

Joint Anatomy and Basic Biomechanics

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MODELS OF SPINE FUNCTION

This chapter provides an academic picture of the applied anatomy and biomechanics of the musculoskeletal system. The human body may be viewed as a machine formed of many different parts that allow motion. These motions occur at the many joints formed by the specific parts that compose the body's musculoskeletal system. Although there is some controversy and speculation among those who study these complex activities, the information presented here is considered essential for understanding clinical correlations and applications. Biomechanical discussions require specific nomenclature, which enables people

working in a wide variety of disciplines to communicate (see Appendix 3). Biomechanics is often overwhelming because of its mathematical and engineering emphasis. This chapter will present a nonmathematical approach to defining clinically useful biomechanical concepts necessary for the ability to describe and interpret changes in joint function. Thorough explanations of biomechanical concepts are discussed in other works.¹⁻³

FUNDAMENTAL CONCEPTS, PRINCIPLES, AND TERMS

Mechanics is the study of forces and their effects. *Biomechanics* is the application of mechanical laws to living structures, specifically to the locomotor system of the human body. Therefore biomechanics concerns the interrelations of the skeleton, muscles, and joints. The bones form the levers, the ligaments surrounding the joints form hinges, and the muscles provide the forces for moving the levers about the joints.

Kinematics is a branch of mechanics that deals with the geometry of the motion of objects, including displacement, velocity, and acceleration, without taking into account the forces that produce the motion. *Kinetics*, however, is the study of the relationships between the force system acting on a body and the changes it produces in body motion.

Knowledge of joint mechanics and structure, as well as the effects that forces produce on the body, has important implications for the use of manipulative procedures and, specifically, chiropractic adjustments. Forces have vector characteristics whereby specific directions are delineated at the points of application. Moreover, forces can vary in magnitude, which will affect the acceleration of the object to which the force is applied.

Levers

A lever is a rigid bar that pivots about a fixed point, called the *axis* or *fulcrum*, when a force is applied to it. Force is

applied by muscles at some point along the lever to move the body part (resistance). The lever is one of the simplest of all mechanical devices that can be called a *machine*. The relationship of fulcrum to force to resistance distinguishes the different classes of levers.

In a first-class lever, the axis (fulcrum) is located between the force and the resistance; in a second-class lever, the resistance is between the axis and the force; and in a third-class lever, the force is between the axis and the resistance (Figure 2-1). Every movable bone in the body

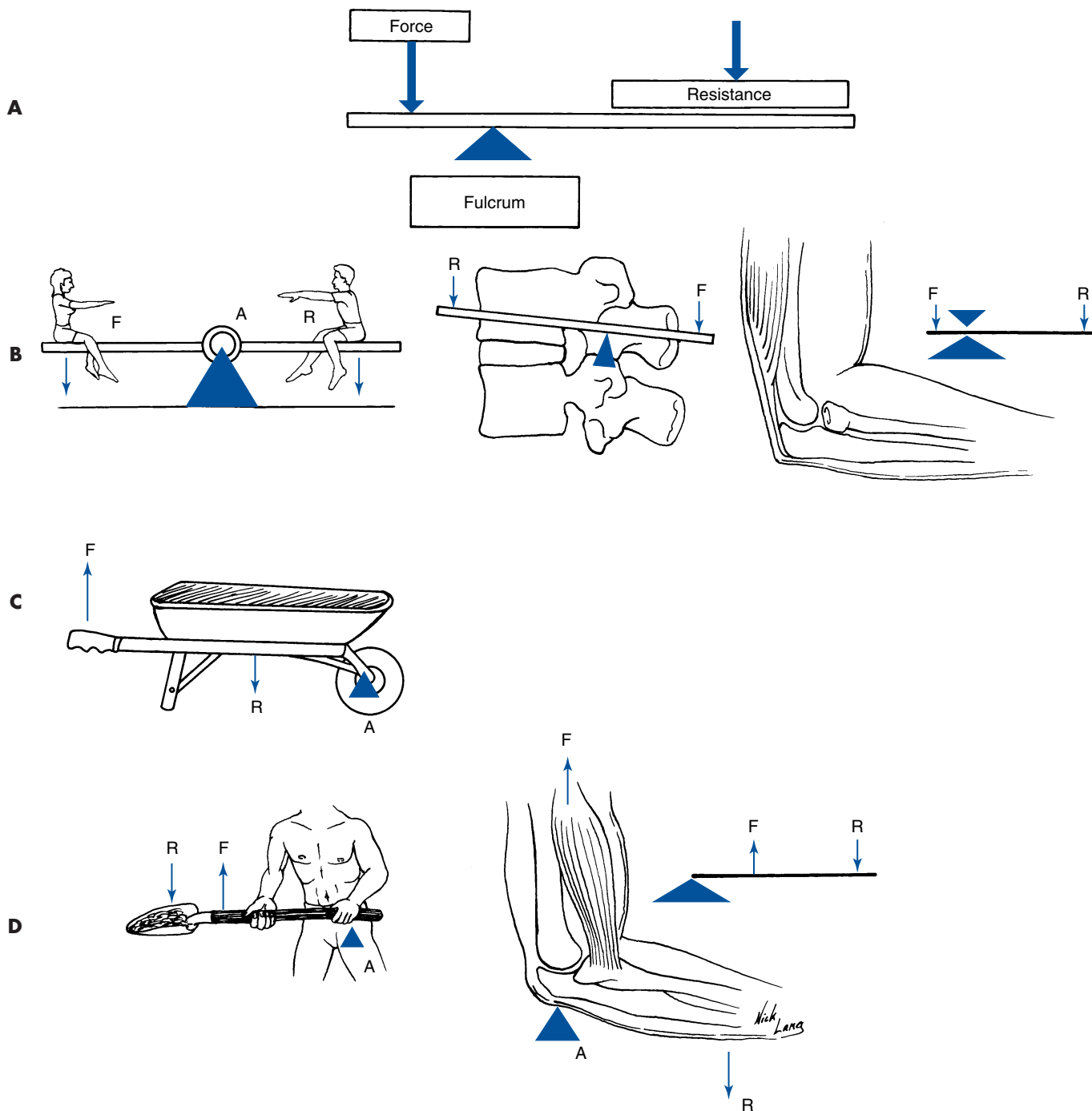


Figure 2-1
 A, Lever system showing components. B, First-class lever system. C, Second-class lever system. D, Third-class lever system. A, Axis (fulcrum); F, force; R, resistance.

acts alone or in combination, forcing a network of lever systems characteristic of the first- and third-class levers. There are virtually no second-class levers in the body, although opening the mouth against resistance is an example.

With a first-class lever, the longer the lever arm is, the less force is required to overcome the resistance. The force arm may be longer, shorter, or equal to the resistance arm, but the axis will always be between these two points. An example of a first-class lever in the human body is the forearm moving from a position of flexion into extension at the elbow through contraction of the triceps muscle.

Third-class levers are the most common types in the body because they allow the muscle to be inserted near the joint and can thereby produce increased speed of movement, although at a sacrifice of force. The force arm must be smaller than the resistance arm, and the applied force lies closer to the axis than the resistance force. An example of a third-class lever is flexion of the elbow joint through contraction of the biceps muscle.

Body Planes

It is also necessary to delineate the specific body planes of reference, since they will be used to describe structural position and directions of functional movement. The stan-

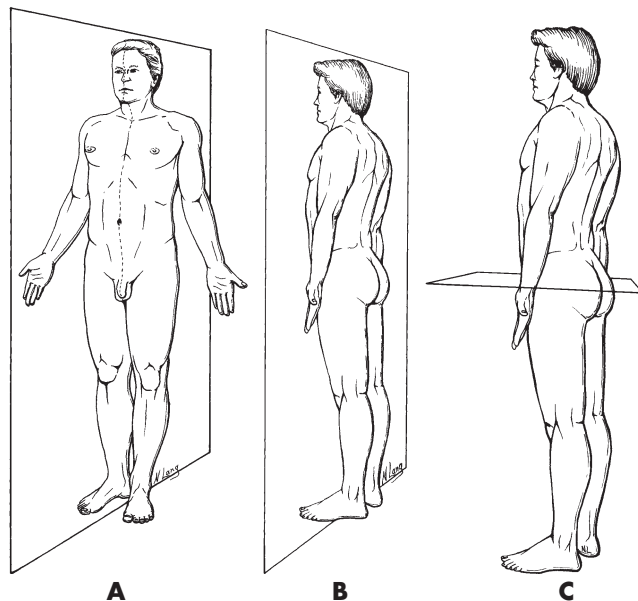


Figure 2-2

A, Midsagittal plane. Movements of flexion and extension take place in the sagittal plane. **B**, Coronal plane. Movements of abduction and adduction (lateral flexion) take place in the coronal plane. **C**, Transverse plane. Movements of medial and lateral rotation take place in the transverse plane.

dard position of reference, or anatomic position, has the body facing forward, the hands at the sides of the body, with the palms facing forward, and the feet pointing straight ahead. The body planes are derived from dimensions in space and are oriented at right angles to one another. The *sagittal plane* is vertical and extends from front to back, or from anterior to posterior. Its name is derived from the direction of the human sagittal suture in the cranium. The *median sagittal plane*, also called the *midsagittal plane*, divides the body into right and left halves (Figure 2-2, *A*, Table 2-1). The *coronal plane* is vertical and extends from side to side. Its name is derived from the orientation of the human coronal suture of the cranium. It may also be referred to as the *frontal plane*, and it divides the body into anterior and posterior components (Figure 2-2, *B*). The transverse plane is a horizontal plane and divides a structure into upper and lower components (Figure 2-2, *C*).

Axes of Movement

An axis is a line around which motion occurs. Axes are related to planes of reference, and the cardinal axes are oriented at right angles to one another. This is expressed as a three-dimensional coordinate system with *x*, *y*, and *z* used to mark the axes (Figure 2-3). The significance of this coordinate system is in defining or locating the extent of the types of movement possible at each joint—rotation, translation, and curvilinear motion. All movements that occur about an axis are considered *rotational*, whereas linear movements along an axis and through a plane are called *translational*. *Curvilinear* motion occurs when a translational movement accompanies rotational movements. The load that produces a rotational movement is called *torsion*; a force that produces a translational movement is called an *axial* or *shear force*.

Joint Motion

Motion can be defined as a continuous change in position of an object. The axis around which movement takes

TABLE 2-1

Body Planes of Movement

Plane of Movement	Axis	Joint Movement
Sagittal	Coronal [<i>x</i>]	Flexion and extension
Coronal	Sagittal (antero-posterior) [<i>z</i>]	Abduction and adduction (lateral flexion)
Transverse	Longitudinal (vertical) [<i>y</i>]	Medial and lateral rotation (axial rotation)

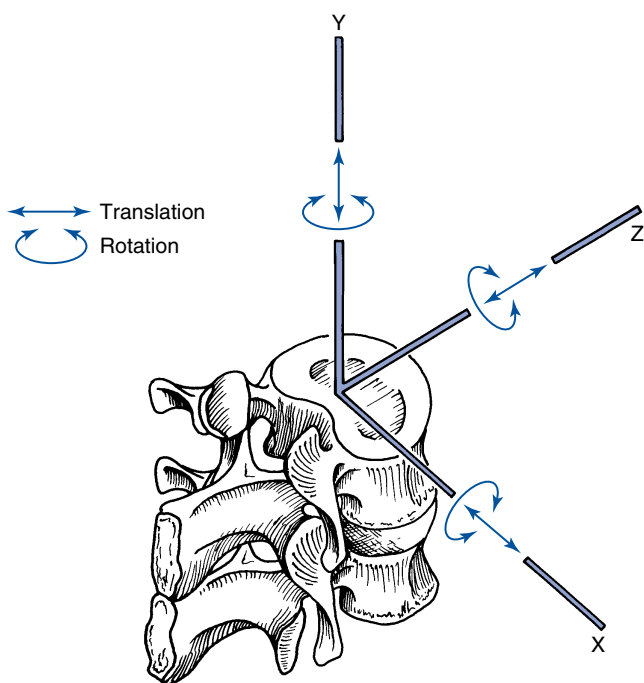


Figure 2-3

Three-dimensional coordinate system identifying the translational and rotational movements along or around the three axes to produce 6 degrees of freedom.

place and the plane through which movement occurs define specific motions or resultant positions. The coronal axis (x-axis) lies in the coronal plane and extends from one side of the body to the other. The motions of flexion and extension occur about this axis and through the sagittal plane. Flexion is motion in the anterior direction for joints of the head, neck, trunk, upper extremity, and hips (Figure 2-4, *A*). Flexion of the knee, ankle, foot, and toes is movement in the posterior direction. Extension is the motion opposite of flexion.

The sagittal axis (z-axis) lies in the sagittal plane and extends horizontally from anterior to posterior. Movements of abduction and adduction of the extremities, as well as lateral flexion of the spine, occur around this axis and through the coronal plane. Lateral flexion is a rotational movement and is used to denote lateral movements of the head, neck, and trunk in the coronal plane (Figure 2-4, *B*). In the human, lateral flexion is usually combined with some element of rotation. Abduction and adduction are also motions in a coronal plane. Abduction is movement away from the body, and adduction is movement toward the body; the reference here is to the midsagittal plane of the body. This would be true for all parts of the extremities, excluding the thumb, fingers, and toes. For these structures, reference points are to be found within that particular extremity.

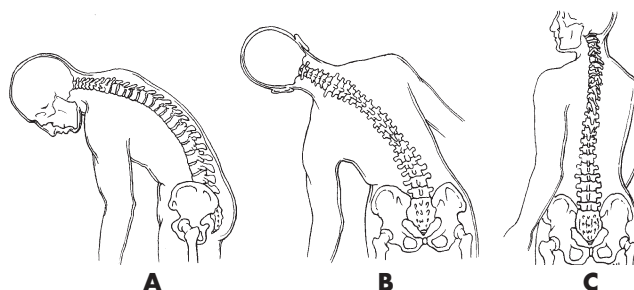


Figure 2-4

A, Sagittal plane movement of flexion. *B*, Coronal plane movement of lateral flexion. *C*, Transverse plane movement of axial rotation.

The longitudinal axis (y-axis) is vertical, extending in a head-to-toe direction. Movements of medial (internal) and lateral (external) rotation in the extremities, as well as axial rotation in the spine, occur around it and through the transverse plane (Figure 2-4, *C*). Axial rotation is used to describe this type of movement for all areas of the body except the scapula and clavicle. Rotation occurs about an anatomic axis, except in the case of the femur, which rotates around a mechanical axis.⁴ In the human extremity, the anterior surface of the extremity is used as a reference area. Rotation of the anterior surface toward the midsagittal plane of the body is medial (internal) rotation, and rotation away from the midsagittal plane is lateral (external) rotation. Supination and pronation are rotation movements of the forearm.

Because the head, neck, thorax, and pelvis rotate about longitudinal axes in the midsagittal area, rotation cannot be named in reference to the midsagittal plane. Rotation of the head, spine, and pelvis is described as rotation of the anterior surface posteriorly toward the right or left. Rotation of the scapula is movement about a sagittal axis, rather than about a longitudinal axis. The terms *clockwise* or *counterclockwise* are used.

Translational movements are linear movements or, simply, movements in a straight line. Gliding movements of the joint are translational in character. The term *slide* has also been used in referring to translational movements between joint surfaces. Posterior-to-anterior (P-A) glide (anterolisthesis) and anterior-to-posterior (A-P) glide (retrolisthesis) are translational movements along the z axis. Lateral-to-medial (L-M) glide and medial-to-lateral (M-L) glide (laterolisthesis) translate along the x axis. Distraction and compression (altered interosseous spacing) translate along the y axis. Curvilinear motion combines both rotational and translational movements and is the most common motion produced by the joints of the body (Figure 2-5).

Moreover, the potential exists for each joint to exhibit three translational movements and three rotational movements, constituting 6 degrees of freedom. The ex-

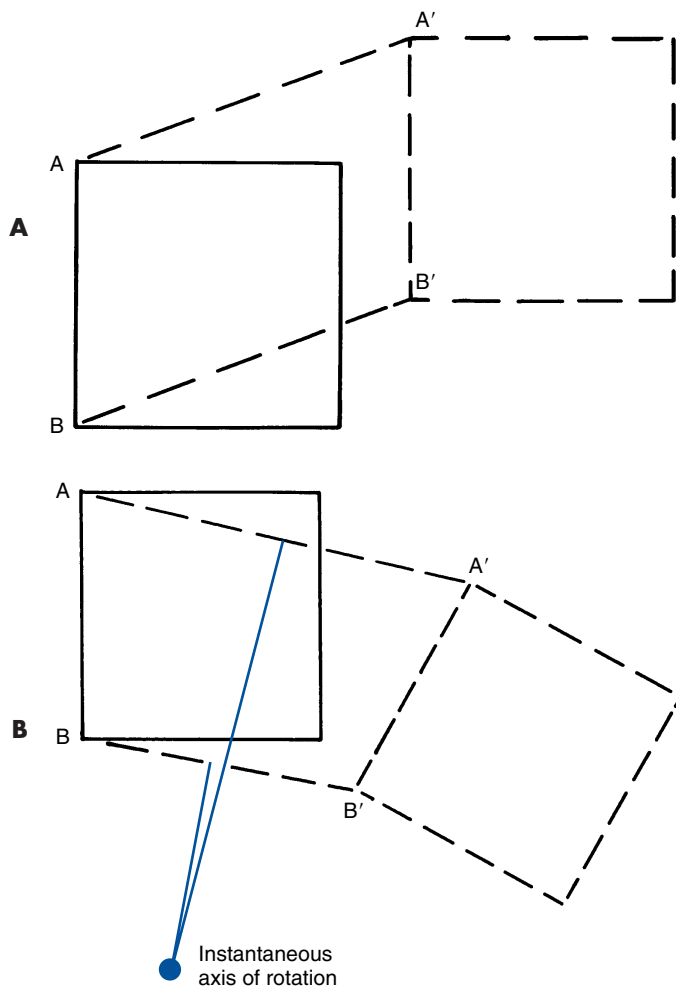


Figure 2-5
A, Translational movement. **B**, Curvilinear movement: a combination of translation and rotation movements.

tent of each movement is based more or less on the joint anatomy and, specifically, the plane of the joint surface. Each articulation in the body has the potential to exhibit, to some degree, flexion, extension, right and left lateral flexion, right and left axial rotation, A-P glide, P-A glide, L-M glide, M-L glide, compression, and distraction.

Joints are classified first by their functional capabilities and then are subdivided by their structural characteristics. Synarthroses allow very little, if any, movement; diarthroses, or true synovial joints, allow significant movement. The structural characteristics of these joints are detailed in Table 2-2.

Synovial Joints

Synovial joints are the most common joints of the human appendicular skeleton, representing highly evolved, movable joints. Although these joints are considered freely movable, the degree of possible motion varies ac-

ording to the individual structural design, facet planes, and primary function (motion vs. stability). The components of a typical synovial joint include the bony elements, subchondral bone, articular cartilage, synovial membrane, fibroligamentous joint capsule, and articular joint receptors. An understanding of the basic anatomy of a synovial joint forms the foundation for appreciation of clinically significant changes in the joint that lead to joint dysfunction.

Bony Elements

The bony elements provide the supporting structure that gives the joint its capabilities and individual characteristics by forming lever arms to which intrinsic and extrinsic forces are applied. Bone is actually a form of connective tissue that has an inorganic constituent (lime salts). A hard outer shell of cortical bone provides structural support and surrounds the cancellous bone, which contains marrow and blood vessels that provide nutrition. Trabecular patterns develop in the cancellous bone, corresponding to mechanical stress applied to and required by the bone (Figure 2-6). Bone also has the important role of hemopoiesis (formation of blood cells). Furthermore, bone stores calcium and phosphorus, which it exchanges with blood and tissue fluids. Finally, bone has the unique characteristic of repairing itself with its own tissue as opposed to fibrous scar tissue, which all other body tissues use.

Articular Cartilage

Articular cartilage covers the articulating bones in synovial joints and helps to transmit loads and reduce friction. It is bonded tightly to the subchondral bone through the zone of calcification, which is the end of bone visible on x-ray film. The joint space visible on x-ray film is composed of the synovial cavity and noncalcified articular cartilage. In its normal composition, articular cartilage has four histologic areas or zones (Figure 2-7). These zones have been further studied and refined so that a wealth of newer information regarding cartilage has developed.

The outermost layer of cartilage is known as the *gliding zone*, which itself contains a superficial layer (outer) and a tangential layer (inner). The outer segment is made up solely of collagen randomly oriented into flat bundles. The tangential layer consists of densely packed layers of collagen, which are oriented parallel to the surface of the joint.⁵ This orientation is along the lines of the joint motion, which implies that the outer layers of collagen are stronger when forces are applied parallel to the joint motion rather than perpendicular to it.⁶ This particular orientation of fibers provides a great deal of strength to the joint in normal motion. The gliding zone also has a role in protecting the deeper elastic cartilage.

TABLE 2-2

Joint Classification

Joint Type	Structure	Example
Synarthrotic		
Fibrous	Suture—nearly no movement	Cranial sutures
Cartilaginous	Syndesmosis—some movement	Distal tibia-fibula
	Synchondrosis—temporary	Epiphyseal plates
	Symphysis—fibrocartilage	Pubes
		Intervertebral discs
Diarthrotic		
Uniaxial	Ginglymus (hinge)	Elbow
	Trochoid (pivot)	Atlantoaxial joint
	Condylar	Metacarpophalangeal joint
Biaxial	Ellipsoid	Radiocarpal joint
	Sellar (saddle)	Carpometacarpal joint of the thumb
Multiaxial	Triaxial	Shoulder
	Spheroid (ball and socket)	Hip
Plane (nonaxial)		Intercarpal joints
		Posterior facet joints in the spine

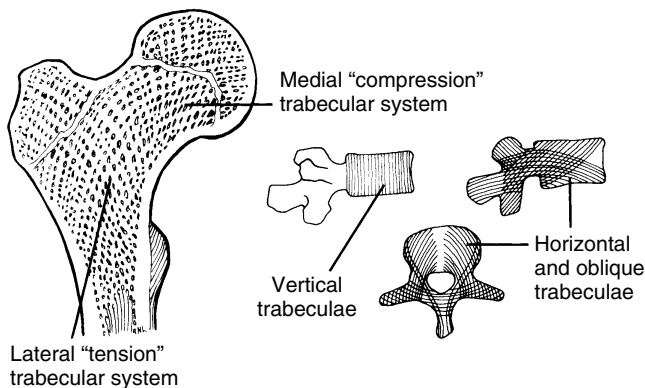


Figure 2-6

Trabecular patterns corresponding to mechanical stresses in the hip joint and vertebra. (Modified from Hertling D, Kessler RM: *Management of common musculoskeletal disorders: Physical therapy principles and methods*, ed 2, Philadelphia, 1990, JB Lippincott.)

The *transitional zone* lies beneath the gliding zone. It represents an area where the orientation of the fibers begins to change from the parallel orientation of the gliding zone to the more perpendicular orientation of the radial zone. Therefore fiber orientation is more or less oblique and, in varying angles, formed from glucuronic acid and *N*-acetylgalactosamine with a sulfate on either the fourth or sixth position. The keratin compound is formed with galactose and *N*-acetylgalactosamine. All of this occurs in linked, repeating units (Figure 2-8).

Articular cartilage is considered mostly avascular. Articular cartilage must rely on other sources for nutrition,

removal of waste products, and the process of repair. Therefore intermittent compression (loading) and distraction (unloading) are necessary for adequate exchange of nutrients and waste products. The highly vascularized synovium is believed to be a critical source of nutrition for the articular cartilage it covers. The avascular nature of articular cartilage limits the potential for cartilage repair by limiting the availability of the repair products on which healing depends. Chondrocytes, the basic cells of cartilage that maintain and synthesize the matrix, are contained within a mesh of collagen and proteoglycan that does not allow them to migrate to the injury site from adjacent healthy cartilage.⁷ Moreover, the articular cartilage matrix may contain substances that inhibit vascular and macrophage invasion and clot formation that are also necessary for healing.⁸ After an injury to the articular cartilage, the joint can return to an asymptomatic state after the transient synovitis subsides. Degeneration of the articular cartilage depends on the size and depth of the lesion, the integrity of the surrounding articular surface, the age and weight of the patient, associated meniscal and ligamentous lesions, and a variety of other biomechanical factors.⁷ Continuous passive motion has increased the ability of full-thickness defects in articular cartilage to heal, producing tissue that closely resembles hyaline cartilage.⁹

Ligamentous Elements

The primary ligamentous structure of a synovial joint is the joint capsule. Throughout the vertebral column, the joint capsules are thin and loose. The capsules are attached to the opposed superior and inferior articular

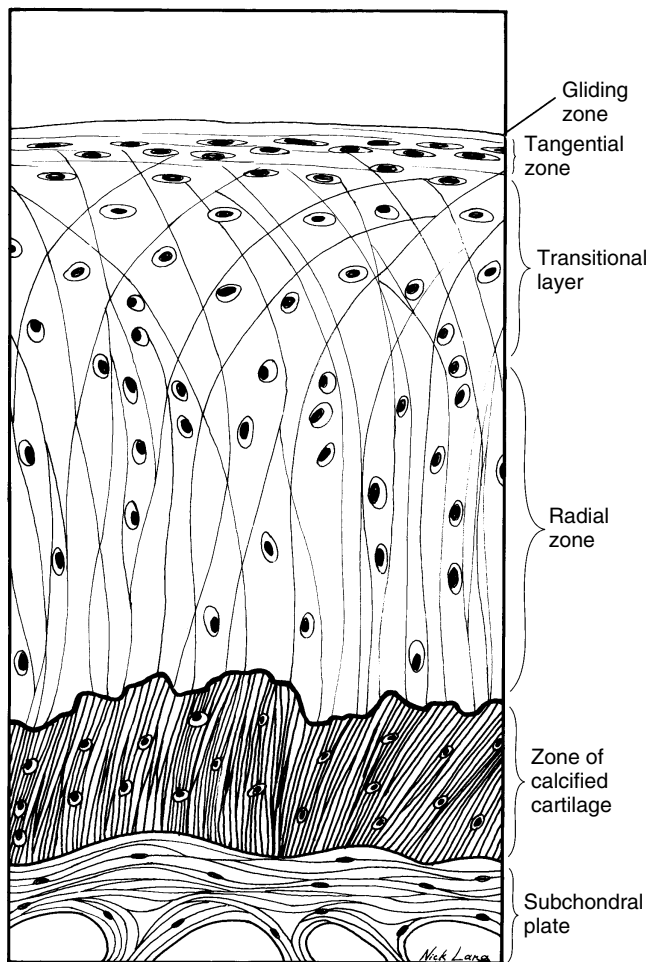


Figure 2-7 Microscopic anatomy of articular cartilage. (Modified from Albright JA, Brand RA: *The scientific basis of orthopaedics*, East Norwalk, Conn, 1979, Appleton-Century-Crofts.)

facets of adjacent vertebrae. Joint capsules in the spine have three layers.¹⁰ The outer layer is composed of dense fibroelastic connective tissue made up of parallel bundles of collagen fibers. The middle layer is composed of loose connective tissue and areolar tissue containing vascular structures. The inner layer consists of the synovial membrane. This joint capsules covers the posterior and lateral aspects of the zygapophyseal joint. The ligamentum flavum covers the joint capsules anteriorly and medially.

Synovial Fluid

Although the exact role of synovial fluid is still unknown, it is thought to serve as a joint lubricant or at least to interact with the articular cartilage to decrease friction between joint surfaces. This is of clinical relevance because immobilized joints have been shown to undergo degeneration of the articular cartilage.¹¹ Synovial fluid is similar in composition to plasma, with the addition of mucin

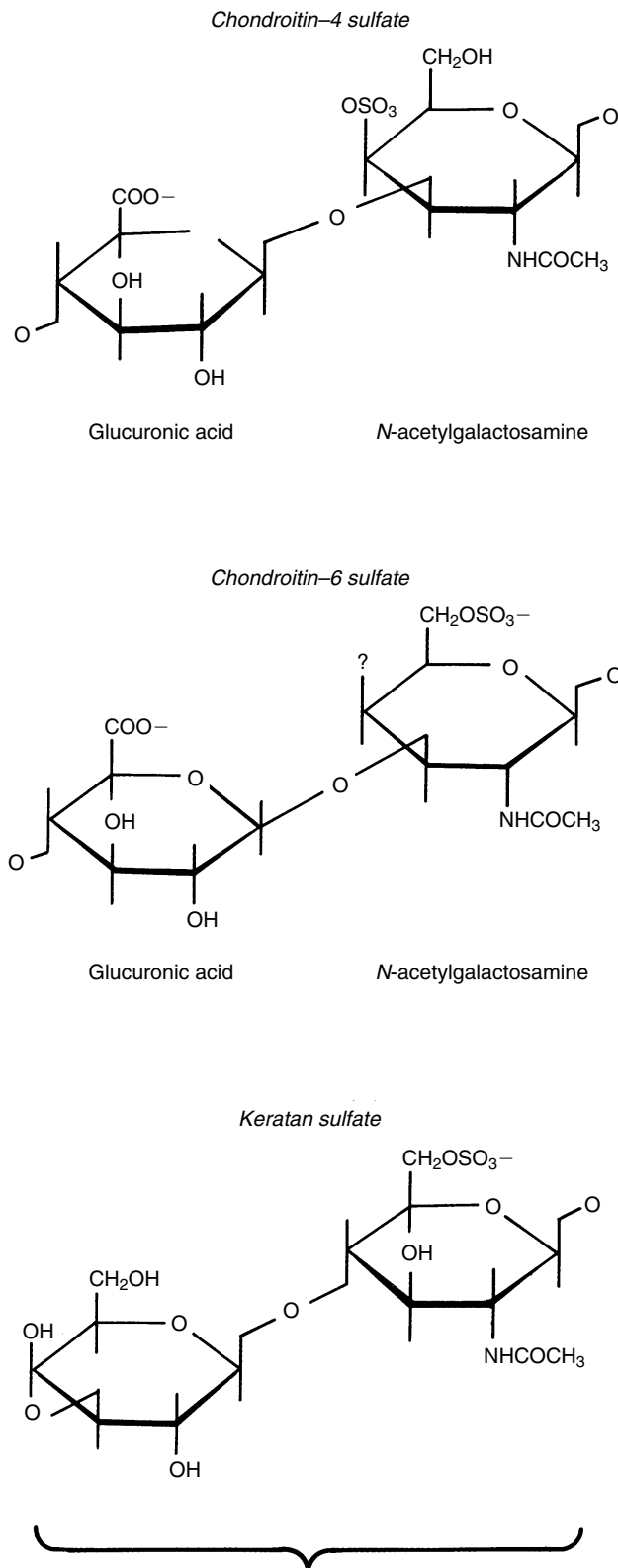


Figure 2-8 Structure of chondroitin and keratin compounds.

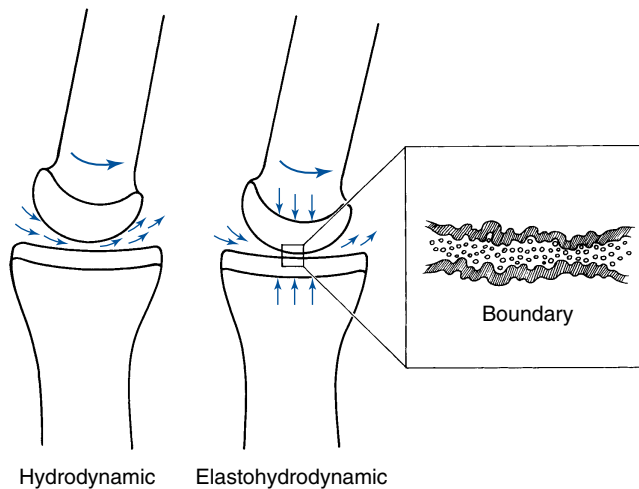


Figure 2-9

Lubrication models for synovial joints. (Modified from Hertling D, Kessler RM: *Management of common musculoskeletal disorders: Physical therapy principles and methods*, ed 2, Philadelphia, 1990, JB Lippincott.)

(hyaluronic acid), which gives it a high molecular weight and its characteristic viscosity. Three models of joint lubrication exist. The controversy lies in the fact that no one model of joint lubrication applies to all joints under all circumstances.

According to the hydrodynamic model, synovial fluid fills in spaces left by the incongruent joint surfaces. During joint movement, synovial fluid is attracted to the area of contact between the joint surfaces, resulting in the maintenance of a fluid film between moving surfaces. This model was the first to be described and works well with quick movement, but it would not provide adequate lubrication for slow movements and movement under increased loads.

The elastohydrodynamic model is a modification of the hydrodynamic model that considers the viscoelastic properties of articular cartilage whereby deformation of joint surfaces occurs with loading, creating increased contact between surfaces. This would effectively reduce the compression stress to the lubrication fluid. Although this model allows for loading forces, it does not explain lubrication at the initiation of movement or the period of relative zero velocity during reciprocating movements.¹²

In the boundary lubrication model, the lubricant is adsorbed on the joint surface, which would reduce the roughness of the surface by filling the irregularities and effectively coating the joint surface. This model allows for initial movement and zero velocity movements. Moreover, boundary lubrication combined with the elastohydrodynamic model, creating a mixed model, meets the demands of the human synovial joint (Figure 2-9).

Articular Neurology

Articular neurology gives invaluable information on the nature of joint pain, the relationship of joint pain to joint dysfunction, and the role of manipulative procedures in affecting joint pain. Synovial joints are innervated by three or four varieties of neuroreceptors, each with a wide variety of parent neurons. The axons differ in diameter and conduction velocity, representing a continuum from the largest heavily myelinated A α -fibers to the smallest unmyelinated C fibers. All are derived from the dorsal and ventral rami, as well as the recurrent meningeal nerve of each segmental spinal nerve (Figure 2-10). Information from these receptors spreads among many segmental levels because of multilevel ascending and descending primary afferents. The receptors are divided into the four groups according to their neurohistologic properties, which include three corpuscular mechanoreceptors and one nociceptor.¹³

Type I receptors are confined to the outer layers of the joint capsule and are stimulated by active or passive joint motions. Their firing rate is inhibited with joint approximation, and they have a low threshold, making them very sensitive to movement. Some are considered static receptors because they fire continually, even with no joint movement. Because they are slow adapting, the effects of movement are long lasting. Stimulation of type I receptors is involved with the following:

1. Reflex modulation of posture, as well as movement (kinesthetic sensations), through constant monitoring of outer joint tension
2. Perception of posture and movement
3. Inhibition of flow from pain receptors via an enkephalin synaptic interneuron transmitter
4. Tonic effects on lower motor neuron pools involved in the neck, limbs, jaw, and eye muscles

Type II mechanoreceptors are found within the deeper layers of the joint capsule. They are also low threshold and again are stimulated with even minor changes in tension within the inner joint. Unlike type I receptors, however, type II receptors adapt very rapidly and quickly cease firing when the joint stops moving. Type II receptors are completely inactive in immobilized joints. Functions of the type II receptors are likely to include the following:

1. Movement monitoring for reflex actions and perhaps perceptual sensations
2. Inhibition of flow from pain receptors via an enkephalin synaptic interneuron neural transmitter
3. Phasic effects on lower motor neuron pools involved in the neck, limbs, jaw, and eye muscles

Type III mechanoreceptors are found in the intrinsic and extrinsic ligaments of the peripheral joints, but they had been previously thought to be absent from all of the synovial spinal joints. However, McLain¹⁴ examined 21 cervical facet capsules from three normal human subjects

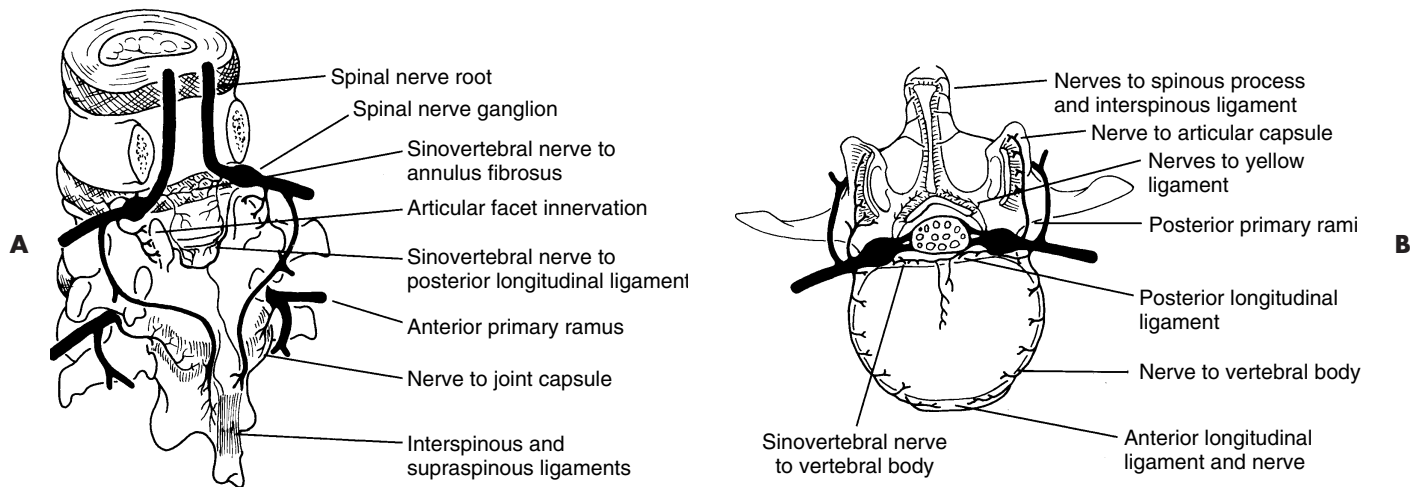


Figure 2-10

Innervation of the outer fibers of the disc and facet joint capsule by the sinuvertebral nerve.

A, Oblique posterior view. **B**, Top view. (Modified from White AA, Panjabi MM: *Clinical biomechanics of the spine*, Philadelphia, 1978, JB Lippincott.)

and found type III receptors, although they were less abundant than either type I or type II. These receptors are very slow adapters with a very high threshold because they are innervated by large myelinated fibers. They seem to be the joint version of the Golgi tendon organ in that they impose an inhibitory effect on motoneurons. Although the functions of type III receptors are not completely understood, it is likely that they achieve the following:

1. Monitor direction of movement
2. Create a reflex effect on segmental muscle tone, providing a “braking mechanism” against movement that overdisplaces the joint
3. Recognize potentially harmful movements

Type IV receptors are composed of a network of free nerve endings, as well as unmyelinated fibers. They are associated with pain perception and include many different varieties with large ranges of sensations, including itch and tickle. They possess an intimate physical relationship to the mechanoreceptors and are present throughout the fibrous portions of the joint capsule and ligaments. They are absent from articular cartilage and synovial linings, although they have been found in synovial folds.^{15,16} They are very high-threshold receptors and are completely inactive in the physiologic joint. Joint capsule pressure, narrowing of the intervertebral disc, fracture of a vertebral body, dislocation of the zygapophyseal joints, chemical irritation, and interstitial edema associated with acute or chronic inflammation may all activate the nociceptive system. The basic functions of the nociceptors include the following:

1. Evocation of pain
2. Tonic effects on neck, limb, jaw, and eye muscles
3. Central reflex connections for pain inhibition

4. Central reflex connections for a myriad of autonomic effects

A relationship exists between mechanoreceptors and nociceptors such that when the mechanoreceptors function correctly, an inhibition of nociceptor activity occurs.¹³ The converse also holds true; when the mechanoreceptors fail to function correctly, inhibition of nociceptors will occur less, and pain will be perceived.¹³

Discharges from the articular mechanoreceptors are polysynaptic and produce coordinated facilitatory and inhibitory reflex changes in the spinal musculature. This provides a significant contribution to the reflex control of these muscles.¹³ Gillette¹⁵ suggests that a chiropractic adjustment produces sufficient force to coactivate a wide variety of mechanically sensitive receptor types in the paraspinal tissues. The A- δ -mechanoreceptors and C-polymodal nociceptors, which can generate impulses during and after stimulation, may well be the most physiologically interesting component of the afferent bombardment initiated by high-velocity, low-amplitude manipulations. For normal function of the joint structures, an integration of proprioception, kinesthetic perception, and reflex regulation is absolutely essential.

Pain-sensitive fibers also exist within the annulus fibrosus of the disc. Malinsky¹⁶ demonstrated the presence of a variety of free and complex nerve endings in the outer one third of the annulus. The disc is innervated posteriorly by the recurrent meningeal nerve (sinuvertebral nerve) and laterally by branches of the gray rami communicantes. During evaluation of disc material surgically removed before spinal fusion, Bogduk¹⁷ found abundant nerve endings with various morphologies. The varieties of nerve endings included free terminals,

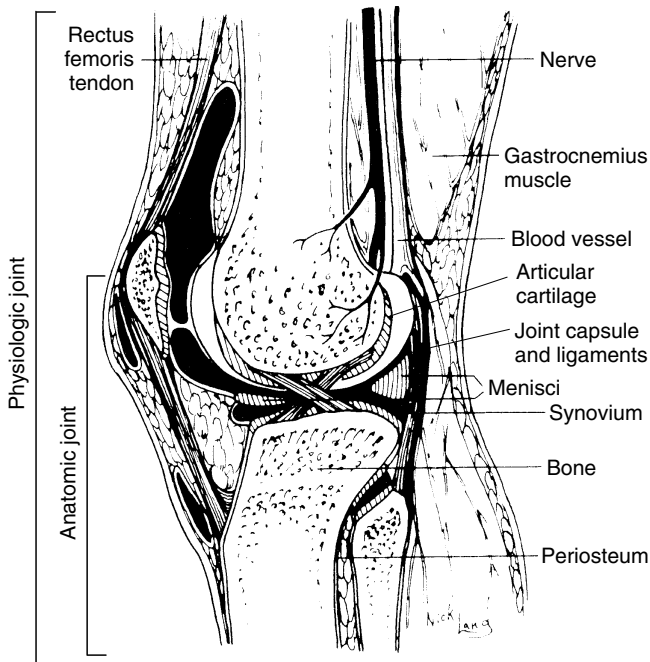


Figure 2-11
Structures that make up the anatomic joint and the physiologic joint in the knee.

complex sprays, and convoluted tangles. Furthermore, many of these endings contained substance P, a putative transmitter substance involved in nociception.

Shinohara¹⁸ reported the presence of such nerve fibers accompanying granulation tissue as deep as the nucleus in degenerated discs. Freemont et al¹⁹ examined discs from individuals free of back pain and from those with back pain. They identified nerve fibers in the outer one third of the annulus in pain-free disc samples, but they found nerve fibers extending into the inner one third of the annulus and into the nucleus pulposus of the discs from the pain sample. They suggest that their findings of isolated nerve fibers that express substance P deep within diseased intervertebral discs may play an important role in the pathogenesis of chronic low back pain. Abundant evidence shows that the disc can be painful, supporting the ascribed nociceptive function of the free nerve endings.¹⁶⁻²⁷

Because structure and function are interdependent, the study of joint characteristics should not isolate structure from function. The structural attributes of a joint are defined as the *anatomic joint*, consisting of the articular surfaces with the surrounding joint capsule and ligaments, as well as any intraarticular structures. The functional attributes are defined as the *physiologic joint*, consisting of

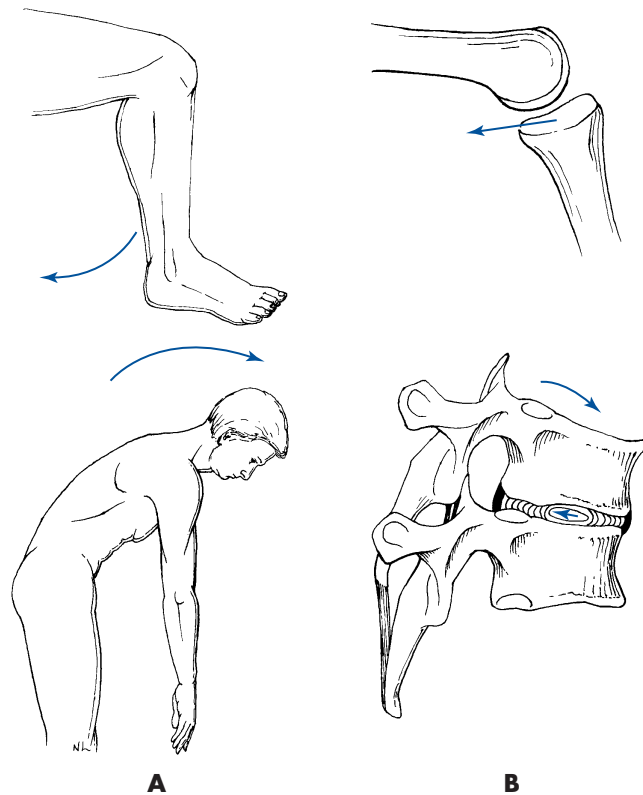


Figure 2-12
A, Osteokinematic movement of knee and trunk flexion.
B, Arthrokinematic movements of tibiofemoral and T6-T7 joint flexion.

the anatomic joint plus the surrounding soft tissues, including the muscles, connective tissue, nerves, and blood vessels (Figure 2-11).

JOINT FUNCTION

The physiologic movement possible at each joint occurs when muscles contract or when gravity acts on bone to move it. This motion is termed *osteokinematic movement*. Osteokinematic movement describes how each bony joint partner moves relative to the other. The specific movements that occur at the articulating joint surfaces are referred to as *arthrokinematic movement*. Consideration of the motion between bones alone or osteokinematic movement is insufficient, because no concern is given to what occurs at the joint and because movement commonly involves coupling of motion around different axes. Furthermore, arthrokinematic movements consider the forces applied to the joint and include the accessory motion present in a particular articulation.

It is therefore important to relate osteokinematic movement to arthrokinematic movement when evaluating joint motion (Figure 2-12). This involves determining the movement of the mechanical axis of the moving bone

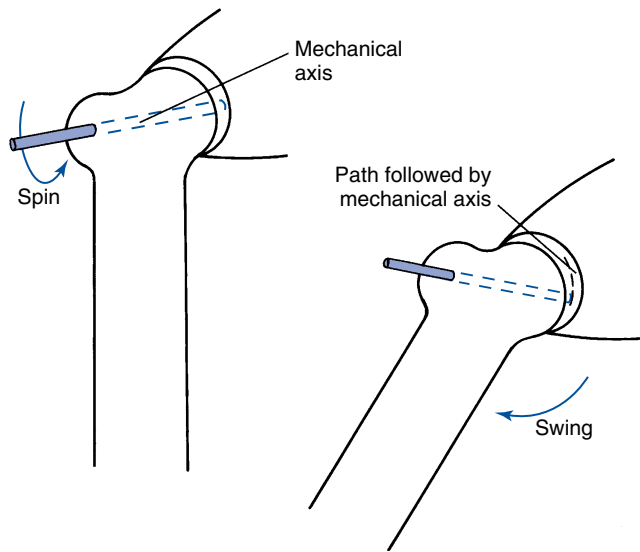


Figure 2-13 Mechanical axis of a joint and MacConail and Basmajian's concept of spin and swing. (Modified from Hertling D, Kessler RM: *Management of common musculoskeletal disorders: Physical therapy principles and methods*, ed 2, Philadelphia, 1990, JB Lippincott.)

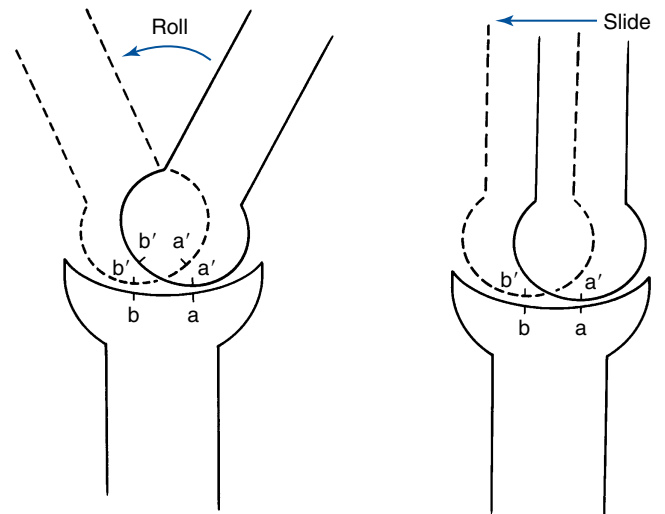


Figure 2-14 Arthrokinematic movements of roll and slide. (Modified from Hertling D, Kessler RM: *Management of common musculoskeletal disorders: Physical therapy principles and methods*, ed 2, Philadelphia, 1990, JB Lippincott.)

relative to the stationary joint surface. The *mechanical axis of a joint* is defined as a line passing through the moving bone, oriented perpendicular to the center of the stationary joint surface (Figure 2-13).

When one joint surface moves relative to the other, spin, roll, slide, or combinations occur. MacConail and Basmajian²⁸ use the term *spin* to describe rotational movement around the mechanical axis, which is possible as a pure movement only in the hip, shoulder, and proximal radius. *Roll* occurs when points on the surface of one bone contact points at the same interval of the other bone. *Slide* occurs when only one point on the moving joint surface contacts various points on the opposing joint surface (Figure 2-14).

In most joints of the human body, these motions occur simultaneously. The concave-convex rule relates to this expected coupling of rotational (roll) and translational (slide) movements. When a concave surface moves on a convex surface, roll and slide movements should occur in the same direction. When a convex surface moves on a concave surface, however, roll and slide should occur in opposite directions (Figure 2-15). Pure roll movement tends to result in joint dislocation, whereas pure slide movement causes joint surface impingement (Figure 2-16). Moreover, coupling of roll and slide is important anatomically because less articular cartilage is necessary in a joint to allow for movement and may decrease wear on the joint.

These concepts are instrumental in clinical decision-making regarding the restoration of restricted joint motion. Roll and spin can be restored with passive range-

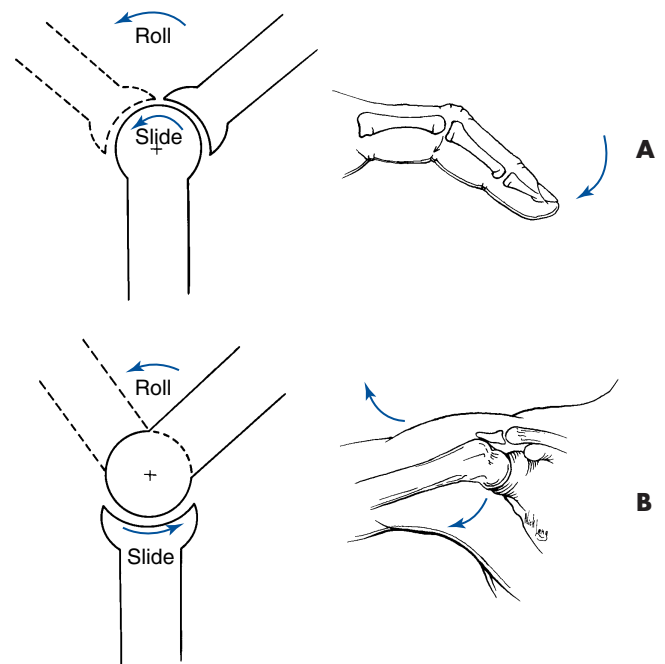


Figure 2-15 Concave-convex rule. **A**, Movement of concave surface on a convex surface. **B**, Movement of a convex surface on a concave surface.

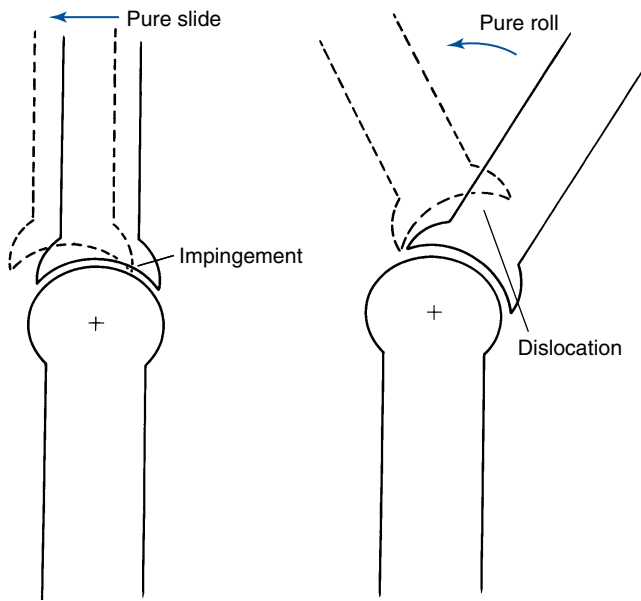


Figure 2-16
Consequences of pure roll or pure slide movements. (Modified from Hertling D, Kessler RM: *Management of common musculoskeletal disorders: Physical therapy principles and methods*, ed 2, Philadelphia, 1990, JB Lippincott.)

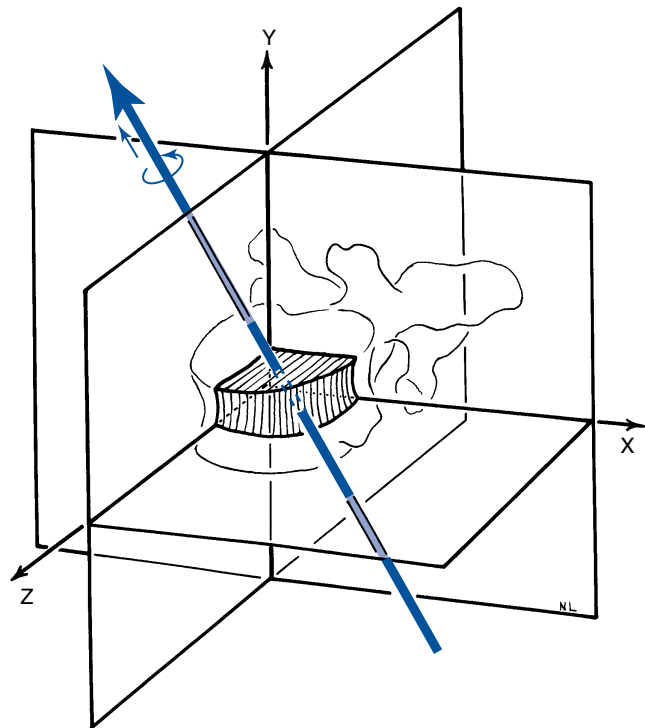


Figure 2-18
Helical axis of motion. (Modified from White AA, Panjabi MM: *Clinical biomechanics of the spine*, Philadelphia, 1978, JB Lippincott.)

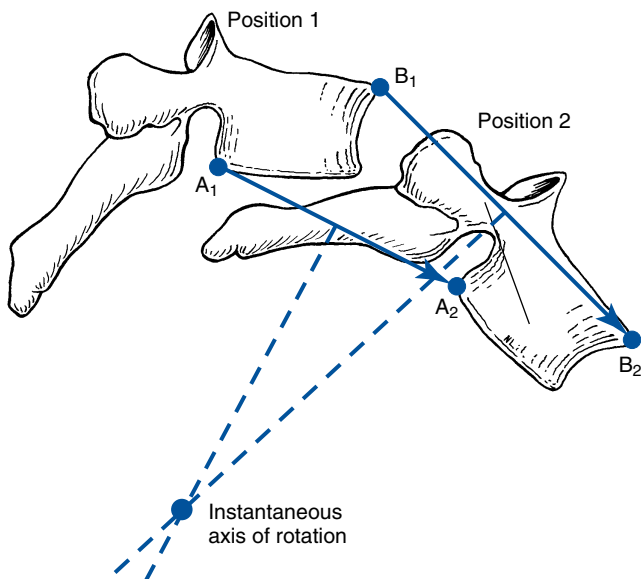


Figure 2-17
Instantaneous axis of rotation. (Modified from White AA, Panjabi MM: *Clinical biomechanics of the spine*, Philadelphia, 1978, JB Lippincott.)

of-motion procedures that induce the arthrokinematic movements of the dysfunctional joint. Manipulative (thrust) techniques are needed to restore slide movements and can also be used for roll and spin problems.²⁹

In addition, when an object moves, the axis around which the movement occurs can vary in placement from one instant to another. The term *instantaneous axis of rotation (IAR)* is used to denote this location point. Asymmetric forces applied to the joint can cause a shift in the normal IAR. Furthermore, vertebral movement may be more easily analyzed as the IAR becomes more completely understood (Figure 2-17). White and Panjabi¹ point out that the value of this concept is that any kind of plane motion can be described relative to the IAR. Complex motions are simply regarded as many very small movements with many changing IARs.¹ This concept is designed to describe plane movement, or movement in two dimensions.

When three-dimensional motion occurs between objects, a unique axis in space is defined called the *helical axis of motion (HAM)*, or screw axis of motion (Figure 2-18). HAM is the most precise way to describe motion occurring between irregularly shaped objects, such as anatomic structures, because it is difficult to consistently and accurately identify reference points for such objects.

Clearly, most movements occur around and through several axes simultaneously, so pure movements in the

TABLE 2-3

Close-Packed Positions for Each Joint

Region	Specific Joint	Close-Packed Position
Fingers	Distal interphalangeal joints	Maximal extension
	Proximal interphalangeal joints	Maximal extension
	Metacarpophalangeal joints	Maximal flexion
Hand	Intermetacarpal joints	Maximal opposition
Wrist	Intercarpal joints	Maximal dorsiflexion
Forearm	Radioulnar joints	5 degrees of supination
Elbow	Ulnohumeral joint	Extension in supination
	Radiohumeral joint	Flexion in supination
Shoulder	Glenohumeral joint	Abduction and external rotation
	Acromioclavicular joint	90 degrees of abduction
	Sternoclavicular joint	Maximal elevation
Toes	Distal interphalangeal joints	Maximal extension
	Proximal interphalangeal joints	Maximal extension
	Metatarsophalangeal joints	Maximal extension
Foot	Intermetatarsal joints	Maximal opposition
Ankle	Tarsometatarsal joints	Maximal inversion
	Tibiotalar joint	Maximal dorsiflexion
Knee	Tibiofemoral joint	Maximal extension and external rotation
Hip	Coxofemoral joint	Maximal extension, internal rotation, and abduction
Spine	Three-joint complex	Maximal extension

human frame rarely occur. The nature and extent of individual joint motion are determined by the joint structure and, specifically, by the shape and direction of the joint surfaces. No two opposing joint surfaces are perfectly matched, nor are they perfectly geometric. All joint surfaces have some degree of curvature that is not constant but changing from point to point. Because of the incongruence between joint surfaces, some joint space and “play” must be present to allow free movement. This joint play is an accessory movement of the joint that is essential for normal functioning of the joint.

The resting position of a joint, or its neutral position, occurs when the joint capsule is most relaxed and the greatest amount of play is possible. When injured, a joint often seeks this maximum loose-packed position to allow for swelling.

The close-packed position occurs when the joint capsule and ligaments are maximally tightened. Moreover, there is maximal contact between the articular surfaces, making the joint very stable and difficult to move or separate.

Joint surfaces will approximate or separate as the joint goes through a range of motion. This is the motion of compression and distraction. A joint moving toward its close-packed position is undergoing *compression*, and a joint moving toward its open-packed position is undergoing *distraction*²⁸ (Table 2-3).

Joint motion consists of five qualities of movement that must be present for normal joint function. These five qualities are joint play, active range of motion, pas-

sive range of motion, end feel or play, and parapsybiologic movement. From the neutral close-packed position, joint play should be present. This is followed by a range of active movement under the control of the musculature. The passive range of motion is produced by the examiner and includes the active range, plus a small degree of movement into the elastic range. The elastic barrier of resistance is then encountered, which exhibits the characteristic movement of end feel. The small amount of movement available past the elastic barrier typically occurs postcavitation and has been classified as parapsybiologic movement. Movement of the joint beyond the parapsybiologic barrier takes the joint beyond its limit of anatomic integrity and into a pathologic zone of movement. Should a joint enter the pathologic zone, there will be damage to the joint structures, including the osseous and soft tissue components (see Figures 3-22 and 3-23).

Both joint play and end-feel movements are thought to be necessary for the normal functioning of the joint. A loss of either movement can result in a restriction of motion, pain, and most likely, both. Active movements can be influenced by exercise and mobilization, and passive movements can be influenced by traction and some forms of mobilization, but end-feel movements are affected when the joint is taken through the elastic barrier, creating a sudden yielding of the joint and a characteristic cracking noise (cavitation). This action can be accomplished with deep mobilization and a high-velocity, low-amplitude manipulative thrust.