervertebral disk.

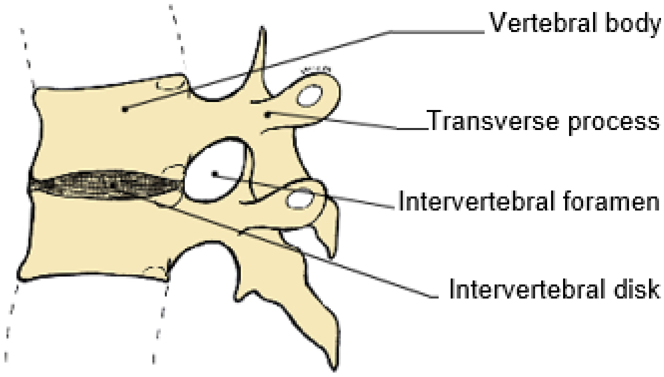



**Figure 67: Intervertebral symphysis. Left lateral view.**

**Figure 68: Left lateral view of the spine.**

## Synovial joints

In a synovial joint, the bones are not directly joined; they are connected by an articular capsule which encloses a fluid-filled joint cavity. These joints are very mobile.

Synovial joint contains the following elements:

- The articular surfaces of at least two bones. The surfaces are covered by a pearly white, smooth hyaline cartilage called an articular cartilage. The joint's stability depends on the congruence between the articular surfaces.
- A joint capsule connecting the bones and enclosing a joint cavity. It has two layers. A fibrous layer (fibrous membrane) is an outer layer formed by dense fibrous tissue which stabilises the joint. It has a low extensibility. A tight capsule leads to a considerable restriction of movements. A synovial layer (synovial membrane) is an inner layer formed by serous

membrane – a specialised soft connective tissue that secrets a serous fluid called synovia.

- Synovia enables the articular surfaces to slide smoothly against each other. It lubricates the joint and supplies the articular cartilage with the nutrients.
- The ligaments connect the articulating bones and can form reinforcement of the joint capsule.
- Some synovial joints contain the articular fibrocartilage which improves the congruence between the articular surfaces. Fibrocartilage is not vascularised and therefore has a limited potential to repair. The articular fibrocartilage can be divided into tree forms. The articular disc is a thin fibrocartilaginous plate between the articular surfaces. The meniscus is a crescent-shaped fibrocartilage in the knee joint. It is thicker on the periphery and gets thinner towards the centre of the joint, thus having a triangular shape on the cut surface. The articular labrum is a complete or incomplete fibrocartilaginous ring attached to a margin of the concave articular surface, further increasing its concavity. It is thickest at the site of attachment and gets thinner peripherally, thus having a triangular shape on the cut surface Examples are glenoid labrum of the shoulder joint and acetabular labrum of the hip joint.

There are several types of synovial joints that differ according to the movements they enable.

**Spheroidal (ball and socket) joint**

A spheroidal articular surface of one bone lies in a cup-like concavity of the other bone. This is the most mobile type of joint. The mobility is possible in all three spatial planes around three axes that are perpendicular to each other. Possible movements are flexion and extension, abduction and adduction, circumduction as a combination of previous four movements, and internal and external rotation.

Example: the shoulder joint.

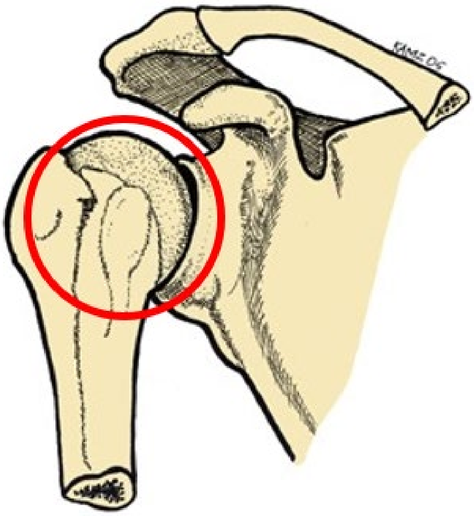


***Figure 69: The right shoulder joint. Anterior view.***

The frontal section of the shoulder joint shows the disproportion between the surface of the humeral head and the glenoid cavity of the scapula.

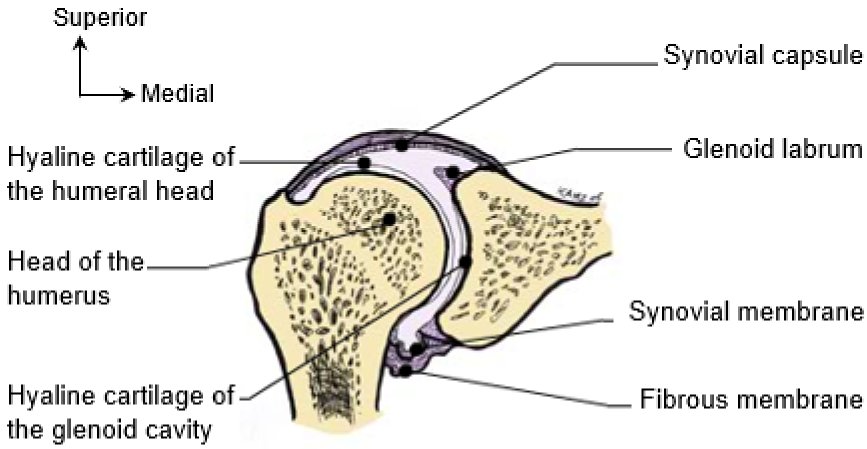



***Figure 70: Frontal section of the right shoulder joint. Anterior view.***

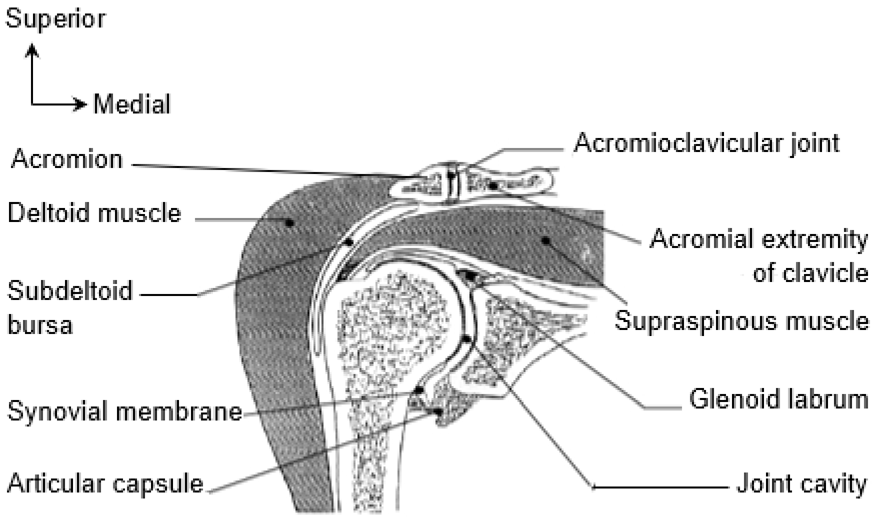



***Figure 71: Frontal section of the right shoulder. Anterior view.***

In a shoulder joint which has extensive mobility, the lax joint capsule allows high range of movements without stretching the capsule. Great mobility rhymes with great fragility! Anterior dislocation of the shoulder joint is the most common type of joint dislocation.

***Figure 72: Photo and X-ray of the right shoulder with a glenohumeral dislocation. Anterior view.***

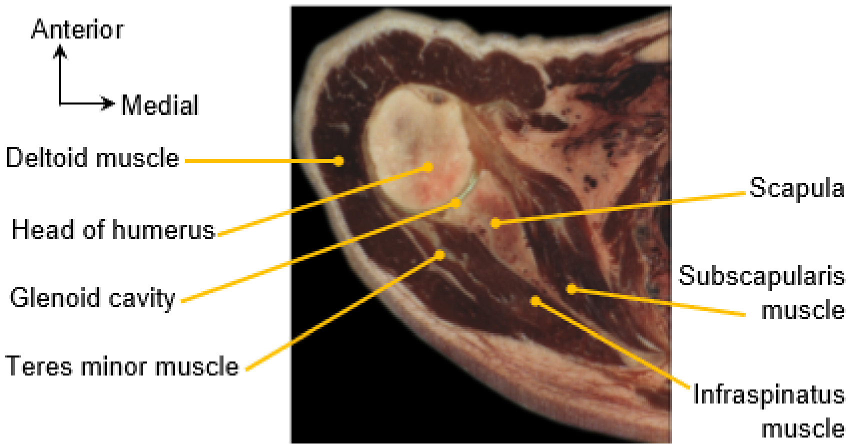



***Figure 73: Cross-section of the right shoulder. Inferior view.***

Another example of the ball and socket joint is the hip joint. It has much more limited range of movements due to the deep concave articular surface.

***Figure 74: View of the acetabular cavity.***

**Ellipsoid (condylar) joint**

An ovoid convex articular surface of one bone lies in an ellipsoid concavity of the other bone. Mobility is possible around two axes. Possible movements are flexion and extension, abduction and adduction, and circumduction as a combination of previous four movements.

Example: the radiocarpal joint.

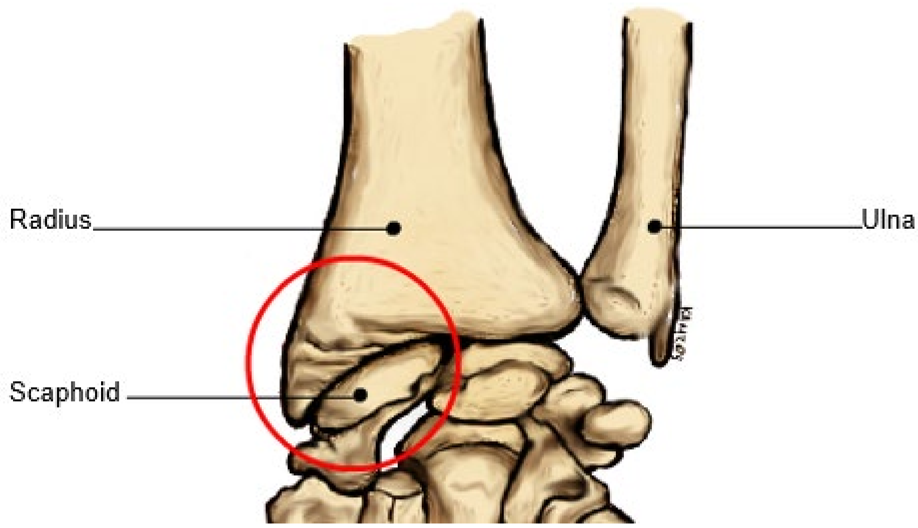



***Figure 75: The right radiocarpal joint. Anterior view.***

**Saddle joint**

A concave-convex articular surfaces of both bones interlock like two saddles perpendicular to one another. Mobility is possible around two axes.
Example: the carpometacarpal joint of the thumb.

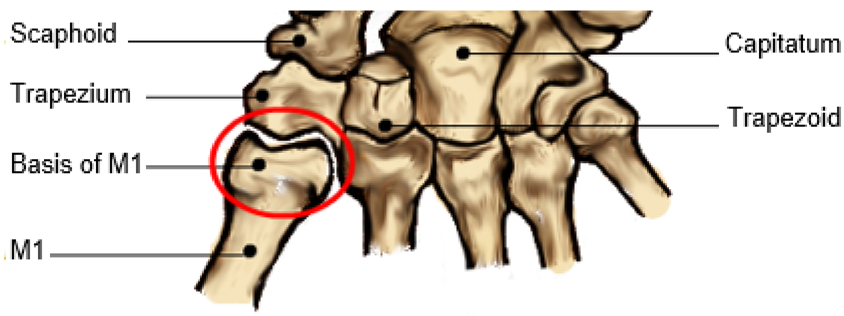



***Figure 76: The right carpometacarpal joint of the thumb. Anterior view. M1 – first metacarpal bone.***

### Bicondylar joint

Two ovoid convex articular surfaces (condyles) of one bone articulate with corresponding articular surfaces of the other bone.

Example: the knee joint.

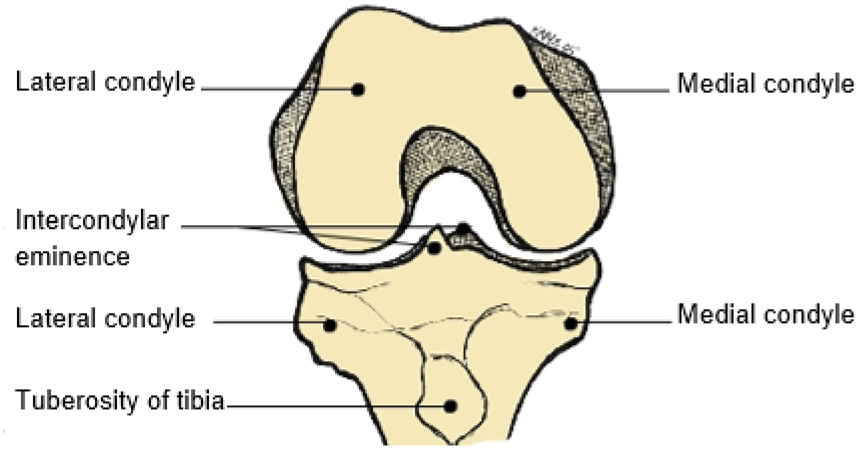



***Figure 77: The knee joint in flexion (patella removed). Anterior view.***

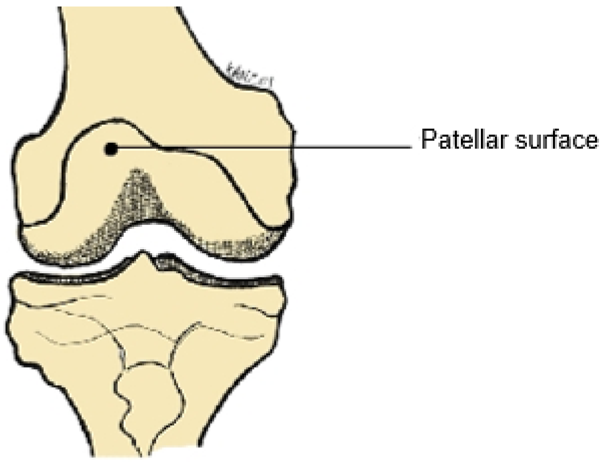



***Figure 78: The knee joint in extension (patella removed). Anterior view.***

In the knee joint, the condyles of femur and the condyles of tibia are not congruent. The stability of the joint depends on the menisci, ligaments and muscles.

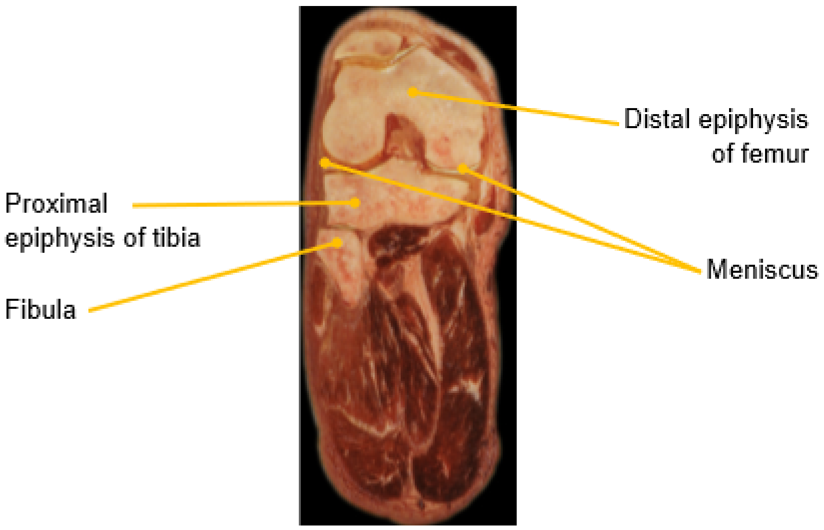



***Figure 79: Frontal section of the knee joint in flexion. Anterior view.***

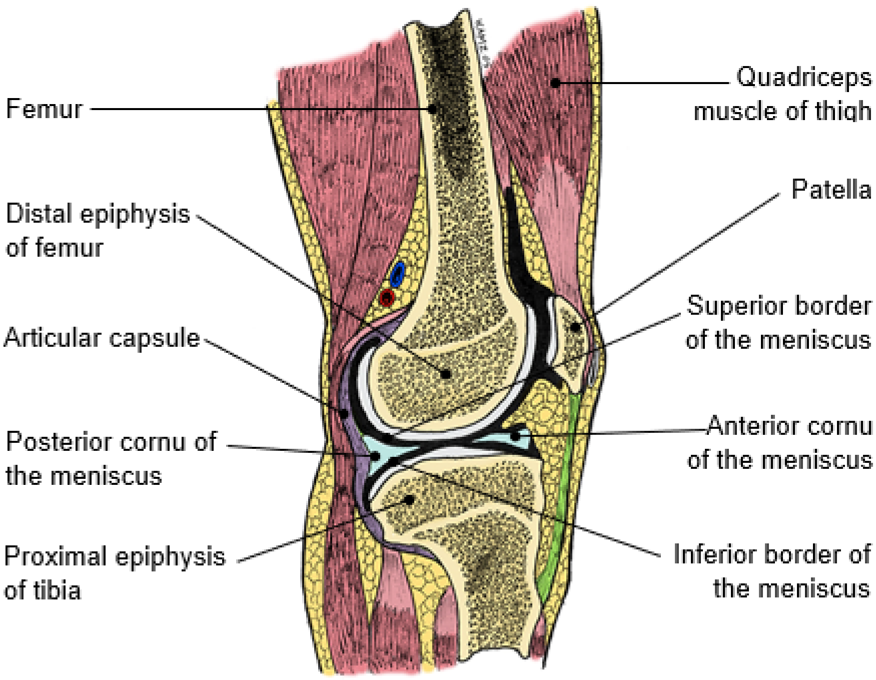



***Figure 80: Sagittal section of the right knee.***

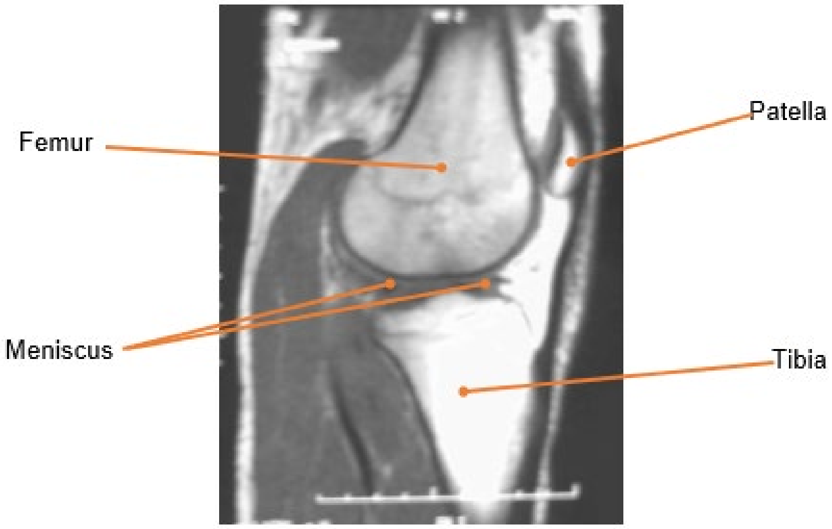



**Figure 81: MRI, sagittal section of the right knee.**

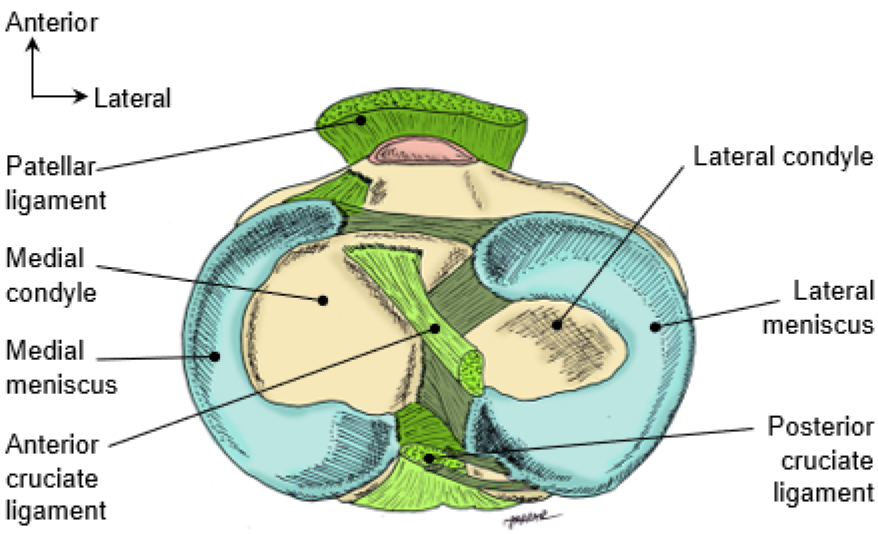



**Figure 82: The right tibial plateau with the menisci. Superior view.**

***Figure 83: The left tibial plateau with the menisci. Superior view.***

**Hinge joint**

A cylindric convex articular surface of one bone is perpendicular to the long axis of the bone and lies in a corresponding concavity of the other bone. Mobility is possible only in the sagittal plane, around single axis. Possible movements are flexion and extension.

Example: the humero-ulnar joint.

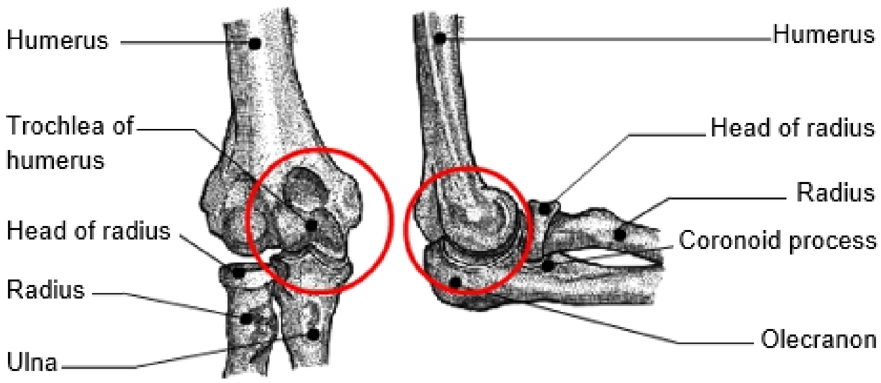



***Figure 84: The right elbow joint. Anterior view in extension and left lateral view in flexion.***

Although a hinge joint is stable, its dislocation is possible, but is usually accompanied by soft tissue trauma.

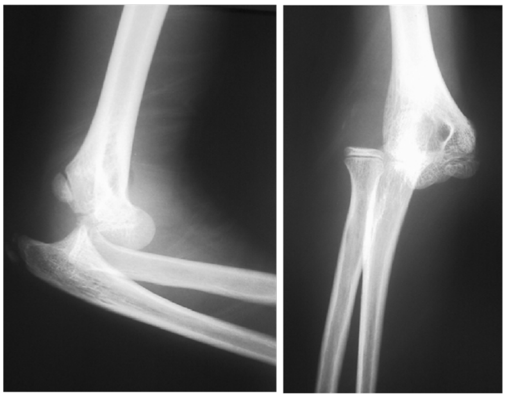


***Figure 85: X-rays of the right elbow showing dislocation. Anterior and lateral projections.***

**Pivot joint**

A cylindric convex articular surface of one bone is parallel to the long axis of the bone and lies in a corresponding concavity of the other bone. Mobility is possible around single, vertical axis. The possible movements are lateral and medial rotation

Example: the proximal and distal radioulnar joints. In the proximal radioulnar joint, the head of radius rotates in the radial incisura on proximal end of ulna. In the distal radioulnar joint, lower end of radius rotates around the head of ulna.

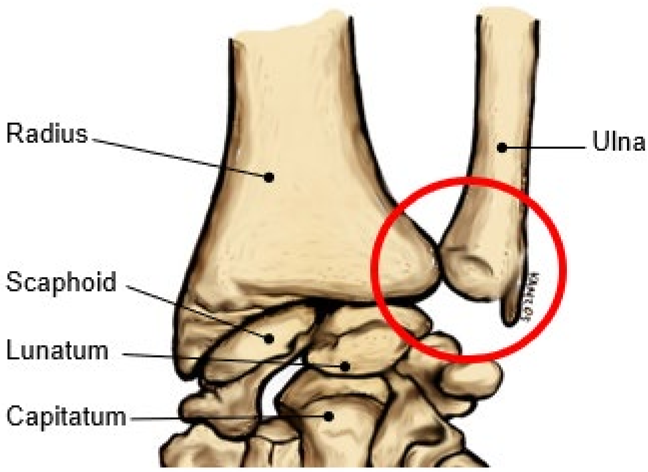



***Figure 86: Distal radioulnar joint.***

**Plane joint**

Articular surfaces of both bones are flat. The only possible movement is very restricted sliding or gliding. Movements are limited by tight joint capsule and strong ligaments.
Example: the acromioclavicular joint.

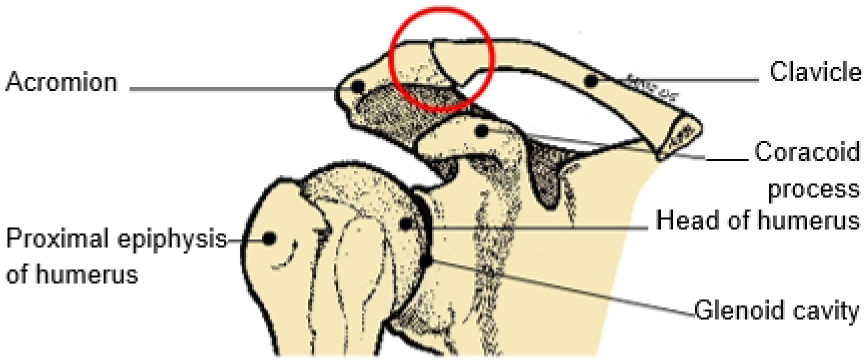



***Figure 87: The right acromioclavicular joint. Anterior view.***

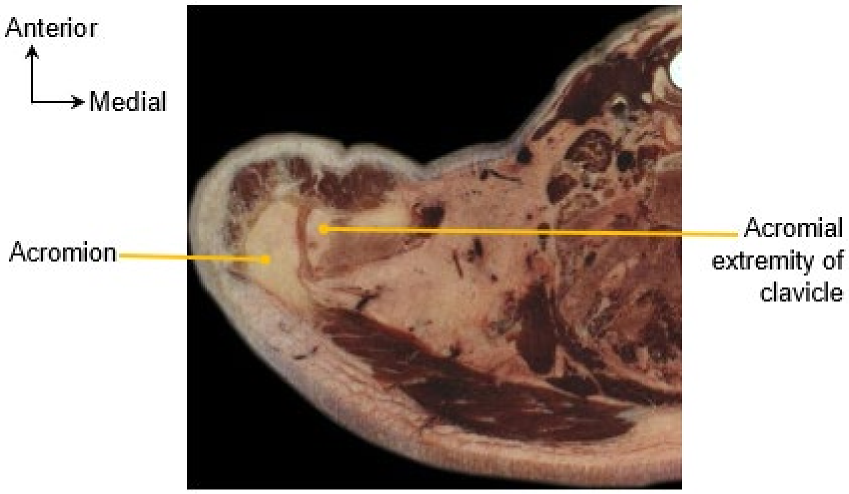



***Figure 88: Cross-section of the right acromioclavicular joint. Inferior view.***

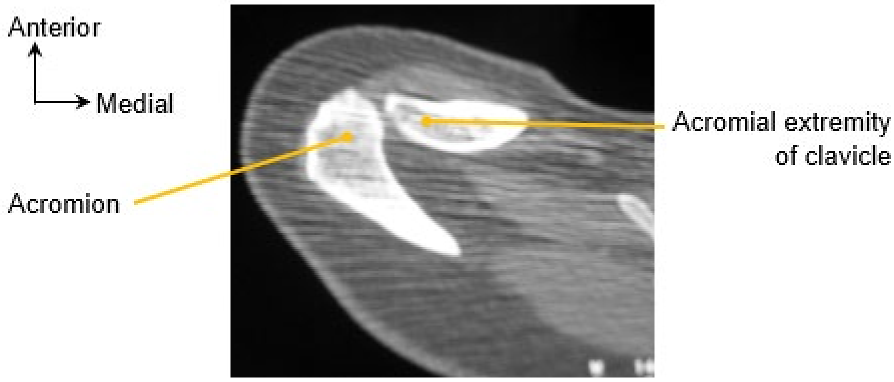



***Figure 89: CT, cross-section of the right acromioclavicular joint. Inferior view.***
Separations of this joint are frequent and often difficult to repair.

# 3 - The muscular system

The muscular system encompasses skeletal muscles, fasciae, synovial bursae and tendon sheaths. The main feature of muscles is their ability to contract.

**Types of muscular tissue**

The muscle is essentially composed of contractile muscle tissue interwoven with fibrous tissue. The muscle cells are also called muscle fibres, or myocytes.

There are three distinct types of muscle tissue: skeletal, smooth, and cardiac muscle tissue.

Striated (skeletal) muscle tissue has a stripped appearance under the microscope. It is innervated by somatic nervous system and contracts voluntarily. It is part of the muscular system.

Smooth muscle tissue does not have a stripped appearance under the microscope. It is innervated by autonomic nervous system and contracts involuntarily. It is mostly located in the wall of the hollow visceral organs (e.g. digestive tract, respiratory tract, urinary tract, blood vessels, etc.). It is part of the visceral and integrating systems.

Cardiac muscle tissue has a stripped appearance under the microscope, but with less stripes than the skeletal muscle tissue. It is innervated by autonomic nervous system and contracts involuntarily. It is located in the wall of the heart.

## *Skeletal muscles*

The main functions of skeletal muscles are producing movements and maintaining the body posture.

The majority of skeletal muscles is attached to the skeletal system.

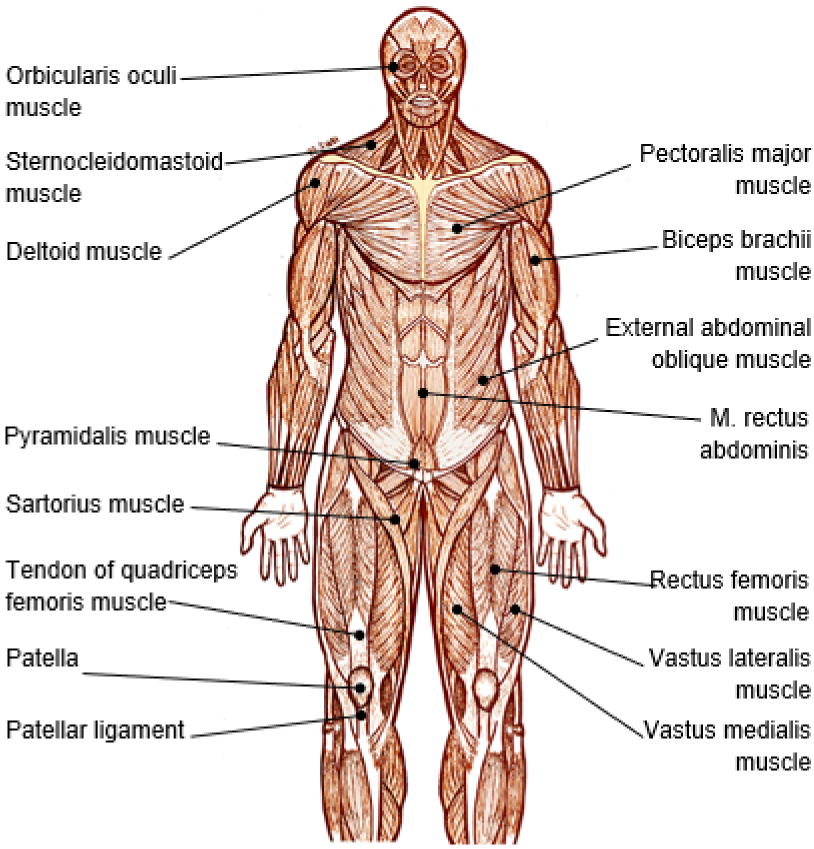



***Figure 90: Skeletal muscles of the human body. Anterior view.***

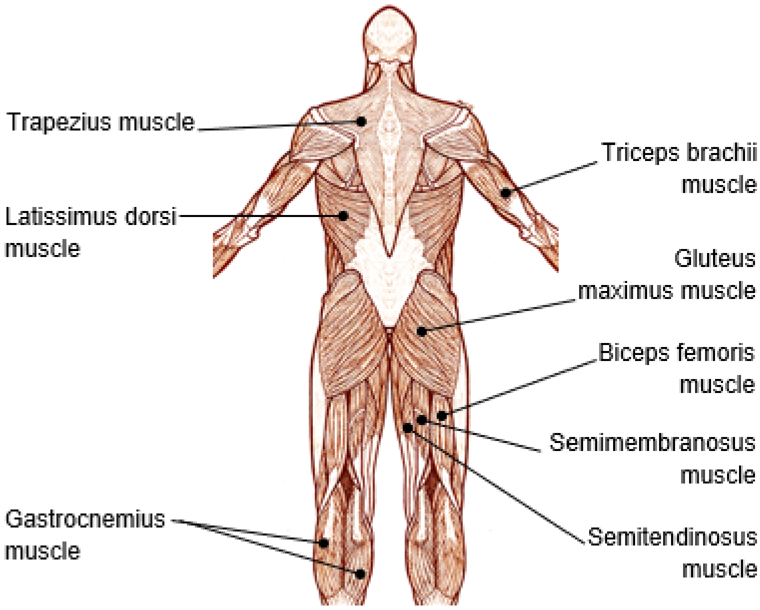



***Figure 91: Skeletal muscles of the human body. Posterior view.***

***Figure 92: Hypertrophy of skeletal muscles.***

**Structure of skeletal muscles**

Most skeletal muscles have fleshy contractile portion composed of striated skeletal muscle tissue and fibrous noncontractile portion composed of collagen fibres. The reddish contractile portion is called the belly, and white noncontractile portion is called the tendon. Muscles are typically attached to bones by tendons.

They may also have different shapes: we distinguish between flat muscles (e.g. latissimus dorsi muscle), fusiform muscles (e.g. sartorius muscle), circular or sphincter muscles (e.g. external anal sphincter), quadrate muscles (e.g. quadratus femoris muscle), multiheaded muscles (e.g. biceps brachii muscle, triceps brachii muscle), multi-bellied muscles (e.g. digastric muscle), etc. These characteristics determine the function of the muscles.

***Figure 93: Flat muscle.***

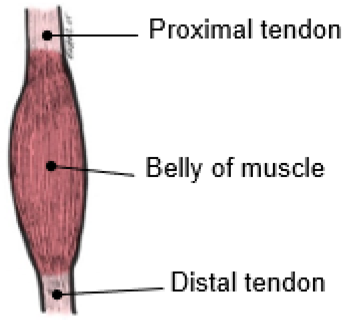



***Figure 94: Fusiform muscle.***

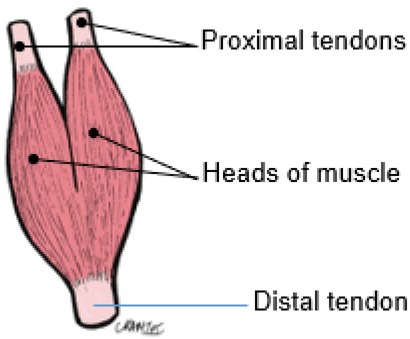



***Figure 95: Bicipital muscle.***

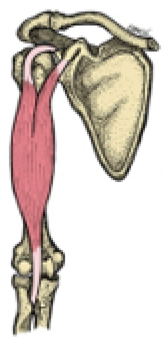


***Figure 96: Biceps brachii muscle.***

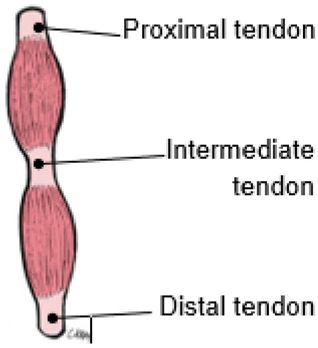



***Figure 97: Digastric muscle.***

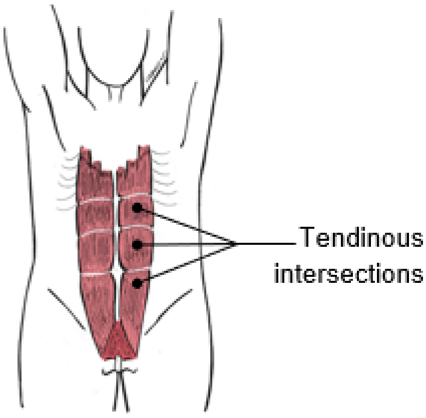



***Figure 98: Rectus abdominis muscle.***

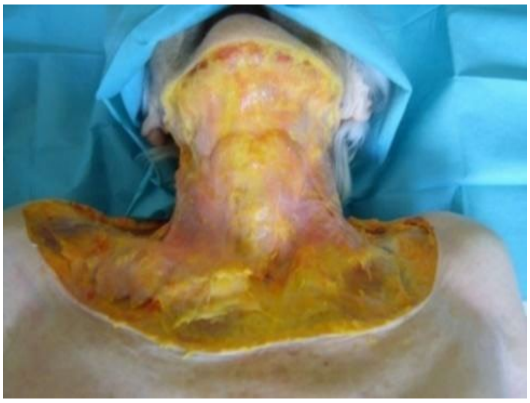


***Figure 99: Neck dissection. Anterior view.***

***Figure 100: Dissection of the right femoral triangle showing anterior thigh muscles.***

***Figure 101: Dissection of the abdomen showing abdominal muscles.***

### Innervation of skeletal muscles

The innervation of skeletal muscles is both motor and sensory. Motor nerve fibres transfer the impulse for muscle contraction. Sensory nerve fibres transfer information from the receptors called the muscle spindles and Golgi tendon organs; they are involved in proprioception and protect the muscle from injury.

Motor neurons originate in the anterior horn of the spinal cord. Each muscle fibre is innervated by single motor neuron. The branches of one motor neuron can innervate several muscle fibres. Each individual motor neuron with all the muscle fibres that neuron innervates constitute a functional unit called the motor unit. The junction between the nerve ending at the muscle fibre is called a neuromuscular junction (motor end-plate). The transmission of signal for contraction from nerve fibre to muscle fibres is ensured by the neurotransmitter acetylcholine. The absence of acetylcholine is pathological and results in muscle weakness (myasthenia).

The force of contraction is determined by the number of muscle fibres contracting. The muscle fibres work in an on/off mode during contraction.

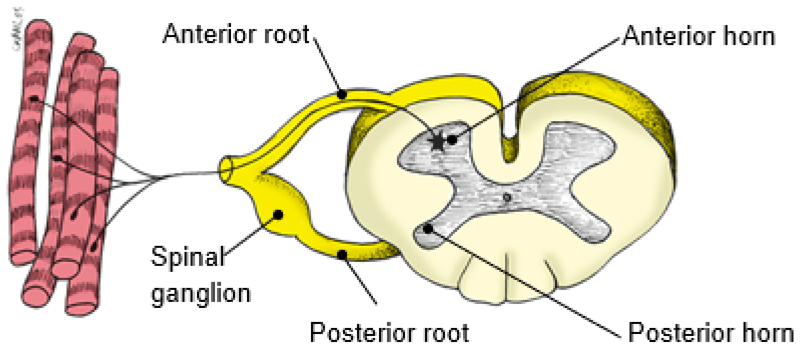



***Figure 102: Motor innervation of skeletal muscles.***

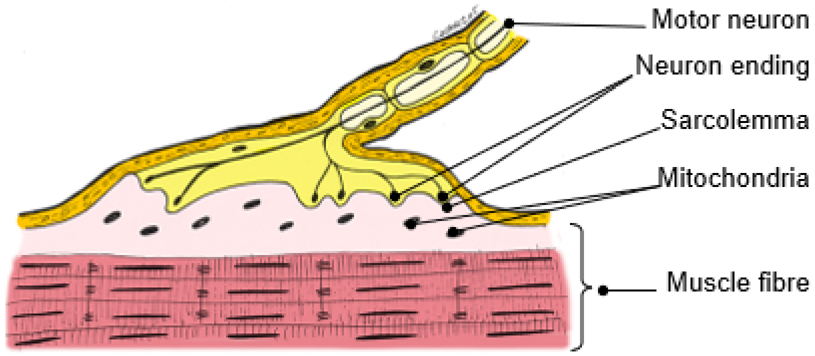



***Figure 103: Motor end-plate***

## Muscles of upper limb

**General overview of the muscle groups**

The muscles are divided into compartments according to their topographical position. These compartments are delimited by fasciae. Compartments also contain the nerves and vessels.

Muscles perform different functions depending on their position. For example, the muscles in the anterior compartment of arm are flexors and the muscles in the posterior compartment of arm are extensors.

The muscles of the upper limb are divided in the following groups:

- scapulohumeral muscles,
- anterior compartment of arm,
- posterior compartment of arm,
- anterior compartment of forearm,
- posterior compartment of forearm,
- muscles of hand.

The movements of the upper limb are also enabled by the muscles of the back and the thorax.

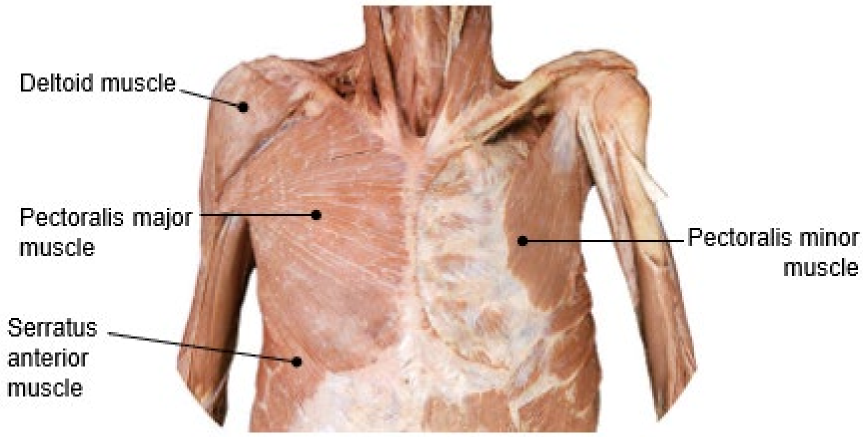



***Figure 104: Muscles of thorax for the upper limb. Anterior view.***

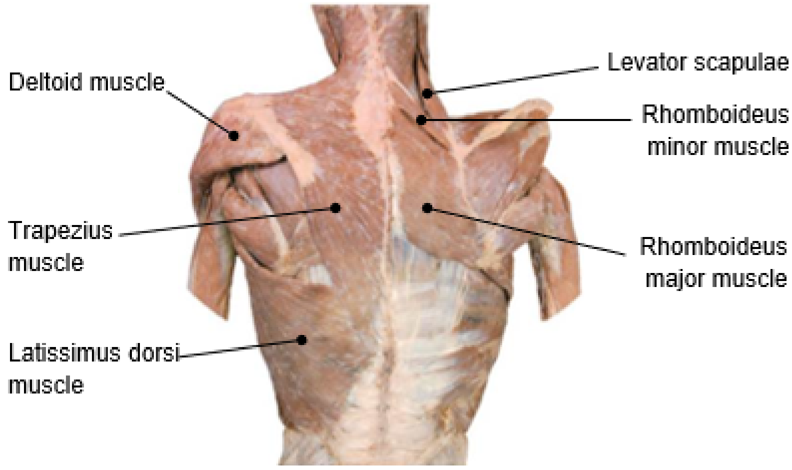



***Figure 105: Muscles of back for the upper limb. Posterior view.***

## Organisation of muscles in compartments

On the arm, muscles are enveloped in the brachial fascia and divided in two muscle compartments: the anterior (flexor) compartment and the posterior (extensor) compartment. The two compartments are separated by the medial and lateral intermuscular septum of arm.

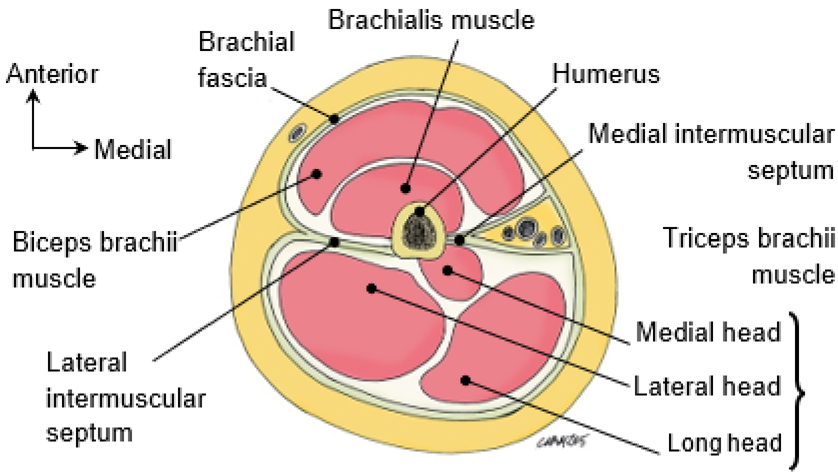



***Figure 106: Schematic cross-section through the middle third of the right arm. Inferior view.***

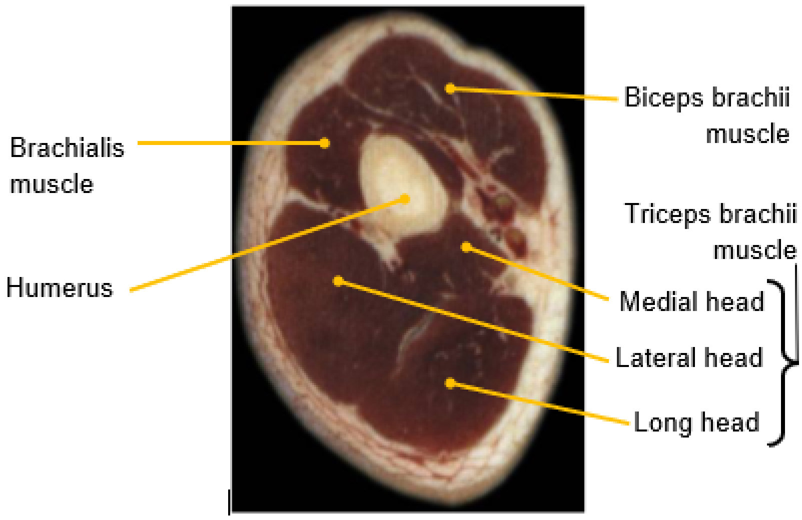



***Figure 107: Cross-section through the middle third of the right arm. Inferior view.***

On the forearm, muscles are enveloped in the antebrachial fascia and divided into anterior (flexor) and posterior (extensor) compartment. Each compartment is further divided into superficial and deep part. Muscles are numerous, enabling fine and precise movements of the hand and the fingers. In the anterior compartment lie two pronators, while in the posterior compartments lies the supinator.

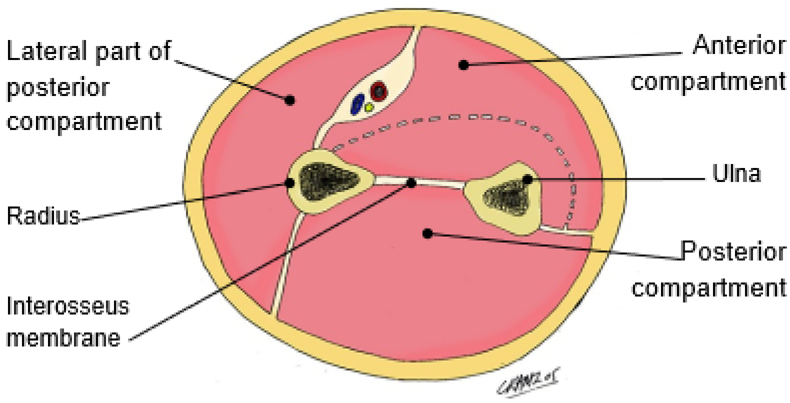



***Figure 108: Schematic cross-section through the middle third of the right forearm. Inferior view.***

## Muscles of lower limb

**General overview of the muscle groups**

The muscles of the lower limb enable standing, walking, etc. They are divided into the following groups:

- Iliopsoas muscle,
- gluteal muscles,
- anterior compartment of thigh,
- medial compartment of thigh,
- posterior compartment of thigh,
- anterior compartment of leg,
- lateral compartment of leg,
- posterior compartment of leg,
- muscles of the foot.

**Organisation of muscles in compartments**

At the level of the gluteal region and the thigh, muscles are enveloped in the fascia lata.

In the gluteal region, muscles are divided in the superficial and deep gluteal muscles.

On the thigh, there are three muscle compartments separated by the medial and lateral femoral intermuscular septum. In the anterior compartment are mostly extensors of knee, in the posterior compartment are flexors of knee, and in the medial compartment are adductors of thigh.

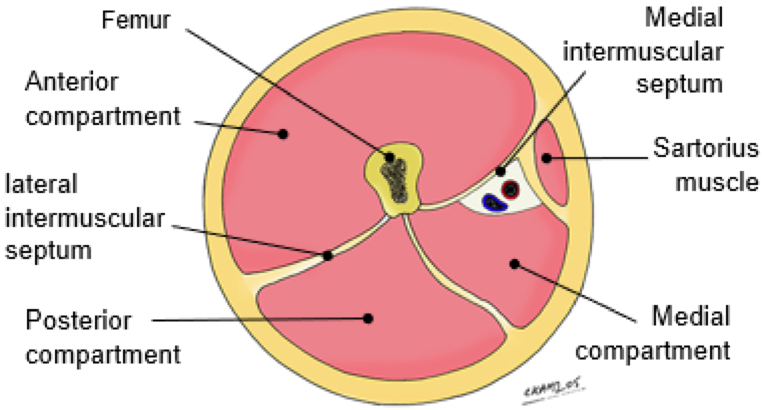



***Figure 109: Schematic cross-section through the middle third of the right thigh. Inferior view.***

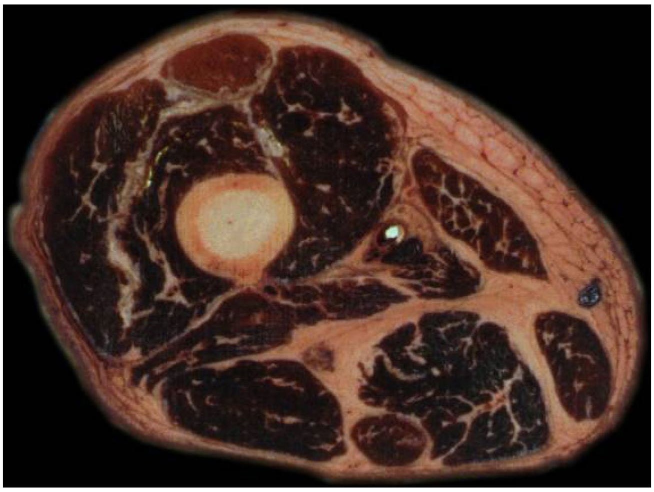


***Figure 110: Cross-section through the middle third of the right thigh. Inferior view.***

On the leg, muscles are enveloped in the crural fascia. They are separated into three compartments by the anterior and posterior intermuscular septum of the leg. In the anterior compartment, are the extensors of the foot and toes, in the posterior compartment are the flexors of the leg and toes, and in the lateral (fibular) compartment are the evertors of the leg.

The transverse crural intermuscular septum separates the posterior compartment into the superficial and deep part.

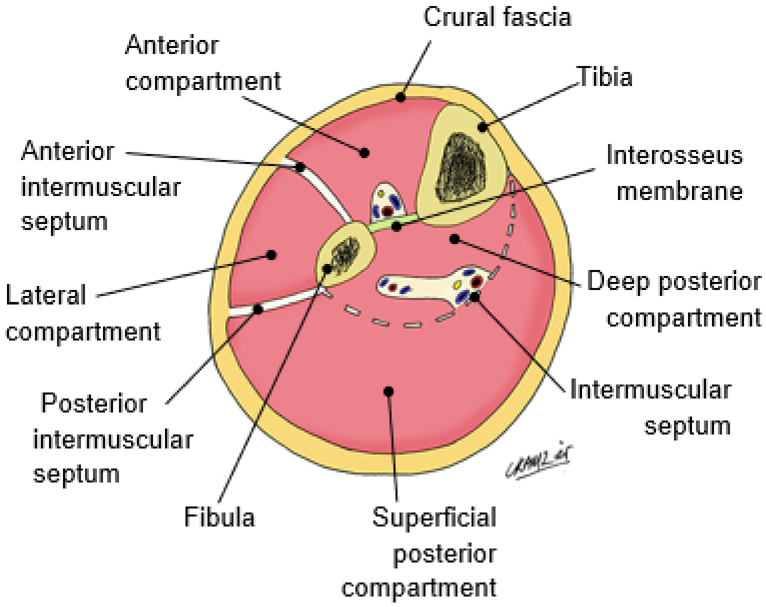



***Figure 111: Schematic cross-section through the middle third of the right leg. Inferior view.***

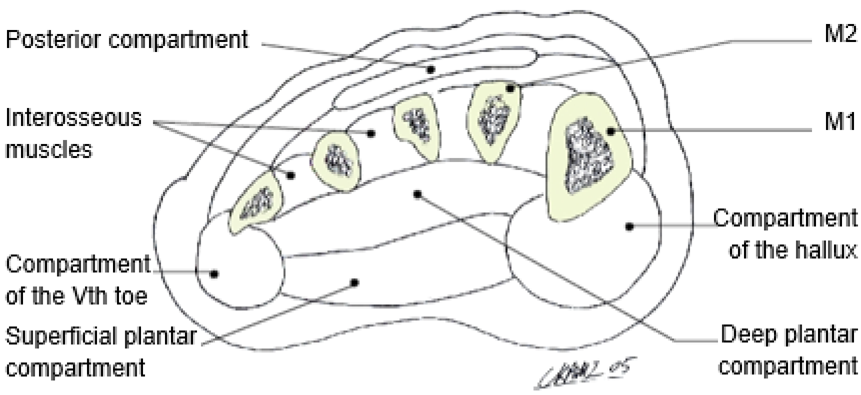



***Figure 112: Schematic cross-section of the foot. M – metatarsal bone.***

The photographs below show claw toes due to post-ischemic retraction of the leg muscles.

***Right foot in profile*** ***Right foot from the front***

***Figure 113: Volkmann syndrome.***

# Chapter 3 - Nervous system

**The objectives of this chapter are:**

1. Define the central and peripheral nervous system.
2. Describe the brain.
3. Name parts of the cerebrum, cerebellum, and brainstem.
4. Describe the spinal cord.
5. Describe the spinal nerves and spinal nerve plexuses.
6. Name the cranial nerves and their functions.
7. Describe the autonomic nervous system.

## 1 - Generalities

The nervous system is a set of structures that enable reception, integration and transmission of sensory information, and generation of adequate response to the information.

Basic cells of the nervous systems are neurons. A neuron has a body (soma), short, branched extensions called dendrites and long extension called axon, which can be enveloped in the myelin sheath.

The nervous system can be divided into categories in diverse ways:

- **Morphological division of the nervous system**
    - Central nervous system comprises the brain and the spinal cord.
    - Peripheral nervous system comprises 12 pairs of cranial nerves and 31 pairs of spinal nerves.
- **Functional division of the nervous system**
    - Nervous system of relational life: the somatic nervous system, conscious and voluntary.
    - Nervous system of vegetative life: the autonomic nervous

system, unconscious and involuntary. It consists of the sympathetic and parasympathetic nervous system.

# 2 - Morphological study of the nervous system

## 2.1 - Central nervous system

In the central nervous system, parts of neurons are arranged in such a way that they form the grey and the white matter:

- **The grey matter** contains mostly the bodies of neurons.
- **The white matter** contains mostly the nerve fibres – the axons with their myelin sheaths.

The central nervous system includes the brain and the spinal cord.

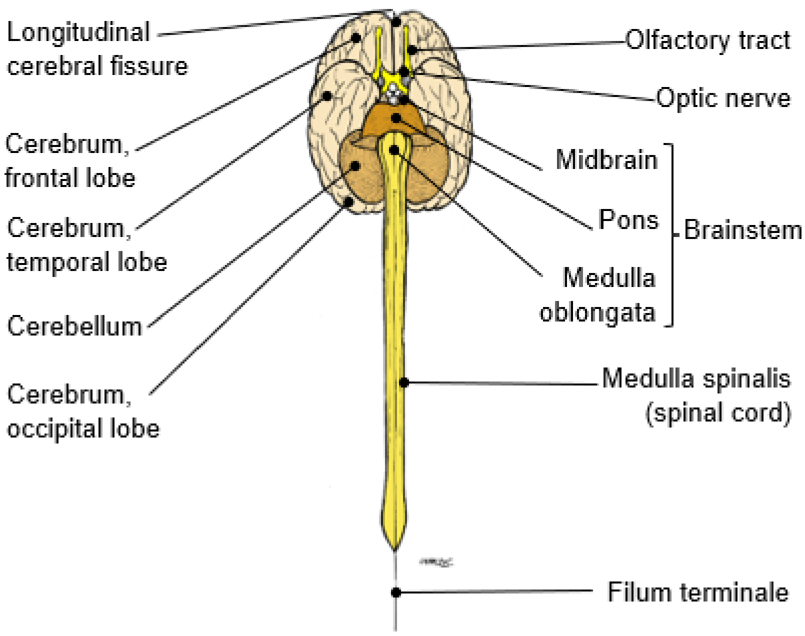



***Figure 114: Anterior view of the central nervous system.***

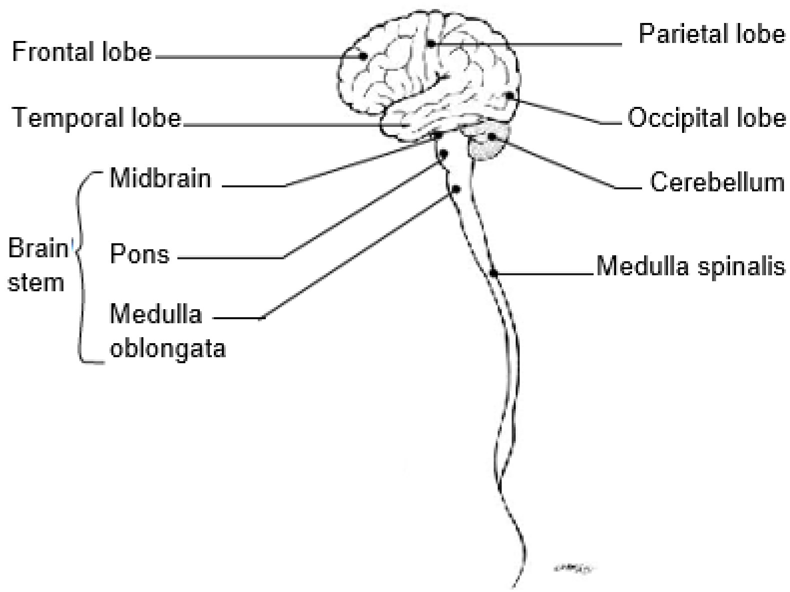



***Figure 115: Left lateral view of the central nervous system.***

## *Spinal cord*

The spinal cord is about 45 cm long tubular structure with a diameter of about 1 cm. It lies within the vertebral canal and terminates at the level of vertebra L2, with the narrowing called the medullary cone. It has two enlargements, the cervical and lumbar one.

The grey matter of the spinal cord is located centrally, forming paired anterior (motor) column and paired posterior (sensory) column. The thoracic and sacral segments have an additional, lateral pair of columns.

On the cross-section, the grey matter has a shape of a letter H and is divided into paired anterior, posterior and lateral horns. The white matter is divided into paired anterior, posterior and lateral funiculi.

The central canal is a longitudinal hollow space in the centre of the spinal cord, spanning throughout its entire length. It is filled with the cerebrospinal fluid.

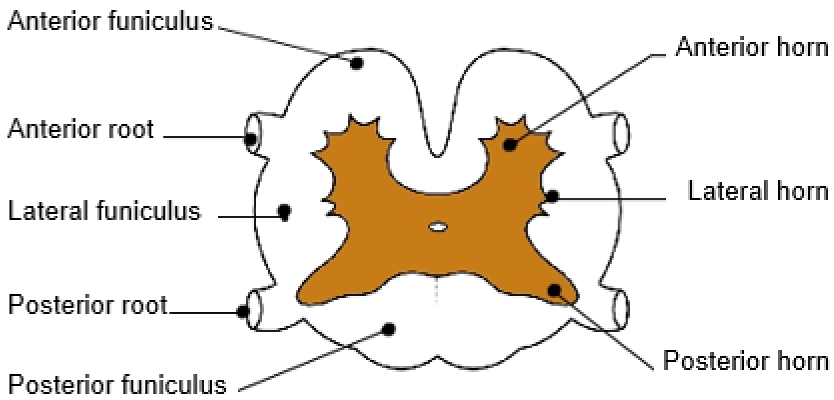



***Figure 116: Cross-section through the spinal cord, morphological areas.***

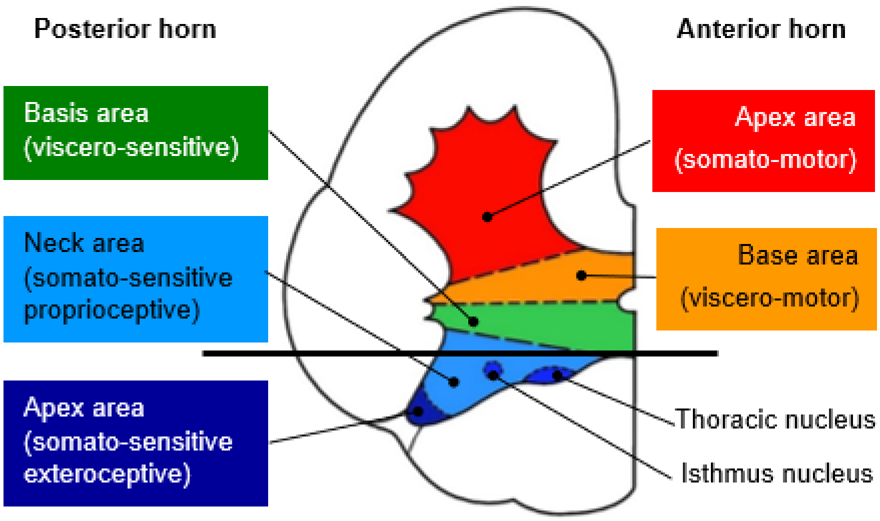



***Figure 117: Cross-section through the spinal cord, functional areas.***

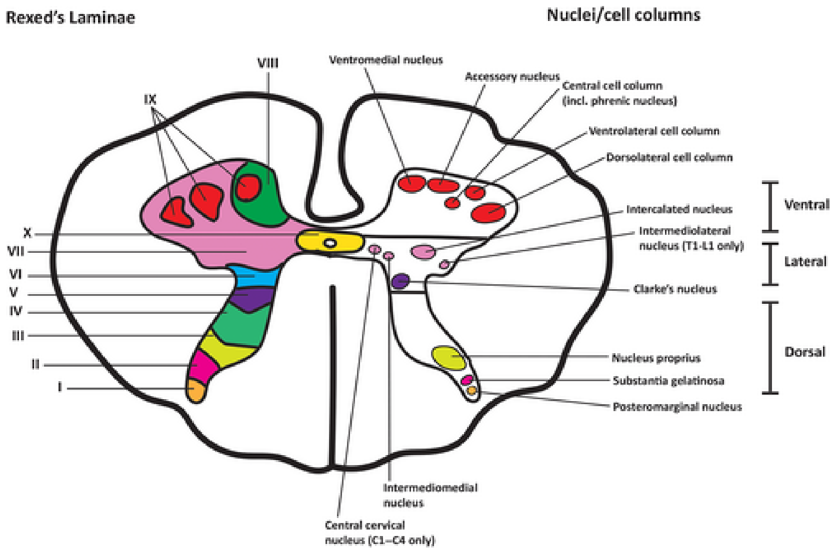



***Figure 118: Cross-section through the spinal cord, lamination of grey matter.***

Acute poliomyelitis is a viral disease that electively affects the anterior (motor) horn of the spinal cord and causes paralysis without affecting sensitivity. Contractures can develop.

***Right leg: lateral view.*** ***Left foot: anterolateral view.***

***Figure 119: Patient with poliomyelitis.***

## Brain

The brain is composed of three parts:

- The brainstem is the site of the vital centres.
- The cerebellum is the site of equilibrium maintenance and motor coordination.
- The cerebrum is the site of analysing and processing centres.

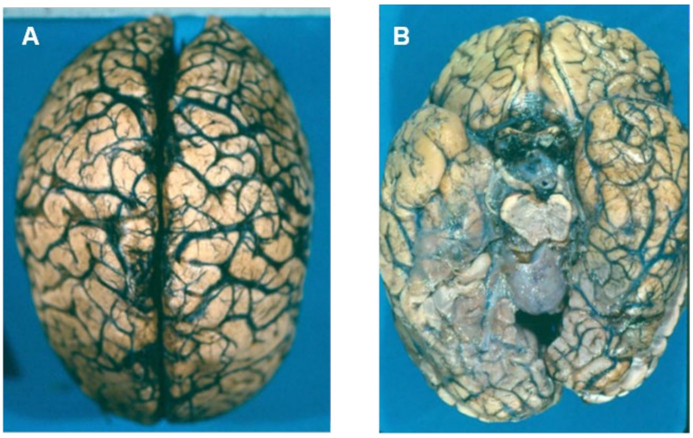



***Figure 120: Superior (A) and inferior (B) view of the brain***

### Cerebrum

The cerebrum is the largest part of the brain and the highest level in functional hierarchy of the central nervous system. It is particularly well developed in humans. It is divided into two parts, the telencephalon and the diencephalon.

The telencephalon is formed by left and right cerebral hemispheres, connected by the corpus callosum. The hemispheres are separated in the midline by a deep sagittal fissure named the longitudinal cerebral fissure. Each hemisphere is divided into four lobes: the frontal, parietal, temporal and occipital lobes. Surface of the hemispheres is folded into ridges called cerebral gyri. The gyri are separated with furrows called cerebral sulci.

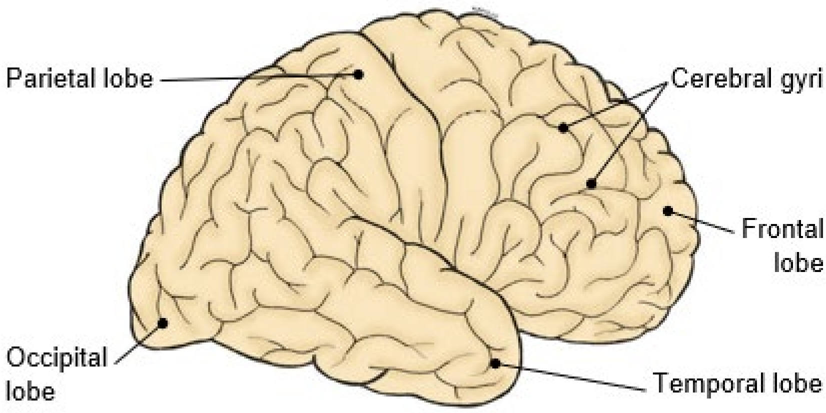



***Figure 121: Right lateral view of the brain.***

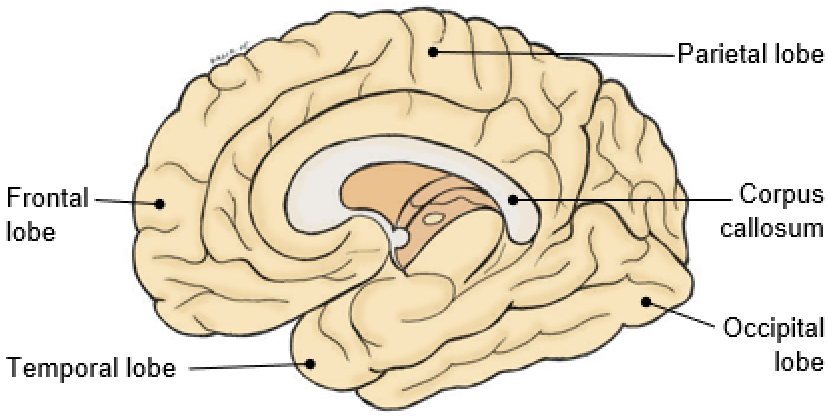



***Figure 122: Median section of the cerebrum. View from the left.***

The diencephalon is a much smaller part of the cerebrum, located in the middle of the brain. Its most important regions are the thalamus, the hypothalamus and the epithalamus.

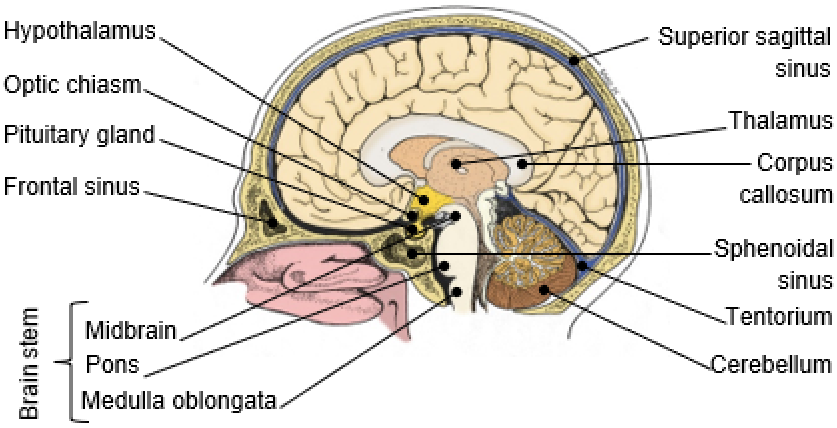



***Figure 123: Median section of the brain. View from the left.***

The grey matter of cerebrum is located on the surface of the hemispheres as the cerebral cortex, and also in the inner part as basal ganglia. In between are the bundles of white matter.

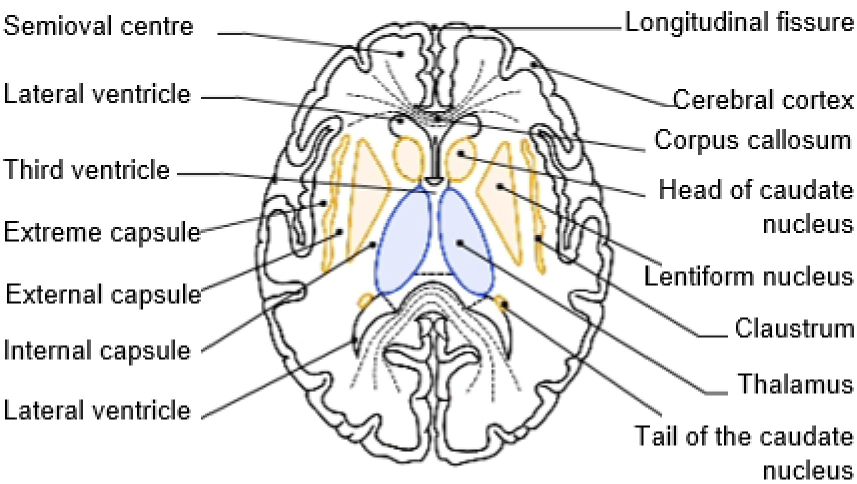



***Figure 124: Scheme of the horizontal section of the cerebrum.***

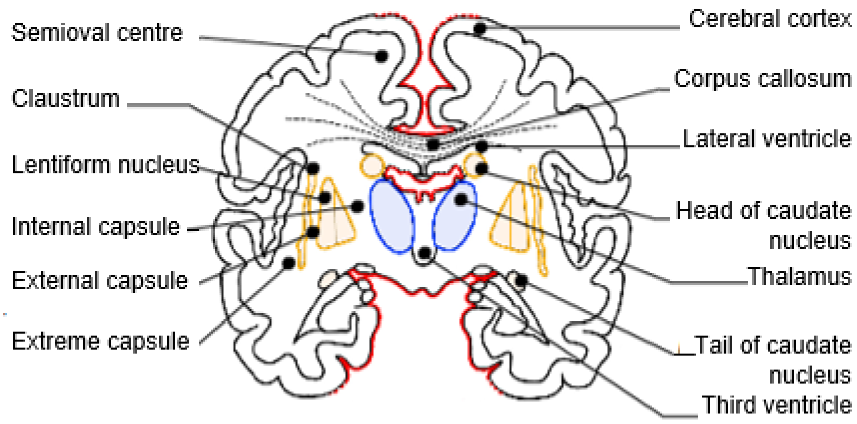



***Figure 125: Scheme of the frontal section of the cerebrum.***

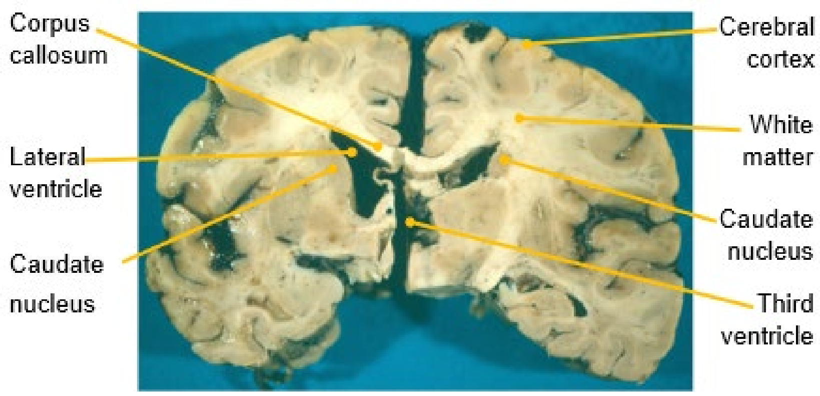



***Figure 126: Photography of the frontal section of the cerebrum.***

## Cerebellum

The cerebellum is located in the posterior cranial fossa, posteriorly to the brainstem to which it is connected by the cerebellar peduncles.

It consists of the left and right cerebellar hemisphere and the vermis in-between them. The grey matter on the surface of cerebellum forms the cerebellar cortex. Some of the grey matter lies in deeper parts, forming the cerebellar nuclei.

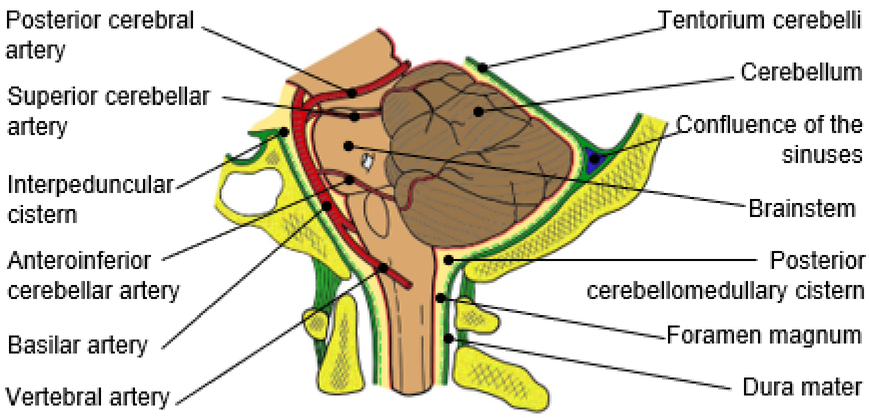



***Figure 127: Sagittal section of the posterior cranial fossa with cerebellum and brainstem, view from the left.***

### Brainstem

The brainstem is located in the posterior cerebral fossa, in front of the cerebellum. It is an important passage between the spinal cord and the brain for the main motor, sensory and association pathways. It is the nerve structure from which most of the cranial nerves originate (cranial nerves III to XII). It is also a site where the so-called vital centres are located, enabling the body to maintain the vitally important functions, such as breathing, heart beating and blood pressure regulation.

The brainstem has a shape of truncated cone. It is 9-10 cm long and widens upwards. The grey matter is situated in the inner part of the brainstem and is intertwined by the white matter, thus forming reticular formation.

The brainstem is divided into three distinctive parts (from bottom to top):

- medulla oblongata (bulb) is continuation of the spinal cord;
- pons is connected posteriorly to the cerebellum;
- midbrain (mesencephalon) is connected superiorly to the cerebrum with paired cerebral peduncles.

**Ventricles of brain**

The ventricles of the brain are hollow spaces in the brain, filled with the cerebrospinal fluid (CSF).

There are four ventricles connected to each other. The lateral ventricles (1st and 2nd ventricle) are the largest and lie inside each cerebral hemisphere. They have a shape of a letter C and reach into all the lobes. Three horns of the ventricle wear the same name as the lobe they lie in while the central part lies inside the parietal lobe. The third ventricle is in the diencephalon. The fourth ventricle is located between the brainstem and the cerebellum.

Each lateral ventricle is connected to the 3rd ventricle through the interventricular foramen, while the 3rd and 4th ventricle communicate through the cerebral aqueduct which lies inside the midbrain. The 4th ventricle communicates with the subarachnoid space.

The ventricles contain choroid plexuses, which secrete about 500 ml of CSF per day. Excessive secretion of CSF can lead to hydrocephalus.

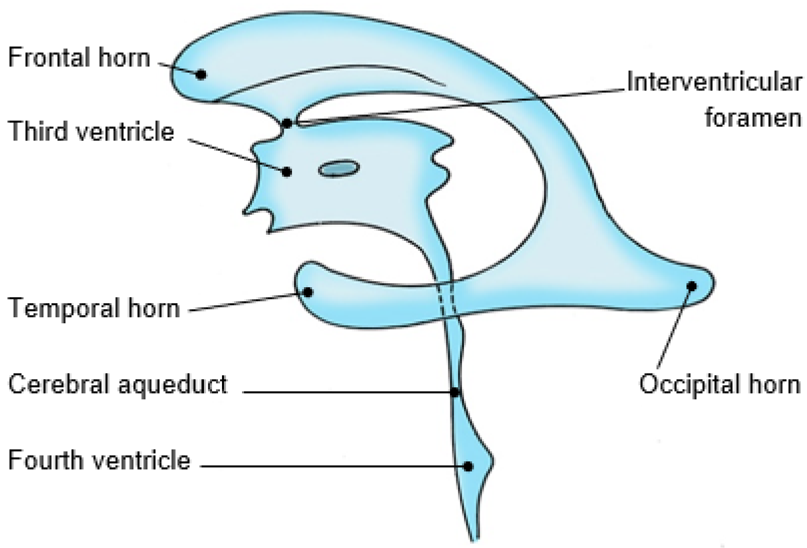



***Figure 128: Ventricles of brain, left lateral view.***

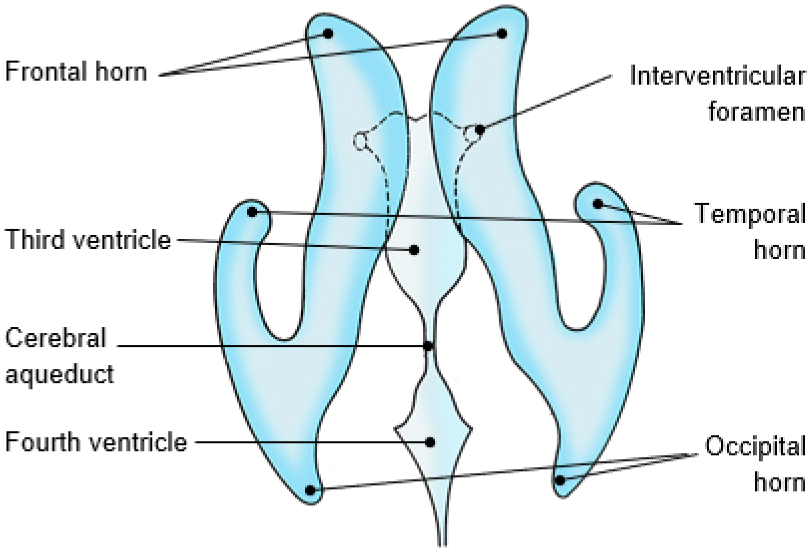



***Figure 129: Ventricles of brain, superior view.***

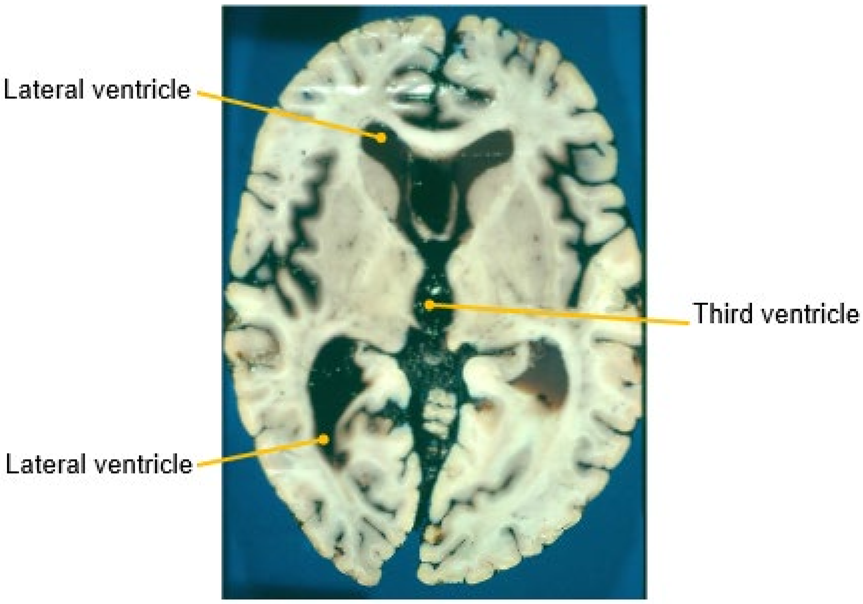



***Figure 130: Horizontal section of the brain showing the ventricles.***

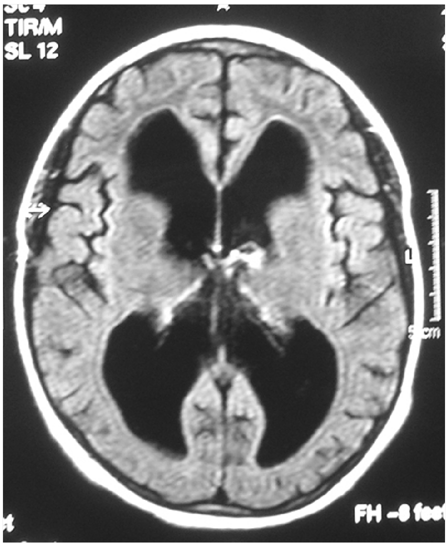


***Figure 131: MRI, horizontal section of the brain showing hydrocephalus.***

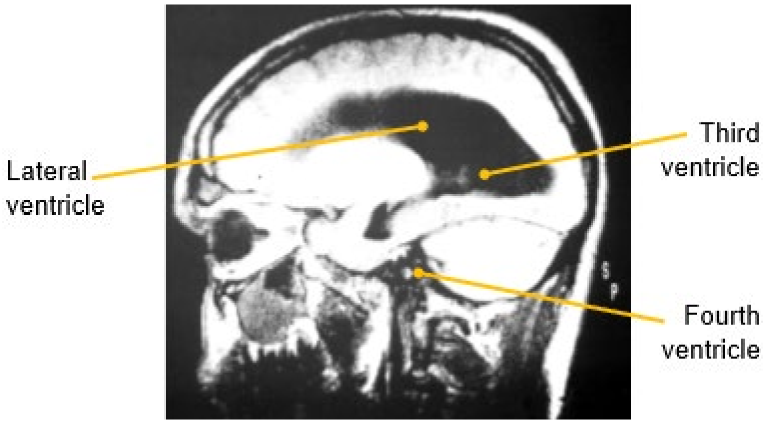



***Figure 132: MRI, sagittal section of the brain showing the ventricles.***

## 2.2 - Peripheral nervous system

The peripheral nervous system is formed by nerves exiting the central nervous system. According to the origin, the peripheral nervous system is divided into the spinal nerves originating from the spinal cord and the cranial nerves originating from the brain.

## Spinal nerves

31 pairs of spinal nerves branch off from the spinal cord:

- 8 pairs of cervical nerves – spinal nerves C1 to C8.
- 12 pairs of thoracic nerves – spinal nerves T1 to T12.
- 5 pairs of lumbar nerves – spinal nerves L1 to L5.
- 5 pairs of sacral nerves – spinal nerves S1 to S5.
- 1 pair of coccygeal nerve – spinal nerve Co.

There are 8 pairs of cervical spinal nerves, although there are only seven cervical vertebrae. The numbering of the nerves starts at the top. The first pair (C1) runs between the occipital bone and vertebra C1. The second pair runs between the vertebrae C1 and C2, so the number of the nerve corresponds to the number of the vertebra below it. The pair of nerves C7 lies between the vertebrae C6 and C7, and the pair of nerves C8 lies between the vertebrae C7 and T1. The following pairs of nerves take the number of the vertebra above it.

The spinal nerve arises from the spinal cord as rootlets which converge to form two nerve roots, the anterior and posterior one.

The anterior root (motor root) of spinal nerve is formed by the axons of motor neurons, arising from the anterior horn of the spinal cord.

The posterior root (sensory root) of spinal nerve is formed by sensory neurons, which are pseudo-unipolar. The bodies of neurons form a knot on the posterior root, called the spinal ganglion. The peripheral axons join the motor fibres in the spinal nerve, and the central axons enter the posterior horn of the spinal cord.

The anterior and posterior root unite at the intervertebral foramen to form the spinal nerve. All spinal nerves are therefore mixed – they contain both motor and sensory fibres.

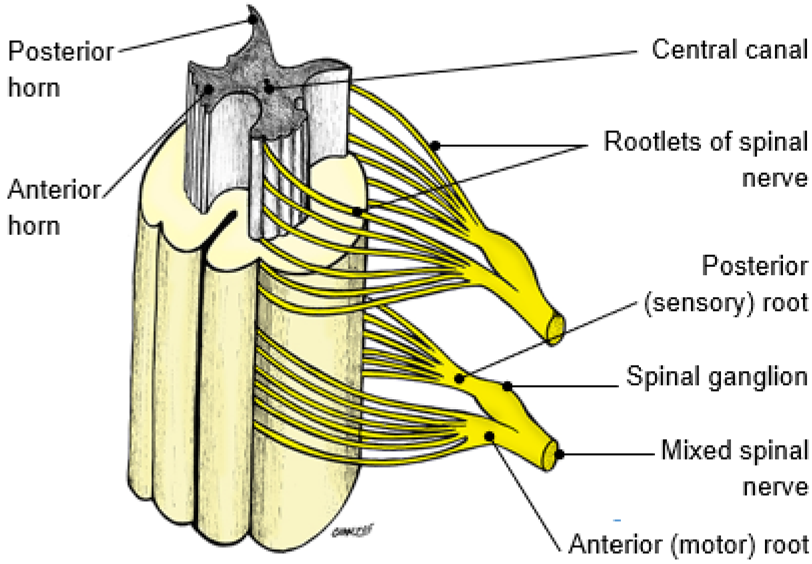



***Figure 133: Spinal nerve, anterior and posterior root, spinal ganglion.***

After exiting the intervertebral foramen, the spinal nerve divides into two branches – the anterior and posterior ramus of the spinal nerve.

The posterior rami remain separate from each other and innervate the deep muscles of the back and the skin above them in a segmental pattern.

The anterior rami innervate the anterior and lateral parts of the trunk and the upper and lower limbs. Only the rami of thoracic spinal nerves remain separate, innervating muscles and skin of the trunk in a segmental pattern. The anterior rami of cervical, lumbar and sacral spinal nerves form the nerve plexuses, from which the peripheral nerves emerge. In Latin, the term plexus means braid. This term efficiently describes the structure of the nerve plexuses.

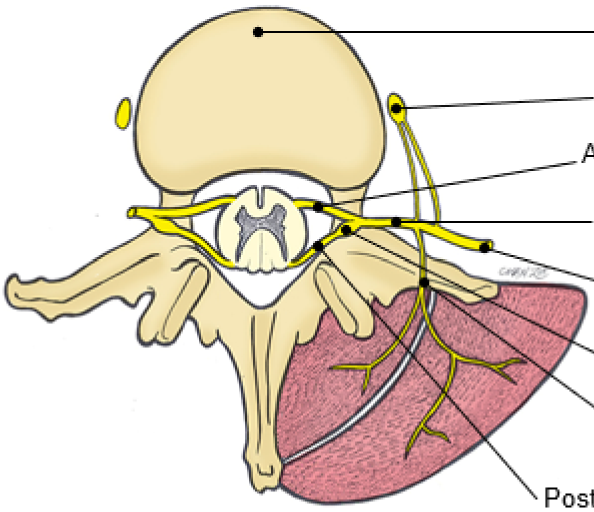



***Figure 134: Spinal nerve: anterior and posterior ramus.***

There are four distinctive nerve plexuses, namely, the cervical, the brachial, the lumbar and the sacral plexus.

### Cervical plexus

The cervical plexus is formed by the anterior rami of spinal nerves C1, C2, C3, C4 and partly C5.

The main nerve of the cervical plexus is the phrenic nerve, which innervates the diaphragm. The plexus also provides motor supply to some neck muscles and cutaneous sensation to the skin of the neck and posterior side of head.

### Brachial plexus

The brachial plexus is formed by the anterior rami of five spinal nerves: C5, C6, C7, C8 and T1. It innervates the upper limb.

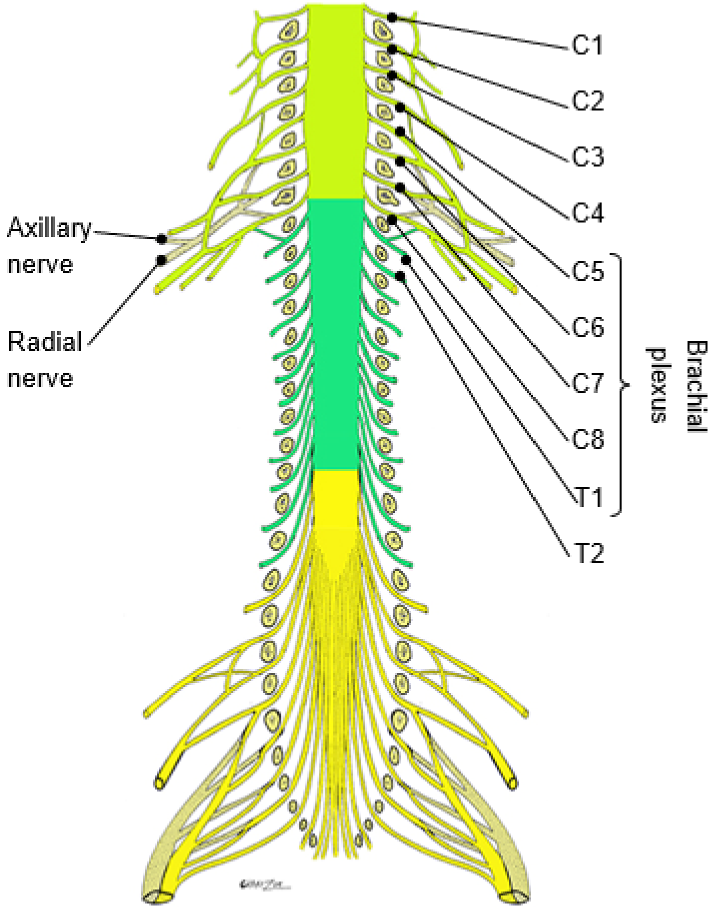



***Figure 135: Brachial plexus.***

The anterior rami of the five spinal nerves forming the brachial plexus unite into 3 trunks: the superior trunk is formed by the nerves C5 and C6, the middle trunk by a single nerve C7, and the inferior trunk is formed by the nerves C8 and T1.

These three trunks enter the axilla and recombine to form 3 cords, named according to their position to the axillary artery: the lateral, medial, and posterior cords. From the cords arise peripheral nerves.

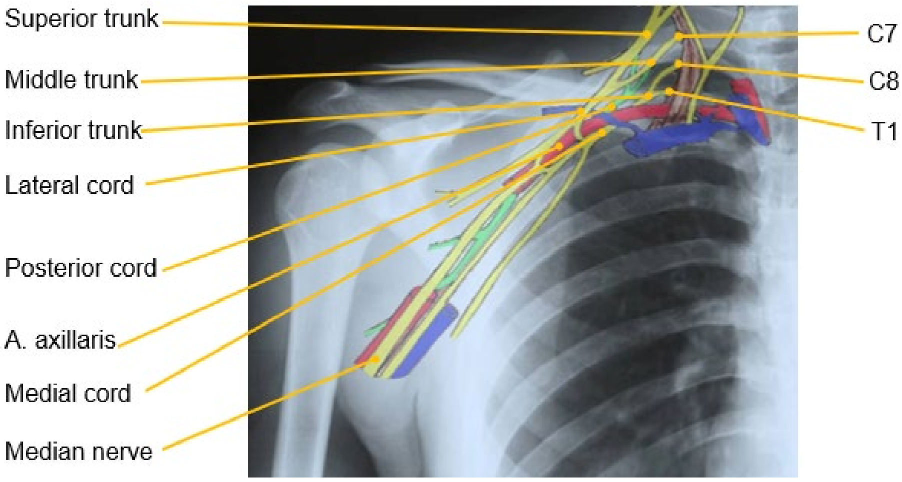



***Figure 136: X-ray of the right shoulder with drawing of the axillary artery and the brachial plexus. Anterior view.***

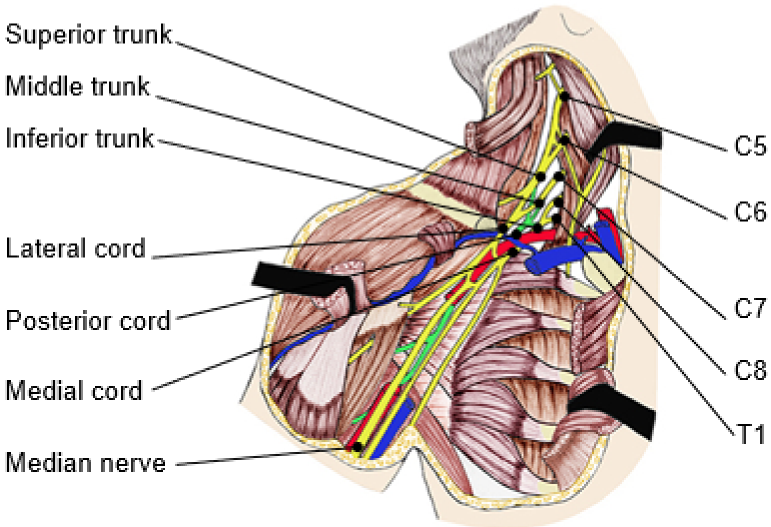



***Figure 137: The right brachial plexus. Anterior view.***

### Lumbar and sacral plexuses

The lumbar plexus is formed by the anterior rami of the spinal nerves L1, L2, L3, and L4. The sacral plexus is formed by the anterior rami of the spinal nerves L4, L5, S1, S2, S3, and S4.

Both plexuses are interconnected, forming the lumbosacral plexus which innervates the lower limb.

The sacral plexus forms the largest peripheral nerve in the body, namely the sciatic nerve which contains the fibres of spinal nerves L4 to S3.

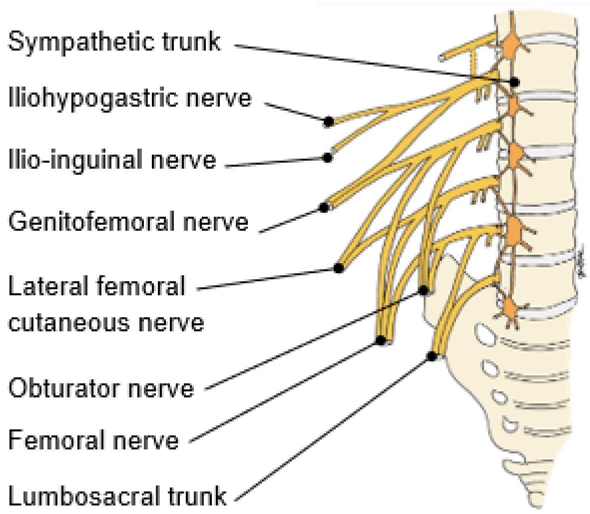



***Figure 138: The lumbar plexus.***

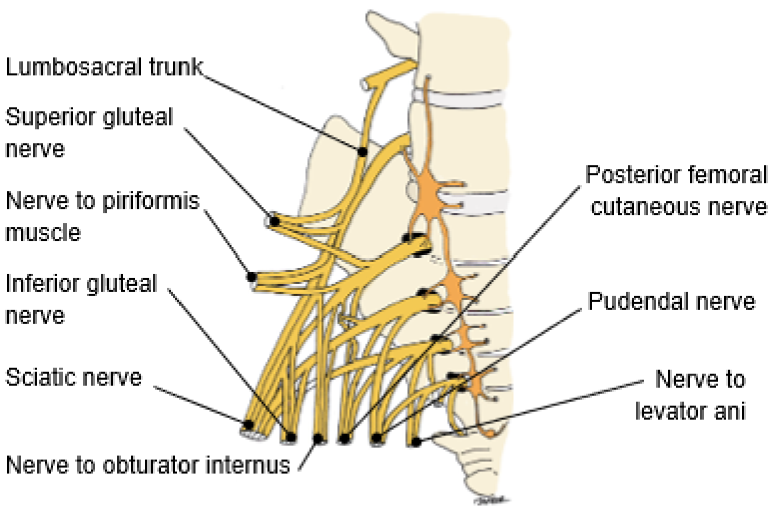



***Figure 139: The sacral plexus.***

**_Figure 140: Lumbar spine dissections._**

## *Cranial nerves*

There are 12 pairs of cranial nerves (CN), numbered from CN I to CN XII from the anterosuperior to the posteroinferior site. With the exception of the CN I and CN II, which originate from the cerebrum, all other cranial nerves originate from the brainstem.

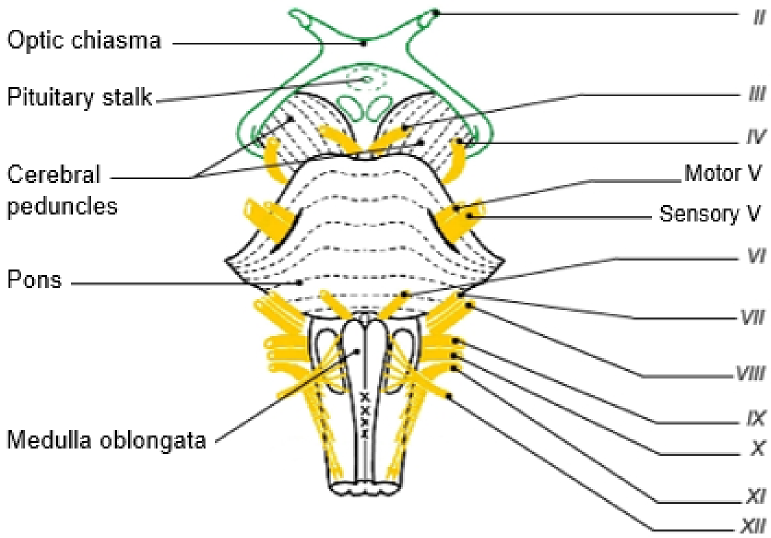



**_Figure 141: Origin of cranial nerves. Anterior view of the brainstem._**

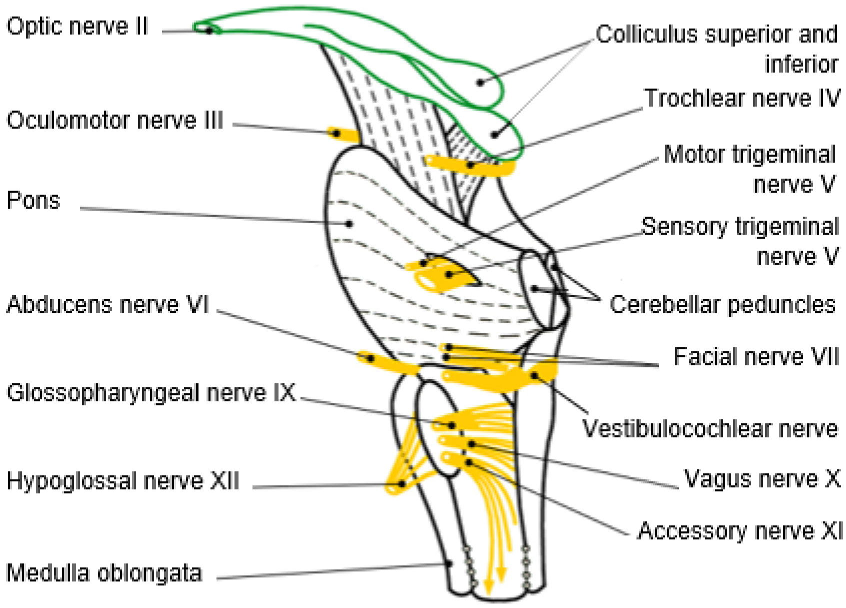



***Figure 142: Origin of cranial nerves. Left lateral view of the brainstem.***

Unlike the spinal nerves which are all mixed, the cranial nerves can contain only sensory fibres, only motor fibres, or both types of fibres. The sensory fibres end in the sensory nuclei inside the brainstem and the motor fibres arise from the motor nuclei inside the brainstem.

Similar to the spinal nerves, which leave the vertebral canal through the intervertebral foramina, cranial nerves leave the cranial cavity through the foramina in the base of the skull. Their course can therefore be divided into the intracranial and extracranial part.

Cranial nerves innervate structures of the head and the neck. The only cranial nerve that extends beyond the neck is the CN X, also called the vagus nerve, which innervates all the thoracic and most of the abdominal visceral organs.

***Table 1: Cranial nerves***

| ***Numerical name*** | ***Name*** | ***Type of fibres*** |
|---|---|---|
| **CN I** | Olfactory nerve | sensory |
| **CN II** | Optic nerve | sensory |
| **CN III** | Oculomotor nerve | motor and parasympathetic |
| **CN IV** | Trochlear nerve | motor |
| **CN V** | Trigeminal nerve | sensory and motor |
| **CN V1** | Ophthalmic nerve | sensory |
| **CN V2** | Maxillary nerve | sensory |
| **CN V3** | Mandibular nerve | sensory and motor |
| **CN VI** | Abducent nerve | motor |
| **CN VII** | Facial nerve<br>+ intermediate nerve | sensory and motor<br>+ parasympathetic |
| **CN VIII** | Vestibulocochlear nerve | sensory nerve |
| **CN IX** | Glossopharyngeal nerve | sensory, motor, and parasympathetic |
| **CN X** | Vagus nerve | sensory, motor, and parasympathetic |
| **CN XI** | Accessory nerve | motor |
| **CN XII** | Hypoglossal nerve | motor |

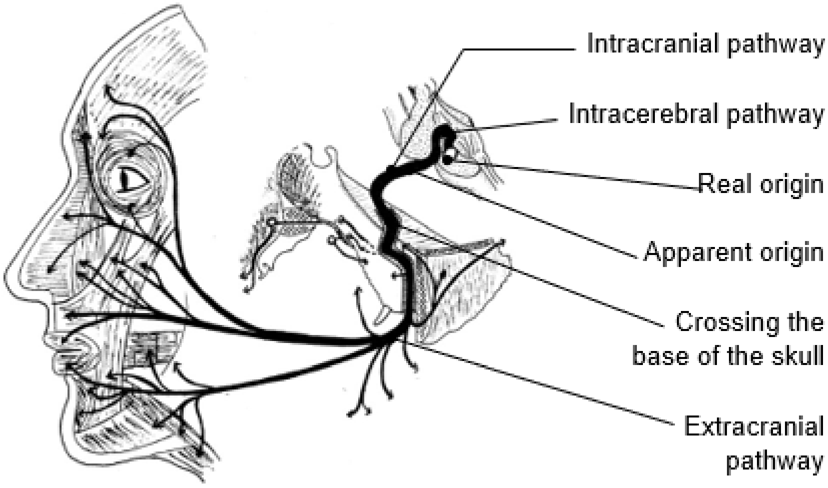



***Figure 143: Cranial nerve pathways: the facialis nerve.***

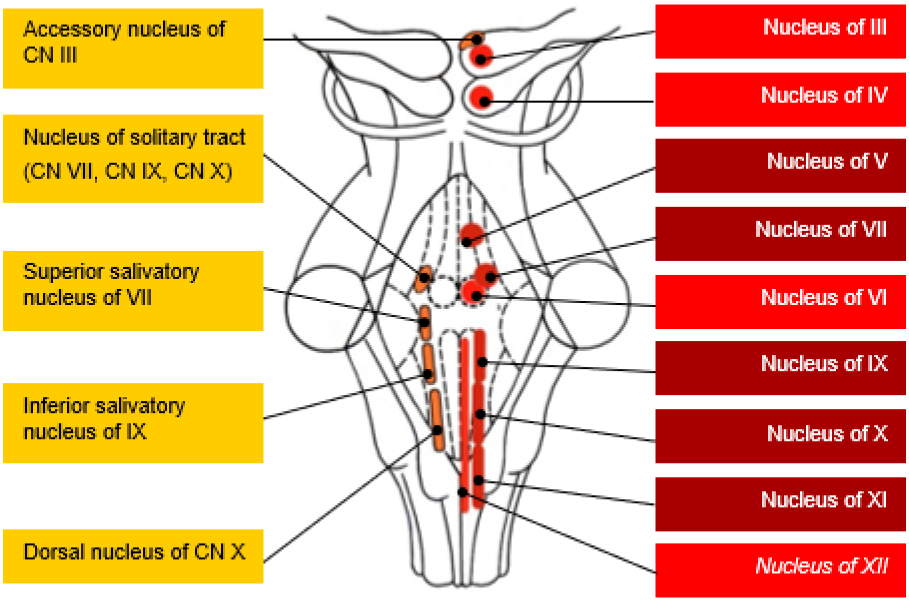



***Figure 144: Diagram illustrating locations of the motor nuclei (nuclei of origin) of cranial nerves.***

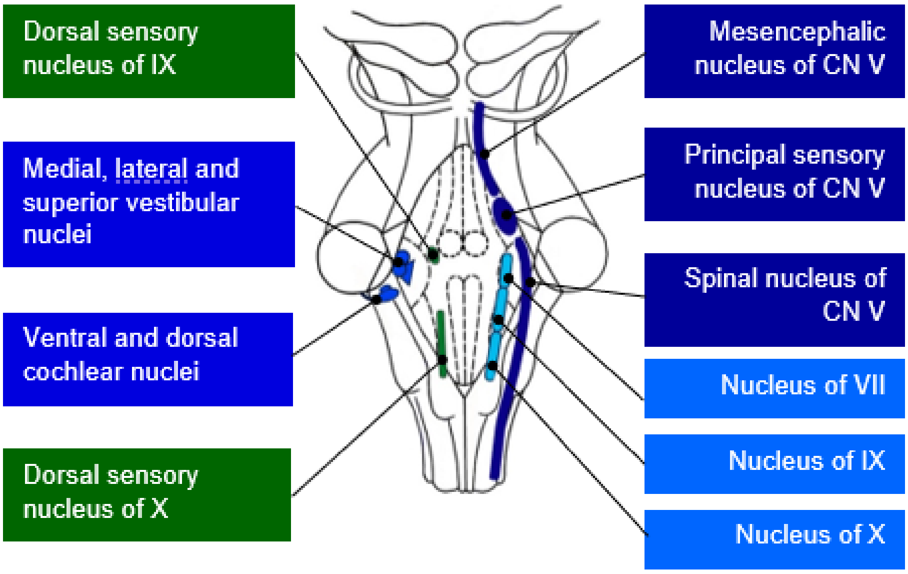



***Figure 145: Diagram illustrating locations of the sensory nuclei (terminal nuclei) of cranial nerves.***

# 3 - Histological study of the nervous system

### Neuron

The neuron is a cell of the nervous tissue and consists of two basic elements: the body (soma; perikaryon) which contains the nucleus, and the extensions, which can be divided into two categories:

- dendrites – short, branched extensions which transmit impulse to the cell body,
- axon – usually a single myelinated extension that primarily conducts impulse away from the cell body; branched nerve ending forms the synapses.

### Peripheral nerve

The peripheral nerves contain bundles of myelinated axons enveloped in the connective tissue.

Each axon is enveloped in a layer of connective tissue called the endoneurium. Several axons are grouped in a bundle called the fascicle. A layer of connective tissue enveloping the fascicle is called the perineurium. A layer of connective tissue enveloping whole nerve is called the epineurium.

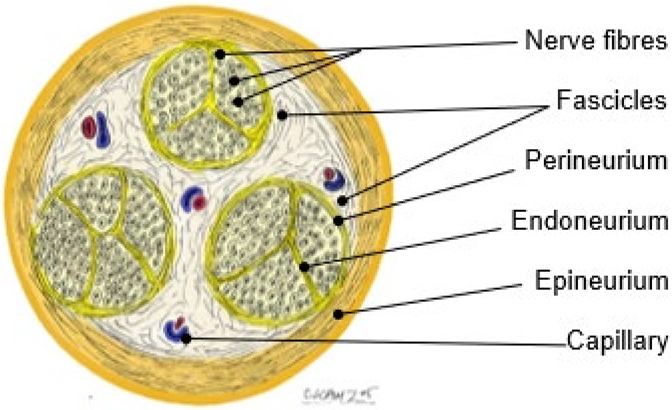



***Figure 146: Cross-section of an axon of peripheral nerve.***

The myelin sheath enveloping the individual axons of peripheral nerves is formed by the Schwann cells.

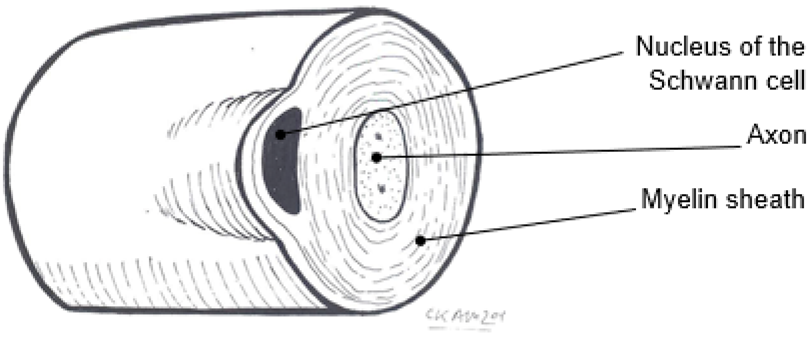



***Figure 147: Myelinated nerve fibre.***

Neurons are connected with each other with the synapses. At the synapse, the electrical signal that travels along the neuron is converted into the chemical signal. A synapse is a gap between two neurons. The neurotransmitters are released from the presynaptic neuron into the synaptic gap, and then binned to the receptors of the postsynaptic neuron. This way information is transmitted from one neuron to the next.

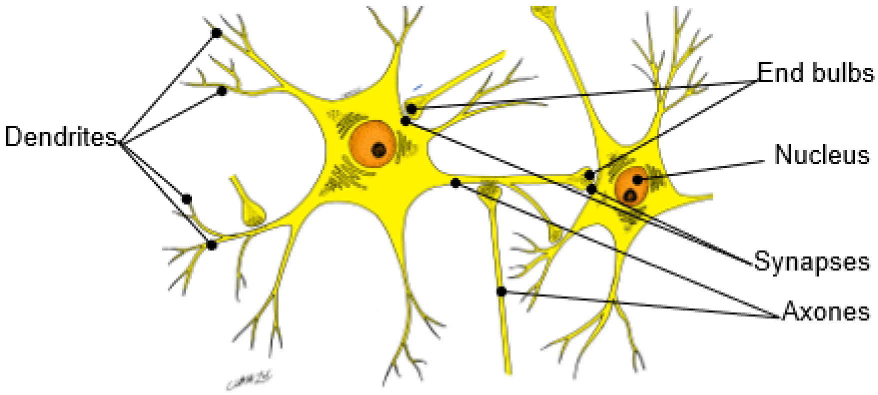



***Figure 148: Synapses.***

**Neuroglia**

The neuroglia, also called glia, glial cells, or gliocytes, are cells of the central nervous system that do not produce or conduct the electrical impulse. The function of the neuroglia is to provide support and protection for the neurons.
There are four types of gliocytes:

- Oligodendrocytes which provide myelin sheath for the axons.
- Astrocytes which form the blood-brain barrier, maintain homeostasis and provide support.
- Ependymal cells which participate in the secretion of cerebrospinal fluid.
- Microglia which are specialised macrophages, capable of phagocytosis.

# 4 - Functional study of the nervous system

## 4.1 - Somatic nervous system

Ascending and descending pathways of somatic nervous system are connected to the cerebral cortex.

**Ascending (afferent) pathways**

Ascending pathways are the sensory pathways. Nerve impulse is transmitted from the receptors on the periphery to the cerebral cortex of the parietal lobe. Primary somatosensory cortex is located at the postcentral gyrus (Brodmann areas 1, 2, and 3). The accuracy of sensory perception depends on the number of receptors on the periphery and the respective area of the cortex. For example, the skin of the face is more sensitive than that of the hand, which in turn is more sensitive than that of the foot.

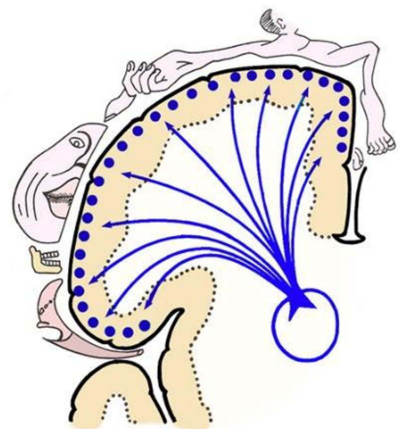


***Figure 149: Sensory homunculus illustrating somatotopic organisation of the primary somatosensory cortex. Frontal section of the cerebral hemisphere.***

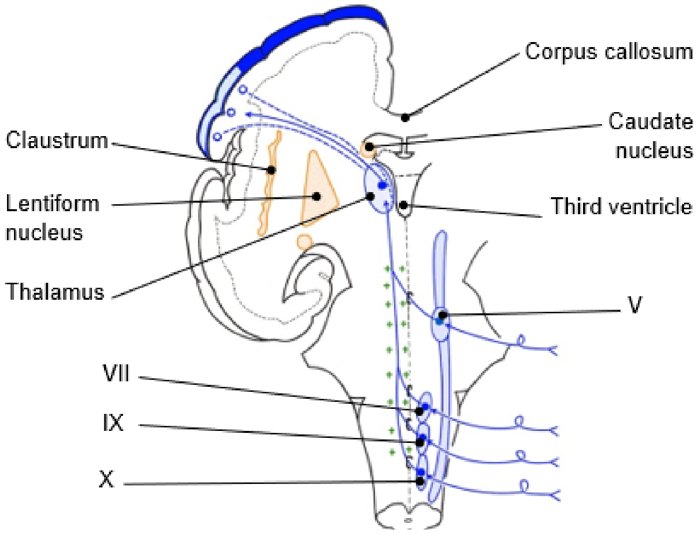



***Figure 150: Ascending tracts of the cranial nerves. Frontal section of brain.***

## Descending (efferent) pathways

Descending pathways are the motor pathways. Nerve impulse is transmitted from the cerebral cortex of the frontal lobe to the skeletal muscles on the periphery. Primary motor cortex is located at the precentral gyrus (Brodmann area 4). The motor pathways are represented by the pyramidal and extrapyramidal tracts.
The paired pyramidal tract is divided into:

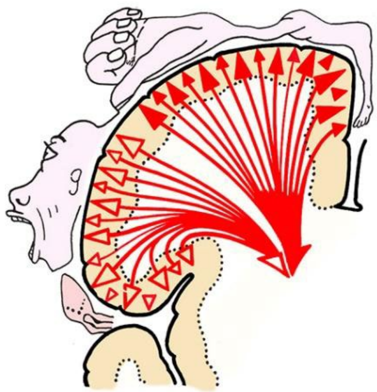


***Figure 151: Motor homunculus illustrating somatotopic organisation of the primary motor cortex. Frontal section of the cerebral hemisphere.***

- Corticonuclear (corticobulbar) pathway: nerve fibres of the central motor neuron run from the primary motor cortex to the motor nuclei of the cranial nerves. At the motor nucleus, impulse is transmitted through the synapse from the central motor neuron to the peripheral motor neuron which runs to the muscles as part of the cranial nerve. Movements of the head and neck, facial mimics, and movements of the eyes are enabled via this pathway.

- Corticospinal pathway: nerve fibres run from the primary motor cortex to the anterior horn of the spinal cord. At the anterior horn, impulse is transmitted through the synapse from the central motor neuron to the peripheral motor neuron which runs to the muscles as part of the spinal nerve.

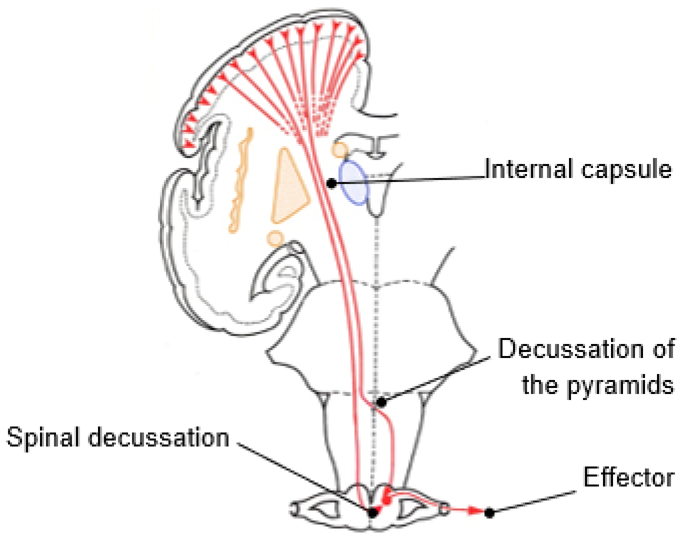



***Figure 152: Scheme of the corticospinal (pyramidal) tract. Frontal section of brain.***

### Decussation

The majority of sensory and motor nerve fibres cross from one side to the contralateral side of the body. The crossing of the left and right pathways is called decussation.

Clinically, a lesion in one cerebral hemisphere results in malfunction on the opposite side of the body.

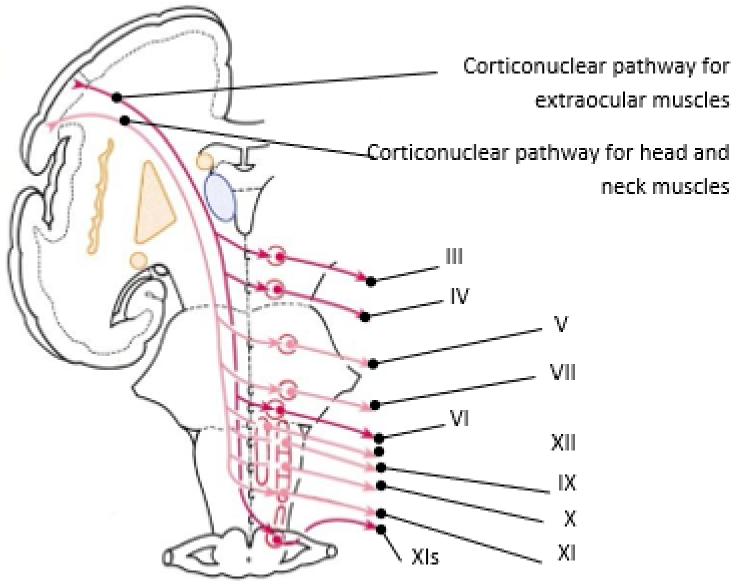



***Figure 153: The corticonuclear pathway. Frontal section of brain.***

## 4.2 - The autonomic nervous system

The autonomic (vegetative) nervous system regulates basic bodily functions, such as respiration, circulation, digestion, urination, sexual arousal and pupillary reflex.

The autonomic nervous system is regulated by reflex actions at the level of spinal cord and brainstem. Parts of the cerebrum involved in the regulation and integration of the autonomic functions are hypothalamus and the limbic system.

The autonomic nervous system consists of two antagonistic systems:

- The sympathetic nervous system, known as the "fight or flight" system.
- The parasympathetic nervous system, known as the "rest and digest" system.

Together with the endocrine glands, the autonomic nervous system forms the neuro-endocrine system.

**Organisation of the autonomic nervous system**

The afferent neurons of autonomic nervous system conduct visceral pain and subconscious visceral sensations important for the reflex response. Their bodies are located in the spinal ganglia or in the cranial sensory ganglia, along with the bodies of somatic afferent neurons.

The efferent neurons of autonomic nervous system conduct impulses to the effectors – smooth muscles, cardiac muscle and glands. Two neurons form the conduction pathway:

- Preganglionic neurons have bodies located in the grey matter of the spinal cord or in the nuclei of the brainstem. Their axons end in the autonomic (visceral) ganglia where they form synapses with the postganglionic neurons.
- Postganglionic neurons have bodies located inside the autonomic ganglia. Their axons end in the organ they innervate, forming synapses with the effectors.

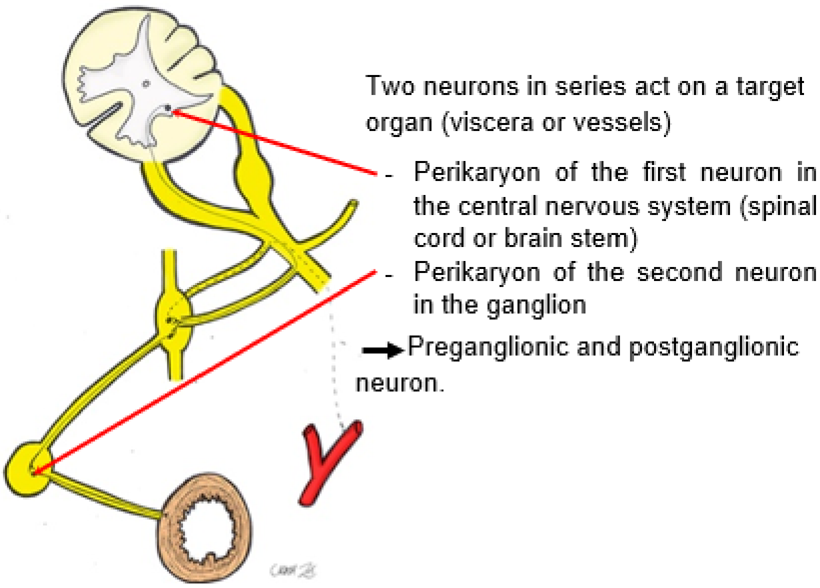



***Figure 154: Arrangement of efferent neurons of the autonomic nervous system.***

### Sympathetic nervous system

The efferent part of sympathetic nervous system is composed of:

- Preganglionic neurons: their bodies are located in the lateral horns of the thoracolumbar segments of the spinal cord (T1 to L2) and their axons travel to the sympathetic ganglia.
- Sympathetic ganglia: paravertebral ganglia are located on each side of the vertebrae forming the paired sympathetic trunk and prevertebral ganglia are located in front of the vertebrae.
- Postganglionic neurons: their bodies are located in the sympathetic ganglia and their axons most often form the periarterial plexuses, which follow the arteries supplying the organ that the neurons innervate.

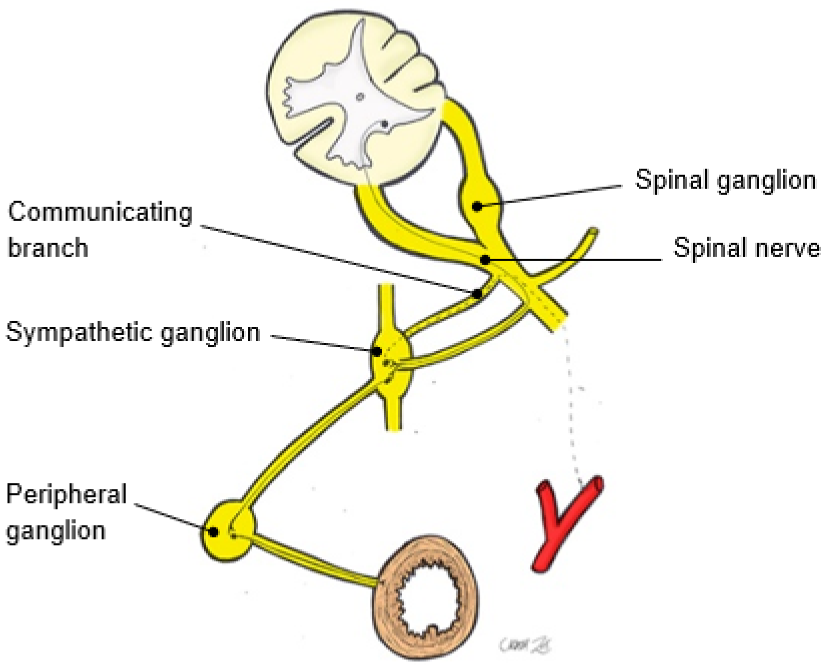



***Figure 155: Sympathetic innervation.***

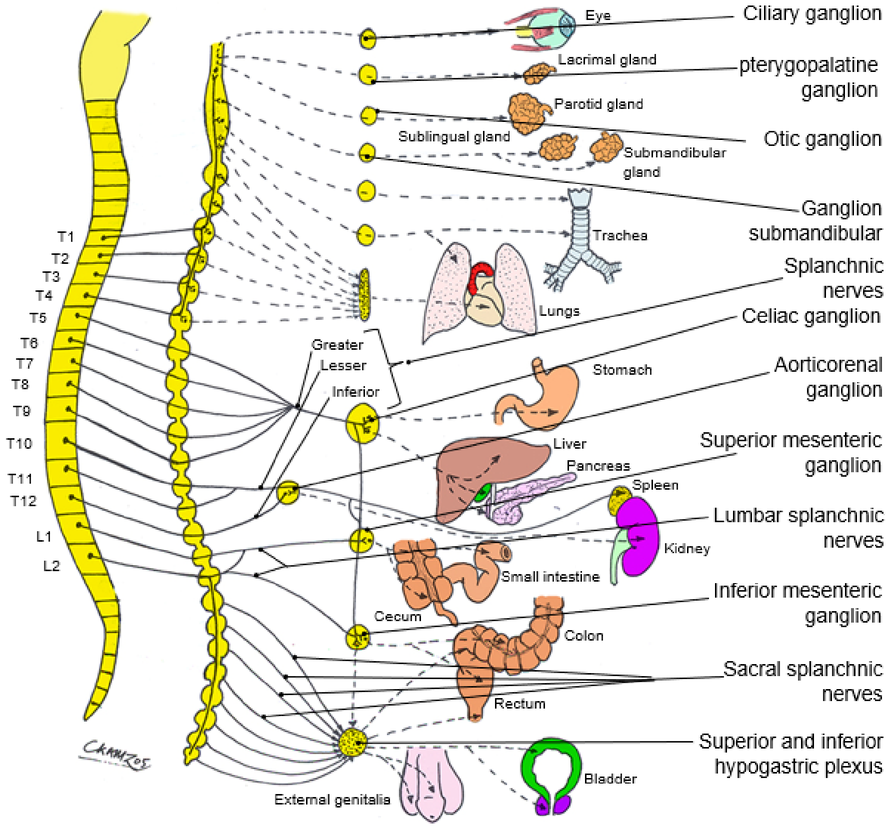



***Figure 156: Sympathetic visceral innervation.***

### Parasympathetic nervous system

The efferent part of parasympathetic nervous system is composed of the cranial and sacral part:

- Cranial parasympathetic outflow: bodies of the preganglionic neurons are located in the grey matter of the brainstem and their axons exit the central nervous system as part of the cranial nerves III, VII, IX, and X.
- Sacral parasympathetic outflow: bodies of the preganglionic neurons are located in the grey matter of the sacral segments (S2 to S4).

- Parasympathetic ganglia are usually located in the wall or close to the wall of the target organ.
- Postganglionic neurons are very short.

Cranial part provides mostly parasympathetic innervation of the head (eye, salivary glands). The only exception is the CN X, which provides parasympathetic innervation of the thoracic and abdominal organs.

Sacral part provides parasympathetic innervation of the pelvic visceral organs and the external genitalia.

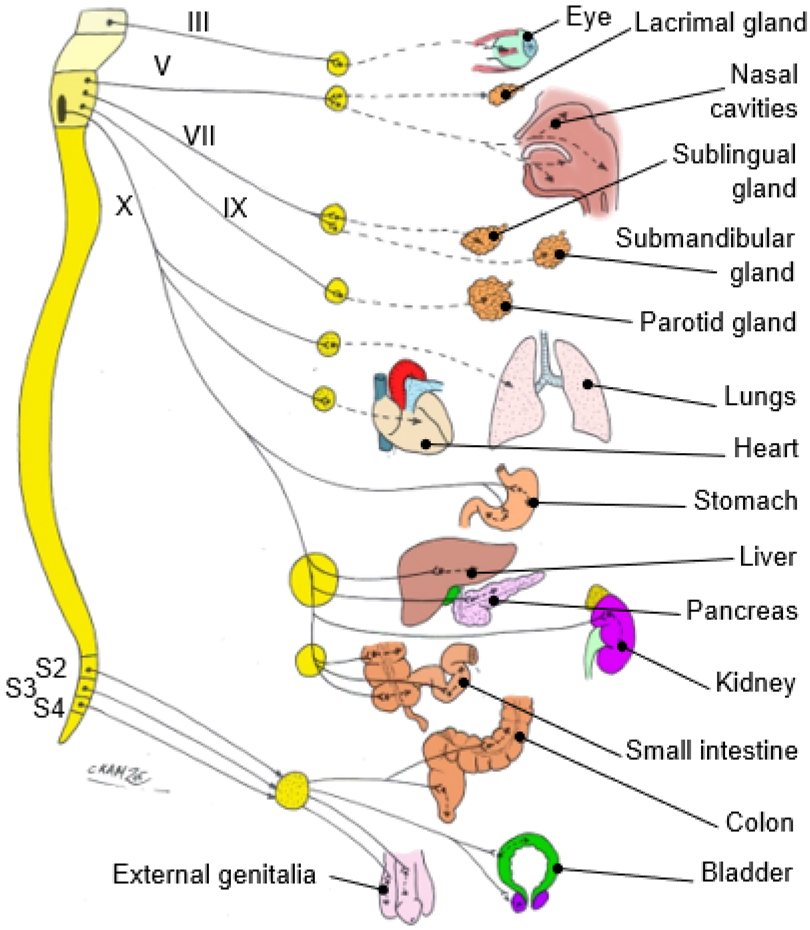



***Figure 157: Parasympathetic visceral innervation.***

## 4.3 - The reflex response

At the level of the spinal cord, connection between the sensory and motor neuron allows rapid, stereotyped involuntary movement named the reflex.

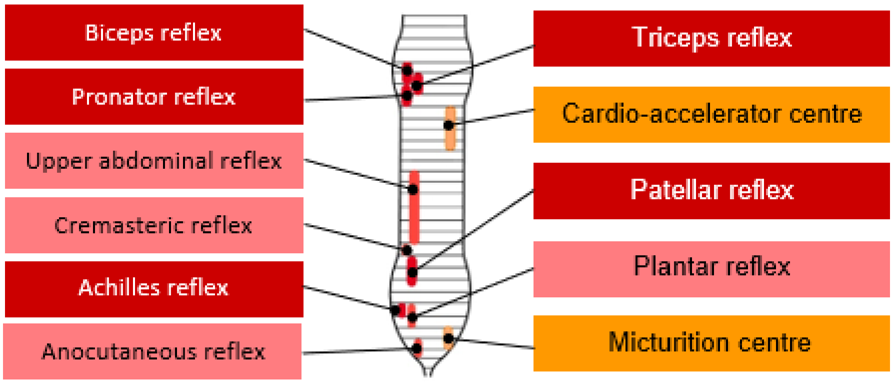



***Figure 158: Spinal cord centers.***

Sensory and motor neuron can be connected directly or through a spinal interneuron. Spinal interneurons do not leave the spinal cord. They receive the afferent input and send the impulse to the motor neurons of either the same segment of the spinal cord or can ascend or descend to reach the motor neurons in higher or lower segments of the spinal cord.

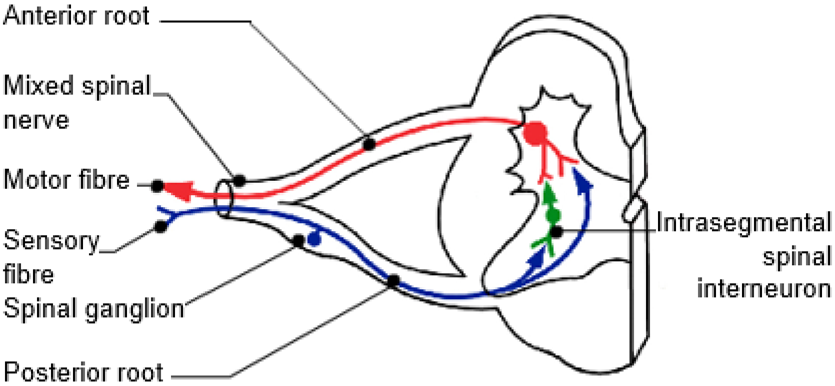



***Figure 159: A reflex arc. Intrasegmental spinal interneuron.***

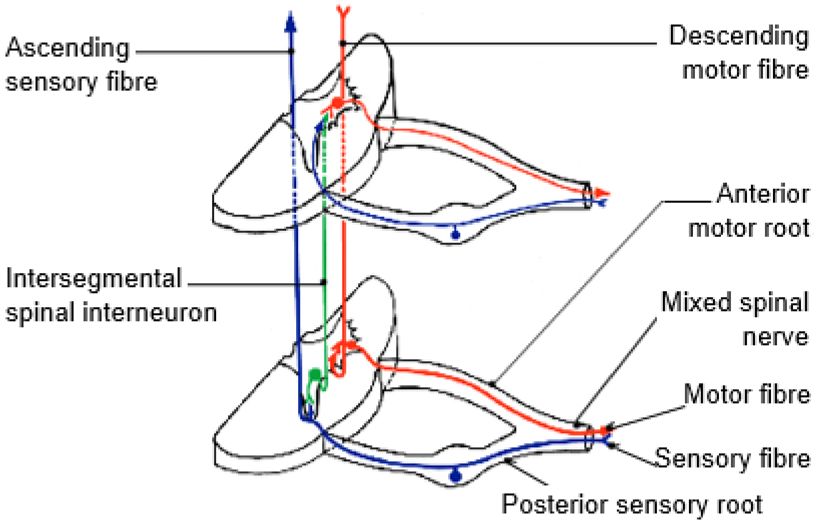



***Figure 160: A reflex arc. Intersegmental spinal interneuron.***

## 4.4 - Projection, association and commissural fibres of the brain

The projection, association and commissural fibres of the brain form the white matter of the brain.

The projection fibres are the ascending (afferent) and descending (efferent) fibres that connect cerebral cortex with other areas of the central nervous system – the deep cerebral nuclei, cerebellum, brainstem and spine.

The association fibres connect different cortical areas of the same hemisphere.

The commissural fibres connect the same cortical area in the opposite hemispheres. The most important bundle of commissural fibres is corpus callosum – a C-shaped thick layer of white matter that curves from front to back superior to the thalamus. It forms a link between the analytic left hemisphere and the creative right hemisphere.

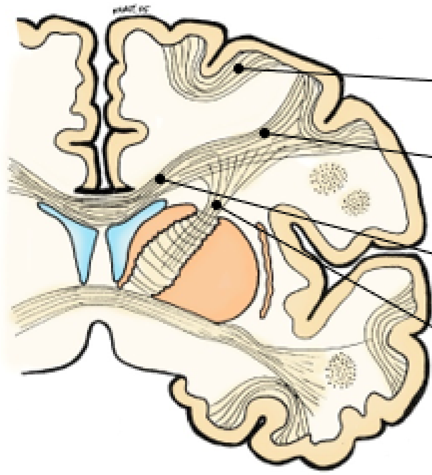



***Figure 161: The white matter of the cerebrum. Frontal section of brain.***

# 5 - Protective elements of the central nervous system

## 5.1 - The bony protection

The bony protection of brain consists of the cranial bones forming the bony case, neurocranium, which encloses the cranial cavity.

The bony protection of spinal cord consists of the vertebrae enclosing the vertebral canal.

## 5.2 - The meninges

The central nervous system is completely enveloped by three membranes, named the meninges: dura, arachnoid and pia.

### Dura

The dura is a strong, thick, fibrous outermost membrane.

The cranial dura consists of two layers – the outer, periosteal cranial dura, which forms the periosteum of the bones enclosing the cranial cavity, and the inner, meningeal cranial dura. Both layers are firmly attached to each other and are only separated at the sites of the venous sinuses.

The cranial dura matter has four double folds:

- the cerebral falx separates the two hemispheres of the cerebrum,
- the cerebellar tentorium separates the cerebrum and the cerebellum,
- the cerebellar falx separates the two hemispheres of the cerebellum,
- the sellar diaphragm forms the roof over the sella turcica.

The spinal dura has only one layer. Together with the periosteum of the vertebral canal it delimits a space called the epidural space, in which the internal venous plexuses are located. This explains the possibility of epidural anaesthesia.

**Arachnoid**

The arachnoid is the middle of the 3 meninges. It loosely surrounds the entire brain and spinal cord. Arachnoid is in direct contact with the dura but can be easily separated from it. Arachnoid and pia are separated by the subarachnoid space which is filled with the cerebrospinal fluid. Note that the subarachnoid space communicates with the fourth ventricle.

The spinal arachnoid extends to the end of the vertebral canal, while the spinal cord ends at the level of L1. A wide part of the subarachnoid space below the L1 level is called the lumbar cistern and allows a safe lumbar puncture, which is usually performed between the vertebral arches of vertebrae L3 and L4.

### Pia

The pia is a highly vascular innermost membrane, closely related to the surface of the brain and spinal cord, extending into the sulci.
In the ventricles of the brain, a double layer of cranial pia together with ependymal cells forms the tela choroidea, which produces the cerebrospinal fluid.

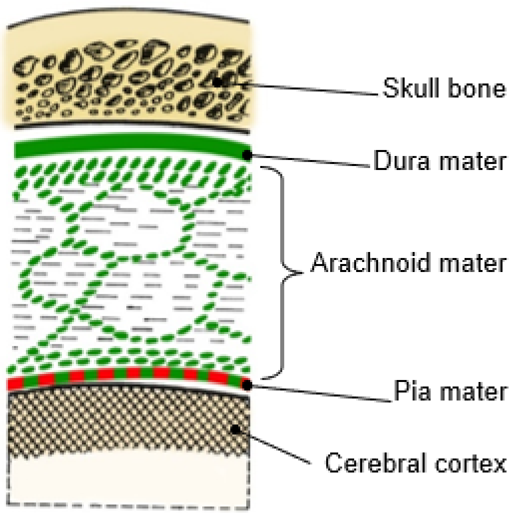



***Figure 162: Cranial meninges.***

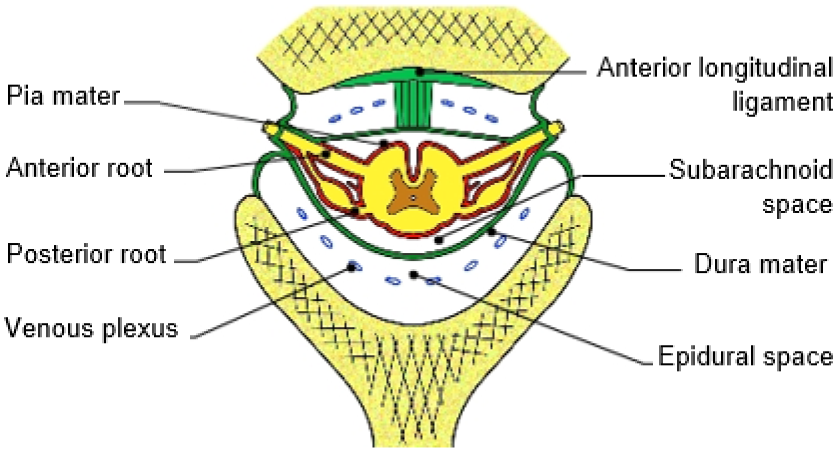



***Figure 163: Spinal meninges.***

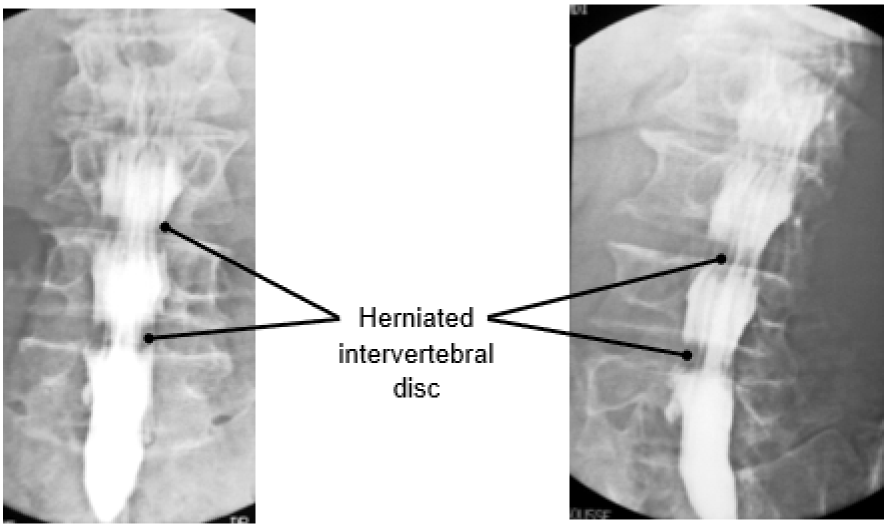



***Figure 164: Radiculography showing compression of the dural sac by the herniated intervertebral discs.***

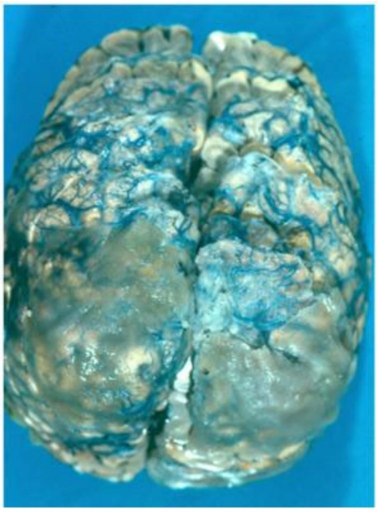


***Figure 165: Photography of meninges in meningitis (a coating is formed in the subarachnoid space).***

# Chapter 4 - Sense organs

**The objectives of this chapter are:**

1. Name the sense organs.
2. Distinguish between the special and general senses.
3. Describe the sense of smell.
4. Describe the sense of taste.
5. Describe the sense of sight.
6. Describe the sense of hearing and balance.
7. Describe the general senses.

## 1 - Generalities

Sense organs allow us to detect information from the world outside the body as well as from the body itself, enabling the nervous system to react properly.

We distinguish between special and general senses.

**Special senses** are perceived by specialised sense organs:

- smell is perceived by the nose,
- taste is perceived by the tongue,
- vision is perceived by the eyes,
- hearing is perceived by the ears,
- balance is perceived by the ears.

**General senses** are perceived by the receptors distributed throughout the body. They include touch, pain, temperature, pressure, vibration, and proprioception.

The cells or structures that detect sensations are called sensory receptors.
According to their structure, there are two types of sensory receptors:

- a neuron with either free nerve endings or encapsulated nerve endings; e.g. pain receptors, touch receptors and olfactory receptors in the nose detecting the smell;
- a specialised receptor cell; e.g. photoreceptors in the eyes detecting the light, taste receptors in the taste buds of the tongue and sound receptors in the ears.

Different sensory receptors detect different types of stimuli from varying sources. Information about the received stimulus is then transferred via sensory neurons to the central nervous system. Different types of stimuli therefore have to be transformed into an electrical signal. The process of transformation is called **transduction**. If the signal is strong enough, an action potential occurs and travels along the nerve fibre.

Sensory neurons transfer the received information into the central nervous system. Information from the special senses is transmitted along the cranial nerves, while information from the general senses is transmitted along the spinal or cranial nerves. The central nervous system enables integration of sensory stimuli and may lead to a motor response.

## 2 - Sense of smell

The sense of smell is perceived by the olfactory organ located in the nasal cavity. The olfactory receptors are free nerve endings of the olfactory neurones and act as chemoreceptors, perceiving the odour particles. They lie in the mucous membrane covering the roof of nasal cavity, called the olfactory mucosa.

The axons of the olfactory neurons pass through the cribriform plate of the ethmoid bone into the cranial cavity and end in the olfactory bulb where they synapse with the neurons of the olfactory nerve (cranial nerve I). The information finally reaches the temporal lobe of the cerebrum where the olfactory cortex is located.

The sense of smell is the oldest of the specialised senses.

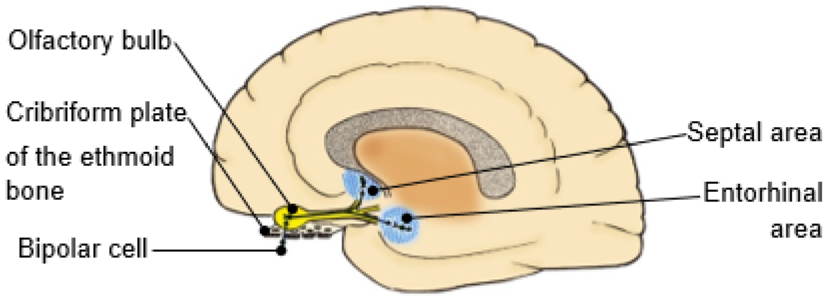



***Figure 166: The olfactory pathway. Sagittal section of the brain, view from the left.***

## 3 - Sense of taste

The sense of taste is perceived by the taste buds located in the tongue.

The dorsum of the tongue is covered with numerous small protrusions called papillae. Within the papillae lie the taste buds and within the taste buds lie the taste (gustatory) receptors. Similar to the olfactory receptors, the taste receptors are also chemoreceptors. They perceive chemical particles dissolved in saliva.

Taste buds are present in all three parts of the tongue: apex, body and root. The apex and the body form the anterior part of the tongue which is located in the oral cavity, while the root forms the posterior part of the tongue, which is orientated towards the oral part of the pharynx. The root and the body of the tongue are separated by a "V" shaped groove, called the terminal sulcus of the tongue.

Two cranial nerves are involved in the transfer of taste information into the central nervous system:

- Facial nerve (CN VII) conducts information from the apex and the body of the tongue.
- Glossopharyngeal nerve (CN IX) conducts information from the root of the tongue.

Information finally reaches the temporal lobe of the cerebrum where the olfactory cortex is located.

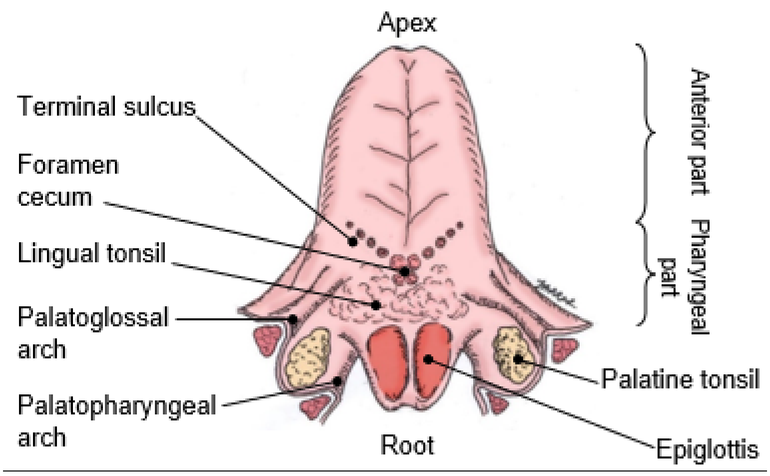



***Figure 167: Superior view of the tongue.***

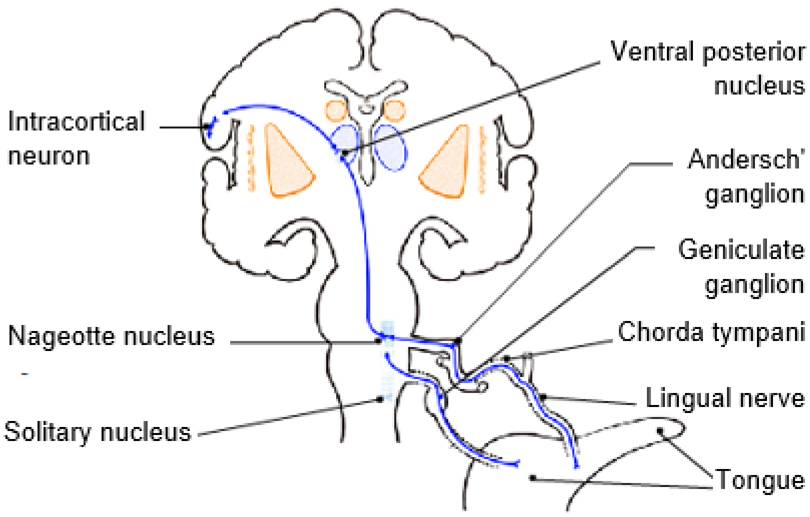



***Figure 168: Taste pathway. Frontal section of brain.***

Taste receptors detect four main taste sensations: sweetness, saltiness, sourness and bitterness. Historically, different tongue areas were stated to be specialised in the detection of a specific taste. Today, neurological evidence indicates that all areas of the tongue are responsive to all taste stimuli.

The perception of taste is closely related to the perception of smell.

# 4 - Sense of sight

The organ of sight is the eye which sits in the orbit. It is formed by the eyeball and the accessory visual structures.

Nerve impulses are conducted through the optic nerve (CN II). Information finally reaches the occipital lobe of the cerebrum where the visual cortex is located.

## 4.1 - Eyeball

The eyeball is designed to receive visual impulses. It has a form of an imperfect sphere. We distinguish two poles of the eyeball, the anterior and the posterior one. Transparent structures of the eyeball allow the light to enter the eyeball and reach the photoreceptors which respond to light.

The eyeball consists of three layers (tunics) enveloping the contents inside.

**Fibrous tunic of the eyeball**

Fibrous tunic is the outermost protective layer of the eyeball, providing the shape of the eyeball and the protection of deeper structures. It is composed of two parts:

- Sclera, which is opaque and forms the majority of the fibrous tunic.
- Cornea, which lies anteriorly, is transparent and forms less than 10 % of the fibrous tunic. Part of the cornea that borders sclera is named corneoscleral junction or corneal limbus.

**Vascular tunic of the eyeball**

Vascular tunic is the middle layer of the eyeball, composed of three parts that are continuous with each other:

- Choroid contains vessels, providing the blood supply. It forms the majority of the vascular tunic.
- Ciliary body lies anteriorly to the choroid. It produces a transparent fluid (aqueous humour) which nourishes the anterior parts of the eyeball and maintains the pressure inside the eyeball (intraocular pressure). The ciliary body also contains the ciliary muscle which enables the eye to adjust its focus to clearly see the objects at different distances (accommodation of the eye).
- Iris is the anterior part of the vascular tunic. It is pigmented and has a form of a ring; the circular opening in the centre of this ring is the pupil. The iris contains two muscles that can change the diameter of the pupil and thus control the amount of light entering the eyeball.

**Inner tunic of the eyeball**

Inner or neural tunic of the eyeball is called retina. It contains the photoreceptors which absorb the light and convert the light impulses into the neural impulses. It also contains the nerve cells. The nerve fibres finally merge to form the optic nerve.

**Structures inside the eyeball tunics**

The eyeball tunics envelop the transparent structures that transmit the light:

- The anterior and posterior chamber of the eyeball are filled with aqueous humour and communicate with each other through the pupil. The anterior chamber lies between cornea and iris, and the posterior chamber lies between iris and lens.
- The lens is a transparent, biconvex, elastic body and lies between iris and vitreous body. Fibres that connect lens to the ciliary body hold the lens in place and transmit the force

produced by ciliary muscle that leads to a change of lens shape and the accommodation of the eye.

- The vitreous body is gelatinous transparent structure filling the majority of the eyeball.

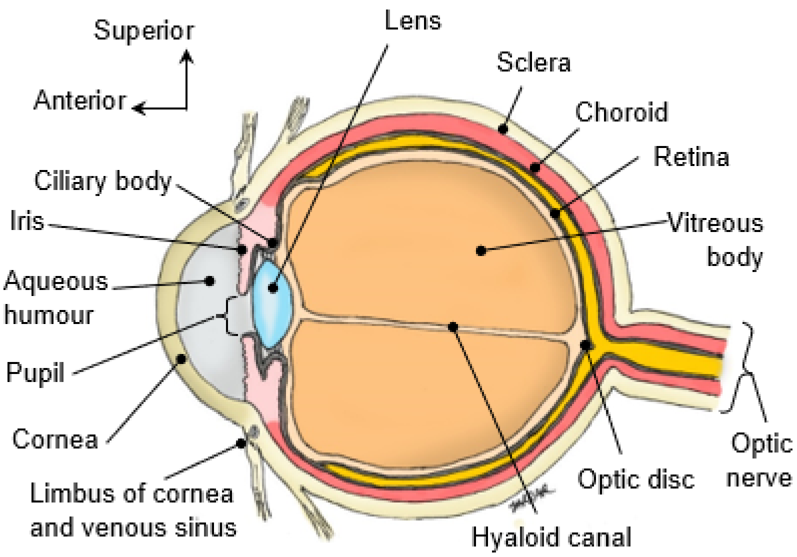



***Figure 169: Sagittal section through the eyeball.***

## 4.2 - Accessory visual structures

Accessory visual structures are indispensable for the normal functioning of the eye, protecting and supporting the eyeball and enabling the movements.

**Extraocular muscles**

There are seven extraocular muscles in the orbital region. Six of them are attached to the eyeball enabling it to move in almost every direction.

One of the extraocular muscles ends in the upper eyelid and elevates the upper eyelid. All muscles are striated, innervated by the somatic nervous system and therefore acting under conscious control.

**Accessory structures for protection and support**

- Conjunctiva is a thin transparent mucous membrane that lines the inner surface of the eyelids and the anterior surface of the eyeball with the exception of cornea.
- Upper and lower eyelid are thin movable folds that protect the eyeball from trauma and excessive light, and maintain the eyeball moist through blinking which smears the tears over the cornea.
- Lacrimal apparatus includes the lacrimal gland and the lacrimal ducts. The gland produces the tears and the ducts drain the tears into the nasal cavity.
- Orbital fat body fills the remaining orbital space between the eyeball, extraocular muscles, nerves and vessels, protecting and supporting them.

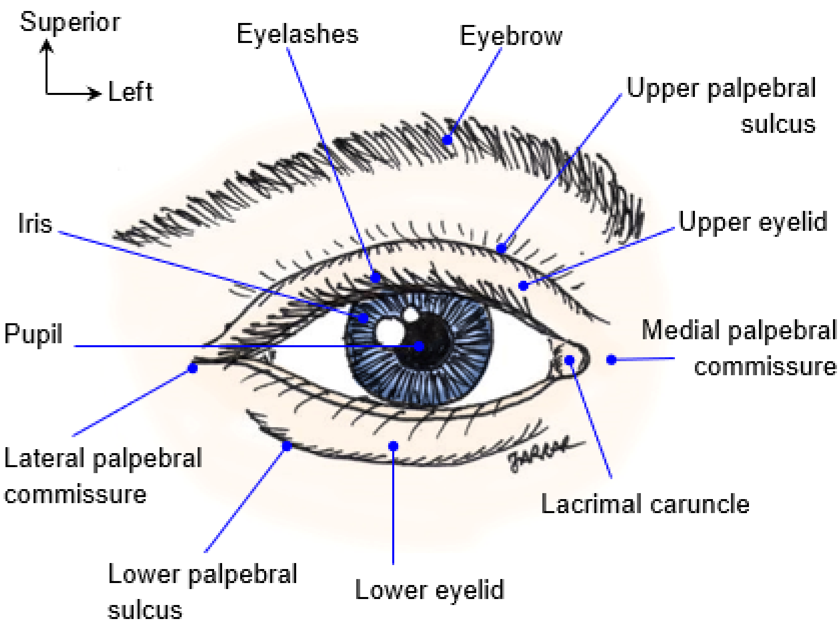



***Figure 170: Front view of the right eye.***

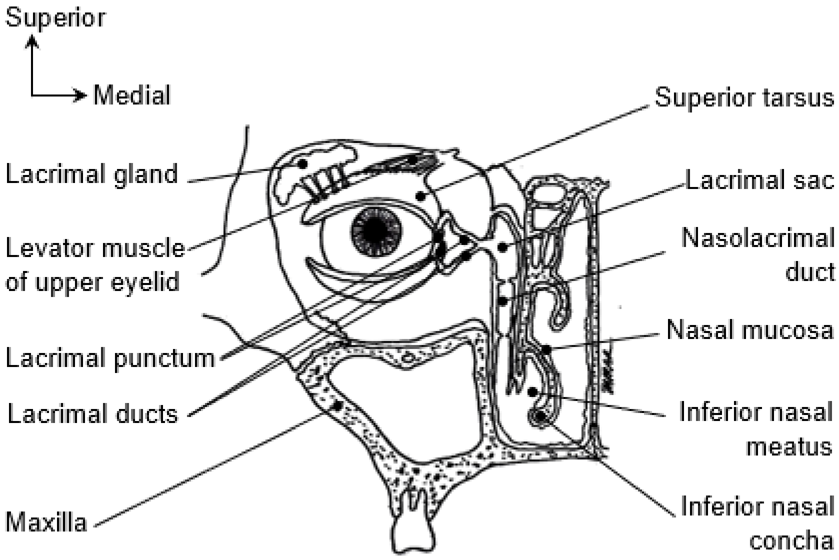



***Figure 171: Overview of the lacrimal apparatus. Frontal section through the right orbita and right nasal cavity.***

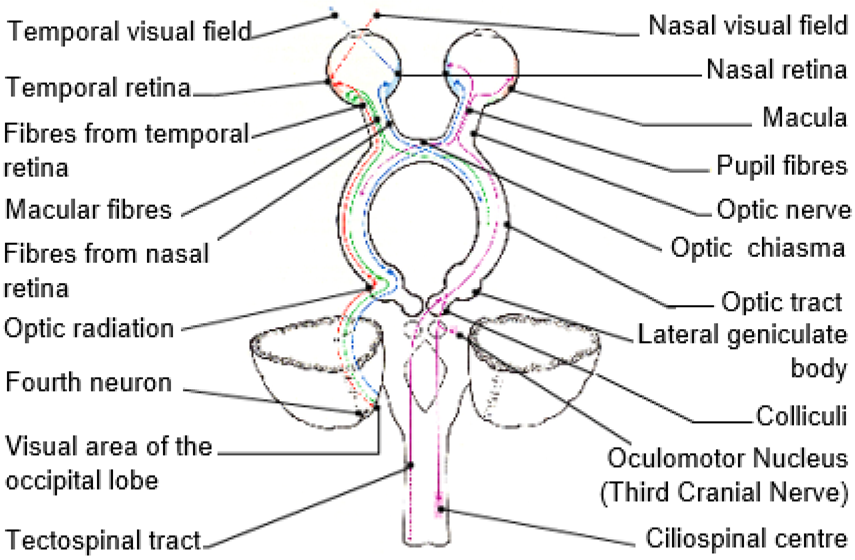



***Figure 172: The visual pathway.***

# 5 - Sense of hearing and balance

The organ of hearing is the ear. It is divided into the external, middle, and internal ear. The internal ear is also the organ of balance.

Nerve impulses are conducted by the vestibulocochlear nerve (CN VIII).

Information finally reaches the temporal lobe of the cerebrum where the auditory cortex is located.

**External ear**

The external ear is designed to collect and conduct the sound waves. It consists of:

- auricle,
- external acoustic meatus,
- tympanic membrane (the eardrum).

After passing through the external acoustic meatus, the sound waves hit the tympanic membrane causing its vibration.

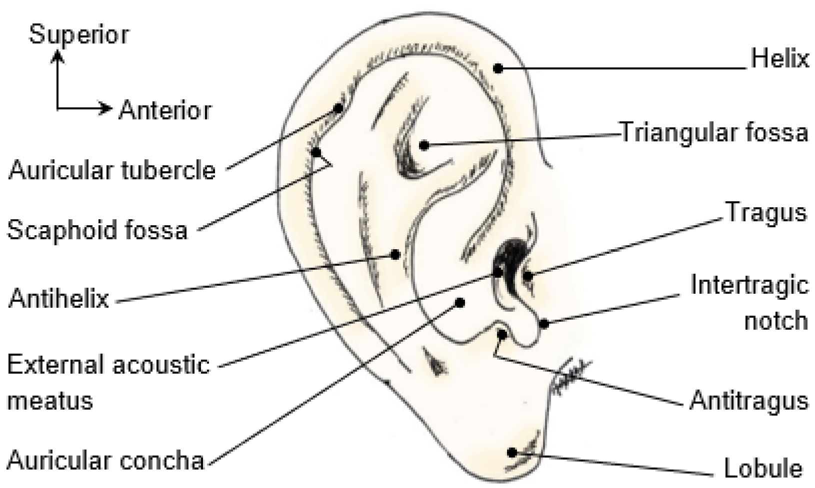



***Figure 173: Lateral view of the right auricle.***

**Middle ear**

The middle ear transmits sound vibrations from tympanic membrane to the inner ear. It is composed of:

- tympanic cavity, inside which there are three auditory ossicles joined by synovial joints, and two muscles of auditory ossicles;
- auditory tube.

Vibrations of the tympanic membrane are transmitted through the tympanic cavity along the three auditory ossicles. Contraction of the muscles of auditory ossicles occurs when the sound is too loud and it prevents excessive movements of the auditory ossicles that could lead to hearing impairment.

The auditory tube, also called the Eustachian tube, connects the tympanic cavity with the pharynx and enables equalisation of pressure on both sides of the tympanic membrane thus preventing its damage.

**Internal ear**

The internal ear lies inside the temporal bone and consists of:

- cochlea – the organ of hearing,
- vestibule and three semicircular canals – the organ of balance,
- internal acoustic meatus.

Inside the cochlea is organ of Corti, which contains the sound receptor cells.

Inside the vestibule are the receptor cells for static balance and inside the semicircular canals are the receptor cells for dynamic balance.

Inside the internal acoustic meatus lies the vestibulocochlear nerve.

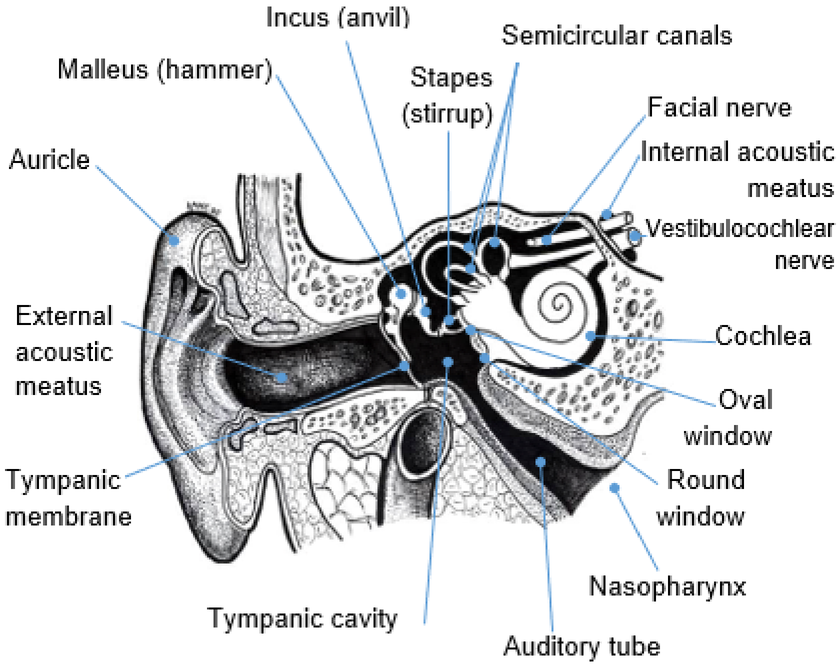



***Figure 174: The external, middle and internal ear.***

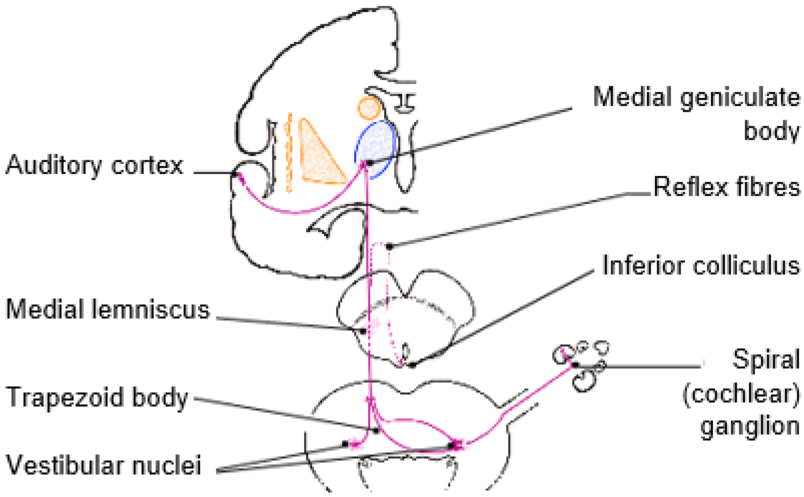



***Figure 175: The auditory pathway.***

# 6 - General senses

General senses are perceived by the receptors in the skin, muscles, tendons, joint capsules, ligaments, walls of visceral organs, etc.

The receptors in the skin provide information about the body environment. There are different types of receptors in the skin; some are free nerve endings of the sensory neuron, while others are encapsulated. They perceive different mechanic impulses (mechanoreceptors), temperature information (thermoreceptors) and pain (nociceptors).

The skin is composed of three layers:

- epidermis (avascular surface layer),
- dermis,
- hypodermis.

In addition to its role as a sense organ, the skin also performs several other functions, such as protection and thermoregulation.

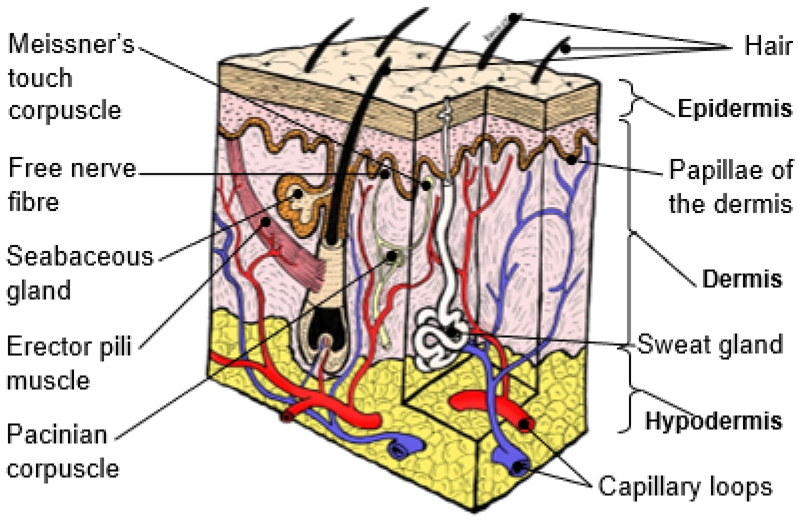



***Figure 176: Diagram of the skin.***

Sensory innervation is provided by the sensory nerves. Each spinal nerve supplies its own skin area, called the dermatome.

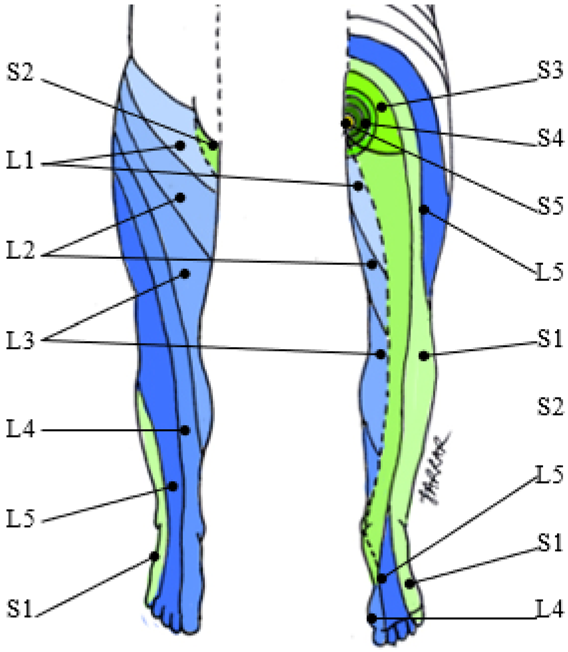



***Figure 177: Dermatomes of the lower limb.***

There are also numerous receptors in the musculoskeletal system, called the proprioceptors. The purpose of proprioception is to provide information about the position of body parts in space, accurate performance of movements and to protect the musculoskeletal system.

# Chapter 5 - Cardiovascular system and lymphoid organs

**The objectives of this chapter are:**

1. Describe the structure of the heart.
2. Describe the blood supply to the heart.
3. Define the systemic circulation.
4. Define the pulmonary circulation.
5. Describe the systemic arteries.
6. Describe the systemic veins.
7. Describe the main lymphatic vessels.
8. Describe the lymphoid organs.

## 1 - Elements of cardiovascular system

The cardiovascular system, also called the circulatory system, is an organ system that supplies the tissues with essential substances and removes waste.

The cardiovascular system is composed of:

- the heart, working as a pump pushing the blood into the vessels;
- the blood vessels, distributing blood throughout the body: arteries carry the blood away from the heart and veins carry the blood to the heart.
- the lymphatic vessels, returning the excessive fluid from the tissues into the blood vessels.

- the blood, a fluid running inside the blood vessels.
- the lymph, a fluid running inside the lymphatic vessels.

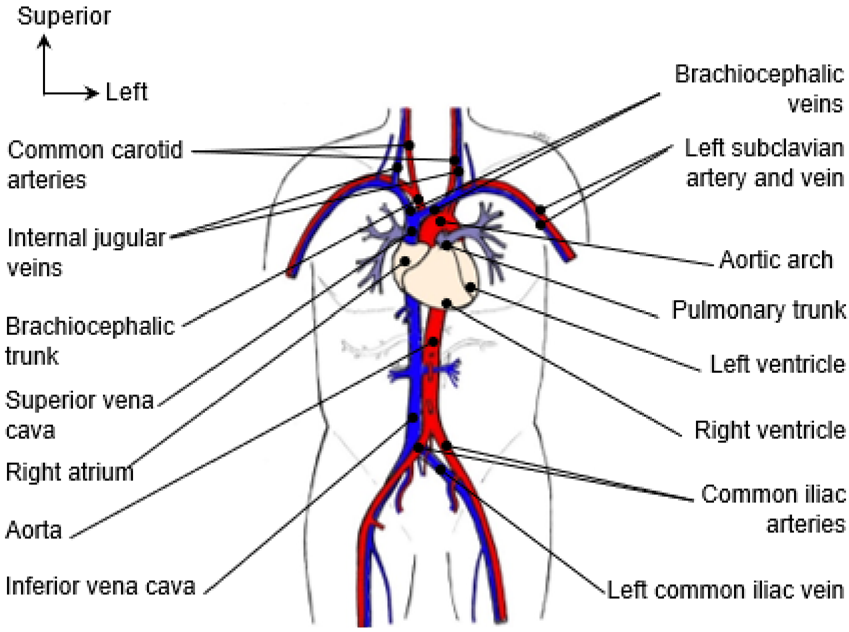



***Figure 178: Diagram of blood circulation. Anterior view.***

## 1.1 - Heart

The heart is a vital organ that is a central element of the cardiovascular system. It functions as a double pump, sending the blood in two blood circuits – the systemic circuit and the pulmonary circuit.

**Structure and organisation of the heart**

The heart is a hollow organ filled with the blood. The heart wall is formed by three layers:

- Myocardium is a muscular layer, composed of a cardiac muscle tissue.

- Endocardium is a thin membrane forming the innermost layer, lining the inner surfaces of the heart chambers, and forming the heart valves.
- Epicardium forms the outermost layer of the heart wall and the innermost layer of the pericardium, which is the sac enveloping the heart.

Cardiac septum divides the heart into the left and right side. Any communication between the two sides is pathological. On each side of the heart there are two heart chambers, atrium, and ventricle. Between the atrium and ventricle lies the atrioventricular valve. Opening and closing of the valve keeps the blood flowing in the correct direction – from atrium into the ventricle.

The right atrium receives deoxygenated blood from the superior and inferior vena cava, and the right ventricle pushes the blood into the pulmonary trunk. Between the right ventricle and the pulmonary trunk lies the pulmonary valve.

The left atrium receives the oxygenated blood from the two left and two right pulmonary veins, and the left ventricle pushes the blood into the aorta. Between the left ventricle and the aorta lies the aortic valve.

**External morphology of the heart**

The heart has a shape of a cone. The base of the heart is positioned postero-superiorly and to the right. It is formed by the atria. The apex of the heart is positioned antero-inferiorly and to the left. It is formed by the left ventricle. The heart can be described as having five surfaces: the anterior or sternocostal surface, the left and right pulmonary surface, the inferior or diaphragmatic surface and the posterior surface, which is the base of the heart.

The circumferential groove on the surface of the heart that separates the atria from the ventricles is called the atrioventricular sulcus or the coronary sulcus.

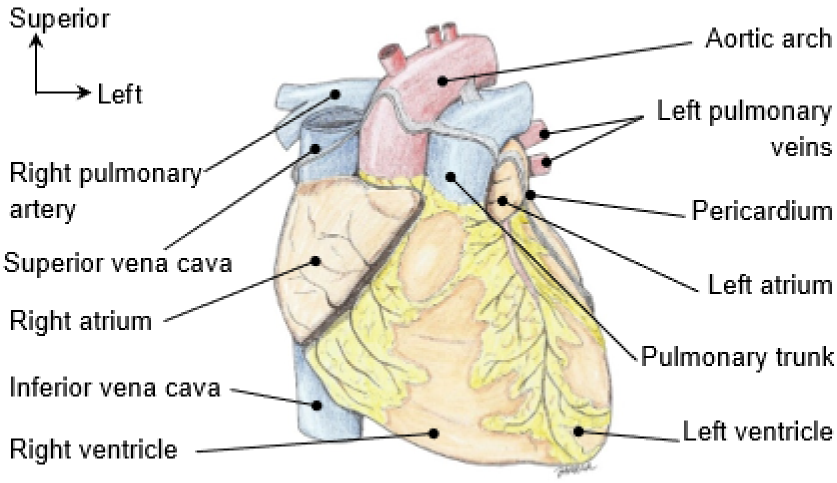



*Figure 179: Anterior (sternocostal) surface of the heart.*

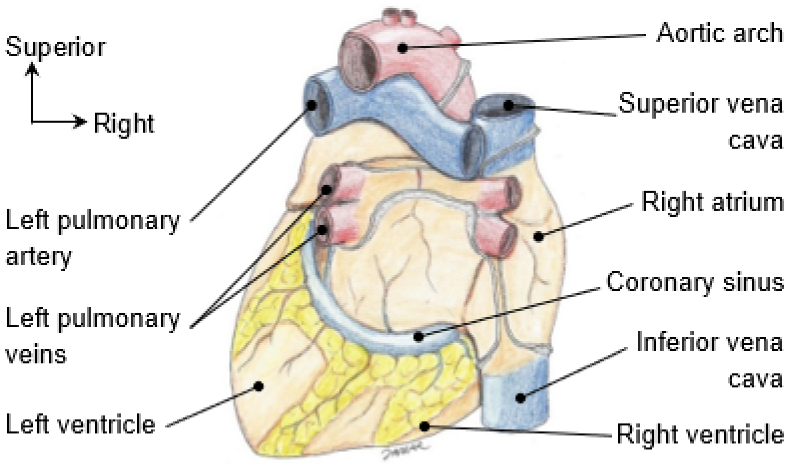



*Figure 180: Posterior and inferior (diaphragmatic) surface of the heart.*

### Blood supply of the heart

The blood to the heart is supplied by two coronary arteries, the first two branches of the aorta.

**The left coronary artery** has a diameter of 7 mm and is only 3-4 cm long. Just before reaching the coronary sulcus, it divides into two terminal branches: the circumflex artery and the anterior interventricular artery.

- The circumflex artery runs inside the coronary sulcus to the left, supplying blood to the lateral and partly the diaphragmatic wall of the left ventricle.
- The anterior interventricular artery runs in the anterior interventricular sulcus towards the apex, where it anastomoses with the posterior interventricular artery. It supplies blood to the anterior wall of the left ventricle, part of the anterior wall of the right ventricle and most of the interventricular septum.

Branches of both arteries supply blood to the left atrium.

**The right coronary artery** has a calibre of 4 to 5 mm at its origin. It passes between the pulmonary trunk and the right auricle to reach the coronary sulcus, inside which it runs to the right. On the posterior side, it gives off the posterior interventricular artery which runs in the posterior interventricular sulcus towards the apex.

The right coronary artery supplies blood to most of the right ventricle, part of diaphragmatic wall of the left ventricle and posterior part of the interventricular septum. It also supplies blood to the right atrium.

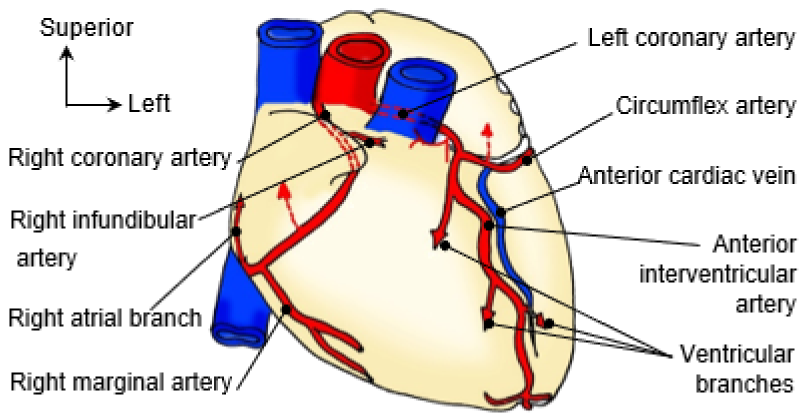



***Figure 181: Blood supply to the heart. Sternocostal surface.***

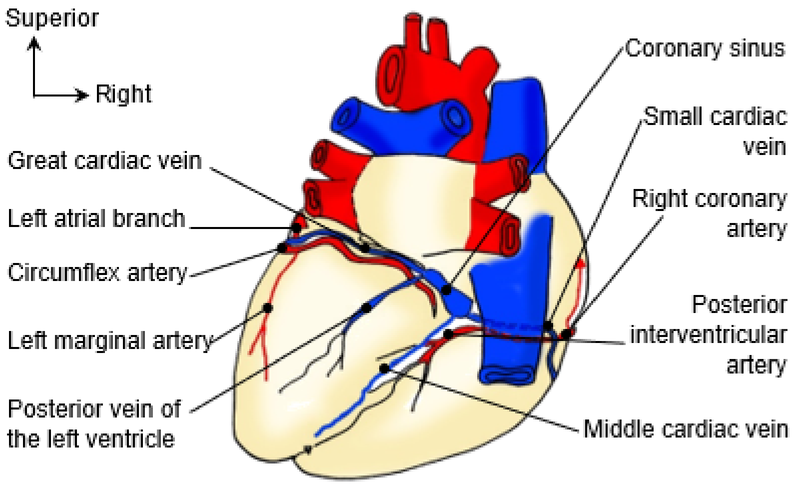



***Figure 182: Blood supply to the heart. Diaphragmatic surface.***

Most of venous blood from the heart wall is collected by the coronary sinus which lies inside the coronary sulcus on the posterior side of the heart and drains into the right atrium.

The great, middle, and small cardiac veins drain into the coronary sinus. The rest of the venous blood flows into the right atrium via the anterior cardiac vein, and into the atria and ventricles via numerous small veins.

**Cardiac conduction system and innervation of the heart**

The heart contractions are initiated and controlled by the conducting system of the heart – a network of specialised cardiac muscle cells that can generate an action potential on their own.

The parts of the conducting system of the heart are the sinoatrial node, the atrioventricular node, the atrioventricular bundle which divides into the left and the right bundle branch, and the Purkinje fibres (subendocardial branches).

The impulse for contraction is normally generated in the sinoatrial node and then conducted through the other parts of the conducting system to the myocardial cells.

The heart is innervated by the autonomic nervous system. The sympathetic nerve fibres innervate the conducting system, increasing the heartrate, and the myocardial cells, increasing the force of contraction. The parasympathetic nerve fibres travel to the heart via the vagus nerve and innervate the conducting system, reducing the heartrate.

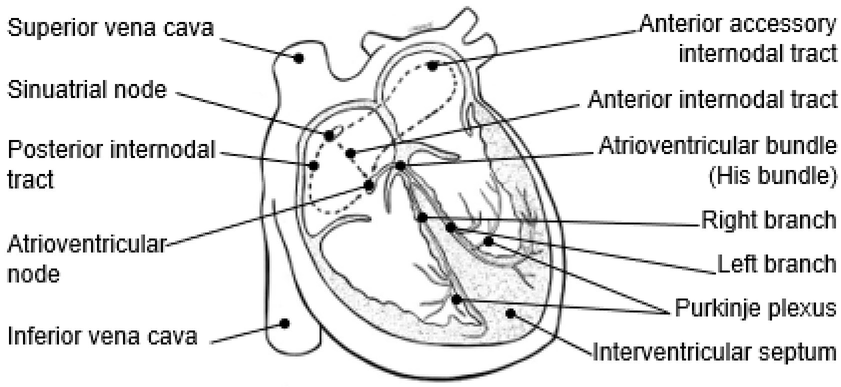



***Figure 183: The conducting system of the heart.***

**Fibrous skeleton of the heart**

The four heart ostia inside which the heart valves lie are surrounded by fibrous rings that form the fibrous skeleton of the heart.

The fibrous skeleton of the heart completely separates the myocardium of the atria from the myocardium of the ventricles, allowing the separated contraction of atria and ventricles. Through the skeleton passes the atrioventricular bundle of the conducting system, transferring the impulse for contraction from atrioventricular node to the ventricles.

The fibrous skeleton of the heart is connected to the membranous part of the ventricular septum.

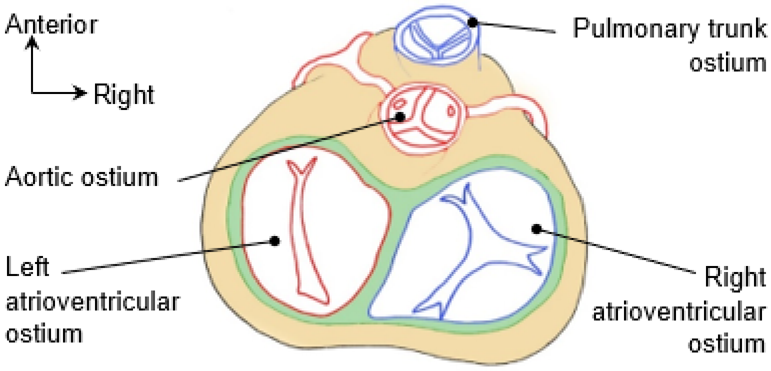



***Figure 184: Fibrous skeleton of the heart.***

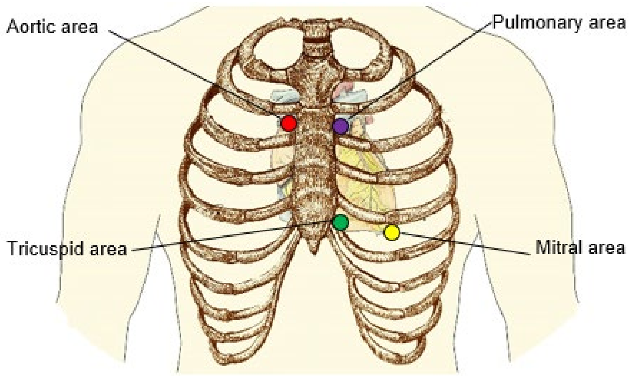



***Figure 185: Heart auscultation points.***

### Blood flow through the heart

The heart is a double pump. The left side of the heart is pushing the blood into the systemic circulation and the right side of the heart is pushing the blood into the pulmonary circulation.

The major circulation or systemic circulation serves to transport oxygen and nutrients to the tissues and to remove carbon dioxide ($CO2$) and other waste products from the tissues. The left atrium receives the oxygenated blood from the pulmonary circulation. Blood flows from the left atrium to the left ventricle through the mitral valve. The left ventricle pushes the blood through the aortic valve into the aorta. The branches of aorta, systemic arteries, finally branch into the systemic capillaries which give off the oxygen and the nutrients into the tissues and receive the carbon dioxide and other waste products of metabolism from the tissues. The deoxygenated blood is collected from the tissues by systemic veins, which finally drain into two great systemic veins entering the right atrium – the superior and the inferior vena cava.

The minor circulation or pulmonary circulation is responsible for enabling the oxygenation of the blood in the lungs. The deoxygenated blood flows from the right atrium to the right ventricle through the tricuspid valve. The right ventricle pushes the blood through the pulmonary valve into the pulmonary trunk. The pulmonary trunk divides into the right and the left pulmonary artery, which enter the right and the left lung, respectively. Inside the lungs they divide to the level of pulmonary capillaries. The pulmonary capillaries receive oxygen from the alveoli and give off carbon dioxide into the alveoli. The oxygenated blood is collected by pulmonary veins, which finally drain into two right and two left pulmonary veins which enter the left atrium.

**Pericardium**

The pericardium is a fibro-serous sac that surrounds the heart and the roots of the great vessels.

The fibrous pericardium completely envelops the heart. It consists of dense connective tissue and is not stretchable. It is firmly attached to the central tendon of the diaphragm, and merges with the outer, fibrous layer of the wall of the great vessels.

The serous pericardium lies inside the fibrous pericardium and is composed of two layers. The outer layer is fused to the fibrous pericardium which is called the parietal layer of serous pericardium. The inner layer is attached to the myocardium, forming the outer layer of the heart wall, the epicardium. It is also named the visceral layer of serous pericardium. Both layers are continuous with each other, enclosing the pericardial cavity. Inside the cavity there is a small amount of serous pericardial fluid which prevents friction during heart contractions.

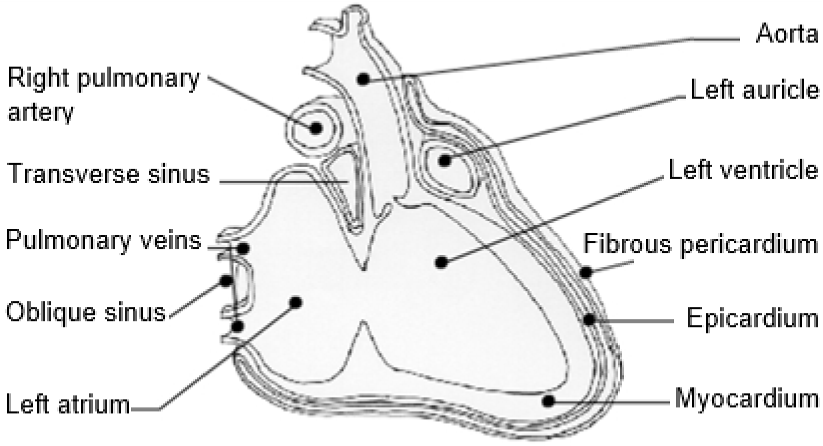



***Figure 186: Section along the longitudinal axis of the heart showing the left heart chambers and the pericardium.***

## 1.2 - Blood vessels

The blood vessels are contractile cylindrical channels through which the blood flows.

The wall of blood vessels has three layers:

- Tunica intima is the innermost layer and consists of epithelial tissue. It is lined by an endothelium, which is formed by a single layer of simple squamous epithelial cells.
- Tunica media is the middle, muscular layer and consists of smooth muscle tissue.
- Tunica externa (adventitia) is the outermost layer and consists of connective tissue.

The arteries have thicker wall than the veins, the thickest layer being the tunica media. The thickest layer of the venous wall is the tunica adventitia.

Depending on their calibre, arteries and veins can be divided into two categories:

- arteries / veins are vessels of bigger calibre,

- arterioles / venules are vessels of smaller calibre.

Arterial and venous systems are connected through the capillary network. Capillaries are the vessels of the smallest calibre. They have very thin and perforated wall which allows the molecular exchange between the blood and the surrounding tissues.

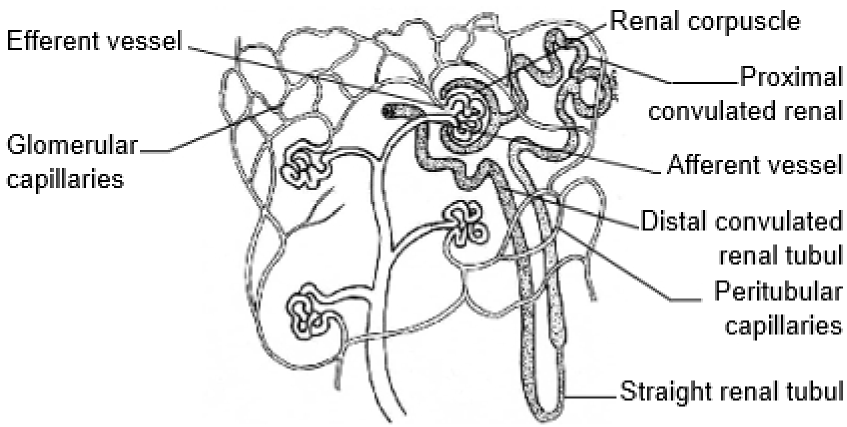



***Figure 187: Arterial capillary plexus of the renal cortex.***

## *Arteries of systemic circulation*

The systemic arteries are vessels transporting the oxygenated blood from the heart to the tissues, supplying them with oxygen and nutrients.

The left ventricle pumps the blood into the arteries with each contraction, causing the distension of the arterial wall. This distension is followed by the arterial wall contraction, sending the blood further along the arterial system. Thus, formed arterial pulsations can be palpated on certain arteries allowing to measure the frequency with which the heart contracts (the heartbeat).

Two or more arteries can be connected to each other. Such a connection is called anastomosis. The anastomoses provide an alternative pathway for blood supply to the target organ or portion of organ in case the primary pathway is obstructed.

Terminal arteries are the arteries that are the only pathway for supplying a portion of organ.

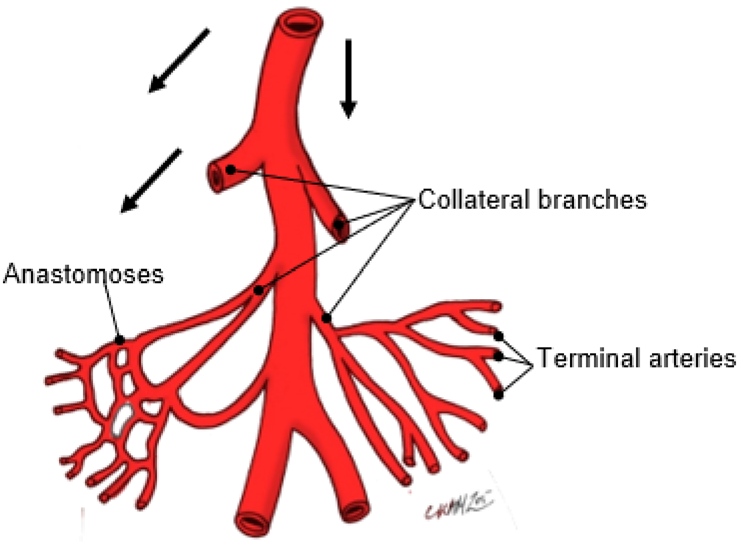



***Figure 188: Anastomoses and terminal arteries.***

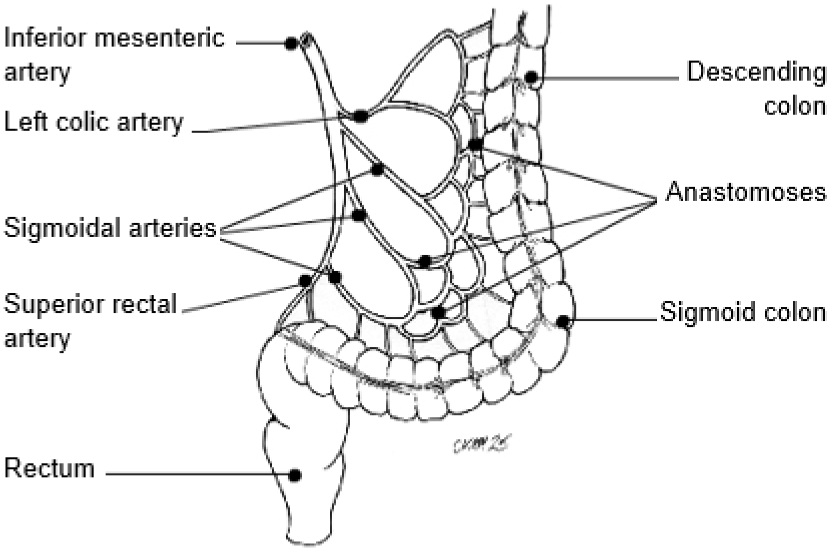



***Figure 189: Anastomoses supplying the colon.***

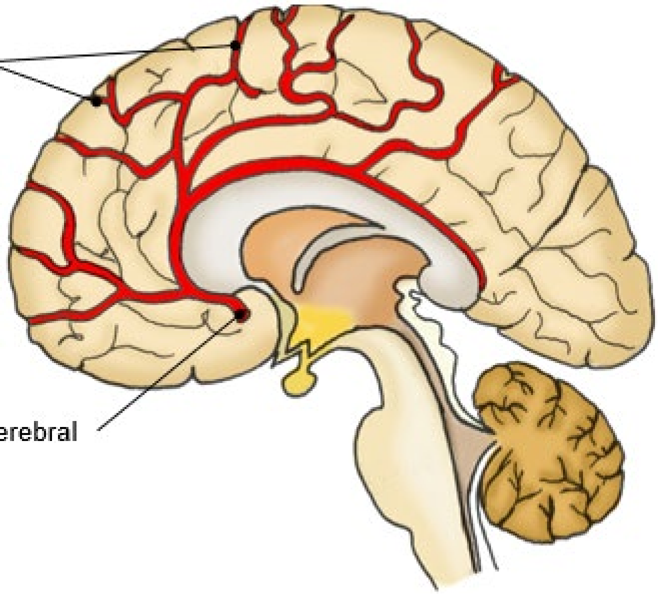



***Figure 190: Terminal arteries supplying the brain. Median section, view from the left.***

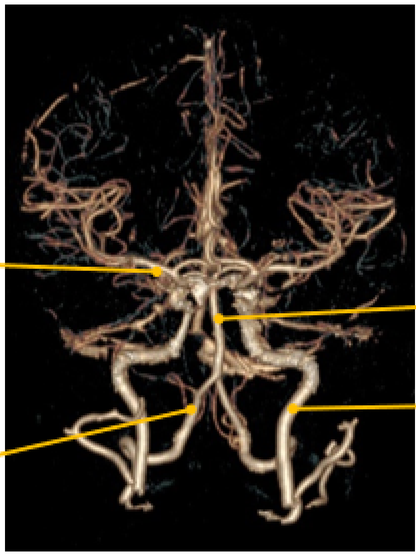



***Figure 191: Reconstruction of the arterial supply to the brain. Anterior view.***

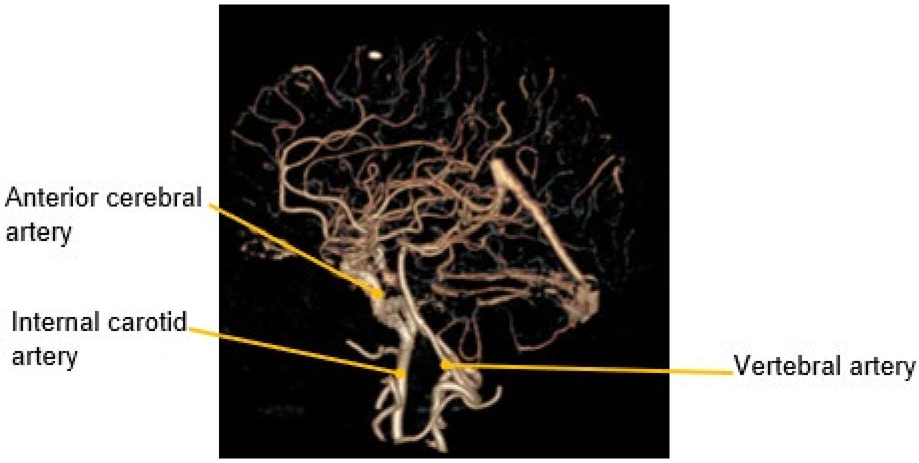



***Figure 192: Reconstruction of the vascular supply to the brain. Left lateral view.***

Collateral artery is a branch of a main artery that runs parallel to the main artery, maintaining the same direction of blood flow. The collateral and main artery can anastomose.

A recurrent artery is a branch of a main artery that after branching off turns in the direction opposite to the main artery. It can then run parallel to the main artery, but the blood flow inside it is opposite to the blood flow in the main artery.

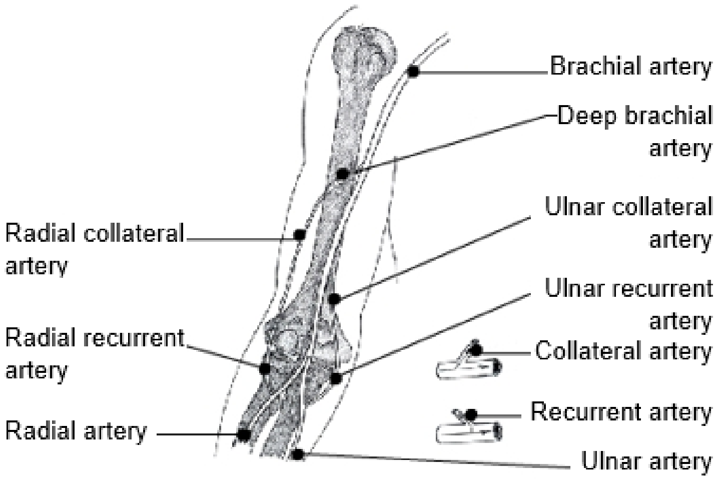



***Figure 193: Arteries around the right elbow joint. Anterior view.***

**Aorta**

Aorta exits the left ventricle and runs through the thoracic and abdominal cavity.

It has three parts: ascending aorta, aortic arch, and descending aorta.

Ascending aorta lies within the pericardium. It supplies blood to the heart.

Aortic arch lies in the superior mediastinum. It supplies blood to the head, the neck, and upper extremities.

Descending aorta lies along the left side of the vertebral column and passes the aortic hiatus in the diaphragm at the level of vertebra T12. According to the position in the thoracic or abdominal cavity, the descending aorta is divided into two parts: the thoracic aorta, which supplies blood to the thorax, and the abdominal aorta, which supplies blood to the abdomen.

At the level of the intervertebral disc L4-L5, abdominal aorta bifurcates into the right and left common iliac arteries, which supply blood to the pelvis and lower extremities.

The ascending aorta has two branches:

- right coronary artery,
- left coronary artery.

The arch of the aorta has three branches:

- brachiocephalic trunk,
- left common carotid artery,
- left subclavian artery.

The thoracic aorta has several branches:

- bronchial branches,
- oesophageal branches,
- pericardial branches,
- mediastinal branches,

- posterior intercostal arteries,
- subcostal artery,
- superior phrenic arteries.

The abdominal aorta also has several branches:

- inferior phrenic arteries,
- lumbar arteries,
- coeliac trunk,
- superior mesenteric artery,
- middle suprarenal artery,
- renal artery,
- ovarian / testicular artery,
- inferior mesenteric artery.

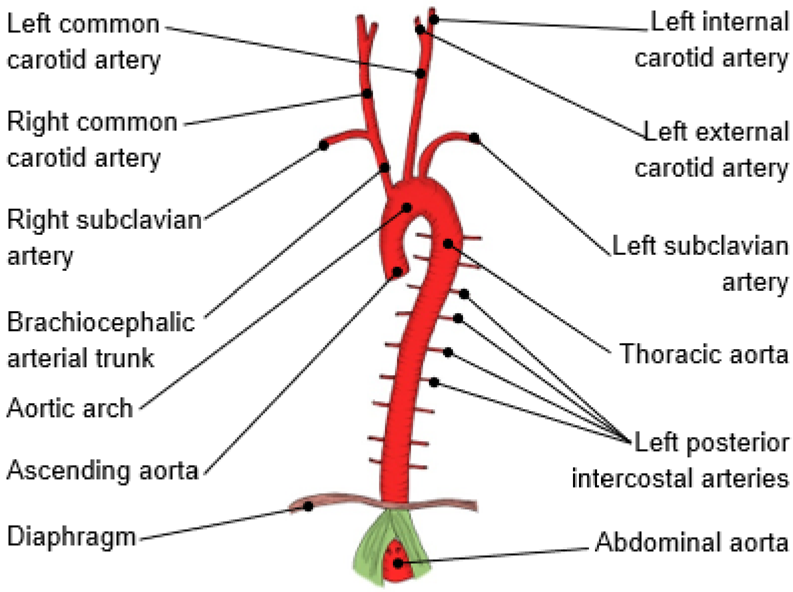



***Figure 194: The thoracic part of the aorta and its branches. Anterior view.***

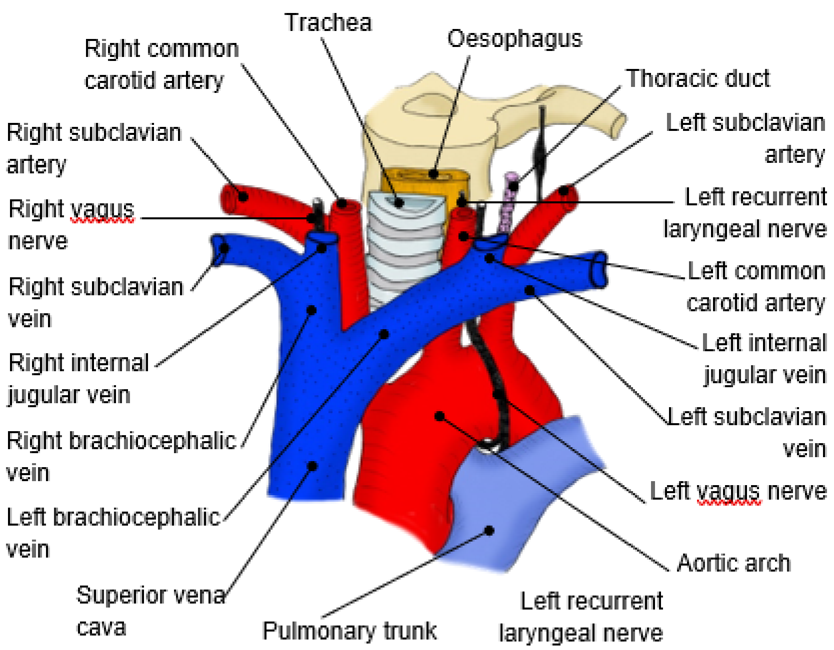



***Figure 195: Topography of aortic arch. Anterior view.***

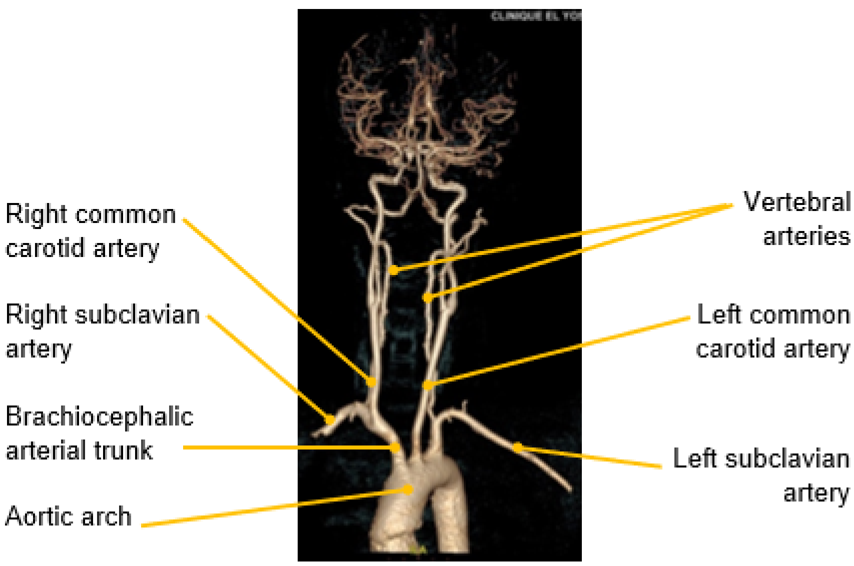



***Figure 196: Reconstruction of the aortic arch with branches. Anterior view.***

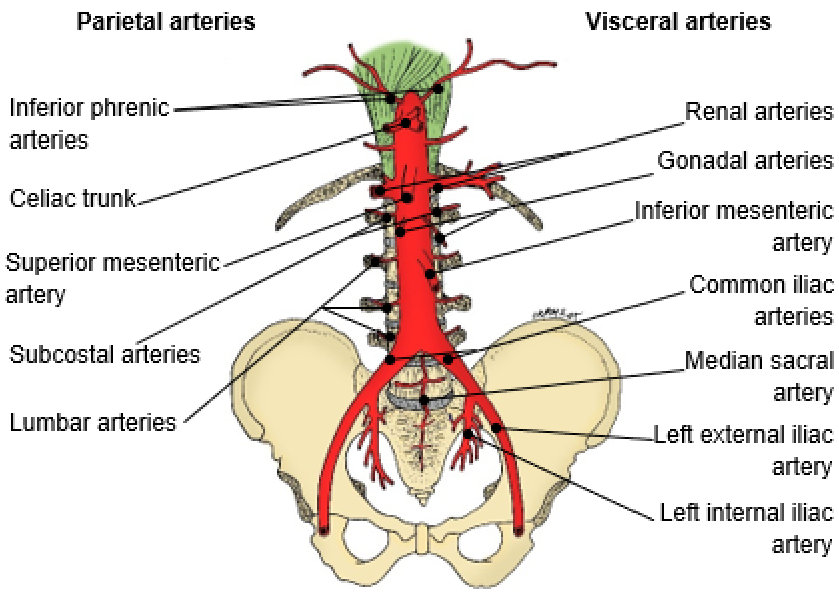



***Figure 197: The abdominal aorta and its branches. Anterior view.***

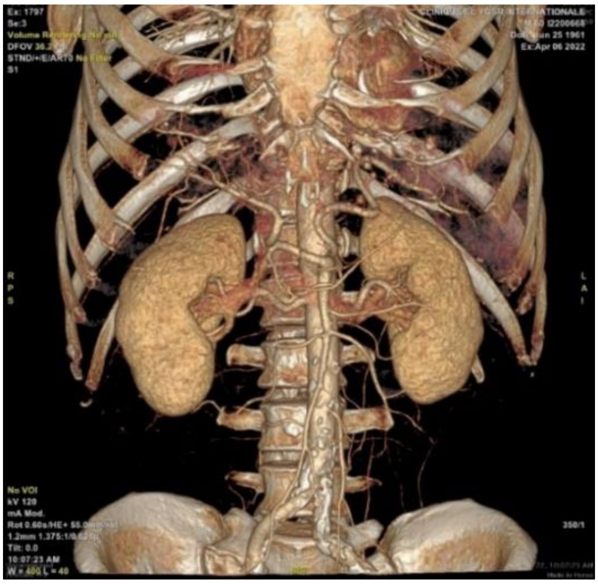


***Figure 198: CT reconstruction of the abdominal aorta. Anterior view.***

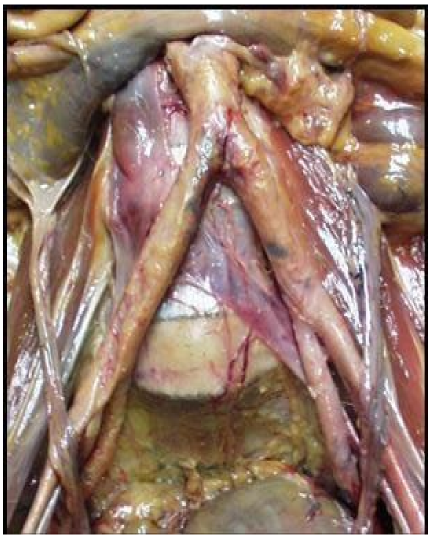


***Figure 199: Aortic bifurcation. Anterior view.***

**Arterial supply of upper limb**

The upper limb is supplied by the subclavian artery. The right subclavian artery arises from the brachiocephalic trunk, while the left one arises directly from the aortic arch.

The subclavian artery enters the upper limb passing through the superior thoracic aperture and then passing under the middle of the clavicle. At the lower margin of the clavicle, it changes its name to become the axillary artery. At the level of the inferior border of the pectoralis major muscle, it is renamed into the brachial artery.

The latter runs across the medial aspect of the arm and enters the cubital fossa on the anterior aspect of elbow, where it divides into two terminal branches: the radial and the ulnar artery.

The radial artery runs on the lateral side of the anterior compartment of the forearm and crosses the wrist laterally to reach the dorsum of the hand. Its final part pierces through the 1$^{st}$ intermetacarpal space and forms the deep palmar arch, anastomosing with the branch of ulnar artery. Branches of radial artery form the dorsal carpal network.

The ulnar artery, which runs on the medial side of the anterior compartment of the forearm, crosses the wrist anteriorly, and ends in the palm forming the superficial palmar arch, anastomosing with the branch of radial artery. On the proximal part of the forearm, it gives off a branch called the interosseous artery.

This artery runs deep in the posterior compartment of the forearm, just behind the interosseous membrane, and ends in the dorsal carpal network.

From the superficial palmar arise the palmar digital arteries, which supply the fingers. From the deep palmar arch arise the palmar metacarpal arteries which supply the metacarpus.

Palpable pulses in the upper limb are axillary, brachial, radial and ulnar pulse.

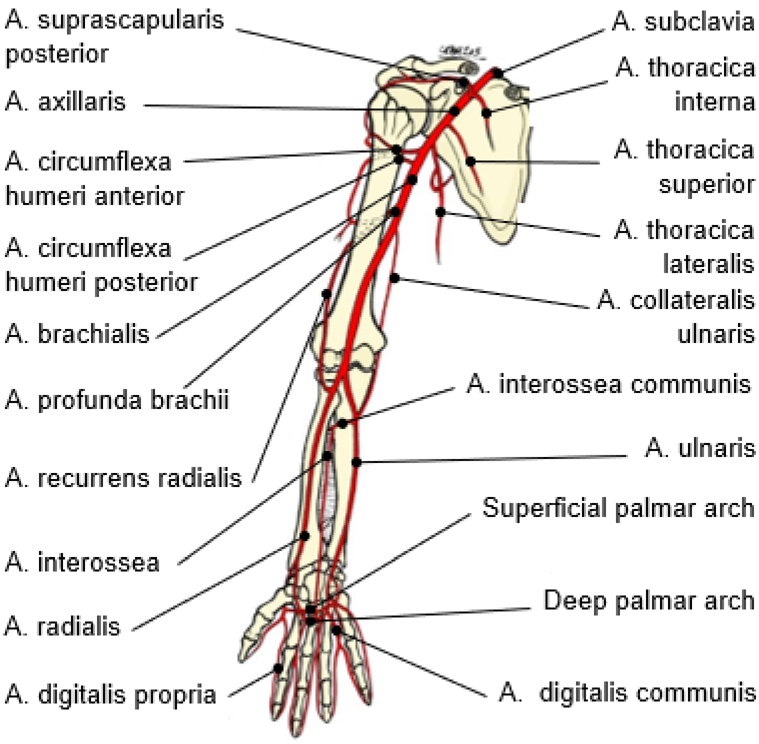



***Figure 200: The arteries of the right upper limb. Anterior view.***

**Arterial supply of lower limb**

The lower limb is supplied by the external iliac artery, which is the branch of the common iliac artery. Left and right common iliac arteries are the final branches of the aorta.

After passing behind the inguinal ligament, the external iliac artery changes its name to the femoral artery. The femoral artery runs from the inguinal ligament towards the knee on the anteromedial aspect of the thigh, between the anterior and medial compartment of the thigh. It then passes through the hiatus in the adductor magnus muscle where it changes the name to become a popliteal artery.

The popliteal artery runs just behind the articular capsule of the knee joint, deep in the popliteal fossa. At the proximal part of the leg, it divides into two terminal branches, the anterior tibial artery and the tibio-peroneal trunk. The latter divides after a short distance into two terminal arteries, the posterior tibial artery and the fibular artery.

The anterior tibial artery crosses the interosseous membrane of the leg and enters into the anterior compartment of the leg, where it runs in front of the interosseous membrane. It crosses the ankle to reach the dorsum of the foot where it is called the dorsal artery of the foot.

The posterior tibial artery runs in the posterior compartment of the leg, close to the transverse crural intermuscular septum. It crosses the ankle behind the medial malleolus and enters the sole of the foot, where it divides into the medial and lateral plantar artery.

The pulses palpable at the level of the lower limb are the femoral, popliteal, and two pedal pulses –the dorsal artery of the foot (from the anterior tibial artery) on the dorsum of the foot, and the posterior tibial artery behind the medial malleolus.

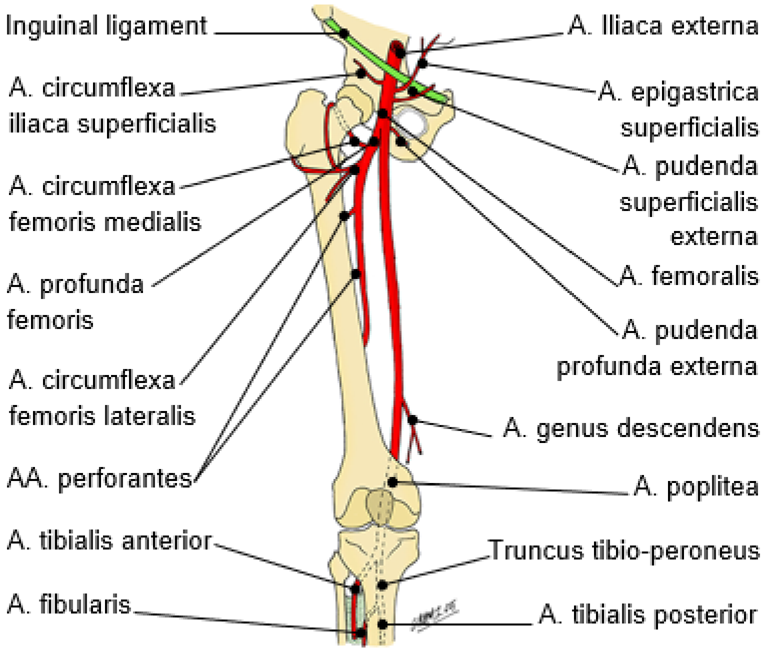



***Figure 201: The arteries of the right lower limb, thigh region. Anterior view.***

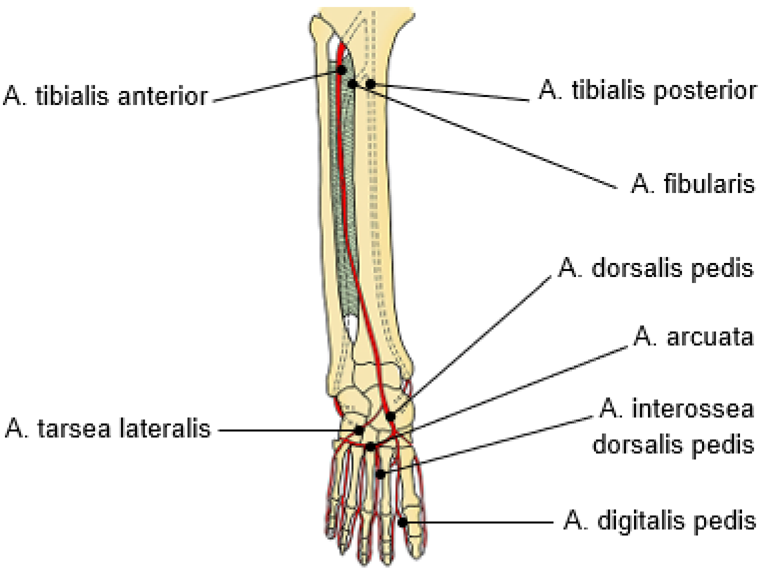



***Figure 202: The arteries of the right lower limb, leg and foot region. Anterior view.***

***Figure 203: Dissection of the femoral triangle. The femoral artery and its branch, the deep femoral artery.***

## Veins of systemic circulation

The systemic veins are vessels transporting the deoxygenated blood from the tissues to the heart, removing the carbon dioxide and other waste products of metabolism from the tissues.

Unlike the arteries, the veins do not pulsate.

Many of the systemic veins have crescent-shaped valves protruding into the lumen at longer intervals, dividing long vessels into segments. The valves prevent the blood to flow away from the heart in the direction of gravity.

While arteries lie only in the deep compartment of the body, veins can be also found just beneath the skin, superficially to the investing fascia which divides the deep and the superficial compartment. The veins are therefore divided into two groups: the deep veins which follow the course of the arteries and the superficial veins in the subcutaneous tissue. The superficial veins eventually cross the investing fascia and drain into the deep veins. The superficial veins can serve as an access route for infusion of fluids in the body, injecting the therapy into the bloodstream, and withdrawal of blood sample for the laboratory testing.

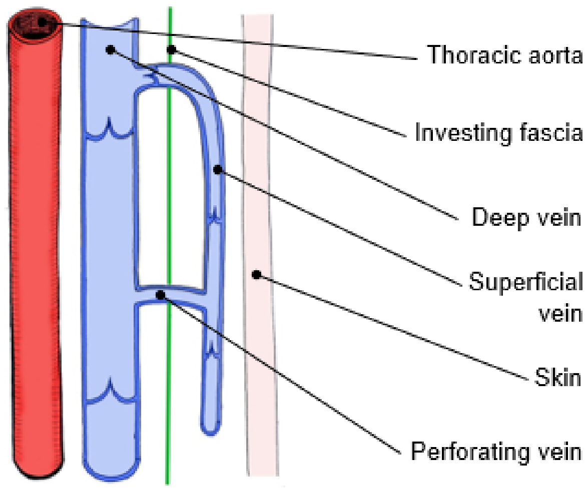



***Figure 204: Deep and superficial veins.***

The deoxygenated blood returns to the heart via two great veins that enter the right atrium: the superior and inferior vena cava. Both veins anastomose through the cavo-caval anastomoses.

Venous blood from the abdominal part of digestive system first collects in a special venous system called the portal venous system, and only after filtration in the liver it enters the caval system.

### Superior vena cava

The superior vena cava lies in the thoracic cavity. It collects venous blood from the upper half of the body. It is formed by union of the right and left brachiocephalic veins and it ends at the level of the ostium of the superior vena cava in the right atrium.

The brachiocephalic vein is formed by union of the internal jugular vein and subclavian vein. The internal jugular vein collects venous blood from the head and the neck, and the subclavian vein collects venous blood from the upper limb.

The azygos vein drains directly into the superior vena cava. It collects venous blood from the thorax. The blood from the left side of the thorax is first collected by the hemiazygos vein and the accessory hemiazygos vein, which drain into azygos vein.

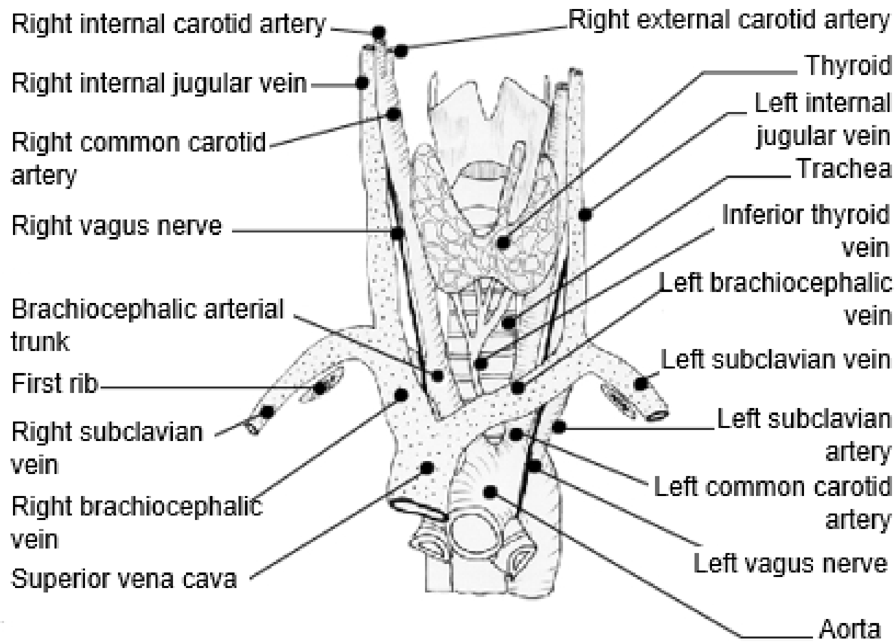



***Figure 205: The superior vena cava.***

***Figure 206: The drawing of the left internal jugular vein.***

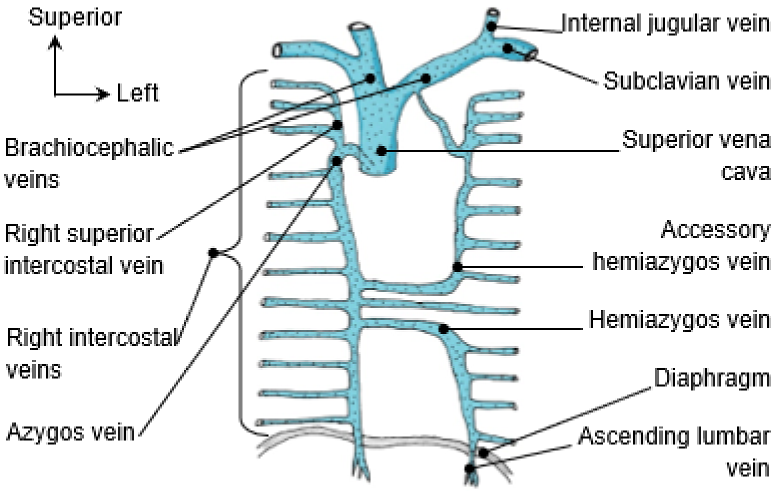



***Figure 207: The azygos, hemiazygos, and accessory hemiazygos veins. Anterior view.***

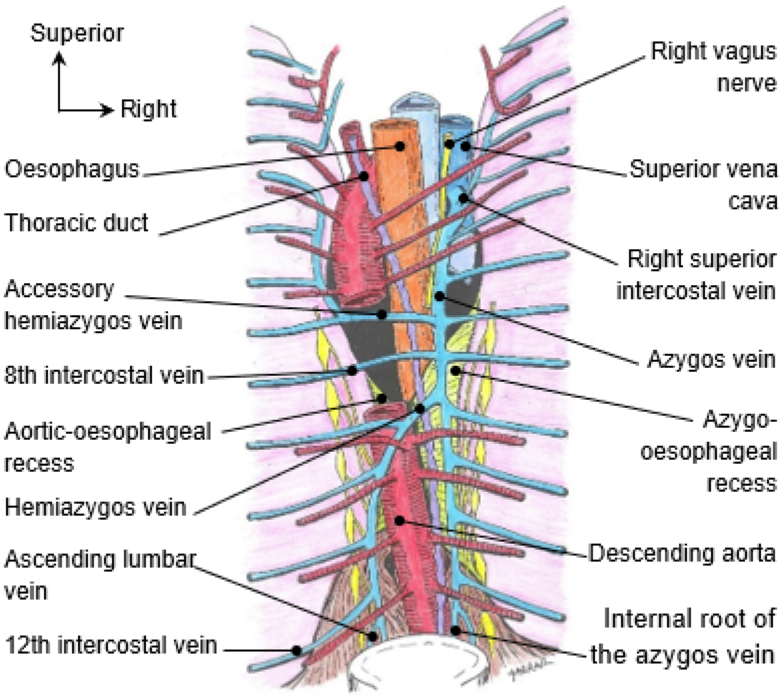



***Figure 208: The azygos, hemiazygos, and accessory hemiazygos veins. Posterior view.***

### Inferior vena cava

The inferior vena cava lies in the abdominal cavity right to the abdominal aorta. It collects venous blood from the lower half of the body. It is formed by union of the right and left common iliac veins at the level of vertebra L5. It passes the caval foramen in the central tendon of the diaphragm at the level of vertebra T8, it immediately enters the pericardium and opens into the right atrium through the ostium of the superior vena cava.

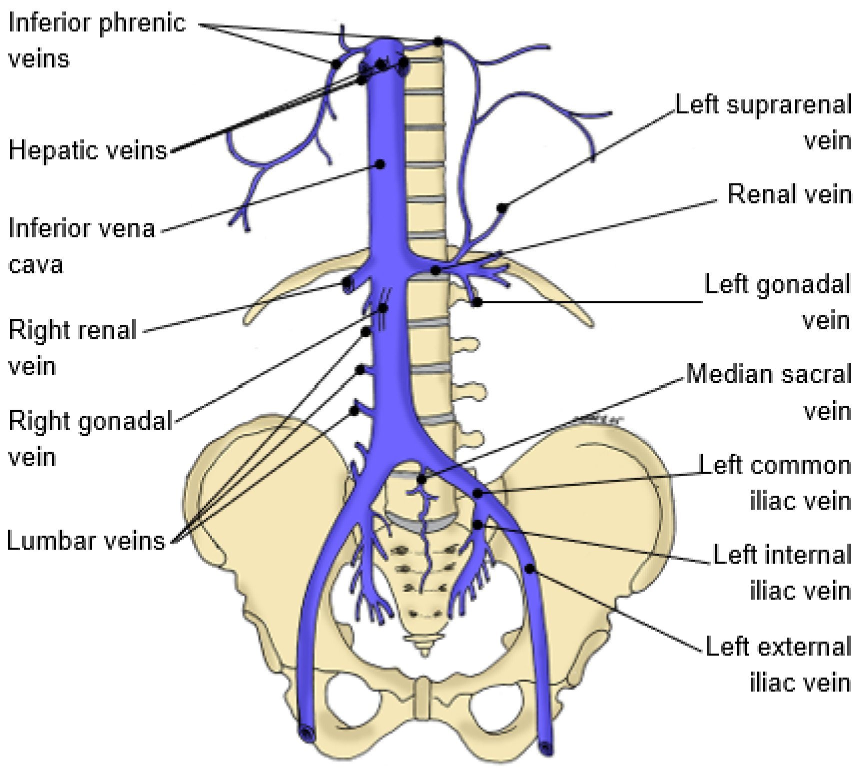



***Figure 209: The inferior vena cava.***

### Portal venous system

A portal venous system is a connection of two capillary networks through veins, without passing through the heart.

Hepatic portal vein collects the venous blood from the capillary network of the abdominal part of the digestive canal, pancreas, and spleen. It delivers blood to the liver. During filtration in the capillary network of the liver, the substances absorbed from the food can be processed if necessary, before entering the inferior vena cava.

### Superficial veins of the limbs

The upper limb has two main superficial veins: the basilic vein, which drains into the brachial vein and the cephalic vein, which drains into the axillary vein.

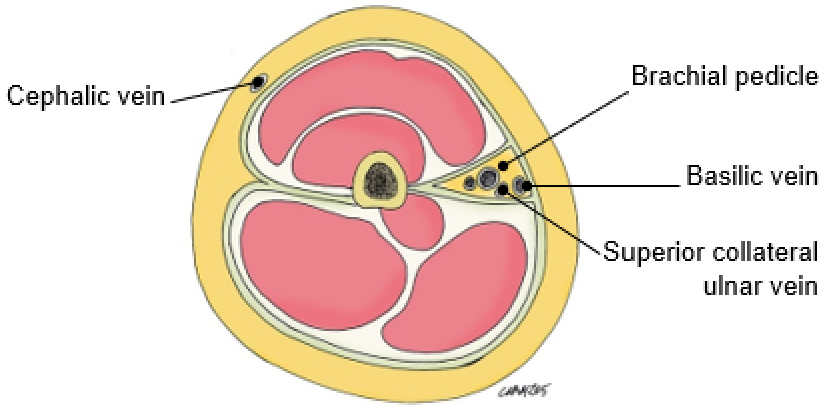



***Figure 210: Transverse section of the middle third of the arm. The basilic vein already crossed the brachial fascia.***

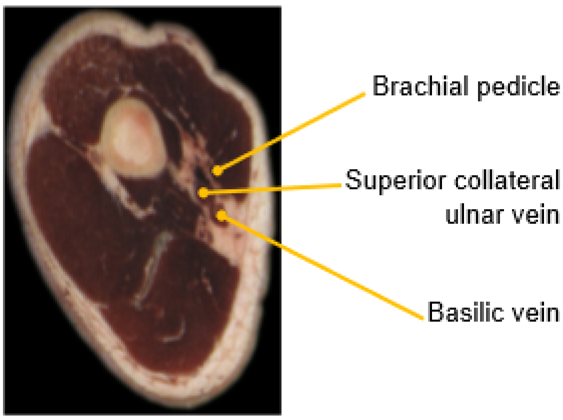



***Figure 211: Transverse section of the middle third of the arm.***

The lower limb also has two main superficial veins: the small saphenous vein, which drains into the popliteal vein and the great saphenous vein, which drains into the femoral vein. Dilated insufficient veins of the lower limbs form varicose veins.

## 1.3 - Lymphatic vessels

The lymphatic vessels are thin-walled vessels structured similarly to the veins. They carry lymph.

Unlike the blood vessels, which are arranged into a closed circle, the lymphatic vessels form an open system. The lymphatic capillaries begin blind-ended in the intercellular space of the tissue. They merge to form bigger lymphatic vessels, but even the biggest have only a diameter of 5 mm or less. The lymphatic vessels finally join the veins and in consequence the lymph enters the bloodstream.

The lymphatic vessels remove the excessive fluid from the tissue and thus maintain the fluid homeostasis. The pores in the wall of lymphatic capillaries are wider than pores in the wall of the blood capillaries. So the particles too big to enter the blood capillaries enter the bloodstream as part of the lymph.

Lymph from the lower part of the body and the left half of the upper part of the body is collected by the thoracic duct which drains into the left venous angle – the angle between the joining internal jugular and subclavian vein. Lymph from the right half of the upper part of the body is collected by the right lymphatic duct.

Before reaching the bloodstream, lymph is filtered through the lymph nodes.

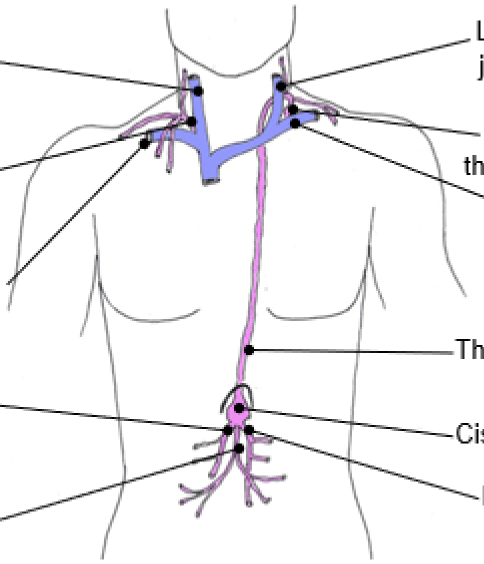



***Figure 212: Lymphatic vessels.***

**Thoracic duct**

The thoracic duct is 40-45 cm long and has a diameter of about 5 mm.

It originates from the upper end of cisterna chyli. The cisterna chyli is a dilated sac in front of the bodies of the vertebra L1 and L2, posteriorly to the abdominal aorta. It collects the lymph from the lower extremities, the pelvis and the abdomen through the right and left lumbar trunks and one or more intestinal trunks.

The thoracic duct passes the diaphragm through the aortic hiatus and ascends posteriorly to the aorta in front of the vertebral column in the posterior mediastinum. It reaches up to the level of vertebra C7 and finally terminates in the left venous angle.

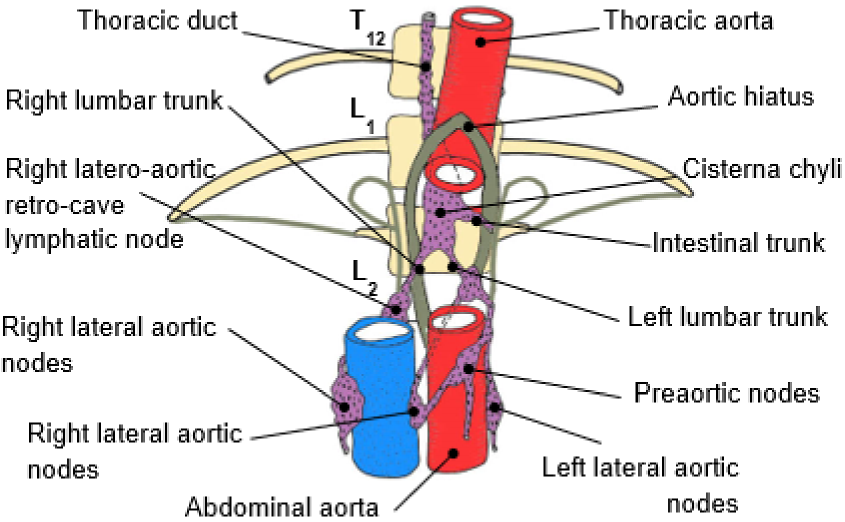



***Figure 213: Origin of the thoracic duct.***

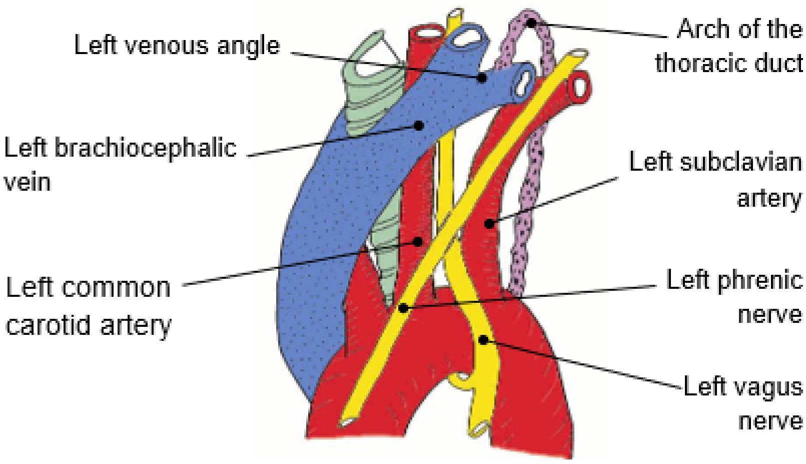



***Figure 214: Termination of the thoracic duct.***

### Right lymphatic duct

The right lymphatic duct drains lymph from the upper right quarter of the body.

It arises from the union of various lymphatic vessels that drain lymph from the right upper extremity and the right side of the head, the neck and the thorax. It is 1-2 cm long and lies at the base of the neck. It terminates in the right venous angle.

# 2 - Lymphoid organs

The lymphoid organs are part of the immune system. Their function is to create an immune defence, protecting the body from infections and other diseases.

The lymphoid organs are divided into two groups:

- Primary lymphoid organs are red bone marrow and thymus. These are the organs in which new lymphocytes develop and mature.
- Secondary lymphoid organs are the spleen, pharyngeal lymphoid ring, and lymph nodes. These are the organs in which mature lymphocytes relocate, and in case of infection, activate and initiate the immune response.

**Red bone marrow**

The red bone marrow, also known as the hematopoietic bone marrow, is a semi-solid tissue that produces new blood cells. It is located in the cavities of the spongy bones or portions of bones.

The red bone marrow contains the hematopoietic stem cells that generate the three different classes of blood cells with a specific function which exit the marrow and become part of the blood:

- Red blood cells, erythrocytes, transport oxygen from the lungs to all the parts of the body. Erythrocytes make up about 40-45 % of the blood volume and give blood its red color.
- White blood cells, leukocytes, are part of the immune system. They protect body from infections and other diseases.

- Platelets, thrombocytes, contribute to haemostasis – the process of stopping the bleeding.

**The spleen**

The spleen is the largest lymphoid organ. Additional function of the spleen is the elimination of aged red blood cells. During the embryonic life, it is able of haematopoiesis.

The spleen lies in the abdominal cavity, underneath the left part of the diaphragm, along the ribs 9-11. It is a soft purple organ enwrapped in a fibroelastic capsule. From the capsule extend the splenic trabeculae, incompletely dividing the parenchyma.

The spleen has two extremities, a posterior and an anterior one, and two surfaces:

- diaphragmatic surface is orientated laterally, convex in shape and leaning onto the diaphragm;
- visceral surface is orientated medially and is in contact with the stomach, left kidney and colon; on this surface is the hilum through which the vessels and nerves pass.

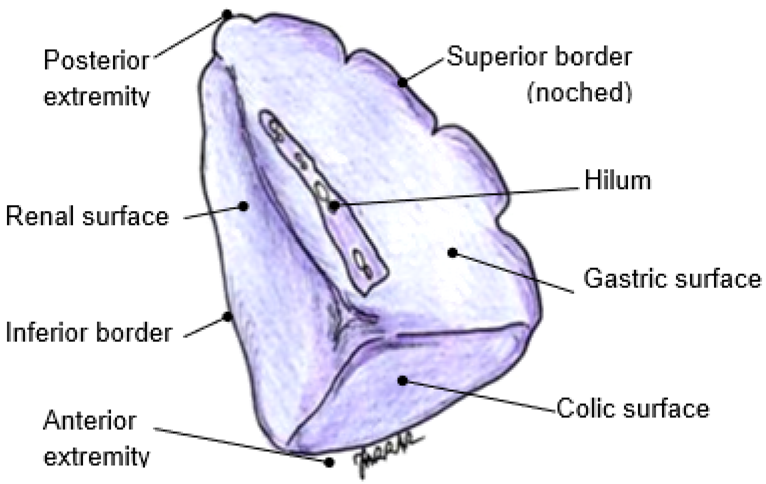



***Figure 215: Antero-internal view of the spleen.***

***Figure 216: View of the spleen.***

Microscopically, the parenchymal tissue of the spleen consists of two major components called the white pulp and the red pulp:

- The white pulp is composed of lymphoid tissue in which lymphocytes proliferate in response to infection.
- The red pulp is a complex system of interconnected spaces with numerous macrophages. When the blood runs through this system, the macrophages remove from the blood old erythrocytes, microorganisms, cellular debris, and other particles.

The spleen is supplied by the splenic artery, a branch of the celiac trunk.

# Chapter 6 - Respiratory system

**The objectives of this chapter are:**

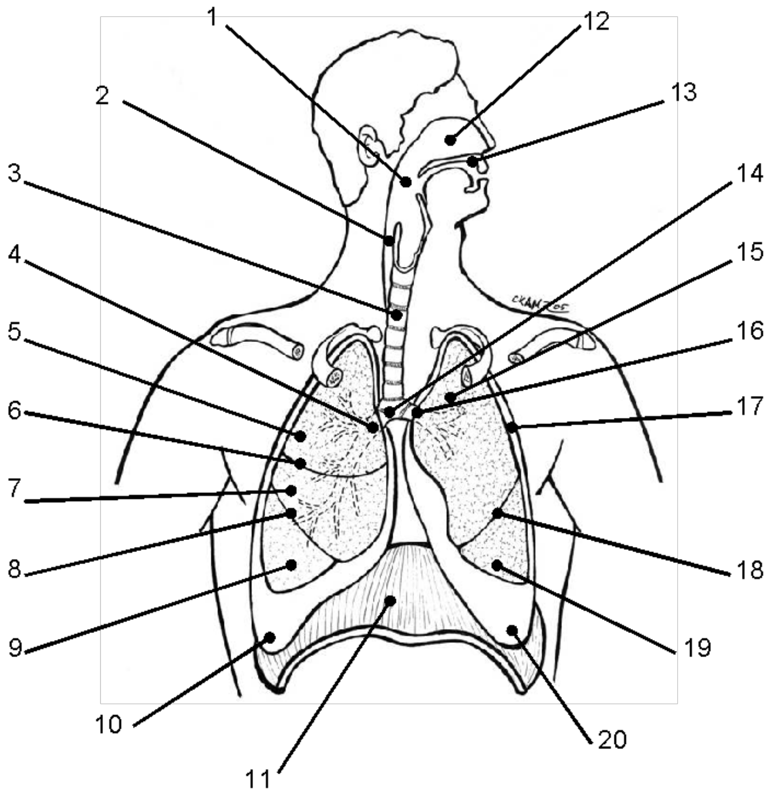
1. Name the parts of the respiratory system.
2. Describe the structure and function of the larynx.
3. Describe the tracheobronchial tree.
4. Describe the right and left lung.
5. Define a pulmonary lobe and a pulmonary segment.
6. Describe the pleura and the pleural cavity.
7. Describe the pulmonary circulation.
8. Describe the mechanics and the muscles of respiration.

## 1 - Elements of respiratory system

The respiratory system allows gas exchange between the blood and the atmosphere. Part of the respiratory system is larynx which enables the formation of vocal sounds.

The respiratory system consists of the following organs:

- nose,
- paranasal sinuses,
- larynx,
- tracheobronchial tree,
- lungs.




1. Pharynx
2. Laryngopharynx
3. Trachea
4. Right main bronchus
5. Right superior lobe
6. Horizontal fissure of right lung
7. Middle lobe
8. Right oblique fissure
9. Right inferior lobe
10. Right costodiaphragmatic recess
11. Diaphragm
12. Nasal cavity
13. Oral cavity
14. Bifurcation of trachea
15. Left superior lobe
16. Left main bronchus
17. Pleura
18. Left oblique fissure
19. Left inferior lobe
20. Left costodiaphragmatic recess

***Figure 217: Scheme of the respiratory system.***

In addition to the organs, the pulmonary circulation is also functionally involved in respiration:

- Right ventricle pumps deoxygenated blood into the pulmonary trunk, which divides into the left and right pulmonary artery which carry the blood to the lungs.
- Pulmonary veins carry oxygenated blood from the lungs to the left atrium.

According to the function, the respiratory system can be divided into two zones:

- the conducting zone for transporting the gases to the respiratory zone;
- the respiratory zone for exchanging the gases between the blood and the inhaled air.

The respiratory tract can also be divided into the upper and lower parts:

- the upper respiratory tract includes nose, paranasal sinuses, pharynx, and portion of larynx above the vocal cords;
- The lower respiratory tract includes portion of larynx below the vocal cords, trachea, bronchi, bronchioles, alveolar ducts, alveolar sacs, and alveoli.

## 1.1 - Nasal cavity and paranasal sinuses

The nasal cavity allows cleaning, heating and humidification of the air. The roof of the nasal cavity is also the site of the organ of smell.

The cavity is divided into the left and right nasal cavity by the nasal septum. The anterior opening into the cavities are the two nostrils. Posteriorly, the nasal cavities communicate with the pharynx through the choanae.

The skeletal roof of the cavity consists of the nasal bone, nasal part of the frontal bone, cribriform plate of the ethmoid bone, and the body of sphenoid bones. The perforated cribriform plate allows passage of the olfactory fibres. The skeletal floor of the nasal cavity is the hard palate, separating the nasal cavity from the oral cavity. The skeletal lateral wall of the nasal cavity is complex, formed by 7 different bones of the cranium. Superior, middle and inferior nasal concha project from the lateral wall into the cavity.

The nasal cavity is lined by nasal mucosa. Specialised epithelium in the respiratory region is called the respiratory epithelium and is formed by ciliated columnar cells. The olfactory region contains the olfactory epithelium.

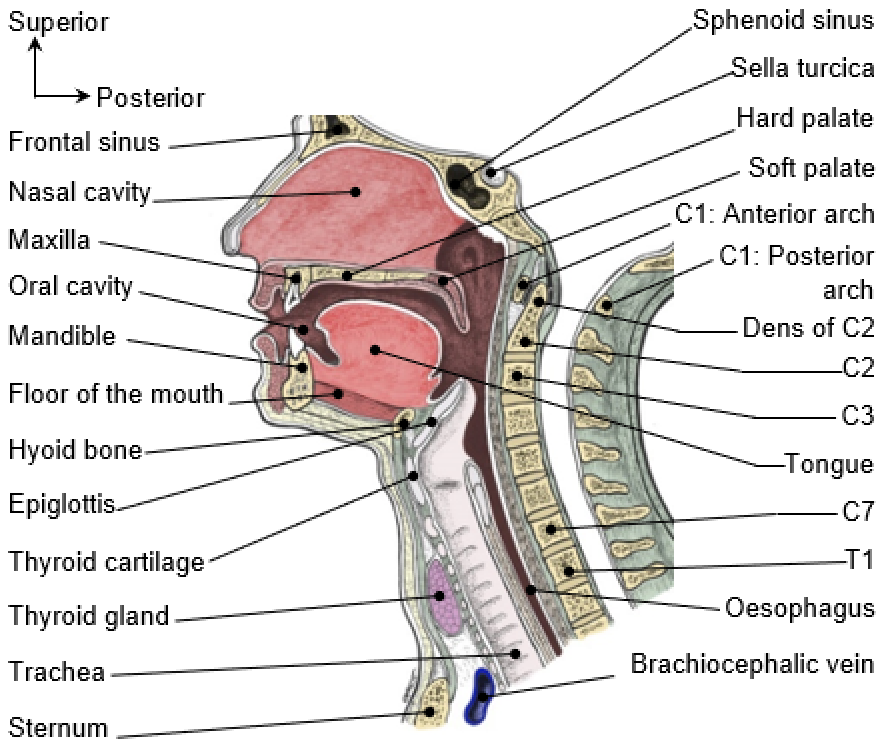



***Figure 218: Sagittal section of the head and neck presenting the location and topography of the nasal cavity.***

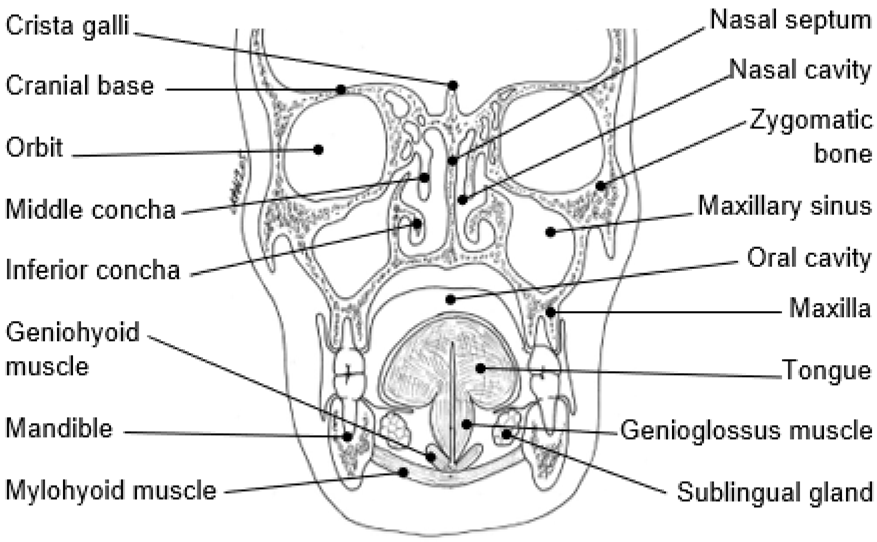



***Figure 219: Frontal section of the head showing the location and topography of the nasal cavity.***

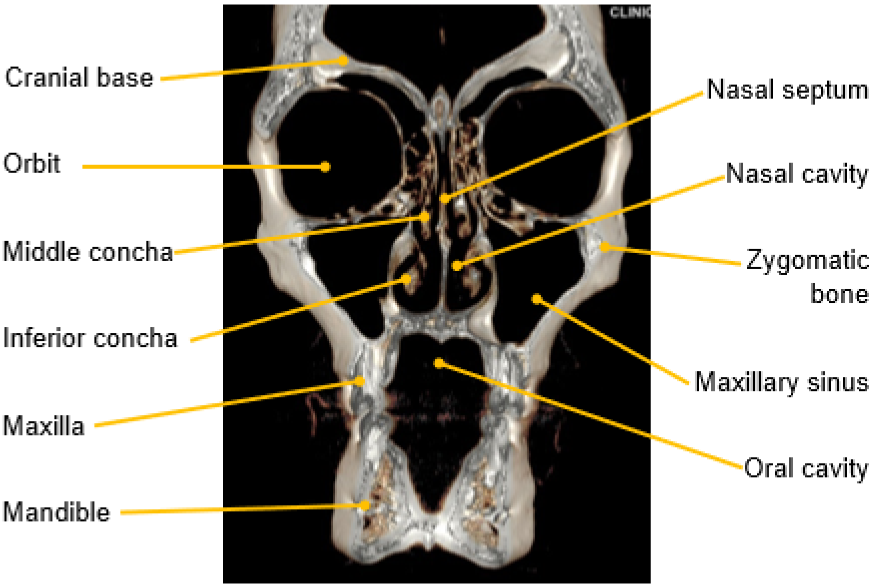



***Figure 220: Reconstruction of the frontal CT sections of the head.***

The paranasal sinuses are air-filled bony cavities of the maxilla, frontal bone, sphenoid bone, and ethmoid bone. They are lined by a mucous membrane and communicate with the nasal cavity through relatively small openings.

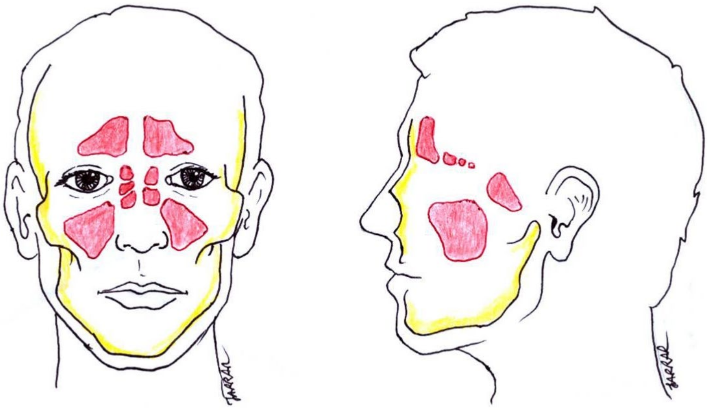


***Figure 221: The paranasal sinuses.***

## 1.2 - Pharynx

The pharynx is a junction of the respiratory and the digestive system: it is a part of the digestive system, but also serves as the conduit for the air. It can be divided into the nasopharynx situated behind the nasal cavity, oropharynx situated behind the oral cavity, and laryngopharynx situated behind the larynx.

## 1.3 - Larynx

The larynx is a part of the respiratory tract between the oropharynx and the trachea. Its skeleton consists of several laryngeal cartilages, connected by membranes, ligaments and synovial laryngeal joints. Tiny laryngeal muscles move the cartilages.

An important part of the larynx are two vocal cords which are essential for phonation. Above the true vocal cords, there are two vestibular folds, also named false vocal cords.

The mucosa lining the laryngeal cavity has a respiratory epithelium, except for the vocal cords which are lined by a stratified squamous epithelium.

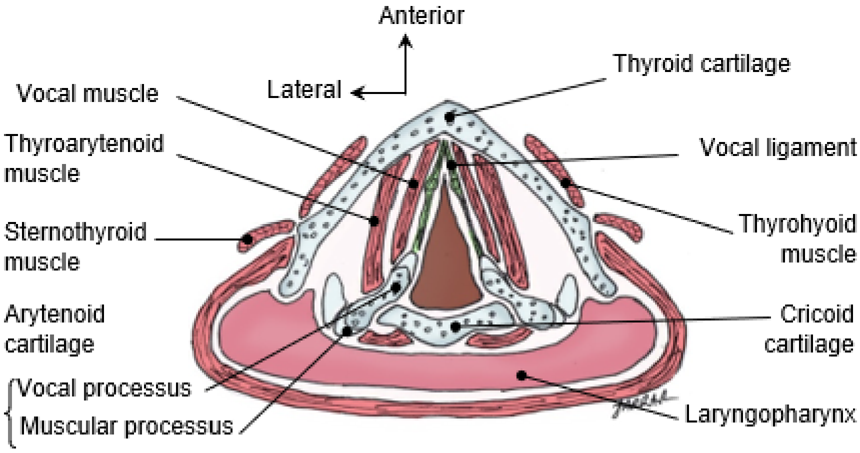



***Figure 222: Horizontal section of the larynx.***

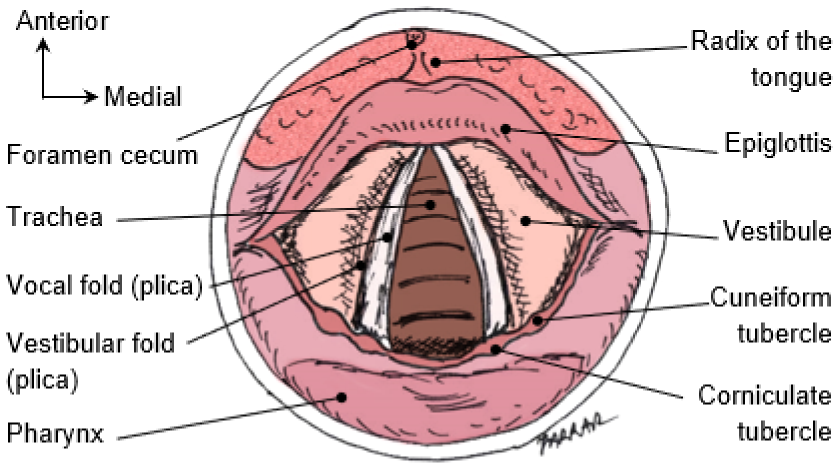



***Figure 223: Laryngoscopy.***

## 1.4 - Tracheobronchial tree

The tracheobronchial tree consists of trachea and bronchi.

The trachea is a fibromusculocartilaginous tube, lined with mucosa on the inner surface. It extends from the larynx in the neck into the thorax where it bifurcates above the heart into the left and right main bronchus.

The left and right main bronchus enter the left and right lung ad divide further inside the lung.

The bronchi have similar wall structure as the trachea. The left and right main bronchus enter the left and right lung, respectively, and then divide further inside the lungs into successively finer divisions.

***Figure 224: Dissection – anterior view of the viscera of the thorax.***

***Figure 225: Branching of the tracheobronchial tree.***

## 1.5 - Lungs

The lungs have a spongy, expandable structure and capability of gas exchange between the inhaled air and the blood. Their average air capacity in the adult is 6 litres.

The left and right lung are located in the lateral parts of the thorax, on each side of the mediastinum.

The lungs have a conical shape, with apex on the top and base at the bottom. They have three surfaces: the costal surface is adjacent to the ribs, the diaphragmatic surface is adjacent to the diaphragm, and the medial surface is oriented medially, towards the mediastinum. Deep fissures divide each lung into the lobes:

- The left lung is divided into the superior and inferior lobe by an oblique fissure.
- The right lung is divided into the superior, middle, and inferior lobe by an oblique and a horizontal fissure.

The lobes are further divided into the segments. Each lung consists of 10 segments.

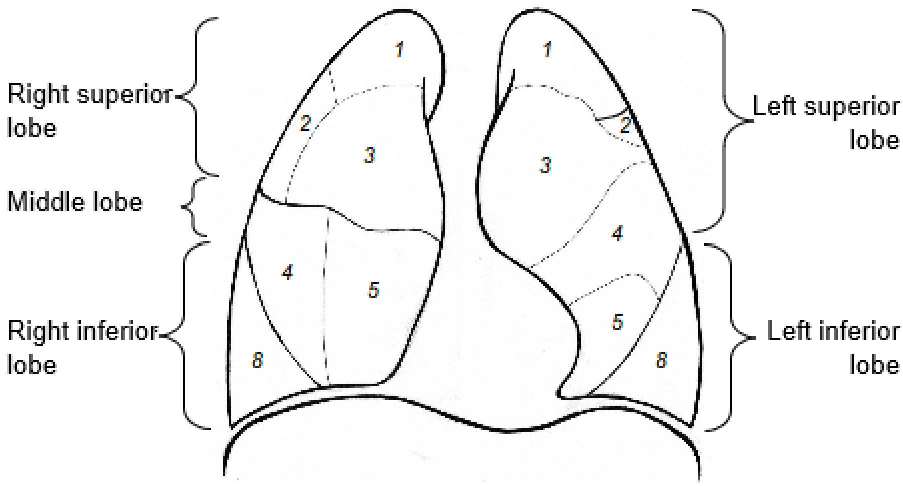



***Figure 226: Lung segmentation. Anterior view.***

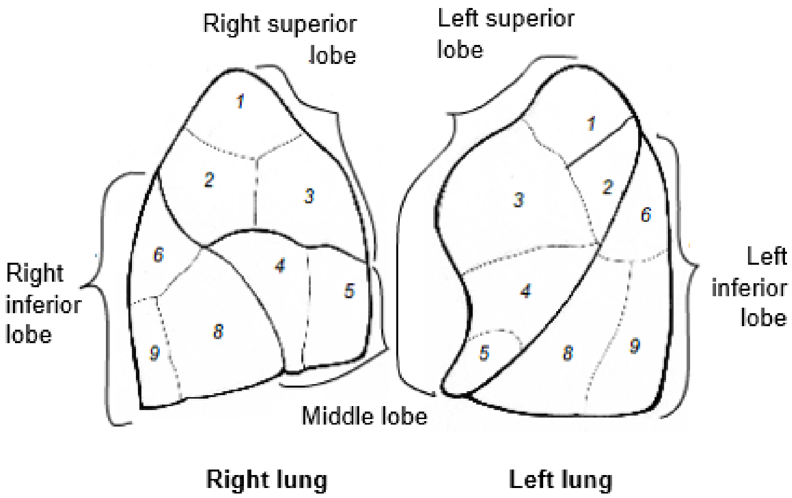



***Figure 227: Lung segmentation. Lateral view.***

On the medial surface of each lung there is a hilum through which passes the root of lung, containing the neurovascular and airway structures entering or leaving the lung parenchyma: the main bronchus, the pulmonary artery, two pulmonary veins, bronchial vessels, lymph vessels and nodes, and pulmonary autonomic plexus.

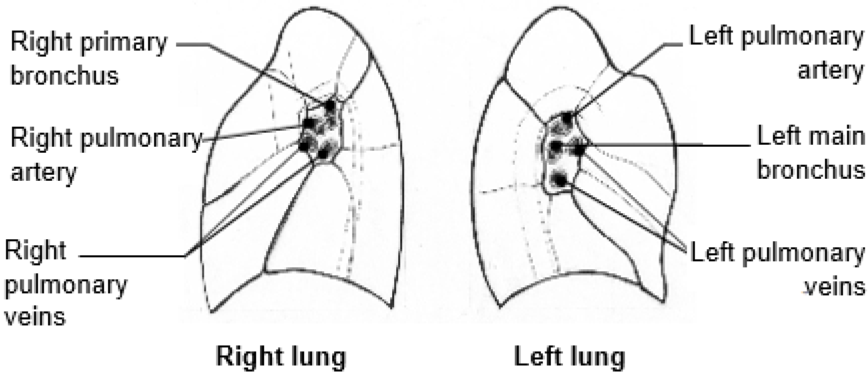



***Figure 228: Medial surface of lung with the hilum of lung.***

Inside the lung, tracheobronchial tree finally branches into the bronchiole, which do not contain the cartilage in their wall. The bronchioles finally divide into the alveolar sacs with numerous alveoli – the balloon-like vesicles surrounded by the capillary network where the gas exchange takes place.

The pulmonary arteries carrying the oxygen-depleted blood closely follow the course of bronchial tree, and pulmonary arteriole can be found in the centre of the alveolar sac. The pulmonary venules carrying the oxygenated blood lie at the periphery of the alveolar sac, and the pulmonary veins do not follow the tracheobronchial tree closely, but lie close to the border between the two pulmonary segments.

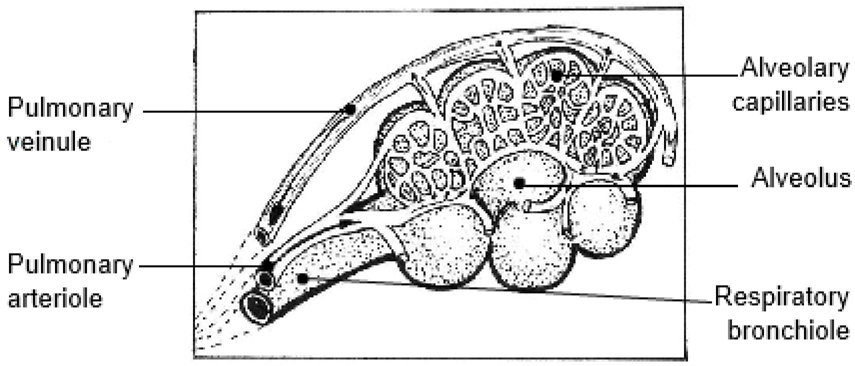



***Figure 229: Gas exchange in the alveolar sac.***

## 2 - Pleura and pleural cavity

The pleura is a double-layered serous membrane that covers each lung and lines the walls of thoracic cavity.

- The visceral pleura is attached to the surface of the lung, extending also into the fissures.
- The parietal pleura lines the thoracic wall. It is attached to the ribs and intercostal spaces laterally, to the thoracic surface of the diaphragm inferiorly, and bounds the lateral aspect of the mediastinum.

The two layers of pleura are reflected one into the other on the medial surface of the lung, around the hilum, extending inferiorly as the pulmonary ligament.

The space between the visceral and parietal pleura is called the pleural cavity. It contains a small amount of serous fluid and allows the lung to expand and contract freely. Each lung is surrounded by its own pleura enclosing the pleural cavity – there is no connection between the left and right pleural cavities. Under normal circumstances, the visceral and parietal pleura are in contact with each other; the space between them only appears when there is an air (pneumothorax) or excessive fluid (pleural effusion) inside the pleural cavity.

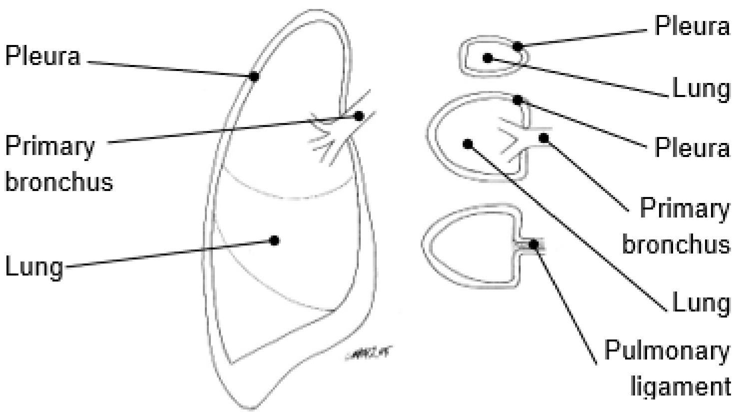



***Figure 230: The pleura.***

## 3 - Pulmonary circulation

The pulmonary circulation enables the oxygenation of the blood in the lungs, at the level of alveoli. In contrast to the systemic circulation, the pulmonary arteries transport deoxygenated blood, and the pulmonary veins transport oxygenated blood.

Non-oxygenated blood enters the right atrium through the superior and inferior vena cava. During diastole, it passes from the right atrium into the right ventricle through the tricuspid valve. During systole, the right ventricle pumps the blood into the pulmonary trunk through the pulmonary valve.

Pulmonary trunk divides into the left and the right pulmonary artery, which enter the left and right lung, respectively, as part of the root of lung.

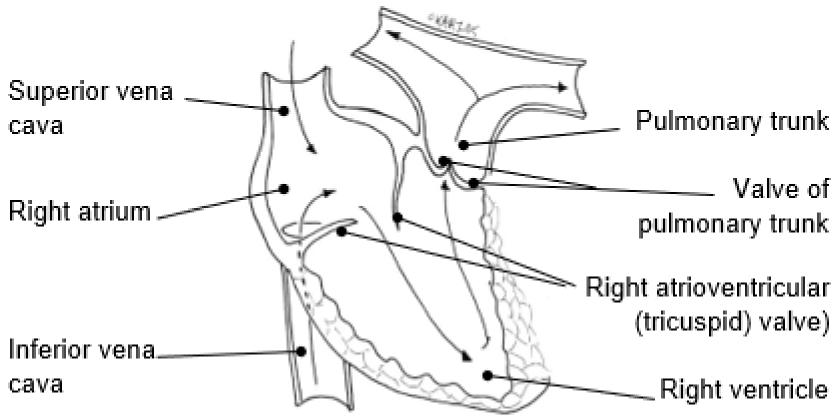



***Figure 231: The right heart chambers.***

The oxygenated blood leaves the lungs through pulmonary veins, two from each lung. The veins carry the blood to the left atrium.

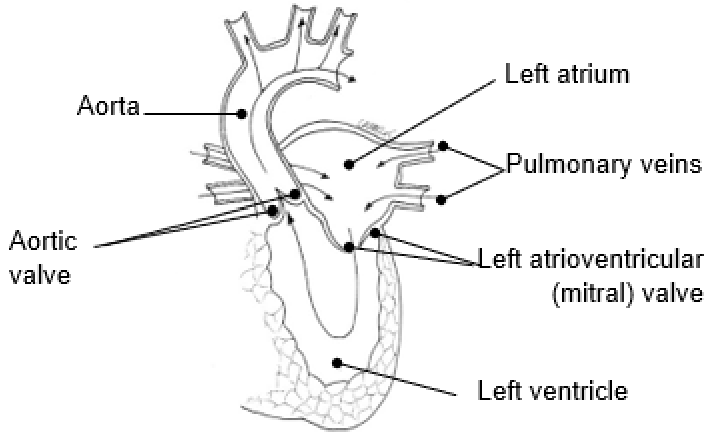



***Figure 232: The left heart chambers.***

# 4 - Mechanics of breathing

During breathing, the contraction and relaxation of muscles result in the changes of the volume of the thoracic cavity. The pressure inside the closed pleural cavity is negative in comparison to the atmospheric pressure, and lungs follow the movements of thoracic cavity:

- During inspiration, the inspiratory muscles contract, and the volume of thoracic cage and the lungs increases. This leads to the decrease in the lung pressure and the air enters the lungs.
- During expiration, the inspiratory muscles relax, and the volume of thoracic cage and the lungs decreases. This leads to the increase in the lung pressure and the air exits the lungs.

The inspiratory muscles are the external intercostal muscles and the diaphragm.

The diaphragm is a dome-shaped thin muscle with centrally placed tendon and it separates the chest cavity above from the abdominal cavity below. It is the most important muscle of respiration. Its peripheral part is muscular and is attached to the inner surface of xiphoid process, costal arch, $11^{th}$ and $12^{th}$ ribs and lumbar vertebrae. Its central tendinous part is called the central tendon.

The diaphragm is pierced by the structures that pass between the thorax and the abdomen. It has three main openings:

- Aortic hiatus is located posteriorly, at the level of vertebra T12.
- Oesophageal hiatus is also located posteriorly, at the level of vertebra T10.
- Caval foramen is located in the central tendon at the level of vertebra T8.

Actions of the diaphragm:

- its contraction flattens the dome, increasing the volume of the thoracic cavity (inspiration);
- its relaxation decreases the thoracic volume (expiration);

- when it uses the anterolateral abdominal muscles, it assists in increasing intra-abdominal pressure (defecation, vomiting, childbirth, etc.).

# Chapter 7 - Digestive system

**The objectives of this chapter are:**

1. Name the components of the digestive system.
2. Name the different sections of the small and large intestine.
3. Name the digestive glands and their location.
4. Describe the vascular supply of the digestive tract.
5. Describe the hepatic vascular system.
6. Describe the pancreatic vascular system.

## 1 - Elements of digestive system

The digestive system consists of a number of organs whose main function is the breakdown of food into small components and their absorption. It includes the digestive tube and accessory organs of digestion.

The digestive tube is about 10 meters long muscular canal that includes seven sections:

- mouth,
- pharynx,
- oesophagus,
- stomach,
- small intestine,
- large intestine.

The accessory organs of digestion are several glands that release their secretions into the lumen of the digestive tube:

- salivary glands,
- liver, gallbladder and extrahepatic bile ducts,
- pancreas.

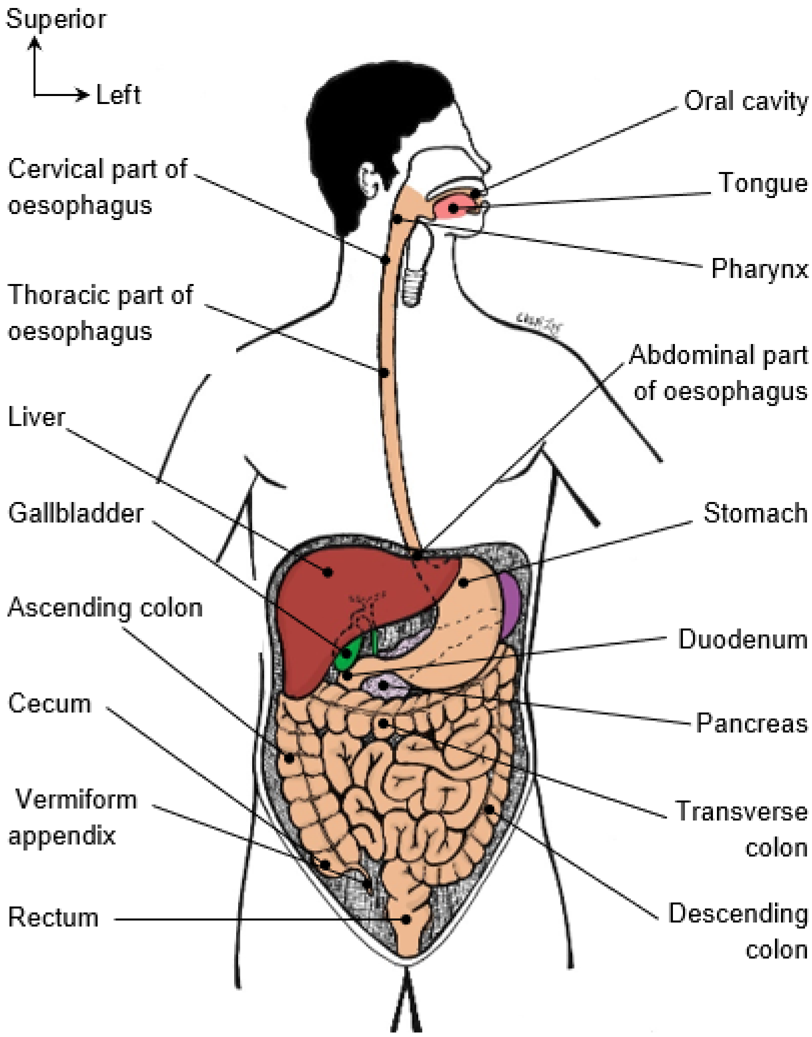



***Figure 233: The digestive tract. Anterior view.***

# 2 - Digestive tube

## 2.1 - Mouth

The mouth is the first part of the digestive tube. The opening between the lips leading to the oral cavity is called the oral opening.
The oral cavity is divided into two parts:

- oral vestibule is the area anterior to the teeth and behind the lips;
- oral cavity proper is the area behind the teeth.

The oral cavity contains the structures necessary for mastication: teeth, tongue and salivary glands.

**Teeth**

The teeth serve to cut and crush food, preparing it for swallowing and further digestion. They also participate in the production of sounds and word articulation.

Deciduous dentition consists of 20 teeth, called deciduous teeth or milk teeth. They begin erupting at the age of about six months and are usually fully erupted by the end of the second year of life.

Adult dentition consists of 32 permanent teeth, 16 in each jaw:

- incisors (4), which cut,
- canines (2), which crack,
- premolars (4), which grind,
- molars (6), which grind.

They start erupting at the age of six, subsequently replacing the deciduous teeth. The last tooth to erupt is the third molar, also named the wisdom tooth, usually erupting between 17 and 30 years of age.

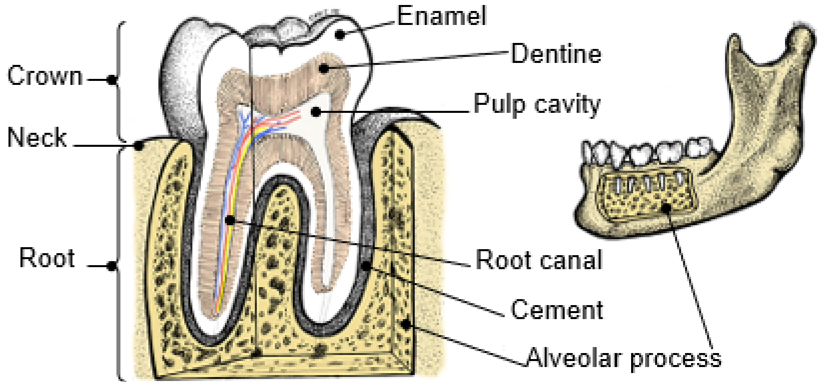



***Figure 234: Frontal section of the tooth in its dental alveolus.***

Currently, there is a universal tooth numbering system in use. The four half arches of teeth are numbered 1 to 4: arch 1 is the right upper arch, then clockwise follow the arches 2 (the left upper arch), 3 (the left lower arch) and 4 (the right lower arch).

The teeth in each arch are numbered from the midline: the first incisor is number 1 and so on until the third molar which is number 8. In deciduous teeth, the numbering follows the same principle.

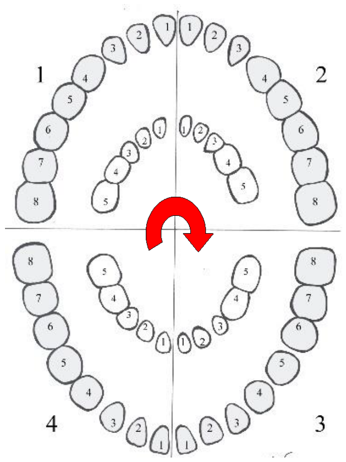



***Figure 235: Numbering system for teeth.***


*Figure 236: Panoramic radiography captures all the teeth in a single image.*

**Tongue**

The tongue is a muscular organ that facilitates the movement of food during mastication (chewing) and assists in swallowing. It is also used for tasting and articulating speech.

The tongue consists of striated muscle tissue and is covered with mucosa. It is divided into the right and left halves by a median fibrous septum.

The anterior part of the tongue is called the apex, the middle part is called the body, and the posterior part is called the root. The upper surface of the tongue is called the dorsum. A shallow groove that runs forward in a shape of V is called the terminal sulcus and separates the body from the root. It is lined by circumvallate papillae.

## 2.2 - Pharynx

The pharynx is a junction of the respiratory and the digestive system. It is located behind the nasal cavity, mouth and larynx and can be divided into nasopharynx, oropharynx, and laryngopharynx. The pharynx is shaped like a funnel, with its wider upper end attached to the occipital bone of the skull and its narrow lower end continuing into the oesophagus at the level of vertebra C6.

## 2.3 - Oesophagus

The oesophagus extends from the pharynx to the stomach. It is about 25 cm long and has a diameter of 2-3 cm. It lies in front of the spine and has three sections:

- the cervical part extends from the level of vertebra C6 to the level of vertebra T1 where it crosses the upper thoracic aperture,
- the thoracic part extends from the level of vertebra T1 to the level of vertebra T10 where it crosses the diaphragm,
- the abdominal part is short, it curves anteriorly to the left and continues into the stomach at the level of vertebra T11.

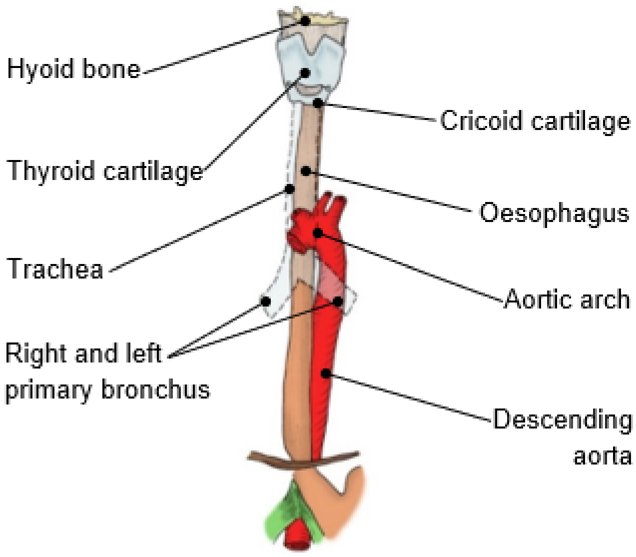



***Figure 237: Topographic relations between the oesophagus, larynx, trachea and aorta. Anterior view.***

The oesophagus crosses the diaphragm through a muscular opening called the oesophageal hiatus. A dehiscence of this orifice leads to a hiatal hernia.

The vagus nerves form a plexus around the lower part of the oesophagus – the posterior and anterior vagal trunks which cross the oesophageal hiatus along with the oesophagus.

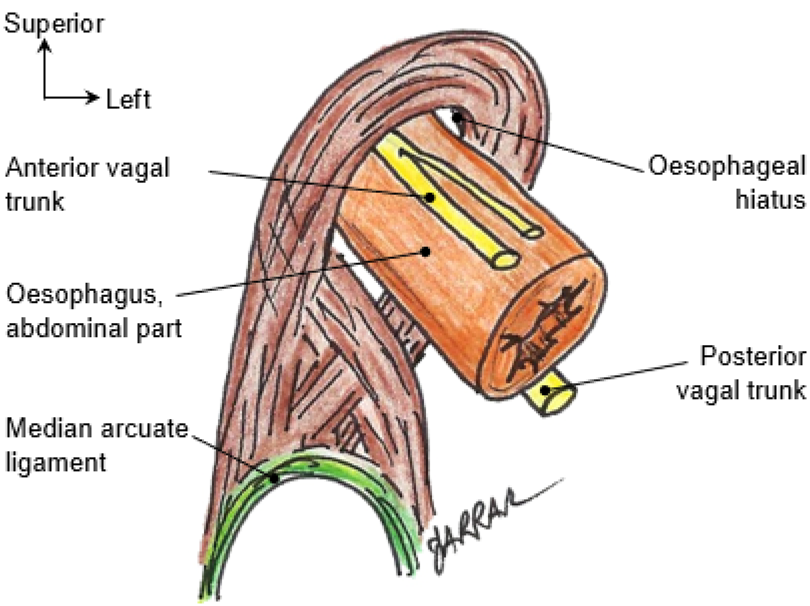



***Figure 238: The oesophageal hiatus. Anterior view.***

## 2.4 - Stomach

The stomach is the most dilated part of the digestive tube. It is roughly J-shaped and lies in the upper part of the abdominal cavity. It temporarily stores food. Its muscular contractions thoroughly mix the food with the gastric acid and the digestive enzymes, produced by the stomach glands.

The stomach has two openings (cardiac orifice and pyloric orifice), two curvatures (greater curvature and lesser curvature), and two walls (anterior wall and posterior wall).

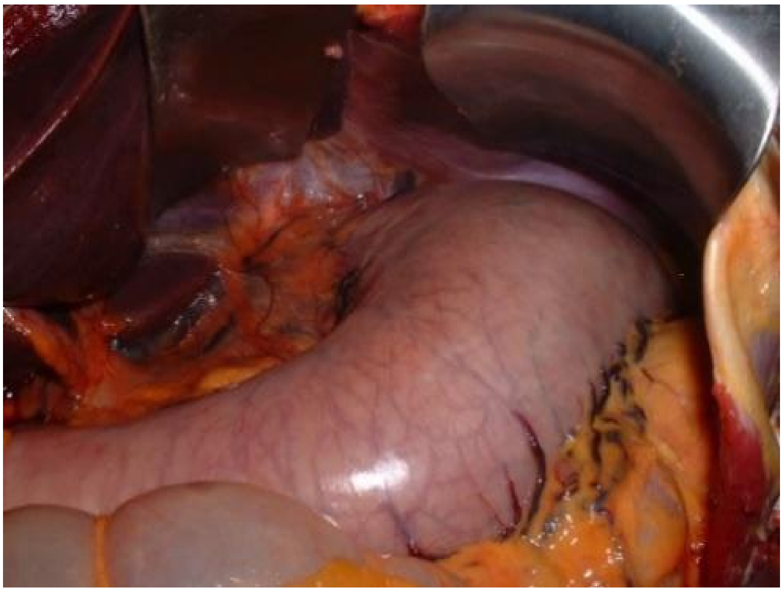


***Figure 239: View of the stomach during the operation.***

The stomach is divided into four parts:

- Cardia is the first part and connects the stomach to the oesophagus.
- Fundus of the stomach is the dome-shaped upper part of the stomach.
- Body of the stomach is the main, central part of the stomach.
- Pyloric part is the final part and connects the stomach to the duodenum. It is formed by pyloric antrum, pyloric canal, and pylorus. Pyloric sphincter surrounds the pyloric orifice at the junction of the stomach with the duodenum.

The stomach can distend if the duodenum is obstructed (stenosing duodenal ulcer, hypertrophic pyloric stenosis).

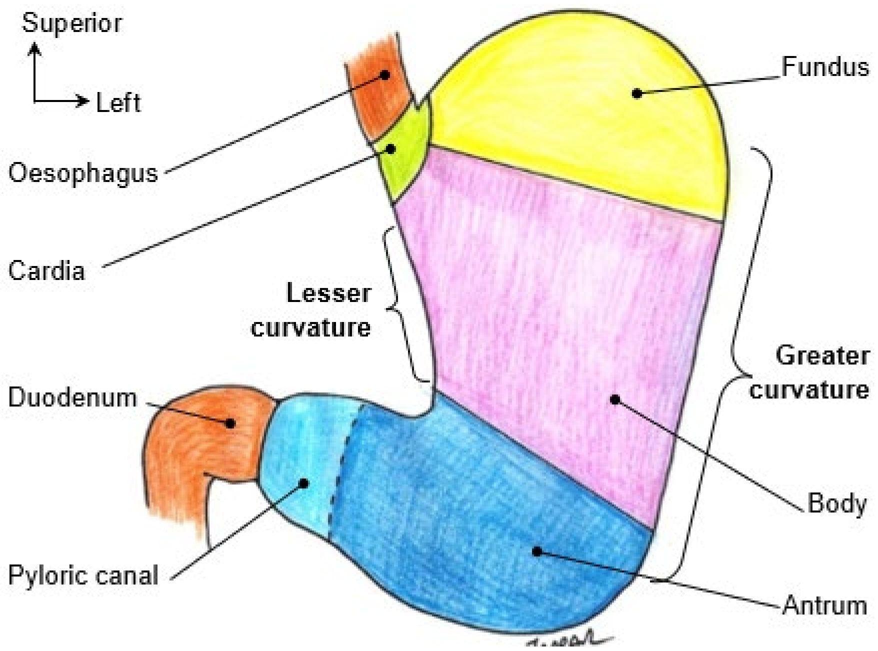



***Figure 240: Parts of the stomach. Anterior view.***

## 2.5 - Small intestine

The small intestine extends from the pylorus of the stomach to the ileocecal junction. It is divided into three parts:

- duodenum,
- jejunum,
- ileum.

**Duodenum**

The duodenum is the first section of the small intestine. It is about 30 cm long and 4-6 cm wide tube in the form of letter C which frames the pancreatic head. According to the position and course, 4 parts of duodenum are distinguished: the superior part, descending part, horizontal part, and ascending part. The pancreatic duct and common bile duct enter the descending part of the duodenum. The majority of the duodenum (except for the beginning and final part) has a fixed position, behind the parietal peritoneum, anchored to the posterior abdominal wall.

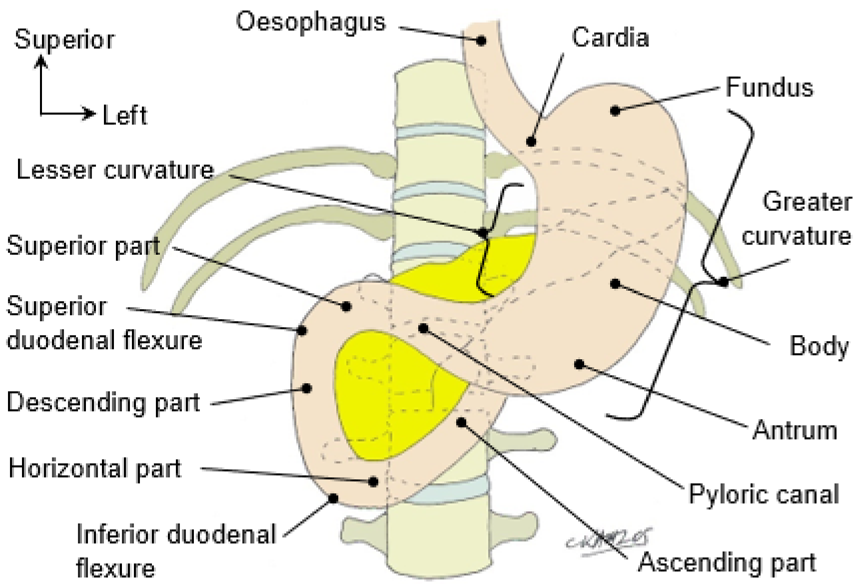



***Figure 241: The stomach and the duodenum. Anterior view.***

### Jejunum and ileum

The jejunum and ileum are movable parts of the small intestine where the products of digestion are absorbed into the bloodstream.

- **Jejunum** begins at the duodenojejunal flexure. It is slightly shorter than ileum and lies mainly in the left upper quadrant of the abdomen. It has a wider lumen and a thicker wall than the ileum and is deep red in colour due to many vessels.
- **Ileum** is the longest part of the small intestine and lies mainly in the right lower quadrant of the abdomen. Small clusters of lymphatic tissue called Peyer's patches that can be found in

the wall of the small intestine are more numerous in the ileum, especially in its distal part.

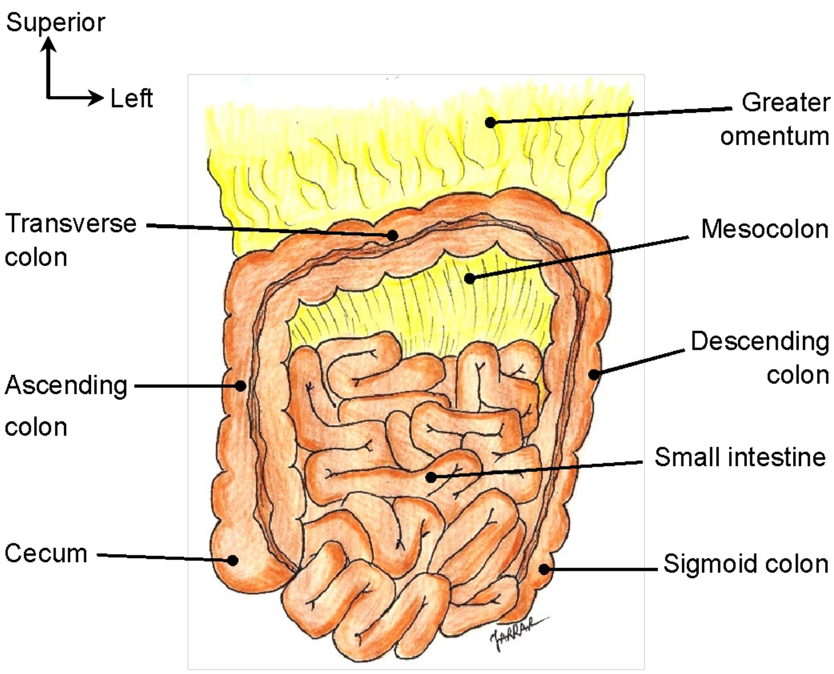



***Figure 242: Arrangement of the jejunum and the ileum. Anterior view.***

## 2.6 - Large intestine

The large intestine extends from the ileocecal junction to the anus. It is about 1.5 meters long and is divided into four parts:

- cecum with the attached appendix
- colon, which is further divided into ascending colon, transverse colon, descending colon, and sigmoid colon;
- rectum;
- anal canal.

In the large intestine, water and electrolytes are absorbed into the blood stream, leaving only the indigestible matter inside the lumen of digestive tube.

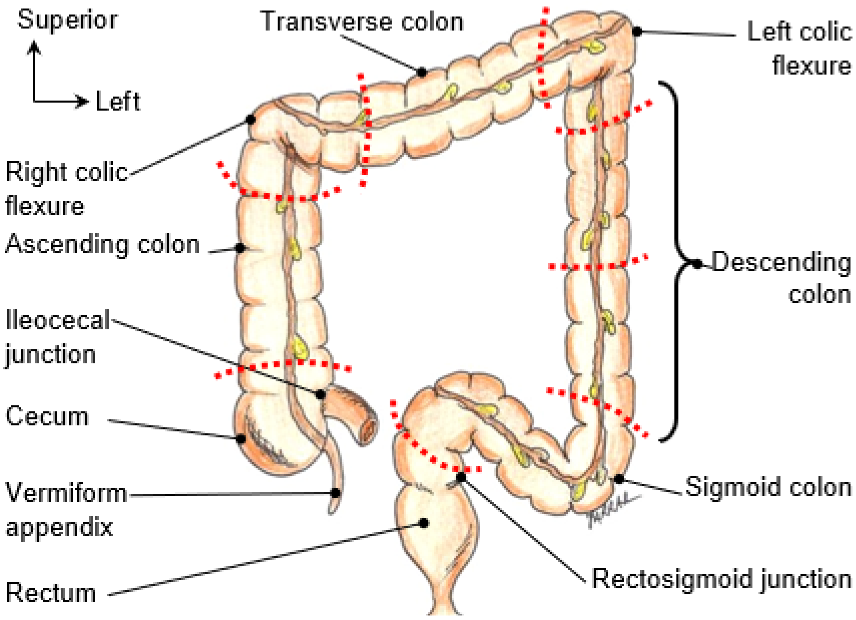



***Figure 243: Arrangement and different segments of the large intestine. Anterior view***

**Cecum** and **appendix** lie in the right iliac region. Cecum is joined to the end of the ileum via the ileocecal valve. It continues upwards as the **ascending colon** until it reaches the liver, where the colon makes the right colic flexure and then continues across the abdominal cavity to the left as the **transverse colon**. When it reaches the spleen, it makes the left colic flexure and continues downwards as the **descending colon**. The final part of the colon is the S-shaped **sigmoid colon**, which enters the pelvis and becomes **rectum** at the level of vertebra S3. The lower part of the rectum is dilated into the rectal ampulla, which serves as the reservoir for faeces storage. The large intestine then narrows into the **anal canal** which ends with the aperture at the terminal end of the digestive tube, called the anus.

The final segment of the digestive tube is equipped with two sphincters. The internal anal sphincter is part of the anal wall and consists of smooth muscle tissue. The external anal sphincter is one of the perineal muscles and consists of striated muscle tissue, enabling the voluntary defecation.

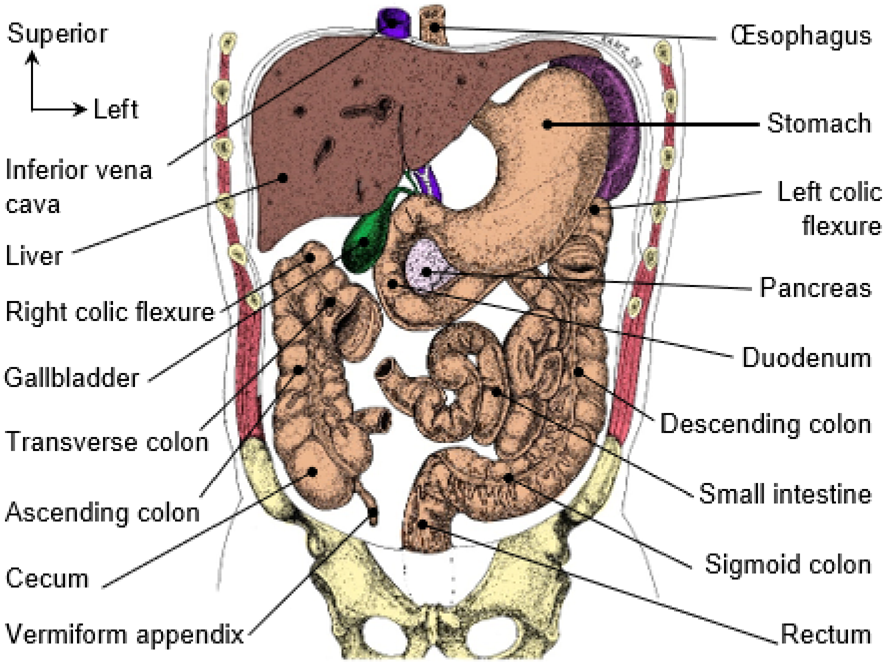



***Figure 244: The digestive tract. Anterior view.***

# 3 - Accessory organs of digestion

## 3.1 - Salivary glands

The salivary glands produce and secrete saliva into the oral cavity. Daily production of saliva is approximately 1.5 litres.

Minor salivary glands are located within the submucosa of the buccal, labial, and lingual mucosa, the soft and the hard palate, and the floor of the mouth.

The major salivary glands are 3 paired glands: the parotid, submandibular and sublingual gland.

**The parotid gland** is the largest salivary gland. It is located in front of the ear, wrapped around the ramus of mandible. It is separated into the superficial and deep lobes by the facial nerve which passes through the gland, dividing into the branches. The parotid duct runs horizontally over the surface of the masseter muscle, crosses the buccinator muscle and opens into the oral vestibule, forming the palpable papilla adjacent to the upper second molar.

**The submandibular gland** lies posterior-inferior to the body of the mandible, wrapping around the posterior border of the mylohyoid muscle which divides the gland into the superficial and deep part. The submandibular duct opens into the oral cavity under the tongue, forming a sublingual caruncle lateral to the lingual frenulum.

**The sublingual gland** is the smallest of the major salivary glands. It is located in the floor of the mouth, within its mucosa (within the sublingual fold) near the lingual frenulum. Numerous sublingual ducts (8 to 20) open into the oral cavity along the margin of the sublingual fold.

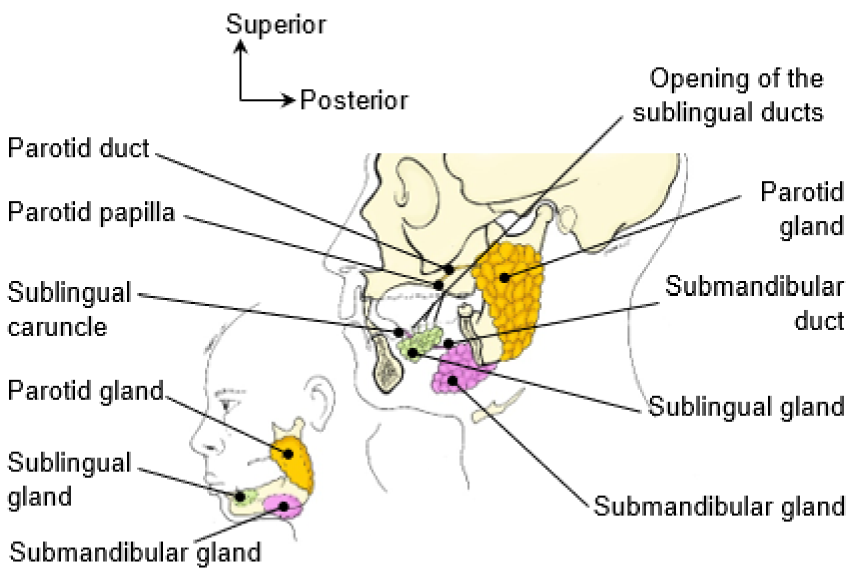



***Figure 245: The salivary glands.***

## 3.2 - Liver

The liver is the largest gland in the human body, weighing approximately 1.5-2 kilograms. It occupies the upper right quadrant of the abdominal cavity, lying just below the diaphragm and behind the right costal arch, extending to the left into the epigastric and also the left hypochondriac region.

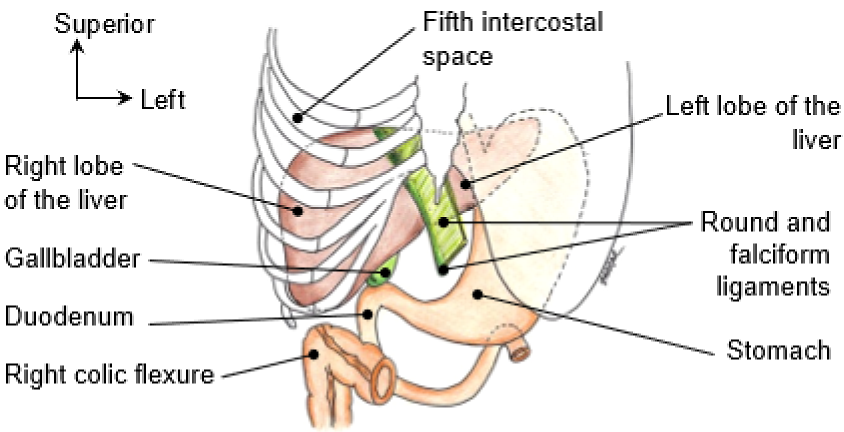



***Figure 246: Location of the liver.***

The liver contributes to the maintenance of homeostasis and has several essential functions, among which are:

- detoxification of the toxins in the food and of waste products of metabolism such as nitrogenous waste products from protein metabolism (ammonium, urea), etc.
- protein synthesis (coagulation factors);
- bile production;
- nutrient storage.

All the venous blood from the abdominal organs of the gastrointestinal system and from the spleen is collected by portal vein and carried into the liver where it is filtered prior to entering the inferior vena cava via the hepatic veins.

**Surfaces and lobes of liver**

The liver is a soft, dark reddish, wedge-shaped organ with two main surfaces – the diaphragmatic and visceral surface one.

**Diaphragmatic surface** is convex and adjacent to the inferior surface of the diaphragm.

**Visceral surface** is concave and faces posteriorly and inferiorly. It is in relation with several abdominal organs: gallbladder, abdominal part of the oesophagus, minor curvature of the stomach, superior part of the duodenum, right colic flexure, right kidney, and right suprarenal gland. On this surface lies the porta hepatis through which pass the portal vein, proper hepatic artery, common hepatic duct, lymphatic vessels, and nerves. The surface is divided into four lobes: the right lobe, quadrate lobe, caudate lobe, and left lobe.

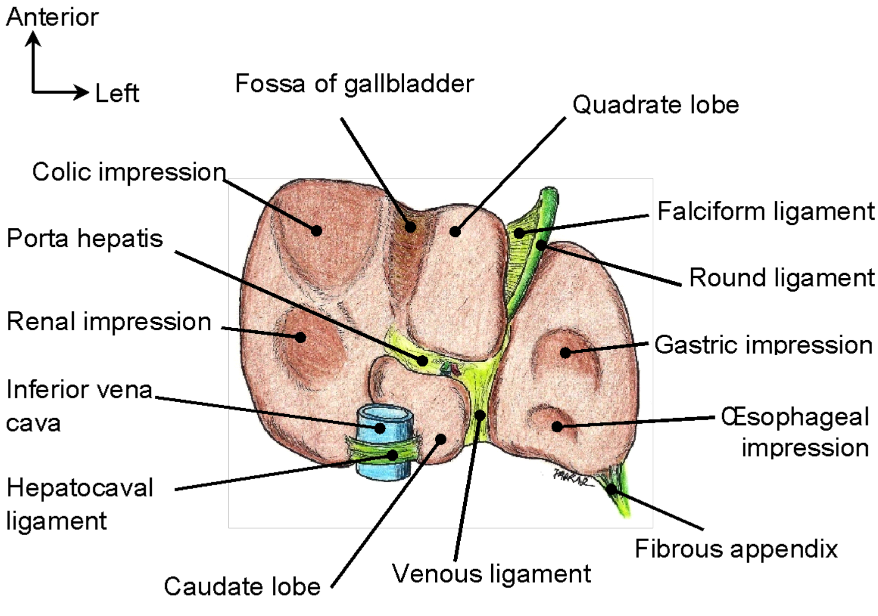



***Figure 247: Visceral surface of the liver.***

**Segmentation of liver**

Functionally, the liver can be divided into 8 independent functional segments based on the position of the veins. The 3 hepatic veins represent the 3 vertical planes, separating the liver in 4 sections. A horizontal plane called the portal plane lies at the level where the portal vein bifurcates into 2 horizontally running branches; the plane divides each liver section into superior and inferior segments.

Each segment has its own vascular inflow, outflow and biliary drainage. In the centre of the segment there is a branch of portal vein, hepatic artery, and bile duct. On the periphery of the segment there is a hepatic vein.

The liver segments are named by numbers from 1 to 8. Segment 1 (I) is the caudate lobe; the segments 2 (II) to 8 (VIII) then follow numbered in a clockwise fashion, starting superiorly in the left hepatic lobe. The liver segmentation is essential for surgical procedures.

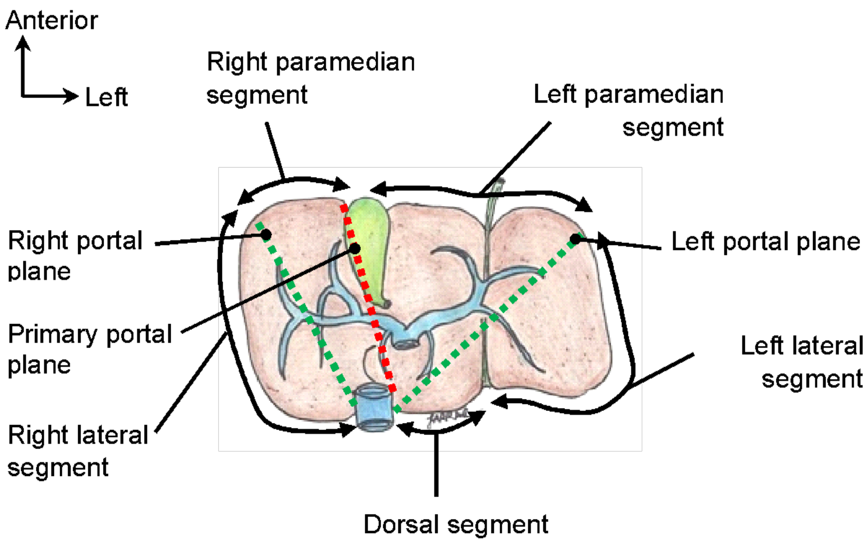



***Figure 248: Planes and liver segments. Inferior view.***

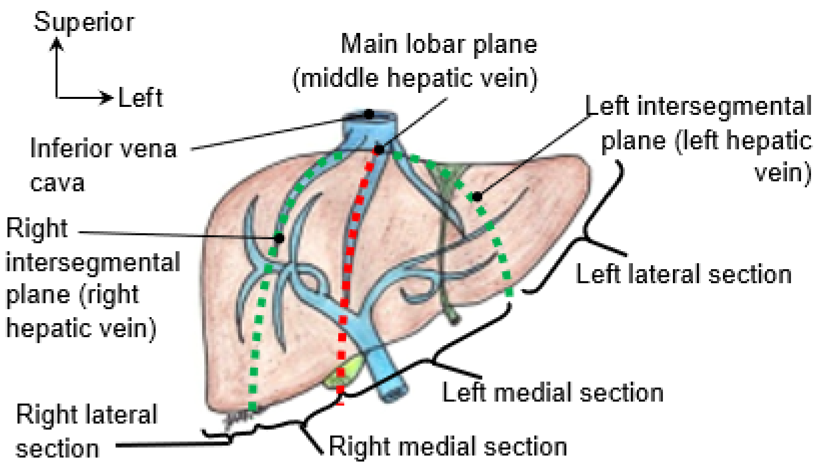



***Figure 249: Sections of the liver and boundary planes between them. Anterior view.***

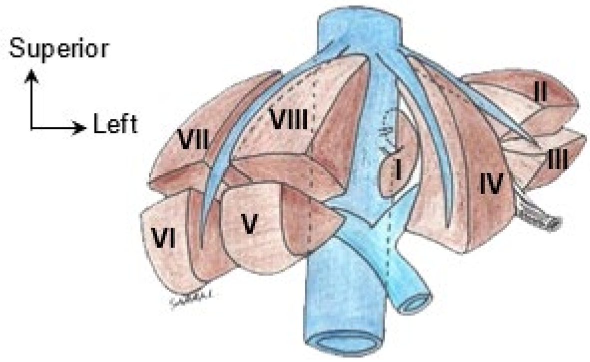



***Figure 250: Segments of the liver. Anterior view.***

## 3.3 - Extrahepatic bile ducts and gallbladder

The bile is synthesised by liver cells called the hepatocytes and secreted into thin tubes in between the hepatocytes called the bile canaliculi. Inside the liver, canaliculi empty into a series of progressively larger ducts. Finally, the left and right hepatic ducts arising from the left and right liver lobe join to form the common hepatic duct.

**Common hepatic duct** is about 4 cm long. It exits the liver through the porta hepatis and joins the cystic duct from the gallbladder to form the bile duct.

**Bile duct** is about 8 cm long. It runs within the free margin of the lesser omentum towards the superior part of the duodenum, then passes behind the superior part of the duodenum and behind the head of the pancreas, ending in the descending part of the duodenum. Just before crossing the wall of the duodenum it usually joins with the pancreatic duct to form the hepatopancreatic ampulla.

**Gallbladder** is about 10 cm long pear-shaped organ that lies on the visceral surface of the liver, in the gallbladder fossa. It receives bile produced in the liver via the common hepatic duct and cystic duct and stores it. During digestion, it releases the bile into the duodenum via the cystic duct and the bile duct.

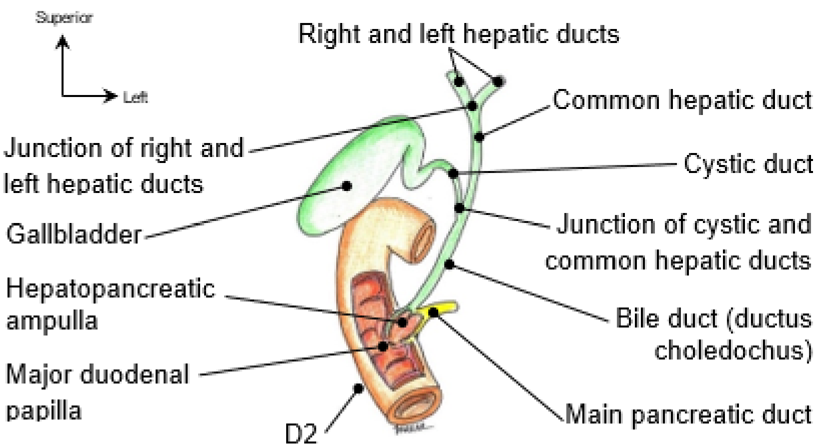



***Figure 251: The extrahepatic bile ducts.***

## 3.4 - Pancreas

The pancreas is a gland with two main functions: its exocrine function is secretion of pancreatic juice with enzymes necessary for food digestion, and its endocrine function is secretion of hormones insulin and glucagon necessary for blood sugar regulation.

It is an elongated organ which lies obliquely across the posterior abdominal wall behind the parietal peritoneum, at the level of vertebrae L1 and L2, in the epigastric and left hypochondriac region.

The pancreas is a soft and lobulated parenchymatous organ divided into the head, neck, body and tail. The head lies to the right side of the spine, in the curvature of the duodenum. The body lies behind the stomach. The tail extends towards the hilum of the spleen.

Two pancreatic ducts drain the pancreatic juice and carry it to the duodenum. The main pancreatic duct (duct of Wirsung) runs across the whole length of the pancreas. It joins with the bile duct to form the hepatopancreatic ampulla (ampulla of Vater) which opens into the descending part of the duodenum at the major duodenal papilla. A smooth muscle sphincter, called the sphincter of Oddi, regulates the secretion of pancreatic juice and bile into the duodenum and prevents reflux from the duodenum. Small gallstones can be trapped at the level of sphincter, blocking the emptying of the hepatopancreatic ampulla. The accessory pancreatic duct opens into the duodenum at the minor duodenal papilla which lies above the major one. Both ducts usually communicate.

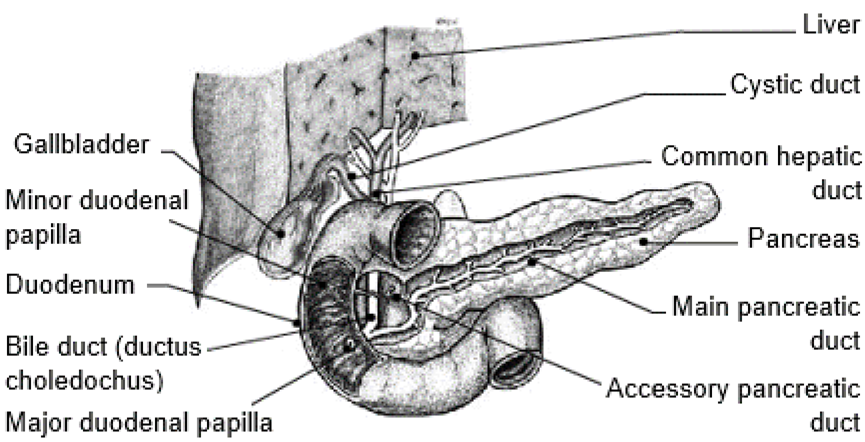



***Figure 252 Pancreas and pancreatic ducts. Anterior view.***

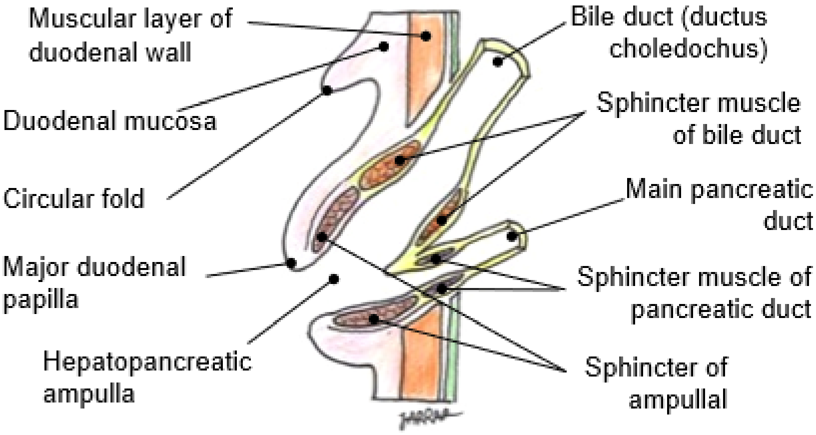



***Figure 253: Section through the hepatopancreatic ampulla showing the sphincter of hepatopancreatic ampulla.***

# 4 - Arterial supply

The abdominal part of gastrointestinal tract is supplied by three visceral branches of the abdominal aorta:

- **The coeliac trunk** arises from the abdominal aorta at the level of the vertebra T12. It is very short and has three terminal branches. The left gastric artery supplies the abdominal part of oesophagus and upper part of the stomach. The splenic artery supplies the spleen, pancreas, and stomach. The common hepatic artery supplies the liver, distal part of the stomach, proximal part of the duodenum, and pancreatic head.
- **The superior mesenteric artery** arises from the abdominal aorta at the level of vertebra L1. It supplies distal part of the duodenum, jejunum, ileum, cecum, appendix, ascending colon, right colic flexure, and the majority of the transverse colon.
- **The inferior mesenteric artery** arises from the abdominal aorta at the level of vertebra L3. It supplies the left third of the transverse colon, left colic flexure, descending colon, sigmoid colon, rectum, and the proximal part of the anal canal.

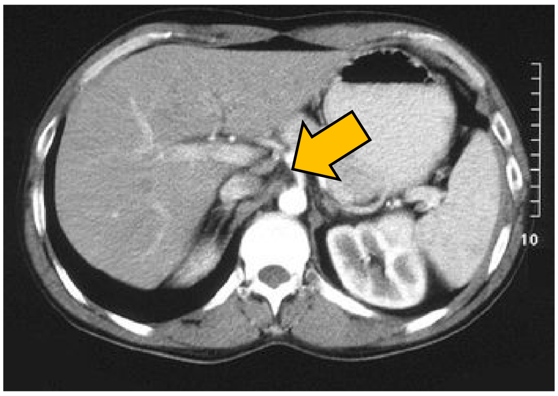


***Figure 254: CT angiography showing the origin of the superior mesenteric artery from the abdominal aorta. Cross-section through the abdomen.***

**Arterial supply of the oesophagus**

The cervical part of the oesophagus is supplied by the inferior thyroid artery. The thoracic part of the oesophagus is supplied by the oesophageal branches that arise from the thoracic aorta. The abdominal part of the oesophagus is supplied by the left gastric artery which arises from the coeliac trunk.

**Arterial supply of the stomach**

The rich blood supply to the stomach is provided by several arteries that arise from the coeliac trunk and anastomose with each other:

- The supply of the lesser curvature is formed by the left gastric artery which is a direct branch of the celiac trunk, and the right gastric artery, a branch of the common hepatic artery.
- The supply of the greater curvature is formed by the left gastroomental artery which is a branch of the splenic artery, and the right gastroomental artery which is an indirect branch of the common hepatic artery.
- Short gastric arteries from the splenic artery supply the posterior wall of the stomach.

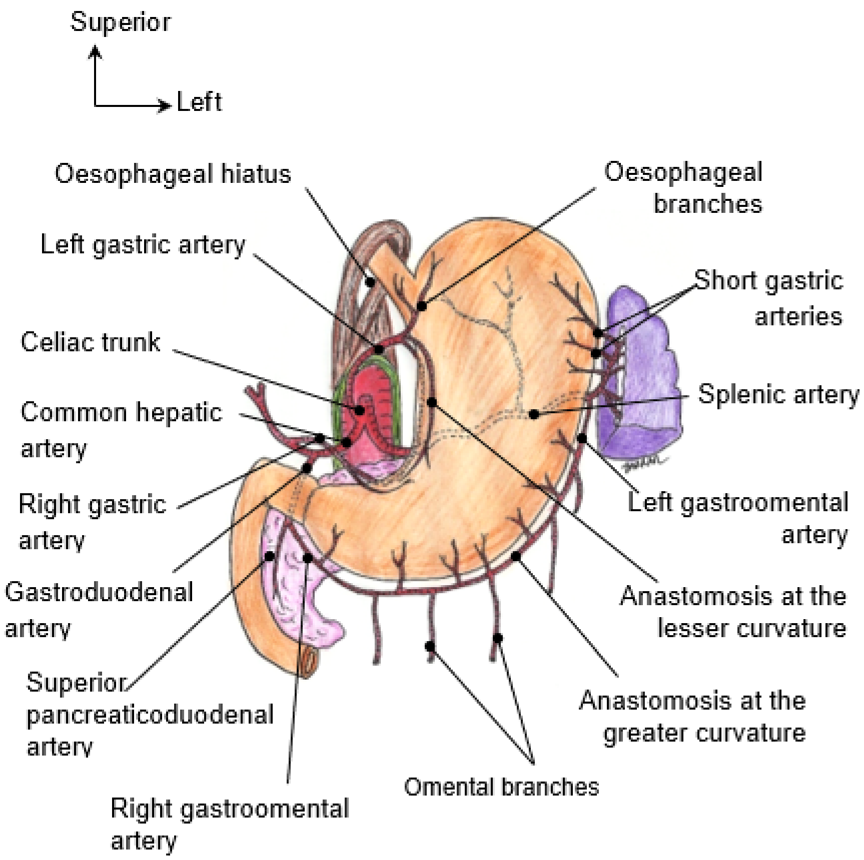



***Figure 255: Blood supply of the stomach.***

**Arterial supply of the small intestine**

The proximal part of the duodenum is supplied by branches of the common hepatic artery which arises from the coeliac trunk, while the distal part of the duodenum is supplied by a branch of the superior mesenteric artery.

Jejunum and ileum are supplied by jejunal and ileal arteries which are all branches of the superior mesenteric artery. They all arise from the left side of the superior mesenteric artery and are interconnected with rich anastomoses in the form of arcades.

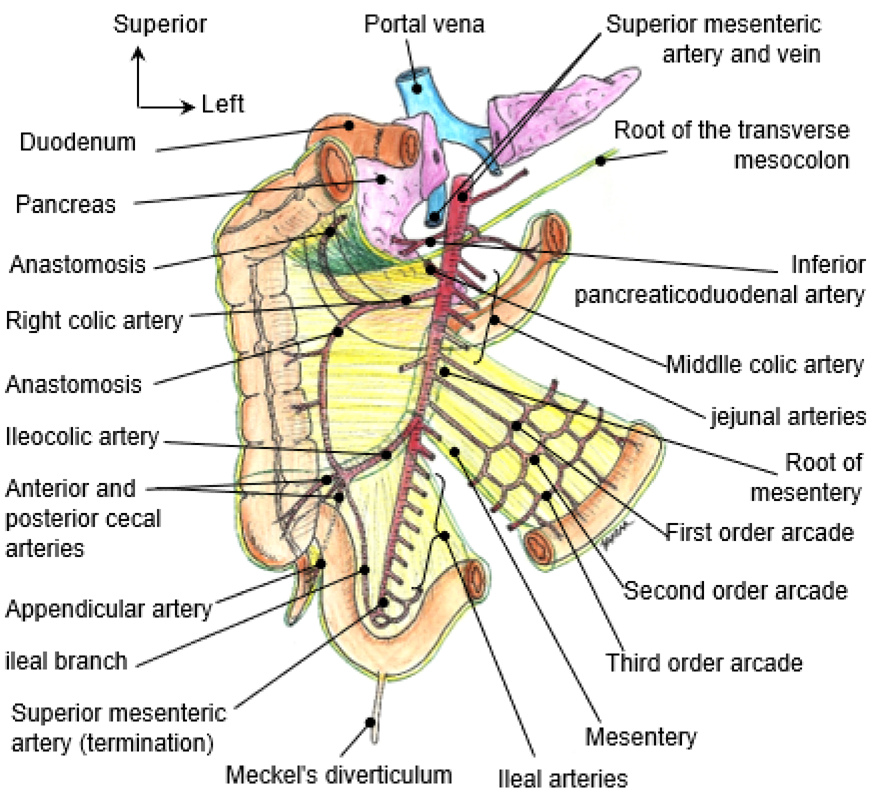



***Figure 256: The superior mesenteric artery and its branches. Anterior view.***

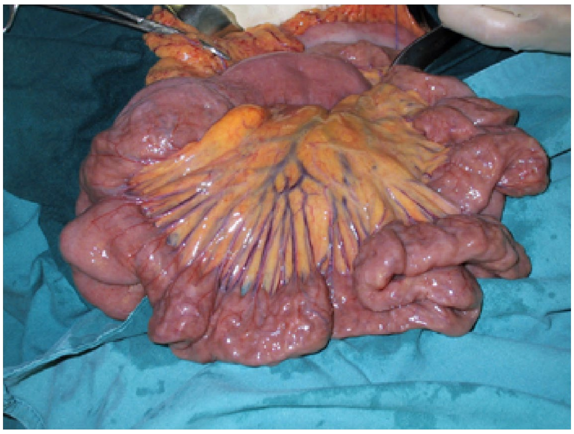


***Figure 257: The vascular arcades of the jejunum and ileum. Operative view.***

### Arterial supply of the large intestine

The cecum with the appendix, ascending colon, right colic flexure and the right 2/3 of the transverse colon are supplied by the branches that arise from the superior mesenteric artery on the right side: the ileocolic artery, right colic artery and middle colic artery.

The left third of the transverse colon, left colic flexure, descending colon, sigmoid colon, rectum, and the proximal part of the anal canal are supplied by branches of the inferior mesenteric artery: the left colic artery, sigmoid arteries, and superior rectal artery. The sigmoid arteries form the arcades.

Each artery has its own territory, which allows identification of vascular or surgical division. The arteries supplying the large intestine are interconnected by a vascular arcade called the marginal artery. The marginal artery provides an important anastomosis between the superior and inferior mesenteric arteries. In some individuals, there is an additional anastomosis called the arc of Riolan. When present, it usually connects the middle colic artery with a branch of the left colic artery.

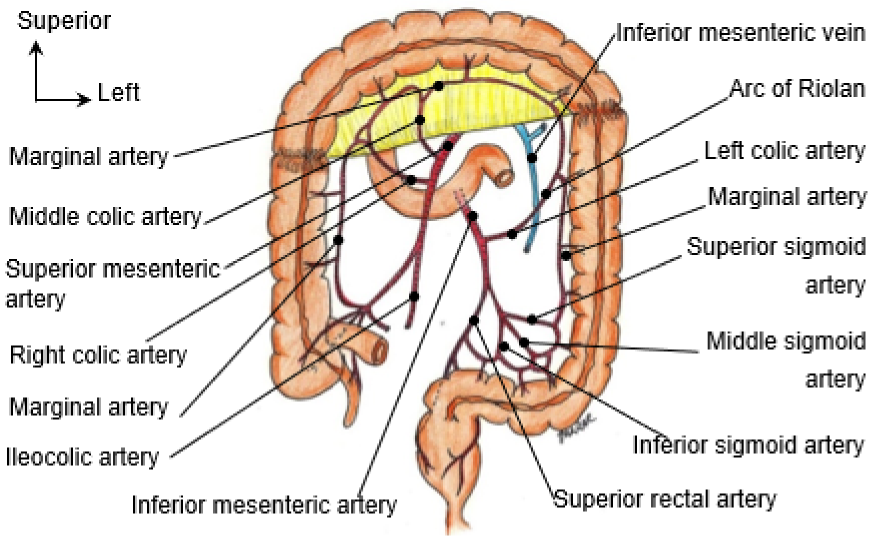



***Figure 258: Arterial supply of the large intestine. Anterior view.***

**Arterial supply of the liver and pancreas**

The liver is supplied by the proper hepatic artery, which is the branch of common hepatic artery. The proper hepatic artery also supplies the gallbladder.

The head of the pancreas is supplied by the same branches of common hepatic artery and superior mesenteric artery that also supply the duodenum. The body and tail of pancreas are supplied by branches of splenic artery.

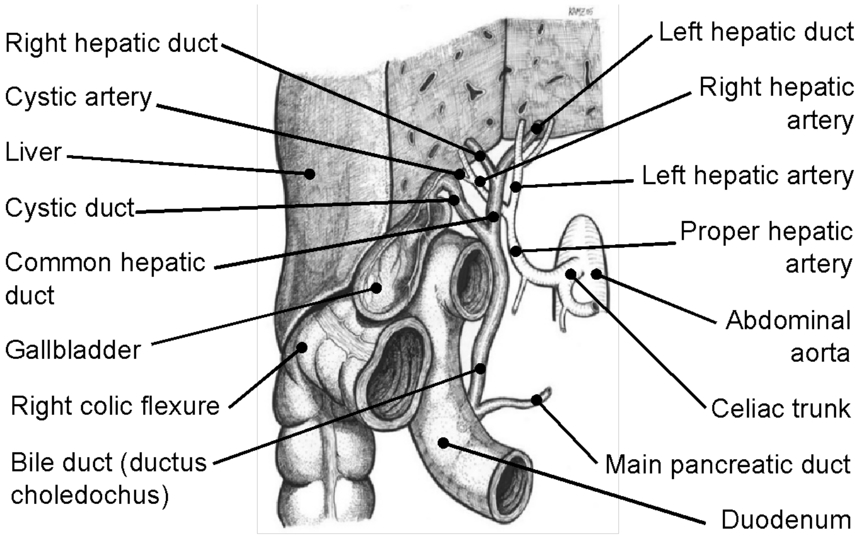



***Figure 259: The bile ducts and their blood supply. Anterior view.***

# 5 - Hepatic portal vein

The venous blood of the abdominal part of the oesophagus, stomach, intestine, pancreas, and spleen is collected by the hepatic portal vein.

The portal vein is formed by fusion of the splenic vein and superior mesenteric vein behind the head of the pancreas. The inferior mesenteric vein usually drains into the splenic vein.

The portal vein then runs towards the visceral site of the liver in the free margin of the omentum minus, accompanied by the bile duct and the proper hepatic artery.

It enters the liver through the porta hepatis and divides into the left and right branch. The blood that is delivered to the liver by the portal vein is filtered by the hepatocytes and returned to the systemic blood flow through short hepatic veins that drain into the inferior vena cava.

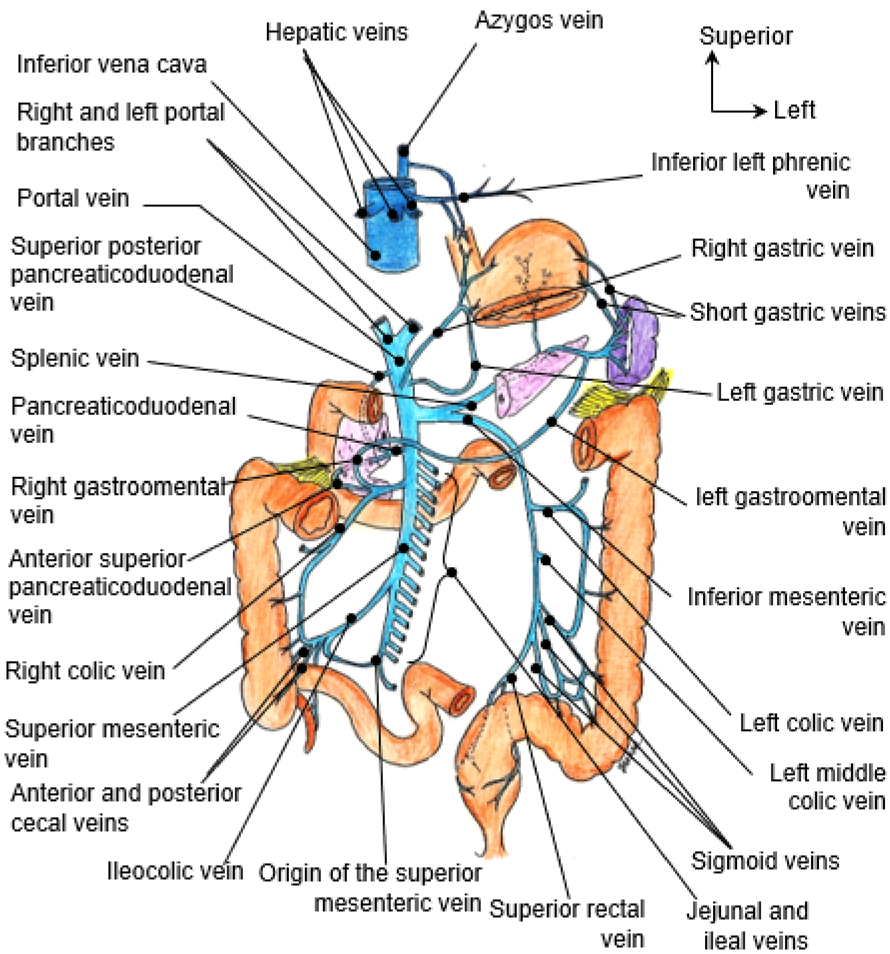



***Figure 260: Tributaries of portal vein. Anterior view.***

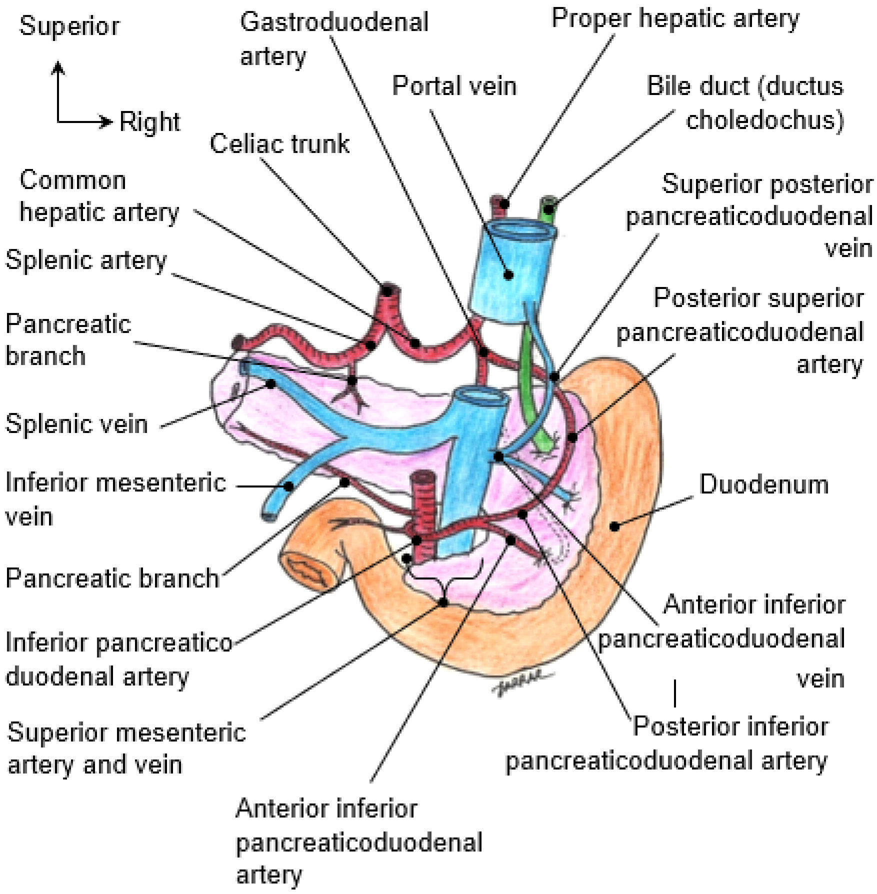



***Figure 261: Formation of the portal vein behind the pancreas. Posterior view.***

## The lymphatic vessels of the digestive tract

**The lymphatic vessels** of the colon follow the arteriovenous pedicles and are divided into five groups. They open into the lymphatic vessels of the intestine, which are involved in the formation of the thoracic duct.

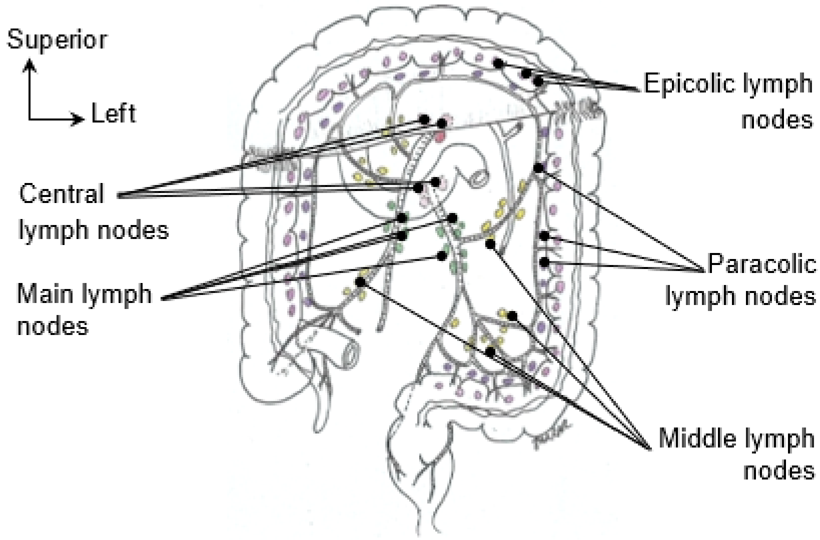



***Figure 262: Lymphatic drainage of the colon. Frontal view.***

# 6 - Peritoneum

The peritoneum is a serous membrane that covers the walls of the abdominopelvic cavity and completely or partially envelops some of the organs of the abdominopelvic cavity:

- The parietal peritoneum is the outer layer that adheres to the abdominal and pelvic walls;
- The visceral peritoneum wraps around the intraperitoneal internal organs;
- The parietal peritoneum is continuous with the visceral peritoneum and reflects from the abdominal wall to the internal organs forming the duplicatures;
- between the parietal and visceral peritoneum is a potential space called the peritoneal cavity; the cavity is filled with a small amount of serous peritoneal fluid secreted by the peritoneum; the fluid minimises the friction during the movements of the abdominal organs.

# 6.1 - Peritoneal structures

### Peritoneal ligaments

The peritoneal ligaments are double-layered folds of peritoneum that connect an abdominal organ to the abdominal wall or to other abdominal organs. The liver, for example, is connected to the diaphragm by the falciform ligament, the coronary ligament, and the right and left triangular ligaments, to the stomach by the hepatogastric ligament, and to the superior part of duodenum by the hepatoduodenal ligament.

### Mesentery

The mesentery is a peritoneal duplicature that suspends an organ from the posterior abdominal wall. Between the two layers of the peritoneum that form the mesentery lies the neurovascular bundle that supplies the organ.

The mesentery of the jejunum and ileum is simply called the **mesentery**. The mesentery of the colon is called the **mesocolon**: more specifically, the transverse mesocolon and sigmoid mesocolon. The mesentery of the vermiform appendix is called the mesoappendix.

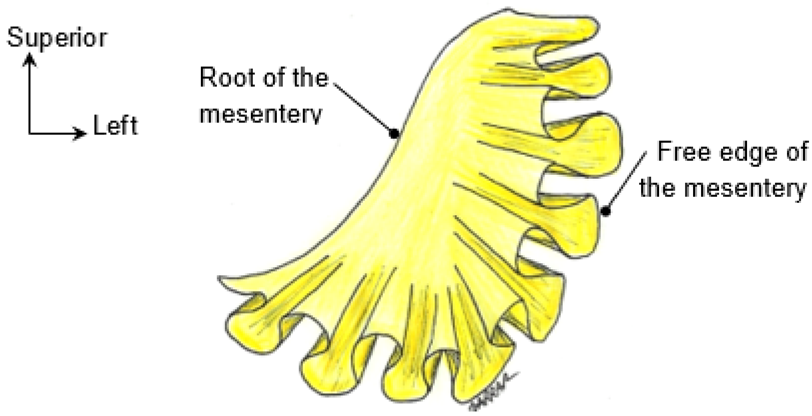



***Figure 263: The mesentery of the jejunum and ileum. Anterior view.***

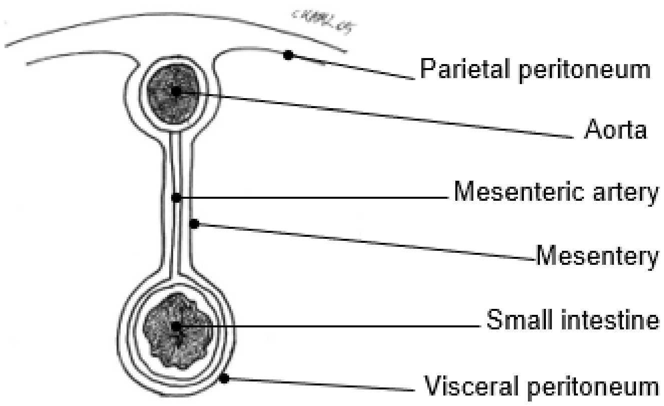



***Figure 264: A scheme of the intraperitoneal organ and the mesentery. Posterior part of the cross-section through the abdominal cavity.***

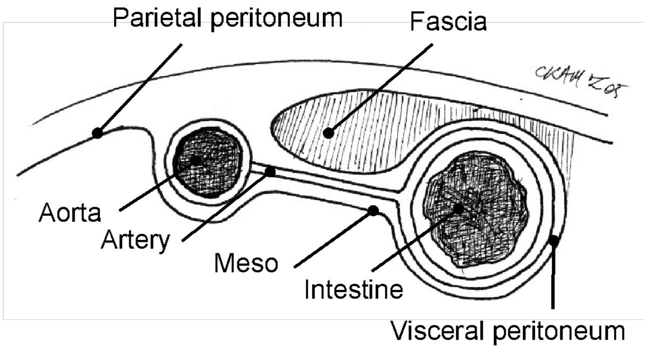



***Figure 265: A scheme of the retroperitoneal organ. Posterior part of the cross-section through the abdominal cavity.***

### Omentum

The omentum is a double-layered fold of peritoneum that extends from the stomach to adjacent organs:

- **Lesser omentum** extends from the lesser curvature of the stomach and proximal duodenum to the liver. It is formed by the hepatogastric and hepatoduodenal ligament. The latter forms the free margin of the lesser omentum and envelops the structures running towards the porta hepatis: the portal vein, proper hepatic artery, bile duct, lymphatic vessels, and nerves.

- **Greater omentum** extends from the greater curvature of the stomach. The proximal part of the greater omentum is attached to the transverse colon, forming the gastrocolic ligament. The distal part hangs freely from the transverse colon like a curtain, covering the anterior surface of the jejunum and ileum.

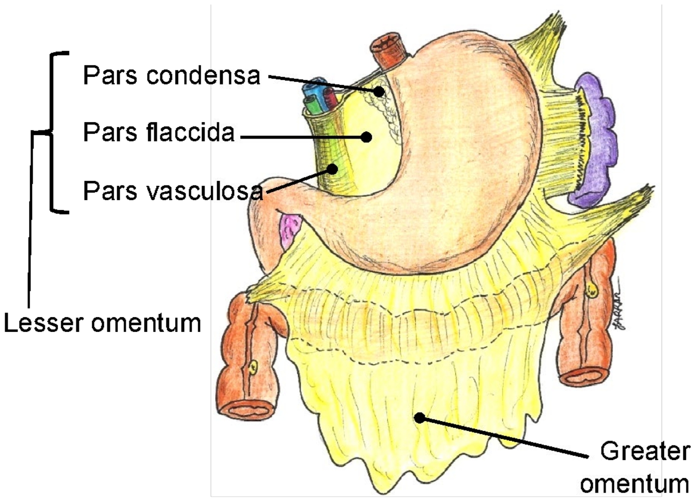



***Figure 266: Anterior view of the two omenta.***

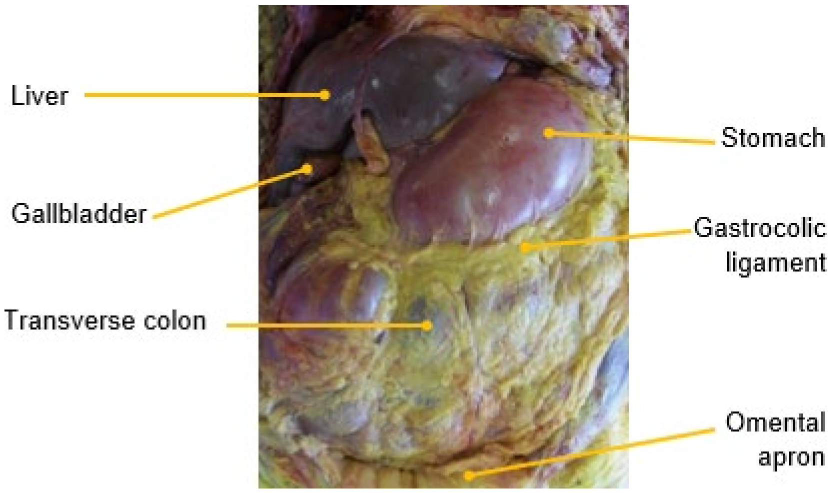



***Figure 267: Parts of greater omentum. Anterior view.***

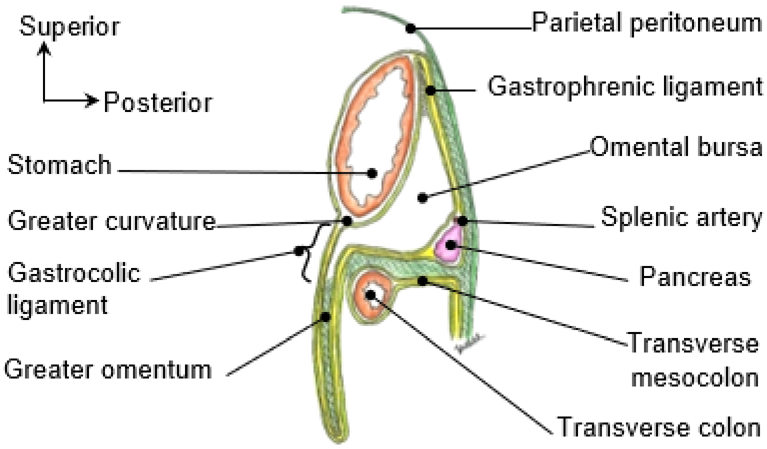



***Figure 268: Scheme of the omental bursa. Sagittal section through the abdomen, view from the left.***

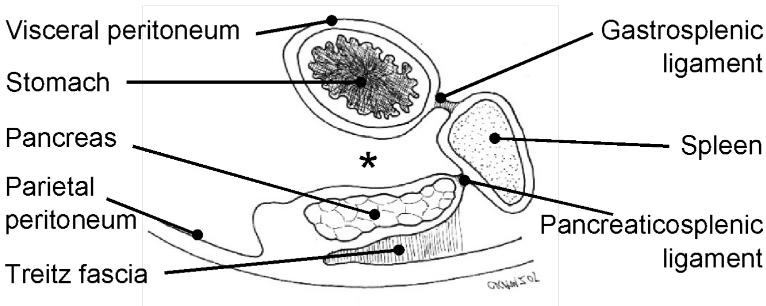



***Figure 269: Scheme of the omental bursa (*). Cross-section through the abdomen.***

## 6.2 - Peritoneal compartments

Peritoneal structures divide the peritoneal cavity into the compartments:

- transverse mesocolon divides the abdominal cavity into the supramesocolic and inframesocolic compartments; mesenterium of small intestine further divides the inframesocolic compartment into the left and right inframesocolic compartment.

- secluded part of the cavity behind the liver, stomach and lesser omentum is called the omental bursa or lesser sac; the omental bursa communicates with the main part of the abdominal cavity (also referred to as the greater sac) through the omental foramen which lies behind the hepatoduodenal ligament.

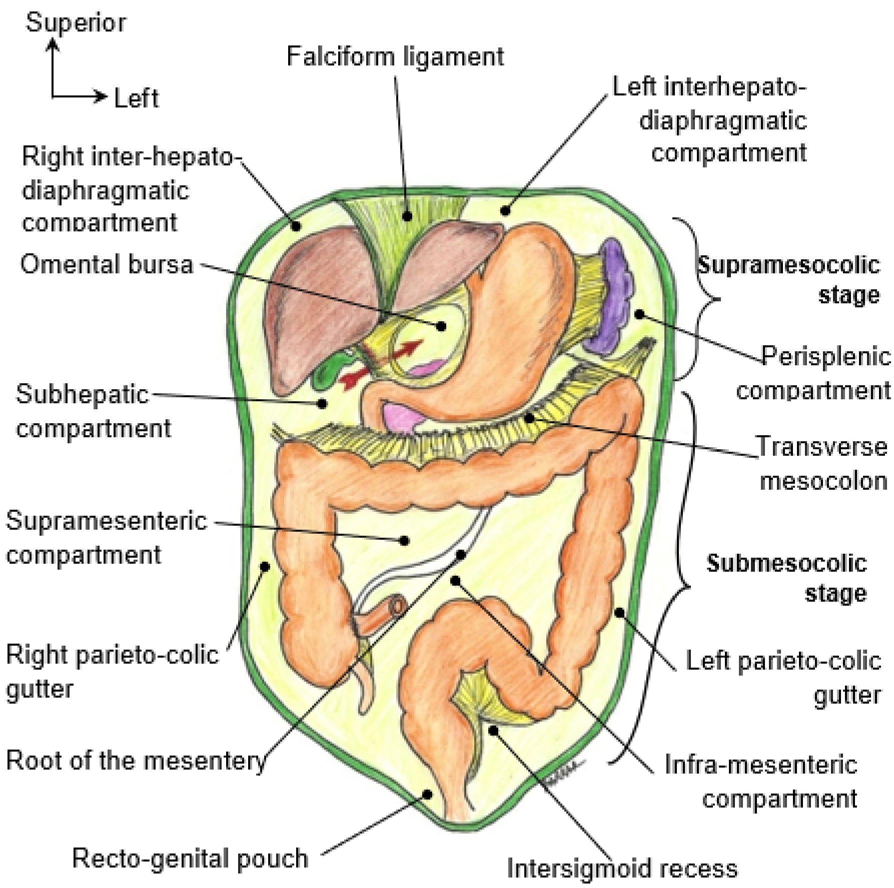



***Figure 270: The compartments of the peritoneal cavity. Anterior view.***

# Chapter 8 – Endocrine system

**The objectives of this chapter are:**

1. Name the endocrine glands.
2. Describe the hypophysis.
3. Describe the thyroid gland.
4. Describe the parathyroid glands.
5. Describe the paraganglionic or chromaffin system.
6. Describe the endocrine function of the thymus, pancreas, and gonads.

## 1 - Introduction

The endocrine system is an additional messenger system of human body, alongside the nervous system. It includes endocrine glands that release their products named hormones directly into the circulatory system. The hormones are then transported by blood to the distant organs, and the organs which have receptors for the hormone will respond to the binding of hormones on those receptors.

The major endocrine glands are the hypophysis (pituitary gland), pineal gland, thyroid gland, parathyroid glands, and suprarenal glands. Additional organs with important endocrine function are the pancreas, which is part of the digestive system, and the ovaries and testes, which are part of the genital system.

Secretion of hormones is under control of the vegetative nervous system. The organ of the nervous system controlling the endocrine glands is the hypothalamus. It connects the nervous system to the endocrine system via hypophysis. This hypothalamic-pituitary system controls all endocrine functions. Regulation of endocrine system function is organised via feedback loops.

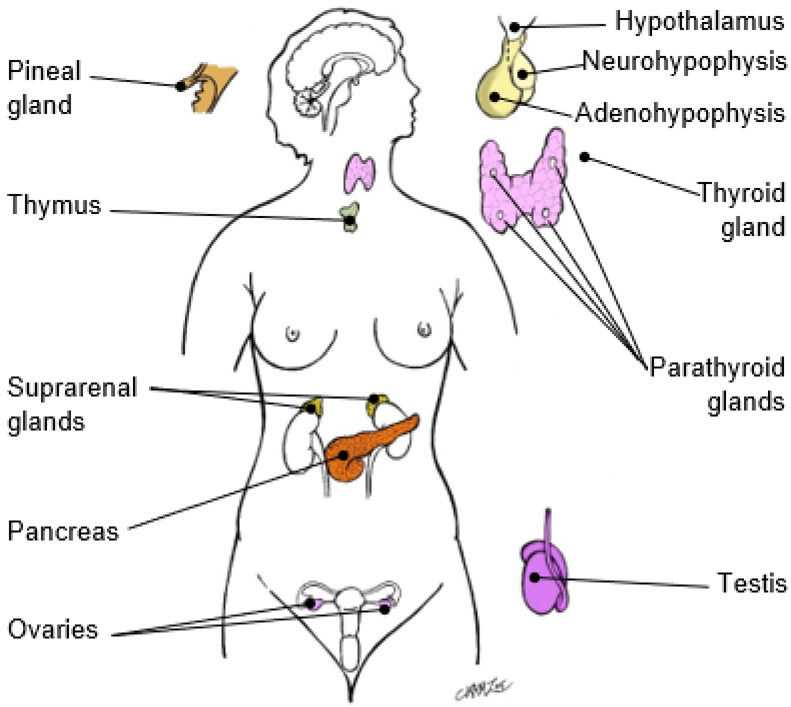



***Figure 271: The endocrine glands. Anterior view.***

## 2 - Hypothalamus

The hypothalamus is a small part of the cerebrum that plays a crucial role in endocrine system. It has a shape of a funnel that hangs below the thalamus. It forms the lower part of the lateral wall of the third ventricle. At its bottom there is the pituitary stalk. It is composed of a large number of nuclei.

## 3 - Hypophysis

The hypophysis or pituitary gland is a pea-sized neuroglandular organ attached to the underside of the hypothalamus by the pituitary stalk (*infundibulum*). It is well protected because it lies in the enclosed part of the sphenoid bone called *sella turcica*, covered by the dural fold. It is positioned just behind the optic chiasma; therefore, tumours of the hypophysis can lead to the loss of vision field.
The hypophysis consists of two parts:

- Adenohypophysis is the larger anterior part arising from the oral ectoderm. It is the glandular part, secreting several hormones that regulate the activity of other endocrine glands and promote protein synthesis (enhance the anabolism).
- Neurohypophysis is much smaller posterior part arising from the neural ectoderm. It is connected to the hypothalamus by the pituitary stalk and presents a collection of axonal projections from the hypothalamus.

The hypophysis is richly supplied with blood. The hypophyseal portal system connects the hypothalamus with the adenohypophysis and enables a quick transport between them.

## 4 - Pineal gland

The pineal gland or epiphysis is a small gland in a shape of a pine cone that projects posteriorly from the posterior end of the roof of the third ventricle of the brain. The pineal gland is essentially made up of groups of cells called pinealocytes which are supported by glial cells. Melatonin is present in high concentrations in the pineal gland. Plasma levels of melatonin increase in the dark and decrease during the day.

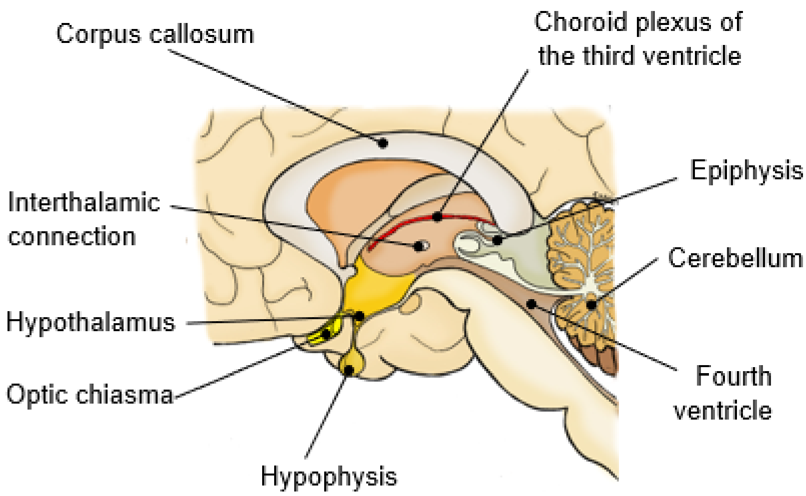



***Figure 272: Hypothalamus, hypophysis and epiphysis. Median cross section through the brain.***

## 5 - Thyroid gland

The thyroid gland is a butterfly-shaped red-brown gland that consists of the right and left lobes connected by a narrow isthmus. Sometimes a pyramidal lobe is present projecting upward from the isthmus. The average weight of the gland is 20-25 grams, and each lobe is about 5 cm long and 3 cm wide.

The thyroid gland is located at the anterior part of the neck, below the larynx, in front of and on the sides of the superior part of the trachea. It is surrounded by the pretracheal fascia along with the other neck viscera.

Vascular supply of the thyroid gland is very abundant and is provided by four arteries that originate from the subclavian artery and the external carotid artery. Venous return is also very rich and is provided by numerous veins.

The hormones secreted by thyroid gland are thyroxine and triiodothyronine which enhance the metabolic rate and protein synthesis, and calcitonin which plays a role in calcium homeostasis.

The role of the thyroid gland is fundamental, affecting metabolism and practically all organs. Hyperthyroidism leads to palpitations and rapid weight loss. Hypothyroidism leads to physical and cognitive slowdown. In children, it is also involved in the growth of long bones and in psychomotor and intellectual development.

The imaging of the thyroid gland can be performed by ultrasound which reveals the structure of the gland. For further information, scintigraphy with radiolabelled iodine or technetium can be performed which reveals not only the size and shape of potential lesions, but also their metabolic activity.

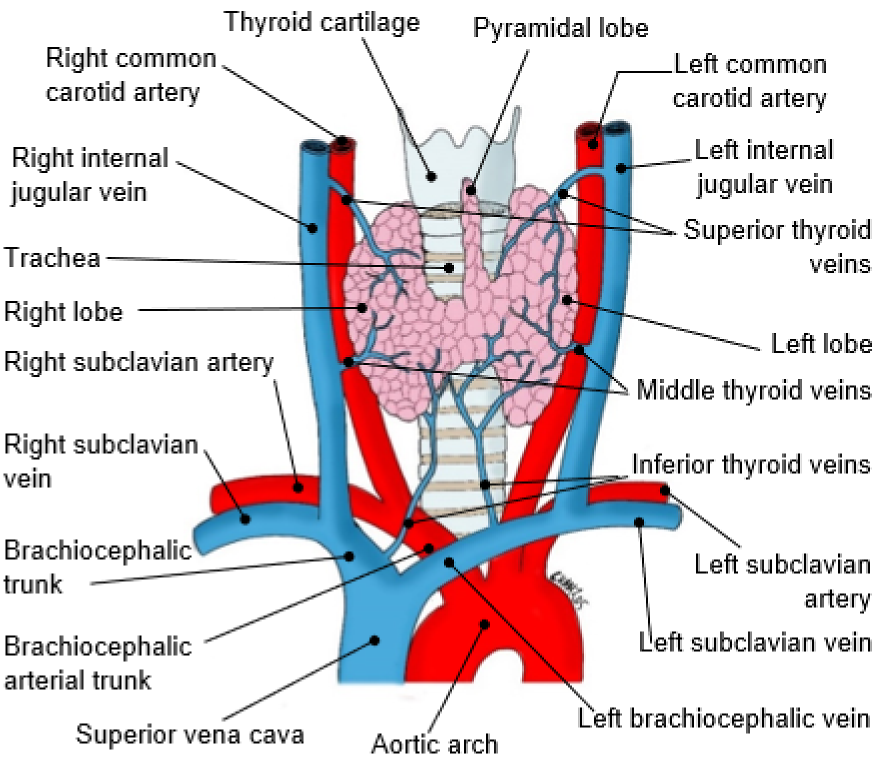



***Figure 273: The thyroid gland. Anterior view*.**

***Figure 274: Dissection of the anterior compartment of the neck showing the thyroid gland. Anterior view.***

## 6 - Parathyroid glands

The parathyroid glands are small egg-shaped glands about 6 mm long. They weigh about 30-35 mg each. There are usually four parathyroid glands, located on the posterior surface of the thyroid gland.

They secrete the parathyroid hormone (PTH) which plays a role in calcium homeostasis.

Vascular supply of the parathyroid glands is the same as of the thyroid gland.

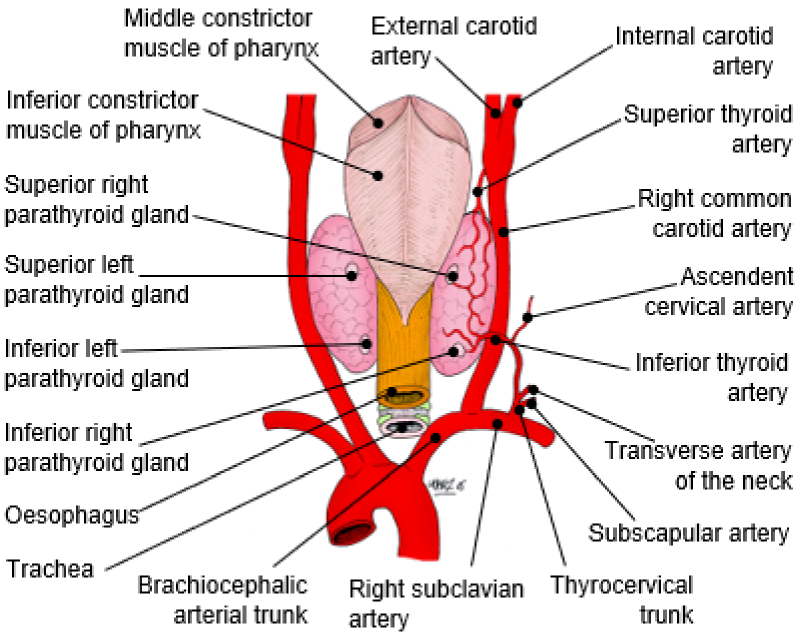



***Figure 275: The neck viscera showing the parathyroid glands. Posterior view.***

## 7 - Suprarenal glands

The suprarenal glands are yellowish retroperitoneal organs that lie on the upper poles of the kidneys. They are surrounded by renal fascia and separated from the kidneys by the perirenal fat. Each gland has a yellowish cortex and a dark brown medulla.

**The cortex of suprarenal gland** secretes three main types of steroid hormones. The mineralocorticoids regulate the electrolyte balance and blood pressure. The glucocorticoids regulate the metabolism and supress the immune system. The androgens are sex hormones and are produced in small quantities.

**The medulla of suprarenal gland** secretes the catecholamines epinephrine and norepinephrine**.** Unlike the cortex, which is regulated by the hypophyseal hormones, the medulla is stimulated by the sympathetic nervous system.

The suprarenal gland has a rich arterial supply up to three arteries arising from the inferior phrenic artery, abdominal aorta, and renal artery.

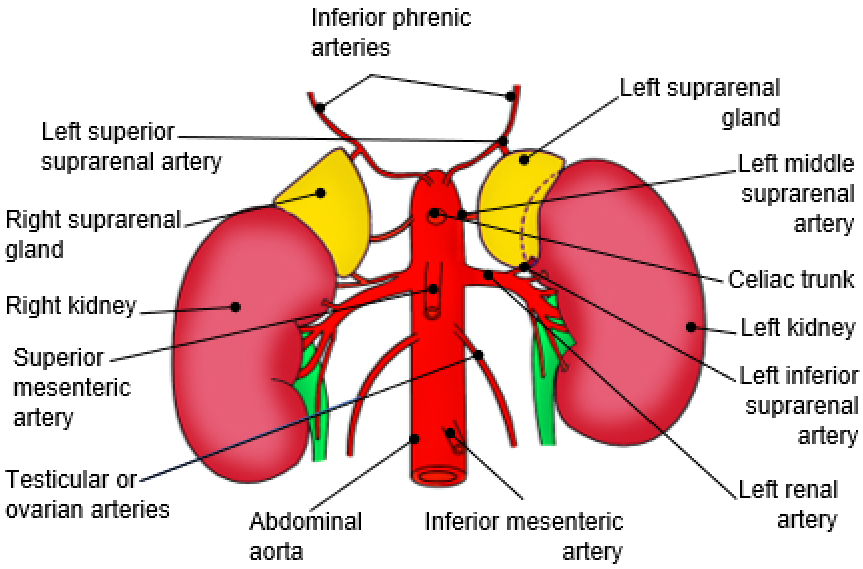


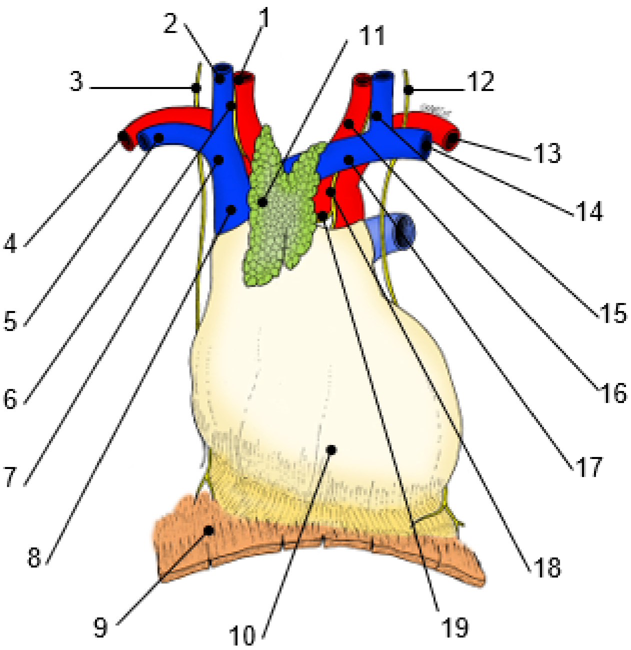

***Figure 276: Blood supply of the suprarenal glands. Anterior view.***

# 8 - Organs of other organ systems with endocrine function

## 8.1 - Thymus

The thymus is a flattened organ located behind the sternum in the superior mediastinum. It can stretch upwards toward the neck or downwards in front of the pericardium. In a new-born, the thymus reaches its largest size in relation to the body size. It continues to grow until puberty, after which it regresses.

The thymus is a specialised primary lymphoid organ in which the T lymphocytes (T cells) mature. It produces several hormones which regulate the T cells maturation.




1. Right common carotid artery
2. Right internal jugular vein
3. Right phrenic nerve
4. Right subclavian artery
5. Right subclavian vein
6. Right vagus nerve
7. Right brachiocephalic vein
8. Superior vena cava
9. Diaphragm
10. Pericardium
11. Thymus
12. Left phrenic nerve
13. Left subclavian artery
14. Left subclavian vein
15. Left internal jugular vein
16. Left common carotid artery
17. Left brachiocephalic vein
18. Left vagus nerve
19. Left recurrent laryngeal nerve

***Figure 277: The thymus. Anterior view.***

## 8.2 - Pancreas

The pancreas is a soft, lobulated organ located on the posterior abdominal wall behind the peritoneum. It is elongated transversely, the head lies within the concavity of the duodenum, and the neck, body, and tail extend to the left. The tail lies in contact with the hilum of the spleen. It is approximately 18 cm long, 3 cm wide and 4 cm high. It weighs about 70 g.

The pancreas is an organ of the digestive system. According to the function, we distinguish between the exocrine and endocrine part of the pancreas. The larger exocrine part of the gland produces the pancreatic juice with digestive enzymes and secrets it into the lumen of the duodenum. The endocrine part of the gland consists of clusters of cells, called the islets of Langerhans, which are scattered between the exocrine acini. The islets are particularly numerous in the tail of the pancreas. The cells of the islets secrete the hormones insulin and glucagon which regulate the blood sugar level.

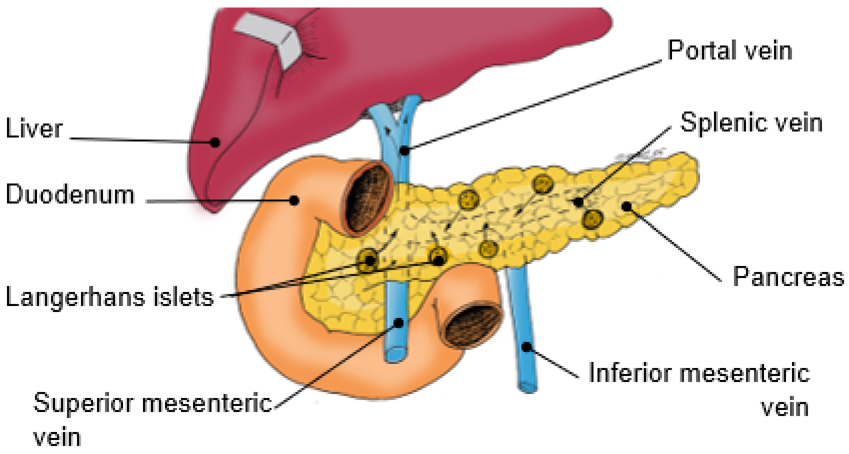



***Figure 278: The pancreas. Anterior view.***

## 8.3 - Testis

**The testis** is a paired egg-shaped organ located in the scrotum. It is part of the male genital system.

The greater part of the gland is made up of seminiferous tubules where spermatogenesis occurs and leads to the production of sperm. The endocrine part of the testis consists of groups of rounded interstitial cells (Leydig cells) embedded in the loose connective tissue between the seminiferous tubules. The Leydig cells produce sex hormones called androgens, primarily the testosterone.

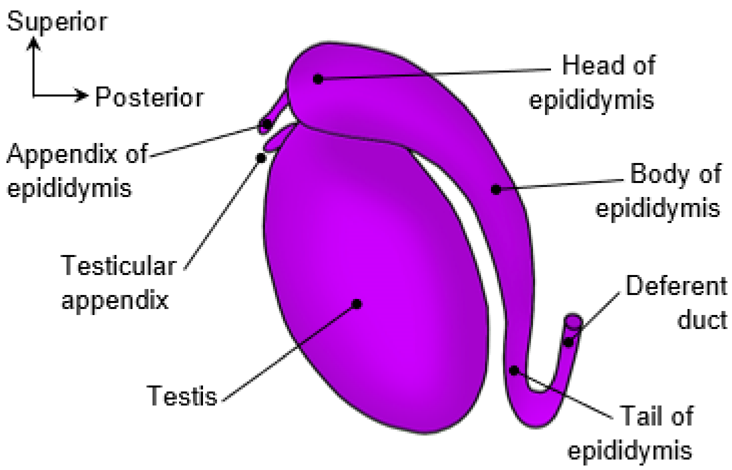



***Figure 279: Lateral view of the testis.***

## 8.4 - Ovary

The ovary is a paired egg-shaped organ located in the pelvic cavity. It is part of the female genital system.

The ovary consists of an outer cortex and an inner medulla. Embedded in the connective tissue of the cortex are ovarian follicles in various stages of development. Inside each follicle lies the ovum. The follicular cells produce and secrete sex hormones, primarily the oestrogen and progesterone.

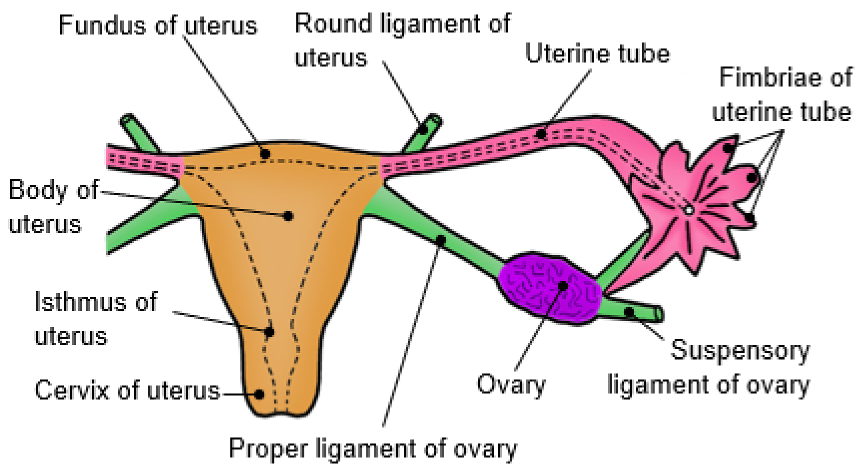



***Figure 280: The anterior view of the ovary.***

# Chapter 9 - Urinary system

**The objectives of this chapter are:**

1. Describe the kidney.
2. State the differences between the two kidneys.
3. Describe the blood supply of the kidney.
4. Name the components of the urinary tract.

## 1 - Elements of the urinary system

The urinary system is a set of structures that are involved in the filtration of the blood and excretion of the urine, and it consists of:

- paired kidneys which perform the functions of filtration, secretion, and reabsorption.
- paired ureters which transfer the urine from kidneys to the urinary bladder.
- urinary bladder which stores the urine before disposal.
- urethra which transfers the urine from the urinary bladder out of the body.

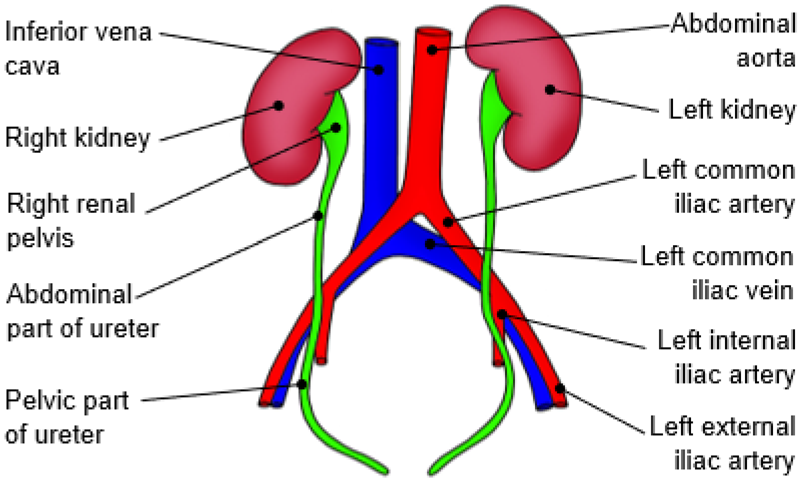



***Figure 281: The urinary system showing the kidneys and ureters. Anterior view.***

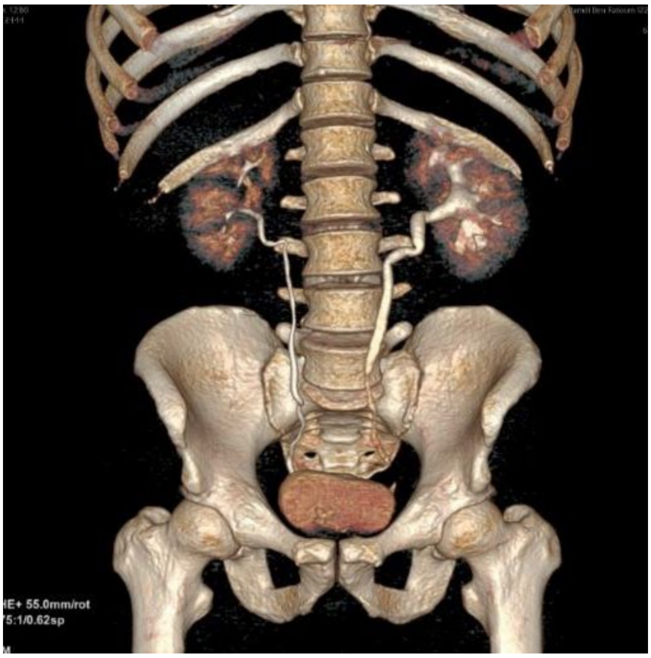


***Figure 282: CT reconstruction of the urinary system. Anterior view.***

## 1.1 - Kidney

The left and right kidneys are parenchymatous organs which filter the blood and form the urine. They lie on the posterior abdominal wall, in the retroperitoneal space behind the parietal peritoneum, between the vertebrae T12-L3. The right kidney lies somewhat lower than the left, because of the liver occupying the space.

### Morphology of the kidneys

The kidneys are bean-shaped, reddish-brown in colour, of firm consistency. They are approximately 12 cm long, 6 cm wide and 3 cm thick, and they weigh about 120-180 g. They are enveloped in a firm fibrous capsule. Their surface is smooth and regular.

Anterior surface of the kidney is oriented anteromedially and adjacent to some of the other organs of the abdominal cavity. Posterior surface of the kidney is oriented posterolaterally and is adjacent to the muscles of the abdominal wall.

The lateral margin is convex. The medial margin is concave in its centre lies the hilum of kidney.

The superior pole is in contact with the diaphragm. The suprarenal gland is situated above it. The inferior pole is pointed more laterally than the superior one.

### Structure of the kidney

The kidney has a lighter brown outer cortex and a dark brown medulla. The hollowed central part of the kidney is called the renal sinus.

The cortex extends towards the renal sinus as renal columns and divides the medulla into 10-15 renal pyramids. The base of pyramids is oriented towards the surface, while the apex called renal papilla projects towards the renal sinus. The urine flows from each renal papilla into the hollow minor calyx which surrounds the papilla. Two or more minor calices join into the major calyx, and major calices join into the renal pelvis. The pelvis exits the kidney through the hilum and narrows into the ureter.

**Blood supply of the kidney**

Blood is supplied to the kidney by the renal artery which is a direct branch of the abdominal aorta. The oxygenated blood delivered by renal artery serves the functional and nutritive purposes. The renal artery divides into the anterior branch and posterior branch. Each of them further divides into the segmental arteries.

Altogether, there are 5 segmental arteries supplying the five renal segments. The renal artery also gives off the inferior suprarenal artery and ureteric branches.

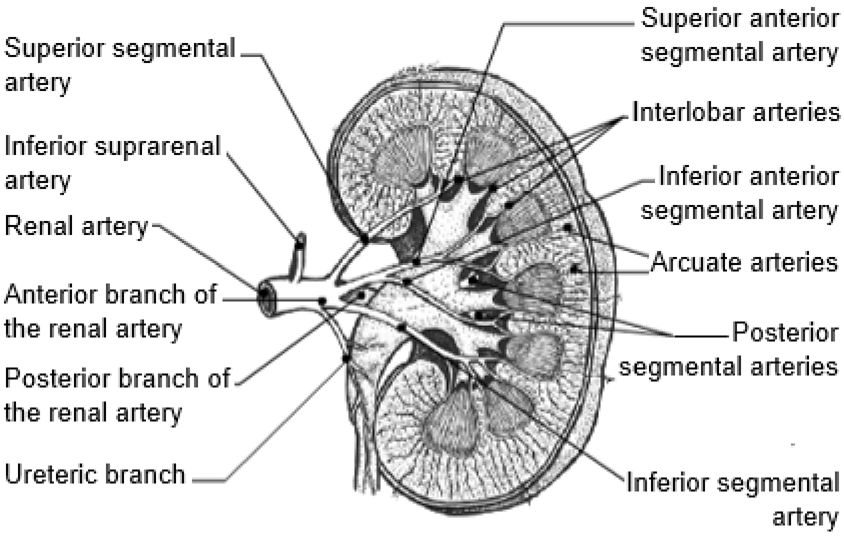



***Figure 283: Blood supply of the kidney.***

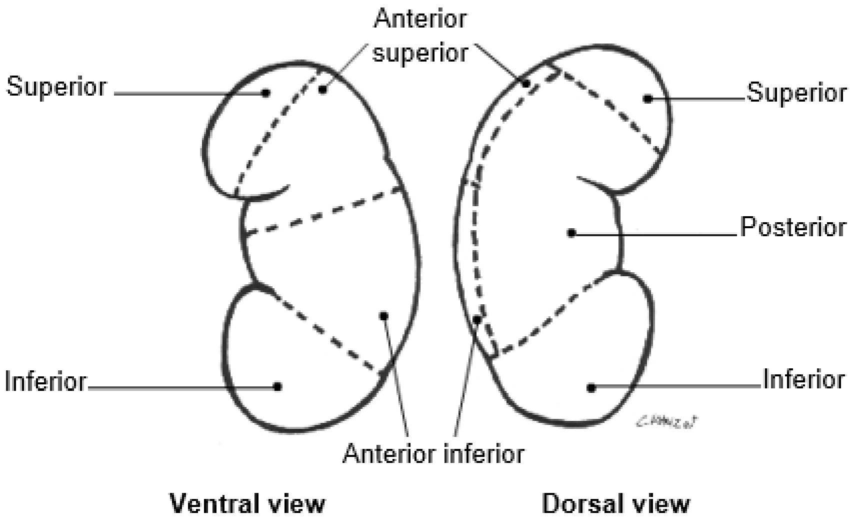



***Figure 284: Vascular segmentation of the kidney.***

Renal veins drain the filtered blood into the inferior vena cava. Renal veins lie anteriorly to the renal arteries. The left renal vein runs posteriorly to the superior mesenteric artery and can get trapped between this artery and the abdominal aorta.

The renal vessels also serve to fix the kidneys.

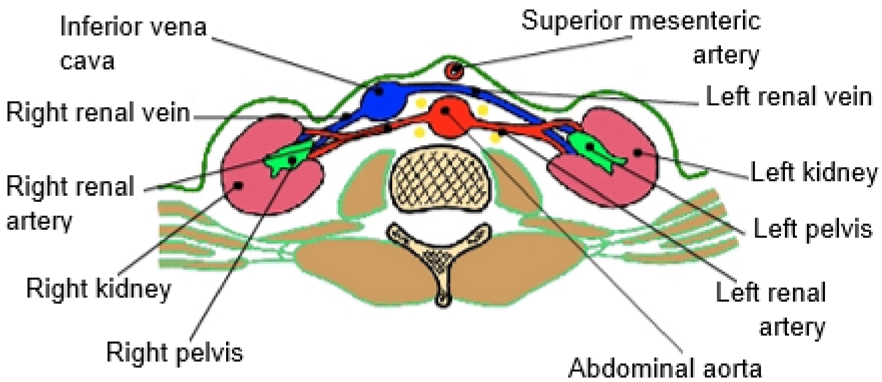



***Figure 285: Transverse section through the retroperitoneal space showing renal vessels.***

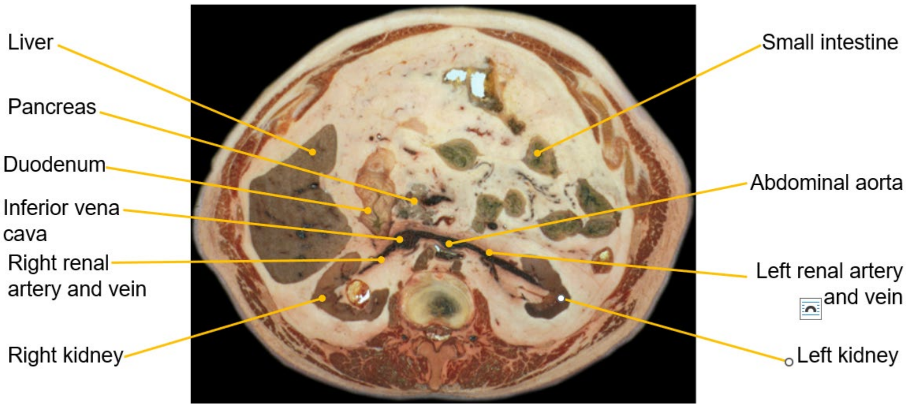



***Figure 286: Transverse section through the abdomen showing renal vessels.***

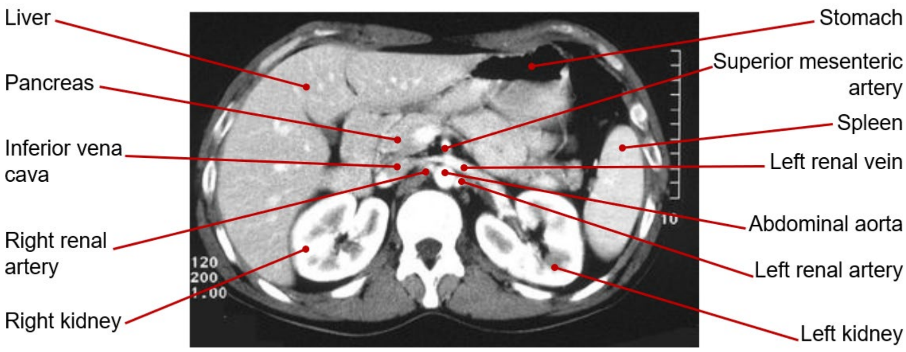



***Figure 287: Transverse CT section of the abdomen showing the renal vessels.***

## 1.2 - Ureter

The ureter is a paired muscular tube that extends from the renal pelvis to the posterior surface of the urinary bladder. It is 20-30 cm long and has a diameter of approximately 3-5 mm. It is lined with the urothelium – the transitional epithelium.

The ureter has three parts:

- The abdominal part runs from the renal pelvis downwards behind the parietal peritoneum, along the psoas muscle which separates it from the transverse processes of the lumbar vertebrae. It ends at the pelvic brim.

- The pelvic part enters the pelvis at the bifurcation of the common iliac vessels and then runs in the subperitoneal space down the lateral pelvic sidewall, anteriorly to the internal iliac artery. It finally turns forward and medially to reach the urinary bladder.
- The intramural part lies within the bladder wall and finally opens into the bladder at the ureteral orifice.

The ureter has three physiological constrictions along its course:

- at the junction of the renal pelvis and the ureter,
- at crossing the pelvis brim over the common iliac artery bifurcation, and
- at the junction of the ureter and the bladder wall.

## 1.3 - Urinary bladder

The urinary bladder is a muscular-membranous reservoir that stores the urine which flows continuously through the ureters. During micturition, it contracts and empties the collected urine through the urethra.

The bladder is very extendable. When empty, it is flattened, but can expand considerably when filled; its capacity is approximately 500 ml (up to 750 ml in male).

The bladder is located in the pelvic cavity, below the parietal peritoneum, close to the pelvic floor, just behind the pubic symphysis. The upper surface of the urinary bladder is covered with parietal peritoneum. In the adult, the empty bladder lies entirely within the pelvic cavity; when it fills, its upper wall rises above the pubic symphysis into the hypogastric region, in the preperitoneal space.

**Structure of the urinary bladder**

The empty bladder is pyramidal in shape. Its main part is called the body of the bladder. The apex of the bladder is the anterosuperior part of the organ, oriented towards the upper part of the pubic symphysis. From the apex to the umbilicus runs the median umbilical ligament, which is a vestige of the embryological urachus. The fundus of the bladder is the posteroinferior part of the organ. It has a triangular shape. The ureters enter the fundus at the two upper angles of the triangle, and the urethra exits the bladder at the lower angle of the triangle. The neck of the bladder is the inferior part of the organ and is continuous with the urethra inferiorly.

A strong smooth muscle forming the wall of the bladder is called detrusor vesicae.

The inner layer of the bladder wall is the mucous membrane with transitional epithelium which stretches when needed. Thick mucosal folds are present in the empty bladder which disappear when the bladder is full. The mucosa of triangular area in the fundus is called the trigone of the bladder and is always smooth, even when the bladder is empty.

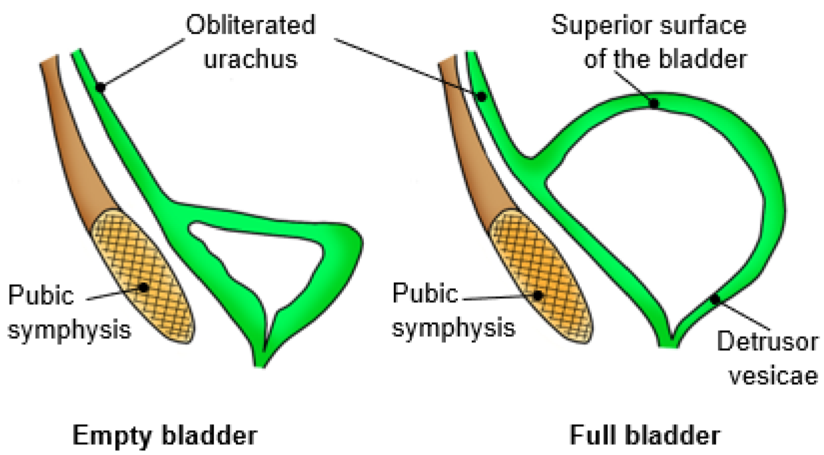



***Figure 288: Median section of the urinary bladder.***

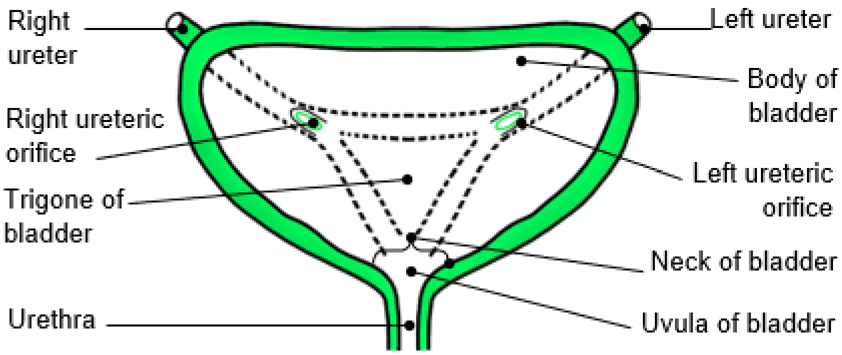



***Figure 289: Frontal section of the bladder showing the bladder trigone. Anterior view.***

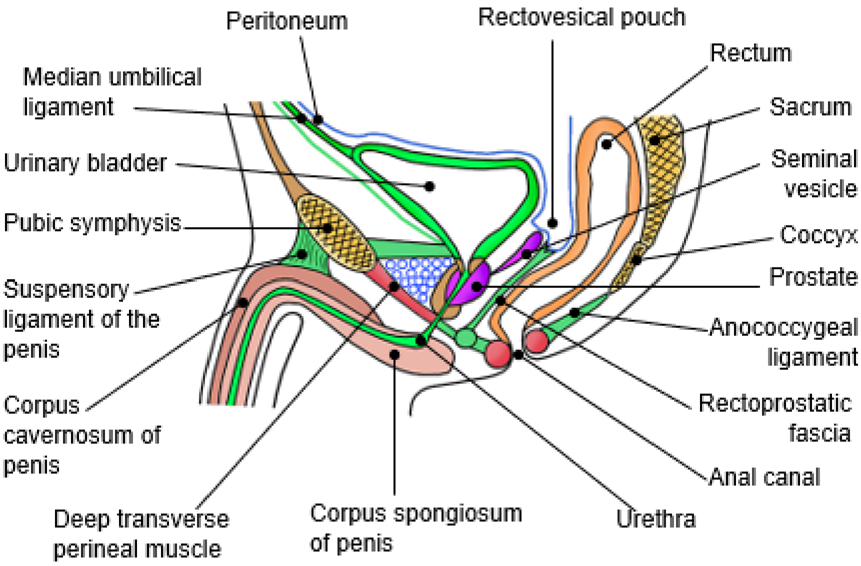



***Figure 290: Median section of the male pelvis.***

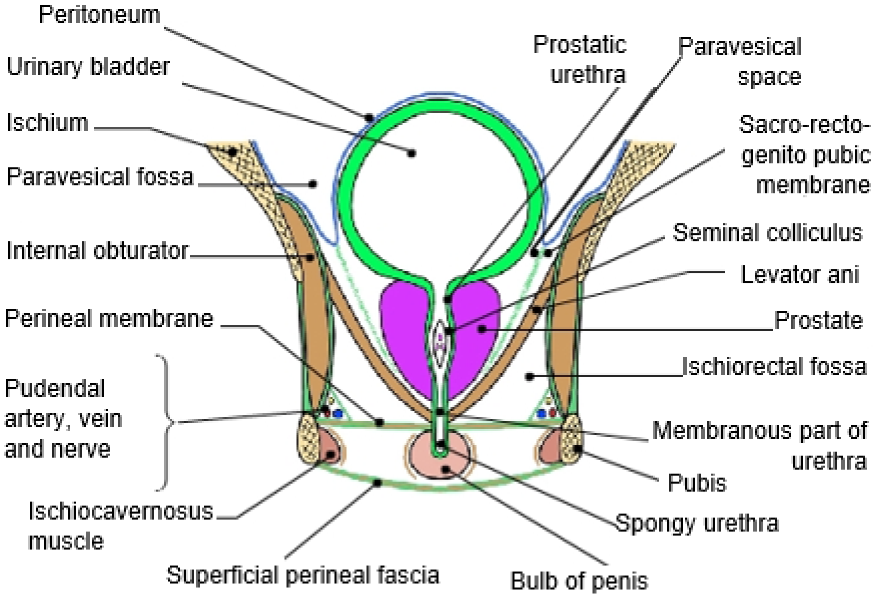



***Figure 291: Frontal section of the male pelvis. Anterior view.***

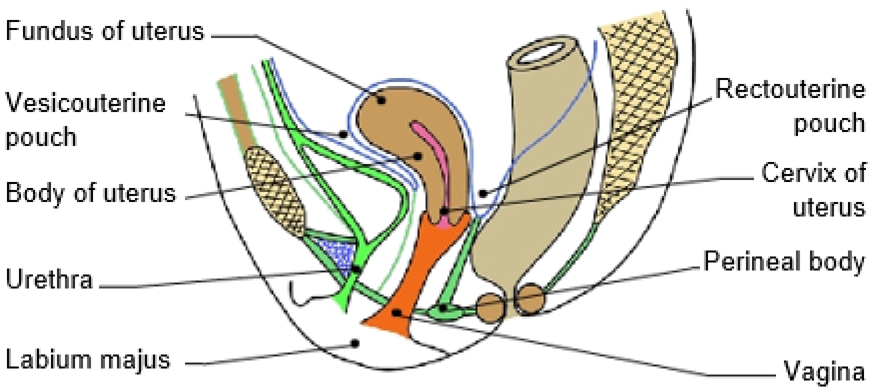



***Figure 292: Median section of the female pelvis.***

## 1.4 - Urethra

The urethra is a tube that transports the urine from the urinary bladder to the exterior of the body.

### Female urethra

The female urethra is about 4 cm long and runs from the internal urethral orifice in the urinary bladder to the external urethral orifice which lies posteriorly to the clitoris and anteriorly to the vaginal orifice.

It is divided into two parts:

- **Intramural part of female urethra** is about 1 cm long and passes through the neck of the bladder. It is surrounded by the internal urethral sphincter.
- **Membranous part of female urethra** passes through the pelvic floor. It is surrounded by the external urethral sphincter.

The shortness of the female urethra and the closeness of its external orifice to the anus are reasons for frequent urinary tract infections.

### Male urethra

The male urethra is about 20 cm long and runs from the internal urethral orifice in the urinary bladder to the external urethral orifice on the glans penis. The external orifice is the narrowest part of the male urethra.

The male urethra does not only transport the urine but also functions as an exit for seminal fluid during ejaculation.

It is divided into four parts:

- **Intramural part of male urethra** is about 1 cm long and passes through the neck of the bladder. It is surrounded by the internal urethral sphincter.

- **Prostatic urethra** is about 3 cm long and passes through the prostate. It is the widest part of the urethra.
- **Membranous part of male urethra** is about 1.5 cm long and lies within the urogenital diaphragm, surrounded by the external urethral sphincter.
- **Spongy urethra** is about 15 cm long and is surrounded by the erectile tissue of the corpus spongiosum of penis.

# Chapter 10 - Genital system

**The objectives of this chapter are:**

1. Describe the testis and its location
2. Describe the excretory ducts and accessory glands
3. Describe the penis
4. Describe the ovary, and its location
5. Describe the uterine tubes, uterus and vagina
6. Describe the external female genital organs.

The male and female genital systems are the organ systems that include all the organs involved in sexual reproduction. According to their position during the embryological development, we distinguish between the internal and external genital organs.

## 1 - Male genital system

The internal organs of male genital system are:

- paired testes,
- paired epididymides,
- paired ductus deferens,
- paired spermatic cords,
- paired seminal glands,
- paired ejaculatory ducts,
- prostate,
- paired bulbo-urethral gland.

The external organs of male genital system are:

- penis,
- scrotum.

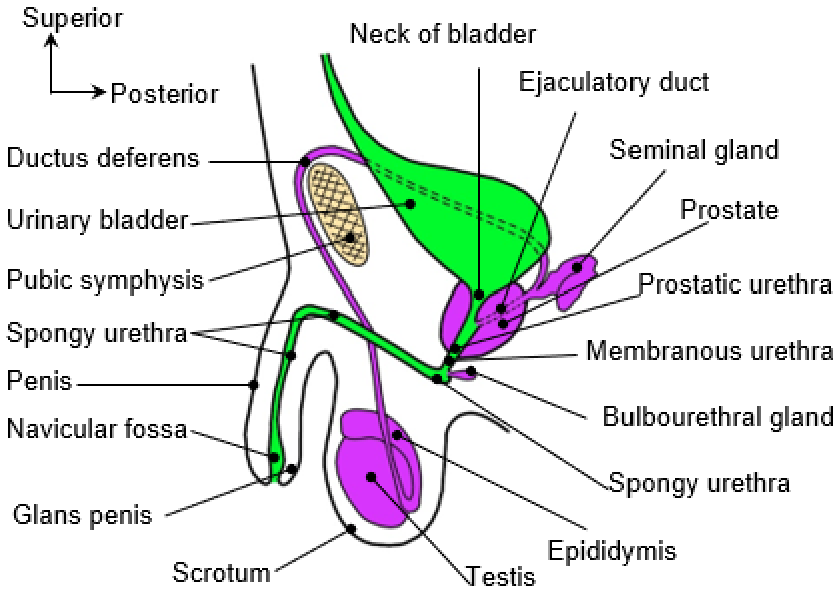



***Figure 293: Schematic representation of the male genital organs. Sagittal section.***

## 1.1 - Testis

The testis is a male reproductive gland, homologous to the female ovary. It lies within the scrotum. Its function is the production of sperm cells, the production of testosterone and other male sex hormones (androgens).

The testis has a slightly laterally flattened ovoid shape. It weighs about 20 grams, and it is about 4-5 cm long and 2-3 cm in diameter. On the testis we can observe the lateral and medial surfaces of testis, the anterior and posterior borders of testis, and the superior and inferior pole of the testis.

Each testis is enveloped in a firm fibrous capsule that is white in appearance and therefore called the tunica albuginea. It gives the testis its whitish appearance and firm consistency. Each testis with its tunica albuginea is enveloped in a double-layered serous membrane, called tunica vaginalis. The inner visceral layer is attached to the tunica albuginea of testis. Posteriorly, where the epididymis is attached to the testis, it continues onto the inner surface of the scrotum as the parietal layer. Between the visceral and parietal layer of tunica vaginalis is the cavity of tunica vaginalis testis with a small amount of clear fluid. The tunica vaginalis is the remnant of a pouch of peritoneum and gives the testis considerable mobility.

From the tunica albuginea stem the septa testis which protrude in the parenchyma of testis and divide it into 250-300 lobules of testis. Each lobule is pyramidal in shape and contains 1-3 highly coiled seminiferous tubules. The tubules are lined by a germinal epithelium that is the site of sperm production. In between the tubules there lies the interstitium with Leydig cells that produce and secrete the testosterone.

The convoluted seminiferous tubules run towards the posterior part of testis and straighten into straight tubules which form a network called the rete testis. From this network originate 9-12 efferent ductules which exit the testis at its posterior border and enter the epididymis.

**Blood supply**

The arterial blood is transported to the left and right testis by the left and right testicular arteries. They are direct branches of the abdominal aorta and arise from the aorta slightly inferiorly to the renal arteries. The testicular artery anastomoses with the artery of ductus deferens which stems from the inferior vesical artery (a branch of internal iliac artery), and with the cremasteric artery which stems from the inferior epigastric artery (also a branch of internal iliac artery).

The venous blood is collected by the pampiniform plexus from which the testicular vein arises. The right testicular vein drains into the inferior vena cava, while the left one drains into the left renal vein.

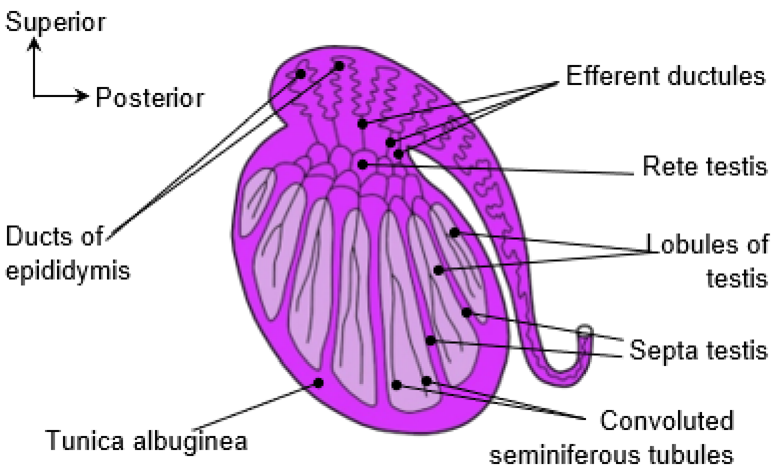



***Figure 294: Sagittal section of the testis and epididymis.***

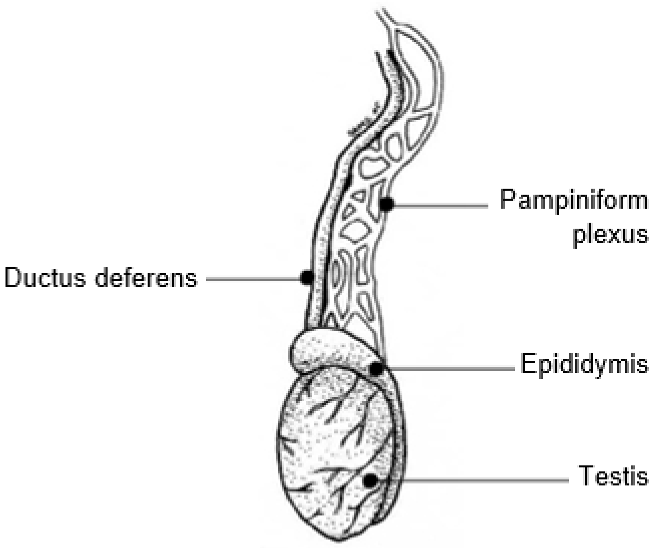



***Figure 295: Venous drainage of the testis and epididymis.***

## 1.2 - Epididymis

The epididymis is an elongated organ attached to the posterior border of each testis. In the epididymis, the sperm cells collect and mature.

The epididymis is divided into three parts: the head, the body and the tail. The head of epididymis is the voluminous superior part into which enter the efferent ductules that stem from the testis. The ductules join into a singular duct which is highly convoluted and forms the body and the tail of epididymis. At the inferior pole of the testis, the duct straightens, turns upwards and continues as the ductus deferens.

The blood supply to the epididymis is the same as that of the testis.

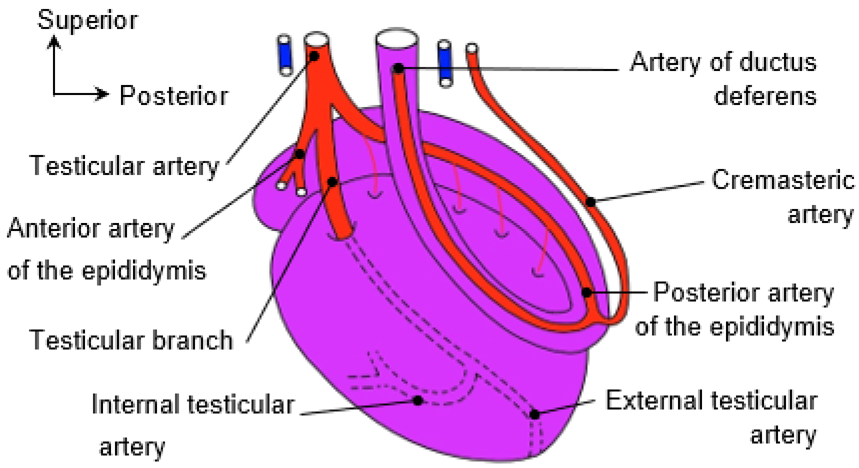



***Figure 296: Schematic presentation of the arteries of the testis.***

## 1.3 - Ductus deferens

The ductus deferens, formerly called the vas deferens, is about 50 cm long tube that transports mature sperm cells from the epididymis to the ejaculatory duct.

First part of ductus deferens (scrotal part) lies inside the scrotum, posterior to the testis and epididymis. Its proximal section forms an acute angle with the tail of the epididymis. When it reaches the superior pole of the testis, it enters the spermatic cord inside which it is positioned posteriorly.

Ductus deferens then passes through the inguinal canal and enters the pelvic cavity, and runs medially towards the fundus of urinary bladder.

The terminal part of the ductus deferens is dilated into ampulla of ductus deferens. The ampulla lies posteroinferior to the fundus of the bladder, anterior to the rectum, medially to the seminal gland. At the base of the prostate it joins with the duct of the seminal gland to form the ejaculatory duct.
The wall of the ductus deferens is very thick due to thick muscular layer comprised of three layers of smooth muscle. Its outer diameter is about 2 mm and the diameter of its lumen is about 0.5 mm.

## 1.4 - Spermatic cord

The spermatic cord is a structure that runs from the abdominal cavity through the inguinal canal to the testis and epididymis in the scrotum. It is formed by several structures enveloped in the coverings.
The coverings of spermatic cord arise from the layers of abdominal wall which bulges during the embryonic development:

- external spermatic fascia: a fibrous outermost layer arising from the aponeurosis of external abdominal oblique muscle;
- cremaster muscle and cremasteric fascia: a muscular middle layer arising from the internal abdominal oblique muscle;
- internal spermatic fascia: a fibrous innermost layer arising from the transversalis fascia.

The contents of spermatic cord are:

- ductus deferens,
- testicular artery,
- pampiniform plexus draining into the testicular vein,
- artery of ductus deferens,
- cremasteric artery,
- lymph vessels,
- sympathetic and parasymphatetic nerves,

- nerve to cremaster (genital branch of the genitofemoral nerve).

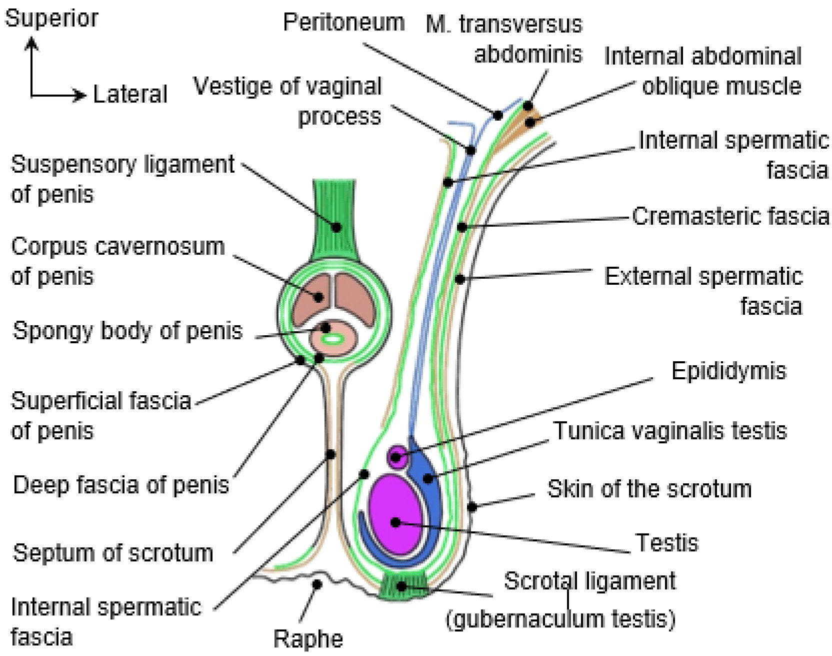



***Figure 297: Frontal section of the coverings of spermatic cord.***

## 1.5 - Seminal gland

The seminal gland (also called seminal vesicle) is about 5 cm long lobulated gland that produces fluid which is part of the semen and is essential for nourishing the sperm cells. It is located on the posterior surface of the urinary bladder, laterally to the ampulla of ductus deferens. The excretory duct of seminal gland joins the ampulla of ductus deferens to form the ejaculatory duct.

## 1.6 - Ejaculatory duct

The ejaculatory duct is about 2 cm long straight tube formed by union of the ampulla of ductus deferens and the excretory duct of seminal gland. It passes through the prostate and opens into the prostatic part of urethra.

## 1.7 - Prostate

The prostate is an organ formed by glandular part and fibromuscular tissue. The glandular part secretes a slightly alkaline milky fluid that forms part of the semen and helps neutralize the acidity of the vagina. The muscular tissue contracts during ejaculation, pushing the semen through the urethra and closing the connection between the urethra and urinary bladder.

The prostate lies at the neck of the urinary bladder, surrounding the prostatic part of urethra. Its superior part is the widest and is called the base, while the inferior part is narrow and is called the apex. The anterior surface is oriented towards the pubic symphysis, and the posterior surface is oriented towards the rectum. The prostate is about 3 cm high, 4 cm wide at the base, and its weight is 20-30 g. It increases in size with age.

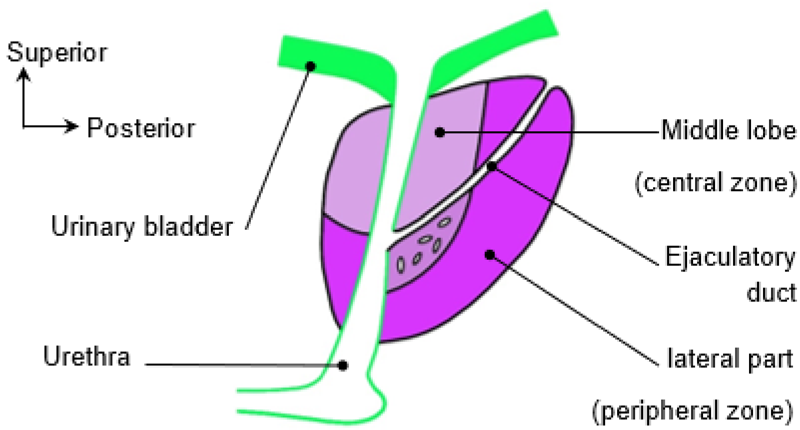



***Figure 298: Sagittal section of the prostate.***

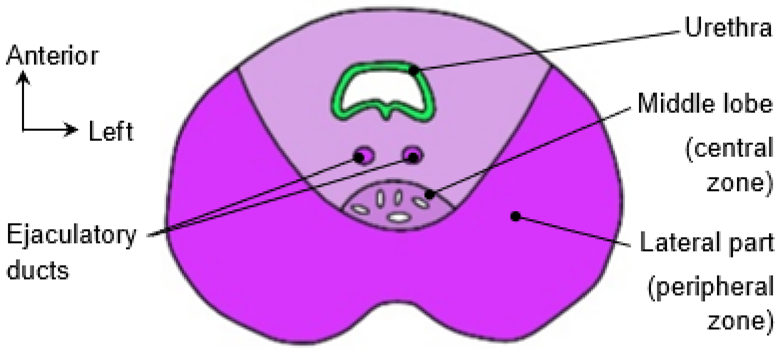



***Figure 299: Cross-section of the prostate.***

## 1.8 - Bulbourethral gland

The bulbourethral gland (also called Cowper's gland) is a small gland, about the size of a pea. It produces an alkaline fluid that lubricates the urethra and neutralizes any acidic urine residue.

The bulbourethral gland lies just below the prostate, at the transversal perineal muscles, lateral to the membranous part of urethra, at the level of the bulb of penis. The duct opens into the spongy urethra.

## 1.9 - Scrotum

The scrotum is a cutaneous sac that contains the testes, the epididymides, and the lower parts of the spermatic cords. It consists of two chambers separated by the septum of scrotum.
The wall of the scrotum consists of two layers:

- Skin of the scrotum, which is thin, wrinkled and pigmented.
- Dartos fascia, which is a superficial fascia with smooth muscle fibres called the dartos muscle. Dartos fascia forms the septum of scrotum.

Inside these two layers, there are the coverings of the spermatic cord surrounding each testis and epididymis, separately in the left and right chamber inside the scrotum: the external spermatic fascia, cremasteric fascia, and internal spermatic fascia.

***Figure 300: Photo of the scrotum.***

## 1.10 - Penis

The penis is a copulatory organ that enables the copulation and micturition. It consists of erectile tissue organised in three corpora: the left and right corpus cavernosum and the corpus spongiosum in which the spongy urethra is situated. A firm fibrous tunica albuginea envelops the corpora.
The penis consists of three parts:

- The root of penis is the fixed proximal part of penis, located in the urogenital triangle of perineum. It consists of the left and right crus penis which are attached to the ipsilateral ischiopubic ramus, and the bulb of penis which lies in between the crura penis and is pierced by the urethra.
- The body of penis is the free pendulous part of penis enveloped in skin, located anteriorly to the scrotum. It consists of the left and right corpus cavernosum which are a continuation of the left and right crus penis, and the corpus spongiosum which is a continuation of the bulb of penis. The corpora cavernosa are separated by the septum penis.

- The glans penis is the free distal end of penis. It consists of the corpus spongiosum. On the tip of the glans penis is the external orifice of the urethra. The prepuce of penis is a fold of the skin that covers the glans. It is connected to the glans by the frenulum of penis.

***Figure 301: External genital organs in men.***

**Blood supply**

The oxygenated blood is supplied to the left and right corpus cavernosum by the left and right deep artery of penis, and to corpus spongiosum by the artery of the bulb of penis. An additional pair of arteries run along the dorsum of penis, called the dorsal arteries of penis. All the arteries are branches of the internal pudendal artery.

The deoxygenated blood is drained into the internal pudendal veins.

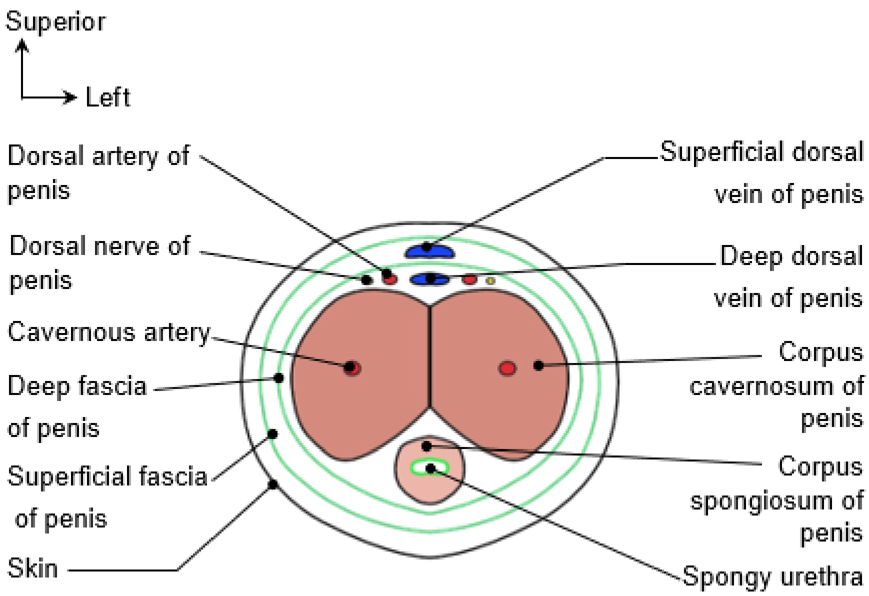



***Figure 302: Cross section of the penis.***

***Figure 303: Dissection of the penis, showing the dorsal veins.***

# 2 - Female genital system

The internal organs of female genital system are:

- paired ovaries,
- paired uterine tubes,
- uterus,
- vagina.

The external organs of female genital system are:

- vulva,
- clitoris.

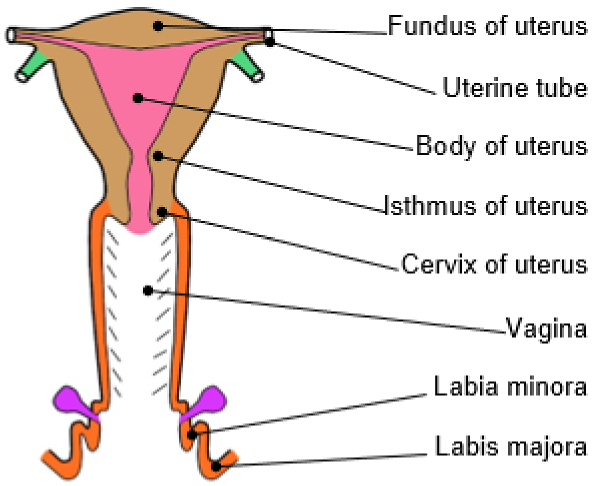



***Figure 304: Frontal section through the uterus and vagina.***

## 2.1 - Ovary

The ovary is a female reproductive gland, homologous to the male testis. It lies within the pelvic cavity. Its function is the production of ova (female germ cells) and the production of female sex hormones, oestrogen and progesterone.

At birth, the ovary has a shape of flattened lamella, which becomes oval in the second year of life. In adult women, ovary has a slightly laterally flattened ovoid shape. It weighs about 10 grams, it is about 4 cm long and 2-3 cm in diameter. Its volume varies according to the menstrual cycle or pregnancy. After menopause, the ovary atrophies.

An ovary is described as having the lateral and medial surfaces of ovary, the free border of ovary (oriented posteriorly) and mesovarian border of ovary (oriented anteriorly), and the tubal extremity of ovary (oriented superiorly towards the uterine tube) and the uterine extremity of ovary (oriented inferiorly towards the uterus).

Each ovary is enveloped in a firm fibrous capsule that is white in appearance and therefore called the tunica albuginea. It gives the ovary its whitish appearance and firm consistency. Deep to the tunica albuginea is the ovarian cortex in which lie the ovarian follicles with ova. The follicular cells produce and secrete female sex hormones. The innermost part of ovary is called the ovarian medulla and contains vessels and nerves.

**Ligaments of ovary**

The proper ovarian ligament is a fibrous ligament connecting the uterine extremity of ovary with the uterus. It is the remnant of the gubernaculum.

The suspensory ligament of ovary is a fold of peritoneum which extends from the tubal extremity of ovary to the wall of pelvis. It contains the ovarian artery and vein.

The mesovarium is a peritoneal duplicature. It is part of the broad ligament of uterus, extending from the mesometrium posteriorly to the mesovarian border of ovary.

**Blood supply**

The arterial blood is transported to the left and right ovary by the left and right ovarian arteries. They are direct branches of the abdominal aorta and arise from the aorta slightly inferiorly to the renal arteries. The ovarian artery anastomoses with the ovarian branch of uterine artery (a branch of internal iliac artery) in the mesovarium.

The venous blood is collected by the ovarian vein. The right ovarian vein drains into the inferior vena cava, while the left one drains into the left renal vein.

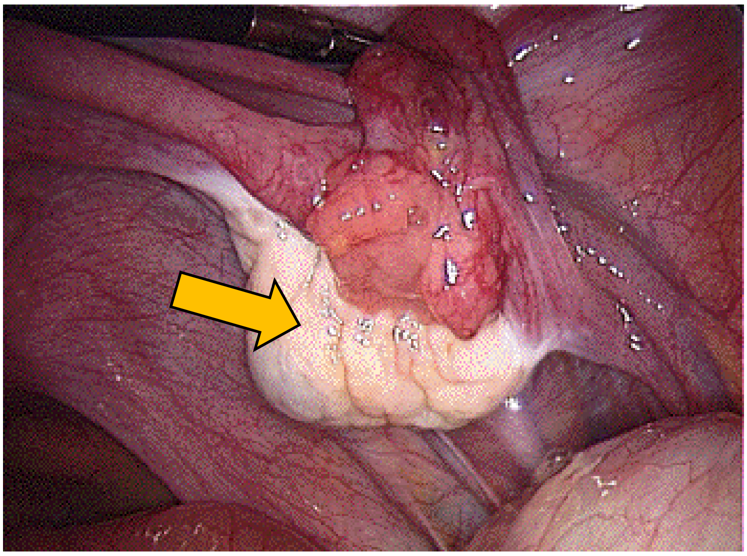


***Figure 305: Laparoscopic view of a normal ovary.***

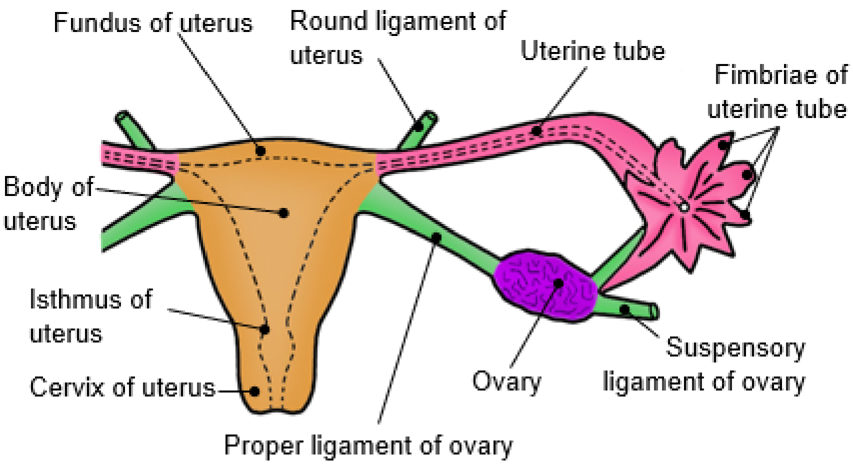



***Figure 306: Schematic representation of the attachments of the ovary.***

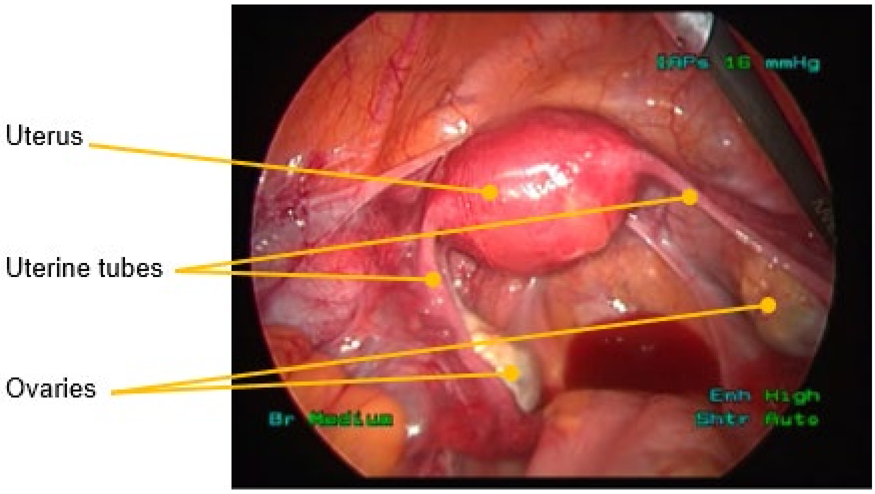



***Figure 307: Laparoscopic view of the ovaries, uterus and uterine tubes.***

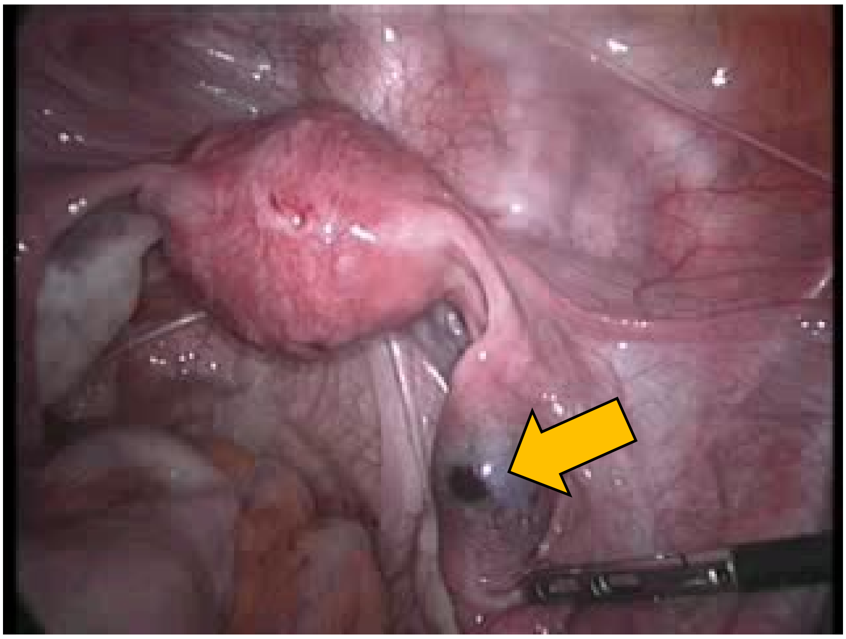


***Figure 308: Laparoscopic view of an ectopic pregnancy.***

***Figure 309: Appearance of a large ovarian cyst.***

## 2.2 - Uterine tube

The uterine tube, also called the Fallopian tube, is a hollow muscular tube that stretches from the uterus towards the ovary. Its function is to convey the mature ovum into the uterine cavity. Conception usually takes place inside the uterine tube.

The uterine tube is about 10 cm long and divided into four parts:

- Intramural part of uterine tube is a part within the myometrium of the uterus. It opens into the uterine cavity with the uterine ostium of uterine tube.
- Isthmus of uterine tube is the narrowest part with a diameter of about 3 mm.
- Ampulla of uterine tube is the longest and widest part with a diameter up to 1 cm. It is the usual place of fertilisation.
- Infundibulum of uterine tube is the funnel-shaped lateral part. It opens into the peritoneal cavity with the abdominal ostium of uterine tube. Finger-like projections called fimbriae emanate from the free edge of the infundibulum and drape over the ovary.

The uterine tube courses between the two layers of the broad ligament at its superior aspect. Part of the broad ligament that envelops the uterine tube is called the mesosalpinx.

## 2.3 - Uterus

The uterus is a hollow organ with thick muscular walls responsible for the development of the embryo and foetus during pregnancy and for the expulsion of the foetus and placenta during the parturition. It is located in the pelvic cavity, posterior to the urinary bladder and anterior to the rectum. Inferiorly it communicates with the vagina.

The uterus has a shape of an inverted pear. In adult women it is about 8 cm long, 5 cm wide at the upper part, and about 2.5 cm thick. It is flattened antero-posteriorly, therefore we distinguish the anterior and posterior surface of uterus and border of uterus which lies laterally.

The uterus consists of three parts:

- The fundus of uterus is the round uppermost part that lies above the openings of uterine tubes.
- The body of uterus is the wide part of uterus that lies below the openings of uterine tubes. Inside the body lies the uterine cavity having a triangular shape on frontal section; the two superior angles of triangle are formed by openings of uterine tubes while the apex is formed by the internal os of uterus (communication of the uterine cavity with the cervical canal).
- The cervix of uterus is the narrowed inferior part of the organ. It consists of a part that lies superior to vagina (supravaginal part of cervix) and a part projecting into the vagina (vaginal part of cervix). Isthmus of uterus is about 1 cm long narrow superior portion of cervix, connecting the cervix with corpus. Inside the cervix lies the cervical canal. The canal communicates with the lumen of vagina through the external os of uterus.

The uterine wall is composed of 3 layers. The innermost layer is called endometrium and consists of mucosa. It has a basal layer and a functional layer. During the menstrual cycle, the functional layer thickens and is shed. The middle layer, called the myometrium, is thick and composed of smooth muscle. The outermost layer is called perimetrium and is formed by peritoneum.

The peritoneum covers the anterior surface of the body of uterus, the posterior surface of the body and supravaginal part of uterus.

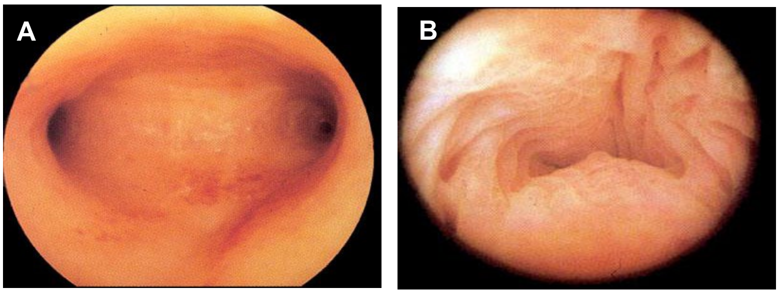



***Figure 310: Hysteroscopy view of the uterine cavity with the openings of uterine tubes (A) and the cervical canal (B).***

**Position of uterus**

In most women, the long axis of the body of uterus is bent forward against the long axis of cervix of uterus (the angle between the body and cervix faces anteriorly); this position is called anteflexion of uterus. In addition, the long axis of cervix of uterus is bent forward against the long axis of vagina (the angle between the cervix and vagina faces anteriorly); this position is called anteversion of uterus.

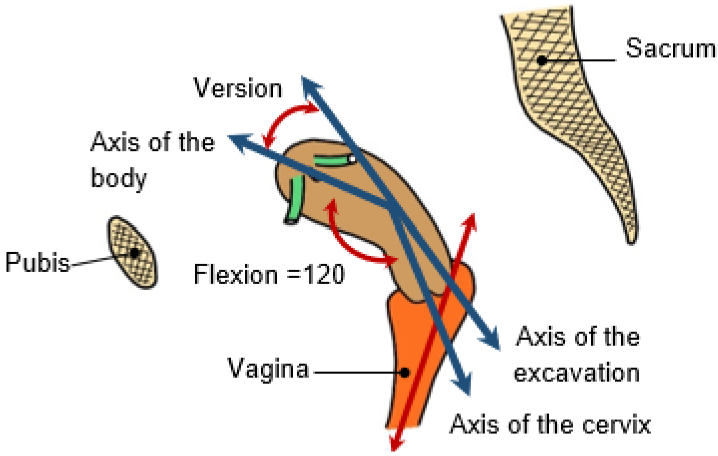



***Figure 311: Diagram showing the anteflexion and anteversion of uterus.***

**Blood supply**

The arterial blood supply to the uterus comes mainly from the uterine artery, a branch of the internal iliac artery.

The venous blood is collected by the uterine vein that drains into the internal iliac vein.

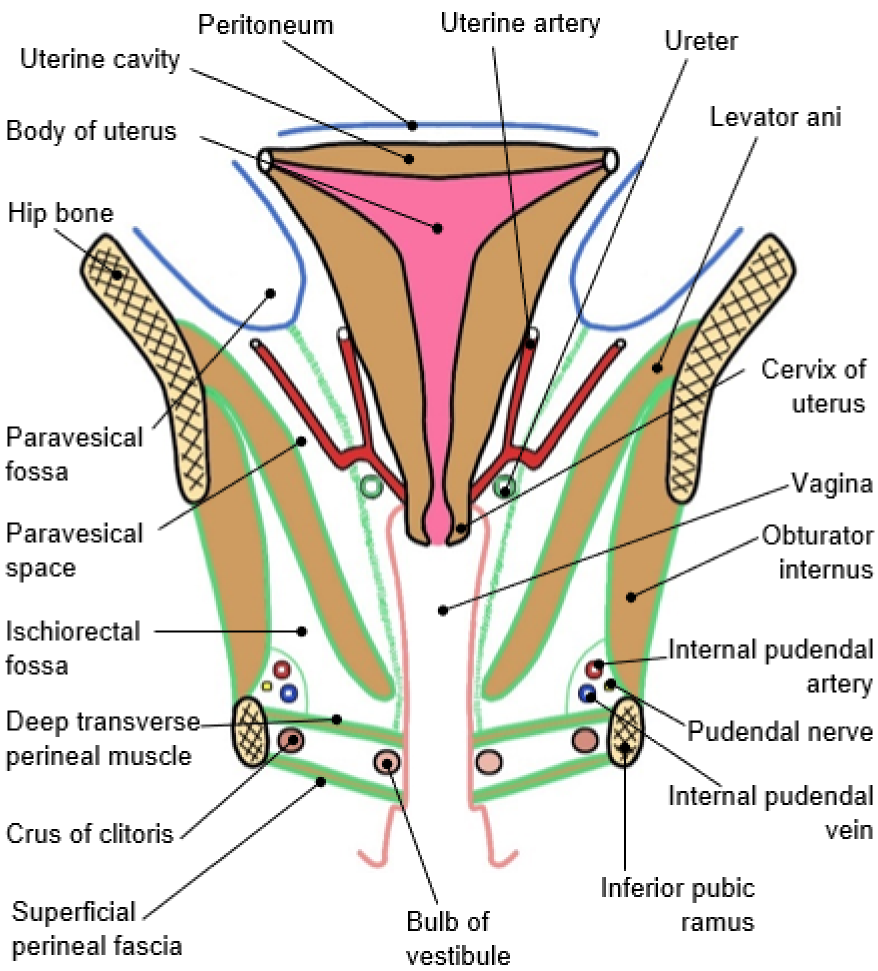



***Figure 312: Frontal section of the uterus in pelvic cavity.***

## 2.4 - Vagina

The vagina is about 8 cm long elastic muscular tube extending from the cervix of uterus to the vestibule. It is located partly above the pelvic floor, in the pelvic cavity, and partly below the pelvic floor, in the perineum. It has a function in menstruation, sexual intercourse and childbirth.

The vagina is flattened antero-posteriorly. Its walls are very elastic. The anterior wall of vagina is in contact with the urinary bladder and urethra. The posterior wall of vagina is in contact with rectum. The superior portion of vagina surrounding the cervix of uterus is called vaginal fornix. The cervix is oriented towards the posterior wall of the vagina, therefore the posterior part of vaginal fornix is deeper than the anterior and the lateral parts. The posterior part of vaginal fornix is covered by peritoneum. Above there is the rectovaginal pouch (pouch of Douglas).

## 2.5 - Vulva and clitoris

The vulva includes the mons pubis, labia majora, labia minora, vestibule of vagina, greater vestibular glands (Bartholin's glands), and lesser vestibular glands. The clitoris is homologous to the penis in the male.

1) **Mons pubis** consists of a mass of subcutaneous adipose tissue anterior to the pubic symphysis covered with the skin with pubic hairs.
2) **Labia majora** are a pair of folds consisting of adipose tissue covered with skin with pubic hairs. They lie inferiorly to the mons pubis. The left and right labium majus are joined by the anterior and posterior commissure of labia.
3) **Labia minora** are two smaller, thinner, hairless skin folds that lie medially to the labia majora. Their anterior ends split into two layers. The upper layers join superior to the clitoris and form the prepuce of clitoris, while the lower layers join inferior to the

clitoris and form the frenulum of clitoris. The joined posterior ends of both labia form the frenulum of labia minora.

4) **Vestibule of vagina** is an area between the left and right labium minus. It contains the vaginal orifice and the external orifice of female urethra as well as the openings of the vestibular glands. Bulbs of vestibule are located on each side of the vestibule, each of them covered by the bulbospongiosus muscle. They consist of an erectile tissue and are homologous to the bulb of penis in the male.
5) **Greater vestibular glands (Bartholin's glands)** are paired pea-sized glands with short ducts on each side of the vagina. They are homologous to the bulbourethral (Cowper's) glands in the male. Their secretion keeps the vulva moist and provides lubrication during sexual intercourse.
6) **Clitoris** is located inferior to the mons pubis, at the anterior end of the vulva. it is composed of paired crura, a body and glans. The crura of clitoris are attached to the ischiopubic rami. Anteriorly, they converge as corpora cavernosa and form the body of clitoris. Distally, the body is topped by the glans of clitoris, which is formed by the joined anterior end of the bulbs of vestibule.

## 2.6 - The breasts

The breasts are part of the organic system called integument. They are located on the anterior thoracic wall, in front of the pectoralis major muscle and its fascia. They are present in both sexes. In females, their function is production of milk to feed infants.

The female adult breast is an apocrine gland, called the mammary gland. It consists of a system of lactiferous ducts embedded in connective and adipose tissue.

The body of each breast is divided into 15 to 20 lobes separated by the connective tissue. Each lobe contains numerous lobules comprised of the tubuloalveolar glands. The secretory ducts (lactiferous ducts) converge towards the nipple. Before opening onto the nipple, each lactiferous duct dilates into the lactiferous sinus.

The nipple is small and surrounded by a coloured area of skin, called the areola.

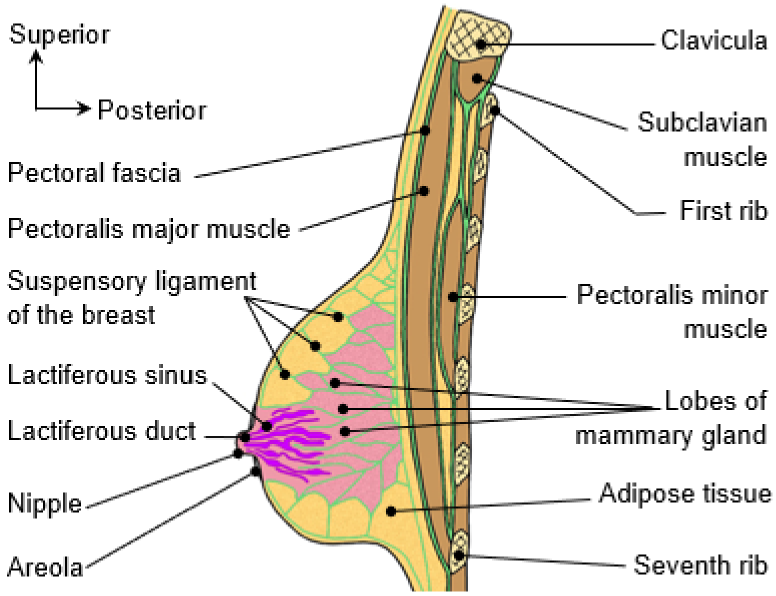



***Figure 313: Sagittal section of the breast.***

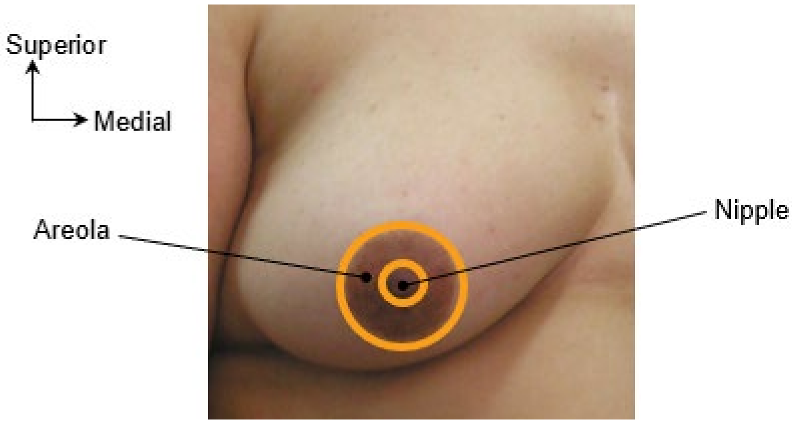



***Figure 314: Photography of the right breast from the front.***

# References


1. Abrahams P. H., Spratt J. D., Loukas M., & Van Schoo, A. (2013). McMinn & Abrahams: Clinical atlas of human anatomy. Elsevier Health Sciences. ISBN: 978-0723-43697-3
2. Brizon J. et Castaing J. Les feuillets d'anatomie ; Fascicule 10 Ostéologie de la tête (1ère partie) ; Fascicule 11 Ostéologie de la tête (2ème partie) et du tronc ; Fascicule 12 Muscles du cou et du tronc. Paris: Maloine, 1953.
3. FIPAT. Terminologia Anatomica. 2nd ed. FIPAT.library.dal.ca. Federative International Programme for Anatomical Terminology, 2019.
4. Gambarelli, J. (1977). Coupes sériées du corps humain: anatomie, radiologie, scanner. Springer. ISBN: 978-2225464645.
5. Hansen J. T. (2010). Netter's Clinical Anatomy. Saunders. ISBN: 978-1-4377-0272-9.
6. Kamina P. (2009). Anatomie clinique: Anatomie générale, membres. Maloine. ISBN: 978-2-224-03183-1
7. Kamina P. (2013). Anatomie clinique: Tête, cou, dos. Educa Books. ISBN: 978-2224033569
8. Kamina P. (2014). Anatomie clinique: Tome 3, Thorax, abdomen. Educa Books. ISBN: 978-2224033828
9. Kamina P. (2014). Anatomie clinique: Tome 4, Organes urinaires et génitaux, pelvis, coupes du tronc. Educz Books ISBN: 978-2224033835
10. Kamina P. (2013). Anatomie clinique: Tome 5, Neuroanatomie. Educa Books. ISBN: 978-2224033606
11. Kapandji A. I. (1975). Physiologie articulaire: schémas commentés de mécanique humaine. Maloine. ISBN: 978-2224010522

12. Kapandji, A. I. (2018). Anatomie Fonctionnelle. Maloine. ISBN: 978-2224035426
13. Monod Cl. Duhamel B. Schémas d'anatomie Ostéologie, 1er fascicule. Paris: Gilbert, 1951.
14. Monod Cl. Duhamel B. Schémas d'anatomie Membres supérieurs, 2èmefascicule. Paris: Gilbert, 1951.
15. Monod Cl. Duhamel B. Schémas d'anatomie Membres inférieurs, 3èmefascicule. Gilbert, 1951.
16. Monod Cl. Duhamel B. Schémas d'anatomie Tête et cou première partie, 4èmefascicule. Paris: Gilbert, 1954.
17. Monod Cl. Duhamel B. Schémas d'anatomie Tête et cou deuxième partie, 5ème fascicule. Paris: Gilbert, 1956.
18. Monod Cl. Duhamel B. Schémas d'anatomie Thorax 6èmefascicule. Paris: Gilbert, 1969.
19. Monod Cl. Duhamel B. Schémas d'anatomie Abdomen, 7èmefascicule. Paris: Gilbert, 1962.
20. Monod Cl. Duhamel B. Schémas d'anatomie Petit bassin 8èmefascicule. Paris: Gilbert, 1958.
21. Monod Cl. Duhamel B. Schémas d'anatomie Système nerveux central 9èmefascicule. Paris: Gilbert, 1970.
22. Netter, F. H. (2014). Atlas of Human Anatomy. Saunders. ISBN: 978-0-8089-2451-7
23. Patel M. et Creyssel J. (1930) Précis d'anatomie médico-chirurgicale. Tome 2. Abdomen-Membres inférieurs. Paris: Editions médicales Norbert Maloine.
24. Paulsen F., & Waschke, J. (2015). Atlas d'anatomie humaine Sobotta: 3 volumes. Paris. Médecine Sciences Publications ISBN: 2257205669
25. Rouvière H., & Delmas A. (2002). Anatomie humaine: descriptive, topographique et fonctionnelle. Tronc. Elsevier Masson. ISBN: 9782294003929
26. Rouvière H., & Delmas A. (2002). Anatomie humaine: descriptive, topographique et fonctionnelle. Tête et cou. Elsevier Masson. ISBN: 2294003918

27. Rouvière H. & Delmas A. (2002). Anatomie humaine: descriptive, topographique et fonctionnelle. Système nerveux central, voies et centres nerveux. Elsevier Masson. ISBN: 978-2294010224
28. Schuenke M., Schulte E., Schumacher, U. & Johnson, N. (2021). General Anatomy and Musculoskeletal System (Thieme Atlas of Anatomy), Latin Nomenclature. Thieme. ISBN: 978-1684200849
29. Standring S. Gray's anatomy. The anatomical basis of clinical practice. 40th edition. London: Elsevier Churchill Livingstone; 2008.
30. Tank P. W., & Gest T. R. (2009). Lippincott Williams & Wilkins Atlas of Anatomy. LWW. ISBN: 978-0-7817-8505-1
31. Waschke J, Böckers TM, Paulsen, editors. Sobotta anatomy textbook. English edition with latin nomenclature. 1st. ed. Munich. Elsevier; 2019.

**Prof. Dr. Slah-Eddine GHANNOUCHI**
Professor of Anatomy at the Faculty of Medicine Ibn El-Jazzar – Sousse.
Doctor ENSAM
Orthopaedic surgeon.
Sworn Judicial Expert.
Email: slaheddine.ghannouchi@gmail.com

**Prof. Dr. Raja DAHMANE**
Professor of Anatomy at the University of Ljubljana, Slovenia
Professor of Anatomy at the Faculty of Health Sciences of Ljubljana, Slovenia
Professor of Anatomy at the Faculty of Medicine of Ljubljana, Slovenia
Email: raja.dahmane@gmail.com

**Dr. Anja BOC**
Doctor of Medicine from the University of Ljubljana, Slovenia
Assistant of Anatomy at the Faculty of Medicine of the University of Ljubljana, Slovenia
Email: anja.boc@mf.uni-lj.si

**Prof. Dr. Mohamed Salah JARRAR**
Professor of Anatomy at the Faculty of Medicine Ibn El-Jazzar – Sousse.
Coordinator of the National College of Anatomy
Coordinator of the CEC of Thoraco-Abdomino-Pelvic Surgical Anatomy
Laboratory of Anatomy and Organogenesis
General and Digestive Surgery Department
CHU Farhat Hached - Sousse, TUNISIA
Email: hammadi.jarrar@gmail.com

**Prof. Dr. Soumaya MOUGOU ZRELLI**
Professor of Histology and Cytogenetics at the Faculty of Medicine Ibn El-Jazzar – Sousse.
Director of the Department of Basic Sciences A.
Cytogenetics Department
CHU Farhat Hached - Sousse, TUNISIA
Email: mougousoumaya@yahoo.fr

**Dr. Sihem KHELIFI**
Doctor of Medicine from the Faculty of Medicine, Ibn El-Jazzar – Sousse.
Responsible for IT management.
Forum/databases.
Anatomy and Organogenesis Laboratory.
Email: sihem.khelifi@gmail.com

**Sen.lect. Robert SOTLER**
Responsible for IT managament of Anatomy
Faculty of Health sciences of Ljubljana
University of Ljubljana, Slovenia
Email: robert.sotler@gmail.com