3 The Bone and Joint Structure

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Abstract

The perfect organization between bone structures and joints, muscles, and ligaments in the formation of movement has been investigated for years. Bones are mechanically connected with neighboring structures around them. A joint is defined as the functional connection between different bones of the skeleton. Without bone and articular structures, any motion cannot occur. Bones, which take part in the kinetic chain in terms of transmission and distribution of force, are only one of the tissues that work together with the joints. Gravity, activity, and mechanical stimuli are essential for bone functionality. Bones can adapt very quickly to situations created by internal and external factors. Apart from trauma, they can give different responses to various diseases that cannot be seen as related to bones. Bone tissue, which is indispensable for mobility in our lives, is also related to our other systems that manage essential functions. In this section, the structure and functions of bone tissue and joints are explained.

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3.1 Bones

Although bones are often thought of as static structures that offer structural support, they actually function as a complete organ. Bones are a perfect example of the principle: "form follows function." While providing structural support for movement and breathing, it also allows motor movements to be performed. It acts as a reservoir for calcium, phosphate, amino acids, and bicarbonate. Besides its functions such as protection of internal organs, transmission of sound waves, and homeostasis, it is also involved in producing cells necessary for the continuation of life in the bone marrow. Moreover, it affects the bone marrow, brain, kidney, and pancreas with the hormones it secretes, such as osteocalcin and fibroblast growth factor-23. Thanks to the organs it affects, it also undertakes the endocrine organ function by helping regulate bone tissue mineralization, fat metabolism, cognitive functions, and glucose metabolism.

3.1.1 Anatomical Structure of Bones

Bone tissue is divided into primary bone tissue (immature bone) and secondary bone tissue (lamellar, mature bone) according to the arrangement of collagen fibers. Primary bone tissue is an immature bone form that is weak due to the irreg-

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ular placement of collagen fibers. Secondary bone tissue is the mature (mature) bone form showing regular and parallel collagen arrangement. Adults have only secondary bone tissue.

Attention!
The transverse growth of bones in childhood and adulthood is the task of the periosteum. A poor bone-healing process in intra-articular femoral neck fractures is due to the absence or very thin structure of the periosteum layer in this region.

Bone consists of two main components: the extracellular matrix, which is organic and inorganic, and cells. The organic component consists of type 1 collagen, noncollagenous glycoproteins, proteoglycans, cytokines, and growth hormones. Type I collagen in the organic structure is responsible for the tensile strength of the bone, while proteoglycans are responsible for the compression. The noncollagenous osteonectin protein is responsible for mineralization and calcium balance. The osteocalcin produced by osteoblasts allows the bone density to be adjusted. Vitamin D stimulates the synthesis of osteocalcin, while parathormone suppresses the synthesis of osteocalcin. Growth factors and cytokines in bone, insulin-like growth factor (IGF), transforming growth factor-beta (TGF-β), bone morphogenic proteins 1–6, and interleukins 1 and 6 are responsible for cell differentiation, activation, growth, and turnover. The inorganic component consists mainly of calcium phosphate organized as hydroxyapatite crystals. It is responsible for the compressive strength of the bone (Fig. 3.1).

The white transparent layer that surrounds all the bones in our body is called the periosteum. The periosteum consists of two layers, fibrous on the outside and osteogenic on the inside. The inner layer of the periosteum, consisting of proliferative bone cells, osteoblasts, and small vessel cells, is located close to the bone. The outer fibrous layer consists of fibroblasts, collagen fibers, and basic material. Collagen fibers in the periosteum are located parallel to the surface. Periosteal collagen fiber bundles called perforating fibers penetrate the bone matrix and connect the periosteum to the bone matrix. These fibers are called *Sharpey's fibers*. *Sharpey's fibers* are found where ligaments and tendons attach to the bones. The direction of collagen fibers is determined by tensile forces. They are located throughout the cortex in areas subject to high tensile forces.

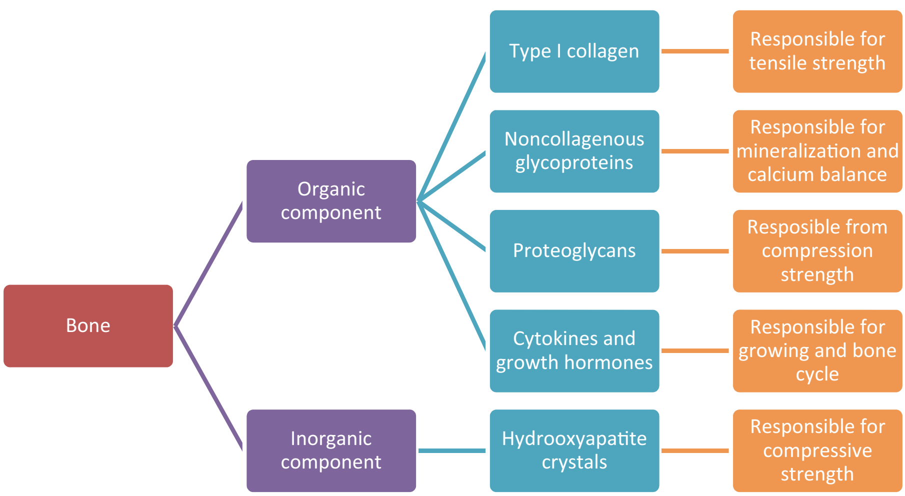


Fig. 3.1 Components and functions of bones

3.1.2 Bone Cells

Four different types of bone cells exist: osteoclasts, osteoblasts, osteocytes, and osteoprogenitor cells. Although these cells have different origins and functions, they work in harmony with each other and in an organized manner to maintain bone homeostasis.

3.1.2.1 Osteoclasts (Catabolic Cells)

A mature osteoclast is a polarized, multinucleated giant cell with a unique morphology. Its main function is to ensure the resorption of the bone matrix. Osteoclasts have receptors sensitive to calcitonin. Interleukin-1 stimulates osteoclastic activity.

3.1.2.2 Osteoblasts (Anabolic Cells)

Osteoblasts are formed from mesenchyme stem cells. It takes part in the production and release of the matrix in the bone structure. Since they are the cells responsible for storing new bones, they play an active role in both skeletal development and fracture healing thanks to this feature. It makes up 6% or less of the total amount of cells in the bones. They accumulate bone matrix around them and eventually become embedded in their own matrix to form osteocytes.

3.1.2.3 Osteoprogenitor Cells

They are mesenchymal cells that can transform into osteoblasts in the Haversian canals, endosteum, and periosteum.

3.1.2.4 Osteocytes

Osteocytes are the most abundant cell type in bones (<90%). It consists of cells as a spider web of interconnected channels, essential for cellular processes. This network-like structure is important for responding to mechanical stimuli and for converting these stimuli into chemical signals that stimulate other bone cells. Cell-to-cell communication is achieved through gap junctions. This also indicates that the osteocyte is not an immobile osteoblast trapped in the bone matrix it has formed. While osteocytes are stimulated by calcitonin, they are suppressed by parathyroid hormone.

Perception of mechanical stimuli directly affects bone formation and resorption by osteocytes. This indicates that osteocytes are the controllers of osteoclast and osteoblast functions. Osteocyte apoptosis has been shown to be a regulatory event for osteoclast formation. In particular, a direct relationship exists between osteocyte apoptosis caused by microfractures and osteoclast formation at the injury site. Osteocytes contribute to increasing osteoclast absorption, re-taking of a high amount of calcium from the bones when it is especially needed by the organism, and regulation of bone mineral homeostasis.

Bones constantly undergo structural and biological changes. In this way, bone remodeling continues throughout life. The skeletal system responds to increased stress, such as resistive strength training, by increasing osteogenesis or causing new bone formation. Bone shape, size, and strength vary depending on the needs in the performance of motor tasks. The bones in the middle ear carry out the transmission of sound waves to the inner ear, although they have minimal strength. Large bones, such as the femur, are extremely strong and can withstand very high stresses before breaking.

Bones have specialized cortical and trabecular structures to perform their functions. The vertebral body, pelvis, and ribs show trabecular bone characteristics, while the femur has both cortical and trabecular bone characteristics. The material properties of bone sections differ. The trabecular bone has less calcium and more water than the cortical bone. The nutrition of the surface of the trabecular bone adjacent to the bone marrow is higher than that of the cortical bone. Absorption occurs along the bony surfaces in the trabecular bone, while in the cortical bone, it occurs in channels that run through the bone. The cortical bone constitutes approximately 80% of the bone mass. Vascular channels are about 30% of this volume. The surface volume ratio of the cortical bone is

Table 3.1 Bone parts and their material properties

Material property	Trabecular bone	Cortical bone
Surface nutrition adjacent to the bone marrow	High	Low
Absorption	Along the bone surface	In channels of bone
Surface-to-volume ratio	High	Low
Amount of calcium	Low	High
Amount of water	High	Low

much lower than that of the trabecular bone. With aging or disease, the cortex becomes more porous, resulting in an increase in surface area and a decrease in bone strength. While 20% of the trabecular bone is bone tissue, the remaining volume is filled with bone marrow and fat. The trabecular bone transfers mechanical loads from the articular surface to the cortical bone and absorbs the shock thanks to its hydraulic feature (Table 3.1).

3.1.3 Histological Structure

The osteon or Haversian system, which is the structural and functional basic unit of the cortical bone, runs parallel to the long axis of the bone. Osteons are important for providing adequate mechanical support and blood supply in the skeletal system. In the center of each osteon is the Haversian canal, which contains blood and lymph vessels, and nerve fibers. The Volkmann canals connecting to the Haversian canals are perpendicular to the major axis of the osteon. The central Haversian canal is surrounded by a concentric layer of mineralized bone "lamella." The small spaces between the lamellae are called lacunae. Lacunae contain osteocytes. Canaliculi are thin channels that connect the lacunae (Fig. 3.2). The canaliculi allow nutrients to reach the osteocytes from the blood vessels in the Haversian canal.

Attention!
Osteons are dynamic bone structures. Their number, structure, and activity change over time in response to external stimuli acting on the bones.

3.1.4 Bone Types

According to their shape, bones are divided into five categories: long, short, flat, irregular (irregular), and sesamoid bones (Fig. 3.3). Bone types and properties are listed in Table 3.2.

Mechanical or chemical stimuli affect bone sections differently. This process can become more complex with sex, age, and disease.

Clinical Information

- Trabecular bone loss in the tibial cortex is greater in bed rest immobilization.
- In patients with chronic kidney disease or those exposed to low-intensity vibration, the strength of the tibia increases due to changes in trabecular bone rather than cortical bone.
- Parathyroid hormone injections increase trabecular bone mass while decreasing cortical bone mass. The significant increase in bone strength is associated with an increase in the trabecular bone.

The mechanical strength of bones and its resistance to fracture depend on the size, volumetric density, and trabecular structure of the bone. Gonadal hormones affect bone compartments differently depending on sex. While testosterone secreted in men and women supports periosteal bone expansion, estrogen prevents cortical bone loss. Trabecular bone loss is prevented by the secretion of estrogen in women and testosterone in men (Fig. 3.5).

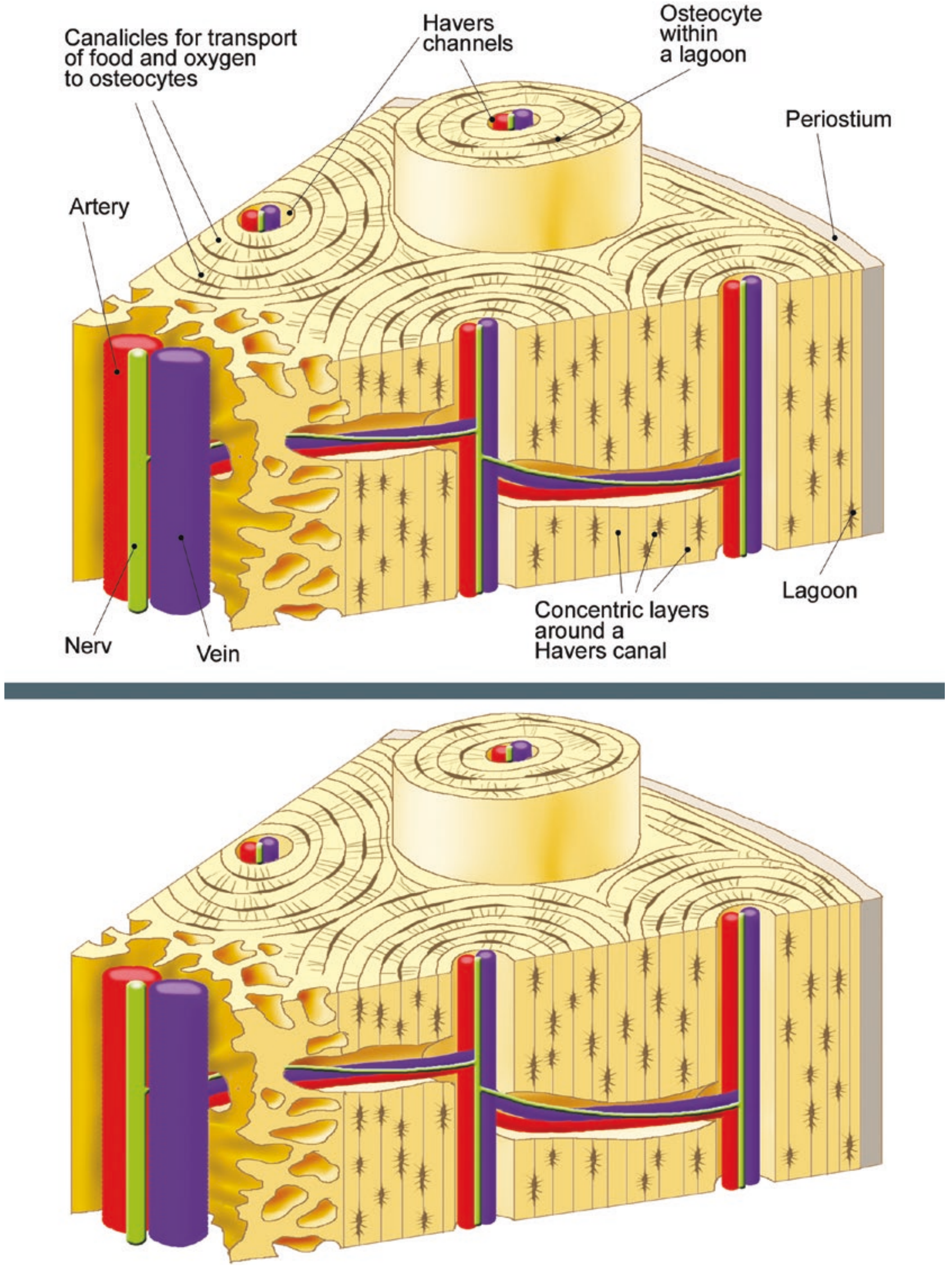


Fig. 3.2 Structure of osteon (Amadeu Blasco/Shutterstock.com)

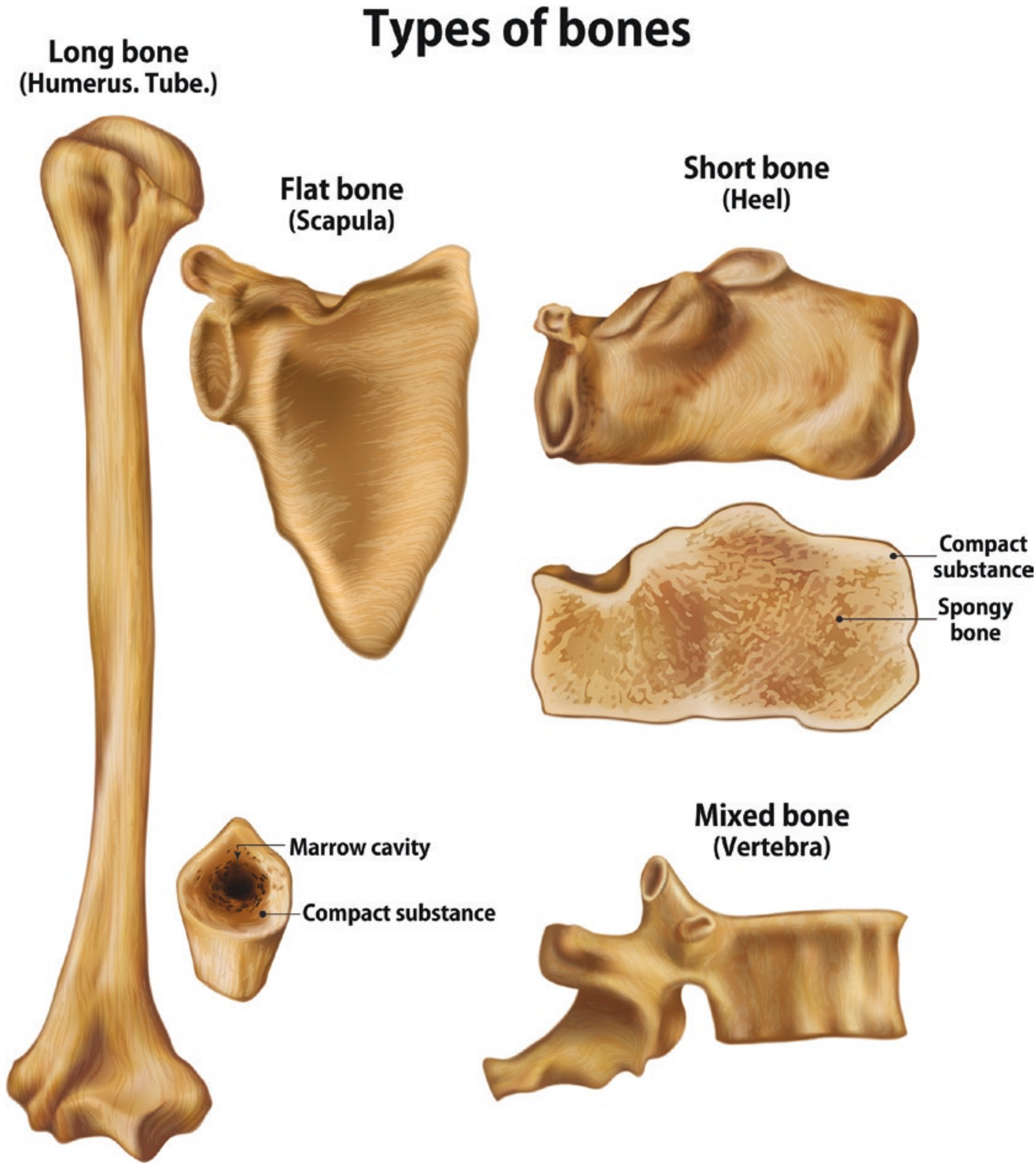


Fig. 3.3 Bone types (studiovin/Shutterstock.com)

Postmenopausal bone loss in women is faster in trabecular bone. However, since the cortical bone makes up 80% of the skeleton, the absolute amount of bone loss from each compartment in the first 10 years is similar.

In the following years, the Haversian canals expand and the bones with an increased surface/volume ratio become weak with the increasing loss of the cortical bone. The loss of regular and dense structures such as the cortical bone affects

Table 3.2 Bone types and properties

Long bones
• They are the main bones of the extremities that are longer than wide • It consists of the diaphysis (elongated central shaft space), epiphysis (two enlarged end portions), and metaphysis (the part between the diaphysis and the epiphysis) • The inside of the bones contains a cavity known as the medullary space, which is filled with bone marrow (Fig. 3.4) • Examples: femur, tibia, and humerus
Short bones
• They are almost equal in length and diameter • Example: carpal bones
Flat bones
• They are weak bones that look like plates • Examples: skull bones and sternum
Irregular bones
• They are irregular bones that do not conform in shape to the three bone types mentioned earlier • Examples: vertebrae
Sesamoid bones
• They are oval-shaped bones located under joints or tendons • Functions: To protect the joint, to protect the tendon by reducing the pressure on it, to change the force vector of the muscle, and to make the movements faster and with less energy consumption • Examples: patella and pisiform

the decrease in bone strength more than the trabecular bone losses. With aging, the diameter of long bones increases more in men than in women, which increases the resistance of the bones to bending stresses on the bones.

Attention!
Since trabecular and cortical bones can be affected differently by hormones and drugs, it is important to evaluate them in each disease process.

3.1.5 Vascularization of the Bones

The mammalian skeleton contains a well-organized vascular network that supplies abundant blood to the bones. Approximately 10–15% of cardiac output at rest is allocated to the nutrition of bone structures. This vascular network in bones ensures the maintenance of bone homeostasis during physiological and pathological conditions (Fig. 3.5). Especially in long bones, vascular anatomy comprises the nutrient arteries; the periosteal, metaphyseal, and epiphyseal arteries; and their venous outflows. After the feeding arteries pierce the periosteum and enter the bones, they pass through the Haversian and Volkmann canals and reach the bone marrow. From here, the bone is fed by giving small branches to the distal and proximal parts of the bones (Fig. 3.6).

The vascular network structure of the bone varies depending on the location of the bone in the skeletal system. For example, arteries in the greater trochanter of the femur enter from the medial, lateral, and superior surfaces of the trochanter and form the vascular network that supplies the trochanteric region. Thanks to this vascular network, the supply of the trochanteric region is separated from the collum femoris, the femoral shaft. The blood supply of long bones changes in line with regional factors such as metabolism, aging, and trauma.

3.1.6 Innervation of the Bones

The bones are stimulated by the muscles and skin nerves (tibial nerve, radial nerve, etc.) overlying them. This is called the *Hilton* rule. The periosteum, mineralized bone, and bone marrow are stimulated by small-diameter myelinated/unmyelinated sensory and autonomic fibers of peripheral nerves. The peripheral nerves innervating the bones travel together with the main artery supplying the bones. The peripheral nerves innervating the bones enter the diaphysis with the artery through the nutrient canal and stimulate the bone marrow cavity. The nerves innervating the articular surfaces enter the bones from both sides of the epiphyses and proceed toward the articular surfaces.

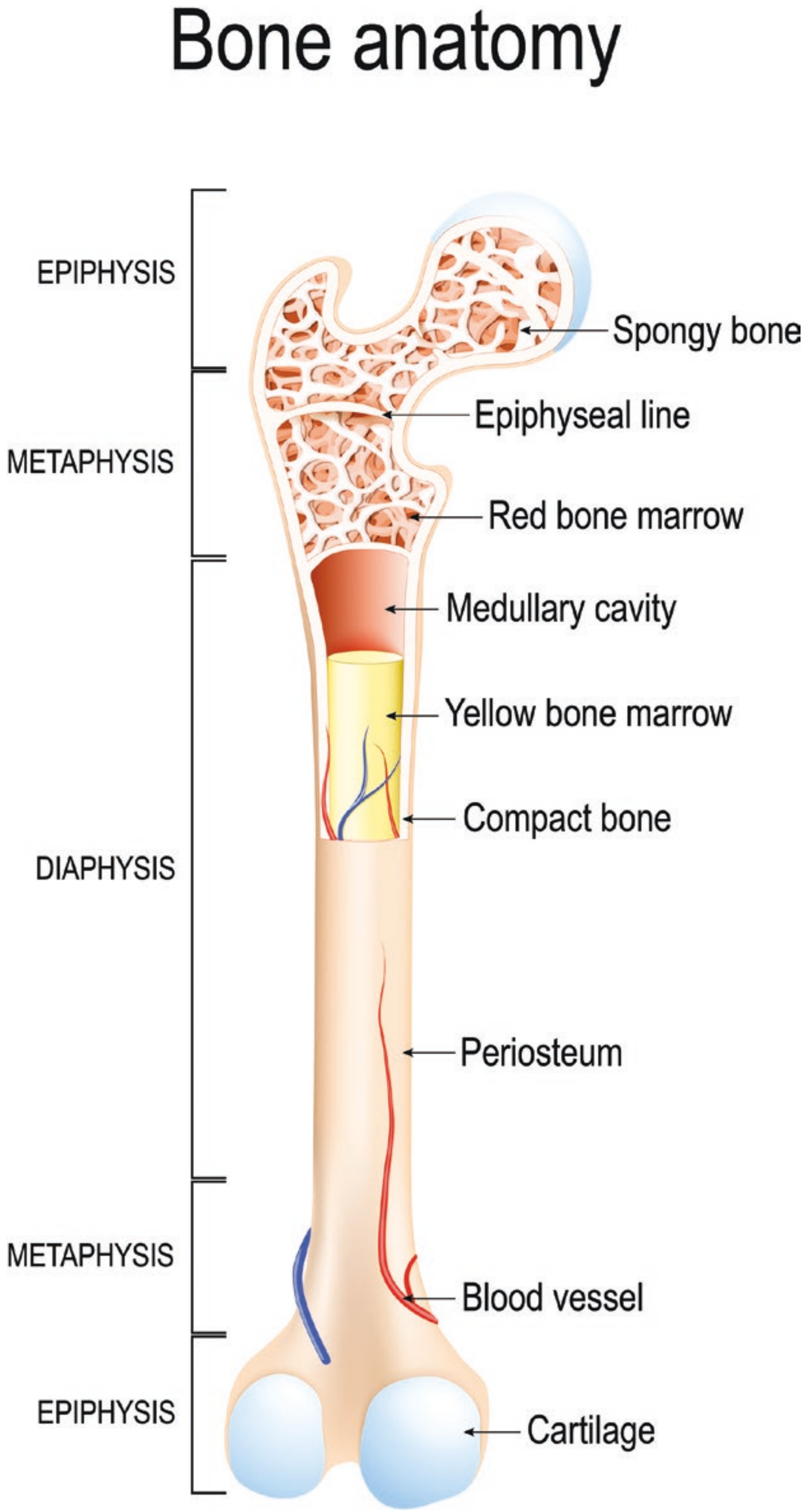


Fig. 3.4 Anatomy of long bones (Designua/Shutterstock.com)

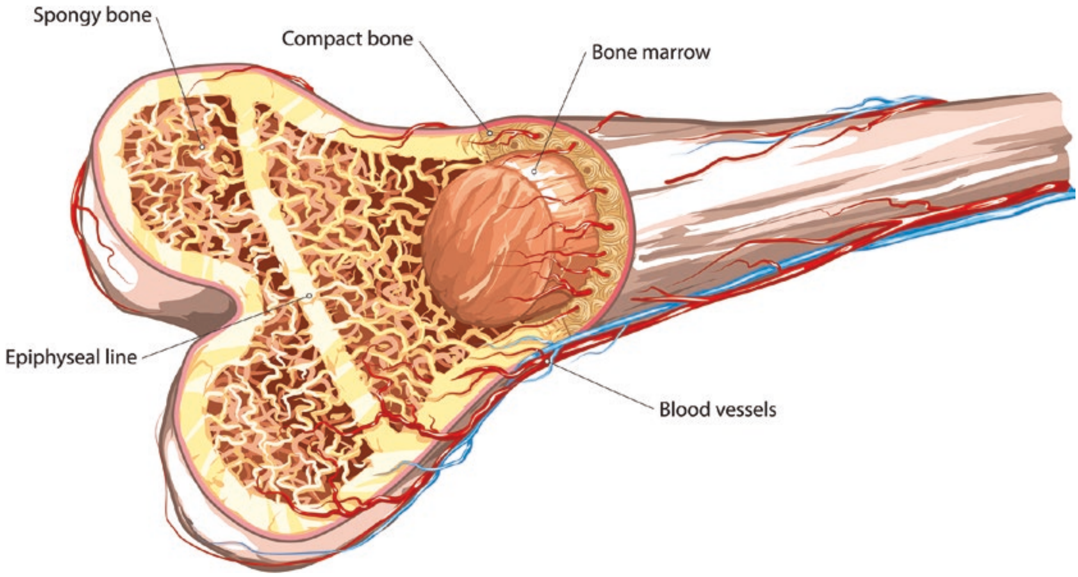


Fig. 3.5 Vascular network in bones (EreborMountain/Shutterstock.com)

3.1.7 Muscular Contribution

Muscle and bone tissue are interrelated in terms of anatomical, mechanical, and metabolic functions. Anatomically, the muscle connects parts of the skeleton through tendinous connections, turning it into a lever system and increasing mobility. Activities such as exercise can create regional adaptations in the bone. Exercises greatly increase the ability of the bone to withstand loads. However, the less change in the mineral content due to loading in bone regions where mechanical loads are high (such as the cortical bone of the collum femoris) causes these regions to be vulnerable to loads.

The mechanical stresses that occur in cortical and trabecular bones with different exercise approaches provide *remodeling* of the bones depending on the amount and direction of the applied force. Long-term, high-intensity exercise increases bone mass in postmenopausal women and women undergoing hormone replacement therapy. Muscle contraction provides severe loads on the bones. Therefore, resistance exercises are recommended to prevent bone loss in situations where there is no gravity, such as prolonged bed rest and space flight. The risk of age-related bone loss and life-threatening fractures in the proximal region of the femur is increased in the geriatric group. Resistance exercise is one way to reduce the effects of age-related bone loss.

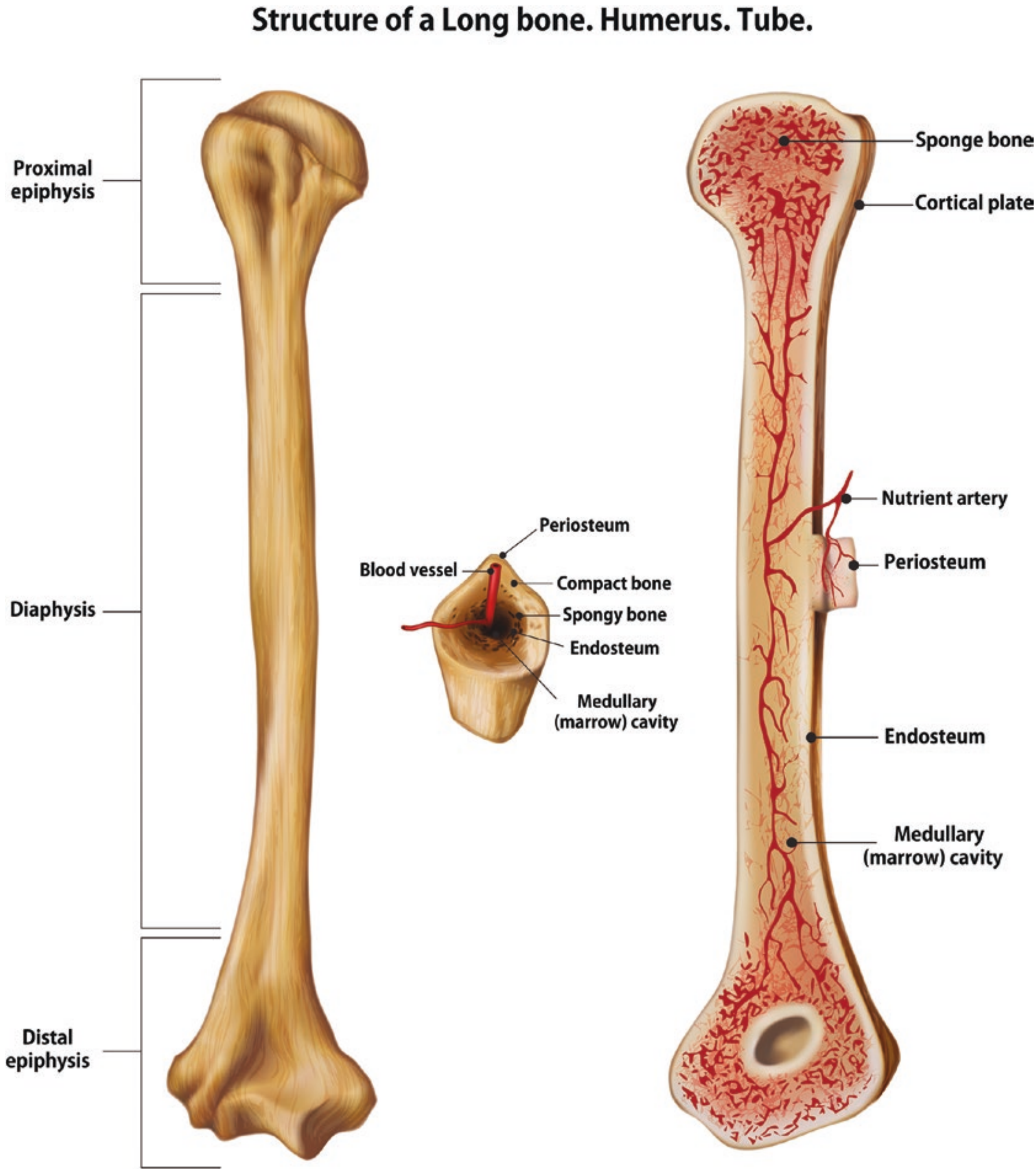


Fig. 3.6 Vascular structure in long bones (studiovin/Shutterstock.com)

3.2 Joints

A joint is defined as the functional connection between different bones of the skeleton. Joints are diverse and versatile skeletal structures. Joints differ not only in anatomical location, architecture, and size but also in the type and degree of movement they allow and in their organic structure. The current and useful classification of joint diversity is largely based on the degree of joint motion. In this section, the joint types, joint nutrition, joint innervation, and anatomical structures within the joint are explained.

3.2.1 Joint Types

Joints can be histologically classified according to the dominant connective tissue type (type) or mobility. Joints are classified histologically as fibrous, cartilaginous, and synovial, and functionally as synarthrosis (immovable joint), amphiarthrosis (semi-movable joint), and diarthrosis (movable joint). Both classifications are related to each other, and synarthrosis joints are fibrous, amphiarthrosis joints are cartilaginous, and diarthrosis joints are synovial (Fig. 3.7).

3.2.1.1 Fibrous Joint

It is an immovable joint composed mainly of collagen, where the fibrous tissue joins the bone ends. Fibrous joints have no mobility (synarthrosis) and joint space. They are divided into three types: sutures, gomphosis, and syndesmosis. Sutures are joints seen in the skull bones, joined in a suture style, and with no mobility feature (Fig. 3.8). During birth, it has a limited range of motion thanks to the connective tissue called fontanelle located between the flat bones in the skull. This allows the skull of the newborn to pass through the birth canal and the development of the brain in parallel with the development of the newborn. As the skull grows, the fontanelles shrink into narrow, fibrous connective tissues called *Sharpey's* fibers. Eventually, the cranial sutures fuse, forming two adjacent plates of the bones. This fusion is called synostosis. Gomphosis is an immovable joint that occurs between the root of the tooth and the socket of the tooth in the mandible and maxilla. A syndesmosis is a small amount of movable

Fig. 3.8 Suture joint (ilusmedical/Shutterstock.com)

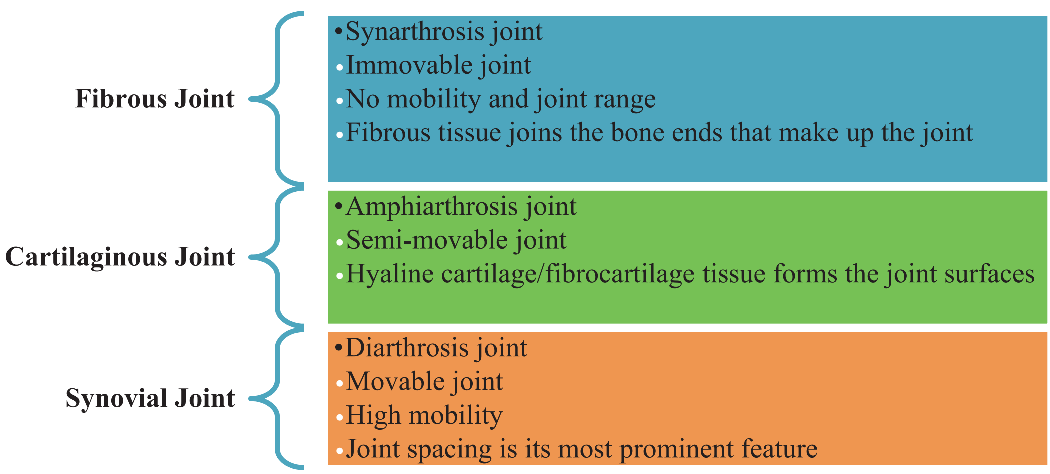


Fig. 3.7 Joint types

joint (amphiarthrosis). In a syndesmosis joint, the two bone surfaces are connected by an interosseous membrane or fibrous tissue. In the upper extremity, the radioulnar joint connects the membrane interossea, the chorda obliqua, and the radius and ulna bones, as an example of a syndesmosis type of joint. In the lower extremity, a syndesmosis joint formed by the distal tibiofibular joint, anterior–posterior tibiofibular ligament, interosseous membrane, and inferior transverse tibiofibular ligament can be given as an example (Fig. 3.9).

Syndesmosis joints vary in their mobility according to their functions. The tibiofibular syndesmosis joint does not allow the movement of the tibia and fibula to provide strength and stability while bearing body weight. The radioulnar syndesmosis joint allows the movement of the radius during the pronation–supination of the forearm.

3.2.1.2 Cartilaginous Joint

In cartilaginous joints, the bony joint surfaces are covered with hyaline cartilage or fibrocartilage tissue. The cartilage on the articular surfaces is divided into *primary* or *secondary cartilaginous joints* according to the type of tissue. The primary cartilaginous joint contains hyaline cartilage. It is found in the joints that occur between the epiphysis and diaphyseal regions of the growing long bones or between the ribs and the sternum. Between the secondary cartilaginous articular surfaces is a hyaline or fibrocartilaginous disk. The symphysis pubis joint is one such joint.

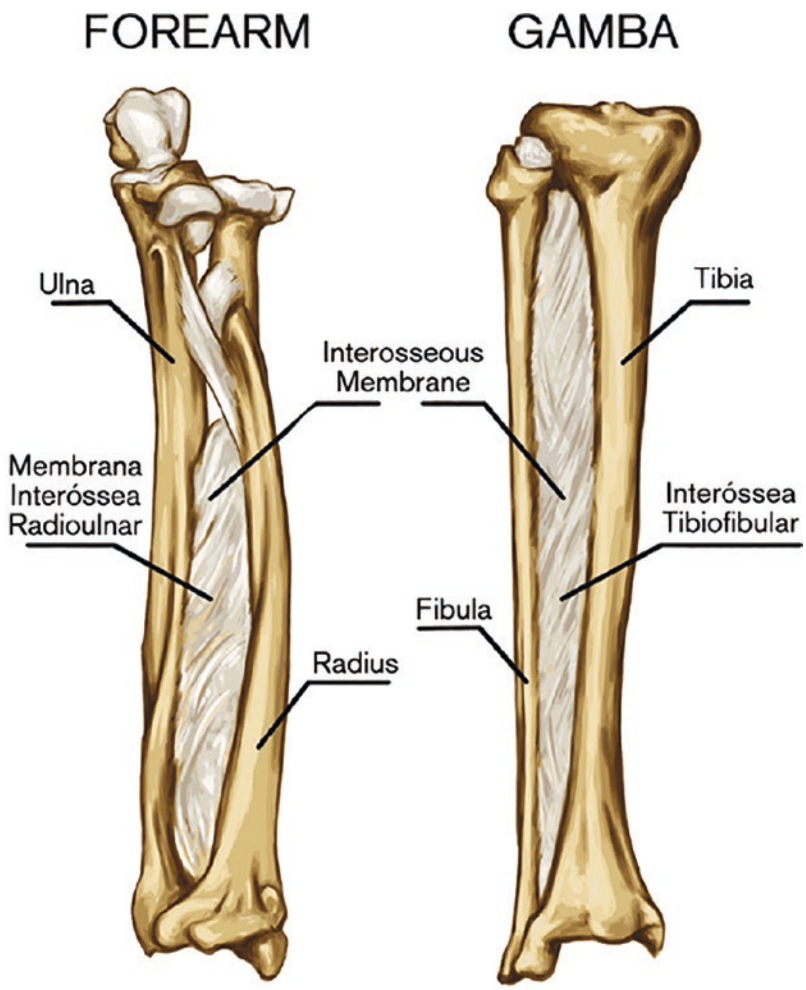


Fig. 3.9 Syndesmosis joint (stihii/Shutterstock.com)

3.2.1.3 Synovial Joint

They are functional joints with high mobility. The joint space is the most prominent feature of the synovial joint. This gap between the joint surfaces has a negative pressure feature (Fig. 3.10). The synovial joint types are listed in Fig. 3.11.

Anatomical Structures Found in the Synovial Joint

Joint Capsule The joint capsule, which is fibrous connective tissue, attaches to the periosteum by enclosing the joint cavity and joint surfaces. It creates negative air pressure by wrapping the joint cavity. The joint capsule consists of two layers: an outer fibrous membrane and an inner synovial membrane (Fig. 3.10). The fibrous membrane is composed of type I collagen, elastin fibers, and nerve fibers containing vessels and mechanoreceptors. The synovial membrane, on the contrary, is a 20- to 40-μm-thick covering layer containing synovial type A and B cells, as well as a subsynovial layer approximately 5 mm thick, consisting of connective tissue, vessels, adipocytes, elastin fibers, and immune cells.

Joint Cavity The joint cavity contains the synovial fluid secreted by the synovial membrane (synovium) surrounding the joint capsule (Fig. 3.10). Thanks to the phospholipids, hyaluronan, and glycoproteins it contains, the synovial fluid reduces the friction force in the joint.

Joint Faces The articular surfaces covered with hyaline cartilage (type II collagen) are avascular. Articular cartilage and synovial membrane are continuous (Fig. 3.10). Type II collagen, aggrecan, and extracellular matrix cells located on the joint surface provide durability to the joint surfaces during movement. Some synovial joints also contain fibrocartilage structures such as the

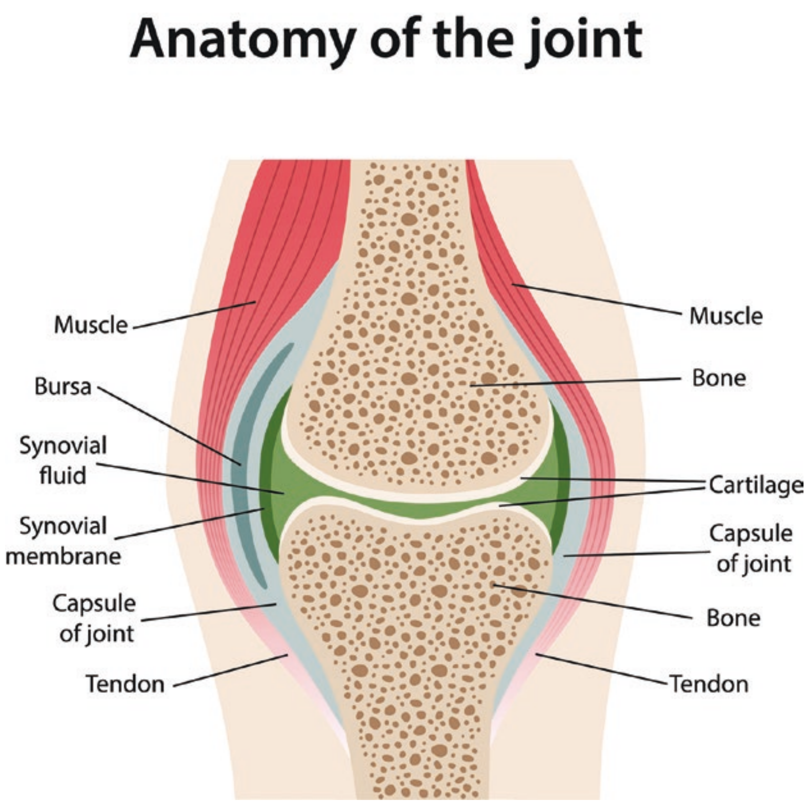


Fig. 3.10 Synovial joint (Olga Bolbot/ Shutterstock.com)

meniscus between the articular surfaces. These structures increase the harmony of the joint surfaces, regulate the distribution of the compression forces acting on the joint surface, and help provide joint stability.

Articular Ligaments The structures that connect the bones making up the joint are called ligaments. There are two types of ligaments in synovial joints: internal and external. Articular cartilage and synovial membrane are continuous (Fig. 3.10). Type II collagen, aggrecan, and extracellular matrix cells located on the joint surface provide durability to the joint surfaces during movement. Some synovial joints also contain fibrocartilage structures such as the meniscus between the articular surfaces. These structures increase the harmony of the joint surfaces, regulate the distribution of the compression forces acting on the joint surface, and help provide joint stability.

Clinical Information
Considering the contribution of elastin fibers to mechanical stability, the content of collagen fibers in the joint capsule and elastin fibers in the joint capsule increases, and the adaptation to this situation is improved to prevent repetitive dislocations in people with shoulder instability.

Attention!
The muscles are critical in providing support to the synovial joints. The muscles and tendons that cross the joint act as a dynamic ligament against the forces acting on that joint. Therefore, muscular strength is

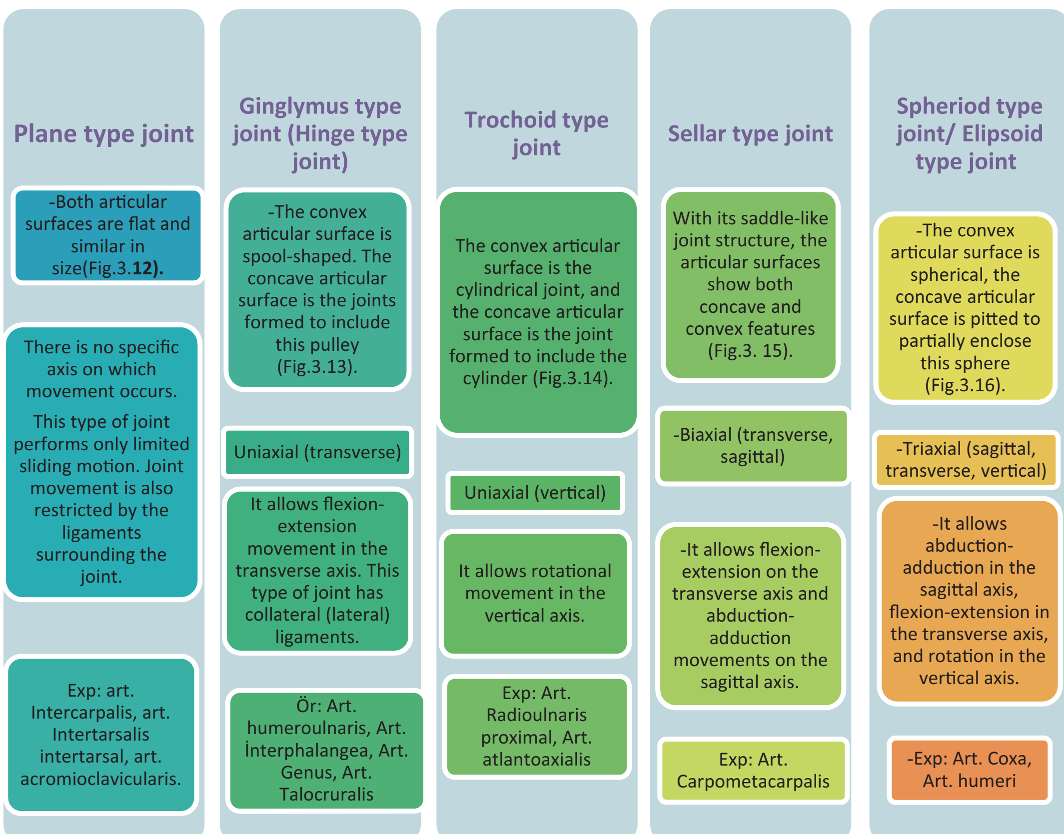


Fig. 3.11 Types of synovial joint

essential for the stability of synovial joints during high-stress activities. It is also very important for joints with weak ligaments (glenohumeral joint, etc.).

Fig. 3.12 Plane-type joint (Medical Art Inc/Shutterstock.com)

Types of Synovial Joints

The main purpose of synovial joints is to prevent the frictional force between the articular surfaces during movement. Synovial joints are classified according to the number of axes (Figs. 3.11, 3.12, 3.13, 3.14, 3.15, and 3.16).

3.2.2 Vascularization of Joints

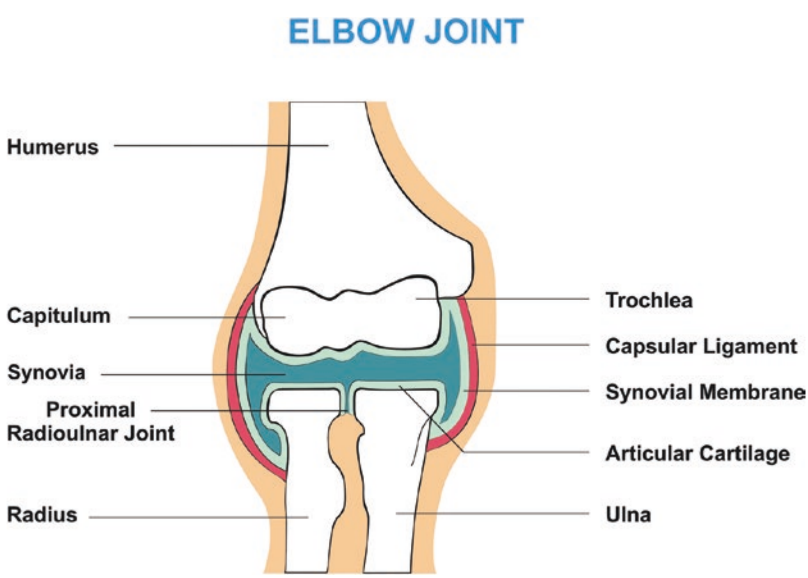
3.2.2.1 Vascularization of Fibrous Joints

Usually, the perforating branches of the proximal vessels are responsible for the nutrition of the joint. For example, the blood supply to the tibiofibular joint is provided by branches from the anterior tibial artery as well as the peroneal artery.

3.2.2.2 Vascularization of Cartilaginous Joints

Only the peripheral parts of the joint have vascular nutrition because the joint cartilage itself is avascular tissue. For example, the intervertebral disks are supplied by capillaries in the peripheral vertebral body.

Fig. 3.13 Ginglymus-type joint (Hinge-type joint) (udaix/Shutterstock.com)



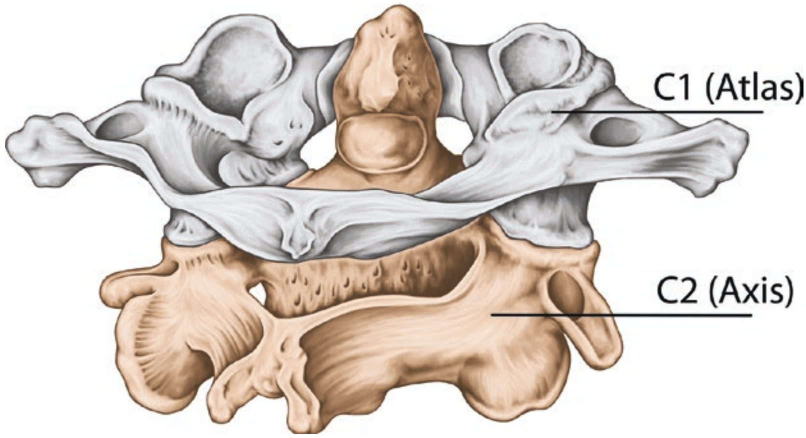


Fig. 3.14 Trochoid-type joint (stihii/Shutterstock.com)

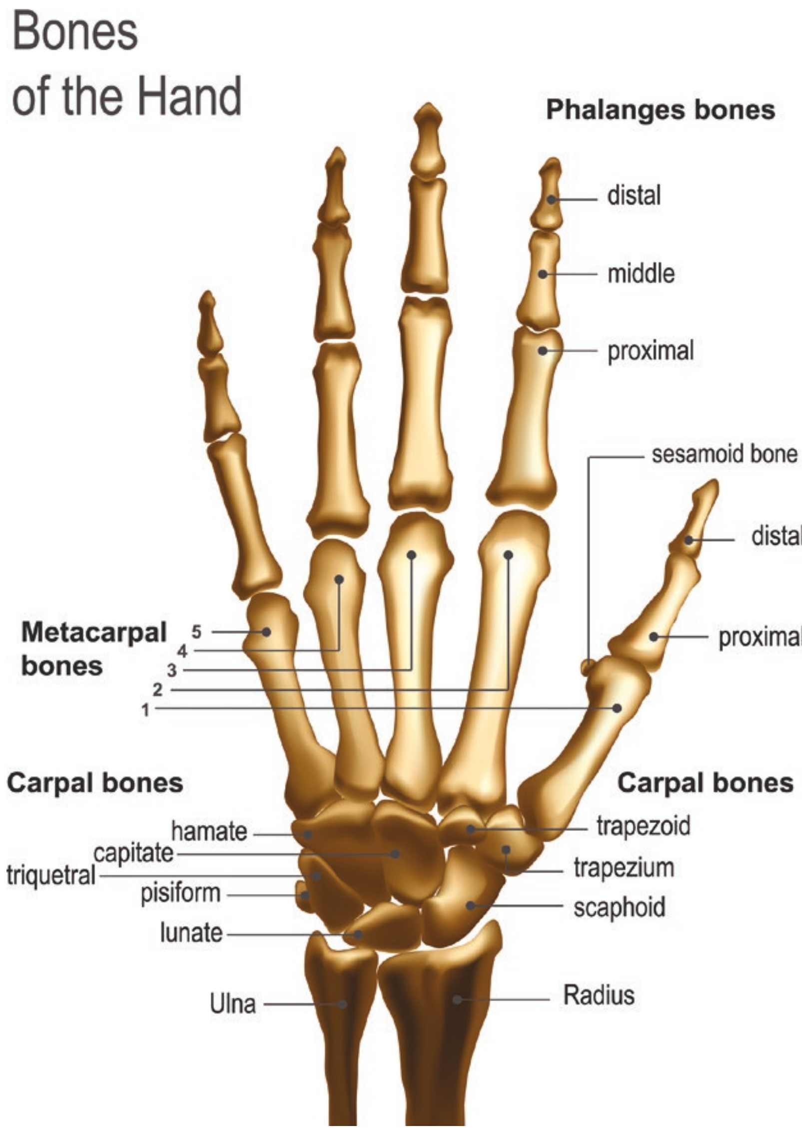


Fig. 3.15 Sellar-type joint (Ira Dvilyuk/Shutterstock.com)

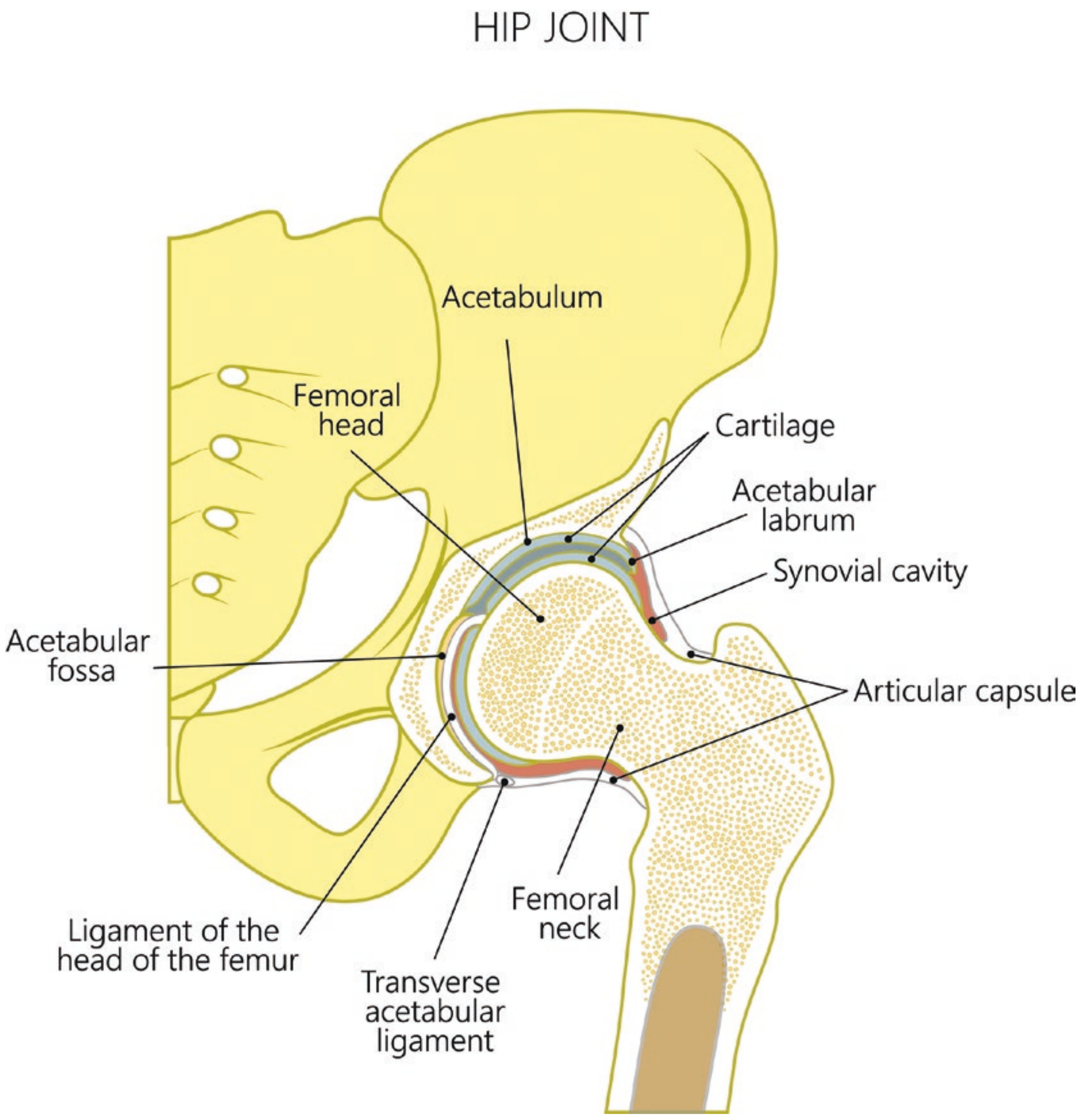


Fig. 3.16 Spheroid type joint (Aksanaku/Shutterstock.com)

3.2.2.3 Vascularization of Synovial Joints

The synovial joints are supplied by a rich arterial network called the periarticular plexus, which extends from both sides of the joint. Some vessels also penetrate the fibrous capsule to form a rich plexus deeper in the synovial membrane. These structures, called the deep plexus, form a ring around the joint margins that supply the joint capsule, synovial membrane, and bones. Articular cartilage, which is avascular hyaline cartilage, is supplied by diffusion from the synovial fluid or subchondral blood vessels.

3.2.3 Innervation of the Joint

Synovial joints have both sensory and autonomic innervation. Autonomic nerves are responsible for controlling vasomotor responses. The sensory nerves of the joint capsule and ligaments provide proprioceptive sensory feedback from the *Ruffini* and *Pacini* mechanoreceptors. The sense of proprioception in the joint allows the reflex control of posture, locomotion, and movement. When the joint is maximally loaded, the afferent signals from the joint area indicate that the joint capsule has not only mechanical stability but also a protective reflexogenic function. *Ruffini* corpuscles are active even when the joint is in a static position and are sensitive to changes in the direction of joint movement, magnitude, and intra-articular pressure. It also helps regulate the stretch reflex and muscle tone under sustained tonic conditions. Any excessive force within the joint resulting from flexion, extension, and rotation movements is reported by *Ruffini* bodies. *Pacini* corpuscles, which adapt quickly, transmit the sensations of rapid joint movement and vibration. *Pacini* corpuscles give a mechanical stimulus when joint movement begins or stops. The free nerve endings transmit widespread pain sensation. The articular cartilage has no nerve innervation.

3.2.4 Intra-Articular Structures

3.2.4.1 Ligaments

Ligaments are fibrous tissues rich in the extracellular matrix, collagen, fibroblast, proteoglycan, and water. Water makes up about 60–70% of the mass of the cytoplasmic matrix. Other components such as elastin and proteoglycan are also incorporated into the cytoplasmic matrix. Collagen constitutes approximately 70–80% of dry weight and is the most important component that carries the load. Type I collagen is the main component of the extracellular matrix of the ligament. In addition, type II, type III, type V, and type XI collagens are also present at a low rate. Type II collagen is usually found at the junction of ligaments and bones. Although the amount of elastin varies according to the properties and function of the ligament, it is usually less than 1% of the dry weight of the ligament. Elastin, together with collagen, gives elasticity and tensile strength to the ligament. Macroscopically, the ligaments can be examined under two headings as visceral ligament and joint ligament. The fact that they are located in different parts of the body is the main reason for the structural difference in the ligaments.

The visceral ligament consists of a single or double layer of peritoneal folds. It is attached to the fascia of the liver, kidneys, and other internal organs. Visceral ligaments keep the internal organs in their proper position, restricting and protecting their movements.

Joint ligaments have important roles in the musculoskeletal system, such as guiding joint movement under low-strength loads, protecting other tissues under high-strength loads, preventing movements beyond the joint range of motion, and providing stability by transmitting tension forces. Articular ligaments exhibit typical nonlinear anisotropic mechanical behavior to perform these tasks. When the loading is small, the collagen fibers in the ligament are in a crimped state. Collagen fibers are compatible with the force applied to the ligament. This situation is represented in the nonlinear end region of the load–strain curve. As the loading increases, the collagen fibers lengthen and the slip between them decreases, increasing the stiffness of the ligament. Collagen fibers maintain their linear elasticity until they reach the stretching threshold. In addition, the mutual sliding effect between the fibrous bundles contributes to the viscoelastic effect of the ligament.

The capillaries in the ligament provide the blood supply necessary for the development of the ligament and its repair after injury. The blood vessels in some ligaments can also provide nourishment to the surrounding bones and other soft tissues.

3.2.4.2 Other Anatomical Structures in the Joint

The meniscus, labrum, and intervertebral disks are located within the joint.

Meniscus

It is a fibrocartilage disk structure that has the ability to transfer the loads acting on the knee joint and to reduce the stress on the articular cartilage like a shock absorber. It increases the harmony of the tibiofemoral joint surfaces. It also has secondary tasks such as increasing stability, lubricity, feeding, and sensing proprioception.

Anatomical Placement of Menisci The menisci are shaped like two crescents located on both the medial and lateral tibial plateaus. The lateral meniscus is C-shaped and covers 75–93% of the lateral tibial plateau, while the medial meniscus is semicircular and covers 51–74% of the medial tibial plateau. The posterior horn of the medial meniscus is firmly attached to the posterior intercondylar fossa (anterior to the attachment of the anterior cruciate ligament [ACL] in the tibia) by bony attachments. Although the anterior horn differs among individuals, the most common location is the flat part of the intercondylar space in front of the ACL. The inferior medial meniscus is attached to the tibia by the medial collateral ligament and coronary ligament. Thanks to these strong connections, the almost immobile medial meniscus becomes more vulnerable to injury. The anterior horn of the lateral meniscus attaches to the anterolateral aspect of the ACL and to the anteromedial aspect of the apex of the lateral tibial eminence. The posterior horn, on the contrary, is located posteromedially of the apex of the lateral tibial eminence, anterior to the tibial attachment region of the posterior cruciate ligament (PCL), and anterolateral to the medial meniscus posterior horn attachment region (Fig. 3.17). Since the lateral meniscus has a more mobile structure than the medial meniscus, it is injured less frequently than the medial meniscus.

Vascular Anatomy of Menisci The fibrous region in the center of the meniscus in adults shows avascular features, and the nourishment of this region takes place by diffusion from the synovial fluid. There is a direct vascular blood supply in 10–30% areas in the periphery of the medial meniscus and 10–25% in the lateral meniscus. The nutrition of these vascular regions is provided by branches of the geniculate and popliteal arteries. When the cross-sectional area of the meniscus is examined, it is divided into

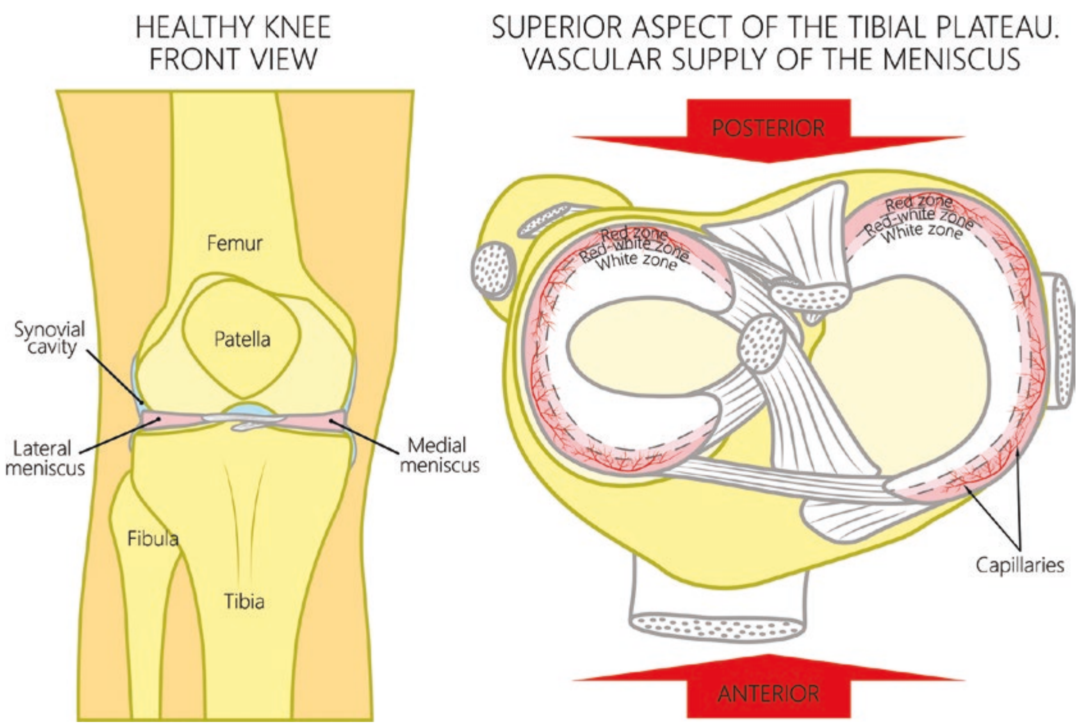


Fig. 3.17 Meniscus and anatomical structures (Aksanaku/Shutterstock.com)

three zones as *red–red*, *red–white*, and *white–white* according to the blood supply feature. The red–red zone in the periphery of the meniscus is fully nourished by the vascular structure, whereas the white–white zone in the center does not have a vascular structure.

Attention!
The red−red zone on the outer part of the meniscus has excellent vascular structure and healing potential. The red−white zone has a moderate vascular structure and healing potential. Since the inner white−white zone does not contain any vascular structure, the healing potential is minimal. It is thought that the low repair capacity after injury in the inner and middle zones of the meniscus is due to the low vascular structures of these zones.

Innervation of the Menisci There are three different mechanoreceptors (*Ruffini corpuscles*, *Pacini corpuscles*, and Golgi tendon organ) that contribute to proprioception and afferent senses in the peripheral two-thirds of the menisci and in the anterior and posterior horns. *Ruffini* corpuscles are unmyelinated and slowly adapt and transmit pain and joint deformation. *Pacini* corpuscles are myelinated, which are sensitive to tension and pressure changes. There is also a rapidly adapting, myelinated Golgi tendon organ, which contributes to the control of the joint range of motion through neuromuscular inhibition. There is no innervation of the one-third central part of the meniscus.

Labrum

One of the static stabilizers of the joint, the labrum shows morphological changes according to the structural needs of the joint. It is located on both sides of the joint: the glenoid and acetabular labrum.

The glenoid labrum is a fibrocartilage structure that surrounds the edge of the glenoid fossa and also deepens the joint. The labrum continues with the joint capsule and attaches to the medial glenoid and the anatomical neck of the humerus (Fig. 3.18). The anterior and inferior parts of the labrum are smaller and weaker than the superior and inferior parts. The main tasks of the glenoid labrum are to increase the contact area between the humeral head and the scapula by expanding the surface area and depth of the fossa, to protect the intra-articular pressure (especially against traction forces), to keep the joint fluid in the joint space, to provide lubrication, and to increase the lubricity of the long head of the biceps brachii muscle. It provides a place of attachment to the joint capsule with ligaments. The vascular nutrition of the glenoid labrum occurs mainly where it makes a peripheral connection with the joint capsule. The self-repairing ability of the labrum is limited in these regions due to less vascular nutrition in the superior and anterosuperior regions.

The acetabular labrum is a "C"-shaped, complex fibrocartilage structure that connects to the edge of the acetabulum. It consists of the ilium, ischium, and pubis. Between the anterior horn and posterior horn attachment of the labrum is the transverse acetabular ligament. The capsular region of the labrum consists of type I and type III collagens, while the articular region consists of type I, type II, and type III collagens. Where the labrum meets the articular cartilage, the collagen fibers are located perpendicular to the junctional surface, except in the anterosuperior region. The parallel location of the collagen fibers in the anterosuperior region to the junction surface reduces the attachment strength of the labrum and causes labral tear pathologies to occur in this region. Thanks to the anatomical structure of the acetabular labrum: (1) the hip joint socket is deepened to stabilize the hip joint; (2) negative intra-articular pressure is provided; (3) deformation of the joint cartilage is prevented by dissipating the stresses coming from the joint; (4) by keeping the joint fluid in the central compartment between the joint surfaces, the friction force between the joint surfaces is reduced; (5) it plays an important role in the perception of proprioceptive and pain sensation; and (6) it helps in chondral nutrition by keeping the joint fluid in the central compartment.

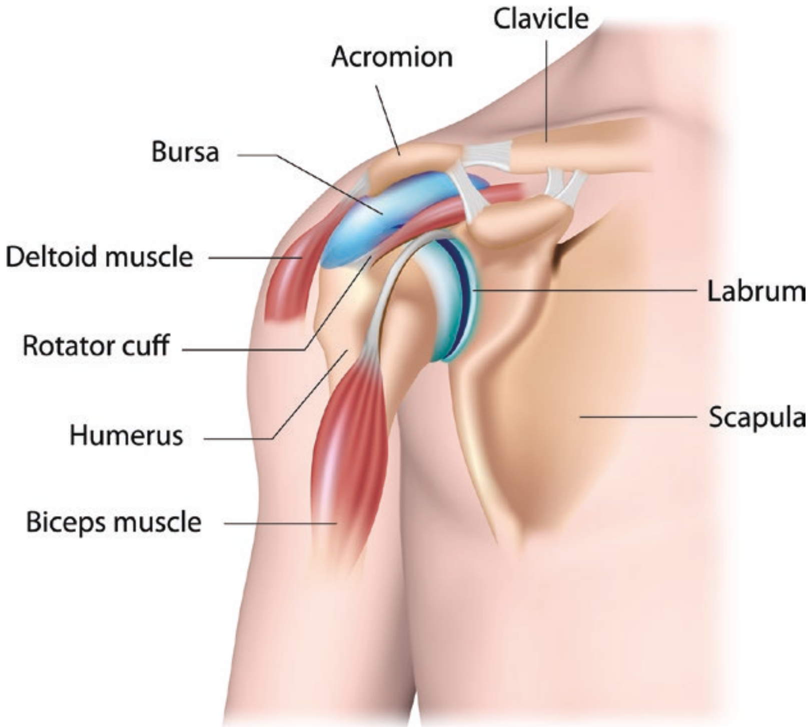


Fig. 3.18 Shoulder joint structures (Alila Medical Media/ Shutterstock.com)

The nutrition of the acetabular labrum is provided by the superior and inferior gluteal arteries, the medial and lateral circumflex arteries, and the intrapelvic vascular system. However, its main nutrition is provided by the connective tissue located between the capsule and the capsular part of the labrum. The capsular part of the labrum is better nourished than the articular part. The innervation of the acetabular labrum is provided by branches of the femoral nerve and obturator nerves. The acetabular labrum contains many different mechanoreceptors and free nerve endings. *Krause* corpuscles are cold sensitive, while *Vater-Pacini*, *Golgi-Mazzoni*, and *Ruffini* corpuscles help in proprioception. Free nerve endings are sensitive to pain, temperature, and tactile sensations. Most of the sensory receptors (86%) are located on the articular surface of the labrum, particularly in the anterosuperior part of the chondrolabral junction. The diversity and numerical redundancy of these neural structures indicate that the labrum is important for proprioception and pain sensations.

Clinical Information
The high level of pain in patients with labral tears is attributed to the high density of mechanoreceptors in the anterosuperior and posterosuperior regions of the acetabulum.

Intervertebral Disk

There are 25 intervertebral disks in the human spine, 7 of which are in the cervical, 12 in the thoracic, 5 in the lumbar, and 1 in the sacral region. The inferior surface of the upper vertebral body and the superior surface of the lower vertebral body articulate with the intervertebral disk. The intervertebral disk constitutes approximately 25–30% of the spine length. It allows the vertebral column to be flexible while absorbing the forces acting on the vertebral column and preventing the vertebrae from rubbing against each other during movement. It consists of three main components: the inner *nucleus pulposus (NP)*, the outer *annulus fibrosus (AP)*, and the *cartilage endplate*, which enable the disk to attach to the vertebrae.

Nucleus Pulposus It is a gel-like structure located in the center of the intervertebral disk. It is the cause of the vertebral column strength and flexibility. Further, 66–86% of the NP consists of water, with the remainder composed of type II collagen (which may also contain types VI, IX, and XI) and proteoglycans.

Annulus Fibrosus It is a ring-shaped fibrous connective tissue surrounding the NP. This structure consists of a combination of 15–25 lamella layers and contains collagen, proteoglycans, glycoproteins, elastin fibers, and extracellular matrix. Each lamella contains collagen fibers arranged in a 60° arrangement in the horizontal plane to the adjacent lamella. This arrangement provides a parallel arrangement of the lamellae and creates a "radial solid." Compared with a fully longitudinally aligned array, this array makes the annulus fibrosus more resistant to compression forces. Products such as automobile tires are inspired by this sequence. The lamellae are connected to each other via translamellar bridges. A balance exists between the number of translamellar bridges per unit area and strength and flexibility. More bridges provide greater resistance to compression forces and limit flexibility, or fewer bridges provide less resistance to compression forces and increase flexibility. The type I collagen content is higher in the outer layer of the annulus fibrosus, whereas the type I collagen content decreases, and the type II collagen content increases as it progresses toward the inner layers. The NP distributes the hydraulic pressure across the intervertebral disk. Thanks to the high water content of the nucleus pulposus, it can distribute the forces acting on the vertebral body in any direction to the entire structure. Considering the general arrangement of the AP fibers in the rostral–caudal direction, it resists the torsional, flexion, and extension movements of the spine. When considered holistically, the intervertebral disks support the spine and keep it flexible. Most intervertebral disks are avascular. The outer part of the AP shows vascular features. The vertebral body is fed by the vessels located at the bony disk junction. Two main ligaments support the intervertebral disk. The anterior longitudinal ligament, which covers the anterolateral surface of the vertebral column from the foramen magnum to the sacrum, prevents hyperextension and anterolateral herniation. Since the posterior longitudinal ligament covering the posterior surfaces of the vertebrae prevents posterior herniation of the intervertebral disks, most of the herniations occur in the posterolateral direction.

3.3 Conclusion

Although bone tissue is thought of as static, it is also dynamic with its soft tissue, endocrine system, and neurophysiological features. It is the key to the musculoskeletal system. Besides providing the functionality and mobility to the humans, it undertakes important tasks for homeostasis together with other important systems. It provides conditions that require mobility and stability by revealing different mechanics in terms of structure together with the joints.

Further Reading

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