The Body

Parts of the Body (A, B)

The body is divided into the main part of the body (*trunk in the broad sense*) and the upper and lower limbs, or *extremities*. The trunk is divided into the head, the neck, and the torso (*trunk in the narrow sense*). The torso consists of the *thorax*, *abdomen*, and *pelvis*.

The upper extremity is joined to the trunk by the shoulder girdle and the lower extremity by the pelvic girdle. The shoulder girdle consists of the clavicles (**1**) and the scapulas (**2**), which lie on the trunk and move upon it. The pelvic girdle, which consists of the two hip (coxal) bones (**3**) and the sacrum (**4**), forms an integral part of the trunk.

General Terms (A–G)

Principal Axes

The *longitudinal (vertical) axis*, or long axis (**5**) of the body, is vertical when the body is in an upright posture.

The *transverse (horizontal) axis* (**6**) is perpendicular to the long axis and runs from left to right.

The *sagittal axis* (**7**) runs from the back to the front surface of the body in the direction of the arrow (Gr: *sagitta*) and is perpendicular to the other two axes.

Principal Planes

Median plane, the plane through the longitudinal axis and the sagittal axis; it is also called the *midsagittal plane* (**8**). It divides the body into two almost equal halves, or *antimeres* (hence is also called *plane of symmetry*). It includes the longitudinal and sagittal axes.

Sagittal or *paramedian plane* (**9**), any plane that is parallel to the midsagittal plane.

Frontal or *coronal plane* (**10**), any plane that contains the transverse and longitudinal axes and is parallel to the forehead and perpendicular to the sagittal planes.

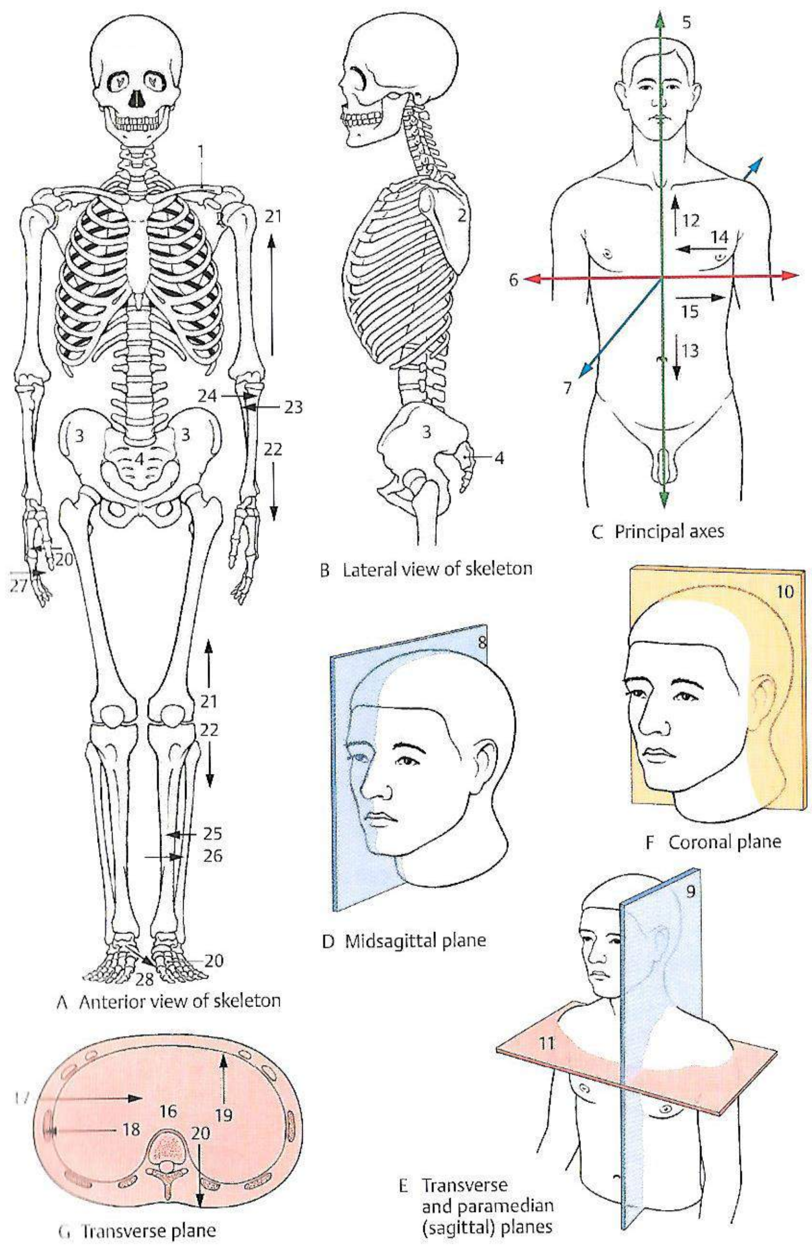
Transverse planes (**11**) lie perpendicular to the sagittal and coronal planes. They are horizontal in the upright posture and contain the sagittal and transverse axes.

Directions in Space

cranial = toward the head (**12**)
superior = upward with the body erect (**12**)
caudal = toward the buttocks (**13**)
inferior = downward with the body erect (**13**)
medial = toward the middle, toward the median plane (**14**)
lateral = away from the middle, away from the median plane (**15**)
medius = in the midline (**16**)
median = in the median plane
deep (profundus) = toward the inside of the body (**17**)
peripheral, superficial = toward the body surface (**18**)
rostral = toward the rostrum (beak), toward the oral and nasal region
anterior = toward the front (**19**)
ventral = toward the abdomen (**19**)
posterior = toward the back (**20**)
dorsal = toward the back (**20**)
proximal = toward the trunk or point of attachment (**21**)
distal = away from the trunk or point of attachment (**22**)
ulnar = toward the ulna (**23**)
radial = toward the radius (**24**)
tibial = toward the tibia (**25**)
fibular = toward the fibula (**26**)
palmar (volar) = on or toward the palm of the hand (**27**)
plantar = on or toward the sole of the foot (**28**)

Directions of Movement

flexion = the act of bending
extension = the act of straightening
abduction = movement away from the median plane
adduction = movement toward the median plane
rotation = movement around an axis
circumduction = circular (circumferential) movement



A Anterior view of skeleton

B Lateral view of skeleton

C Principal axes

D Midsagittal plane

E Transverse and paramedian (sagittal) planes

F Coronal plane

G Transverse plane

The Cell (A)

The smallest living entity is the *cell*. There are unicellular organisms, *protozoa*, and multicellular organisms, *metazoa*. Human cells range in size from 5 to 200 µm. They live for different lengths of time. Some cells survive for only a few days, for example granular leukocytes of the blood, and others survive the whole of the human life span, for example nerve cells.

Cells differ in shape depending on their function (e.g., muscle cells are elongated).

Each cell consists of the cell body, *cytoplasm* (**1**), and the nucleus, *karyoplasm* (**2**), which contains one or more *nucleoli* (**3**). The nucleus is separated from the cytoplasm by a double membrane, the *nuclear envelope* (**4**).

Cytoplasm

The cytoplasm is subdivided into **organelles**, **cytoskeleton**, and **cell inclusions**. These structures are contained in a fluid matrix, the **cytosol**.

The cell membrane, the *plasma membrane* or *plasmalemma* (**5**), appears as a trilamellar structure in electron micrographs. The cell surface is irregular and may exhibit thin processes, *microvilli*. The cell membrane is covered by a coating, the *glycocalyx*, which is approximately 20 nm thick. The glycocalyx is species specific as well as cell specific, thus facilitating cell-cell recognition.

Organelles

The endoplasmic reticulum (ER) (**6**) consists [illegible] The rough ER is involved in protein synthesis, while the smooth ER fulfills various other functions (e.g., it plays a role in lipid metabolism in hepatocytes).

The *mitochondria* (**7**) are of special importance as they provide the cell with energy. They are long, flexible, rod-shaped organelles that move about in the cytoplasm. They vary in number and size depending on the type and functional state of the cell.

The *Golgi apparatus* (**8**) consists of several *dictyosomes*, or *Golgi stacks*. Each dictyosome consists of a stack of disc-shaped cisterns. The Golgi apparatus is responsible for formation and supplementation of the glycocalyx but is also involved in the synthesis and modification of carbohydrates and polypeptides produced in the ER.

Other organelles are the *lysosomes* (**9**) and *peroxisomes* (microbodies).

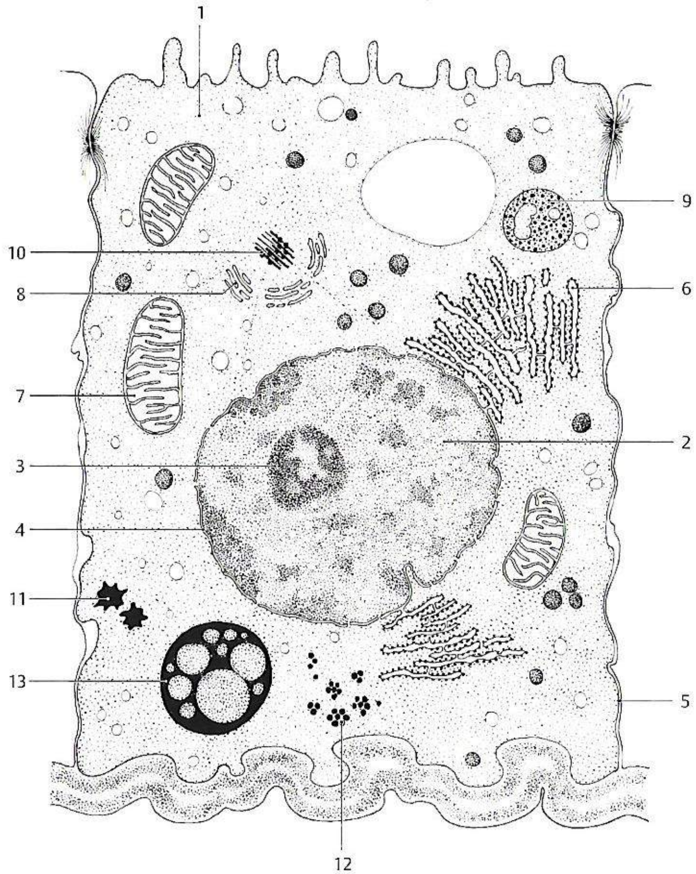
Cytoskeleton

The cytoskeleton consists of *microtubules* (including the *centrioles*, **10**, and *basal bodies*), *actin filaments* (microfilaments), and various cell-specific *intermediate filaments*. The two centrioles usually lie near the nucleus; together with the specialized cytoplasm surrounding them, the *centroplasm*, they form the *centrosome* (microtubule-organizing center). The cytoskeleton plays a major role in cell movement as well as intracellular movement (see p. 6).

Cell Inclusions

These include ribosomes, *lipids* (**11**), *glycogen* (**12**), *pigments* (**13**), *crystals*, and other insoluble components contained within a liquid matrix.

14 Vacuoles



A Diagram of a cell according to electron-microscopic findings
(from Faller, A.: Der Körper des Menschen, 13th ed. Thieme, Stuttgart, 1999)

Cell Nucleus (A, B)

The **nucleus** (A), composed of karyoplasm, is essential for the life of the cell. Its size depends on the size of the cell. Normally cells possess one or more nuclei. The nucleus is usually visible in living cells because it is more refractive than the cytoplasm; it is separated from the cytoplasm by the delicate birefringent nuclear membrane (1). Upon fixation, a network-like structure, *chromatin* (2), becomes visible in the *interphase nucleus* (the resting nucleus between cell divisions). The chromatin carries the genetic material; it condenses in the *dividing nucleus* to form the *chromosomes*.

The micronucleus, or *nucleolus* (3), consists of proteins and is rich in ribonucleic acid (RNA). The number and size of the nucleoli vary a great deal among different cells. In the cells of females, each active nucleus contains a clump of chromatin, the *sex chromatin* (Barr body, 4), which is attached to the nuclear membrane or the nucleolus. It can be used to determine the sex of a cell and thus of an individual. The sex chromatin is particularly easy to see in white blood cells (granulocytes) where it assumes the shape of a drumstick. In order to make the diagnosis of female sex, at least six drumsticks must be visible in 500 granulocytes.

Vital Cell Functions (C–H)

Every cell displays **metabolic activity**, which can be divided into *structural metabolism* and *functional metabolism*. Structural metabolism is the ability of a cell to assimilate ingested material to build up cellular structures, while functional metabolism is involved in cellular functions.

The uptake of particulate material is called phagocytosis, that of liquids pinocytosis. The release of substances by glandular cells is called secretion. The sum of oxidative processes within the cell is called cell respiration.

Among cellular **movements**, cytoplasmic movement is the most important one and includes movements of mitochondria, vesicles, and inclusions. More pronounced movements occur during each cell division. The cells themselves move by ameboid movement initiated by cytoplasmic processes called *pseudopodia*. Ameboid movement is especially pronounced in white blood cells (such as granulocytes and monocytes). Certain cells move by means of *cilia*, or *kinocilia*, which arise from basal bodies (*kinetosomes*). When joined together, ciliated cells form a **ciliated epithelium** and create *ciliary movement*. A cell with only one prominent cilium (*flagellum*) is called a *flagellated cell*.

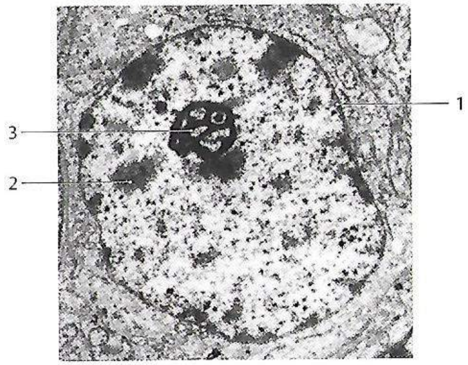
Reproduction of cells takes place by cell division. We distinguish between *mitosis*, *meiosis*, and *amitosis*. Each cell division requires division of the nucleus. The interphase nucleus changes into the dividing nucleus, and the chromosomes become visible and perform characteristic movements (*karyokinesis*) toward the two poles of the *mitotic spindle*.

The process of **mitosis** is subdivided into different phases, called the *prophase* (**C**), *prometaphase* (**D**), *metaphase* (**E**), *anaphase* (**F, G**), and *telophase* (**H**). The nuclei of the two daughter cells are subsequently reorganized into interphase nuclei (*reconstruction phase*).

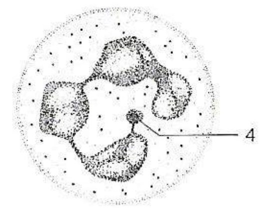
During **meiosis** (*reductional division*) the number of chromosomes per cell is reduced by half from the diploid to the haploid complement. The reduction takes place in both male and female germ cells during the first (or second) meiotic division and is required in preparation for fertilization.

During **amitosis** (*direct nuclear division*) the nucleus is divided by simple cleavage without chromosomal condensation and without the formation of a mitotic spindle. The distribution of chromosomes is therefore random. The nuclear division may or may not be followed by division of the cell.

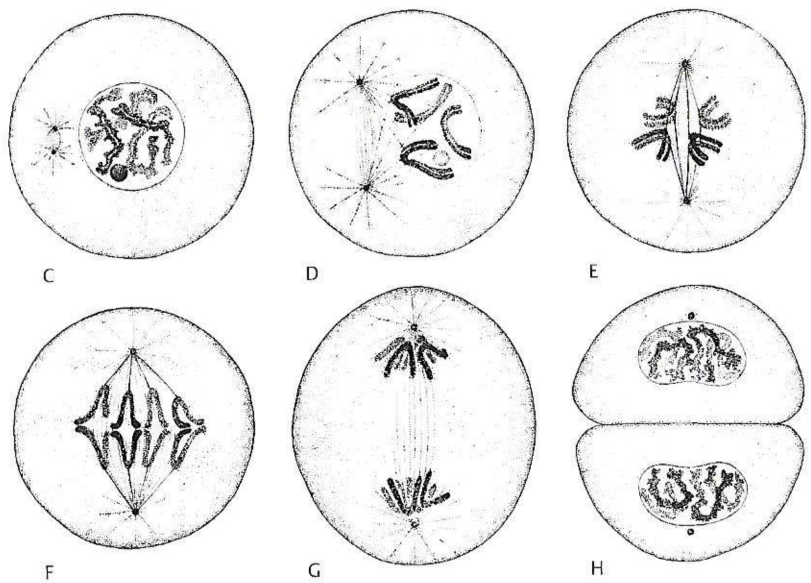
For more details, see Histologie, Zytologie und Mikroanatomie des Menschen by Leonhardt, H., 8th ed. Thieme, Stuttgart, 1990; Taschenatlas der Zytologie, Histologie und mikroskopischen Anatomie by Kühnel, W., 11th ed. Thieme, Stuttgart, 2002, and 12th ed., Thieme, Stuttgart, 2008.



A Cell nucleus, x 12,000; electron micrograph



B White blood cells with sex chromatin attached to the segmented nucleus, x 1,000 (panels A and B taken from Leonhardt, H.: Human Histology and Cytology, 8th ed. Thieme, Stuttgart, 1990)



C–H Diagram of mitosis (from Leonhardt, H.: Human Histology, Cytology, and Microanatomy, 8th ed. Thieme, Stuttgart, 1990)

Tissues

Tissues are aggregations of similarly differentiated cells and their derivatives. Multiple tissues may be associated to form an **organ.** The manner in which different cells are associated determines the different types of tissues. A more common system of classifying tissues is based not on the manner of association of cells but on their histologic structure and physiologic functions. **Epithelial**, **supportive**, and **muscular tissues** are described in this volume. Nervous tissue is discussed in Volume 3.

Epithelial Tissues (A–G)

Epithelial tissues are associations of closely adjoining cells. They can be classified according to **function**, as well as the **organization** and **shape** of their epithelial cells.

On the basis of their **functions**, superficial, glandular, and sensory epithelia can be distinguished. **Superficial epithelium** is, first of all, *a protective epithelium* that forms a covering for the external and internal body surfaces, prevents bacteria from entering the body, and keeps the body from drying up. Moreover, epithelia such as the *secretory and absorptive types* bring about the exchange of materials; that is, they can, on the one hand, take up substances (absorption) and, on the other hand, eliminate various substances (secretion). Epithelial tissue is also responsive to stimuli. This reception of stimuli takes place via the superficial epithelium through the induction of various specialized epithelial cells.

Glandular epithelium is a collective term for all epithelial cells that form a secretion and release it to an external or internal surface by an excretory duct (**exocrine glands**) or release it directly into the vascular system as a hormone (**endocrine glands**).

Exocrine glands can be classified as *endoepithelial* or *exoepithelial* depending upon their relationship to the superficial epithelium. Likewise, these glands can be divided into eccrine, apocrine and holocrine glands on the basis of the amount and manner of their secretions.

Eccrine cells are always ready to secrete and occur within the respiratory, digestive, and genital tracts (see Vol. 2). Apocrine glands are represented by the mammary and sweat glands; holocrine glands are represented by the sebaceous glands.

The **sensory epithelia** are specialized epithelia within the sensory organs and are discussed under that heading.

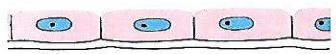
All epithelial cells rest upon on a basement membrane (*basal membrane*) which represents the boundary layer to the underlying connective tissue.

On the basis of their **organization**, epithelia can be divided into **simple** (single-layered, **A, B, C**), **stratified** (multilayered, **D**), or **pseudostratified** (**F**) epithelia. In the stratified epithelium only the deepest layer of cells makes contact with the basement membrane, whereas in the pseudostratified epithelium all cells contact the basement membrane, but not all the cells reach the surface.

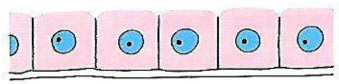
Epithelial cells can be classified by their **shape** as **squamous** (**A**), **cuboidal** (**B**), or **columnar** (**C**).

Squamous epithelium, a markedly protective epithelium, may be *nonkeratinized* or *keratinized*. The epithelium of the skin is keratinized squamous epithelium, whereas nonkeratinized squamous epithelium (**E**) is found in parts of the inner surfaces of the body that are particularly vulnerable to mechanical stresses, such as the oral cavity. Simple nonkeratinized squamous epithelium consists of attenuated, pavement-like cells that include serous membranes (**mesothelium**) and the epithelial lining of blood and lymphatic vessels (**endothelium**). Columnar and cuboidal cells that have processes, or cilia, are classified as **ciliated epithelium** (**F**), which lines the respiratory tract, for example.

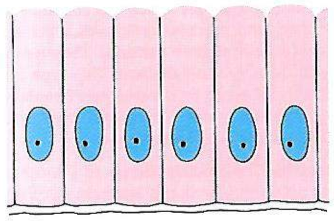
Cuboidal and columnar epithelia possess secretory and absorptive properties. They are found, for example, in the renal tubules (cuboidal) and in the intestinal tract (columnar). **Transitional epithelium** (**G**) is a special form of epithelium. Its cells can adapt themselves to different conditions of tension (distension and contraction) and make up the epithelium that lines the excretory portion of the urinary tract.



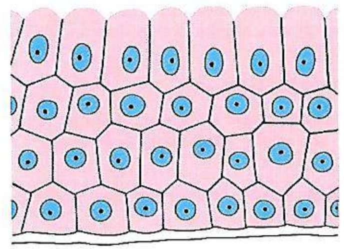
A Simple squamous epithelium (pavement epithelium)



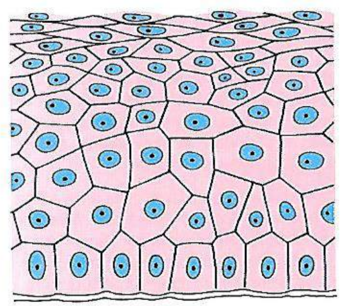
B Simple cuboidal epithelium



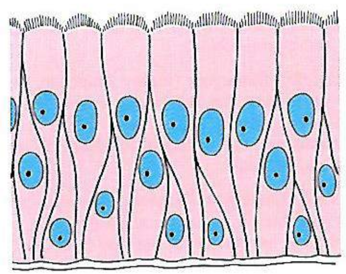
C Simple columnar epithelium



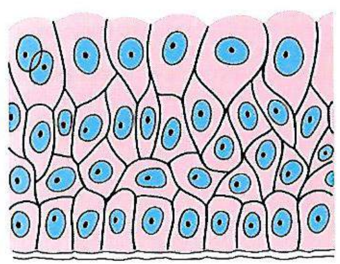
D Stratified columnar epithelium



E Squamous stratified epithelium (nonkeratinized)



F Pseudostratified ciliated epithelium



G Transitional epithelium

Connective Tissue and Supporting Tissues

These tissues consist of complex aggregations of cells, including **fixed** and **free cells**, and **intercellular substance**. The fixed cells are named according to the type of tissue, for example, connective tissue cells, cartilage cells, bone cells, etc. The intercellular substance in mature supporting tissue consists of *ground substance* and *differentiated fibers*.

The principal types are

Connective tissue: embryonic, reticular, interstitial, and rigid connective tissue and fatty (adipose) tissue

Cartilage tissue: hyaline cartilage, elastic cartilage, and fibrocartilage

Bone

Connective Tissue (A, B)

In addition to fixed and free cells, the intercellular substance contains reticular, collagenous, and elastic fibers, and ground substance, (proteoglycans and glycoproteins).

Fixed cells: **fibrocytes** (highly branched cells; their precursors, the fibroblasts, are able to produce intercellular substance and fibers), **mesenchymal cells**, **reticular cells**, **pigment cells**, and **fat cells**.

Free cells: **histiocytes** (polymorphic cells), **mast cells** (capable of ameboid movement) and, less commonly, **lymphocytes**, **plasma cells**, **monocytes**, and **granulocytes**.

The **intercellular substance** contains fibers—*reticular (lattice) fibers*—which resemble collagen in their structure (see below). They form fiber networks around capillaries, in basement membranes, around renal tubules, and elsewhere. The second group of *collagen* fibers consist of fibrils held together by an amorphous adhesive substance. They are found in all kinds of supporting tissues. They are wavy, almost unstretchable, and always occur grouped in bundles. This type is found particularly in tendons, the tympanic membrane, etc. Different types of collagen (I and III) are found in connective tissue, and these are dependent on the structure of the collagen molecules. Finally there are the (yellowish) *elastic fibers*, which are also arranged in networks. They occur in arteries near the heart, certain ligaments (ligamenta flava, see p. 56) and elsewhere. The intercellular substance also includes the **ground substance**, which is partly produced by the tissue cells. It is involved in the exchange of materials between tissue cells and the blood.

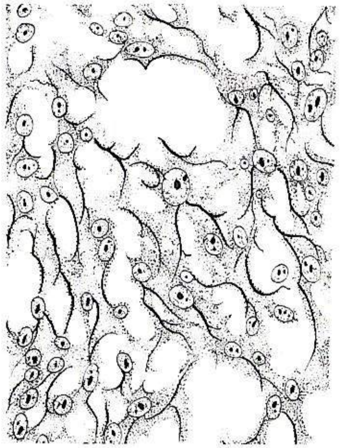
Embryonic connective tissue: contains mesenchymal cells and a mucinous, gelatinous ground substance. The most important type is mesenchyme.

Reticular connective tissue (**A**) contains reticular fibers and *reticular cells*, which are able to phagocytize and store material. They have a remarkably active metabolism. This type of connective tissue can be divided into *lymphoreticular* (in lymph nodes, etc.) and *myeloreticular* (bone marrow) connective tissue.

Interstitial connective tissue is a loose tissue with no particular shape. Its main purpose is to fill in the gaps between different structures (muscles, etc.) while also allowing for mobility between tissue layers. In addition to these functions, interstitial connective tissue takes part in general metabolism and regeneration. As well as cells (fibrocytes, fat cells) it contains collagen, elastic, and lattice fibers, and ground substance.

Rigid connective tissue (**B**) contains a high proportion of collagen fibers and fewer cells and less ground substance than interstitial connective tissue. It is found in the palmar and plantar aponeuroses, in tendons, etc.

Fatty tissue contains large cells with a flattened, eccentrically located nucleus. *Monovacuolar white fatty* (adipose) *tissue* should be distinguished from *plurivacuolar brown fat*. The latter is more abundant in infants and less so in adults (e.g., the renal fat capsule). In addition to fat cells, it contains interstitial connective tissue and shows some lobular structure. **Depot fat**, which depends on nutritional status, is distinguished from **structural fat**, which is independent of nutrition. The latter occurs in joints, bone marrow, the buccal fat pads, etc. Depot fat is most common in the subcutaneous fat layer. It is broken down according to requirements and the cells take on the form of reticular cells. After very marked weight loss (cachexia), these areas fill up with a collection of fluidserous fat cells.



A Reticular connective tissue, x 300

B Dense connective tissue in the corium, x 300 (panels A and B taken from Leonhardt, H.: Human Histology, Cytology, and Microanatomy, 8th ed. Thieme, Stuttgart, 1990)

Cartilage (A–C)

Cartilage is compressible as well as flexible, yet **resistant to pressure and to bending**, and is soft enough to be cut. It consists of cells and intercellular substance, which is almost devoid of vessels and nerves. The nature of the intercellular substance determines the type of cartilage, which can be subdivided into **hyaline**, **elastic**, and **fibrous** forms.

Cartilage cells, or *chondrocytes*, are fixed cells rich in water, glycogen, and fat. They have a vesicular appearance, with a spherical cell shape and spherical nucleus. The *intercellular substance*, which is very rich in water (up to 70%), forms the basis of the protective function of cartilage. Cartilage is almost avascular and free of nerves; it is composed of fibrils or fibers and an amorphous ground substance containing proteoglycans, glycoproteins, lipids, and electrolytes.

Hyaline Cartilage (A)

Hyaline cartilage is slightly **bluish** and milky and contains abundant collagenous fibrils (converted to gelatin by boiling) and scattered elastic networks within its intercellular substance. In articular cartilage, the collagen fibrils are always aligned in the direction of the greatest stresses. The cells occupying the cartilaginous lacunae are surrounded by a capsule that is separated from the remaining intercellular substance by the *cellular halo*. The cells, which can be organized more or less into rows or columns (see p. 16), form, together with the cellular halo, a *chondrone* or *territory*. This grouping always consists of several daughter cells originating from one cell. Cartilage is surrounded externally by a connective tissue covering, the *perichondrium*, which is more or less continuous with the cartilage itself.

Hyaline cartilage exposed to pressure (articular surfaces of the lower limb) contains more glycosaminoglycans (chondroitin sulfate) than less stressed hyaline cartilage (e.g., articular surfaces of the upper limb).

The lack of sufficient blood vessels may favor degenerative processes inside the cartilage. These are initiated by the "unmasking" of collagenous fibers; that is, the collagenous fibrils become visible in the microscope. Since the content of water and chondroitin sulfate decreases with age, the stress capacity of hyaline (articular) cartilage decreases.

Calcification of hyaline cartilage occurs very early in life.

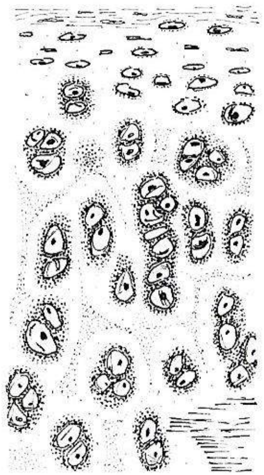
Hyaline cartilage is found in joint cartilage and rib cartilage, in respiratory tract cartilage, in epiphyseal disks and in the precursors of those parts of the skeleton that undergo chondral ossification. **Epiphyseal disk cartilage** contains columns or rows of cartilage cells, a structure that enables growth of cartilage (see p. 16) and subsequently of the bone that follows it.

Elastic Cartilage (B)

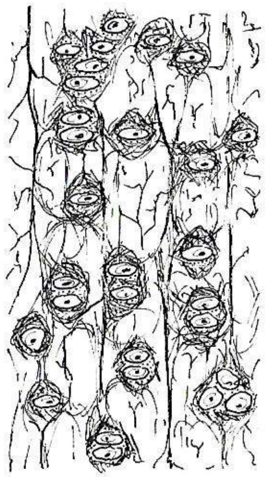
In contrast to the bluish hyaline cartilage, elastic cartilage is **yellowish** in color. Its intercellular substance is rich in elastic fibers and contains fewer collagen fibrils. The large proportion of elastic fibers makes this type of cartilage particularly pliable and elastic. It does not contain calcified deposits. It is found in the auricle, the epiglottis, etc.

Fibrocartilage (C)

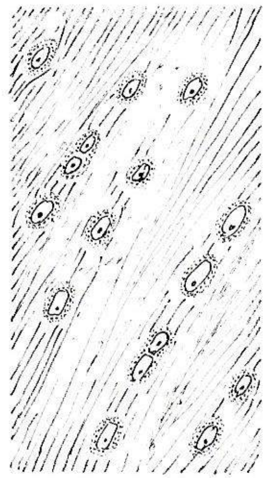
Fibrocartilage, also known as connective tissue cartilage, contains fewer cells than the other types but has many *bundles of collagen fibers*. It is found particularly in parts of the intervertebral disks (see p. 54) and of the symphysis pubis (see p. 22).



A Hyaline cartilage (rib cartilage), x 180



B Elastic cartilage (ear cartilage), x 180



C Fibrocartilage (intervertebral disk), x 180
(Figs. A–C taken from Leonhardt, H.: Human Histology, Cytology, and Microanatomy, 8th ed. Thieme, Stuttgart, 1990)

Bone (A, B)

Bone tissue (osseous tissue) consists of bone cells (*osteocytes*), *ground substance*, *collagenous fibrils*, a *cement substance*, and *various salts*. The ground substance and collagenous fibrils form the intercellular substance, the *osteoid*. The fibrils belong to the organic part, the salts to the inorganic part. The most important salts are calcium phosphate, magnesium phosphate, and calcium carbonate. In addition, compounds of calcium, potassium, and sodium with chlorine and fluorine are found.

Clinical tip: The salts confer hardness and strength. A salt-free or "decalcified" bone is pliable. A deficiency in calcification may result from vitamin deficiency as well as from hormonal disturbances. A vitamin deficiency may arise, for example, when there is an absence of ultraviolet light exposure resulting in a failure to convert provitamins into vitamins. Inadequate calcification leads to a softening of the bone, for example in rickets.

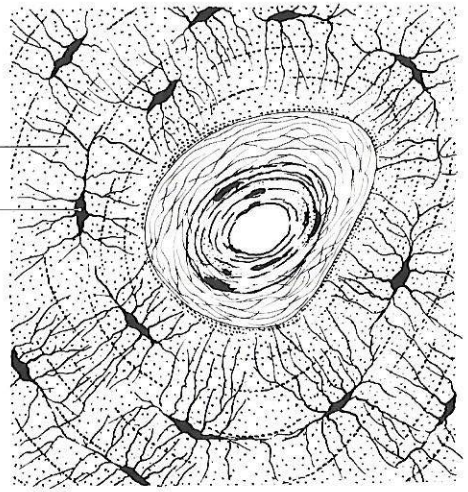
The organic constituents, like the salts, are also responsible for the strength of a bone. When there is inadequate organic material, the elasticity of the bone is lost, and as a result the bone becomes brittle and can no longer withstand stress. The relationship between inorganic salts and collagenous fibrils becomes altered during life. In the newborn the content of inorganic salts amounts to about 50% and this rises to 70% in the elderly along with a loss of elasticity, as the bone becomes less flexible and shock resistant. Destruction of the organic matter can also be induced artificially by exposure to heat.

Two types of bone can be distinguished on the basis of the arrangement of its fibrils: **woven bone** (reticulated) and **lamellar bone**. Nonlamellar, woven bone corresponds structurally to ossified connective tissue and in humans primarily occurs only during development. In the adult it is found only in the capsule of the inner ear and along the sutures of the cranial bones.

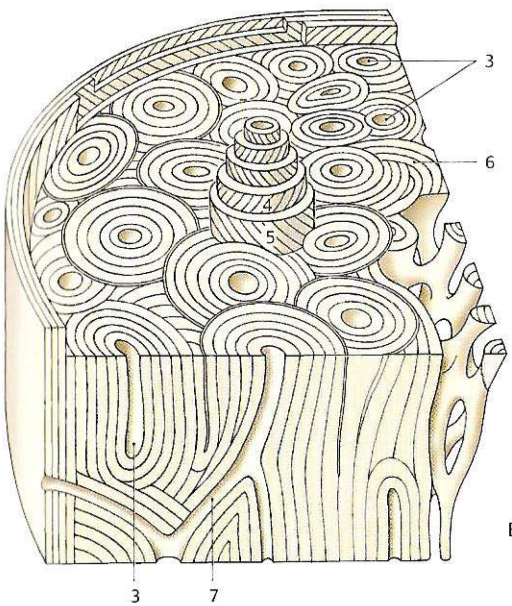
The substantially more common and more important **lamellar bones** (**A, B**) exhibit a distinct stratification produced by layers of parallel collagen fibrils that are called *lamellae* (**1**). These lamellae alternate with layers of *osteocytes* (**2**). The lamellar arrangement takes place around a vascular canal, the *central canal*, or *haversian canal* (**3**), which, together with its lamellae, constitutes an osteon or *haversian system* (**A**). The collagenous fibers are approximately 2 to 3 µm thick and are arranged spirally in such a way that a right (**4**) and a left spiral (**5**) lamella (5–10 µm thick) alternate with one another, producing an increase in stability.

Between the osteons are *interstitial lamellae* (**6**), which are the remnants of former osteons. The vascular canals in the osteons communicate with smaller *oblique canals*, which are called *Volkmann's canals* (**7**). The structure and organization of the osteons are dependent on the stresses in the bone. When there is a change in stress, the osteons become reconstructed, as evidenced by macroscopic observation. In this case, attention should be especially paid to the behavior, within the femur, of the *trajectories*, the lines of tension, which are developed in response to the stresses.

The nourishment of bone takes place from the periosteum (see p. 20). Bone marrow is nourished via the nutrient foramina (nutrient arteries).



A Haversian system (osteon), x 400. In the center is a haversian vessel with perivascular connective tissue (from Leonhardt, H.: Human Histology, Cytology, and Microanatomy, 8th ed. Thieme, Stuttgart, 1990)



B Diagram of the compact part of the diaphysis of a long bone

Development of Bone (A–C)

Bone formation (*osteogenesis*) is based on the activity of *osteoblasts* (**1**), which are specialized mesenchymal cells. Osteoblasts secrete an intercellular substance, *osteoid*, which consists initially of soft ground substance and collagen fibers. Osteoblasts develop into *osteocytes*, the definitive bone cells. At the same time multinucleated *osteoclasts* (**2**) develop; these bone-degrading cells are associated with the absorption and remodeling of bone.

We distinguish *direct bone formation (intramembranous ossification)* (**A**) from *indirect bone formation (chondral ossification)* (**B, C**).

Intramembranous ossification, *osteogenesis membranacea* (**A**), is the development of bone from connective tissue. The latter contains many mesenchymal cells that develop via osteoblasts (**1**) into osteocytes. At the same time, osteoclasts (**2**) develop and collagen fibers also appear. The original bone is membrane bone and is later remodeled into lamellar bone. The skull cap, the facial bones, and the clavicles develop as intramembranous bones.

Chondral ossification, *osteogenesis cartilaginea* (**B, C**), requires preformed parts of skeletal cartilage (cartilage models), which will then become replaced by bone. Growth is possible only as long as cartilage still remains. The prerequisite for replacement bone formation is the presence of *chondroclasts*; these are differentiated connective tissue cells that degrade cartilage and thus enable the osteoblasts to form bone. Two types of replacement bone formation are recognized—*endochondral* (**C**) and *perichondral ossification*.

Endochondral ossification (**3**) begins inside the cartilage, and occurs predominantly in the epiphyses. The **epiphyses** are the ends of the long bones (see p. 20), while the shafts are called **diaphyses**. *Perichondral ossification* (**4**), which originates in the perichondrium (**5**), is confined to the diaphysis. The *epiphyseal disk* (growth plate) (**6**), which is necessary for growth in length, forms a layer between the epiphysis and the diaphysis. That part of the shaft adjacent to the epiphyseal disk is called the **metaphysis** and develops first on an endochondral basis (see below).

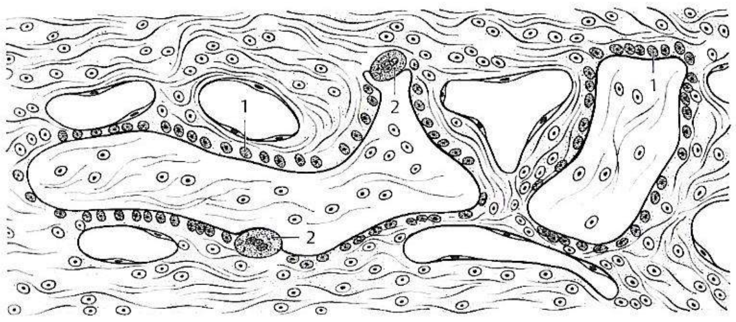
Clinical tip: An *apophysis* is a bony protuberance that does not arise from its own ossification center but develops purely in response to tendon traction. An example is the mastoid process (see pp. 288 and 290).

Within the epiphyseal cartilage, the processes of ossification occur in separate zones. In the epiphysis there is the *zone of reserve cartilage*, a capping of hyaline cartilage that is not affected by bone formation in the epiphyseal plate. Next to this inactive cartilage is the *zone of growth* (**7**), where the cartilage cells form columns. Here the cartilage cells divide, thus increasing in number. The next layer closer to the shaft is the *zone of maturation* (**8**); it contains vesicular cartilage, and calcification is already occurring. It is followed by the *zone of ossification*, where cartilage is degraded by chondroclasts and replaced with bone by osteoblasts. Some remnants of cartilage remain, so that the endochondral bone (**9**) of the diaphysis can be distinguished from the perichondral bone. It will later be replaced by perichondral bone. The endochondral bone is destroyed by the invading osteoclasts.

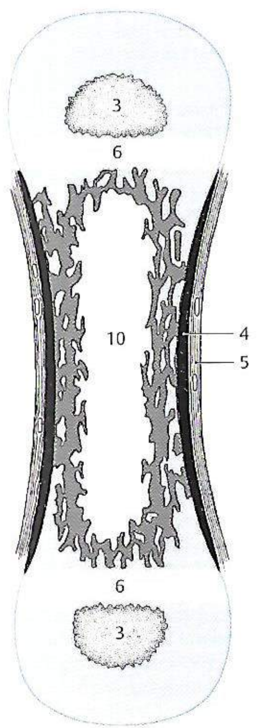
The increase in bone diameter in the region of the diaphysis is brought about by the deposition of new bony material on the outer surface beneath the cellular layer of the periosteum. The *bone marrow cavity* (**10**) becomes larger as a result of bone destruction. All growth processes are regulated by hormones.

The bony anlages in the epiphyses first appear after birth, except for those in the distal femoral epiphysis and the proximal tibial epiphysis. In both of these epiphyses, and in the cuboid bone, osteogenesis begins just before birth in the 10th intrauterine month (a sign of maturity).

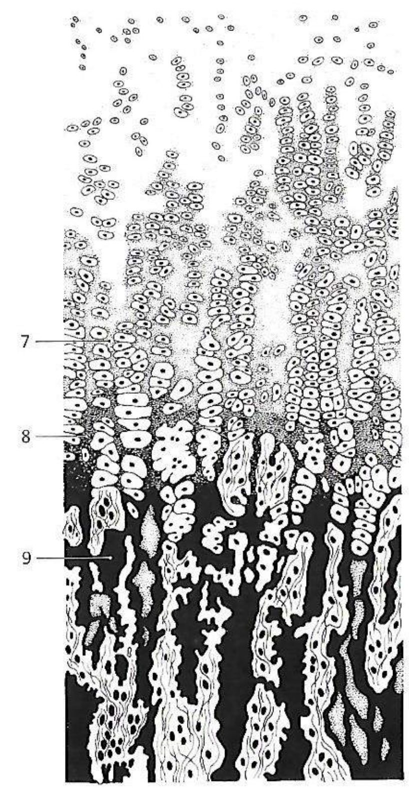
Clinical tip: After closure of the epiphyseal disk X-rays show a fine line, later, in adolescence, known as the **epiphyseal disk scar.**



A Intramembranous ossification



B Chondral ossification of a long bone (diagram). Endochondral ossification in the epiphyses and perichondral ossification in the diaphysis



C Ossification in the region of the epiphyseal disk cartilage

Muscular Tissue (A–D)

Muscular tissue is characterized by elongated cells containing myofibrils formed from myofilaments. These myofibrils are responsible for the contractility of the muscle cells. Three types of muscular tissue can be distinguished on the basis of fine structure and physiologic characteristics: smooth (**A**), striated (**B**, **D**), and cardiac muscle (**C**).

Smooth Muscle (A)

Smooth muscle consists of spindle-shaped cells, each being 40 to 200 µm long and 4 to 20 µm thick, with a central nucleus. These myofibrils are difficult to demonstrate and do not have transverse striations. Transverse reticular fibers join adjacent muscle cells and bind groups into functional units. Smooth muscle is not under voluntary control; axons synapse directly with the muscle cells (see Vol. 3).

Hormonal influences may cause smooth muscle to increase in length and to proliferate; that is, there may not only be an increase in the size of the cells but cells may also be newly formed. An example is the uterus, the muscle fibers of which may reach a length of 800 µm.

Striated Muscle (B, D)

Striated muscle consists of muscle cells (muscle fibers) which may be 10 to 100 µm thick and up to 15 cm long. The nuclei lie immediately beneath the surface of the cells in the direction of the long axis of the muscle fibers. The myofibrils are easily visible and are responsible for the longitudinal striations. The transverse striations are due to the periodic alternation of smaller, lighter, singly refractive (isotropic) zones (I bands) and wider, darker, double refractive (anisotropic) zones (A bands). The A bands contain a light zone (H band) with a fine, dark middle line (M band), and the I bands show a delicate, anisotropic intermediate line (Z band). The myofibrillar segment that lies between two Z bands is called a sarcomere.

Each skeletal muscle cell contains several nuclei. The cytoplasm (*sarcoplasm*) contains a variable number of mitochondria (*sarcosomes*). According to their function, a distinction is made between *twitch* muscle fibers and *tonic* muscle fibers. The twitch muscle fibers include red (fast twitch) muscle fibers with high myoglobin and mitochondria content (for long-term stress performance) and white muscle fibers with high myofibril content (for short-term maximum stress performance).

The color of a muscle is due to its blood supply and the myoglobin in solution in the sarcoplasm. In addition, the color is determined also by the water content and the abundance of fibrils. This explains why different muscles differ in color. Thinner fibers with fewer fibrils and less water content are light in color, while thicker fibers appear darker.

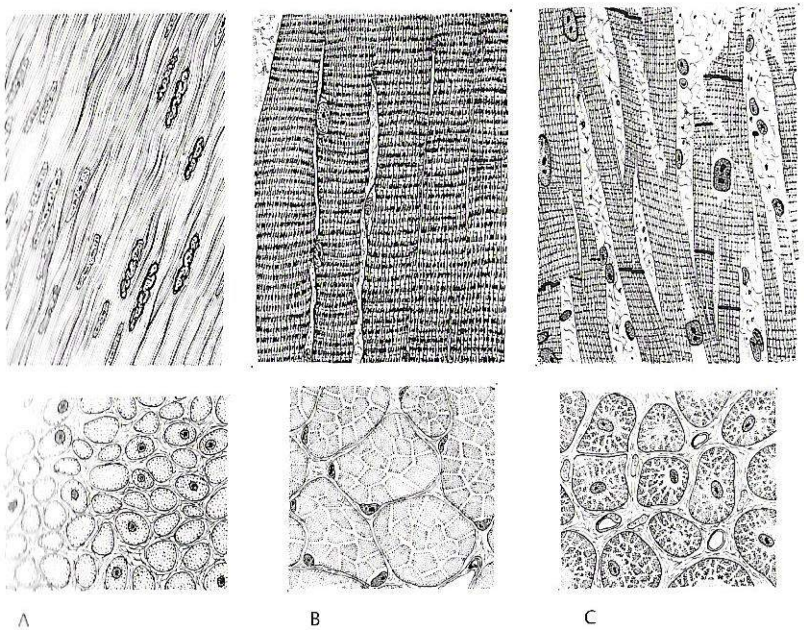
The *sarcolemma* encloses individual muscle fibers as a connective tissue sheath. There is a delicate layer of connective tissue, the *endomysium*, between the fibers. Several muscle fibers are surrounded by the *internal perimysium*, and together they form the primary muscle bundle (fascicle).

The *external perimysium* is a connective tissue layer that combines several primary bundles to form a muscle.

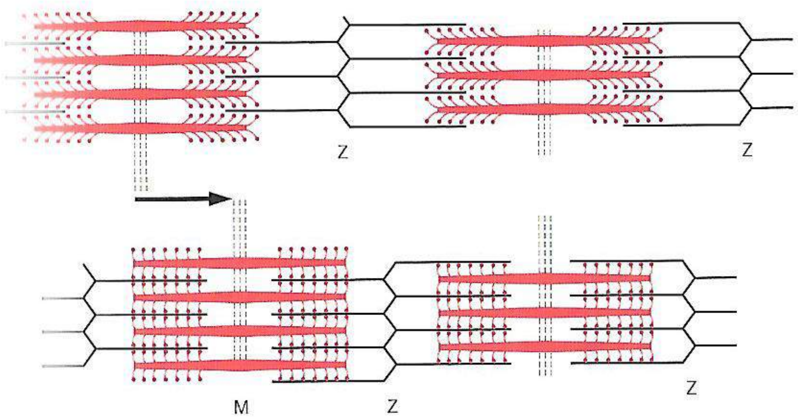
Striated skeletal muscles are voluntary muscles, and they are innervated via motor end plates (neuromuscular junctions) (see Vol. 3).

Striated Cardiac Muscle (C)

The muscle fibers of the heart contain a large amount of sarcoplasm and form networks. Transverse striations are present, but the sarcomeres are shorter and the I band is narrower than in skeletal muscle. In cardiac muscle fibers the nuclei lie centrally. *Sarcosomes* are far more numerous than in skeletal muscle. In addition, cardiac muscle tissue contains highly refractile, transverse *intercalated disks*, which lie at the position of a Z band. Further details are given in Volume 2.



Longitudinal section (top row) and transverse section (bottom row) of smooth muscle (A), striated muscle (B), and cardiac muscle (C), x 400 (from Leonhardt, H.: Human Histology, Cytology, and Microanatomy, 8th ed. Thieme, Stuttgart, 1990)



D Diagram of myofibrils during relaxation (top) and contraction (bottom)

General Features of the Skeleton

Classification of Bones (A–F)

The **bones** form the bony **skeleton** and, with the joints, they represent the passive locomotor system, which is controlled by the active locomotor apparatus, the musculature. The different shapes of bones are dependent on their function and their position in the body. Macroscopically, two differently constructed portions can be distinguished. A rather *dense compact* or *cortical bone* (**1**) is generally observed on the surface. Within the short and flat bones and in the epiphyses and metaphyses of the long bones, there is a spongelike meshwork formed of individual bony trabeculae, *trabecular* or *spongy bone* (**2**). Between the meshes is the bone marrow or medulla. In the flat bones of the skull, the compact material is called the *external* (**3**) and *internal* (**4**) *laminae* and in between them is the *diploë* (**5**), corresponding to the spongy bone.

Long Bones (A–C)

A long bone as, for instance, the humerus (**A**), consists of a *body* (**6**) and two *ends* (**7**). In the center of the shaft (body) of a long bone (**B**, **C**) is the bone marrow or *medullary cavity* (**8**), which contains red or yellow bone marrow. This cavity is the reason for the name "tubular bones." Tubular bones grow mainly in *one* direction.

Flat Bones (D)

Flat bones consist of two layers of compact bone between which there may be found spongy material. Flat bones include the scapula and several bones of the skull, for example the parietal bone (**D**). Basically, growth in flat bones proceeds in *two main* directions.

Short Bones (E)

The short bones, which include, for instance, the small bones of the wrist (e.g., the capitate bone [**E**]), have a spongy core surrounded by compact bone.

Irregular Bones

These include all those bones, such as vertebrae, which do not belong to any of the preceding groups.

Pneumatized Bones (F)

These bones contain air-filled cavities lined by mucous membrane (**9**). They are found in the skull (ethmoid, maxilla [**F**], etc.).

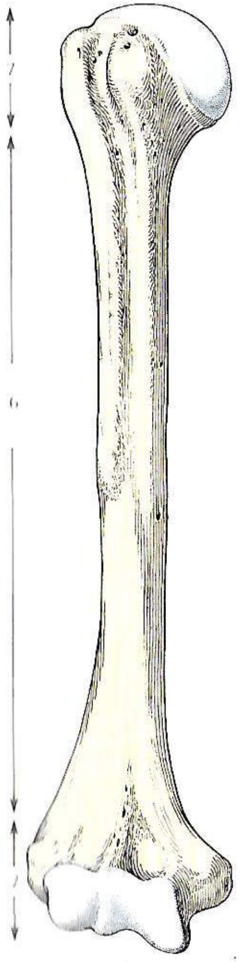
Sesamoid Bones

These mostly occur in the skeleton of the hands and feet. They may also be found in tendons, for example the *patella*, the largest sesamoid bone in the body.

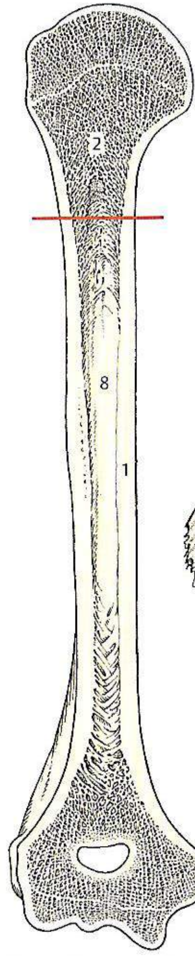
Periosteum

The **periosteum** covers all parts of the bone that are not joint surfaces. It consists of a *fibrous layer* and an *osteogenetic layer* forming the cambium layer. It contains many blood and lymph vessels and nerves. The latter account for the pain felt after a blow to a bone. Larger blood vessels in the outer layer send numerous capillaries to the inner, cell-rich layer. This is the site of the osteoblasts, which build up bone. After fractures, formation of new bone starts in the periosteum.

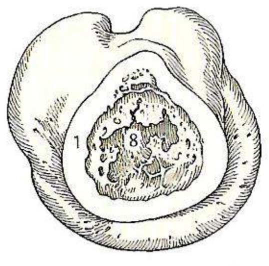
Blood vessels and nerves reach the bone through nutrient foramina. Some bones have canals that also serve for the passage of vessels, usually only veins, which are known as emissary veins. They are found, for example, in the vault of the skull.



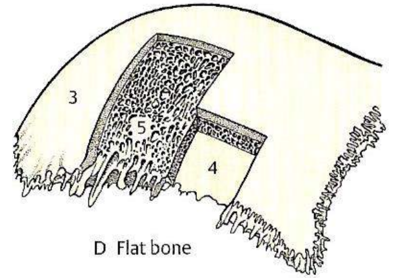
A Long bone



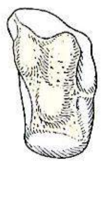
B Longitudinal section through a long bone



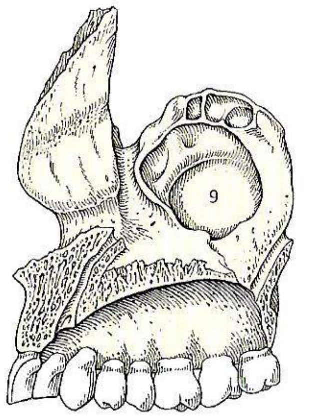
C Long bone, transverse section in the proximal third (red line in B), viewed toward the proximal end



D Flat bone



E Short bone



F Pneumatized bone

Joints between Bones

The individual bones of the skeleton are connected either *continuously* or *discontinuously*. Continuous bony joints comprise the large group of **synarthroses**, in which two bones are joined directly by various tissues.

Continuous Joints between Bones (A–H)

Fibrous Joint (A–E), Syndesmosis

In a syndesmosis two bones are joined by collagenous or elastic connective tissue. The union may be expansive or narrow. The *interosseous membrane* (**1**) in the forearm is a very taut syndesmosis consisting of collagenous connective tissue. More elastic syndesmoses are the *ligamenta flava* between the vertebral arches.

The **sutures of the skull** are a particular type of syndesmosis (**B–E**). These sutures retain connective tissue, which has persisted between the bones developing from connective tissue. Only when the connective tissue has completely disappeared does the growth of the skull cease and do the sutures fuse. The sutures of the skull are classified according to their shape: *serrate suture* (**B**) with sawlike edges, as in the sagittal suture; *squamous suture* (**C, D**) where one bone overlaps another, as between the parietal bone and the temporal bone; and last, *plane suture* (**E**) as between the nasal bones.

A specialized type of fibrous joint is the **gomphosis**, a peg-and-socket joint found in the fixation of the teeth in the alveoli of the jaw. Here, the tooth is joined to the jaw by connective tissue, which permits a slight degree of displacement.

Cartilaginous Joint (F), Synchondrosis

The second, large group of continuous bony joints is formed by the synchondroses (**2**), which are joints of hyaline cartilage between two bones. During adolescence, these are always found in the *epiphyseal disks*. Hyaline cartilage material is also present between the first, sixth, and seventh ribs and the sternum. The cartilaginous material disappears from those sites where it only permits growth. Epiphyseal disks or cartilage are subsequently completely replaced by bony material.

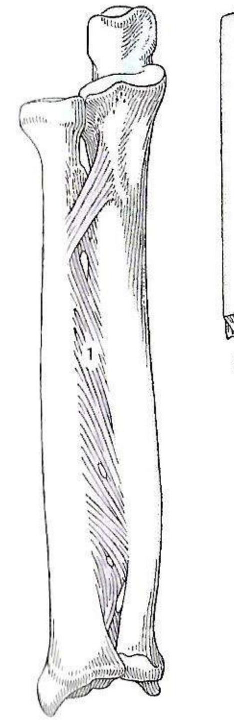
Symphysis (G)

Symphyses are also cartilaginous joints in which two bones are bound by fibrocartilage and connective tissue, for example between the two pubic bones (*pubic symphysis* **G**).

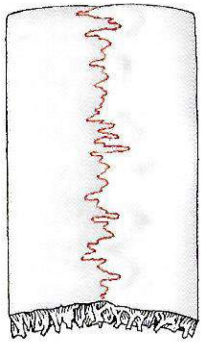
Bony Union (H), Synostosis

This is the firmest possible joint between two bones, for example between the parts of the hip bone, or between epiphyses and diaphyses after growth has ceased.

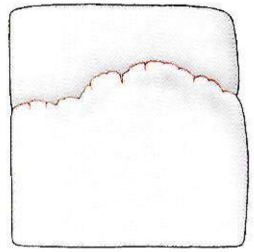
Clinical tip: Synovial joints may sometimes become synostotic. However, they are then not called synostoses, but ankyloses (stiffened joint). An **ankylosis** presupposes that the joint was previously movable, and the alteration is usually the result of a disease process. Physiologic ankylosis is regarded as the fusion of the articular processes of the sacral vertebrae.



A Interosseous membrane

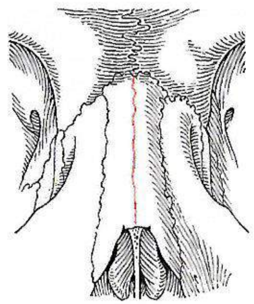


B Serrate suture

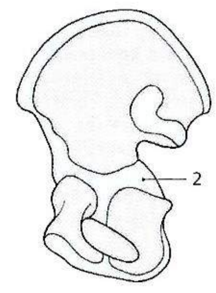


C Squamous suture

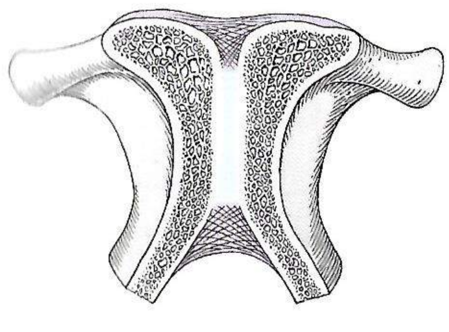
D Squamous suture in cross section



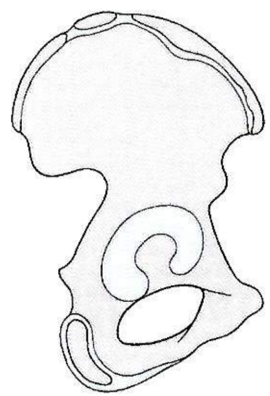
E Internasal suture



F Hip bone, medial view; cartilaginous interstices still present



G Symphysis



H Hip bone, lateral view; cartilaginous interstices closed

Discontinuous Joints between Bones (A–C)

These joints, **diarthroses** or **synovial joints**, consist of *articular surfaces* (**1**), an *articular capsule* (**2**), a *joint cavity* (**3**) between the articular surfaces, and, according to need, some *additional features* (strengthening ligaments, intercalated disks, articular lips [labra], and bursae).

In a joint with two articular surfaces or bodies, that articular body which is moved is the *movable segment*; the one at comparative rest is the stationary or *fixed segment*.

To assess the degree of mobility of a joint, it is necessary to determine the *angle of excursion* (**4**), that is, the angle between its *initial* and *final* positions. The angle of excursion of a joint may be reduced by various factors. They include, in addition to the tension of the articular capsule, additional ligaments that restrict movement (*ligamentous limitation*, see p. 26), bony processes (*bony limitation*), and limiting surrounding soft tissues (*soft tissue limitation*). The *midposition* (**5**) is that position between the initial and final positions in which all parts of the joint capsule are under equal tension.

Clinical tip: The range of movement of a joint is now stated in terms of the neutral-0 position based on the SFTR method of *Russe* and *Gerhardt* (**C**). The neutral-0 position of all joints is that occurring in an upright posture with the arms hanging at the sides and the palms facing forward. There is a distinction between anatomical and anthropological methods of measurement. Movements are measured in the **S**agittal plane, **F**rontal plane, and **T**ransverse plane and during **R**otation (SFTR). In the numbers given, it should be remembered that the first figure always refers to extension, retroversion, abduction, external rotation, supination, or a movement to the left corresponding to the function of the joint. The second number is the neutral-0 position and the third is the final position in opposition to that of the first movement.

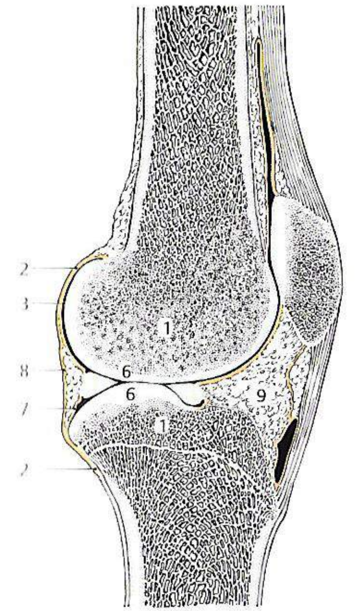
Articular Surfaces

A joint possesses at least two articular surfaces. They are usually covered by hyaline cartilage (**6**) and occasionally by fibrocartilage or connective tissue interspersed with fibrocartilage.

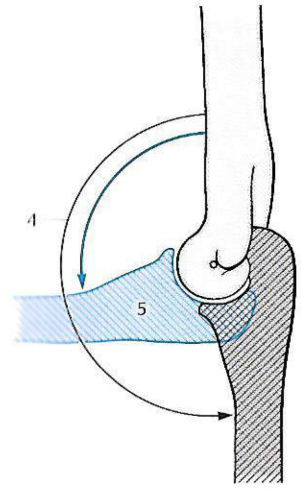
The cartilage is tightly interlocked with the bone, and its surface is shiny and smooth. The thickness of the cartilage layer varies from 2 to 5 mm, although the patella has some very thick areas, up to 6 mm. The cartilage is nourished via the synovial fluid as well as by diffusion from the capillaries in the synovial membrane.

Joint Capsule

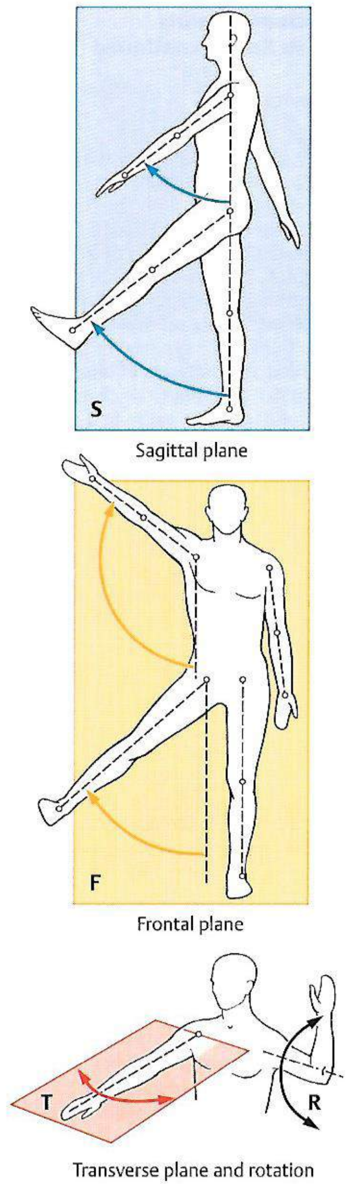
The joint capsule may be taut or loose and is attached to the bone near the cartilage-covered surfaces. It consists of two layers, the inner *synovial membrane* (**7**) and an *outer fibrous membrane* (**8**). The synovial membrane contains elastic fibers, blood vessels, and nerves. The amount of blood supply is directly related to the degree of activity so that very active joints are more richly vascularized than less active ones. The synovial membrane possesses inward-facing processes containing fat, the *plicae synoviales* (**9**), synovial folds, and *synovial villi*. The fibrous membrane is of variable thickness and contains a large quantity of collagen fibers and very few elastic ones. Irregularities in the thickness of the fibrous membrane may result in weak spots through which the synovial membrane may protrude; these cyst-like protrusions are called *ganglia* by the surgeon.



A Section through knee joint



B Angle of excursion and middle position



C Neutral-0 method and SFTR recording

Discontinuous Joints between Bones, continued

Joint Cavity (A, C)

A joint or articular cavity (**1**) is a cleftlike capillary space that contains *synovial fluid*. This is a clear, viscous, mucin-containing fluid resembling albumin. The fluid acts as a lubricant and aids nutrition of the articular cartilage. Its viscosity is determined by its content of hyaluronic acid and is temperature-dependent—the lower the temperature, the higher the viscosity of the synovial fluid. Since synovial fluid may also be regarded as a dialysate of blood plasma, its chemical and physical characteristics may be of diagnostic value in a variety of diseases.

Additional Features (A–D)

Ligaments (**2**). Ligaments are designated by their function as *reinforcing ligaments* (for the joint capsule), *guiding ligaments* (in movements), or *restrictive ligaments* (to constrain movements). According to their position there are *extracapsular*, *capsular*, and *intracapsular* ligaments.

Articular disks or **menisci** (**3**) consist of collagenous connective tissue containing fibrocartilage. A disk divides the joint cavity completely; a meniscus, only partly. They affect the direction of movement, ensure good contact between the moving parts, and may, in certain circumstances, produce two completely independent joint spaces, as, for instance, in the mandibular and sternoclavicular joints. Regeneration of disks after injury or removal is possible.

Articular labra (**4**) consist of collagenous connective tissue with scattered cartilage cells and serve to enlarge the joint surface.

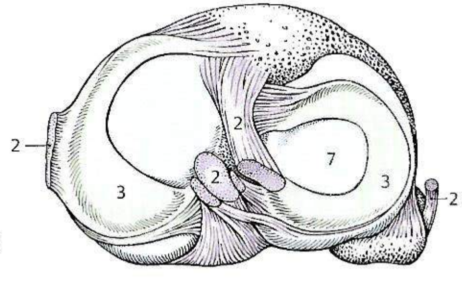
Bursae and **synovial pouches** may communicate with the joint cavity (**5**). They form large or small, thin-walled sacs lined by synovial membrane (**6**). They create a weak point in a joint but also serve to enlarge the joint space.

Maintenance of Contact

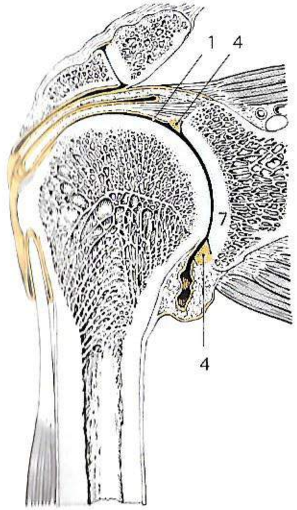
There are various forces that act on the two articular surfaces and maintain contact between them. First, there are the muscles that span the joint and ensure a certain degree of contact between the articular surfaces. Next, there may be accessory capsular ligaments to increase the degree of contact. In addition, there is a certain degree of surface adhesion and, as another important factor, atmospheric pressure. Atmospheric pressure holds the articular surfaces together with a force equal to the product of the area of the smaller joint surface and the air pressure.

Clinical tip: Joints are subject to **age-related changes**; the avascular articular cartilage (**7**) loses its elasticity with aging.
Surfaces covered by cartilage undergo age-related alterations (**8**) and may degenerate. Outgrowths from the cartilage margins may occur, which are sometimes invaded by bone-forming cells. In such instances the cartilage becomes ossified and restricts joint mobility. Such processes may affect small joints such as intervertebral joints, and they may occur in young people if the joints in question are overstressed.
The "vacuum phenomenon," first described by Fick, refers to linear or crescent-shaped lucencies that appear in radiographs of joints and are caused by tissue gases entering the joint.

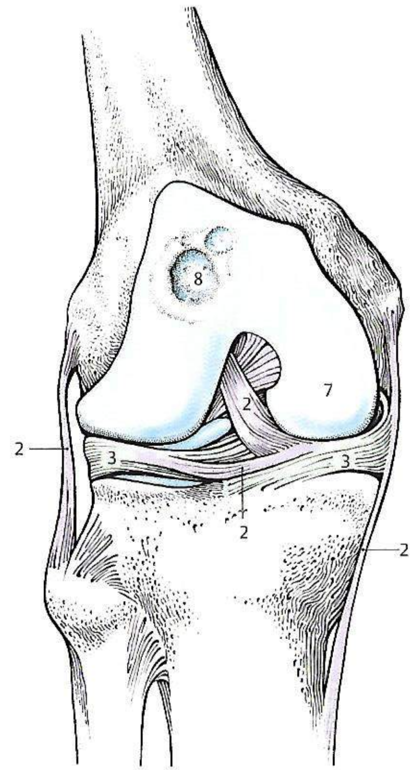
A Section through knee joint



B Menisci



C Section through shoulder joint



D Knee joint, anterior view

Classification of Joints (A–F)

Joints may be classified by various criteria. One classification is related to the **axes** and subdivides joints into monaxial, biaxial, and multiaxial articulations. A second classification divides the joints according to their **degrees of freedom**, which indicate the mobility of articular surfaces relative to each other. Joints are therefore divided into those with one, two, or three degrees of freedom. Another classification makes use of the **number of articular surfaces** and so separates simple from complex joints. A *simple joint* consists of only two surfaces contained in one capsule. If more than two surfaces are present in the capsule, the joint is called a *complex joint* (e.g., elbow joint, **B**).

Different types of joints may be combined. *Joints combined of necessity* are found at different points on two bones (e.g., proximal and distal radioulnar joints). *Forcibly combined joints* are activated by one or more muscles that span several joints, for example hand and finger joints by the flexors of the fingers (see p. 173).

Joints may also be classified according to the **shape of the articular surfaces**:

A *plane joint*, a joint with two flat surfaces, possesses two degrees of freedom, and gliding movements are possible (e.g., the small vertebral joints, zygapophyseal joints).

A *hinge joint* or *ginglymus* (**A**) consists of a convex and a concave articular surface. The concave articular surface often has a ledge-shaped elevation that fits into a groove of the convex one. Tense lateral ligaments (**1**) help to fix the joint more firmly. Hinge joints have one degree of freedom (e.g., the humeroulnar articulation, **B**). Ginglymus and trochoid articulations (below) are collectively known as *cylindrical joints*.

Trochoid joints include the pivot joints and the rotary joints. Both have one axis and one degree of freedom, and both have one convex cylindrical surface and a corresponding concave joint surface. The joint axis runs through the cylindrical surface. In a pivot joint the convex (peglike) surface rotates within the concave surface, which is enlarged by ligaments (annular ligament, **2**; e.g., in the proximal radioulnar joint, **B**). In a rotary joint the concave articular surface rotates around the convex surface (e.g., the distal radioulnar joint).

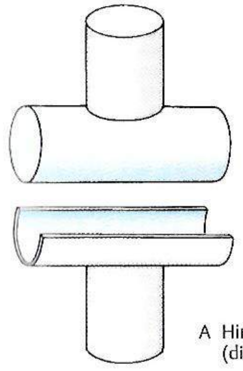
Ellipsoidal or condylar joints have a convex and a concave elliptical joint surface. They have two degrees of freedom and are multiaxial, with two principal axes. When the movements are combined, a circumduction is possible, for example the radiocarpal joint.

A *saddle joint* (**C**) consists of two saddle-shaped articular surfaces each having a convex and a concave curvature. It has two degrees of freedom and two main axes, but is in fact multiaxial. Circumduction is possible (e.g., the carpometacarpal joint of the thumb, **D**).

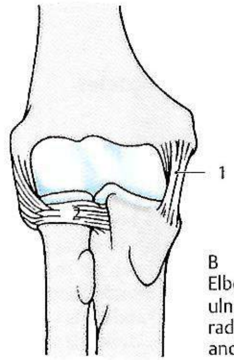
Ball-and-socket or *spheroidal joints* (**E**) are multiaxial and consist of a globular bony head within a cup or socket. They have three degrees of freedom and three principal axes (e.g., shoulder joint, **F**). A special type of ball-and-socket joint is the *enarthrosis* in which the socket extends beyond the equator of the head. The hip joint is usually an enarthrosis in which the socket (acetabulum) is enlarged solely by the articular labrum.

A special type of joint is the fixed joint or *amphiarthrosis*. This type has very limited mobility since both the ligaments and the capsule are taut and the articular surfaces are rough, as in the sacroiliac joint.

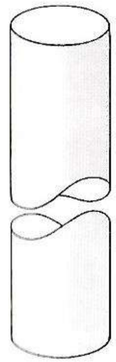
General Anatomy



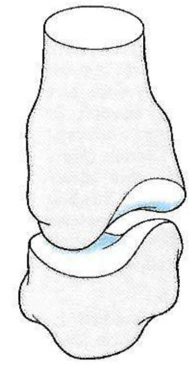
A Hinge joint (diagram)



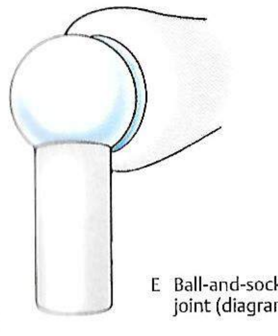
B Elbow joint with humeroulnar joint, proximal radioulnar joint, and humeroradial joint



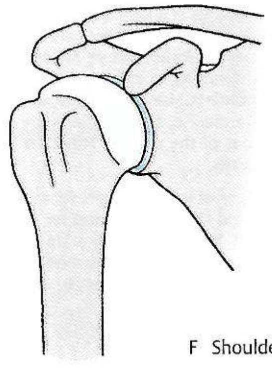
C Saddle joint (diagram)



D Carpometacarpal joint of thumb



E Ball-and-socket joint (diagram)



F Shoulder joint