CHAPTER 2

Basic Structure and Function of the Joints

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TOPICS AT A GLANCE

INTRODUCTION

A *joint* is the junction or pivot point between two or more bones. Movement of the body as a whole occurs primarily through rotation of bones about individual joints. Joints also transfer and dissipate forces owing to gravity and muscle activation throughout the body.

Arthrology—the study of the classification, structure, and function of joints—is an important foundation for the overall study of kinesiology. Aging, long-term immobilization, trauma, and disease all affect the structure and ultimate function of joints. These factors also significantly influence the quality and quantity of human movement.

This chapter focuses on the general anatomic structure and function of joints. The chapters contained in Sections II to IV review the specific anatomy and detailed function of the individual joints throughout the body. This detailed information is a prerequisite for the effective rehabilitation of persons with joint dysfunction.

CLASSIFICATION AND DESCRIPTION OF JOINTS

Classification Based on Anatomic Structure and Movement Potential

One common method to classify joints focuses primarily on anatomic structure and their subsequent movement potential (Table 2–1).[27] Based on this scheme, three types of joints exist in the body and are defined as *synarthrosis*, *amphiarthrosis*, and *diarthrosis*.

SYNARTHROSIS

A *synarthrosis* is a junction between bones that is held together by dense irregular connective tissue. This relatively rigid junction allows little or no movement. Examples of synarthrodial joints include the sutures of the skull, the teeth embedded in the mandible and maxillae, the distal tibiofibular joint, and the interosseous membranes of the forearm and leg. The epiphysial plate of a growing bone is also classified as a synarthrodial "joint" by some.[27] Because the function of an epiphysis is skeletal growth rather than motion, this classification is not used here.

The function of a synarthrosis is to bind bones together and to transmit force from one bone to the next with minimal joint motion. A synarthrodial joint allows forces to be dispersed across a relatively large area of contact, thereby reducing the possibility of injury.

AMPHIARTHROSIS

An *amphiarthrosis* is a junction between bones that is formed primarily by fibrocartilage and/or hyaline cartilage. Perhaps the most familiar example of an amphiarthrosis is the interbody joint of the spine. This joint uses an intervertebral disc

TABLE 2-1. Classification of Joints Based on Anatomic Structure and Movement Potential

	Joint Material	Available Motion	Primary Function	Examples
Synarthrosis	Dense, irregular connective tissue	Negligible	Binds bones within a functional unit, disperses forces across the joined bones	Sutures of the skull Teeth embedded in sockets of the maxillae and mandible Interosseous membrane of the forearm and leg Distal tibiofibular joint
Amphiarthrosis	Hyaline cartilage or fibrocartilage	Minimal to moderate	Provides a combination of relatively restrained movement and shock absorption	Intervertebral disc (within the interbody joints of the spine) Xiphisternal joint Pubic symphysis Manubriosternal joint
Diarthrosis (synovial joint)	True joint space filled with synovial fluid and surrounded by a capsule	Extensive	Provides the primary pivot points for movement of the musculoskeletal system	Glenohumeral joint Tibiofemoral (knee) joint Interphalangeal joint Apophyseal (facet) joint of the spine

and embedded nucleus pulposus to provide a rugged, resilient cushion that absorbs and disperses forces between adjacent vertebrae. Other examples of amphiarthrodial joints are the pubic symphysis and the manubriosternal joint. These joints allow relatively restrained movements. They also transmit and disperse forces between bones.

DIARTHROSIS: THE SYNOVIAL JOINT

A *diarthrosis* is an articulation that contains a fluid-filled joint cavity between bony partners. Because of the presence of a synovial membrane, diarthrodial joints are more frequently referred to as *synovial joints.* Synovial joints are the majority of the joints of the upper and lower extremities.

Diarthrodial, or synovial, joints are specialized for movement and always exhibit seven elements (Fig. 2-1). The joint cavity is filled with (1) *synovial fluid.* This provides nutrition and lubrication for the (2) *articular cartilage* that covers the ends of the bones. The joint is enclosed by a peripheral curtain of connective tissue that forms the (3) *articular capsule.* The articular capsule is composed of two histologically distinct layers. The internal layer consists of a thin (4) *synovial membrane,* which averages three to ten cell layers thick. The membrane acts as a barrier to adjacent capillaries, permitting only the fluid and solutes of blood plasma into the synovial fluid of a normal joint. Blood cells and large proteins, such as antibodies, are normally excluded from the synovial space. The cells of the synovial membrane also manufacture and add hyaluronate and lubricating glycoproteins (i.e., lubricin) to the joint fluid.[26]

The external, or fibrous, layer of the articular capsule of the synovial joint is composed of dense irregular connective tissue. The articular capsule provides support between the bones and containment of the joint contents. Certain regions of the fibrous capsule are thicker in order to resist or control specific motions. The thickened regions of connective tissue represent (5) *capsular ligaments.* Examples of prominent capsular ligaments are the anterior glenohumeral ligaments and the medial collateral ligament of the knee. The joint capsule is supplied with small (6) *blood vessels* with capillary beds

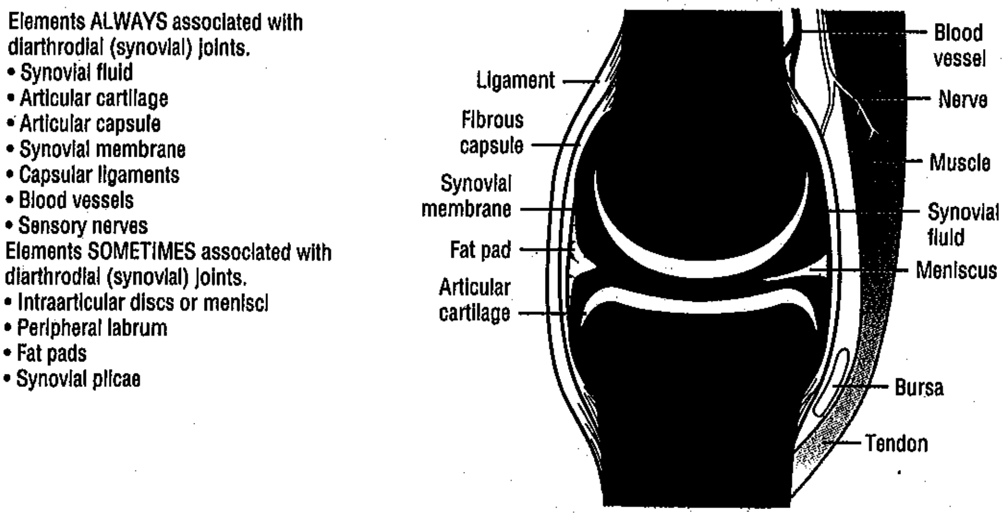


FIGURE 2-1. Elements associated with a typical diarthrodial (synovial) joint. The synovial plicae are not depicted.

that penetrate as far as the junction of the fibrous capsule and synovial membrane. The (7) *sensory nerves* also supply the fibrous capsule with appropriate receptors for pain and proprioception.

To accommodate the wide spectrum of joint shapes and functional demands, other elements may sometimes appear in synovial joints (see Fig. 2–1). *Intraarticular discs,* or *menisci,* are pads of fibrocartilage imposed between the articular surfaces of synovial joints. These structures increase articular congruency and improve force dispersion. Intraarticular discs and menisci are found in several joints of the body (see Box). Menisci are occasionally found in the apophyseal joints of the spine, but their function, constancy, and frequency remain controversial.[1,8,29,30]

Intraarticular Discs (Menisci) Are Found in Several Synovial Joints of the Body

- Tibiofemoral (knee)
- Distal radioulnar
- Sternoclavicular
- Acromioclavicular
- Temporomandibular

Two large synovial joints of the body possess a *peripheral labrum* of fibrocartilage. The labrum extends from the bony rims of both the glenoid cavity of the shoulder and the acetabulum of the hip. These specialized structures deepen the concave member of these joints and support and thicken the attachment of the joint capsule. *Fat pads* are variable in size and positioned within the substance of the joint capsule, interposed between the fibrous capsule and the synovial membrane. Fat pads are most prominent in the elbow and the knee joints. They thicken the joint capsule, causing the inner surface of the capsule to fill nonarticulating synovial spaces (i.e., recesses) formed by incongruent bony contours. In this sense, fat pads reduce the volume of synovial fluid necessary for proper joint function. If these pads become enlarged or inflamed, they may alter the mechanics of the joint.

Synovial plicae (i.e., synovial folds, synovial redundancies, or synovial fringes) are slack, overlapped pleats of tissue composed of the innermost layers of the joint capsule. They occur normally in joints with large capsular surface areas such as the knee and elbow. Plicae increase synovial surface area and allow full joint motion without undue tension on the synovial lining. If these folds are too extensive or become thickened or adherent due to inflammation, they can produce pain and altered joint mechanics.[3,4,15]

Classification of Synovial Joints Based on Mechanical Analogy

Thus far, joints have been classified into three broad categories according to the anatomic structure and subsequent movement potential: synarthrosis, amphiarthrosis, and diarthrosis. Because an in-depth understanding of synovial joints is so crucial to an understanding of the mechanics of movement, they are here further classified using an analogy to familiar mechanical objects or shapes (Table 2–2).

TABLE 2–2. Classification of Synovial Joints by Analogy

	Primary Angular Motions	Mechanical Analog	Anatomic Examples
Hinge joint	Flexion and extension only	Door hinge	Humeroulnar joint Interphalangeal joint
Pivot joint	Spinning of one member around a single axis of rotation	Door knob	Proximal radioulnar joint Atlantoaxial joint
Ellipsoid joint	Biplanar motion (flexion-and-extension and abduction-and-adduction)	Flattened convex ellipsoid paired with a concave trough	Radiocarpal joint
Ball-and-socket joint	Triplanar motion (flexion-and-extension, abduction-and-adduction, and internal-and-external rotation)	Spherical convex surface paired with a concave cup	Glenohumeral joint Coxofemoral (hip) joint
Plane joint	Typical motions include a slide (translation) or a combined slide and rotation	Relatively flat surfaces apposing one another, like a book on a table	Intercarpal joints Intertarsal joints
Saddle joint	Biplanar motion; a spin between the bones is possible but may be limited by the interlocking nature of the joint	Each member has a reciprocally curved concave and convex surface oriented at right angles to one another, like a horse rider and a saddle	Carpometacarpal joint of the thumb Sternoclavicular joint
Condyloid joint	Biplanar motion; either flexion-and-extension and abduction-and-adduction, or flexion-and-extension and axial rotation (internal-and-external rotation)	Mostly spherical convex surface that is enlarged in one dimension like a knuckle; paired with a shallow concave cup	Metacarpophalangeal joint Tibiofemoral (knee) joint

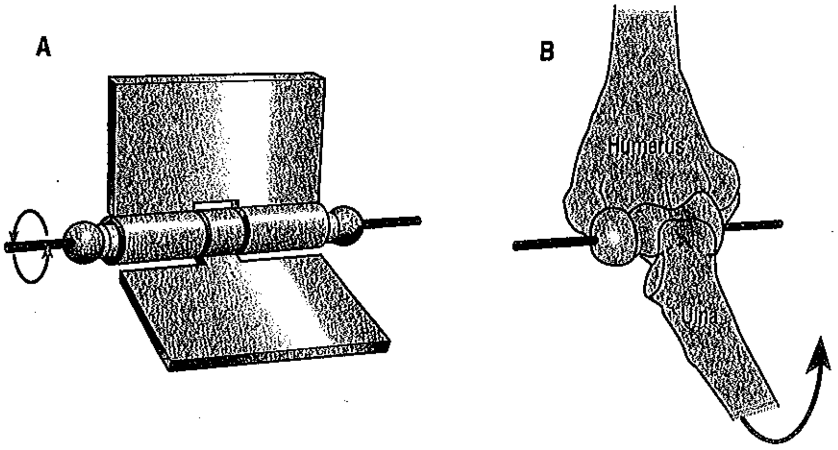


FIGURE 2–2. A hinge joint *(A)* is illustrated as analo gous to the humeroulnar joint *(B)*. The axis of rota tion (i.e., pivot point) is represented by the pin.

A *hinge joint* is analogous to the hinge of a door, formed by a central pin surrounded by a larger hollow cylinder (Fig. 2–2*A*). Angular motion at hinge joints occurs primarily in a plane located at right angles to the hinge, or axis of rotation. The humeroulnar joint is a clear example of a hinge joint (Fig. 2–2*B*). As in all synovial joints, slight translation (i.e., sliding) is allowed in addition to the rotation. Although the mechanical similarity is less complete, the interphalangeal joints of the digits are also classified as hinge joints.

A *pivot joint* is formed by a central pin surrounded by a larger cylinder. Unlike a hinge, the mobile member of a pivot joint is oriented parallel to the axis of rotation. This mechanical orientation produces the primary angular motion of spin, similar to a doorknob's spin around a central axis (Fig. 2–3*A*). Two excellent examples of pivot joints are the proximal radioulnar joint, shown in Figure 2–3*B*, and the atlantoaxial joint between the dens of the second cervical vertebra and the anterior arch of the first cervical vertebra.

An *ellipsoid joint* has one partner with a convex elongated surface in one dimension that is mated with a similarly elongated concave surface on the second partner (Fig. 2–4*A*). The elliptic mating surfaces severely restrict the spin between the two surfaces but allow biplanar motions, usually defined as flexion-extension and abduction-adduction. The radiocarpal joint is an example of an ellipsoid joint (Fig 2–4*B*). The flattened "ball" of the convex member of th joint (i.e., carpal bones) cannot spin within the elongate trough (i.e., distal radius) without dislocating.

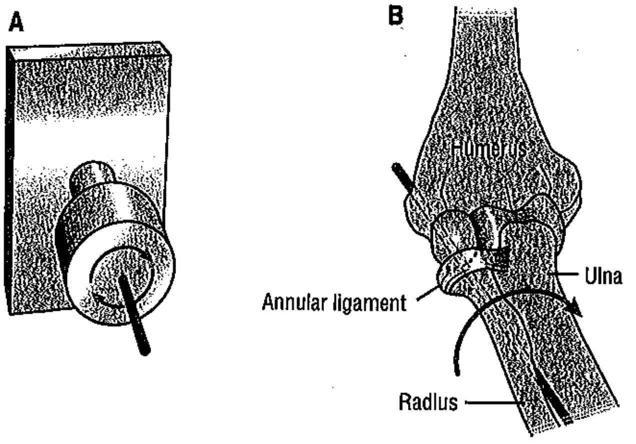


FIGURE 2–3. A pivot joint *(A)* is shown as analogous to the proximal radioulnar joint *(B)*. The axis of rotation is represented by the pin.

A *ball-and-socket joint* has a spherical convex surface tha is paired with a cuplike socket (Fig. 2–5*A*). This joint pro vides motion in three planes. Unlike the ellipsoid joint, th symmetry of the curves of the two mating surfaces of th ball-and-socket joint allows spin without dislocation. Ball-and-socket joints within the body include the glenohumera joint and the hip joint.

A *plane joint* is the pairing of two flat or relatively fla surfaces. Movements combine sliding and some rotation o one partner with respect to the other—much like a book can be slid over a tabletop (Fig. 2–6*A*). As depicted i Figure 2–6*B*, most of the intercarpal joints are considered t be plane joints. The internal forces that cause or restric movement between carpal bones are supplied by tension i muscles or ligaments.

Each partner of a *saddle joint* has two surfaces: one surface is concave, and the other is convex. These surfaces are oriented at approximate right angles to one another and are reciprocally curved. The shape of a saddle joint is best visualized using the analogy of a horse's saddle and rider (Fig. 2–7*A*). From front to back, the saddle presents a concave surface reaching from the saddle horn to the back of the saddle. From side to side, the saddle is convex stretching from one stirrup across the back of the horse to the other stirrup. The rider is also doubly curved, presenting convex and concave curves to complement the shape of the saddle. The carpometacarpal joint of the thumb is the clearest example of a saddle joint (Fig. 2–7*B*). The reciprocal, interlocking nature of this joint allows ample biplanar motion, but limited spin between the trapezium and the first metacarpal.

A *condyloid joint* is much like a ball-and-socket joint except that the concave member of the joint is very shallow (Fig. 2–8*A*). Condyloid joints usually allow 2 degrees of freedom. Ligaments or bony incongruity restrains the third degree. Condyloid joints often occur in pairs, such as the knee (Fig. 2–8*B*), the temporomandibular joints, and the atlantooccipital joints (i.e., occipital condyles with the first cervical vertebra). The metacarpophalangeal joint of the finger is also an example of a condyloid joint. The root word of the term "condyle" actually means "knuckle."

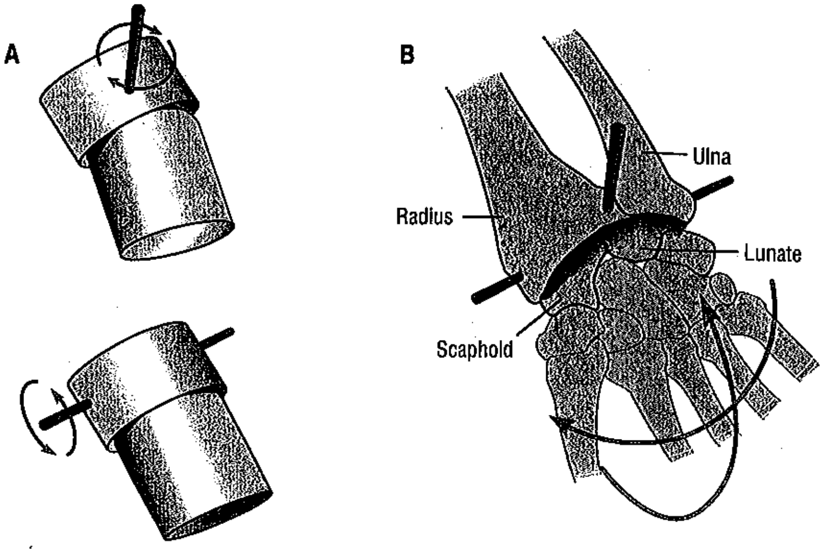


FIGURE 2–4. An ellipsoid joint *(A)* is shown as analogous to the radiocarpal joint (wrist) *(B)*. The two axes of rotation are shown by the intersecting pins.

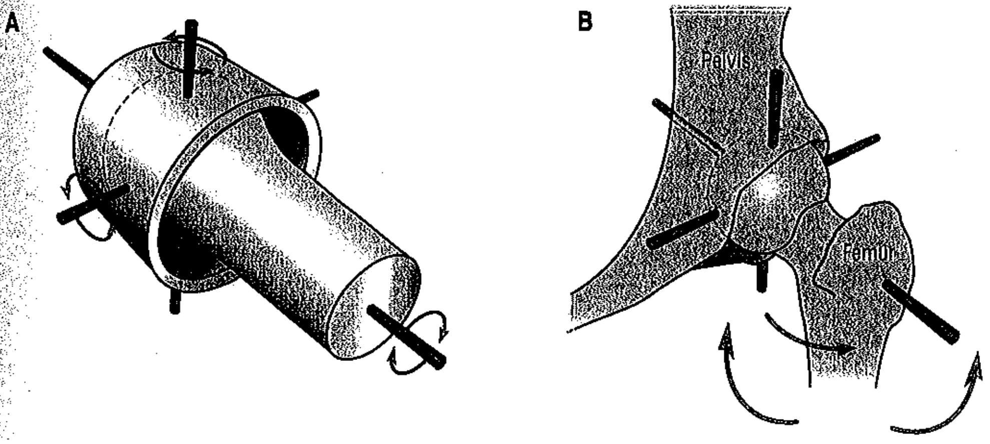


FIGURE 2–5. A ball-in-socket articulation *(A)* is drawn as analogous to the hip joint *(B)*. The three axes of rotation are represented by the three intersecting pins.

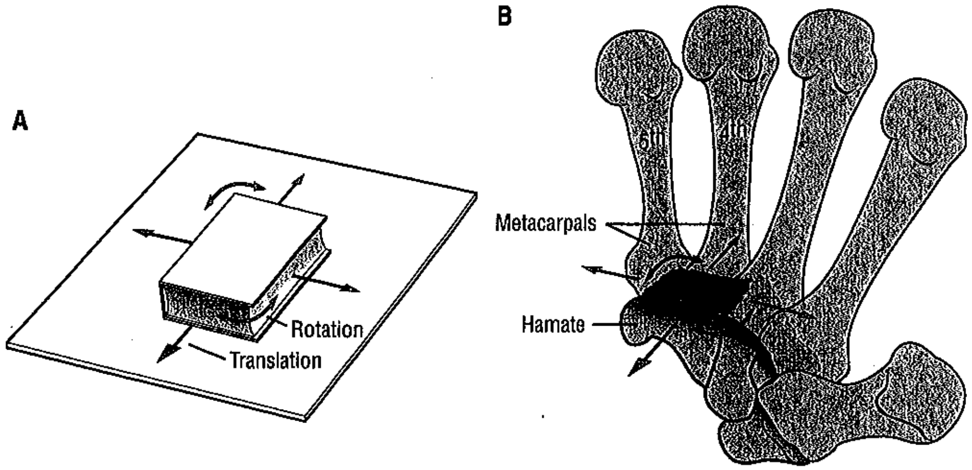


FIGURE 2–6. A plane "joint" is formed by opposition of two flat surfaces *(A)*. The book moving on the table top is depicted as analogous to the combined slide and spin at the fourth and fifth carpometacarpal joints *(B)*.

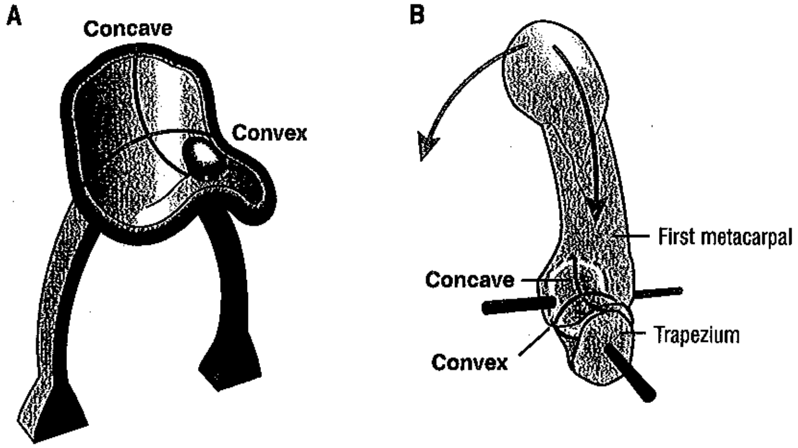


FIGURE 2–7. A saddle joint (*A*) is illustrated as analogous to the carpometacarpal joint of the thumb (*B*). The saddle in *A* represents the trapezium bone. The "rider," if present, would represent the base of the thumb's metacarpal. The two axes of rotation are shown in *B*.

The kinematics at condyloid joints vary based on joint structure. At the knee, for example, the femoral condyles fit within the slight concavity provided by the tibial plateau. This articulation allows flexion-extension and axial rotation (i.e., spin). Abduction and adduction, however, are restricted primarily by ligaments.

Simplifying the Classification of Synovial Joints: Ovoid and Saddle Joints

It is often difficult to classify synovial joints based on an analogy to mechanics alone. The metacarpophalangeal joint (condyloid) and the glenohumeral joint (ball-and-socket), for example, have similar shapes but differ considerably in the relative magnitude of movement and overall function. Joints always display subtle variations that make simple mechanical descriptions less applicable. A good example of the difference between mechanical classification and true function is seen in the gentle undulations that characterize the intercarpal and intertarsal joints. These joints produce complex multiplanar movements that are inconsistent with their simple "planar" mechanical classification. To circumvent this difficulty, a simplified classification scheme recognizes only two articular forms: the ovoid joint and the saddle joint (Fig. 2–9). Essentially all synovial joints with the notable exception of planar joints can be categorized under this scheme.

An *ovoid joint* has paired mating surfaces that are imperfectly spherical, or egg-shaped, with adjacent parts possessing a changing surface curvature. In each case, the articular surface of one bone is convex and the other is concave.

A *saddle joint* has been previously described. Each member presents paired curved surfaces that are opposite in direction and oriented at approximately 90 degrees to each other. This simplified classification system allows the generalization to the arthrokinematic patterns of movement as a roll, slide, or spin (see Chapter 1). This generalization is used throughout this text.

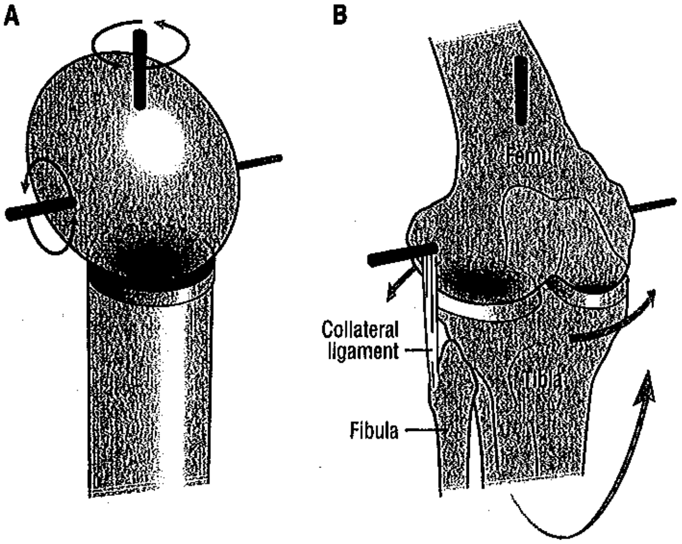


FIGURE 2–8. A condyloid joint is shown (*A*) representing an analogy to the tibiofemoral (knee) joint (*B*). The two axes of rotation are shown by the pins. The frontal plane motion at the knee is blocked by tension in the collateral ligament.

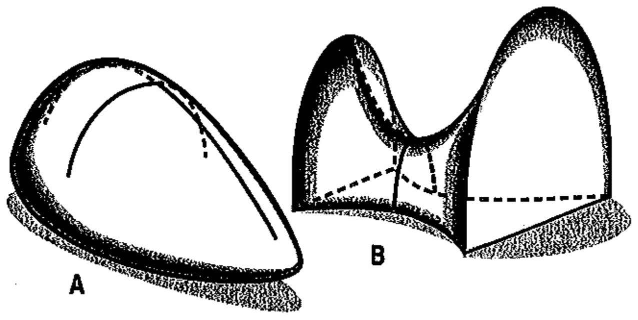


FIGURE 2–9. Two basic shapes of joint surfaces. *A*, The egg-shaped *ovoid surface* represents a characteristic of most synovial joints of the body (for example, hip joint, radiocarpal joint, knee joint, metacarpophalangeal joint). The diagram shows only the convex member of the joint. A reciprocally shaped concave member would complete the pair of ovoid articulating surfaces. *B*, The *saddle surface* is the second basic type of joint surface, having one convex surface and one concave surface. The paired articulating surface of the other half of the joint would be turned so that a concave surface is mated to a convex surface of the partner.

AXIS OF ROTATION

In the analogy using a door hinge (see Fig. 2–2*A*), the axis of rotation (i.e., the pin through the hinge) is *fixed*, because it remains stationary throughout the rotation of the door. With the axis of rotation fixed, all points on the door experience equal arcs of rotation. In anatomic joints, however, the axis of rotation is rarely, if ever, fixed during bony rotation. Finding the exact position of the axis of rotation in anatomic joints is therefore not as obvious. A simplified method of estimating the position of the axis of rotation in anatomic joints is shown in Figure 2–10*A*. The intersection of the two perpendicular lines drawn from a-a′ and b-b′ defines the *instantaneous axis of rotation* for the 90-degree arc of knee flexion. The term instantaneous indicates that the location of the axis holds true only for the particular arc of motion. The smaller the angular range used to calculate the instantaneous axis, the more accurate the estimate. If a series of line drawings are made for a sequence of small angular arcs of motion, the location of the instantaneous axes can be plotted for each portion within the arc of motion (Fig. 2–10*B*). The path of the serial locations of the instantaneous axes of rotation is called the *evolute*. The path of the evolute is longer and more complex when the mating joint surfaces are less congruent or have greater changes in their radii of curvature, such as the knee. The smaller the individual arcs used for calculation, the more accurate is the resulting evolute.

In many practical clinical situations it is necessary to make simple estimates of the location of the axis of rotation of a joint. These estimates are necessary when performing *goniometry*, measuring torque about a joint, or when constructing a prosthesis or an orthosis. A series of x-ray measurements are required to precisely identify the instantaneous axis of rotation at a joint (see Fig. 2–10*A*). This method is not practical in ordinary clinical situations. Instead, an *average axis* of rotation is assumed to occur throughout the entire arc of motion. This axis is located by an anatomic landmark that coincides with the *convex member* of the joint.

BIOLOGIC MATERIALS THAT FORM CONNECTIVE TISSUES WITHIN JOINTS

The composition, proportion, and arrangement of biologic materials that compose the connective tissue within joints strongly influence their mechanical performance. The fundamental materials that make up the connective tissues of a joint are *fibers, ground substance,* and *cells*. These biologic materials are blended in various proportions based on the mechanical demands of the joint.

Fundamental Materials That Form the Connective Tissues within Joints

1. Fibers
    - Collagen (types I and II)
    - Elastin
2. Ground substance
    - Glycosaminoglycans
    - Water
    - Solutes
3. Cells

Fibers

Various types of collagen fibers and elastic fibers occur in joints. *Collagen fibers* are made of short subunits (fibrils), which are wound in a helical structure much like short threads. These threads are placed together in a strand, several of which are spirally wound into a rope. Twelve collagen types have been described,[27] but two types make up the

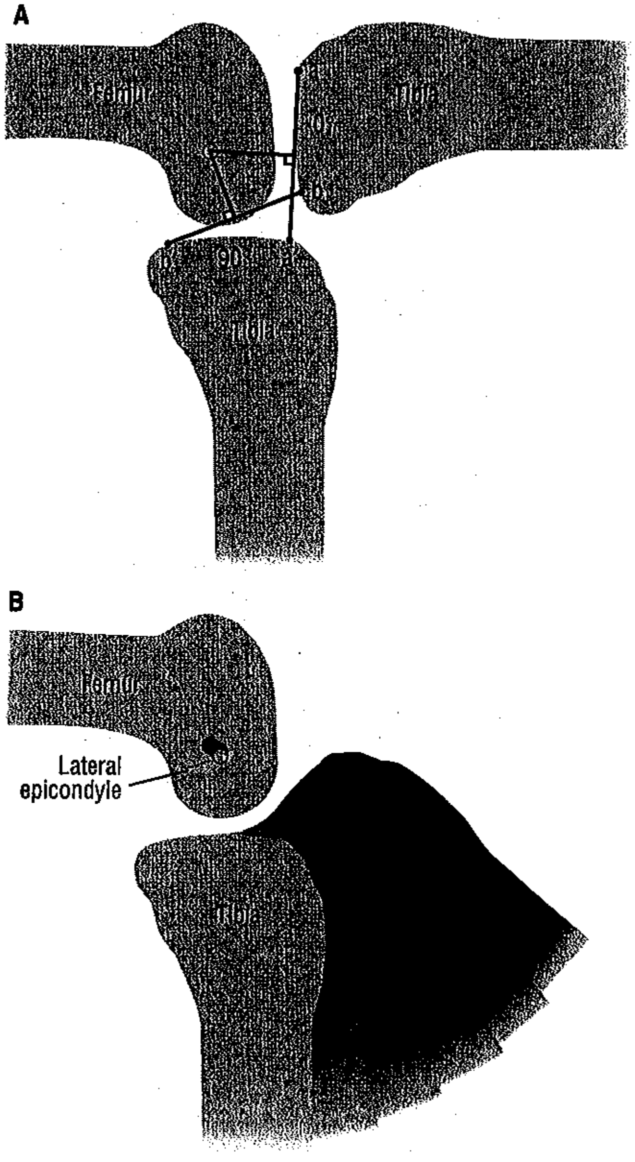


FIGURE 2–10. A simplified method for determining the instantaneous axis of rotation for 90 degrees of knee flexion *(A)*. With the use of x-ray, two points (a and b) are identified on the tibial plateau. With the position of the femur held stationary, the same two points are identified following 90 degrees of flexion (a′ and b′). Next, two perpendicular lines are drawn from a-a′ and b-b′. The point of intersection of these two perpendicular lines identifies the instantaneous axis of rotation for the 90-degree arc of motion. This same method can be repeated for many smaller arcs of motion, producing several slightly different axes of rotation *(B)*. The path of the "migrating" axes is called the evolute. At the knee, the average axis of rotation is oriented in the medial-lateral direction, piercing the lateral epicondyle of the femur.

majority of collagen in normal joints—type I and type II. *Type I collagen fibers* are thick, rugged fibers that are gathered into bundles and elongate very little when placed under tension. Being relatively stiff, type I collagen fibers are ideal for binding and supporting the articulations between bones. Type I collagen is therefore the primary protein found in ligaments and fibrous joint capsules. This type of collagen also makes up the parallel fibrous bundles that compose tendons—the structures that transmit the force of muscle to bone.

Two Predominant Types of Collagen Fibers in Normal Joints

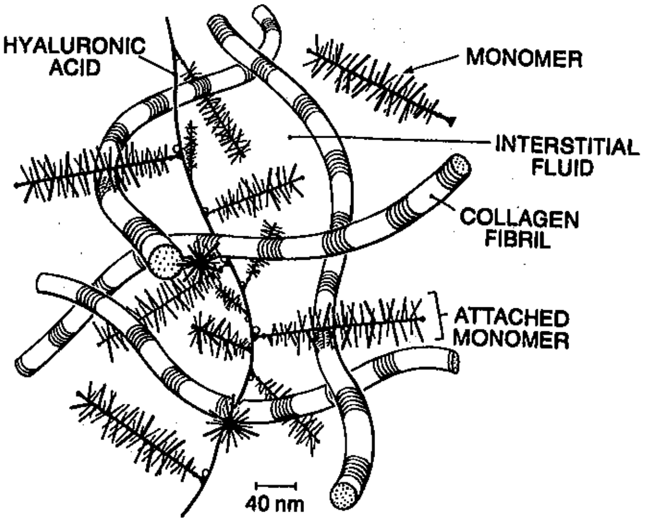
- *Type I:* thick, rugged fibers that elongate very little when stretched; compose ligaments, tendons, and fibrous capsules.
- *Type II:* thinner and less stiff than type I fibers; provide a flexible woven framework for maintaining the general shape and consistency of structures such as hyaline cartilage.

Type II collagen fibers are thinner than type I and possess slightly less tensile strength. These fibers provide a flexible woven framework for maintaining the general shape and consistency of more complex structures, such as hyaline cartilage. Type II collagen still provides internal strength to the tissue in which it resides.

In addition to collagen, the connective tissues within joints have varying amounts of *elastin fibers*. These fibers are composed of a netlike interweaving of small elastin fibrils that resist tensile (stretching) forces, but they have more "give" when elongated. Tissues with a high proportion of elastin readily return to their original shape after being deformed. This property is useful in structures that undergo significant deformation, such as the cartilage of the ear, or in certain spinal ligaments that help return a bone to its original position after movement.

Ground Substance

Collagen and elastin fibers are embedded within a water-saturated matrix known as *ground substance*. The ground substance of joint tissues is made of *glycosaminoglycans (GAGs)*, *water*, and *solutes*. The GAGs are highly branched and negatively charged amino sugars that are strongly bonded with water. Structurally, the GAGs resemble long bottle brushes that are strongly hydrophilic due to their negative charge (Fig. 2–11). Water provides a fluid medium for diffusion of nutrients within a tissue. In addition, water assists with the mechanical properties of tissue. The tendency of GAGs to imbibe and hold water causes the tissue to swell. Swelling is limited by embedded collagen or elastin fibers anchored into an adjacent supporting structure, such as bone or dense bands of fibers. The interaction between the restraining fibers and the swelling GAGs provides a turgid structure that resists compression, much like a balloon or a water-filled mattress. An example of such a structurally dynamic material is articular cartilage. This important tissue provides an ideal surface covering for joints and is capable of dispersing the millions of repetitive forces that have an impact on joints throughout a lifetime.



AGGREGATE IN COLLAGEN MESHWORK

FIGURE 2–11. Schematic drawing of the molecular organization of cartilage. A glycosaminoglycan (GAG) molecule is formed by a hyaluronic acid center thread to which proteoglycan monomers are attached, forming a bottle brush configuration. The GAG molecule is shown interlacing between collagen fibrils. Water fills much of the space within the matrix. (From Nordin M, Frankel VH: Basic Biomechanics of the Musculoskeletal System, 2nd ed. Philadelphia, Williams & Wilkins, 1989.)

Cells

The *cells* within connective tissues of the joints are responsible for maintenance and repair. In contrast to skeletal muscle cells, these cells do not confer significant mechanical properties on the tissue. Damaged or aged components are removed, and new components are manufactured and remodeled. Cells of connective tissues of the joints are generally sparse and interspersed between the strands of fibers or embedded deeply in regions of high GAG content. This sparseness of cells in conjunction with limited blood supply often results in poor or incomplete healing of damaged or injured joint tissues.

TYPES OF CONNECTIVE TISSUES THAT FORM THE STRUCTURE OF JOINTS

Four types of connective tissues predominate in joints: *dense irregular connective tissue, articular cartilage, fibrocartilage*, and *bone*. Anatomic and functional details of the four connective tissues are listed in Table 2–3. The table also includes clinical correlates associated with each tissue.

Dense Irregular Connective Tissue

Dense irregular connective tissue is found in the fibrous external layer of the articular capsule and ligaments. Structurally, this connective tissue has a high proportion of type I collagen fibers that are arranged in bundles and aligned to resist the natural stresses placed on the tissue. The connective tissue bundles function most effectively when they are stretched parallel to their long axis. After the initial slack is pulled tight, the ligaments and joint capsule provide immediate tension that restrains undesirable motion between bony partners.

The fibrous joint capsule and ligaments resist forces from several directions. To accomplish this, the fiber bundles within the connective tissues are arranged in several dominant directions, unlike the parallel alignment of collagen bundles found in a tendon (Fig. 2–12).[6,20] The GAGs and elastin fiber content are usually low in dense irregular connective tissue.

When trauma or disease produces laxity in the ligament or capsules, muscles take on a more dominant role in restraining joint movement. Even if muscles surrounding a ligamentously lax joint are strong, there is loss of joint stability. Compared with ligaments, muscles are slower to supply force due to the electromechanical delay necessary to build active force. Muscle forces often have a less than ideal alignment for restraining undesirable joint movements, and they often cannot provide the most optimal deterrent force.

Articular Cartilage

Articular cartilage is a specialized type of hyaline cartilage that forms the load-bearing surface of joints. Articular cartilage covering the ends of the articulating bones has a thickness that ranges from 1 to 4 mm in the areas of low compression force and 5 to 7 mm in areas of high compression.[16,25] The tissue is avascular and aneural. Unlike regular hyaline cartilage, articular cartilage lacks a perichondrium. This allows the opposing surfaces of the cartilage to form ideal load-bearing surfaces. Similar to periosteum on bone, perichondrium is a layer of connective tissue that covers most cartilage. It contains blood vessels and a ready supply of primitive cells that maintain and repair underlying tissue. This is an advantage not available to articular cartilage.

Chondrocytes of various shapes are located within the ground substance of different layers or zones of articular cartilage (Fig. 2–13*A*). These cells are bathed and nourished by nutrients within the synovial fluid. Nourishment is facilitated by the "milking" action of articular surface deformation during intermittent joint loading. The chondrocytes are surrounded by predominantly type II collagen fibers. As depicted in Figure 2–13*B*, the fibers are arranged to form a restraining network or "scaffolding" that adds structural stability to the tissue. The deepest fibers in the calcified zone are firmly anchored to the subchondral bone. These fibers are linked to the vertically oriented fibers in the adjacent deep zone which, in turn, are linked to the obliquely oriented fibers of the middle zone, and finally to the transversely oriented fibers of the superficial tangential zone. The series of chemically interlinked fibers form a netlike fibrous structure that entraps the large GAG molecules beneath the articular surface. The GAGs in turn attract water that provides a unique element of rigidity to articular cartilage. The rigidity increases the ability of cartilage to adequately withstand loads.

Articular cartilage distributes and disperses compressive forces to the subchondral bone. It also reduces friction between joint surfaces. The coefficient of friction between two surfaces covered by articular cartilage and wet with synovial fluid is extremely low, ranging from 0.005 to 0.02 in the human knee for example. This is 5 to 20 times lower and more slippery than ice on ice, which has a coefficient of 0.1.[17] The impact of normal weight-bearing activities, therefore, is reduced to a stress that typically can be absorbed without damaging the skeletal system.

The absence of a perichondrium on articular cartilage has the negative consequence of eliminating a ready source of primitive perichondrial fibroblastic cells used for repair. Even

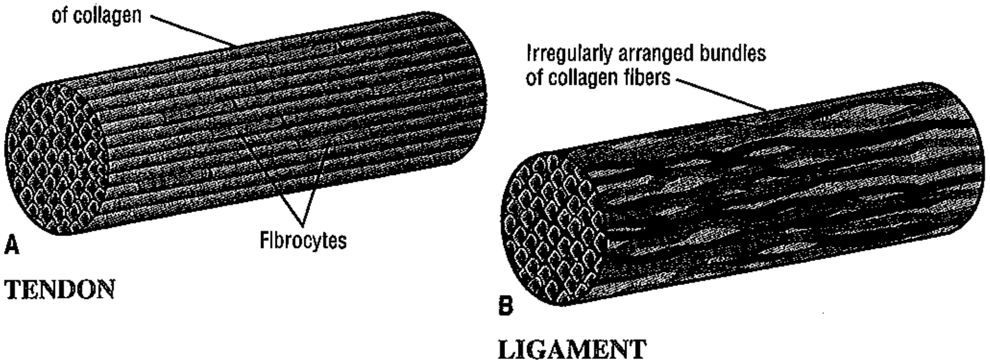


FIGURE 2–12. Diagrammatic representation of the fibrous organization of tendons and ligaments. *A*, The bundles of collagen in a *tendon* are tightly packed and arranged parallel to one another. The arrangement allows the tendon to transmit unidirectional tensile forces from a muscle without having to take up slack in the bundles. The cells that maintain this connective tissue (fibrocytes) are few in number and flattened between the collagen bundles. *B*, A *ligament* has collagen bundles that are less parallel to one another. This allows the ligament to accept tensile forces from several different directions while holding two bones together. Bundles may be organized parallel to the most common lines of tension. The fibrocytes of the ligament are not shown in this drawing but are few in number and flattened.