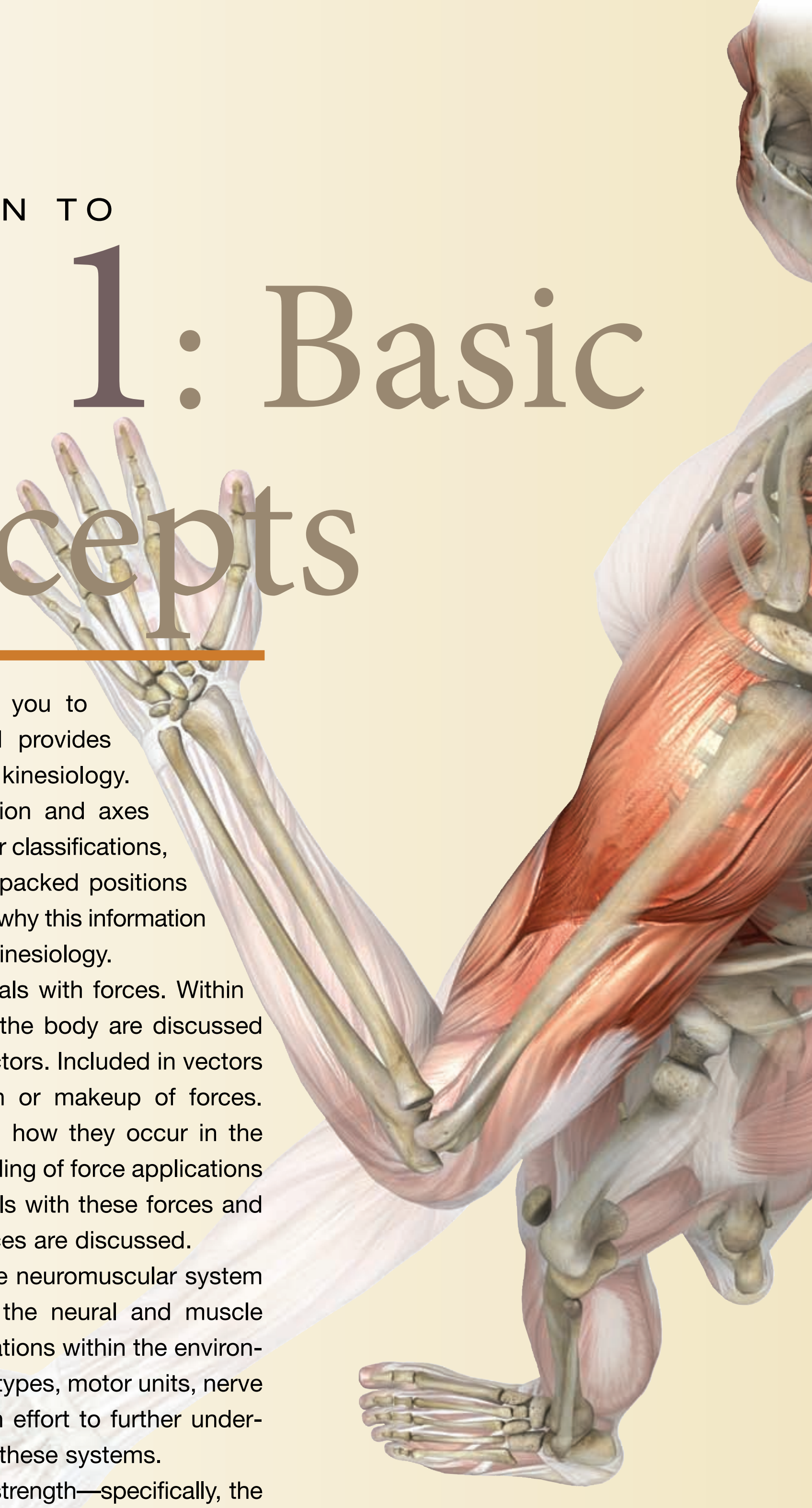
Brunnstrom's

Clinical Kinesiology

SIXTH EDITION

INTRODUCTION TO

Unit 1: Basic Concepts



The first unit of the text introduces you to the basics of kinesiology. Chapter 1 provides information on the kinematics of kinesiology. Information is presented on planes of motion and axes within the body, various kinds of joints and their classifications, kinematic chain concepts, open- and close-packed positions of the joints, degrees of freedom of joints, and why this information is important to the understanding of clinical kinesiology.

Chapter 2 introduces kinetics. Kinetics deals with forces. Within this chapter, the types of forces applied to the body are discussed along with Newton's Laws of Motion, and vectors. Included in vectors is an expanded discussion on composition or makeup of forces. Additionally, various levers and torques and how they occur in the body are presented. To add to the understanding of force applications in functional applications, how the body deals with these forces and how clinicians are able to estimate these forces are discussed.

Chapter 3 moves into the physiology of the neuromuscular system and how the unique interactions between the neural and muscle systems allow the body to respond to stimulations within the environment. A discussion of muscle fiber structure, types, motor units, nerve fibers, and joint receptors is presented in an effort to further understand the dynamic interrelationship between these systems.

Chapter 4 provides information on muscle strength—specifically, the types of muscle contraction, how the muscles function against gravity and outside forces, and how the structure and physiology of muscle determine strength output of any muscle. A brief discussion on how strength is measured is also presented.

CHAPTER 1

Basic Concepts in Kinesiology: Kinematics

"Never be afraid to try something new. Remember, amateurs built the ark. Professionals built the Titanic."
—Author Unknown

CHAPTER OUTLINE

LEARNING OUTCOMES

This chapter provides the basic information required to begin a study of kinesiology. By the end of this chapter, you should be able to:

- ❑ Use basic kinesiology terminology when describing movement of the body and the body segments in space;
- ❑ Define kinematics, osteokinematics, and arthrokinematics and give examples of the use of each of these terms and their relevance to studying kinesiology;
- ❑ Identify the cardinal planes of the body and be able to demonstrate movement in each of the three cardinal planes—sagittal, frontal, and transverse—and the axes for these motions;
- ❑ Describe the different types of motion, such as translatory and rotary, and relate these to motions within the human body;
- ❑ Describe and define joint motion in terms of degrees of freedom, joint structural type and amount, and direction of motion;
- ❑ Define and describe the common materials found in joints and summarize their functional significance to joint structure—joint capsule, synovial fluid, ligament, and bursa;
- ❑ Describe and give examples of joints classified as uniaxial, biaxial, and triaxial and define degrees of freedom;
- ❑ Describe and cite examples of movements in an open and a closed kinematic chain;
- ❑ Describe and cite examples of the different types of arthrokinematic surface motions that occur between joint surfaces—rolling, spinning, sliding;
- ❑ Describe and cite examples of different joint shapes and explain the concave-convex principle;

- ❑ Define and give examples of close-packed and open-packed joint positions and describe compression compared to distraction of those joint surfaces and how these factors are relevant to joint function;
- ❑ Explain the functional and clinical relevance of demonstrating competence in describing joint motion and human movement in kinematic terms.

CLINICAL SCENARIO

Jamie, a clinician in the health professions, is attending her son's Little League game when another player appears to have hurt his finger. Jamie watches with concern from the sidelines as the volunteer coach, who happens to be the insurance man in Jamie's neighborhood, calmly announces that the finger is just "jammed." He proceeds to start to minister to the little boy, telling him to stay still and he will "pull it out." Jamie is facing a dilemma. What is the best course of action and how should Jamie go about it?

Historical Perspective: A Glance at the Past

Welcome to a study of Kinesiology! You are about to embark on an adventure that will expand your knowledge of the human body and provide you with an appreciation of the beauty of human movement. Kinesiology is not a one-dimensional study that requires you to learn lists of facts about anatomical structure; rather, it is literally the study of *movement*. This journey will require you to be *actively* engaged in your learning process. Part of your learning will be through your own movement and the movements of your peers. As a new student in kinesiology, you are joining the ranks of many others, for kinesiology has a very long and impressive history.

Studying kinesiology actually dates back to ancient Greece to the times of Aristotle and Hippocrates; as you may recall, ancient Greece is often associated with the Olympic Games and the Greeks' enthusiasm for athletic performance and sports. Later, famous anatomist and physician Claudius Galen (131–201 AD) advanced the knowledge of kinesiology by studying two human skeletons on display in Alexandria and dissecting hundreds of pigs and apes. Based on such scrutinizing study, he produced intricate descriptive analyses of the human form; his detailed descriptions of the musculature of the hand are very close to what is still known to be accurate today. During the second century, Galen introduced terms that we still use today and will discuss in these first chapters; his terms include words such as diarthrosis, synarthrosis, agonist, and antagonist that will become very familiar to you as you move through the chapters in this book. During the early phase of the Renaissance, Leonardo da Vinci (1452–1519) emerged as one of the greatest artists of all times, well known, even today, for his beautiful artistic depictions of the human body. He dissected hundreds of bodies so that he could gain an understanding of the musculature and form of the human body; we see that knowledge and appreciation expressed in his artwork (Fig. 1.1A). Da Vinci was soon followed by Galileo (1564–1642) and then Giovanni Borelli (1608–1679). These scientists gave mathematical expression to the events related to human movement and wrote of the mechanics of muscle action, equilibrium as it relates to the center of gravity, the relationship between muscle force and its angle of application, and the relation of the moments of rotation to lever arms in the body. [1]

So, let us proceed to not only understand but also appreciate the findings of these early investigators. Following the findings of these early enthusiasts of human movement, others have continued to improve and evolve our knowledge of how the body moves. By the time you have completed this text, you will join the list of distinguished individuals who have come to understand and appreciate human movement.

Introduction

You know already that kinesiology is the study of human motion and has been studied for several centuries. Today, kinesiology has used the findings from over the centuries combined with modern technology to create a highly sophisticated means of analysis of

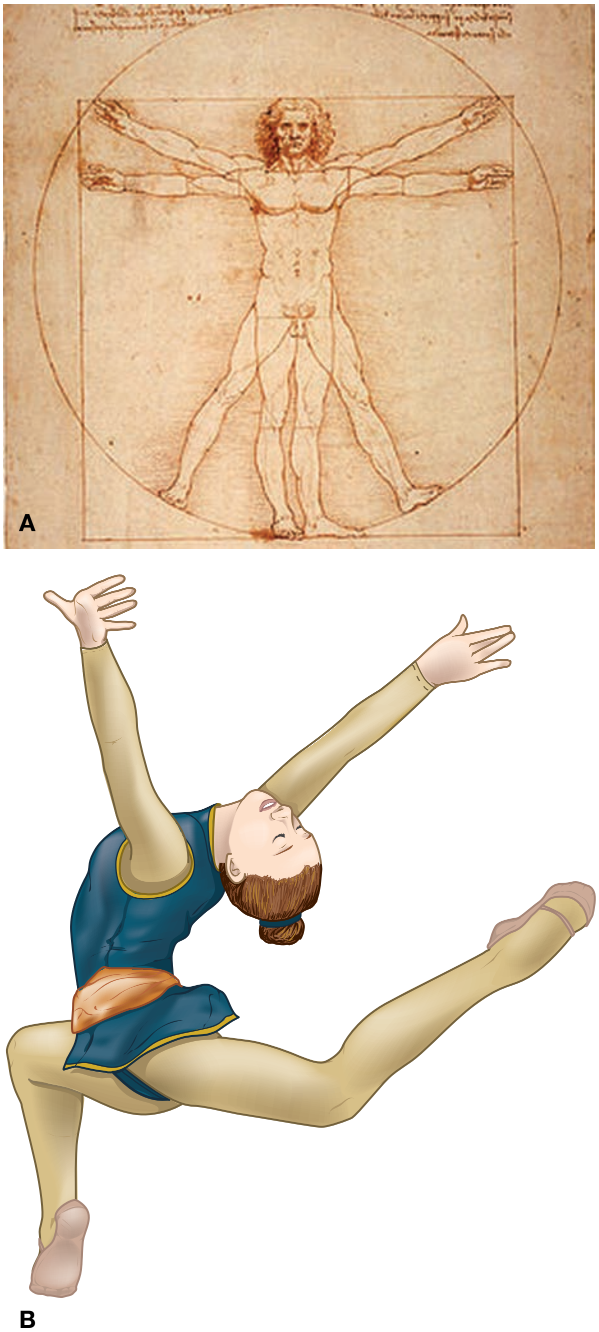


Figure 1.1 From ancient times until the present day, an appreciation of the beauty of the human form in motion has always captivated the attention of artists, scientists, health professionals, and athletes.

human movement. This scientific evolutionary study of simple as well as complex motions evolves from pondering numerous questions: How does a person walk? What joints and muscles are involved in throwing, reaching, climbing, swinging a golf club, getting dressed, driving a vehicle, brushing your teeth? How much motion is required at each of the joints to execute efficient and effective movements? What is the sequence of muscle requirements used in the simple act of shaking a person's hand?

This inquiry into human motion evolved from purely art to a mixture of art and science, combining theories and principles gleaned from anatomy, physiology, anthropology, physics, mechanics, and biomechanics. **Biomechanics** is the application of the principles of mechanics to the living human body. Kinesiology is actually a combination of art and science; it involves an appreciation of the beauty of human movement with an understanding of the scientific principles that provide that movement. Clinical kinesiology is the application of kinesiology to environments of the health care professional.

The purpose of studying clinical kinesiology in health care is to understand movement and the forces acting on the human body and to learn how to manipulate these forces to prevent injury, restore function, and provide optimal human performance. This text presents the basics of kinesiology with an emphasis on clinical application for the health care professional.

Although humans have always been able to see and feel posture and motion, the forces affecting motion (gravity, muscle tension, external resistance, and friction) are never seen. These forces acting on the body are fundamental to human motion and to the ability to modify it. The human body assumes many diverse positions (Fig. 1.2A,B,C). To discuss human movement, it is imperative that we use a common language. If you were to embark on a study of computer science, it would be necessary for you to learn language that includes terms such as "hard drive," "bytes," "disc space," and "flash drive," to name a few examples. The same is true when embarking on a study of kinesiology: A common language is essential for understanding the topic and communicating with others. Some of the terms in this text may be familiar to you and others may not. To assist you in understanding these terms, there is a glossary for all bold-faced terms at the end of this text with indications of where the term is first used and defined within the text. It may be helpful to refer to this glossary throughout your readings.

Kinesiology Terminology

Movement is the essence of kinesiology. Within the study of movement are two terms that are used to further delineate this study of human movement. These terms are defined first.

Figure 1.2 Examples of the variety of joint and segment positions that the human body can assume during functional activity: A) demonstrates flexion and extension positions of joints; B) emphasizes motions of abduction and adduction; and C) illustrates rotation. A view of these positions in three dimensions is even more complex.

Human Movement: Kinetics and Kinematics

Much of the terminology we use is derived from one of two sub-studies of human movement: kinetics or kinematics. **Kinetics** concentrates on the forces that produce or resist the movement. **Kinematics**, on the other hand, deals with types of motion or movement without regard for the forces that produce that motion. When discussing kinematics, we include descriptors such as the type of motion, the direction of the motion, and the quantity of the motion. Quantity of motion is discussed in units such as degrees of motion or the amount of linear distance a body or segment moves. A kinematic description of human movement features the position and movement of the body segment, including the joints and their relationship to each other and to the external world. This description may highlight the movement of a single point on the body, the position of several segments on an extremity, or the position or motions of a single joint and its adjacent joint surfaces. Kinematics uses the three-dimensional system used in mathematics and physics to describe the orientation of the body and its segments in space. The use of this system helps us identify and predict motion of the body and its segments.

Kinematics is further subdivided into two subtopics according to the specific focus of motion—osteokinematics and arthrokinematics. **Osteokinematics** concerns the movements of the bony partners or segments that make up a joint, and **arthrokinematics** focuses specifically on the minute movements occurring within the joint and between the joint surfaces. This chapter describes and discusses elements of kinematics and how to study, describe, and assess human movement using the descriptive language of osteokinematics and arthrokinematics. Before we can begin a discussion on osteokinematics and arthrokinematics, let us identify other terms basic to the understanding of human motion. Kinetics and the forces related to the production of human movement is the content of the next chapter.

Planes of Motion and Axes of Motion

The body and its segments move in planes of motion around axes of motion. The human body moves in three planes of motion in the world. These planes of motion are called **cardinal planes** of motion (Fig. 1.3). The three axes around which these planes rotate, in physics terms, are *x*, *y*, and *z*. These axes, depicted in Figure 1.3, are the *x* or medial-lateral axis runs side to side and is located in the frontal plane; the *y* or vertical axis runs up and down or superior-inferior and is in a transverse plane; and the *z* or anterior-posterior axis runs from front to back and is in the sagittal plane.[2] All movement can be described as occurring along a plane of motion and around that plane of motion's axis.

These axes of motion are also described in functional terms in reference with the **anatomical position**. The anatomical position is a reference position of the body in a static, or nonmoving, position. The anatomical position is universally described as a standing position with the feet, knees, body, and head facing forward, and the shoulders rotated so the palms of the hands also face forward with the fingers extended. From this point of reference, motion and planes of motion are defined. As mentioned, the three planes of motion are the frontal, sagittal, and horizontal planes, and their corresponding axes include the anterior-posterior, medial-lateral, and superior-inferior axes of motion, respectively.

Frontal Plane

The **frontal** plane is also known as the **coronal** plane (XY plane), so named because it is parallel to the frontal bone along the coronal skull suture. This plane divides the body into front and back parts. It rotates around an axis that is perpendicular to it: the anterior-posterior axis. Motions that occur within the frontal plane are (Fig. 1.3):

- Abduction and adduction (hip, shoulder, digits)
- Ulnar and radial deviation (a type of abduction/adduction at the wrist)
- Lateral flexion or bending (neck, trunk)

In summary, these motions occur within the frontal plane and around an axis that lies at right angles to the frontal plane, proceeding from the anterior to posterior aspect of the body.

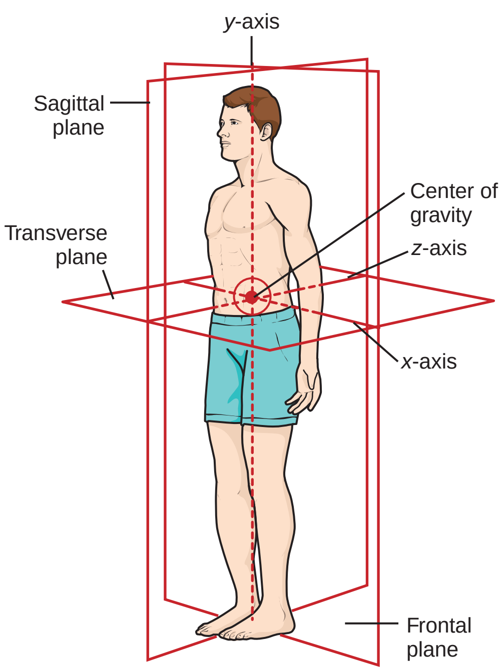


Figure 1.3 The three cardinal planes and axes of the body as seen in standing in anatomical position.

Sagittal Plane

The **sagittal plane** (YZ plane) is so named because it is parallel to the sagittal suture of the skull, dividing the body into right and left sides. Photographically, this is a side view. The clearest examples of joint motions occurring in the sagittal plane are defined as flexion and extension (neck, trunk, elbow and many others) and dorsiflexion and plantarflexion (ankle).

These motions within the sagittal plane pivot around an axis that is perpendicular to this plane and traverses from the medial side of the body to the lateral side of the body (x-axis). This axis of motion is a medial-lateral axis.

Horizontal Plane

The **horizontal** or **transverse** plane is so named because it is parallel to the horizon and the floor (XZ plane). It divides the body into upper and lower parts. Rotations occur in this plane around a longitudinal or y-axis. As with other axes relative to their plane of motion, this axis lies perpendicular to the transverse plane in a cephalocaudal direction and is referred to in physics as the y-axis and in kinesiology as a superior-inferior axis, vertical axis, or longitudinal axis. Motions that occur within the transverse plane are:

- Medial and lateral rotation (hip and shoulder)
- Pronation and supination (forearm)
- Eversion and inversion (foot)

Segment and Body Motion

Some of the terms used to describe motions in the previous section may be foreign to you. In this section, they are defined and specific segments providing these motions are identified. All human movement is defined in terms of planes and axes of motion.

Naming Movements at Joints

Since joints are the articulations between two bony partners or segments, the naming of joints follows a very simple convention. We name joints by using the names of the two bones that form the joint, typically by naming the proximal bone first. For example, the articulation at the wrist is between the distal radius and proximal row of carpal bones; hence, the wrist joint is the radiocarpal joint. Descriptive directional terminology is used to describe the type of movements seen between the two articulating joint segments as described below (Fig. 1.4).

Flexion is a bending movement so that one bone segment moves toward the other and a decrease in the

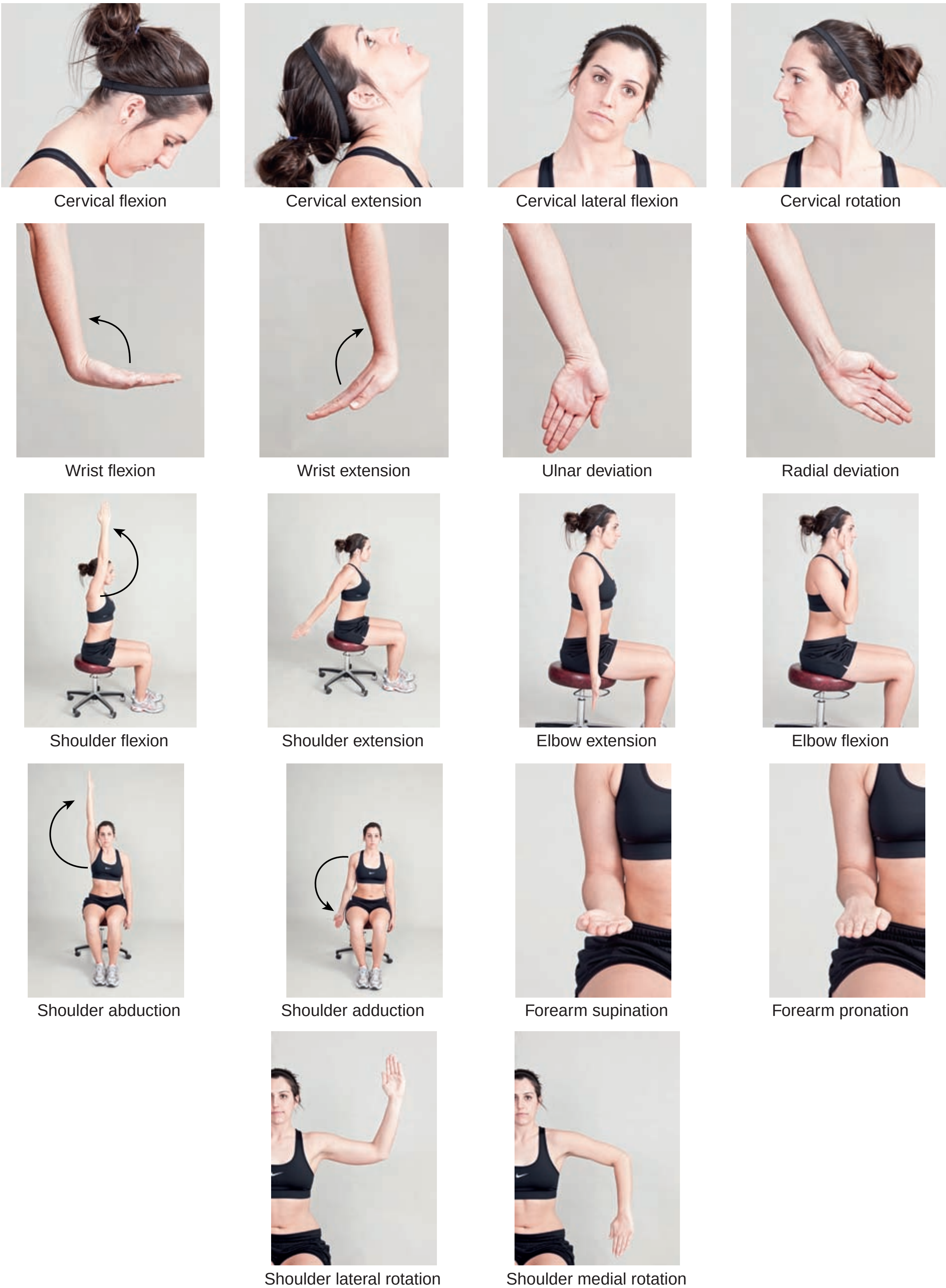


Figure 1.4 Types of joint movement.

Continued


Trunk rotation


Trunk lateral flexion


Trunk flexion


Trunk extension


Hip abduction


Hip adduction


Hip flexion


Hip extension


Hip medial rotation


Hip lateral rotation


Knee flexion


Knee extension


Ankle dorsiflexion


Ankle plantarflexion


Ankle adduction


Ankle abduction


Ankle inversion


Ankle eversion

Figure 1.4—cont'd

angle of the joint occurs in the sagittal plane around a medial-lateral axis. Conversely, flexion's countermovement partner in the opposite direction but along the same plane is extension. **Extension** is the movement of one bone segment away from the other bone, producing an increase in the joint angle. If extension goes beyond the anatomic reference position, it is called **hyperextension**. For example, at the elbow (we now will use the correct kinesiology naming system and call it the "humeroulnar" joint), when the anterior surface of the forearm approximates the anterior surface of the upper arm, the joint moves into flexion. Please note that flexion of the humeroulnar joint may be accomplished either by flexion of the forearm toward the arm, as in bringing a cup to your mouth, or by flexion of the arm toward the forearm, as in performing a chin-up. Since the joint segments producing movement may change their role as the moving segment or the stationary segment, it is so important to always know the reference points so an accurate description of motion is possible.

Flexion is labeled differently for some specific joints or segments. Flexion movement of the ankle (talotibial) joint, for example, occurs as the dorsum of the foot moves toward the anterior surface of the tibia, but this motion is called **dorsiflexion** rather than flexion. At this same joint, extension movement in which the foot's dorsum moves away from the tibia is called **plantarflexion.**

Abduction is a position or motion of a segment away from the midline, and **adduction** is a position or motion toward the midline. Abduction and adduction occur in the frontal plane around an anterior-posterior axis. Usually, when we talk about midline, we mean the midline of the body. In the fingers and toes, however, the reference for midline is different; the middle finger in the hand is the midline for the fingers, and the second toe is the midline in the foot. In the fingers and toes, movement toward those midline reference points is called adduction and motion away from them is called abduction. As with flexion and extension, the wrist (radiocarpal) joint also has unique terms for some of its abduction-adduction motions. Adduction is called **ulnar deviation** or **ulnar flexion** because it is a sideways motion moving the little finger toward the ulna, and abduction is called **radial deviation** or **radial flexion** because it is a sideways motion moving the thumb toward the radius. Another example of a change in motion terminology involves the axial skeleton. A sideways movement of the neck or trunk within the frontal plane is not abduction or adduction, but **lateral flexion**; this term is further clarified by referring to the direction of motion as either right lateral flexion or left lateral flexion.

Rotation is movement of a bony segment around a longitudinal or vertical axis in the transverse plane. Rotation is further clarified by naming its direction so that **medial** (or internal) **rotation** is a turning toward the midline or inward, and **lateral** (or external) **rotation** is turning toward the side or away from the midline. In this text, we will adhere to the terms lateral and medial rotation as the preferred terms rather than external and internal rotation since they more accurately describe the movements. Examples of these types of rotation occur at the hip and shoulder. **Pronation** is a specific term used to describe the rotation into a palm-down position of the forearm. **Supination** is the partnered specific term used to describe the rotation into a palm-up position of the forearm. Supination and pronation are terms also used in describing movement of the foot, but these terms related to foot motion are presented in more detail in Chapter 11. **Inversion** and **eversion** are additional terms used to describe specific types of rotational movements in the foot. These specific motions are also described in detail in Chapter 11.

Retraction and **protraction** are movements along a line parallel to the ground such as we will see when we study the movements of the scapula in Chapter 5 and when we study pelvic motion in Chapter 9.

Special Cases

We have already presented some changes from the "usual" terms that are unique to specific joints. There are also cases in which terms change because the location of the plane of motion changes. Such a case involves the thumb. The thumb is a special case because its normal position is rotated 90° from the plane of the hand. Therefore, motions of flexion and extension occur in the frontal plane rather than the sagittal plane, and abduction and adduction occur in the sagittal plane rather than the frontal plane (see Fig. 7.8). Two additional examples of special cases are forearm supination and pronation with the elbow in flexion and hip medial rotation and lateral rotation with the hip in flexion. As the forearm rotates, the motion no longer occurs on a longitudinal axis but on an anterior-posterior axis, and likewise, the flexed hip also rotates on an anterior-posterior axis. A good foundation of understanding of body motion and position is vital to understanding how these planes and axes of movements change with changes in position. These concepts will be presented throughout the text.

Osteokinematics: Joint Motion in Terms of Position and Type

This section of the chapter describes movement from an osteokinematic perspective in kinematic terms.

Osteokinematic motion is what we easily visualize and feel as the bones move during functional activities. Osteokinematic motion is described using the terms just discussed.

Definition

Osteokinematics regards the movements of our bony levers through their ranges of motion. This motion is produced by muscles. Osteokinematics describes the movement that occurs between the shafts of two adjacent bones as the two body segments move with regard to each other. Examples of osteokinematic motion are the forearm flexing toward the humerus at the elbow or the tibia increasing the angle with the femur during extension of the knee. Osteokinematic motions are described as taking place in one plane of the body (frontal, sagittal, or transverse) and around their corresponding axes.

Description of Types of Motion

The body and its segments move one of two ways: Motion is either translatory or rotary. These motions are defined and explained in this section.

Translatory Motion

In **translatory**, or **linear**, motion, the motion occurs along or parallel to an axis. Linear motion means that all points on the moving object travel the same distance, in the same direction with the same velocity, and at the same time. An example of translatory motion is an elevator moving straight up and down within an elevator shaft. This movement is in a straight line. It is also called **rectilinear.**

Curvilinear is another subset of linear motion in which the object travels in a curved path such as that which occurs when tossing a ball to a friend. Thus, any point on the object can be used to describe the path of the total object.

In the human body, there are few examples of true translatory, or linear, joint motions. The closest example of a motion that is translatory or linear is the sliding of the carpal bones next to each other. These concepts are presented in Chapter 7.

Rotary Motion

In **rotary,** or **angular,** motion, the motion occurs in a circle around an axis. Rotary movements occur around an axis or a pivot point, so every point on the object attached to the axis follows the arc of a circle. Individual points on the object move at different velocities, and the velocity of each point is related to its distance from the axis of motion. An example of this is a game of "crack the whip," commonly played on ice skates. The person who is the anchor is the center of motion, or the axis. The last person on the end of the "whip" moves much faster than those individuals closer to the center because the distance he must travel is farther, and yet all members of the "whip" complete one revolution at the same time. The same concept is true when you bat a ball; the end of the bat moves much faster than the shoulders at the axis end, so the ball can be hit with the bat a lot farther than it can be thrown with the arm.

In simplified terms, joint motions occur around an axis and are rotary, whereby every point on a bony segment adjacent to the joint follows the arc of a circle, the center of which is the joint axis. Rotary motions take place about a fixed or relatively fixed axis, and the pivot point for this angular or rotary motion is called the **axis of rotation**, located within or near the surface of the joint. For example, with the humerus stabilized in elbow flexion and extension, the forearm rotates around the axis of the elbow joint. Individual points on the forearm segment move at different velocities, with the velocity of each point related to its distance from the axis of motion; the farther the distance from the axis of motion, the greater the velocity of that point (Fig. 1.5).

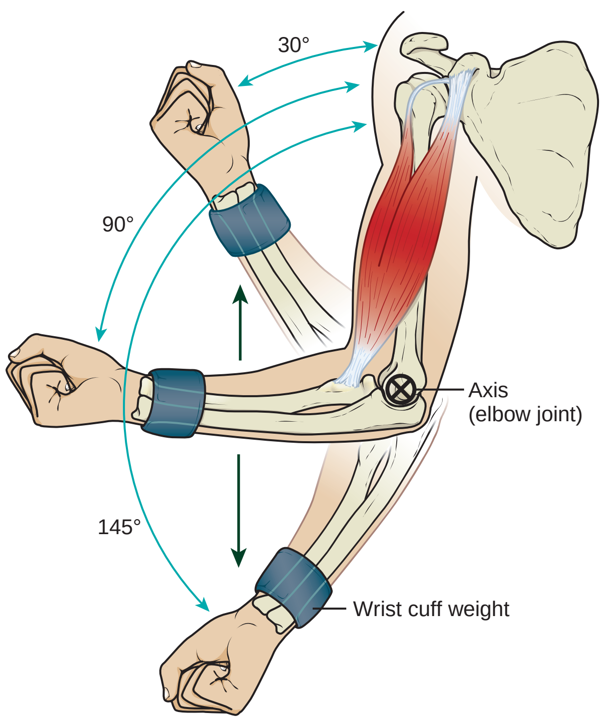


Figure 1.5 Motion at a joint depicted as angular motion. Note the difference in distance traveled at varying points in the body segment.

Impact of Translatory and Rotary Motion

Functional motion involves a combination of linear and rotary movements. In walking, the trunk and the body as a whole move in a forward direction to create a translatory movement of the body forward, but this forward body motion is produced by rotary motion of the hip, knee, and ankle. The upper extremity combines rotary motions at the shoulder, elbow, radioulnar, and wrist joints to provide a translatory path for a baseball during a pitch. In order to closely study functional movement, it is crucial that we analyze each specific joint's unique contribution to the overall movement pattern of the extremity or body as a whole. As we will see in the sections that follow, motions at joints are dictated by the shape and congruency of the articulating joint surfaces, exerted forces, and the number of planes within which they move.

Degrees of Freedom

The ability of the body to transform joint angular motion into efficient translatory motion of body segments involves the degrees of freedom of motion.[3,4] **Degrees of freedom** is the number of planes within which a joint moves. Given that the body and its segments move in three planes of motion, the degrees of freedom are maximal at three degrees as well. When studying the following section, refer to Figure 1.6 and Table 1–1 to see a summary of joint structure and function.

Joints that move in one plane around one axis have one degree of freedom. These joints are **uniaxial** (moving around a single axis) and include two types because of their structural anatomy: **hinge** or **pivot**. Examples of uniaxial hinge joints are the interphalangeal and elbow joints, which perform motions of flexion and extension in the sagittal plane around the medial-lateral axis. The radioulnar joint is another uniaxial joint that permits supination and pronation within the transverse plane around a longitudinal or vertical axis. In summary, uniaxial joints are restricted to an arc of motion in a single plane around a single axis.

If a joint moves around two axes, the segments moves in two planes, and the joint has two degrees of freedom of motion. These joints are **biaxial** and include three structural types: **condyloid**, **ellipsoidal**, and **saddle**. The root word of "condyloid"—"condyle"—means knuckle, so a condyloid-joint shape is a spherical convex surface partnered with an opposing concave surface, as seen in the metacarpophalangeal joints of the hand (your knuckles) and the metatarsophalangeal joints of the foot. An ellipsoidal structure has a spindle-like shape in which one somewhat flattened convex surface articulates with a fairly deep concave surface such as seen at the radiocarpal joint at the wrist. Both condyloid and ellipsoidal joints permit flexion-extension within the sagittal plane around the medial-lateral axis and abduction-adduction within the frontal plane around an anterior-posterior axis. A saddle joint is a biaxial joint in which each bony partner has a concave and convex surface oriented perpendicular to each other, like a rider in a saddle. The carpometacarpal joint of the thumb is a saddle joint, but this joint is actually a modified biaxial joint that is discussed in Chapter 7.

Ball-and-socket joints, such as the hip and glenohumeral joints, are **triaxial** and have three degrees of freedom. Movement takes place about three main axes, all of which pass through the joint's center of rotation. At the hip and shoulder, the axes of motion are similar: The axis for flexion-extension has a medial-lateral direction; the axis for abduction-adduction has an anterior-posterior direction; and the axis for rotation courses in a superior-inferior direction in the anatomical position. Three degrees of freedom of motion are the greatest number of degrees of motion a joint can possess. Figure 1.6 depicts the various joint structural types.

Unless otherwise stated, joint motion occurs with the proximal segment fixed and the distal segment moving. For example, when the elbow flexes or extends, the proximal segment of the joint (humerus) is fixed or stabilized as the distal segment (forearm) moves.

It is through the summation of two or more joints and their degrees of freedom that body segments may gain sufficient degrees of freedom to produce complex yet smooth functional movement. An example of a well-coordinated, successive movement combination is circumduction. **Circumduction** is a motion in which the moving segment follows a circular path. Circumduction occurs in triaxial joints and is actually a combination of straight planes motions.

Normal function involves motion in combined planes and axes. The multiple degrees of freedom of the body's segments permit a wide selection of movement patterns. In the simple movement of rising from a supine to a standing position, 21 different combinations of the arm, leg, and head-trunk components have been documented in healthy young adults.[5]

Clinical Goniometry

Goniometry (Gr. *gonia,* angle, and *metron,* measure) is a valuable clinical measurement used to define the quantity of joint motion, either actively or passively. Since it measures the relative position of two bony segments, goniometry is a way to measure and record the osteokinematic motion available at the joint. Although sophisticated joint motion analysis equipment is available

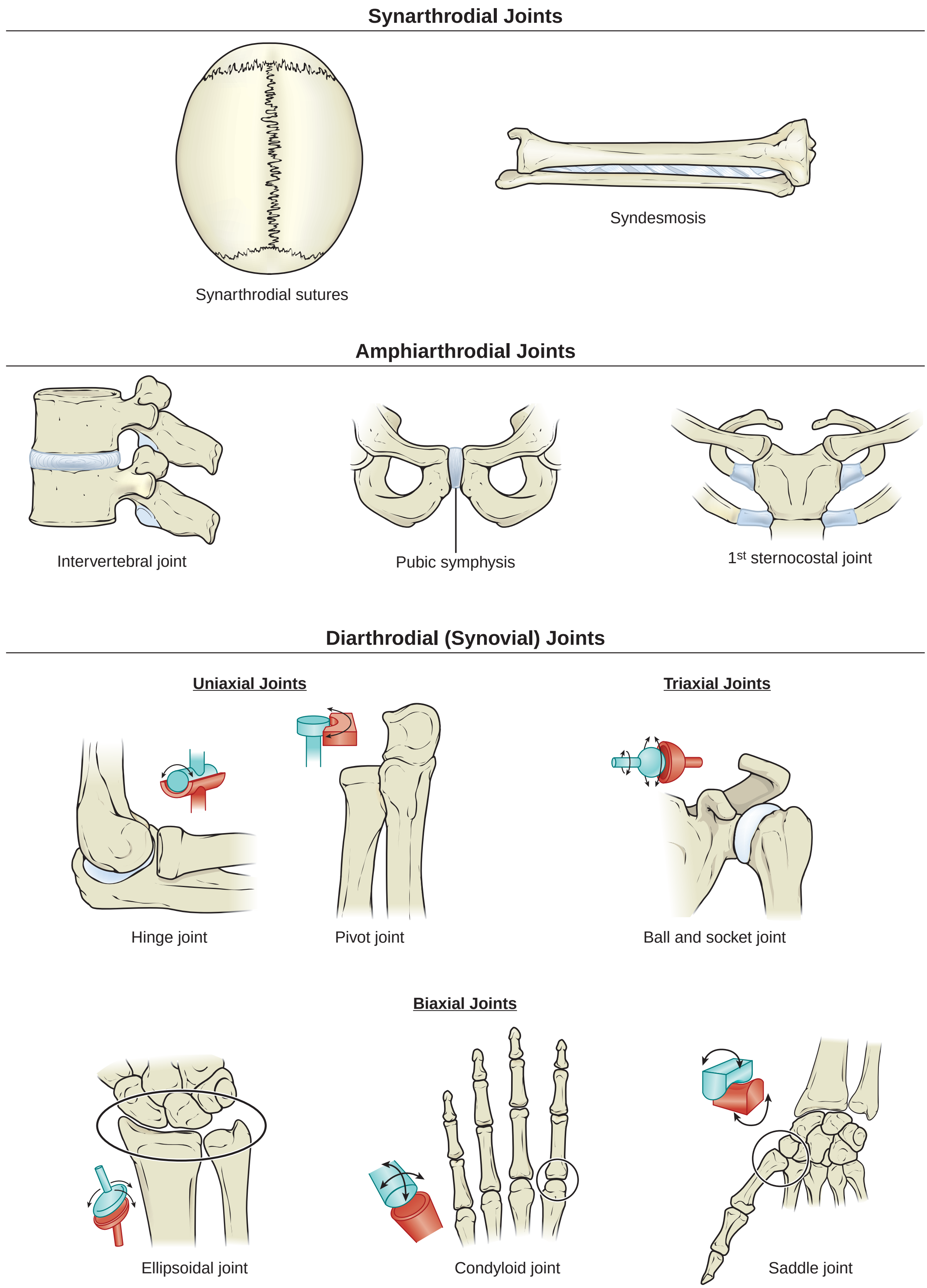


Figure 1.6 Various joint structure types: synarthrodial, amphiarthrodial, and diarthrodial (synovial); hinge, condyloid, ellipsoidal, saddle, pivot, and ball and socket.

TABLE 1–1 | JOINT CLASSIFICATION BY STRUCTURE AND FUNCTION

Type	Structure/ Shape	Primary Function	Motion	Example
I. Synarthrosis				
Syndesmosis	Fibrous	Stability, shock absorption and force transmission	Very slight	Tibiofibular articulation
II. Amphiarthrosis	Cartilaginous	Stability with specific and limited mobility	Limited	Pubic symphysis Intervertebral joints 1st sternocostal joint
III. Diarthrosis	Synovial w/ligaments	Mobility	Free according to degrees of freedom	
a. Nonaxial	Irregular plane surfaces	Contributory motion	Gliding	Between carpal bones between tarsal bones
b. Uniaxial 1° freedom				
	Hinge (ginglymus: Greek: hinge)	Motion in sagittal plane	Flexion, extension	Elbow, interphalangeal joints of fingers and toes, knee, ankle
	Pivot Trochoid: Greek: wheel shape)	Motion in transverse plane	Supination, pronation, inversion, eversion	Forearm, subtalar joint of foot, atlas on axis
c. Biaxial 2° freedom				
	Condyloid : Generally spherical convex surface paired with a shallow concave surface	Motion in sagittal and frontal planes	Flexion and extension, abduction and adduction	Metacarpophalangeal joints in hand and foot
	Ellipsoidal: Somewhat flattened convex surface paired with a fairly deep concave surface	Motion in sagittal and frontal planes	Flexion and extension, radial and ulnar deviation	Radiocarpal joint at wrist
	Saddle: Each partner has a concave and convex surface oriented perpendicular to each other; like a rider in a saddle	Motion in sagittal and frontal planes with some motion in transverse plane	Flexion and extension, abduction and adduction, opposition of thumb	Carpometacarpal joint of thumb
d. Triaxial 3° freedom	Ball and socket: a spherical type "ball" paired with a concave cup	Motion in all three planes: sagittal, frontal and transverse	Flexion and extension, abduction and adduction, rotation (medial and lateral)	Shoulder, hip

PRACTICE POINT

When range of motion is limited, there is a corresponding limitation in body segment function. This functional outcome increases impairment and risk of injury and decreases optimal function. Sometimes even loss of motion in one degree of freedom is severely disabling, as would occur in a finger joint of a professional typist, violinist, or baseball pitcher.

in clinical laboratories, a manual **goniometer** is the most frequently used tool. A goniometer looks like a protractor with two arms hinged at a fulcrum, or axis. The arms of the goniometer are placed parallel to the joint's two body segments with the goniometer's axis superimposed on the joint (Fig. 1.7). The goniometer measures the body joint's range of motion in each plane of movement, such as glenohumeral flexion, hip abduction, and forearm supination. For details on the techniques of goniometry, there are several comprehensive texts available on the topic such as the text by Norkin and White.[2]

Goniometric measurement is a useful tool for the health care professional in assessing and recording progress or change in motion during treatment of pathological conditions. Many textbooks provide values for normal adult range of motion, but standardized normal tables comparing all the variables involved such as age, sex, body build, and type of motion (active or passive) have not been established. Table 1–2 displays goniometric values that may be used as guidelines for the approximate normal joint range of motion in normal adults. Because of individual variations in build and body type, it is useful to use these standardized values as a reference, but it is most important to use the individual's own "normal" for reliable comparison by measuring the uninvolved, or contralateral, extremity segment, assuming that it is present and unimpaired. In Table 1–2, the values in bold type are rounded numbers that are convenient to remember as the amount of normal motion for the extremity joints. The values in parentheses are the range of *average* normal motions reported in several sources.[6-12]

Normal individual ranges of motion vary with bony structure, muscular development, body fat, ligamentous integrity, gender, and age. Slender individuals and those with normal joint laxity may have more range of motion than those who have greater muscular development or

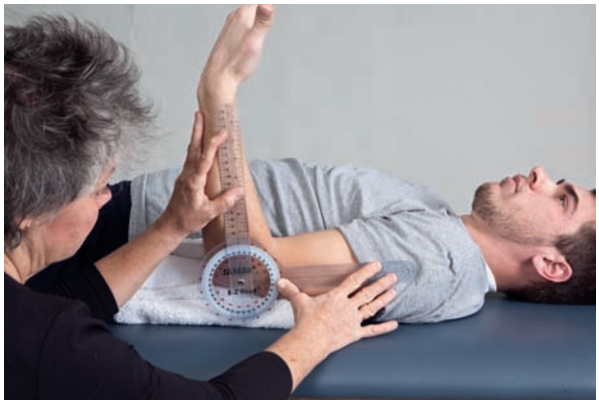


Figure 1.7 Application of a goniometer to measure the position of the elbow in the sagittal plane. The stationary arm of the goniometer is aligned parallel to the long axis of the subject's arm. The moving arm of the goniometer is aligned parallel to the long axis of the forearm, and the axis or fulcrum of the goniometer is placed over the axis of the elbow joint.

who are obese. For example, Dubs and Gschwend[13] measured index finger hyperextension in over 2000 people and found wide variability, from 100° to 10°. They found that joint laxity was greater in females than in males and decreased with age. Males showed a more rapid decrease in range during adolescence and a greater overall decrease compared to their female counterparts. The ranges of motion of some joints during infancy and childhood may differ markedly from the average adult values.

End Feel

When a normal joint is moved passively to the end of its range of motion, resistance to further motion is palpated by the examiner. First described by Cyriax,[14] this resistance is called the **end feel** and is normally dictated by the joint's structure. Resistance is described as hard,

PRACTICE POINT

Pathologic limitations of joint motion, such as caused by edema, pain, or soft tissue shortening, restrict normal function. Contributions to functional movement from multiple segments and joints within an extremity are an advantage used to maintain function during isolated joint impairment. For example, the person who cannot fully pronate the forearm can still have normal hand function by compensatory increases in wrist, elbow, shoulder, and even trunk motions. A person with a stiff knee can walk using compensatory motions of the ankle, hip, back, or the opposite lower extremity. Such compensation, however, occurs at a price of increased energy expenditure and/or increased stress on other structures. Years of compensatory use may result in repetitive microtrauma and dysfunction in the compensating segments.

TABLE 1–2 | SUMMARY RANGES OF JOINT MOTION

SHOULDER	flexion **0° to 180°** (150° to 180°) extension **0°** hyperextension **0° to 45°** (40° to 60°) abduction **0° to 180°** (150° to 180°) medial rotation **0° to 90°** (70° to 90°) lateral rotation **0° to 90°** (80° to 90°)
ELBOW	flexion **0° to 145°** (120° to 160°) extension **0°**
FOREARM	supination **0° to 90°** (80° to 90°) pronation **0° to 80°** (70° to 80°)
WRIST	neutral when the midline between flexion and extension is 0° and when forearm and third metacarpal are in line flexion **0° to 90°** (75° to 90°) extension **0° to 70°** (65° to 70°) radial deviation/abduction **0° to 20°** (15° to 25°) ulnar deviation/adduction **0° to 30°** (25° to 40°)
FINGERS	MCP flexion **0° to 90°** (85° to 100°) MCP hyperextension **0° to 20°** (0° to 45°) MCP abduction **0° to 20°** MCP adduction **0°** PIP flexion **0° to 120°** (90° to 120°) DIP flexion **0° to 90°** (80° to 90°) IP extension **0°**
THUMB	MCP flexion **0° to 45°** (40° to 90°) MCP abduction and adduction (NEGLIGIBLE) IP flexion **0° to 90°** (80° to 90°)
HIP	flexion **0° to 120°** (110° to 125°) hyperextension **0° to 10°** (0° to 30°) abduction **0° to 45°** (40° to 55°) adduction **0°** (30° to 40° across midline) lateral rotation **0° to 45°** (40° to 50°) medial rotation **0° to 35°** (30° to 45°)
KNEE	flexion **0° to 120°** (120° to 160°) extension **0°**
ANKLE\FOOT	neutral with foot at a right angle to the leg and knee flexed plantarflexion **0° to 45°** (40° to 50°) dorsiflexion **0° to 15°** (10° to 20°) inversion and eversion (see Chapter 11).
TOES	MTP flexion **0° to 40°** (30° to 45°) MTP hyperextension **0° to 80°** (50° to 90°) MTP abduction (slight) IP flexion **0° to 60°** (50° to 80°) IP extension **0°**

The values in bold type are round numbers that are convenient to remember in estimating the amount of normal motion typically present. The values in parentheses are the ranges of average normal motion reported in several sources.

KEY:
DIP = distal interphalangeal joint
IP = interphalangeal joint
MCP = metacarpophalangeal joint
MTP = metatarsophalangeal joint
PIP = proximal interphalangeal joint

SOURCES: American Academy of Orthopaedic Surgeons, 1965; Departments of the Army and Air Force, 1968; Kendall, Kendall, and Wadsworth, 1971; Daniels and Worthingham, 1986; Gerhardt and Russe, 1975; and Kapandji, 1982 and 1987.

firm, or soft. A **hard,** or **bony, end feel** is felt when motion is stopped by contact of bone on bone, as in elbow extension when the olecranon process of the ulna moves snugly into the olecranon fossa of the humerus. A **firm,** or **capsular, end feel** is one in which the limitation feels springy because it occurs from the resistance encountered from the capsular, or ligamentous, structures. Wrist flexion is an example of firm end feel. A **soft end feel** is felt at the end of available range of motion when soft tissues approximate each other, such as when the muscle bulk of the arm contacts the fleshy muscle bulk of the forearm at the end of elbow flexion. All of these end feels are normal and dictated by the structure of the joint.

Pathologic end feels occur either at a different place in the range of motion than expected or have an end feel that is not characteristic of the joint. An **empty end feel** is a pathologic type denoting pain on motion but absence of resistance. An empty end feel is present when the joint lacks normal soft tissue stability and a supporting structure is not intact, which is indicative of serious joint injury. Normal end feels are pathologic if they occur when they should not. For example, a bony end feel that occurs in knee flexion because of a bone fragment within the joint is not normal, nor is a soft end feel in elbow extension because of excessive edema.

Kinematic Chains

In kinesiology, a combination of several joints uniting successive segments constitutes a **kinematic chain.** In the human body, movement occurs because of this combination of multiple joints working cooperatively to produce the desired outcome. For instance, reaching for a book on a shelf in the library is an example of this concept as the arm is a chain of joints from the scapula, thorax, shoulder, elbow, forearm, and wrist to the fingers and thumb that all work together in this movement chain to produce the desired motion. We can take this example a step further, and also identify the links from the neck, trunk, pelvis, and lower limbs that may be used to reach for a book on a top shelf. In this example, the links within the upper extremity are free to move (open) and offer the necessary mobility to execute the task. However, the lower extremity joints are fixed (closed) but equally important to this task.

It is important to recognize that human movements are combinations of open and closed kinetic chain movements. These kinetic or kinematic chains are used to describe or analyze a movement skill. Kinematic chains are either open kinematic chains (OKC) or closed kinematic chains (CKC).

Open and Closed Kinematic Chains

In an **open kinematic chain (OKC)**, the distal segment of the chain moves in space whereas in a **closed kinematic chain (CKC)**, the distal segment is fixed, and proximal parts move.[15] Open chain motion occurs when reaching for an object, bringing the hand to the mouth, or kicking a ball (Fig. 1.8A). In open chain motions, segment motion is not dependent on another segment, so one segment can either move or not move, regardless of what other segments in the chain are doing. Open chain movements are highly variable since all of the participating joints are free to contribute any number of degrees of motion to the entire unit's movement. Open chain movements are required for many skilled extremity movements, and because the variability is so high, stability is sacrificed for mobility and risk of unskilled movement and even risk of injury can be a factor. Open chain movements also produce faster motion than closed chain movements.

Equally important to daily function are closed chain motions. Closed chain motions occur when the distal

PRACTICE POINT

From the thorax to the finger, at least 19 degrees of freedom in planar motions can be identified.[15] Such freedom of motion constitutes the mechanical basis for performance of skilled manual activities and the versatility of the upper extremity. In the lower extremity and trunk, there are 25 or more degrees of freedom between the pelvis and the toe. The sum total of these joints and degrees of freedom allow a number of daily functions, from permitting the foot to adjust to an irregular or slanting surface to maintaining the body's center of gravity within the small base of support of one planted foot. Debating the *exact* number of degrees of freedom in a complete kinematic chain is really not necessary for clinical purposes. However, such realization provides additional appreciation for the extreme complexity and demands of the body by even simple movements in daily function. What an incredible masterpiece the human body is!

segment is fixed and the proximal segments move. Closed chain motion occurs during activities such as a chin-up, push-up, standing from a seated position, or a half-squat exercise (Fig. 1.8B). Movement of one segment in closed chain motion requires all the segments to move. When the ankle starts to move, the knee and hip must also move; the ankle is unable to move independently of the other two joints in the lower extremity. When a person uses the armrest of a chair to assist in rising from the chair (or performs a push-up), the hand is fixed and the forearm and shoulder move in relation to the hand, the arm moves away from the forearm (elbow extension), and the arm moves toward the trunk (shoulder adduction). Closed kinematic chain activities do not have the speed of motion that open chain activities produce, but they do provide more power and strength for functional activities.

Both open and closed kinematic chain motions occur in different segments during functional body motion as in Figures 1.2 and 1.8. Most activities of the human body involve a combination of open and closed chain events. Walking is a good example; we are in a closed chain position when we place our weight on the limb and in an open chain activity when the limb swings forward.

Figure 1.8 A) As the player winds up to kick the ball, the distal segments of the upper extremities are free to move (open kinematic chain), the distal end of the right lower extremity is also in an open chain, whereas the distal end of the left lower extremity is fixed in stance (closed kinematic chain). B) In performing a push-up, the distal segments at both the upper and lower extremities are fixed (closed kinematic chain).

Arthrokinematics: Joint Surface Motion

Although human joints have been compared with geometric shapes and mechanical joints such as the hinge, pivot, plane, sphere, and cone, the exquisite motions and capabilities of human joints are much more complicated than these simple geometric comparisons. The fact that no human joint throughout the body has yet been replicated satisfactorily by any joint replacement design is testimony to the complication and sophistication of the body's joints. The phenomenal superiority of human joints to man-made joints is due not only to the physiologic capacities of biologic joints, such as low coefficient of friction, presence of sensation and proprioceptive feedback, and dynamic growth responses to wear and use, but also to the mechanical complexities of human joints.

Definition

Whereas osteokinematics is concerned with the movement of the shafts of the bones and is primarily under voluntary control, arthrokinematics is concerned with how the two articulating joint surfaces actually move on each other. One of the factors that provides for the complexity of human joints is their arthrokinematic movements. Although these motions are not voluntary, they are vital for normal joint function and mobility.

Types of Joints

Joints can be classified structurally and functionally by describing the type and amount of motion allowed. You will see that structure and function are intimately related: Structure allows for functional purpose in movement and the functional requirement actually dictates the structure. Functionally, some types of joints are primarily responsible for providing stability whereas others offer primarily mobility.

Joint Structure

Arthrology (Gr. *arthron,* joint) is the study of the classification, structure, and function of joints. Joint structure and function are intimately related, as we shall see in the following sections which clearly demonstrate that understanding the anatomy or structure of a joint lends itself to understanding how that joint will function and vice versa. The most common and simplest joint classification system focuses on the structure of joints with three main types identified: **synarthrosis, amphiarthrosis,** and **diarthrosis** (Table 1–1).

Synarthrodial Joints

Joints whose primary purpose is to offer stability are joints which are largely fibrous in structure. These joints are synarthroses (noun, plural) or synarthrodial joints (adjective). These names should be easy to remember because as you know, the prefix *syn* comes from Greek meaning "together" or "joined,"[16] very descriptive of the function of this type of joint. Think of other uses of that prefix in words you have commonly used before such as synonym (words with like meaning). These joints are bound by fibrous connective tissue, known for its strength, and the fit between the two bony segments is very tight, with the joint surfaces highly congruent. Examples of a synarthrodial joint structure are the sutures of the skull; they are very stable and fit very tightly, like perfectly matched puzzle pieces. Synarthrodial joints are further divided into other main subtypes that further illustrate this relationship between structure and function.

A **syndesmosis joint** is a synarthrodial joint such as the joints between the radius and ulna and between the tibia and fibula. Syndesmosis joints are joined by a strong interosseous membrane, in which the close relationship of these pairs of bones next to each other is highly desirable with little or no mobility allowed.

Another example is the tight fit of a tooth in its socket; this is a synarthrodial **gomphosis** joint. The overall functions of synarthrodial joints are to maximize stability and allow force dissipation over highly congruent joint connecting surfaces.

Amphiarthrodial Joints

Joints that provide both stability and mobility are called amphiarthrosis (noun) or amphiarthrodial joints (adjective). The prefix *amphi* comes from Greek meaning "on both sides" or "double,"[16] very descriptive of the function of this type of joint. Think of other uses of that prefix in words you have commonly used before such as amphitheatre (partly under cover and partly outside) and amphibian (lives sometimes on land and sometimes in water). Amphiarthrodial joints are hallmarked by a cartilaginous structure with combinations of both fibrous and hyaline (or articular) cartilage and typically have a disc between the bony partners. The disc serves to tighten the fit between the two bony partners and to offer shock absorption. Examples of amphiarthrodial joints include the intervertebral joints of the spine, the pubic symphysis, and the first sternocostal joint. All of these joints offer a great deal of stability and a very specific or limited amount of mobility. The pubic symphysis, for example, is stable most of the time but during pregnancy, the disc is softened and its supporting ligaments become lax gradually by hormonal changes so that when delivery is imminent, the joint provides the required mobility to allow for the birth of the baby.

Diarthrodial Joints

Joints whose purpose is primarily to provide mobility are called a diarthrosis (noun) or diarthrodial joints (adjective). The prefix *di* meaning "twice, double or two,"[16] is descriptive of the fact that, functionally, this type of joint provides almost all of our joint mobility; these joints have several anatomical features which ensure necessary stability while still permitting mobility for function. The key structural component of diarthrodial joints is that they all have a joint capsule. This capsule connects the distal end of one joint segment to the proximal end of the other joint segment. The capsule maintains a small amount of fluid, called synovial fluid, within the joint space. For this reason, diarthrodial joints are also called **synovial joints.**

Joint Capsule

Although joint capsules vary widely in size and thickness, the capsules have several common features. Picture the joint capsule as a double-layered and somewhat baggy balloon, often with many folds. The outer layer is thicker than the inner layer and is primarily comprised of dense irregular fibrous tissue, called the **stratum fibrosum.** This makes sense since fibrous tissue occurs in areas requiring strength. The fibrous outer layer offers additional joint stability and protects the joint. Within its folds are multiple joint neural receptors. These afferent receptors are proprioceptors, which detect joint angle, joint position, and changes in joint position for the central nervous system. Joint proprioceptors are discussed further in Chapter 3. The inner synovial layer is thinner, highly vascular and known as the **stratum synovium.** It produces and secretes a pale, viscous **synovial fluid** into the joint space. Synovial fluid constantly nourishes and lubricates the mobile joint surfaces.

PRACTICE POINT

The anatomy of the joint capsule demonstrates an interesting contrast and shows how structure and function are closely tied. The inner capsular layer has a rich vascular supply is important for nourishment for the joint surfaces; however, this layer is poorly innervated. On the other hand, the outer synovial layer is laden with innervating joint receptors, which are important for detecting joint position and motion. Imagine what happens with any pathology accompanied by joint swelling, such as an acute sprain or even the pronounced and chronic swelling at the ankles seen in people with congestive heart failure. The swelling expands the joint capsule, causing it to distend and distort the afferent joint receptors, rendering them less sensitive to detecting joint position and movement. Imagine the functional consequences of such a problem and the importance of balance and proprioceptive training during rehabilitation. In the case of the elderly person with chronic joint swelling, think of the risk of falls and the need for balance retraining. In the case of a basketball player who sprains the ankle and suffers injury to the joint proprioceptors, do you think that this may increase the risk of re-injury or reduce the athlete's ability to run or jump safely?

Diarthrodial joint and synovial joint are interchangeable terms. These joints are the most common type of human joint and are subdivided and classified by the number of axes about which they move. The number of axes of these joints is determined by the structure of the bony joint surfaces, a factor that further demonstrates the ever-present relationship between structure and function. The classification system of uniaxial, biaxial and triaxial joints and their types has been previously described. Table 1–1 presents an overall summary of joint classification by structure and function.

The surfaces of these synovial joints are not purely geometric with flat, cylindrical, conic, or spherical designs. All joint surfaces are described as either **ovoid** (egg-shaped) or **sellar** (L., saddle) in shape.[17, 18] Most synovial joints are ovoid. In an ovoid shape, the radius of curvature varies from point to point.[19] The ovoid articular surfaces of two bones forming a joint create a convex-concave paired relationship. The concave-convex joint relationship may range from "nearly planar," as in the carpal and tarsal joints, to "nearly spheroid," as in the glenohumeral and hip joints. In engineering, the convex curvature is called the "male" component, and the concave curvature is called the "female" component. The center of rotation is in the convex component at some distance from the joint surface. In most cases, the ovoid surface of one bone in a pair is larger than its companion, as clearly seen in the glenohumeral joint (Fig. 1.9). This structural arrangement permits a large range of motion with an economy of articular surface and reduction in the size of the joint. Some joints are called sellar joints because they resemble the matching of a rider in a saddle (reciprocal reception). As mentioned, each joint surface has both convex and concave curvatures that are perpendicular to each other (Fig. 1.10) and are matched with oppositely designed joint surfaces in its partner segment. Examples of sellar joints include the carpometacarpal joint of the thumb, the sternoclavicular joint, and the ankle (talocrural joint).

Other Materials Found in Synovial Joints

Materials commonly found associated with synovial joints include cartilage, ligaments, articular discs, the joint capsule, synovial fluid, and bursae. The joint capsule and synovial fluid have been previously described, but the following descriptions highlight some of the unique features of these other important joint structures.

There are three types of cartilage: fibrous, hyaline or articular, and elastic. These are all described in basic anatomy texts. For our purposes here, it is useful to remember that fibrous cartilage is known for its strength and shock absorption potential whereas hyaline cartilage is very smooth and actually slippery. Hyaline cartilage is also known as articular cartilage because it covers the ends of the articulating ends of the bones forming the joints. Joints may also contain fibrocartilaginous discs; the menisci at the knee are examples. These fibrocartilaginous discs serve to improve the fit between the joint's bony surfaces and to absorb some of the impact forces imparted to the joints. Occasionally, one surface of the joint, for example in the hip and shoulder, may be rimmed with a fibrous labrum, which forms a ring or lip around the outer edge of the

PRACTICE POINT

It is important to differentiate between joint **dislocation** and joint **subluxation**. A dislocation quite literally means that the two bony segments forming a joint are completely disassociated from each other. Such an injury usually means that significant damage to the capsule has occurred. Dislocation usually occurs secondary to acute trauma. In cases of shoulder or hip dislocations, the labrum may also be torn. A subluxation, on the other hand, occurs when there is a separation of the two bony partners, and the joint partners are partially disassociated from each other. Subluxation may occur over time, such as in hip subluxation in children with cerebral palsy or shoulder subluxation in persons with hemiplegia secondary to a cerebrovascular accident, or it may occur acutely when a joint suffers profound forces sufficient to disrupt some of the stabilizing elements but not enough to separate the joint segments entirely. Acute subluxation occurs most commonly in sports; in these cases, the partially disassociated segment usually spontaneously relocates.

they move on each other. Once again, we will see that structure and function are intimately related: Structure will allow for the joint's functional purpose, and the function can be achieved because of the joint's structural characteristics. Although we have seen that the main osteokinematic movements at joints are rotary in nature, it is important to note that when surfaces move or rotate around each other, the joint surfaces also undergo simultaneous arthrokinematic motions. When a joint moves in an arthrokinematic movement, three types of basic motion can occur between the two surfaces: (1) rolling or rocking, (2) sliding or gliding, and (3) spinning.[19] Most joint movements involve a combination of these motions. As previously mentioned, when a joint moves, usually one of the joint surfaces is stable and the other surface moves on this relatively fixed base.[21]

Rolling (or **rocking**) is a rotary, or angular, motion in which each subsequent point on one surface contacts a new point on the other surface, such as in "rolling" a ball across the floor (Fig. 1.11). **Sliding** (or **gliding**) is a translatory, or linear, motion in which the movement of one joint surface is parallel to the plane of the adjoining joint surface, such as when a figure skater "glides" across the ice. In sliding or gliding, one point of reference (the skate blade) contacts new points across the adjacent surface (the ice). **Spinning**, as in "spinning" a top, is a rotary, or angular, motion in which one point of contact on each surface remains in constant contact with a fixed location on the other surface. Most normal joint movement has some combination of rolling, sliding, and spinning. The knee joint shows this most clearly. If there were only a rolling of the condyles of the femur on the tibial plateau, the femur would roll off the tibia and the knee would dislocate (Fig. 1.11A). Instead, when the femur extends on the fixed tibia, as it does when an individual rises from a seated to a standing position, the femoral condyles slide as they roll and so maintain contact with the tibial condyles (Fig. 1.11B). In the last few degrees of knee extension in a closed kinetic chain, the femur spins (medially rotates on the tibia) to achieve full knee extension. This combination of roll, slide, and spin allows a large range of motion within a joint while using a small articular surface. If a joint possessed only one of these arthrokinematic motions, its range of motion would be limited or its joint surfaces would need to be larger to accomplish the same range of motion.

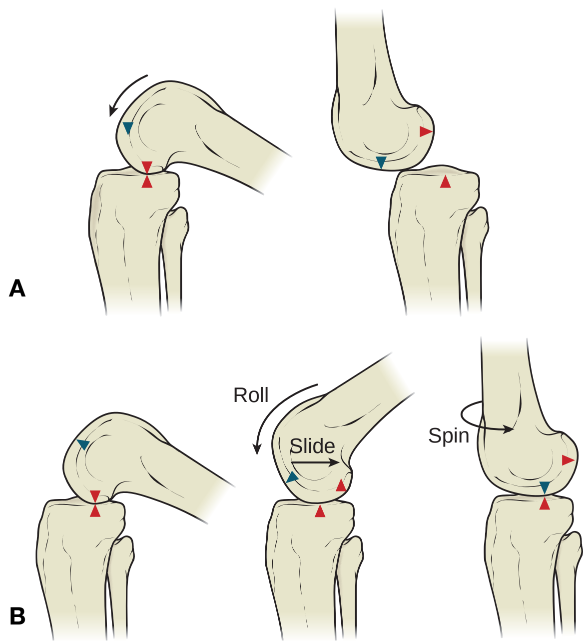


Figure 1.11 Movements of joint surfaces: A) Pure rolling or hinge motion of the femur or the tibia would cause joint dislocation; B) Normal motion of the knee demonstrates a combination of rolling, sliding, and spinning in the last 20° of extension (terminal rotation of the knee).

follows a principle related to its mechanical properties known as the **convex-concave principle**. Although it has been biomechanically demonstrated not to be a steadfast rule at all joints,[24-27] this principle states that if the bone with the convex joint surface moves on the bone with the concave surface, the convex joint surface slides in the direction opposite to the bone segment's rolling motion (Figs. 1.11 and 1.13). If the bone with the concave surface moves on the convex surface, the concave articular surface slides in the same direction as the bone segment's roll does. The proximal interphalangeal joint of the index finger is used as an example in Figure 1.13. When flexion of this joint occurs at the proximal phalanx, points on this bone's convex joint surface move in a direction that is opposite to that of the shaft of the proximal phalanx (Fig. 1.13B). On the other hand, if the concave surface of the middle phalanx moves on the fixed proximal phalanx, the joint surface of the middle phalanx moves in the same direction as the moving middle phalanx (Fig. 1.13C).

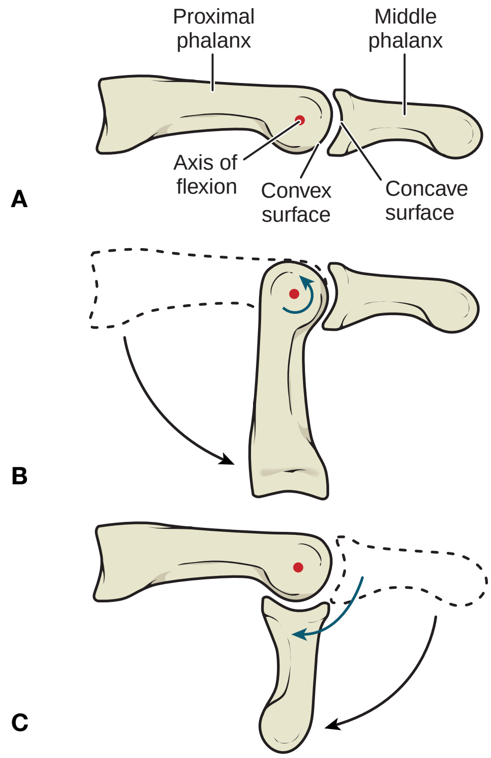


Figure 1.13 Lateral view of the proximal interphalangeal joint of the index finger **(A)** in extension and **(B & C)** in flexion. In **B**, when the bone with the convex joint surface moves into flexion, the joint surface slides in an opposite direction to the motion of the shaft of the bone. In **C**, when the bone with the concave joint surface moves into flexion, the joint surface moves in the same direction as the shaft of the bone. (Black arrow denotes the rolling of the bony segment; green arrow denotes the sliding of the joint surface.)

Joint Axes in Function

Because of the incongruity of joint surfaces and the motions of roll, slide, and spin, human joint axes are complex. A joint's axis does not remain stationary like a mechanical door hinge; rather, the center axis of a human joint moves as the joint position changes, usually following a curvilinear path (Fig. 1.14). This change in position of the center of axis of rotation is called the instantaneous axis of rotation. The largest movement of this axis occurs in the knee, elbow, and wrist. In addition, the joint's *instantaneous axes or rotations* are seldom exactly perpendicular to the long axes of the bones but are frequently oblique. This is particularly noticeable, for example, as when the little finger is flexed into the palm. The tip of the finger points to the base of the thumb rather than to the base of the fifth metacarpal. In another example, when the elbow is extended from full flexion with the forearm in supination, the forearm

PRACTICE POINT

These oblique axes and changing positions of the joint centers of rotation create challenges and necessitate compromise when mechanical appliances and joints are applied to the body, as in goniometry, orthotic devices, and exercise equipment. Mechanical appliances usually have a fixed axis of motion that is perpendicular to the moving part. When the mechanical and anatomic parts are coupled, perfect alignment can occur at only one point in the range of motion. At other points in the range of motion, the mechanical appliance may bind and cause pressure on the body part, or it may force the human joint in abnormal directions. Thus, the placement of mechanical joints is critical where large ranges of motion are desired. Although many advances have been made, the search continues for mechanical joints that more nearly approximate the complexity of human joints.

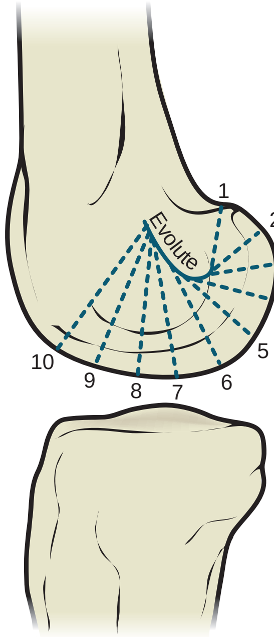


Figure 1.14 Changing radius of curves of the femoral condyles. The axis of motion for flexion and extension moves: number 1 represents the radius for curvature in flexion and number 10, the radius in extension.

laterally deviates 0 to 20°. This lateral deviation of the forearm from the humerus is called the carrying angle and is discussed in Chapter 6 (see Fig. 6-2).

Close-Packed and Open-Packed Joint Positions

The surfaces of a joint's segments usually match each other perfectly in only one position of the joint. This point of congruency (coinciding exactly) is called the **close-packed position.**[19] When in this position, (1) the maximum area of surface contact occurs, (2) the attachments of the ligaments are farthest apart and under tension, (3) capsular structures are taut, and (4) the joint is mechanically compressed and difficult to distract (separate). In all other positions, the joint surfaces do not fit perfectly and are incongruent; these are called **open-packed,** or **loose-packed,** positions. In the open-packed positions, the ligamentous and capsular structures are slack, and the joint surfaces may be distracted several millimeters. Open-packed positions allow the necessary motions of spin, roll, and slide typically with an increase in accessory movements and decreased joint friction. The position at which there is the least congruency and at which the capsule and ligaments are loosest or most slack is the **resting position.** The resting position is unique for each joint type but usually occurs when the joint is positioned near its midrange. The resting position is often used as the preferred joint position when joint mobilizations are applied to a joint to gain mobility, especially during earlier treatment sessions (Fig. 1.15).

The close-packed position is usually at one extreme in the joint's range of motion. For example, the close-packed position is in full extension for the elbow, wrist, hip, and knee; dorsiflexion for the ankle; and full flexion for the metacarpophalangeal joints. In these positions, the joint's capsule and ligaments are taut, and the joint has great mechanical stability with reduced need for muscle forces to maintain the position. For example, when the metacarpophalangeal joints are in 90° of flexion, lateral motion (abduction) cannot occur. This is an advantage in gripping when muscle forces can be directed to finger flexion rather than being needed to also keep the fingers from spreading. The hips and knees are in their close-packed positions in extension. This close-packed position of these joints permits erect standing with little or no contraction of the muscles of the hips or knees. When an individual "rests" on the joint ligaments rather than using muscle force to maintain a position, energy expenditure is reduced.

Clinical Applications

Application of arthrokinematic principles is basic to the assessment of the integrity of joint structures and use of joint mobilization techniques in the treatment of **hypomobile** or painful soft tissues. Normally, ligaments and capsular structures limit passive accessory motions in open-packed positions. If a ligament ruptures, the ligament no longer provides motion control so the joint may be **hypermobile.** If joint soft tissue structures are in an acute inflammatory stage, the joint's accessory motion will be painful and hypomobile. Some angular joint motions, such as wrist flexion and extension, occur because of an exquisite coordination of several joints. The wrist has at least 12 articulations between the midcarpal and radiocarpal joints that must all function properly for full wrist movement to occur (see Fig. 1.9C). In a person with pain and limitation of wrist flexion, localization of the impairment is made by a thorough and carefully detailed evaluation, including assessment of the accessory movements at each of these articulations.

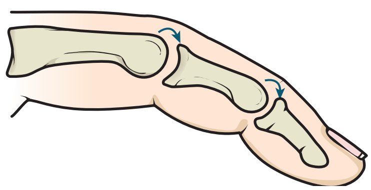


Figure 1.15 A normal interphalangeal joint in resting position.

CHAPTER 2

Mechanical Principles: Kinetics

"Give me a lever long enough and a fulcrum on which to place it and I shall move the world."

—Archimedes, 287 BC–212 BC

Greek mathematician, physicist, engineer, inventor, and astronomer

CHAPTER OUTLINE

LEARNING OUTCOMES

This chapter identifies the mechanical and physics principles of force applications that are relevant to human movement. By the end of the chapter, you should be able to:

- ❑ Identify the four forces that act upon the body;
- ❑ Explain the three classes of levers and provide an example of each in the human body;
- ❑ List Newton's laws of motion and distinguish how they apply to the human body;
- ❑ Identify the elements of a force vector diagram and explain the tangential force and its significance in joint motion;
- ❑ Describe a free body diagram and its function in kinesiology;
- ❑ Explain why muscle and joint reaction forces are often larger than the external forces applied to the body;
- ❑ Ascertain the ratio formulas for a right triangle;
- ❑ Describe the differences between force and torque;
- ❑ Provide a clinical example of the applications of Newton's laws of motion;
- ❑ Offer a clinical example of how to alter a quadriceps exercise to increase resistance provided to a patient without increasing the weight.

CLINICAL SCENARIO

William wished he had paid more attention to his physics professor during his sophomore year. He is now taking a kinesiology class that he really enjoys, but he does not recall much of the physics concepts his current professor is now reviewing. He is lost when Professor Violet starts discussing how bones are levers and muscles provide torque to move them. He is not sure he even remembers the difference between torque and force. As Professor Violet continues her presentation, William is intrigued when she states that we can change the amount of work a muscle must do just by changing where we apply the force against that muscle. William wonders, "How can that be?" and "What does that have to do with physics?"

Introduction

So that we understand how muscles and their neural innervations create motion, we need to investigate how they respond when the body segments experience outside forces applied to them. **Kinetics** deals with forces that produce, stop, or modify motion of either the body as a whole or the individual body segments. **Kinematics**, as you learned in Chapter 1, deals with motion of the body and/or its segments without regard to the forces acting to produce those motions. This chapter advances from the ideas of the movements you learned in the first chapter to how those movements occur through the application of various forces. Forces within the body and forces outside the body both affect how a body moves. Muscles produce forces to move our body. Many factors influence how the muscles function to provide us with the mobility, ability, and variability we have to interact with our environment, meet the demands our bodies face, and perform meaningful activity. Fortunately, there are laws of motion that help us anticipate performance needs. Throughout this chapter, we will investigate these laws and see how they influence movement and outcomes. Understanding how these laws determine both body motion and environmental factors will help us understand movement of the body's segments that will be studied in subsequent chapters. A note of caution for those with a phobia of physics: This chapter contains some basic physics applications, but they will be explained sufficiently to make sense and will be applied only when necessary to further your understanding of the clinical application of how laws of motion are relevant to the body and our interests as clinicians.

Determinants of Motions

Before we can appreciate force applications, we must be able to describe body motion. Motion is simply the displacement of a body or one of its segments from one point to another. Five variables determine and describe body or segmental motion:

1) Type of motion;
2) Location of the motion;
3) Magnitude of the motion;
4) Direction of the motion; and
5) Rate of motion or rate of change at which the motion occurs.

Let us take a brief look at each of these variables. An understanding of these principles may provide for a greater understanding of the forces acting on the body.

Types of Motion

As was mentioned in Chapter 1, because the body is made up of rigid segments that are connected together by joints, there are two types of motion that occur in the body: translatory motion and rotary motion. **Translatory motion** occurs as a linear displacement. In other words, movement is in a straight line. For example, translatory motion occurs when you reach across your desk to pick up a pencil. Your arm, forearm, wrist, and hand move in a straight motion across the desk. Whenever there is translatory motion in the body, some rotation movement usually accompanies it. For example, as you reach across the desk for a pencil, the forearm, wrist, and hand are moving in a straight line, but the shoulder is rotating. **Rotary motion** is movement of a rigid segment around an axis. This is also known as angular displacement. In true rotary motion, the axis is fixed so each part of the rigid segment that rotates around the axis moves through the same angle at the same time. In the body, true rotary motion does not usually occur because there is some shifting of the axis (joint) during motion. As you may have already realized, body movement is a combination of linear and rotary motions. Walking is a good example: The entire body moves from one point to another in a straight line, but rotary motions of the hip, knee, and ankle accomplish this body movement.

Location of Motion

Because the body is three-dimensional, we must create a frame of reference for body movement in three dimensions. These three dimensions, or axes, of movement were presented in Chapter 1. You recall that the x-axis, also called the coronal axis, frontal axis or mediolateral (left-to-right) axis, is the horizontal axis, whereas the y-axis is the vertical axis, or longitudinal axis, and the z-axis is the sagittal axis, or anterior-posterior axis. Body motion occurs around these axes within their planes of motion. A plane of motion is perpendicular to the axis of motion around which it rotates.

Body segmental movements occur within these three planes of motion. Each segment is variable in how many of these planes it is able to move. The number of planes in which a segment moves is primarily dependent upon the shape of the joint, so each joint's planes of movement will be discussed as we go through each segment in subsequent chapters.

Magnitude of Motion

Distance is how far a force moves a body. This is also known as the magnitude a body or segment is displaced. It is measured in either linear or rotary distance. Linear distance is measured in meters or feet. Rotary distance is measured in degrees (as in degrees of a circle) and is described as **range of motion** when discussing joint motion. A full circle of motion is 360°.

Direction of Motion

Since body motion occurs around joint axes, let's first address rotary motion. If we refer to the axes of movement, it is easier to understand the directions of movement. Motion has a positive and a negative component. Similar to a common graph, moving along the x-axis toward the right is positive and toward the left is negative. Moving along the y-axis upward is positive and downward is negative. Finally, moving along the z-axis toward the front or anteriorly is positive and moving backward or posteriorly is negative. In the anatomical position, movement in the x-axis (medial-lateral axis) occurs in the sagittal plane and provides flexion and extension; movement on the z-axis (anterior-posterior axis) occurs in the frontal planes and includes abduction and adduction; and rotation motions occur on the y-axis (superior-inferior or vertical axis) in the transverse plane.

Now, let's jump from rotary to translatory motion. We already know that translatory motion is also produced by the body and its segments. As with rotary motion, translatory motion can occur along any of the three axes of motion. Linear motion, however, is described according to both the axis of motion in which it occurs and whether the motion is going toward a positive or a negative direction. For example, translatory motion is positive if it occurs as motion to the right along the medial-lateral axis (x-axis), forward motion along the AP (z-axis), and upward motion along the vertical axis (y-axis). Negative motions occur in opposite directions on these axes.

PRACTICE POINT

Movement of planes around axes can be a difficult concept to grasp, so perhaps this activity may make it more understandable for you: Take a piece of paper, poke a hole in its center, and place a pencil in the hole; you now have an axis (pencil) and a plane of movement (paper). Position the pencil in one of the three axes of motion and rotate the paper around the pencil to see the movement that occurs in each plane. Identify both the axis you have the pencil in and the plane of motion in which the paper is rotating. The plane of motion is always perpendicular to the axis of motion. Place the pencil in each axis of motion and identify each plane of motion within which the paper moves while spinning around an axis.

Rate of Motion and Change of Motion

When motion occurs, the rate of motion is an important consideration. **Velocity** is the rate at which a body or segment moves. In translatory motion, it is measured in meters or feet per second (m/s, ft/s, respectively), but in rotary motion the measurement is degrees per second (°/s). **Acceleration** is the rate at which a change in velocity occurs. Acceleration can be either a positive or a negative number. If it is positive, the segment is moving faster and faster, but if it is negative, the segment is slowing down more and more. If the motion is linear, the measurement is m/s per second or ft/s per second (m/s^2 or ft/s^2, respectively). If the motion is rotary, the measurement is °/s per second ($°/s^2$). We have already discussed the definition of force. However, when we talk about motion occurring around an axis, force is called **torque.** Therefore, torque is merely force applied in an arc of motion around an axis.

Forces

Kinetics is the study of forces acting on the body. Motion occurs because of these forces. When we discuss forces, there are several words commonly used to describe forces and their effects. **Displacement** is the motion of a body or segment that occurs when force is applied. A **force** is a push or a pull that produces displacement. Forces have two dimensions—magnitude and direction. In other words, an applied force is going to have a certain magnitude or quantity, say 5 pounds, *and* will also have a certain direction of movement, say upward, if you lift an object overhead. Perhaps the easiest way to visualize a push or a pull is to imagine a tug-of-war (Fig. 2.1). If both teams pull on the rope with the same force, no movement of the rope occurs. The system is balanced because both forces are equal; this is a state of **equilibrium.** If the forces are unbalanced as one team pulls harder or one team slips, movement will occur in the direction of the stronger force.

Figure 2.1 Forces at equilibrium in a tug-of-war.

Types of Forces

Whenever the body moves, it encounters forces. From a functional standpoint, four primary sources of force affect body movement:

- **Gravity.** The most prevalent force that all structures encounter is gravity. Gravitational force is commonly referred to as the "weight" of an object, body, or body segment. If an appliance or object is attached to a body segment—such as a dumbbell in a hand or a cast on a leg—that object increases the weight (or pull of gravity) of that segment. Since gravity is an important factor in body motion, it is discussed in more detail below.
- **Muscles.** Muscles produce forces on their bone segments by either active contraction or passive stretching. Muscle force provides motion of body segments and of the entire body.
- **Externally applied resistances.** These devices are numerous and are whatever the muscles must work against to produce motion. Examples of externally applied resistances include exercise pulleys, manual resistance, doors, or windows.
- **Friction.** Friction is the resistance to movement between two objects that are in contact with each other. Friction can be advantageous or disadvantageous by providing stability if optimum, retarding motion if excessive, and leading to instability if inadequate

Forces act on a mass. "Mass" and "weight" are terms that are often interchanged, but they are not the same. A **mass** is the amount of matter contained within an object, whereas **weight** is the force of gravity acting on the object. Weight is actually the pull of gravity with an acceleration force of 32 ft/sec/sec or 32 ft/s^2 (9.8 m/sec/sec or 9.8 m/s^2). If you weigh yourself at sea level at the equator, your weight will be greater than if you weigh yourself on the top of Mount Everest because, although your mass has not changed, the pull of gravity is less when it is farther from the center of the earth so your weight is less. The confusion comes with the labels that are interchangeably used to incorrectly describe mass and weight. Mass is measured in kilograms (kg), but the term is often used to identify weight. In the US system, few people are familiar with the correct term for mass, so "pounds" is identified with mass when, in fact, it is a measure of force (gravity's force). However seldom used, the proper US term for mass is **slug**. One slug is equal to 14.59 kg. When used as mass, 1 pound is equal to 0.031 slugs. **Newtons** is the term for force in the metric system: 9.8 Newtons is equivalent to 1 kgf (kilogram-force). See Tables 2–1 and 2–2 for definitions and conversions between the metric and US systems.

A **moment** is the result of force acting at a distance from the point of motion, or the axis. In mathematical terms, a moment (M) is the product of this distance (d) and the force (F): M = d × F. In translational forces, d is the length of the **lever arm** (or the perpendicular distance from the force vector to the center of motion), but in rotary forces, the lever arm is the **moment arm** (or the perpendicular distance from the force vector to the joint's axis of motion). If we look at the moment formula, we can see why distance of a force from an axis of motion is important in determining a force application. For example, if we have a mass of 10 pounds (4.45kg) with its distance to the center of motion at 12 in. (30cm), we know that it has a force-arm of 10 lb × 12 in. (4.45 kg × 30 cm), or 120 in.-lb (133.5 kg-cm). However, if the lever arm were shortened to 6 in. (15cm), the force arm would decrease to 60 in.-lb, or 66.75 kg-cm. If we apply this formula to a rotary motion, how moment arm length influences force becomes even clearer. As an example, imagine a 5-lb (2.27-kg) weight placed at the ankle on a lower extremity that weighs 25 lb (11.36 kg) as in Figure 2.2. The distance from the ankle (where the 5-lb weight is attached) to the hip (the axis of motion) is 3.5 ft (3.15m). Therefore, the amount of force required of the hip flexors to lift the leg and ankle weight is 3.5 ft × (5 lb + 25 lb), or 1.067 m × (2.27 kg + 11.34 kg). In order to lift the leg with the weight attached, the hip flexors must create a moment of 105 ft-lb or 14.52 m-kg. However, if the knee is flexed with the distance from the weight to the hip at 3 ft (0.91 m), then the hip flexor's moment requirement is 90 ft-lb, or 12.39 m-kg.

Forces are expressed as a combination of their magnitude and rate of change in direction, or acceleration. If we look at the formula for force, it may make more sense. The mathematical formula for force is $F = m \times a$, where F is the amount of force created, m is the mass of the object, and a is the acceleration of the object. Force

TABLE 2–1 | CONVERSION FACTORS

Mass	
1 slug (sg)	= 14.59 kilograms (kg)
1 gram (gm)	= 0.001 kilogram (kg)
Force	
1 pound (lb)	= 4.448 Newtons (N)
1 Newton (N)	= 0.225 pound (lb)
1 dyne	= 0.00001 Newton (N)
1 pound (lb)	= 0.45 kilogram (kg)*
1 kilogram (kg)*	= 2.2 pound (lb)
Distance	
1 foot (ft)	= 0.3048 meter (m)
1 inch (in)	= 2.54 centimeters (cm)
1 centimeter (cm)	= 0.01 meter (m)
Torque (bending moment)	
1 foot-pound (ft-lb)	= 1.356 Newton-meters (N-m)
1 dyne-centimeter (dyne-cm)	= 0.0000001 Newton-meter (N-m)

*The kilogram is a unit of mass, but it is commonly used as a unit of force instead of the correct unit, Newton.

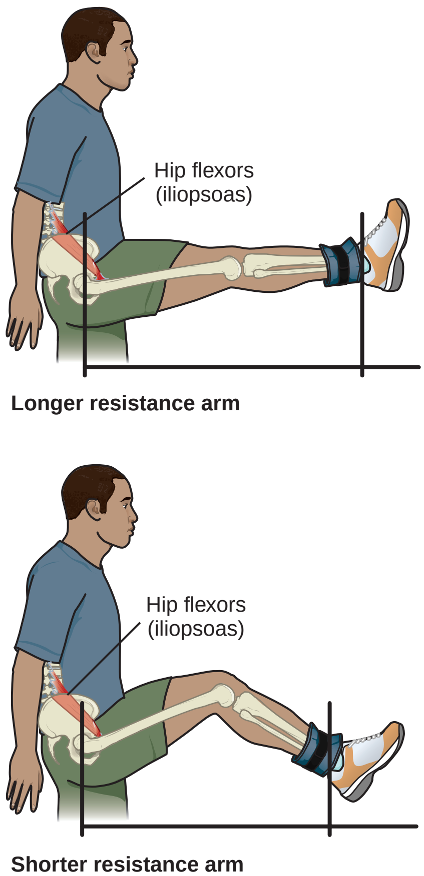


Figure 2.2 Changing the length of the lever arm changes the force requirements. With the knee flexed, the lever arm length of the amount of force pulling against the muscles lifting the leg reduces, so the muscle does not have to work as hard to lift the leg and cuff weight.

PRACTICE POINT

In a clinical situation, if a patient does not have enough muscle strength to overcome an external resistance, such as a cuff weight, an easy way to reduce the external resistance is to shorten the cuff weight's moment arm. The other more obvious way is to reduce the weight and maintain the weight's position at the more distal point on the extremity; however, if the lightest cuff weight available was 5 lb, its force could be easily adjusted by changing its placement on the extremity.

is expressed in either British units (sometimes called US units) or metric units. Since the metric system is the system most scientists and professional publications use, metric units are also referred to as the International System of Units (SI). The US system uses ounces, pounds, feet, and inches whereas the SI system uses grams, kilograms, meters, and centimeters. We will provide both in this text to make it easier to appreciate forces. Based on the formula for force, we know that forces are expressed with two components, mass and acceleration. In SI units, we see mass expressed as Newtons (N), and in US units, it is pounds (lb or #); 1 pound = 4.448 Newtons. Since force is a combination of mass and acceleration, forces are labeled as Newton-meter per second^2 (N-m/s^2) or foot-pound/second^2 (ft-lb/s^2) in SI or US units, respectively.

Newton's Laws of Motion

Sir Isaac Newton (1643–1727) was a mathematician who identified and articulated the laws that govern all motion. He observed that when forces were applied to an object, motion of that mass could be predicted. These three fundamental laws governing motion that we continue to use today deal with inertia, acceleration, and action-reaction.

Newton's First Law of Motion: Inertia

Newton's first law of motion states that **if a body is at rest, it will remain at rest, and if a body is in uniform motion, it will remain in motion, until an outside force acts upon it.**[1] The property of a body that resists change in motion or equilibrium is defined as **inertia.** Therefore, this law is the law of inertia, and sometimes you may see it called the law of equilibrium. As strange as it may seem, they are essentially the same: One label looks at this law of motion from what occurs because of this law and the other takes the perspective of what must be overcome. Let's take a look first at this law from an inertia perspective before we see it from an equilibrium view. We know from physics that **inertia** is the reluctance of a body to change its current state, whether it is stationary or moving uniformly. For example, if you want to move a file cabinet from one side of your desk to the other, it takes a lot more force to initiate the cabinet's movement than it does once you get it moving. That is inertia. Inertia is what must be overcome in order to cause a change in the body's (in this case, the file cabinet's) position.

Individuals who refer to Newton's first law of motion as a law of equilibrium take the perspective of what must be disturbed to satisfy the law. When a body is at rest, it is in a state of static equilibrium: The forces are all equal so no motion is occurring. For example, a 1500-lb car parked in the driveway is in static equilibrium because gravity is pulling down at 1500-lb and the driveway is pushing up at 1500-lb. When a body is in a uniform motion, it is in a state of dynamic equilibrium because it is moving at a uniform rate; if the car's cruise control is set at 50 miles per hour (mph), then the car is moving uniformly over the road at a constant pace, or uniform rate. In either the static or dynamic equilibrium case here, acceleration is not occurring, so the car's acceleration is zero. If, however, a force is applied to the car in either static or dynamic equilibrium, equilibrium is no longer present, and the body's acceleration is no longer zero. For example, if the car moving at 50 mph is suddenly hit from behind by another vehicle going 70 mph, the car is now going faster than 50 mph, causing acceleration to occur because an outside force affected its uniform motion. Let's take another example: A hockey puck sitting undisturbed on an ice rink is in static equilibrium because the weight or force of the puck pushing down on the ice is balanced by an equal force of the ice pushing up on the puck. After the puck is struck (accelerated) by an outside force, this outside force accelerates the puck to move in a lateral direction. Once the puck moves, it is again in equilibrium (this time, dynamic equilibrium) and moves in a uniform direction and at a uniform velocity until other forces are impressed upon it. These outside forces include either friction between the ice and puck to decelerate the puck's velocity or collision with a stick or wall to change the puck's direction and velocity.

In its simplest terms, Newton's first law of motion may be stated this way: A force is required to start a motion, to change direction or speed of a motion, and to stop a motion. In mathematical terms, the law states:

$$\Sigma F = 0$$

In this formula, F is force and Σ (sigma) is the total sum of all the forces. All of these forces equal zero so the object is in equilibrium. There can be several forces acting on a body, but in our example of the puck sitting on the ice, there are only two—the downward force, or weight, of the puck on the ice, and the force equal to that coming from the upward force of the ice. If the total forces are not equal, $\Sigma F \neq 0$, then the body is accelerating or decelerating.

Translatory applications of this law can be disastrous when a person is transported in a wheelchair, on a stretcher, or in an automobile, and the vehicle is stopped suddenly. If the person is not attached to the vehicle (e.g. by a seat belt), the body continues forward until stopped by another force ("If a body is in uniform motion, it will remain in motion, until an outside force acts upon it"). Seat belts or restraining straps are recommended, and frequently required, to prevent injuries caused by abrupt stops of wheelchairs and stretchers, as well as of automobiles. Whiplash neck injuries from rear-end collisions of automobiles occur because the automobile seat and the person's body are impelled forward as a unit while the unsupported head remains at rest. The violent stretching of the neck structures then produces a force to rapidly "whip" the head and neck first into flexion, then extension, with resulting injury to both posterior and anterior structures of the head and neck.

Newton's Second Law of Motion: Acceleration

The same force or forces acting on different bodies cause the bodies to move differently. Newton's second law of motion states: **The acceleration (a) of a body is proportionate to the magnitude of the net forces (F) acting on it and inversely proportionate to the mass (m) of the body.** As an equation, it is expressed as:

$$a \propto \frac{F}{m}$$

More simply stated, a greater force is required to move (or stop the motion of) a large mass than a small one. Let's expand on an example we had with Newton's first law of motion. According to this second law of motion, we know that the larger the mass (the bigger the body), the more force it takes to move it if it is stopped or stop it if it is moving. This time, you have a full two-drawer file cabinet and a full four-drawer file cabinet to move. It is much easier to move the two-drawer file cabinet across the floor than the four-drawer file cabinet. According to Newton's second law of motion, to cause acceleration of the file cabinets, it takes more force to move the larger four-drawer than the smaller two-drawer file cabinet.

This law is pertinent in clinical situations. For example, let us assume you have two patients with a grade 5/5 in gastrocnemius strength, but the first patient is a 250-lb football player and the second patient is a 100-lb dancer. Although their strength grades are both normal, you should not expect each of them to lift 250 lb in a heel-raise exercise.

Newton's Third Law of Motion: Action-Reaction

Newton's third law of motion states that **for every action force there is an equal and opposite reaction force.** This means that whenever one body applies a force to another body, that second body provides an equal force in the exact opposite direction with equal magnitude as the first body; one body or object provides the action and the other provides the reaction force. The easiest way to discuss this law is to present an example: If you hold your notebook in your hand, there are two equal forces acting on it—your arm muscles to keep the notebook in the position you desire it to be and gravity pulling it to the ground. The forces acting on the

PRACTICE POINT

A clinical application of the first law of motion occurs when a patient with a grade 3/5 hip flexor attempts unsuccessfully to lift the leg upward to perform a straight leg raise. The patient may be able to complete the motion if the clinician begins the motion; in this case, the clinician overcomes inertia and the patient is then able to lift the leg unaided.

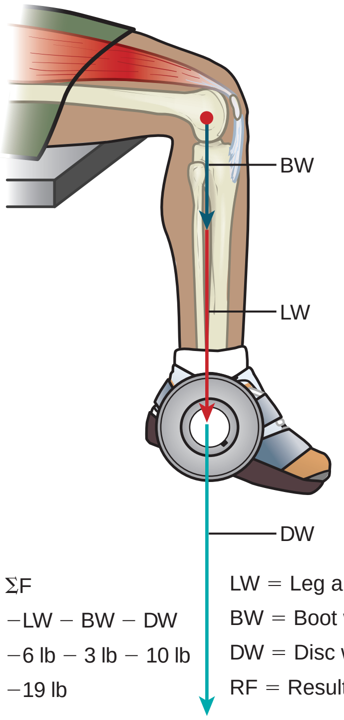


Figure 2.6 Forces acting at the knee joint when the subject is sitting with a weight at the ankle. The algebraic composition of the resultant force is given (negative sign indicates that the direction of the force is down).

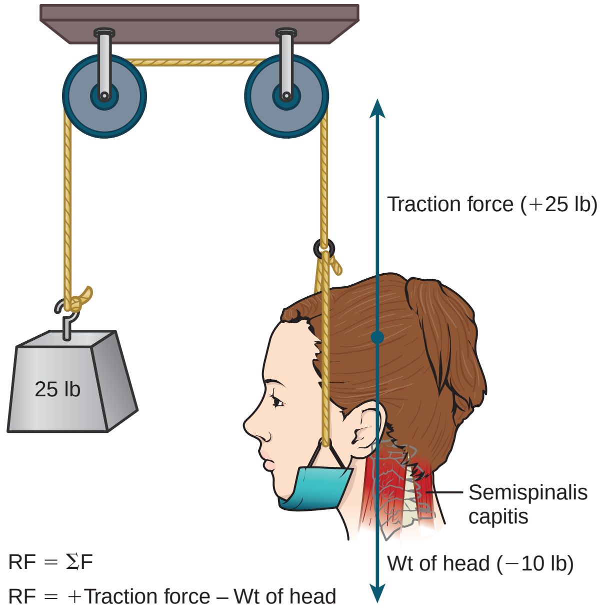


Figure 2.7 Resultant vector force when forces oppose each other. The weight of the head produces a downward force whereas the traction produces an upward force. A counterbalance force of 10 lb from the traction unit eliminates the downward force of the weight of the head, so the actual traction force applied to the cervical spine is 15 lb.

the sum of the individual forces is the total force (RF = ΣF). In both methods, the resultant force is the same. Since the knee joint is not moving with these forces pulling on it, we know that the resultant force is equal in force and opposite in direction to the forces of the joint's ligaments, fascia, and capsule, which are holding the joint in place. If these soft tissue structures were unable to provide an equal force to these distracting forces, the joint would dislocate. When the body segment is stable and no motion occurs, the forces are in balance or in equilibrium. In such a case, the sum of the forces is zero (the positive forces equal the negative forces).

Levers

Muscles apply forces that produce movement of the body's levers. A simple machine that consists of a rigid bar that rotates around an axis, or fulcrum, is a **lever.** In biomechanics, the principles of levers assist in visualizing the more complex system of forces that produce

PRACTICE POINT

We can also find the resultant force in a linear force system when the forces act in opposite directions. In the clinical example in Figure 2.7, we see a patient receiving cervical traction. The traction force in this example is 25 lb (111N), but the weight of the head and neck (10 lb) reduces the amount of traction force actually applied. In this case, the effective upward traction force on the cervical spine is really 15 lb (67 N). Since weight of the head is approximately 10 pounds, any traction weight less than that will not provide sufficient counterbalance weight to produce effective cervical traction.

rotary motion in the body. Reducing body segments to levers helps us to understand the foundations for therapeutic applications in treatment.

The three elements of mechanical levers include the axis (A) and two forces, the resistance force (R), and the moving (or holding) force (F). The perpendicular distance from the axis to the line of action of the resistance is the **resistance arm**. The perpendicular distance from the moving force to the axis is the **force arm**. Lever systems in the body include the body segment as the lever and the joint as the axis. The forces acting on the body segment include the external forces as the resistance force and the muscles, or internal forces, as the moving force. The relative position of the axis, resistance arm, and force arm to one another define the different classes of levers. Figure 2.8 illustrates each of the classes of levers discussed below as well as a common example and an example within the human body.

First-Class Lever

First-class levers, such as a seesaw or balance scale (Fig. 2.8A, B), gain either force or distance, depending on the relative lengths of the force arm and the resistance arm. If two forces are equal on either side of a first

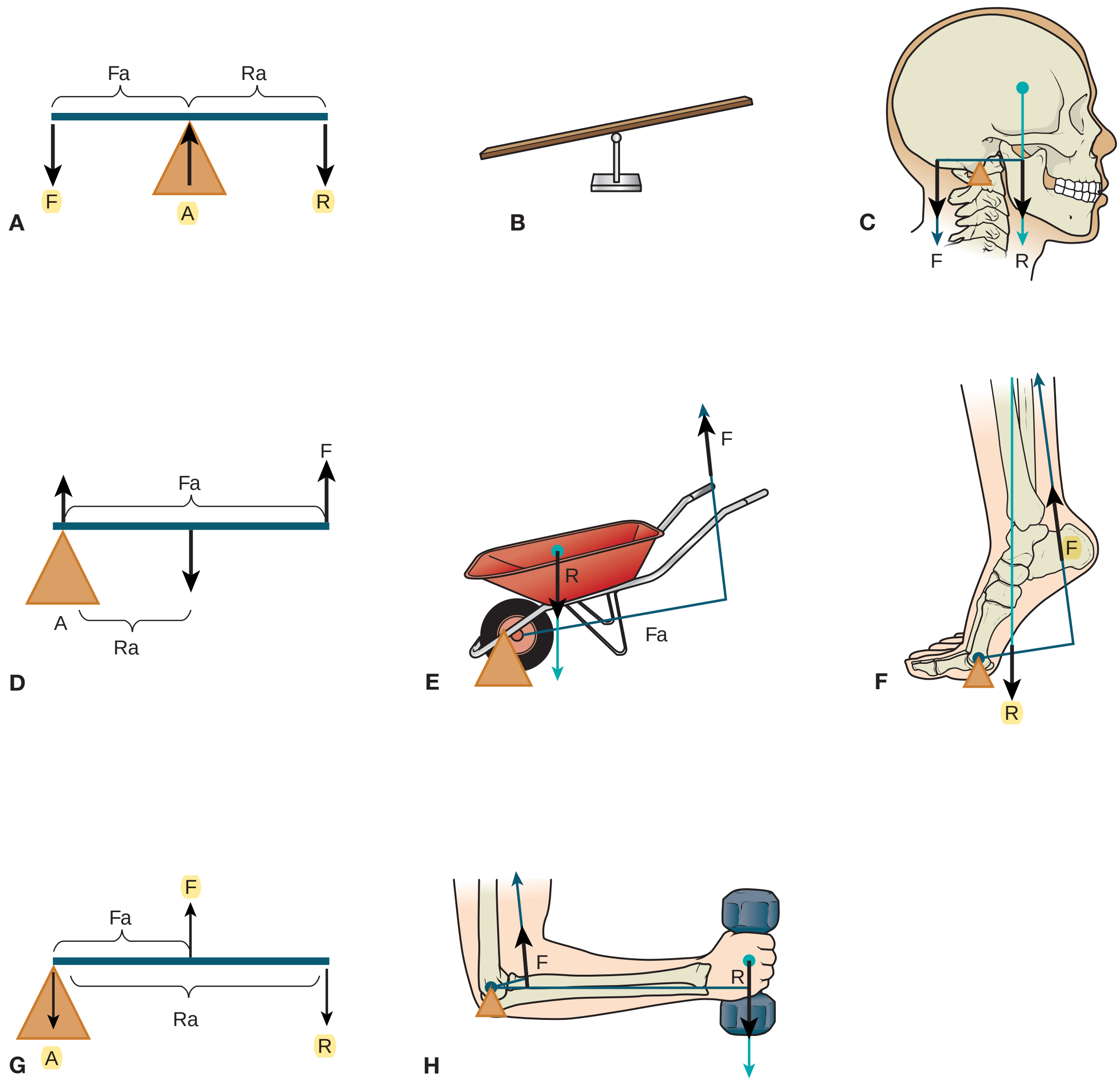


Figure 2.8 Classes of levers are represented in geometry, common activities or tools, and the body: A–C = first class; D–F = second class; G–H = third class. F = Force; Fa = force arm; R = resistance; Ra = resistance arm.

length is 1 ft and Resistance B's arm length is 2 ft, it would not matter if Force A was 10 lb or 30 lb; Resistance B would still not have to produce as much force to be equal to Force A. This is so since Force A at 10 lb × 1 ft will produce 10 ft-lb, but Resistance B would have to be only 5 lb (5 lb × 2 ft = 10 ft-lb) to create a force equal to Force A. If Force A was 30 lb, then it would create (30 lb × 1 ft) 30 ft-lb of force; however, in order to equal Force A, Resistance B would only have to be 15 lb (15 lb × 2 ft).

Assuming forces to be equal in magnitude, the mechanical advantage lies with the force that has the longer lever arm in first-class levers. In second-class levers, the force will always have a greater mechanical advantage because its lever arm is always longer than the resistance arm. However, in third-class levers, the reverse is true; the resistance force always has the mechanical advantage since its lever arm is always longer than the force arm. In clinical application to body segments, whenever the force arm of the working muscle is shorter than the resistance arm of the segment moved by the muscle, the muscle must exert more force to lift the segment. On the contrary, when the muscle's force arm is longer than the resistance arm of the segment, the muscle does not have to work as hard to lift the body part. As mentioned, most muscles in the body work as third-class levers; this means that muscles will usually need to produce more force to move the segment than the weight of the extremity it is lifting.

Static Equilibrium

In the fundamental Newtonian equation $F = ma$, F represents the sum or resultant of **all the forces** acting on the body or segment. When that body or segment is not moving, it is in the state of static equilibrium and acceleration is zero ($\Sigma F = 0$). Remember that since a force has two dimensions, we must consider both its magnitude and its direction. If clockwise force is positive and counterclockwise force is negative and we know that joints move in an arc, then we also know the force's directions. Static equilibrium equations for the forces on the three-lever systems in Figure 2.8 can be written in the following manner (using positive and negative signs for direction):

Static equilibrium:	$\Sigma F = 0$
First-class lever:	$\Sigma F = -F + R = 0$
Second-class lever:	$\Sigma F = -F + R = 0$
Third-class lever:	$\Sigma F = -F + R = 0$

(Refer to Figure 2.8 for the abbreviations.)

Thus, if two of these forces are known, the unknown third force can be calculated.

Since clinical forces are usually dynamic and continually changing as a segment moves through its range of motion, they are very difficult to calculate; therefore, static equilibrium is usually used to estimate forces applied to the body at a specified joint position. We present a few formulas in this chapter and explain how they are used to help you to understand and appreciate the forces that occur clinically. These forces are important since they affect our daily patient treatments. For example, the force between the joint surfaces at the ankle in standing when standing on one leg is greater than the entire body weight. This fact is true because the line-of-gravity line of the body falls not through the ankle joint, but slightly anterior to the lateral malleolus. Therefore, the person is prevented from falling forward by the gastrocnemius-soleus muscle's contraction force pulling on the tibia. As we see in Figure 2.9, the combined downward pulls of gravity and the contraction of the muscle provide compression force on the ankle. Without going into the specific computations to get the answer, it is sufficient to realize that a muscle creates a compression force on the joint when it contracts so the total amount of force on the joint is more than just the body's weight.

Torque

As has been mentioned, torque is force which is applied around an axis; therefore, torque produces joint motion. Similar to the formula for force, torque (τ), or moment

PRACTICE POINT

Force arm and resistance arm play important roles in clinical rehabilitation. If you position a patient lying on his side and provide the patient with manual resistance to his hip abductors, your force arm will be longer if you apply your resistance at his ankle rather than at his knee. Positioning your hand at the ankle will allow you to provide appropriate resistive force without exerting as much effort as would be required of you with your hand on the patient's knee.

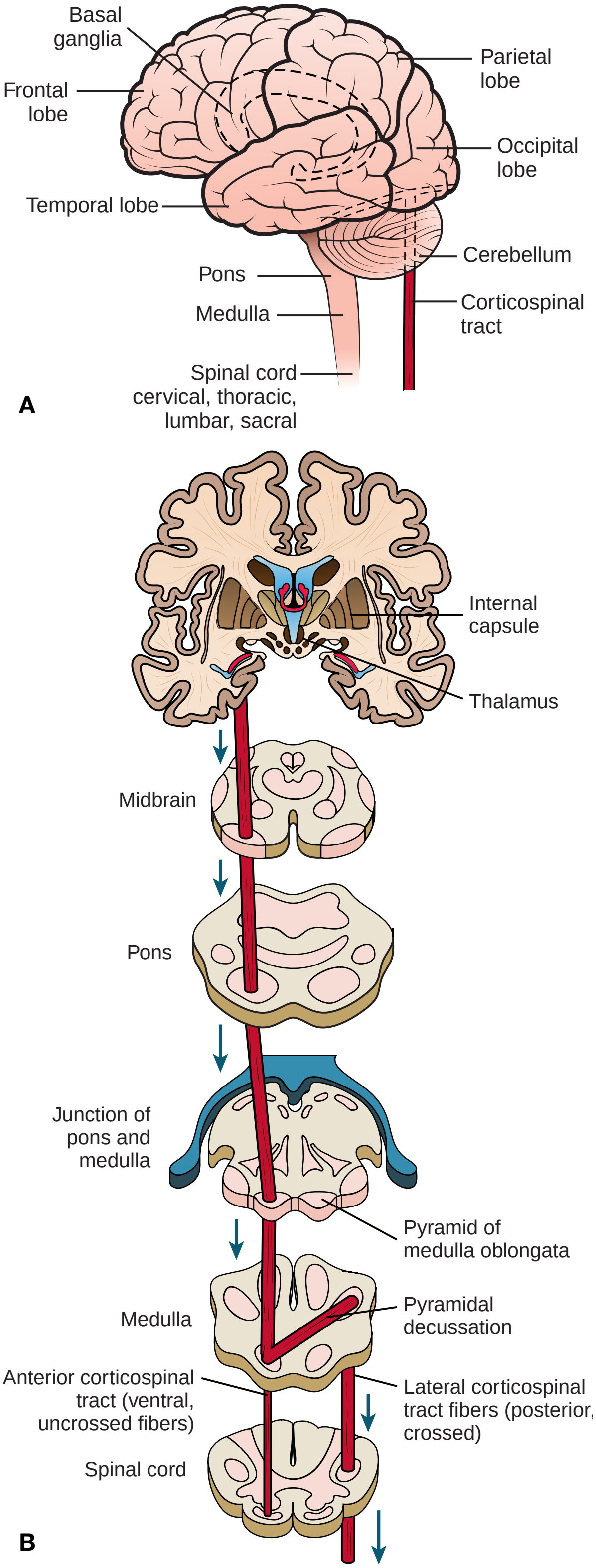


Figure 3.15 A) Central nervous system areas primarily involved in the control of movement; B) shows a cross-sectional view from the internal capsule and thalamus and inferior structures of the midbrain and spinal cord.

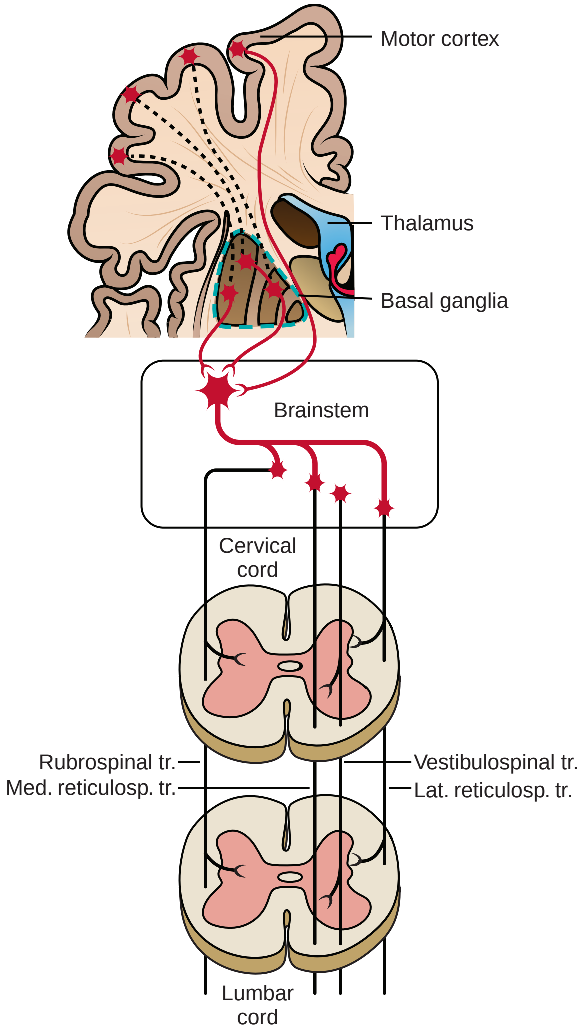


Figure 3.16 Schematic diagram of courses of important tracts that do not cross within the pyramids of the medulla, contributing to supraspinal motor control to the spinal cord. The neuron with a thick axon in the brainstem symbolizes the crossing of most of these extrapyramidal motor fibers to the opposite side at that level and does not imply convergence. Pathways from the motor cortex to the nuclei in the brainstem are partly collaterals of the corticospinal tract and partly separate efferents. Details of connectivity among the brainstem structures involved in motor activity are extremely complicated; this representation is greatly simplified. Note that the structures and tracts exist on both the left and right sides; however, for simplicity, only one side is illustrated.

"informed" of the exact locations of different parts of the body at each instant to assist in controlling posture and movement.

Proprioception (L. *proprio,* one's own, plus *ceptive,* to receive) is a more inclusive term than kinesthesia and refers to the use of sensory input from receptors in muscle spindles, tendons, and joints to discriminate joint position and joint movement, including direction, amplitude, and speed, as well as relative tension within tendons. Proprioceptive impulses are transmitted predominantly over group I afferent fibers and are integrated in various sensorimotor centers to automatically regulate postural muscle adjustments and maintain postural equilibrium.

Several types of **somatosensory** (Gr. *soma,* body, plus L. *sensorius,* pertaining to sensation) inputs also are important in maintaining postural equilibrium. For example, pressure sensations from the soles of the feet provide information about the distribution of load between the two feet and whether the weight is more forward or backward on the feet.

Postural equilibrium is crucial for both static position and dynamic motion. Without it, the body is unable to function. Its importance is underscored by the number of systems the body uses to achieve equilibrium during static and dynamic activities. In addition to proprioceptors and somatosensory receptors, the body uses two additional input mechanisms to aide in equilibrium: the vestibular system and the visual system. The vestibular receptors in the inner ears provide awareness of head orientation and movements. Anyone who has had a middle ear infection can testify to the importance of the vestibular system in balance. Vision of where the body and its segments are relative to the surrounding environment also assist in maintaining equilibrium. In fact, visual input sometimes serves as the primary means of maintaining equilibrium when the proprioception system is impaired. The importance of equilibrium is observed not only during daily activities but also when performing various sports or when assessing impairments of equilibrium and suggesting solutions to balance problems. Even static equilibrium is affected by vision. Try standing on one leg with your eyes open and then with your eyes closed, and you will quickly realize how much you use vision for equilibrium.

Movement or “Motor” Control

When considering the control of movement, we must realize that movement and posture are exceedingly intricate and complex, and may be affected by an abundance of factors. For example, several systems must be intact for appropriate regulation of posture and movement. The neuromuscular systems must be intact, including the muscles that experience excitation or inhibition, muscles spindles, GTOs, neuromuscular junctions, peripheral nerves that innervate the muscles, spinal cord ascending and descending pathways, cortical motor centers, and the interconnections of these systems. The skeletal system, including the bones, ligaments, joints, joint capsules, and joint receptors also must be unimpaired. In addition, the respiratory, cardiovascular, and digestive systems must supply energy sources for muscular contractions and for the maintenance of the neuromusculoskeletal systems. Furthermore, accurate sensory input of the internal and external environments must be provided.

In order to perform skilled motor activities, a highly integrated set of motor commands is required to activate or inhibit several muscles in the proper way and in the proper sequence. We *cannot* view movement simply as the action of the various systems which carry out the movement task; rather, there is a highly complex organization and regulation in play that orchestrates our ability to move. **Motor control** refers to this dynamic regulation of posture and movement. Muscle **synergy** (Gr. *synergia,* together) is a term used to describe functional coordinated muscle activation, such as seen during functional movement when muscles typically work together as a group.[49]

Motor control requires the individual to maintain and change posture, and his or her movement response is based on an interaction between the individual, task, and environment. This interaction utilizes the contributions of many systems to orchestrate coordinated movement. These systems are not arranged in a **hierarchy** (Gr. *hierarchia*, rule or power of the high priest), in which one is more important than the other. Rather, they are a functioning **heterarchy** (Gr. *heteros*, other and *archos*, rule), in which the contributing systems work parallel to each other.[1]

Heterarchy recognizes that different levels of motor control exist and that portions of the nervous system interact with each other. In the heterarchy of motor control, cortical centers interact not only with each other but also with brainstem and spinal regions of the central nervous system, with the peripheral nervous system, and with ascending and descending pathways.[50, 51] In this heterarchy, information regarding the environmental milieu both inside and outside the body is provided to the central nervous system, specifically to the cerebral cortex, basal ganglia, and cerebellum, which plan, initiate, execute, coordinate, and regulate movement and posture. These centers also coordinate the timing of specific movements, whether simple or complex, the sequencing and synchronization of movements, as well as the amount of force generated. Which region is considered the “controller” varies, depending on the motor task desired and on the information provided to the central nervous system at a given time. Therefore, no one area is responsible for the control of all movement and posture.[52] The brainstem and spinal cord generate patterns of movement that are referred to as pattern generators, sometimes further clarified as central or stepping pattern generators.[5, 49, 53] Other

PRACTICE POINT

If we take an example of a motor skill, all of these factors may be more easily appreciated. Kicking a ball towards a target is a complex motor skill. Many cognitive components are first assimilated. The weight of the ball, the distance of the target, the wind speed and direction are all factors that the individual consciously considers before kicking a ball. In the early days of this skill acquisition, the individual also had to rely on his or her coordination and balance input to be able to stand securely on one foot while moving the contralateral leg from hip extension to hip flexion. Additionally, hip abduction to adduction and medial to lateral rotation motions were likely included in the performance. Other joint motions the nervous system had to control included the knee and the ankle. Cocontraction of trunk muscles was necessary for posture control during the kick. Sensory input regarding muscle length, tension, and changes in length as the individual approached the ball were continually being fed, received, and responded to by the neuromuscular system. Once the ball was kicked, the neural system obtained the feedback regarding the performance: Was the ball kicked far enough? Where did the ball land in relation to the target? What part of the foot came in contact with the ball? Where in relation to the body was the foot and leg when contact with the ball was made? The nervous system collects all this data; the subsystems self-organize and alter the next attempt based on this input.

muscle tone, and to improve the ability to regulate posture and movement. These professionals also realize the importance of practice to enhance skill and recognize that more than just the neuromusculoskeletal system must be enhanced to augment performance. It is important to acknowledge that cognitive strategies such as mental practice and imagery, as well as positive self-talk, are important for the client's success.[75-77] Principles of cognition used to enhance motor performance may be applied clinically so that an individual's mindset for rehabilitation is productive to facilitate recovery.

Functional Applications and Clinical Considerations

Neuromuscular impairments encompass a diverse group of problems that constitute a major constraint on functional movement. Impairments of motor control may result from many diseases, injuries, or developmental disabilities and can result from pathology to any part of the movement system. Pathological conditions that affect any part of the neuromuscular system, including motor, sensory, perceptual, and cognitive elements, will result in associated signs, symptoms, and impairments.[78] Other factors may be involved in motor control dysfunction, including the skeletal, cognitive, visual or vestibular systems. Since this chapter deals with movement control and primarily the neuromuscular aspects involved in the control of movement, we will continue to focus on impairments that affect these structures and contribute to alterations in movement.

Impairments are the typical consequences of the disease or pathological process, further defined as the loss or abnormality of function, at the tissue, organ, or system level, resulting in constrained movement. Examples of primary motor impairments include weakness, abnormalities in muscle tone, and motor coordination problems.[1, 68] In addition to primary impairments, secondary impairments also contribute to movement problems. These secondary impairments do not result from the pathology directly, but rather develop as a result of the consequences of the primary impairment and may be preventable. Examples of secondary impairments include loss of range of motion or contracture.[78]

The ability to produce and coordinate an appropriate movement response requires production of muscular force, activation and sustenance of muscle activity, and the coordination and timing of muscle activation patterns. The primary motor system impairments that interfere with functional movement are muscle weakness, abnormalities of muscle tone, and coordination problems.[68]

Muscle Weakness

Muscle weakness is defined as an inability to generate normal levels of muscular force and is a major impairment of motor function in patients with nervous and/or muscular system damage.[68] Lesions within the CNS, PNS, or muscular system can produce weakness. It is important to differentiate the weakness from where in the movement system the damage is located. By definition, damage to the descending motor control systems in the CNS is associated with lesions affecting upper motor neurons, anywhere from the spinal cord superiorly.[68] This damage will produce signs of upper motor neuron (UMN) damage. Upper motor neuron lesions are associated with hypertonicity, or hypotonicity, depending on the site of the lesion and the time of onset (acute vs. chronic). Depending on the extent of the lesion, weakness in the patient with an upper motor neuron lesion can vary in severity from total loss of muscle activity (paralysis or plegia) to a mild or partial loss of muscle activity (paresis).[68] Paresis results from damage to the descending motor pathways, which interferes with the brain's excitatory drive to the motor units, thereby resulting in a loss of descending control of the lower motor neurons.[79] The end result is an inability to recruit and modulate the motor neurons, leading to a loss of movement.

Upper motor neuron lesions are accompanied by secondary abnormal muscle tone and altered motor control.[68, 80] The range of muscle tone abnormalities found within patients who have UMN covers a broad spectrum, ranging from complete flaccidity (loss of tone), to spasticity (hypertonicity).[68] Changes in muscle tone will vary depending on the specific lesion. Following an upper motor neuron lesion, weakness occurs due to loss of motor unit recruitment, changes in recruitment patterns, and changes in firing rates. Additionally, changes occur in the properties of the motor units and in the morphological and mechanical properties of the muscle itself. These secondary changes happen as adaptations to loss of innervation, immobility, and disuse. In upper motor neuron lesions, reduced numbers of motor units and reduced firing rates of motor units have been reported.[14, 81] Within two months of the insult, patients with hemiparesis resulting from a stroke show up to a 50% reduction in motor units on the affected side. Individuals who have had a stroke display atrophy in motor units on the hemiparetic side. The remaining motor units require more time to contract, and they fatigue more rapidly. Altered recruitment and decreased motor unit firing accounts for this apparent weakness.[82] The degree of weakness may differ for different muscle groups. Given that the pyramidal tract is the primary pathway for voluntary goal-directed movement, it has been suggested that interruption of this pathway produces a greater impairment in prime mover muscles.[83] Prolonged paresis, a primary neuromuscular impairment, also produces secondary musculoskeletal impairments. Changes in muscle tissue resulting from damage to upper motor neurons suggest that muscle may not be as "strong" due to changes in the properties of the muscle and the presence of denervated muscle fibers.[82] Specific changes at the motor neuron secondary to the upper motor neuron damage can decrease a patient's ability to produce force.

Muscle weakness most often results from direct injury to the muscle. A wide continuum of injuries, from contusions to ruptures, produce weakness, initially from the injury itself, and secondarily from inactivity and disuse following the injury during the recovery phase. Pain, whether in an injured muscle or in a joint on which the muscle acts, reduces the individual's willingness to move the muscle. When a muscle is not used at its normal functional level, weakness ensues.

Regardless of the underlying etiology or pathology, when a muscle is not used or exercised, muscle weakness and atrophy occur. When a muscle does not function for long periods of time, the quantity of actin and myosin myofilaments in the muscle's fibers actually decrease. This change is reflected in reduced diameters of individual fibers, and diminished overall muscle cross-sectional area.[91] Muscle wasting is due, at least in part, to a decrease in protein synthesis coupled with increased protein degradation; these changes cause alterations in contractile properties and a resultant loss in the muscle's ability to develop and hold tension.[31, 92] In response to decreased use, skeletal muscle also undergoes an adaptive remodeling; this process includes a transition from slow to fast myosin fiber types, a fuel shift toward glycolysis, decreased capacity for fat oxidation, and energy substrate

PRACTICE POINT

Clinicians formerly believed that prescribing strength training was not appropriate for patients with UMN pathology. Research has demonstrated that improvements in strength not only contribute to an improvement in functional performance, but that there is also no indication of any associated increase in spasticity.[79-89] Strength training is thought to not only improve voluntary motor control, but it also appears to prevent or slow down some of the mechanical changes and denervation changes seen in muscle tissue following UMN damage.[87, 90] The shift in emphasis to the functional significance of weakness in patients with CNS lesions has led to increased attention on strengthening programs for both adults and children with CNS disorders.

accumulation in the atrophied muscle.[93] A loss of peak muscle force and functional muscle strength results from these changes.[31] **Disuse atrophy** is a term used to specifically describe this atrophy that occurs when a person or limb is immobile, such as during bed rest, or when a limb is restricted in a sling, brace, or cast.[94–96] Current research demonstrates that this disuse atrophy begins within 4 hours of the start of bed rest![97]

Abnormal Muscle Tone

As described briefly earlier, typically muscle tone is characterized by a state of readiness of muscle to perform the task demands to be placed on it. The level of excitability of the pool of motor neurons controlling a muscle, the intrinsic muscle stiffness, the absence of neuropathology, and the level of reflex sensitivity determine this state of readiness. A hallmark of central nervous system pathology is the presence of abnormal muscle tone. Abnormally high (hypertonia) or abnormally low (hypotonia) muscle tone are universally recognized clinical signs of nervous system pathology. Flaccidity and hypotonia are states of muscle hypotonicity, while spasticity and rigidity are states of hypertonicity. Typically, upper motor neuron lesions oftentimes results in hypertonia and lower motor neuron lesions in hypotonia. Terms related to abnormal muscle tone are found in Table 3–4.

Coordination Problems

Coordinated movement involves multiple joints and muscles that are activated at the appropriate time and with the correct amount of force so that smooth, efficient, and accurate movement occurs.[68] The essence of coordinated movement, therefore, is the synergistic organization of multiple muscles for purposeful motion, not just the capacity to fire an isolated muscle contraction. Incoordination can result from pathology in a wide variety of neural structures, including the motor cortex, basal ganglia, and cerebellum. Uncoordinated movement may be displayed through the manifestation of abnormal synergies, inappropriate coactivation patterns, and timing problems.

As mentioned earlier, **synergy** is a group of muscles that often act together as if in a bound unit. Nicolai Bernstein[100] used the term synergy to aptly describe the functional muscle groups that produce motor behavior. Lesions to corticospinal centers can also lead to the ability to recruit only a limited number of muscles controlling a movement. The result is the emergence of mass patterns of movement, referred to as abnormal synergies. Abnormal synergies reflect an inability to move a single joint without simultaneously generating movement in other joints. Abnormal synergies are stereotypical patterns of movement that don't change or adapt to environmental or task demands.[1,68]

Coordination problems can also be manifested as abnormalities with muscle activation patterns and difficulties with muscle sequencing. Inappropriate coactivation of muscles is an example of a sequencing problem. Coactivation, which means that the agonist and antagonist both fire, is normally present in the early stages of learning a skilled movement. Coactivation is commonplace in young children just learning to balance and during early walking patterns. Adults also frequently demonstrate coactivation when attempting to learn a new task. In the neurologically intact adult, coactivation is atypical unless during the early stages of learning a new skill. Coactivation requires unnecessary energy expenditure and results in inefficient movement. Inappropriate coactivation occurs in central nervous system disorders in both children and adults. This inappropriate and ungraded coactivation of agonist and antagonist contributes to functional limitations in force generation. Coactivation has been demonstrated in adults following a stroke and in children with cerebral palsy during walking and the performance of common functional skills.[101,102]

PRACTICE POINT

It is important to recognize how quickly skeletal muscle atrophy occurs in response to disuse. Disuse atrophy can be delayed and decreased in severity by intermittently contracting the muscle isometrically during any period of immobilization or relative inactivity.[98] Exercise and proper nutrition have both resulted in protein synthesis stimulation in muscle and tendon with obvious implications for rehabilitation management.[99] On the other hand, clinicians are cautioned that if atrophy has already occurred, strenuous exercise of atrophied muscle can lead to muscle damage, including sarcolemma disruption and distortion of the myofibrils' contractile components.[97] Prevention with early intervention is truly the best practice.

Uncoordinated movement can also be manifested as an inability to appropriately time the action of muscles, to activate muscles in the appropriate sequence, or to scale or grade the force needed. There can be many facets to timing errors including problems initiating the movement, slowed movement execution, and problems terminating a movement. All of these timing errors have been observed in individuals with neurological damage. Coordination problems, characterized by problems in muscle activation, sequencing, timing, and scaling, can create a tremendous obstacle to efficient functional movement.

Since coordination requires adequate strength and ROM, uncoordinated movement is often characterized by some degree of weakness, fatigue, or instability. Likewise, body segments weakened by injury or disuse may suffer inadequate coordination and sequencing. Even as a patient fatigues during rehabilitation exercises, coordination becomes more difficult. As previously mentioned, muscle recruitment occurs in normal muscles from single joint muscles to multiple joint muscles. Proper muscle sequencing is also important in daily activities, but if correct sequencing is not present, the individual is at risk of injury at the most and inefficient movement at the least. Such consequences place additional stresses on other body segments. For example, studies have demonstrated that muscle recruitment and sequencing vary between back patients and normal groups.[103, 104] It is unclear, however, if the changes in recruitment were the cause of pain or the result of pain. In either situation, an individual is not able to function optimally if proper muscle activation and recruitment sequencing is dysfunctional.

Involuntary Movements

Involuntary movements are a common motor sign of neurological damage and can take many forms. **Dystonia** is a syndrome dominated by sustained muscle contractions, frequently causing abnormal postures, twisting or writhing movements, and repetitive abnormal postures. Dystonic movements usually result from basal ganglia disturbances.[1]

Tremor is defined as a rhythmic, involuntary, oscillatory movement of a body part.[106] A tremor results from damage to the CNS. A **resting tremor** is a tremor occurring in a body part that is not voluntarily activated and is supported against gravity. Resting tremors is a symptom of Parkinson's disease and is secondary to basal ganglia dysfunction. An **intention tremor** occurs when the individual attempts purposeful movement of an extremity. Intention tremors often accompany cerebellar lesions.

Common Pathological Conditions Affecting Movement System Function

The movement system can be impacted by numerous pathological conditions that affect any contributing

TABLE 3–4 | ABNORMAL MUSCLE TONE TERMINOLOGY

Term	Origin of Term	Definition	Clinical Examples
Flaccid	L. *flaccidus,* weak, soft, lax	complete loss of muscle tone	Flaccidity is often seen in the acute stage of injury, immediately following a CNS injury, but it can also be secondary to a lower motor neuron lesion. In patients with flaccidity, deep tendon reflexes (DTRs) are absent.
Hypotonia	Gr. *hypo,* under and *tonos,* tension	reduction in muscle stiffness	Characterized by low muscle tone, weak neck and trunk control, poor muscular co-contraction, and limited stability. Patients with hypotonia present with weakness, a decreased ability to sustain muscle activation, a decreased ability to coactivate muscle groups, abnormal joint mobility patterns, and a delayed or ineffective exhibition of normal postural responses.
Hypertonia	Gr. *hyper,* over, above and *tonus,* tension	excessive muscle tone	See spasticity

Peripheral Nerve Injury

Peripheral nerves (Figs. 3.2 and 3.3) may be damaged by disease or trauma. Acute injury includes lacerations or other causes of partial or complete severance of the nerve. Other acute or repetitive injuries may occur from pressure or compression of the peripheral nerve. If the damage is complete, flaccid paralysis of muscle fibers supplied by the damaged lower motor axons will result when the muscles no longer receive efferent signals.

A common peripheral nerve lesion in the upper extremity affects the median nerve. The median nerve is susceptible to damage at the wrist, where it may be compressed within the carpal tunnel. Remember from your study of anatomy that the tendons of the long finger flexors and the median nerve pass under the flexor retinaculum (L. *retinaculum,* a rope or cable). In instances of essential narrowing of the carpal tunnel through anatomical constraints, enlargement of soft tissue structures, or swelling of structures within the tunnel, compression of the median nerve within the carpal tunnel often results in carpal tunnel syndrome. Symptoms associated with the compression of the median nerve include decreased sensation in the area innervated by the nerve, pain and, if the condition progresses, atrophy with weakness of muscles innervated by the median nerve. Peripheral nerves in the more proximal upper extremity also suffer injury secondary to fractures. For example, a fracture of the humerus may cause a lesion of the radial nerve, resulting in weakness or total loss of function of the elbow and wrist extensors. In the lower extremities, the sciatic nerve is a frequent site of pathology.

Peripheral nerve injuries may result in muscular imbalance. Muscle imbalance occurs when one group of muscles is opposed by an impaired muscle group. This condition can then lead to secondary deformities. For example, following a lesion of the ulnar nerve, the individual is predisposed to developing a "claw hand" deformity. In this case, the long flexors and extensors of the fingers are not affected by the ulnar nerve deficiency. Their pull, however, is opposed by nonfunctioning intrinsic muscles in the hand so the balance between the long finger flexors and long finger extensors is lacking. Without occasional movement, adhesions can form between tendons and the sheaths that surround them, as well as between adjacent bundles of muscle fibers. When tissues crossing a joint remain in the same position for prolonged periods, a contracture forms, whereby the tissues adapt to the shortened position and exhibit a decrease from normal joint range of motion. These complications may be prevented by using passive physical activity to maintain full range of movement and increase flow of blood and lymph through the area. Splints also may assist in preventing contractures.

Cerebral Palsy

Cerebral palsy (L. *cerebrum,* brain; *palsy,* paralysis) is a general term used to describe a group of motor disorders that generally result from damage to the developing brain. As one of the most common developmental disabilities, cerebral palsy results from a lesion to the brain during prenatal (L. *prae,* before, plus L. *natal,* birth), perinatal, or early postnatal stages of life. The brain lesion causes a nonprogressive but permanent damage to one or more areas of the brain. Although cerebral palsy is defined as a neurologically static condition, it can be considered orthopedically progressive in nature. Depending on the sites of the neurologic lesion, an individual with cerebral palsy may show a variety of motor or other impairments. Because of the close relationship of motor functions with other neural functions and because of the potential diffuse nature of the lesion, the individual with cerebral palsy also may demonstrate sensory, communicative, perceptual, and/or cognitive impairments.

PRACTICE POINT

Loss of sensation can be a more serious problem than loss of muscle strength for a person with a peripheral nerve lesion. Individuals with impaired sensory function may exhibit a loss of awareness of location or position of certain body segments, reduced pressure sensation, deficient temperature detection, and/or loss of pain sensation. If such sensory deficiencies exist, the person may not detect when blood flow is occluded by external pressure or when the part is in contact with excessively hot or cold objects. Various sensory losses place the affected body segment at risk for traumatic injuries, ischemia (Gr. *ischein,* to suppress, plus *haima,* blood), burns, pressure sores, and subsequent infections.

Cerebrovascular Accident

The central nervous system is very vulnerable to reduction of its blood supply. Cerebrovascular accidents (CVAs), or strokes (from the Greek term *streich,* meaning "to strike"), occur when the blood supply to an area in the CNS is disrupted. Residual problems following a stroke vary greatly depending on numerous factors such as the cause of the CVA, the affected CNS area, the extent of the damage, and the functions of the damaged area(s). The clinical deficits may include weakness or paralysis of the muscles of the face, trunk, and/or extremities; impairment of sensation and proprioception; visual deficits; cognitive difficulties; language impairments; and perceptual problems. Impairment of motor and sensory impulse conduction is likely to produce paralysis of muscles on the side contralateral (opposite) to the lesion, causing the clinical presentation referred to as hemiplegia.

Basal Ganglia Disorders

The basal ganglia are generally responsible for the regulation of posture and muscle tone. They convert plans for movement into programs for movement by affecting the motor planning areas of the motor cortex, particularly with respect to the initiation and execution of movements. The most common complex of symptoms resulting from disturbance of basal ganglia connections is Parkinson's disease. Individuals with Parkinson's disease demonstrate movement characterized by slowness of movement; rigidity of facial expressions; decreased or absent communicative gestures; a hesitant, shuffling gait with small steps; and resting tremor of the hands.

Athetosis is another movement disorder involving the basal ganglia. Athetosis, however, results in slow, writhing movements that are exhibited especially in the upper extremities. Basal ganglia disorders also include chorea, a complex disorder in which the individual has involuntary, sudden, nonpurposeful movements.

Cerebellar Disorders

The cerebellum regulates balance and coordination. It is responsible for regulating and adjusting the accuracy, intensity, and timing of movement as required by the specific movement task. It sequences the order of muscle firing when a group of muscles work together to perform a complex task such as ambulation or reaching.[66] The cerebellar pathways control balance, coordination, and movement accuracy on the ipsilateral body side, as opposed to the contralateral-control feature associated with the cerebral cortex. Cerebellar lesions cause distinctive motor symptoms. Cerebellar damage can cause any number of errors in the kinematic parameters of movement control, including difficulties with timing, accuracy, coordination, and regulation of intensity.

Summary

This chapter gave an overview of the human movement system and its main structural components. The anatomy and physiology of muscle tissue was reviewed and an organizational framework for studying the human nervous system was described. Motor control, as a dynamic and heterarchical system controlling functional human movement, was discussed. Movement impairments and their functional consequences were defined and described. Common primary impairments that affect human movement were described. For the purposes of illustration, a few commonly encountered pathological conditions that cause disordered movement were introduced with a focus on the functional consequences to movement.

CLINICAL SCENARIO SOLUTION

Joseph has cerebral palsy, and so the weakness that he demonstrates in his lower extremities is caused by a lack of movement control secondary to the developmental nature of that disability. Spasticity is a symptom of upper motor neuron brain damage, secondary to the pathological condition which caused his cerebral palsy. The ulnar nerve injury sustained in Joseph's left upper extremity will result in motor and sensory loss of function to the muscles supplied by the ulnar nerve below the injury, functionally resulting in lost innervation to many of the muscles required for a full grasp. Because the ulnar nerve injury is a lower motor neuron lesion, it will regenerate and function will return over a period of a few months. The transient nature of the ulnar nerve injury is in contrast to the more permanent weakness and overlying spasticity seen in his lower extremities due to the cerebral palsy.

CLINICAL SCENARIO

Two promising track athletes on scholarships at Rochester State University have been in this country for only a couple of weeks. They are both from Ireland and have never experienced workouts as extensive as those that their new coach has been having them perform since they arrived on campus. Both athletes, Owain and Xavier, reported to the injury clinic this morning. They each suffered the same complaints. They had a lot of pain in their hamstrings and calf muscles after their long hill workouts yesterday. They both complained that it was difficult to get out of bed, and the pain in their hamstrings was especially uncomfortable. The clinician who examined each of them found it curious that they both suffered the same symptoms, but she suspected that she knew what the problem was.

Introduction

In the last chapter, we explored the microscopic elements involved in muscle structure and the neural elements that provided muscle activity and responses. This chapter explores the muscles at a macroscopic level. Now that you have an appreciation of the physiological function of the neuromuscular system, we can move on to realize what happens when the factors you learned in the last chapter are put to functional use. This chapter will help you understand how muscles move joints and limbs to produce daily activity and functions without a thought given to their effort. Whereas the last chapter dealt with physiology, this chapter deals with mechanics.

To make muscle mechanics easier to understand, muscle forces are depicted as acting at a single point on the body. This simplification is helpful in demonstrating principles of biomechanics, but it is important to keep in mind that many complex forces impact function. Muscles are not the only force producers affecting motion. Other soft tissues may also transmit forces of muscles through their attachments to fascia, ligaments, cartilage, joint capsules, and tendons of other muscles, as well as to bones. Active and passive structures affecting motion are presented in this chapter.

Muscle Activity

Chapter 3 guided your understanding of the neuromuscular physiology that provides muscle activity via the motor unit. Muscle contraction occurs when several motor units fire asynchronously, and the magnitude of that muscle contraction is dependent upon the number of motor units firing and how often they fire. These factors determine a muscle's activation, but there are other factors that influence how much force, or strength, a muscle ultimately exerts. Before we address the topic of strength, however, we must first identify the types of actions a muscle performs. Along with that information, we must understand how one muscle interacts with other muscles and how it responds to its own functions. This section deals with these topics.

Recording Muscle Activity

Recording muscle output and activity using surface, needle, or indwelling wire electrodes is called electromyography (EMG), (L. *elektra,* lit, brilliant, pertaining to electricity; Gr. *myos,* muscle; and L. *graphicus,* to write). Each pair of electrodes is connected to a "channel" of the recording apparatus (Fig. 4.1). The use of multi-channel instruments allows the contraction and relaxation patterns of several muscles to be recorded simultaneously during a particular movement or joint position. Using EMG, the sequence of activation and relaxation, as well as the relative amount of activity of specific muscles, can be studied as they perform various isolated or coordinated functions. Some of the earliest careful studies of kinesiology using EMG were performed by Inman and co-workers[1] in their analysis of shoulder motions. Reports on the uses and limitations of kinesiologic EMG include those by Clarys[2], Basmajian[3], and Heckathorne and colleagues[4]. Reports

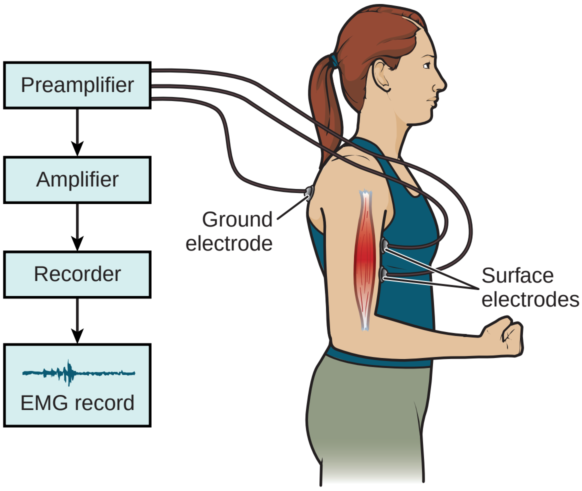


Figure 4.1 Using electromyography to record muscle activity. Electrodes are placed over the muscle to detect changes in electric potential associated with muscle fiber activation. The electrical activity "seen" by the electrodes is greatly amplified by electronic equipment, recorded, and stored for later analysis.

of the use of EMG techniques for kinesiologic studies include those by Ebersole [5], Smidt [6], and Perry.[7] A more detailed discussion of the use and limitations of kinesiologic EMG is presented in Chapter 12.

Muscle Activation

A muscle is able to produce different types of muscle tension, either with or without movement. There are different types of motions that muscle activation produces. This section briefly describes each of them.

Isometric

When a muscle produces force with no apparent change in the joint angle, the activation is **isometric** (Gr. *isos,* equal; *metron,* measure). Isometric activations are also called static, or holding, contractions. During functional activities, isometric activation stabilizes joints. For example, to reach forward with the hand, the scapula must be stabilized against the thorax.

Concentric

A shortening of the muscle is a **concentric activity.** Examples include the quadriceps muscle when an individual rises from a chair or the elbow flexors when an individual lifts a glass of water to her mouth. Concentric motion occurs as the muscle shortens and the muscle's proximal and distal insertion points move closer towards each other. Concentric activity produces acceleration of body segments.

Eccentric

When the muscle lengthens during activation, it is an **eccentric activity.** For example, the quadriceps activates eccentrically when the body moves from standing to sitting, as do the elbow flexors when lowering the glass of water from the mouth to the table. Eccentric motion occurs as the muscle lengthens and the muscle's points of insertion move away from each other. Eccentric motion often occurs against gravity as the muscle controls the speed with which gravity moves the joint. Eccentric activity decelerates body segments and provides shock absorption as when landing from a jump or in walking.

Concentric motion is sometimes also referred to as **positive work** whereas eccentric motion is **negative work**. Positive work is force exerted by the muscle to produce movement of a joint; in other words, the motion is produced *by* the muscle. On the other hand, negative work occurs when an outside force produces joint motion while the muscle controls the rate at which that motion occurs; an external force, often gravity, is responsible for motion that is done *to* the muscle during negative work.

Isotonic

The word **isotonic** is derived from the Greek *isos,* equal, and *tonus,* tension. The term was originally used by muscle physiologists to refer to the contraction of a muscle detached from the body and lifting a load vertically against gravity. The connotation was that shortening of the muscle occurred and the load on the muscle was constant throughout the excursion. Truly

PRACTICE POINT

Most clinicians do not have routine access to EMG analysis of muscle activity. Clinicians are more inclined to use their palpation skills to identify when a muscle is active or relaxed. Muscle palpation is an important clinical skill which is based on a comfortable familiarity of surface anatomy and comprehensive knowledge of three-dimensional anatomy. It is best to palpate a muscle when it is lightly contracting so as to avoid contraction of surrounding muscles.

isotonic contractions seldom, if ever, occur when muscles are acting through the lever systems of the body. Even so, the term is often used, although incorrectly, to refer to a contraction that causes a joint to move through some range of motion, as in flexing the elbow while holding a weight in the hand. Even though the weight remains the same throughout the movement, the tension requirements of the muscle change continuously with changing leverage, and the torque exerted by the weight changes with changing joint angles.

Isometric and 'isotonic' activities are sometimes referred to as "contractions." However, "contraction" means "shortening;" it is not necessarily an accurate term since shortening does not occur in either isometric activation or eccentric activity. Nevertheless, "contraction" is commonly used as a noun with isometric or eccentric as its adjectives.

Isokinetic

An **isokinetic** (Gr. *isos,* equal; *kinetos,* moving) contraction occurs when the rate of movement is constant. In the 1960s, an electromechanical device (an isokinetic dynamometer) was developed that limits the rate of movement of a crank-arm or a pulley to some preset angular velocity regardless of the force exerted by the contracting muscles. In 1967, Hislop and Perrine described the concept and principles of isokinetic exercise.[8] The axis of rotation of the crank arm of the isokinetic device is aligned with the anatomic axis of the moving joint, and the device lever is matched to the skeletal lever (Fig. 4.2). A subject contracts the muscle group being exercised or evaluated, and the device controls the speed of body movement without permitting acceleration to occur. "During isokinetic exercise, the resistance accommodates the external force at the skeletal lever so that the muscle maintains maximum output throughout the full range of motion."[8] A clinician can apply a similar accommodating resistance throughout the range of motion by manually resisting the motion. This manually applied, accommodating resistance is a valuable therapeutic technique. With practice and experience, the clinician continuously adjusts the amount of resistance offered so that the motion speed is essentially constant throughout the range, thereby approaching an isokinetic condition.

Figure 4.2 An example of an isokinetic exercise and testing unit. Isokinetic dynamometers may be used for testing and exercising muscle groups isokinetically, isometrically, concentrically, or eccentrically. Depending on the specific unit, force or torque exerted by the muscle group is recorded along with joint angles and motion. The computer provides calculations for average peak torque, work, and power.

Muscle Anatomic Activity

Muscle fiber types and muscle attachment sites are presented in this section. They are anatomical designs that influence how a muscle reacts to stimulation and also how a muscle performs during functional activities.

Muscle Attachments

Anatomically, muscles are described by their **proximal attachments** (origin), **distal attachments** (insertion), and **actions** in producing specific joint motions. Although knowledge of the anatomic attachments and actions is essential to the study of kinesiology, it is important to recognize that these factors can predict muscle function when all of the following conditions are present:

(1) The proximal attachment is stabilized;
(2) The distal attachment moves toward the proximal attachment (concentric contraction);
(3) The distal segment moves against gravity or a resistance; and
(4) The muscle acts alone.

Unfortunately, these circumstances rarely occur in normal function.

However, the anatomical attachments and actions of muscles are a good starting point for novice clinicians to begin their understanding of kinesiology. After all, knowing where a muscle's proximal and distal attachments are and understanding the motion a muscle produces is essential to appreciating more complicated muscle functions. Once you know insertions and actions of muscles, you can recall other factors that affect functional application of muscle activity. For example, if the proximal biceps brachii attachment is stabilized, the elbow will flex when the muscle activates; however, when any muscle contracts, it shortens at both ends, so if neither end of the biceps is stabilized, the shoulder flexes and the elbow flexes when the biceps contracts. We can take this notion in another direction to better understand muscle function in a closed chain activity: If the distal segment of a muscle's attachment is stabilized, then the proximal segment is the moving end of the muscle. Since a muscle can produce either a shortening (concentric) or lengthening (eccentric) motion, biceps function changes depending on which type of muscle movement occurs. Therefore, when the proximal end is stabilized and the elbow flexes, the activated biceps produces a concentric force; however, when the elbow extends with gravity, the biceps produce an eccentric force to guide the speed of gravity's pull on the elbow. In fact, gravity is often the force against which muscles act, so eccentric force production of muscles commonly occurs during functional antigravity activity. Most human activity is the result of more than one muscle. Muscles perform functional activity conjointly, either with the assistance of other muscles acting as synergists or with other muscles assisting joint or segmental stabilization.

In summary then, it is necessary to identify a muscle's proximal and distal insertions and its actions, but knowing these factors provides only part of the picture; a true appreciation of how the body produces functional activity production occurs with the realization that movement results from the of modification of these factors: (1) Proximal attachments often move toward fixed distal attachments (closed kinematic chain); (2) Contractions can be concentric, eccentric, or isometric; (3) Movement of the distal segment is often assisted by the force of gravity; and (4) Muscles seldom if ever act alone—they more often act with other muscles.

Since gravity plays a profound role in functional activities, it is interesting to realize that muscles that are named for their function and the joint they cross may not be the muscles that perform the activity. For example, when the hand is placed over the edge of a table with the palm facing the floor and the wrist is slowly flexed, the wrist flexors are inactive; the motion is performed by an eccentric contraction of the wrist extensors. Therefore, an awareness of gravity's influence on motion is vital to understanding functional activity.

Muscle Fiber Types

Chapter 3 described the differences in muscular fiber types. As you recall, there are three types of skeletal muscle fibers. These types may be classified several different ways, according to their metabolic function, structure, chemical composition, or mechanical functions. Two of these fiber types are opposite to one another in most of these categories, and the third one is a blend of the two. Because they may be classified in different ways, they are referred to differently, depending on which classification system is used. Take a quick look at Table 3–2 so you may quickly recall the various classification systems and the characteristics of each fiber type. The major classification system most frequently used identifies the three fiber types as I, IIa and IIb. Types I and IIb are opposite to one another, and type IIa is a blend of the two. It should be kept in mind that these fiber types are on a continuum with type I at one end and type IIb at the other. Type IIa is a meshing of these two types, so some of the type IIa fibers are more similar to type I fiber types whereas others are more similar to type IIb fibers.

Each individual has a combination of these fiber types throughout the body. Some muscles may have more of one fiber type than another and this arrangement varies from one individual to another.[9-10] Although an individual is born with type I and type II fibers, they may change later in life according to the individual's activity and hormone levels.[10] As we age, muscle fibers also change with a reduction in the amount of type II fibers.[11]

To some extent, the type of fibers within a muscle is determined by that muscle's function.[11] Muscles that work against gravity as we sit or stand are called antigravity muscles or postural muscles. Since we may sit or stand for prolonged periods, these muscles contain more slow-twitch or type I muscle fibers. Prolonged standing or sitting requires continual minor adjustments in posture, so these muscles must have fibers that resist fatigue and are able to maintain sustained activity. These muscles include the soleus, peroneals, quadriceps, gluteals, rectus abdominis, upper extremity extensors, erector spinae group, and short cervical flexors. On the other hand, muscles that are used for rapid movement during explosive activities are mobility muscles or nonpostural muscles. These muscles contain more type II muscle fibers.[12] These movement muscles produce force and power rapidly but have low endurance; therefore, they cannot sustain activity for prolonged periods. These muscles include the gastrocnemius, hamstrings, and upper extremity flexors.

Muscle Functional Activity

As has been mentioned, muscles rarely act alone during functional activities. Sometimes a muscle is the primary mover, but at other times, it may assist or oppose an action. Although there are various terms in the literature that describe these functions, three primary terms are used in this text. They are presented here.

Agonist

A muscle that is the principle muscle producing a motion or maintaining a posture is the **agonist** (Gr. *agon*, contest). An agonist actively contracts to produce a concentric, eccentric, or isometric contraction. Agonists are sometimes referred to as prime movers.

Antagonist

An **antagonist** (Gr. *anti*, against) is a muscle or a muscle group that provides the opposite anatomic action of the agonist. During functional activities, the antagonist is usually inactive during the activity so it neither contributes to nor resists the activity, but its passive elongation or shortening allows the desired activity to occur. For example, when a fork is brought to the mouth, the biceps is the agonist providing the movement while the triceps is the antagonist that remains relaxed, passively lengthening to allow the movement to occur.

Synergist

A muscle that contracts at the same time as the agonist is a **synergist** (Gr. *syn*, with, together; *ergon*, work). A muscle may provide synergistic action in different ways. One way is that it may provide identical or nearly identical activity to that of the agonist. An example is the brachioradialis working with the brachialis during elbow flexion.

Another way a synergist may function is to obstruct an unwanted action of the agonist, such as when the wrist extensors prevent wrist flexion when the long finger flexors contract to grasp an object. This type of synergistic activity is a common functional feature of muscles that perform more than one motion. Look at the action of wrist radial deviation as an example. The flexor carpi radialis performs both wrist flexion and radial abduction; similarly, the extensor carpi radialis longus performs both wrist extension and radial abduction. When frontal plane radial abduction occurs, both muscles act synergistically to radially abduct the wrist while the extension and flexion actions of the muscles are neutralized.

Another way synergists act is to stabilize proximal joints for distal joint movement. When synergists act in this manner, they work isometrically at joints that are not being moved by the agonists to stabilize the proximal joint, allowing the desired motion at the more distal segment to occur.

Muscles work more often as synergists than as either agonists or antagonists. When an agonist contracts, its force causes both its proximal and distal attachments to move. To prevent movement of the muscle from both of its attachments and allow the desired movement to occur, one of the muscle's attachment sites must be stabilized; which end—the proximal or distal attachment site—is stabilized depends on the intended activity. Stabilizers are mentioned throughout this text as important factors of joint motion. In fact, without stabilizers, agonistic movement is inefficient and ineffective.

PRACTICE POINT

Some clinicians argue that an antagonist contracts with the agonist to produce a motion such as a squat exercise; however, it has been found that the antagonist's activity is a fraction of the agonist's contraction force.[13-15] In this example, the antagonist (hamstrings) works more as a synergist to the quadriceps, not providing the movement but stabilizing the joint to permit the agonist's desired motion of knee flexion to occur. This rationale makes intuitive sense since if an agonist and an antagonist both contracted with comparable force, movement could not occur. Clinicians desiring to increase strength of the hamstrings would do better to create an exercise that uses the hamstrings as the agonist rather than count on the squat exercise to provide significant strength gains.

Two exercises readily point to the importance of stabilizers during functional movements. One quick exercise is to close the hand into a very firm grip; you are able to palpate tension not only in the finger flexors within the anterior forearm, but also in the posterior forearm, biceps and triceps in the arm, and even the shoulder muscles. These muscles all contract isometrically to stabilize the upper extremity to allow your firm grip to occur. Another exercise example is a sit-up. Lie supine with your lower extremities fully extended and your hands on top of your head. Attempt to do a sit-up and notice that both your trunk and your legs lift off the surface. The hip flexors, like other muscles, contract at both ends, so if one end is not stabilized, both ends of the muscle move. Clinicians must realize how muscle contraction produces either proximal or distal motion so when inadequate stabilization is present during rehabilitation activities, it is easily recognized and corrected. Clinicians must also understand the importance of stabilization during functional activities and appreciate which muscles must function and what their strength requirements are to provide that stabilization.

The relationships of muscles as agonists, antagonists, and synergists are not constant. They vary with the activity, position of the body, and the direction of the resistance which the muscle must overcome. These changing relationships are illustrated in the EMG recordings (Fig. 4.3) of the triceps brachii and the biceps-brachialis muscles during the motions of elbow flexion and extension (Fig. 4.3A1) When the seated subject flexes the elbow to lift a load in the hand, the elbow flexors contract concentrically as agonists (Fig. 4.3A2). The antagonistic extensors are relaxed to elongate and permit elbow flexion motion. As the elbow extends to lower the load to the side, the flexors perform an eccentric activity and are still classified as agonists (Fig. 4.3A3). The extensors remain inactive and are still the antagonists. However, when the subject moves to supine with the shoulder in 90º of flexion and performs the same motions of elbow flexion and extension, the agonist-antagonist relationships are reversed (Fig. 4.3B1). Here, the elbow extensors are the agonists for elbow flexion (eccentric contraction) (Fig. 4.3B2) and for elbow extension (concentric contraction) (Fig. 4.3B3), while the flexors are the antagonists and remain relaxed for both motions.

An interesting switch in the agonistic-antagonistic classification also occurs with these same motions of elbow flexion and extension when the subject is in supine with the arm at the side (Fig. 4.3C1). Now the biceps-brachialis muscles are the agonists for the first part of elbow flexion, but as the elbow passes 90º, the direction of the resistance force changes, and the triceps becomes the agonist (Fig. 4.3C2). The agonist for elbow extension from this position to 90º is the triceps, but once the elbow moves on the other side of to 90º, the elbow flexors (eccentric contraction) control the elbow movement to the start position (Fig. 4.3C3). This change in responsibility changes with gravity's pull on the weight and the relative position of the center of mass to the pull of gravity. Application of manual resistance throughout the motion of flexion (Fig. 4.3D1) and then extension (Fig. 4.3D2) further illustrates the principle that muscles act according to the resistance they meet rather than the motion.

Other examples of the varying relationships among these muscles are shown in Figure 4.4. As seen in this example, the biceps acts as an agonist in supination (along with the supinator), and the triceps acts as a synergist to prevent elbow flexion. When a muscle has multiple functions like the biceps but only one of its motions is desired, the antagonist to the undesired motion is often recruited to serve as a synergist so the undesired motion is prevented from occurring.

Muscle Characteristics

Forces applied to muscles produce stresses to those muscles. A **stress** is a force or load that is applied to a body, segment, or muscle. Stresses may occur as compression, distraction, shear, torsional, bending, twisting, or any combination of these stresses. The muscles and their connective tissue resist these stresses in similar fashion. If they are unable to withstand the stress, injury occurs. Muscle and its surrounding connective tissue possess mechanical and physical properties that provide resistance to stresses. These characteristics are presented in this section. The most important properties are described along with why they are important and how we can use these characteristics to our advantage in exercise and rehabilitation.

Viscosity

Viscosity is the resistance to an external force that causes a permanent deformation. It is a term that is usually applied to fluids. Think of tar versus oil. Although both are viscous, tar has more viscosity than oil. If tar is heated, it becomes less viscous and more easily moldable. Human tissue also has viscosity. Clinicians use the fact that elevating temperature reduces viscosity by applying heat to tissue before stretching it. Lowering tissue temperature, on the other hand, increases the tissue's viscosity. If you have ever been outside without gloves or mittens on a cold day, you know this already because you may recall how stiff your fingers and hands were when you first entered a warm building.

Elasticity and Extensibility

Extensibility and elasticity are closely related. **Extensibility** is the ability to stretch, elongate or expand. **Elasticity** is the ability to succumb to an elongating force and then return to normal length when the force is released. The potential energy that is released by tissue when it is stretched is also the energy that allows tissue to return to its normal length following release of a stretch force. The more elasticity a tissue possesses, the more extensibility, or temporary elongation, it is able to demonstrate. If you take two rubber bands, a thick one and a thin one, and stretch them both with an equal amount of force, you find that the thin one has more elasticity than the thick one; it is able to stretch farther and still return to its normal length when you release the stretch.

Just as elasticity and extensibility are directly related to each other, viscosity is indirectly related to them. The more extensibility a tissue has, the less viscosity it has, and vice versa. Muscle and connective tissue have both properties of viscosity and elasticity and are referred to

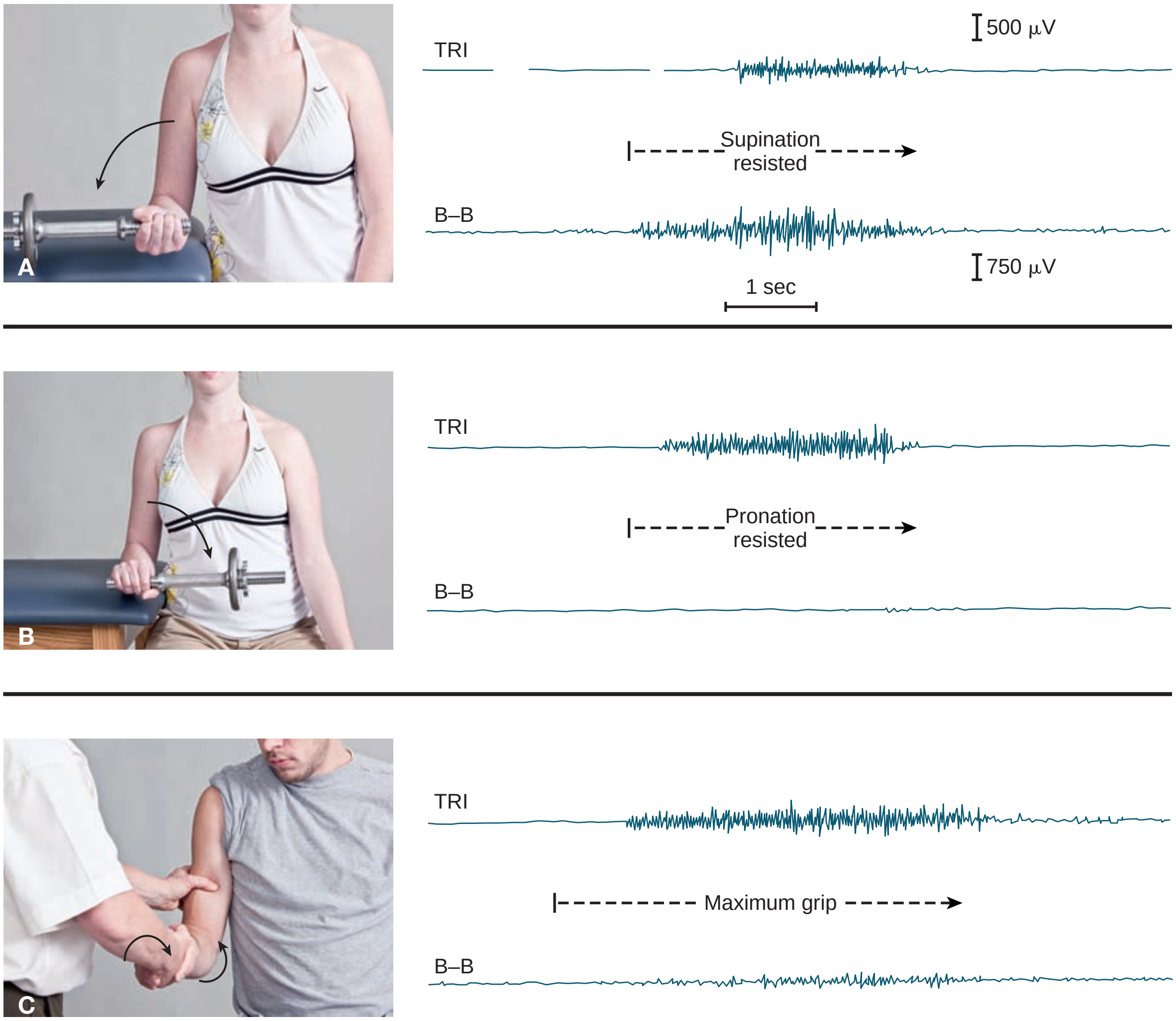


Figure 4.4 Synergistic actions of biceps and triceps during forearm activities. Electromyographic recordings with the subject sitting, the elbow flexed to 90°, and the forearm supported. An isometric contraction at the start of forearm supination requires synergistic activity of the triceps to prevent the biceps from flexing the elbow. TRI = Triceps. B–B = Biceps brachii and brachialis.

as viscoelastic tissue. Tissue that has **viscoelasticity** has the ability to resist changing its shape when a force is applied to it, but if the force is sufficient to cause change, the tissue is unable to return to its original shape. Not only do muscle and connective tissue possess this quality, but all tissues do. In fact, all structures do. Very rigid structures are more viscous and less elastic; very pliable structures are more elastic and less viscous. If you have ever seen an old building with its original windows, it may appear that the window glass looks wavy—the glass has succumbed to the continual pull of gravity and is unable to return to its original clear, see-through structure. This property of viscoelasticity of any structure adheres to the stress-strain principle.

Stress-Strain

As we have mentioned, stress is a force or load that the body or its parts resists. How well those structures are able to resist a stress is dependent upon its ability to deform. This is **strain** of a structure: the amount of deformation it is able to tolerate before it succumbs to the stress. All structures, natural and man-made, have their own specific relationship between stress and strain. This is called the **stress-strain curve** or **stress-strain principle**. Although it varies from one structure to another and from one type of tissue to another, a curve for connective tissue serves to represent a generic stress-strain curve for human tissue (Fig. 4.5). The initial section of the stress-strain curve is the *toe region*. In

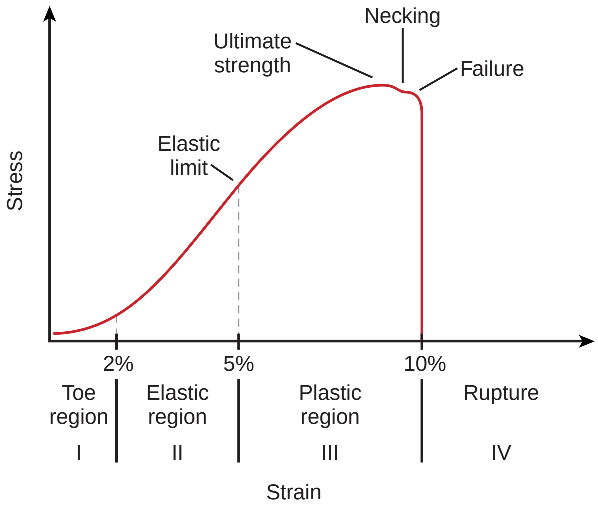


Figure 4.5 Stress-strain curve. Whereas stress is the amount of force applied to a structure, strain is the deformation that occurs with the application of stress. A structure has its own ability to withstand stresses applied to it. This ability is dependent upon the degree of deformation allowed in the toe, elastic, and plastic regions of its stress-strain curve. When the stress applied to a structure moves into the necking range, the next phase is failure of the structure to withstand further stress.

a resting state, tissue has a crimped or wavy appearance. When stress is applied to the tissue, this slack is taken up within the toe region of the stress-strain curve. Once the tissue is elongated to the point at which the slack is taken out of the structure so it becomes taut, the stress force moves the tissue into the *elastic range*. This elastic range is the point at which the tissue's elastic properties are stressed. The tissue strain and the amount of stretch move through a linear relationship when there is a direct relationship between the amount of stress applied to the tissue and the tissue's ability to stretch. If the force or load is released at any time during either of these two ranges, the tissue returns to its normal length. On the other hand, if the force applied continues to increase, the tissue moves from its elastic range into its *plastic range*. In this range, there is microscopic damage to the structure; some of the tissue ruptures because it is unable to withstand this amount of stress. It is at this point that permanent change in the tissue's length occurs. If the force is released at this point, the tissue is elongated compared to what it was prior to the stress application. If the amount of stress continues to increase past the plastic range, the tissue moves into the *necking range*. At this point, more and more microscopic ruptures occur until the tissue becomes macroscopically damaged. It is at this time that the force or load required to create tissue damage is less than previously because the tissue is weakening. If the stress increase continues, immediately before the tissue ruptures entirely, a give in the structure is felt and then the tissue rips apart, moving into the *failure range*. Continuity of the tissue is lost when tissue failure occurs.

Creep

Creep is the elongation of tissue from the application of a low-level load over time. The old glass in the window of the old home that was described earlier underwent deformation by creep. The changes that occur with creep occur in the plastic range of tissue or structures so the changes are permanent. We experience creep on a daily basis. If you measure your height in the morning and then again in the evening, you will discover that you are taller in the morning. The long-term effect of gravity on our tissues causes this height difference by the end of the day. Creep can be either advantageous or deleterious. For example, an individual with a tight Achilles tendon will find it very difficult to effectively stretch such a large, firm structure using a normal short-term stretch. However, using a prolonged stretch of perhaps 10 minutes may produce sufficient creep to increase the flexibility of the Achilles. This is especially true if the prolonged stretch is repetitive.

Muscle Strength

Muscle strength is a general term without a precise definition. Among the many definitions of strength are the

PRACTICE POINT

If a clinician wants to increase the flexibility of a tight joint capsule, a temporary change in the structure's length occurs with a stretch that approaches the capsule's elastic range. However, if the clinician wants to improve range of motion of the joint, the capsule must be stretched into its plastic range. A combination of joint mobilization techniques and stretching exercises must provide this stress to produce a permanent increase in flexibility.

PRACTICE POINT

Creep may also be injurious to the body. If a creep load is more stressful than the tissue is able to tolerate, repetitive bouts applied over time may cause the tissue to become structurally fatigued. Structural fatigue occurs with an accumulation of stress from repeated bouts of application. In bones, we call these **stress fractures**; in tendons, we may refer to it as **tendinopathy.**

state of being strong, the capacity of a muscle to produce force, and the ability of a muscle to generate active tension. How well muscles are able to produce force depends upon a number of factors. In addition to neurologic, metabolic, endocrine, and psychological factors that affect muscle strength, many other factors determine muscle strength.

If bones create levers and joints, muscles provide the forces by which motion occurs in the body. Motion of the body's levers occurs as muscles which cross joints produce force to move those levers. How well this force is produced depends on a number of factors unique to each muscle or muscle group. These factors that influence muscle performance include:

- the muscle's size;
- the architecture of muscle fibers;
- the passive components of the muscle;
- the physiological length of the muscle or length-tension relationship of the muscle;
- the moment arm length of the muscle;
- the speed of muscle contraction;
- the active tension; and
- age and gender

Each of these topics is discussed in this section.

Muscle Size

Muscle size refers to two parameters: length and width. If muscle fibers are placed side by side—as in *parallel* to each other—the muscle's width is greater. On the other hand, if muscle fibers are placed end to end, they are in *series* to each other. As a rule, parallel muscle fibers provide greater force and series muscle fiber arrangements provide greater speed of motion. Given two muscles of the same length, the muscle with a greater width is stronger than one that has a smaller diameter or width. A good rule of thumb to remember is that when there are muscles of variable lengths crossing a joint, the longer muscles provide that segment's mobility whereas the shorter muscles provide its stability. For example, the short multifidus muscles that attach from one spinal segment to the adjacent vertebrae provide spinal stability whereas the longer erector spinae muscles that attach across several spinal segments provide spinal motion.

In terms of cross section, it is well known that larger muscles in normal subjects are stronger than smaller ones. It is also known that muscle size may increase (**hypertrophy**) or decrease (**atrophy**) with exercise or inactivity, respectively. Clinicians are often called upon to measure these changes. However, measurement of actual size and changes in size is difficult. Magnetic resonance imaging (MRI) provides an anatomic cross section of the muscle, so the area of muscle tissue can be measured and small size changes can be detected.[16-17] Muscle biopsies can also measure small size changes.[18] Both of these techniques, however, are expensive, and the biopsy is invasive. Circumferential measurements lack accuracy because they also include skin, fat, fluid, vasculature, and bone and depend on a subjective judgment of the amount of tension on the tape measure.[19] However in spite of their inaccuracy, circumferential measurements are most often used clinically since it is inexpensive and convenient. An important key factor in using circumferential measurements is to be precise and consistent in both the procedure and the recording of the procedure.

Fiber Architecture

All skeletal muscles have the same basic architecture. An entire muscle may be divided into sections called fascicles, or bundles. Within these bundles are numerous muscle fibers. Recall that the number of muscle fibers is one of the factors that determine a muscle's ability to produce force. The more muscle fibers a muscle has, the more force that muscle has the potential to exert.

One skeletal muscle fiber is a single muscle cell which is enclosed by a plasma membrane called the sarcolemma. Each muscle cell contains substances: Some are necessary for cell metabolism and others are the contractile elements of the cell. These contractile structures are myofibrils. There are several myofibrils within each cell. The myofibrils contain protein filaments—actin and myosin. It is at the actin and myosin level that muscle contraction occurs.

Not only is the basic cellular design relevant to strength, but investigators have shown a strong correlation between the physiologic cross-sectional area of a muscle and the maximal force that the muscle can produce.[20] A line that transects each fasciculus at a right angle determines the physiologic cross section of a muscle. Hence, the fiber arrangement of a muscle is fundamental to its strength. By knowing the various fiber arrangements of muscles, we can determine its cross-sectional area and then predict whether the muscle has relatively great or little force production potential.

Muscle fiber arrangement of an entire muscle at the macroscopic level is either **fusiform** (strap) or **pennate** (L. *penna,* feather). In fusiform muscles, the fascicles are parallel and long throughout the muscle. The sartorius is an example of a strap, or fusiform, muscle.[21] These muscles are designed to produce greater shortening distance but less force. Pennate fascicles, on the other hand, attach at oblique angles to a central tendon. There are different pennate designs of muscles, depending upon the number of fiber arrangements within a muscle. Unipennate muscles have one parallel fiber arrangement whereas bipennate muscles have two groups of parallel fibers running to one central tendon. Most muscles in the body are multipennate muscles with more than two pennate groups attaching to more than one centralizing tendon. Pennate fascicles are shorter than fusiform fascicles; they produce greater forces to the sacrifice of speed since their total cross section is larger. Since muscle strength is proportional to the total cross-sectional area of the muscle, strength of pennate muscles is related to the combined cross-sectional size of the pennate muscle. Therefore, total strength of pennate muscles is the sum of the cross-sectional areas of each pennate. The architectural design of most muscles in the body is multipennate.[22] Figure 4.6 demonstrates the various muscle fascicle arrangements.

Passive Components

As in all body structures, muscle is surrounded by connective tissue called **fascia**. Although this connective tissue is composed of various cells and ground substance, its predominant cell type is collagen. Collagen is the protein that forms the majority of the white fibers of fascia. Muscle structural levels from the microscopic fibers to the entire muscle are each encased by a sleeve of fascia; these layers of fascia have different names to identify their structural level. Each muscle cell or fiber is surrounded by a fascial layer called the **endomysium**. **Perimysium** surrounds groups of muscle fibers or fascicles. The **epimysium** is the fascial layer surrounding the entire muscle. These fascial layers are interconnected with each other as well as with the fascia covering the muscle's tendons. Collectively, these fascial layers form a muscle's **passive elastic component**. The fascia is passive since it is unable to change its length actively but complies with the muscle's change in length. Because the fascial fibers surrounding a muscle are parallel to the muscle fibers, muscle fascia is also known as the muscle's **parallel elastic component**. When a muscle elongates beyond the point at which its slack is removed, the fascia becomes passively stretched as the muscle continues to lengthen. This *parallel* elastic component design is in contrast to the tendon and its fascia that are positioned at either end of the muscle; the tendon and its fascia provide the muscle's **series elastic component**. This name is given to the tendon and its fascia because of their series arrangement with the muscle: tendon–muscle–tendon. This configuration allows the contracting muscle fibers to transfer their forces along the tendon to the bone to produce motion.

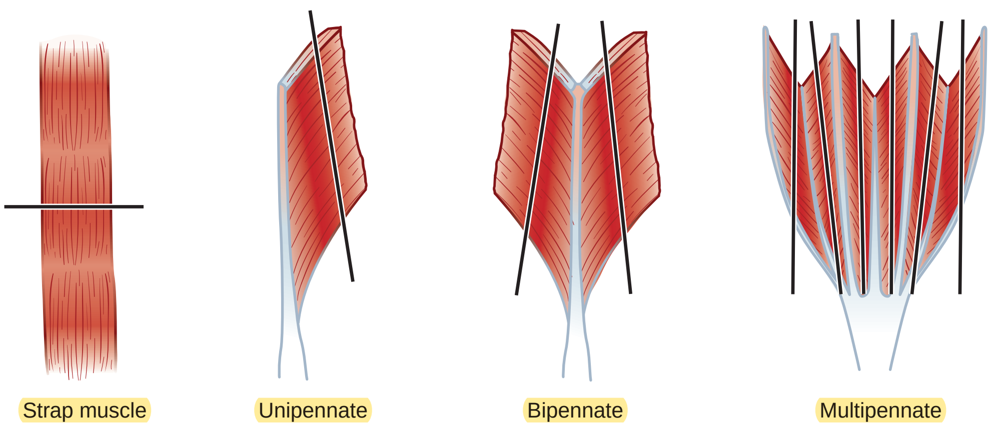


Figure 4.6 Fusiform and pennate muscles with their cross-sections identified. Multipennate muscles have larger cross sections (black lines through the muscle fibers represent cross sections) than unipennate muscles, and the more pennates a muscle has in its fiber arrangement, the greater force it is able to produce.

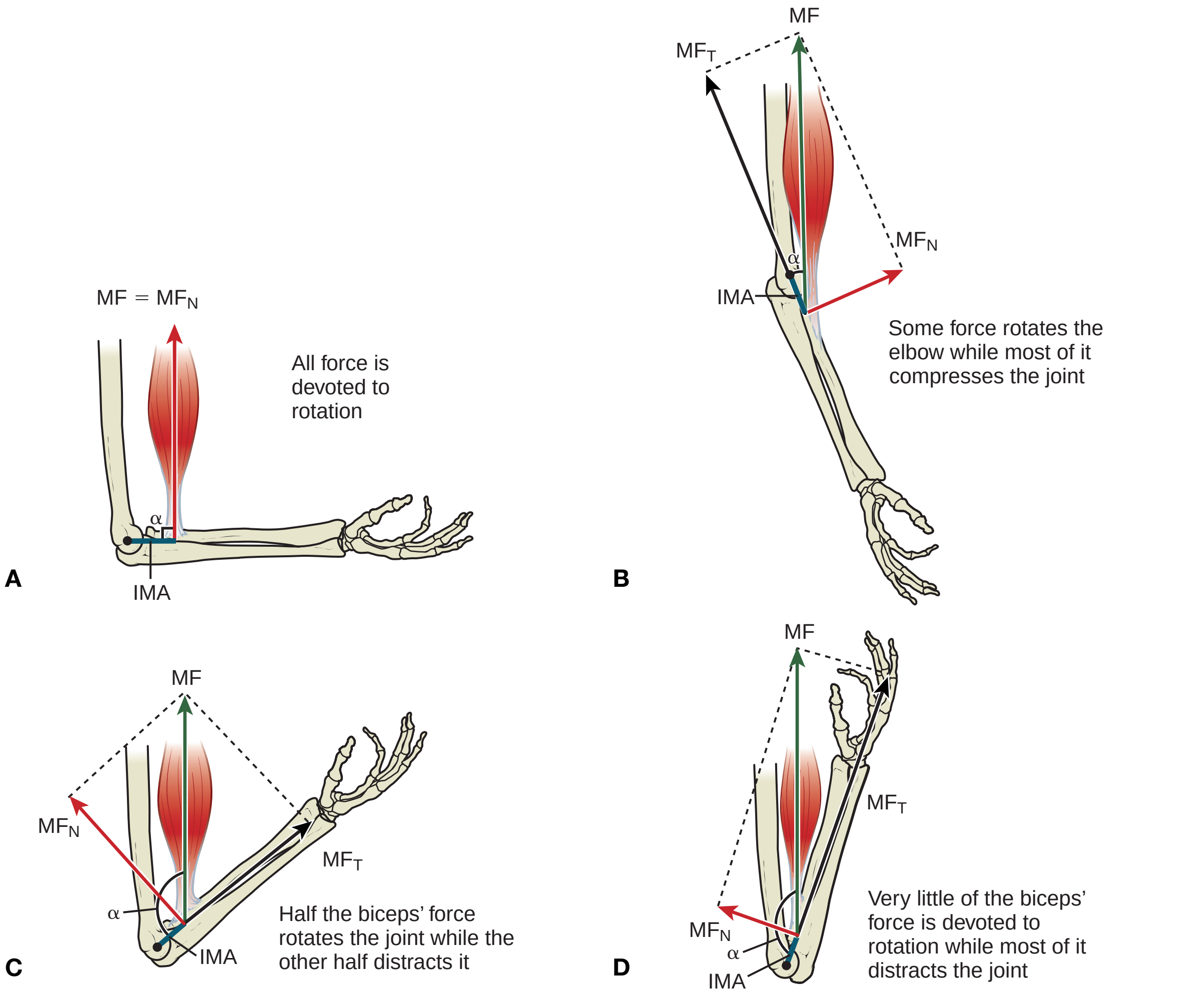


Figure 4.10 A) When the muscle's moment arm is perpendicular to the muscle, all of its force produces joint rotation. B–D) When it is not perpendicular, some of its force is directed to either compression or distraction of the joint and the rest to joint rotation.

from 90°, the less the force of the biceps is devoted to rotation and the greater amount of its force produces either distraction or compression.

Using this elbow example, we see that as the joint moves through its range of motion, muscles producing the movement experience a change in their moment arms, both in length and in the position at which it is relative to the segment. This means that at some points in the range of motion, a muscle generates a large torque (rotational force) and sometimes it produces less torque, depending upon when that muscle's moment arm is perpendicular to its body segment. As we have previously discussed, the muscle's physiological length (length-tension) also influences its strength, or ability to produce force. Although it is likely that the mechanical influence is greater, the physiological and mechanical factors both influence a muscle's ability to produce force *in vivo*. Therefore, they must both be considered when determining the optimal position for a rehabilitative exercise. In addition to these mechanical and physiological influences, the speed of a muscle's contraction also impacts the muscle's ability to produce a force.

Speed of Contraction

Speed is rate of motion. Velocity is rate of motion in a particular direction. The rate of muscle shortening or lengthening substantially affects the force a muscle can develop during activation. The relationship between the maximum force developed by a human muscle and the speed of contraction is shown in Figure 4.11. As the speed of a concentric contraction becomes slower, the muscle's force development increases.[28–29] When there is no motion, this is a maximum isometric contraction, or zero-velocity, contraction. A muscle's decreased ability

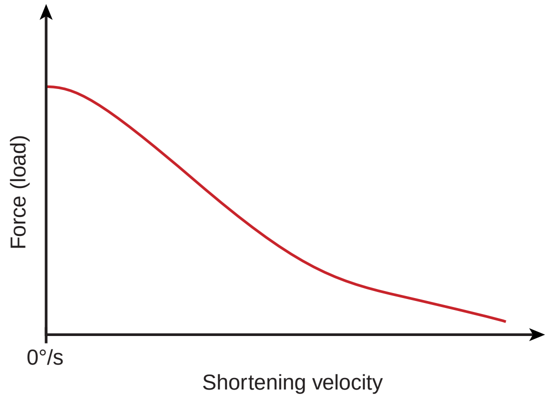


Figure 4.11 Force-velocity during concentric activity. The faster a muscle moves concentrically, the less force it is able to produce.

to produce a contraction force with increasing speed of shortening is based of the number of links between the actin and myosin filaments that can be formed per unit of time (Fig. 4.12). The maximum number of crossbridges that can be formed occurs at slow speeds. The more rapidly the actin and myosin filaments slide past each other, the smaller is the number of links that are formed between the filaments in a unit of time so less force is developed. There is a loose inverse relationship between the muscle's speed of contraction and the amount of force a muscle is able to produce concentrically. It is important to remember that from a clinical perspective, the faster a muscle moves through a range of motion, the less weight it is able to work against, or lift.

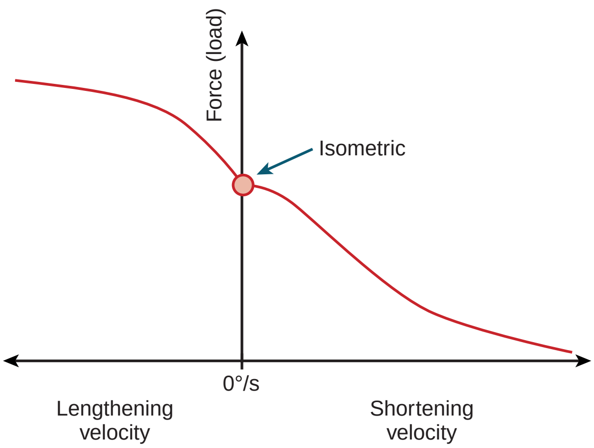


Figure 4.12 The passive length-tension portion of a skeletal muscle's length-tension curve demonstrates the effect of passive tissue tension of a muscle. Passive tension occurs as the result of stretch on parallel and series elastic components when a muscle is elongated. To a point, as a muscle moves faster eccentrically, it produces greater force.

On the other hand, as the muscle lengthens during activity, there is a difference in the relationship between speed of contraction and force production than that which occurs with muscle shortening. As seen in Figure 4.12, muscle strength actually increases as speed increases during eccentric contraction until the speed reaches a point at which the muscle is unable to control the load.

Active Tension

Active tension is the force produced by a muscle. Active tension in a muscle is created by activation of the crossbridges between the actin and myosin elements within muscle fibers. Assuming a normally interacting neuromotor system, active tension is the most important factor in the production of muscle forces used for functional activities. How much active force a muscle contraction is able to produce is determined by the number of motor units that are recruited and the firing rate of the active motor units.[30] Also, the greater the number of muscle fibers activated, the greater the active tension that is produced. The number of muscle fibers within one motor unit varies. There is an inverse relationship between the size of the motor neuron and its excitability; the larger the axon, the less excitable it is.[31]

Not only does the size of the neuron innervating the motor unit matter, but the size of the muscle fiber being innervated is related to the sequential triggering of muscles. Elizabeth Henneman and her associates[32] found a direct relationship between the size of the neuron and the size of the fibers it innervated. In other words, the larger motor units contained the larger neuron and also contained the larger-sized muscle fibers. They concluded that it is reasonable to assume that the smaller muscle fibers, since they are innervated by smaller nerve fibers, are activated before larger muscle fibers.

The type of muscle fiber recruited within a muscle influences the amount of tension produced by a muscle. The type II muscle fibers are facilitated when a rapid or forceful response is required. However, type I muscle fibers are active for postural corrections during prolonged positioning; they frequently fire as needed to make small corrections so a position is maintained in spite of either external factors, such as wind or standing on a boat, or internal factors, such as heart or lung activity, which cause minute changes in the body's position. Once a motor unit receives a stimulus sufficient to cause activation, the muscle fibers within that motor unit contract and immediately relax. If there is a series of stimuli provided to the motor unit, it will produce repeated contractions of the muscle fibers within the motor unit. Fast, repetitive firing will produce repeated contractions at a rate sufficient to cause a sustained contraction of the muscle fibers. The more motor units that are recruited and contract in this manner, the more forceful is the muscle's contraction.

Motor units are recruited in a systematic order.[30, 33–34] Smaller motor units are recruited before larger ones. Smaller motor units usually produce less tension, last a longer time, and require less energy than the larger motor units.[33–34] Recruitment first of smaller motor units and then later of larger motor units, if and when they are needed, assures conservation of energy and efficiency of movement. If greater forces or a higher intensity of activity is required, the larger motor units are recruited to improve the muscle's response to increased or short-term activity demands.

In summary, motor units are recruited in an order according to the size of the motor unit (smaller ones are recruited first), the size of the muscle cells (smaller ones are recruited before larger ones), and the type and speed of conduction of the muscle fibers (slower type I are recruited before faster type II). The smaller motor units are slower to respond but last longer than the larger ones which respond quickly with strong bursts. Therefore, type I motor units are recruited for posture.

As with motor units, some investigators have demonstrated that muscles are also recruited in a systematic manner.[34] Most of the research on this topic has been performed on postural muscles with mixed results. Some researchers find that there is no consistent firing sequence[35–36] whereas others reveal that sequence patterns do exist in muscle firing.[37–38] There seems to be a pattern for some activities but not others and for some muscles but not others. For example, it has been found that an inhibition of erector spinae muscles occurs as an anticipatory adjustment as the person prepares to rise out of a chair.[39] When an individual is in a prone position, Ana Sakamoto and her associates[40] found a consistent sequence of muscle firing starting with the semitendinosus and followed by the contralateral erector spinae, then the ipsilateral erector spinae, and finally the gluteus maximus. Some investigators have found changes in muscle firing sequences with changes in speed of muscle contraction and in subjects with sacroiliac pain or sacrolumbar dysfunction.[36–38, 41–42] Katsuo Fujiwara and associates[35] investigated movement patterns and muscle activity and discovered that although subjects had variable methods of movement patterns and muscle recruitment, each subject performed his or her own pattern consistently over repeated trials. Based on these findings, it may be that, although motor units are systematically recruited, movement patterns rely more on the individual's development of his or her personal strategy. Additional investigations are needed on this topic of movement patterns and muscle recruitment.

Age and Gender

Males are generally stronger than females. In both genders, however, muscle strength increases from birth through adolescence, peaking between the ages of 20 and 30 years, and gradually declining after 30 years of age. For example, the grip strength of the dominant hand of males and females between ages 3 and 90 is plotted in Figure 4.13. As seen in Figure 4.13, the muscle strength of young boys is approximately the same as that of young girls up to the age of puberty. Thereafter, males exhibit a significantly greater grip strength than females, with the greatest differences occurring during middle age (between ages 30 and 50). As individuals age, the number of motor units decline.[43] The greater strength of males appears to be related primarily to the greater muscle mass they develop after puberty. Up to about age 16, the ratio of lean body mass to whole body mass is similar in males and females, as indicated by studies of creatinine excretion and potassium counts. After puberty, however, the muscle mass of males becomes as much as 50% greater than that of females, and the ratio of lean body mass to whole body mass also becomes greater. On the other hand, muscle strength per cross-sectional area of muscle is similar in males and females.[44] The proportion of fast-twitch and slow-twitch muscle fibers in specific muscles is also similar in the two groups.[44]

Although muscle strength is related to age and gender in the population as a whole, many exceptions to the general rule can be found because of two factors: 1) the large variation in the rate at which biologic maturation occurs; and 2) the large variation in individual genetics and specific conditioning levels which are acquired and maintained through proper diet and exercise.[45]

Passive Excursion of Muscles

The paired agonist-antagonist relationship of muscles throughout the body requires that each muscle have the ability to accommodate and change length both passively and actively to permit joint motion. For example, Morrison determined that the hamstrings and quadriceps muscles change their length 3 to 4 inches (8 to 10 cm) during normal walking.[46] The **functional excursion** of a muscle is the distance to which the muscle is capable of shortening after it has been elongated as far as the joint(s) over which it passes allows. Weber[47] investigated the excursions of several muscles and found that these muscles were able to shorten from 34% to 89% of their longest length, with an overall average shortening value

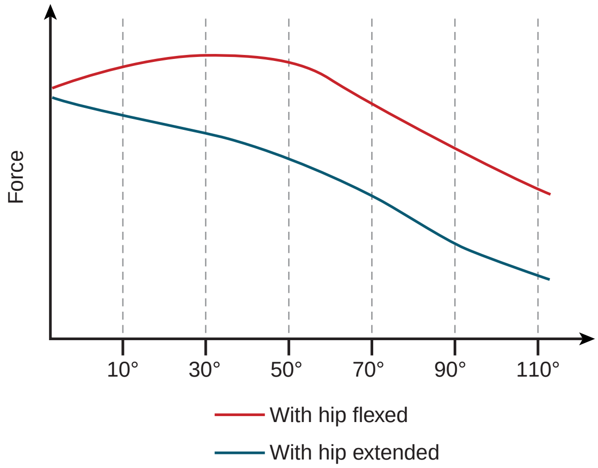


Figure 4.21 Maximum isometric force curves of the knee flexor muscles (semimembranosus, semitendinosus, biceps femoris, and gastrocnemius). Notice that the hip position changes the amount of force available for knee flexion.

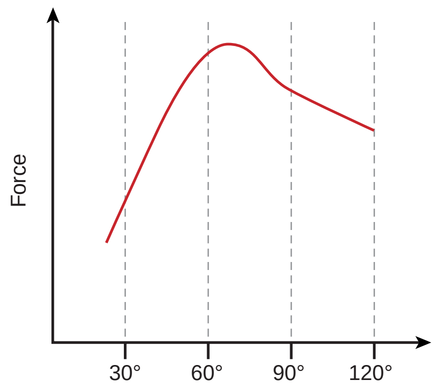


Figure 4.22 Maximum isometric force curves of the knee extensor muscles (quadriceps femoris). Based on data from Williams and Stutzman.[86]

provide large forces during their midranges of motion. For example, great strength of the elbow flexors must be available at a joint angle of 90° of flexion (Fig. 4.18) since that is the angle at which the elbow is positioned for carrying heavy objects. Maximum strength requirement of the knee extensor muscles occurs at 60° of flexion, the position at which great force is needed to elevate the body when a person rises from a chair or climbs stairs.

In Figures 4.19 and 4.20, maximum isometric forces of antagonistic muscle groups are recorded. At one point in the range, one muscle is stronger. At another point, the muscles have equal strength. At the other end of the motion, the antagonistic muscle is stronger. Therefore, when discussing which muscle group is stronger or ratios of strength, be sure to reference a specific point in the range of motion to make your discussion meaningful.

Exercise-Induced Muscle Injury

Muscles are among the most commonly injured orthopedic structures in the body. Injuries to muscles occur as gradual or acute onset injuries. Most muscle injuries, however, occur during eccentric and deceleration activities. Two injuries common in strenuous exercise are attributed to the great forces that occur with maximum eccentric muscle contractions because these contractions can produce up to twice the force of a maximum isometric contraction.

Delayed-Onset Muscle Soreness

One of these common muscle injuries is **delayed-onset muscle soreness (DOMS)**, which begins about 24 hours after the activity and may continue for up to 10 days post-exercise.[88] Other functional signs of DOMS are a decrease in range of motion because of pain and a decrease in maximum concentric and eccentric muscle forces of +50%, depending on the intensity of the exercise.[89–91] Biochemical signs of injury and destruction of muscle contribute to abnormally high levels of creatine kinase (a muscle enzyme) and myoglobin in venous blood, as well as increased plasma concentrations of myosin heavy-chain fragments from slow-twitch muscle fibers.[92,93] Structural damage to the Z-lines with a zigzag appearance and, sometimes, dissolution has been found. (Remember from Chapter 3 that the Z-lines border the ends of the sarcomeres and are a base of attachment of the actin myofilaments.) This alteration of the Z-line changes the alignment of the myofilaments, and, in some cases, the myosin filaments are absent.[90,94] Recovery from the functional and structural injuries of DOMS requires from 5 to 30 days, depending on the severity of the initial exercise. If, after recovery, the eccentric exercise or activity is repeated, it has been found that muscle soreness does not occur, and the muscle adapts to the exercise. Even greater eccentric forces can be made; there are minimal signs of muscle damage, but if injury occurs, recovery is more rapid.[89,92]

Hamstring Strain

A second common type of exercise-induced muscle injury is the muscle strain, and of the muscles strained, hamstrings strains occurs most often, especially in sprinting and jumping activities. This is a sudden and sometimes severe injury, frequently causing the athlete to fall to the ground in agony. In severe injuries, it is a macro-muscle tear of a hamstring with hemorrhage into the muscle. The tear occurs during the late swing phase and early stance phase of running. At this time,

CHAPTER 12

Stance and Gait

"The ultimate measure of a man is not where he stands in moments of comfort and convenience, but where he stands at times of challenge and controversy."
Martin Luther King, Jr., 1929–1968.
American pastor, activist, and leader in the African-American Civil Rights Movement

CHAPTER OUTLINE

LEARNING OUTCOMES

This chapter provides a descriptive analysis of upright stance control and gait. By completion of this chapter, the reader should be able to:

- ❑ Indicate the typical alignment seen in upright stance posture and summarize the mechanisms that preserve upright postural control;
- ❑ Use gait terminology fluently when describing or analyzing human gait;
- ❑ Describe gait by using the kinematic spatial and temporal descriptors seen in walking;
- ❑ Summarize the main functional tasks associated with gait;
- ❑ Identify the phases of the gait cycle and the main functional tasks associated with each phase;
- ❑ Summarize the basic angular joint displacements at the pelvis, hip, knee, and ankle that occur during the gait cycle and translate these into the functional minimal range of motion requirements for gait;
- ❑ Explain the muscular activation patterns at the trunk, pelvis, and lower extremities that occur during the gait cycle;
- ❑ Summarize the age-related differences seen in the gait characteristics of children, mature and older adults;
- ❑ Illustrate common methods of gait analysis;
- ❑ Explain gait efficiency and the factors that contribute to this efficiency;
- ❑ Describe the functional consequence on locomotion of commonly encountered pathological conditions;
- ❑ Contrast and compare walking to running.

CLINICAL SCENARIO

Morgan is working with Cody, a distance runner who injured his right knee while downhill skiing during his vacation. The knee was placed in a brace, and Cody was limited to nonweight-bearing on the limb for three weeks. Now that he has progressed to full weight-bearing as tolerated, it is Morgan's responsibility to advance him from walking to running again. The first day Cody put weight on the right limb, he was unable to walk normally. Morgan expected this and is prepared to instruct Cody in the proper technique.

Introduction

This first chapter in Unit 4 describes and summarizes the two most common functional tasks we engage in throughout our day: controlling our posture and walking. It is amazing how smoothly these two daily tasks are performed and how efficiently our bodies orchestrate them without conscious effort. When is the last time you ever really paid any attention to what muscles you were using, for example, as you stood in line to buy your books or buy a ticket to a game or show? Do you realize that when you walk, more than 1,000 muscles synchronize to move more than 200 bones around 100 joints?[1] Your study of kinesiology in the preceding chapters has prepared you well for delving into the next step of clinical kinesiology: analysis of human movements. It is easier and most logical to begin with a static activity such as posture and move on to what is arguably the most common activity we perform on a daily basis—walking.

This chapter is divided into three main sections: The first section assesses proper upright stance posture; the second section analyzes walking gait; and the final section investigates running gait. As we have done throughout this text, the most important first step for us will be to define and describe the unique terminology of these activities so we all communicate using a common language.

In contrast to our four-legged friends, human beings are **bipedal** (L., *bi,* two, plus *pes,* foot). In most cases, we attain the independent ability to stand and walk within the first year or so of life. Moving from one place to another is broadly defined as **locomotion** (L., *locus,* place, plus *movere,* to move; in this case, moving from one place to another) and includes many forms of movement, including examples such as rolling, crawling and creeping, walking, running, and even hopping and skipping. Locomotion specifically in the *upright* bipedal form occurs along a sequential progression that begins with standing and advances to walking, then running. These activities require skills such as starting, stopping, changing direction, and altering speed.[2] **Gait** is upright locomotion in the particular manner of moving on foot, which may be a walk, jog, or run. **Walking** is a particular form of gait and the most common of human locomotor patterns. **Ambulation** (L., *ambulare,* to move about) is defined in a broad sense as a type of locomotion and is more often used in the clinical sense of describing whether or not someone can walk freely or with the assistance of some device.

Stance Posture

Posture is a general term that is defined as an alignment of body segments, a position or attitude of the body, the relative arrangement of body parts for a specific activity, or a characteristic manner of bearing one's body. Posture and movement are intimately related; movement begins from a posture and may end in a different posture in the same location or the same posture but a different location, such as when a person is in a sitting position and then moves to a standing position or when a standing person walks across the street.

Postural adjustments are rapid and automatic in normal function. This postural control requires multiple-system interactions such as the proprioceptive, visual, and vestibular sensory systems networking with the musculoskeletal system (see Chapter 3). A complete presentation of posture includes a description of standing posture, sitting posture, and the myriad complexities of postural control. Since this chapter deals primarily with gait, we will limit our discussion to stance and the kinesiological concepts related to maintaining an effective and efficient upright standing posture as a preparation to gait. Refer to other texts for an in-depth discussion and additional information on postural control.

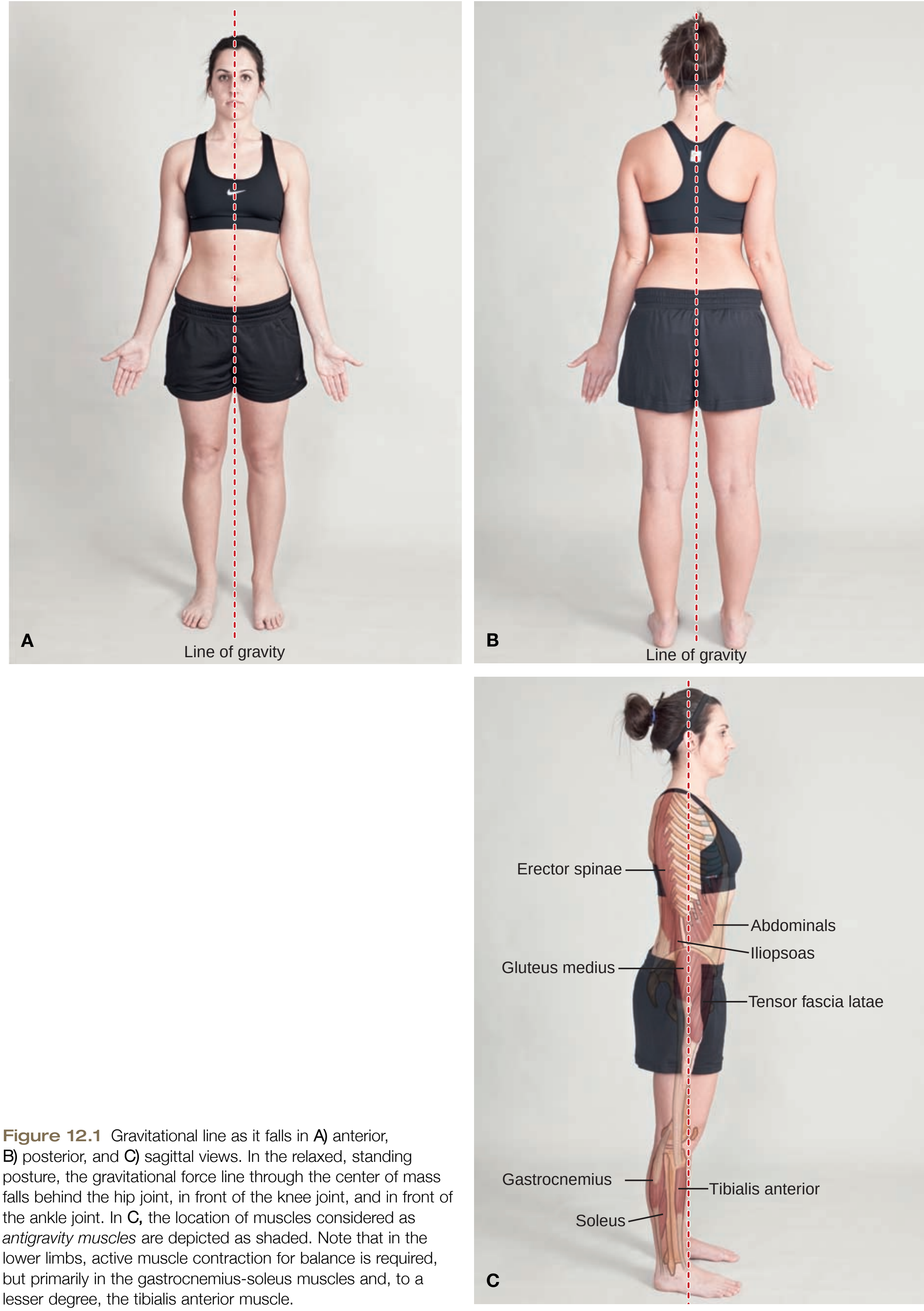


Figure 12.1 Gravitational line as it falls in **A)** anterior, **B)** posterior, and **C)** sagittal views. In the relaxed, standing posture, the gravitational force line through the center of mass falls behind the hip joint, in front of the knee joint, and in front of the ankle joint. In **C,** the location of muscles considered as *antigravity muscles* are depicted as shaded. Note that in the lower limbs, active muscle contraction for balance is required, but primarily in the gastrocnemius-soleus muscles and, to a lesser degree, the tibialis anterior muscle.

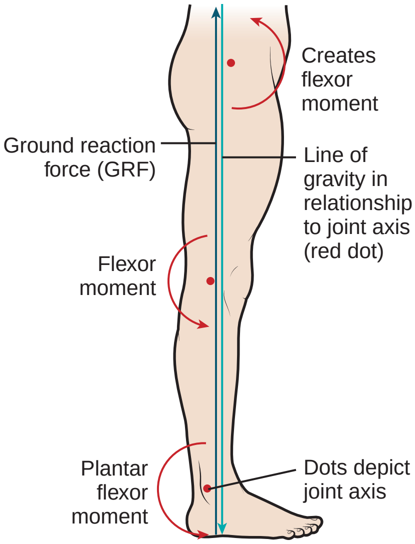


Figure 12.2 Drawing depicts how the line of gravity exerts a torque force that needs to be counteracted by an internal reaction force on the opposite side of the joint.

gravity up the body, we see that it falls on the concave side of each vertebral curvature, requiring a counteractive force on the convex side. In the trunk region, the erector spinae counteract the anterior gravitational pull on the thoracic spine, whereas the anterior head and neck musculature and the abdominals provide counterbalance at the cervical and lumbar areas, respectively. At body regions in which the line of gravity falls directly through a joint axis, there is no external moment applied, so the body is not required to produce a counteractive force at those joints to maintain the joint's position.

Postural Sway

To maintain a standing position, the body's relatively high center of gravity (COG) or center of mass (COM) at S_2 must remain within its relatively small base of support. The body is unable to maintain a perfectly stationary posture during standing. Ongoing organ functions such as respiration and cardiac contractions and ongoing neural adjustments cause small motions, so the body automatically and continually seeks and reestablishes equilibrium; this is called **postural sway** (Fig. 12.3). Postural sway

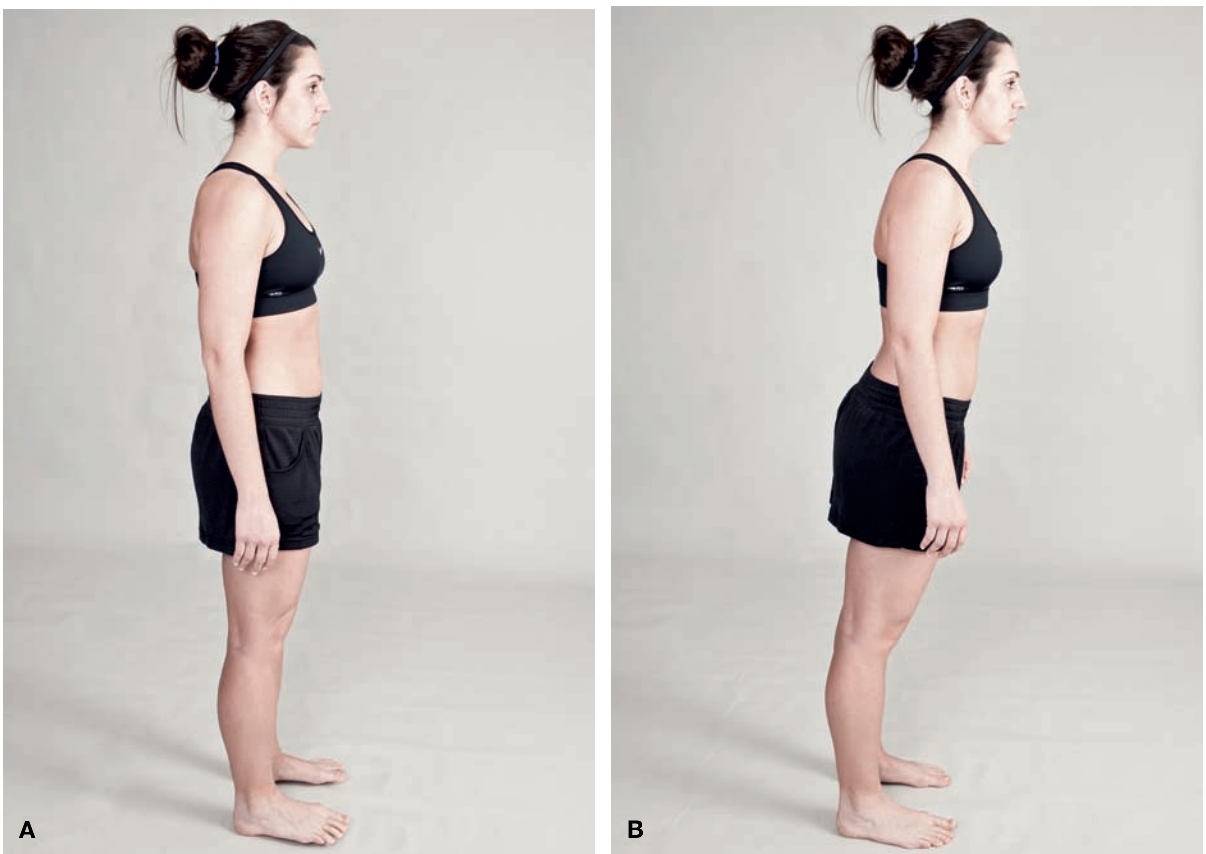


Figure 12.3 Postural sway is characterized by automatic adjustments, primarily at the ankle, to retain upright balance. A) Posterior. B) Anterior. Typical values as measured on a balance platform: mean amplitude of sway in inches = .13 × .15 Y; length of path = 32.2; velocity = .54 inch/sec. When balance is disturbed, an ankle strategy is used to reestablish equilibrium: A) disturbance posteriorly activates the anterior tibialis and B) disturbance anteriorly activates the soleus muscle.

produce responses in leg muscles causing the distal-to-proximal balance corrections seen with the ankle strategy. However, research has now shown that triggers in the trunk and neck occur simultaneously with the ankle triggers, suggesting that a variety of other proprioceptive input contributes to postural responses.[19]

Hip strategy

Control of posture that comes from the hip, pelvis, and trunk is called a **hip strategy.** When the body is challenged to maintain posture because of large shifts in the body's line of gravity, the ankle strategy is insufficient to make the needed correction. Hip strategy is preferred when the postural challenge is large, fast, or if the support surface is too small to accommodate the ankle forces mentioned previously. Increasingly, the importance of trunk and hip input contributing to upright posture and its role in shaping balance strategy is being realized.[19] Its full role is yet to be understood.

Stepping or Reaching Strategies

Stepping or **reaching strategies** are used for very large or very fast changes and result in realignment of the COM within the base of support using steps, hops, or reaches in the direction of the change.[17] It is readily apparent that these strategies are required with sudden changes in body position to avoid instances such as collision with another body or object, adjustment to an overpowering force, or a change in position required because of an unanticipated need.

Walking Gait

Gait is the method by which land mammals move from one location to another. It may also be referred to in general terms as *locomotion*, but locomotion may include any method of movement from one location to another. The term used synonymously with gait is *ambulation.* Although we each develop our own specific style of gait, there are normal parameters within which we all move to provide an efficient method of transport. It is interesting to realize that people are often easily recognized by their gait, yet normal gait is amazingly similar from one individual to another. When abnormalities in anatomy or pathology in function occur, gait modifications must follow in order for ambulation to occur. This section provides information on normal and abnormal gait. How gait changes as the body moves through the life span is also covered. Gait includes both walking and running; this unit will delve first into walking gait and then into running gait.

Gait Terminology

Gait is defined as the manner or style of walking. Gait is discussed and investigated by its most fundamental unit, the gait cycle. One **gait cycle** is the time from when the heel of one foot touches the ground to the time it touches the ground again. The gait cycle is also known as a **stride**. The gait cycle is divided into two phases: stance (Fig. 12.5A) and swing (Fig. 12.5B). Stance phase and swing phase are subdivided and described in various ways. You will encounter some differences when reading different authors and their

PRACTICE POINT

The use of recovery strategies occurs regularly in everyday situations. Imagine standing in line, patiently waiting to get a lunch tray. Suddenly, someone steps into the line and grabs a tray. The automatic response is to shift weight from the balls of the feet to the heels to avoid contact. A slight lean back might be needed; this is the ankle strategy at work to keep the body balanced and to avoid a fall.

Use of hip and stepping or reaching strategies may occur during body motion or when the body is statically positioned. An example of an adjustment when moving is an individual climbing back to his seat on the bleachers for the second half of an exciting basketball playoff. Trying not to spill soda onto the people already seated, a weight shift at the hips is used. The upper body moves forward and back to hold the handheld objects stable as the individual finds his footing because of the limited space between seats. Imagining the ongoing activities within the stadium, the hip strategy may have just saved another person from tumbling down the steps as the individual turns to see why the crowd is suddenly cheering and begins to lose their balance.

Finally, a stepping and reaching strategy protects another spectator from falling when the individual fails to realize he has one more step before he reaches the floor and flails his arms and legs as he struggles to regain postural control and balance.[18]

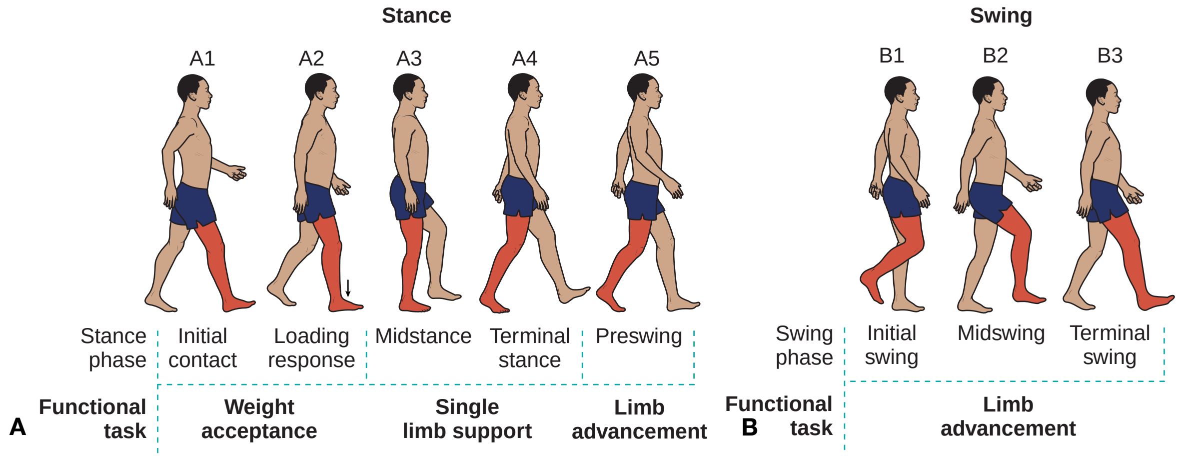


Figure 12.5 Gait Cycle Phases and Timing. **A)** Stance Phases: 1. Initial Contact; 2. Loading Response; 3. Midstance; 4. Terminal Stance; 5. Preswing. **B)** Swing Phases: 1. Initial Swing; 2. Midswing; 3. Terminal Swing.

use of slightly varying terminology systems. The traditional terminology system was developed first and describes the components of the gait cycle by naming the event or the critical action associated within each phase, such as heel strike, foot flat, heel off, or toe off. The second system is the Rancho Los Amigos (RLA) terminology, developed by Jacquelin Perry, a prominent gait researcher from this premier gait analysis center in California, which emphasizes the functional task associated within each phase.[20] Institutions around the country may use either RLA terminology or traditional terminology, depending on regional preferences. Since many experienced clinicians often interchange the terminology systems, therefore, it is advantageous for learners to become familiar with both systems.

We will use the RLA terminology system in this text (Table 12–1). This system divides the stance phase into five subphases and the swing phase into three.[20] Since walking may be performed at different speeds, one complete gait cycle is identified as 100% with the phases and subphases signified by percentages of the whole cycle. When the foot first makes contact with the floor, this begins the gait cycle, so the start of the cycle is at 0% time and continues on until one full cycle to 100% occurs, when the same foot initially contacts the floor again. At ordinary walking speeds, the stance phase comprises approximately the first 60% (62%) and the swing phase includes the last 40% (38%) of a single gait cycle, so the very end of the swing phase occurs at 100% of the cycle. At normal adult walking speeds, one cycle lasts 1 second and has a length of 1.4 meters.[20, 21] Figure 12.5 depicts a full gait cycle for the left and right lower extremities. Note that the right limb is shaded in the figure and is the reference leg throughout this chapter. It is important to also note that there are two times within the gait cycle when both feet are in contact with the ground, totaling about 20% (22%) of a gait cycle—10% at the beginning and 10% at the end of the stance phase. This time when both feet are in stance is called **double support.** During the middle 40% of its stance, the lower extremity is in **single limb support.** The duration of double support varies inversely with the speed of walking. In slow walking, this time is comparatively long in relation to the swing phase; but as the speed increases, double support time decreases.

As mentioned, each phase of the gait cycle is divided into subphases. Stance phase includes the subphases of initial contact, loading response, midstance, terminal stance, and preswing. The stance phase begins when the foot first makes contact with the ground. The heel is usually the foot section that makes **initial contact**, but other parts of the foot may contact the ground first in the presence of some pathologic conditions. After the foot makes initial contact, the foot moves so the entire plantar surface contacts the ground; this is the loading response. During this phase, the body's impact forces with the ground are absorbed. As the stance phase continues, the body's COM moves directly over the foot; this is **midstance**. As the body continues its forward movement and the heel lifts off the floor, the stance phase progresses into **terminal stance**. Stance ends at **preswing** when the toes leaves the ground. Swing phase includes initial

TABLE 12–1 | PHASES AND SUBPHASES OF THE GAIT CYCLE: DEFINITION AND TIMING

Phase	Definition and Description	Contralateral Limb
Stance Phase 60% gait cycle: 0%–60%		
Initial Contact 0%–2%	Floor contact, typically with heel. This is the initial period of double support.	End terminal stance
Loading Response 2%–10%	Body weight transferring to limb and foot lowering to floor **Double support continues.*	Preswing
Midstance 10%–30%	Begins at onset unilateral stance when opposite foot is lifted through to when HAT is aligned over single limb **Unilateral stance*	Midswing
Terminal Stance 30%–50%	Heel rises or "heel off," limb advances over forefoot and trunk moves ahead of support limb with the limb now trailing in extension	Terminal swing
Preswing 50%–60%	Floor contact is onto metatarsal heads coinciding with opposite foot making contact; ends with toe-off **Onset of second period of double support*	Initial contact-Loading
Swing Phase 40% gait cycle: 60%–100%		
Initial Swing 60%–73%	Foot lifted, and knee flexes to shorten limb and meet demand to accelerate	Early midstance
Midswing 73%–87%	Limb now under and then anterior to HAT and positioned almost directly opposite contralateral stance limb; maximum knee flexion	Late midstance
Terminal Swing 87%–100%	Begins with tibia perpendicular to floor through full limb advancement forward as limb decelerates for initial contact	Terminal stance

swing, midswing, and terminal swing. Swing begins at the point the foot is no longer in contact with the floor with **initial swing**. When the tibia is perpendicular to the floor and during the middle part of the swing, it is in the **midswing** phase. **Terminal swing** is the third and final portion of the swing phase; the leg prepares to make initial contact again with the ground during terminal swing. The moment the foot makes contact with the ground, the swing phase ends and stance phase begins again. Since Figure 12.5 shows both right and left limbs, a comparison of timing during stance of one limb and swing of the contralateral limb may be observed (see Table 12-1). Keep in mind that, in the presence of pathology, some of these subphases may not occur or may occur with altered timing. These subphases are presented in more detail in the successive sections.

Functional Tasks of Gait

From a functional perspective, there are three fundamental tasks associated with human gait: weight acceptance, single limb support, and limb advancement.[22] The stance phase plays a role in all three of these basic tasks, each of its subphases contributing to varying degrees.[23] Initial contact and loading response are the two subphases primarily responsible for weight acceptance. Single limb stance occurs at midstance and is the time when balance during ambulation is most precarious. The body's center of mass has shifted laterally and is centered over only one supporting limb at this time. Limb advancement creates forward motion of the body and includes the stance subphases of terminal stance and preswing; these subphases provide propulsive forces to move the limb forward and thereby move the body forward. The stance subphases utilize effective force absorption and efficient energy expenditure to accomplish these tasks.[24]

The swing phase is concerned with only one of the three fundamental tasks: limb advancement. Limb advancement during the swing phase requires sufficient clearance of the foot from the floor. The limb performs this activity during the first half of swing and prepares for initial contact during the latter half of swing. During the first two subphases of the swing phase, initial swing and midswing, the limb flexes at the hip, knee, and ankle to functionally shorten the limb so the foot clears the floor. The knee then begins rapid extension in terminal swing to lengthen the limb; this motion increases step length and forms a rigid limb in preparation for stability at initial contact.[24] Table 12–2 summarizes the requirements of gait, the purpose of each subphase and the ranges of motion and the primary muscular requirements of each subphase's activity.

Kinematics of Gait

A kinematic study of gait includes describing gait in terms of its spatial and temporal characteristics (how and when the foot hits the ground) and how the entire body and its segments move through space. The following section describes normal gait from a kinematic perspective.

Spatial and Temporal Characteristics of Gait

Spatial characteristics are those variables that are easily visualized by looking at the feet as they make a walking pattern on the ground, such as when visible footprints are produced during a walk on the beach. These characteristics include: step length, stride length, step width, and angle of progression (Fig. 12.6). **Step length** is the distance between the initial contact (measured at the midpoint of the heel) of one foot to the initial contact of the opposite foot. In other words, as you step forward with your right foot, your right step length is from where your left foot contacted the ground (usually at the heel) to the corresponding point where your right foot contacts the

TABLE 12–2 | FUNCTIONAL REQUIREMENTS OF SUBPHASES OF GAIT

Phase	Functional Task	Joint Angle Requirement	Prime Muscular Force
Initial Contact	Makes contact with surface Weight acceptance	Ankle: 0º Knee: 3°–5º flexion Hip: 25°–30º flexion	Tibialis anterior Quadriceps Gluteus maximus and medius
Loading	Weight acceptance Shock absorption	Ankle: 15º plantarflexion Knee: up to 15º flexion Hip: 25°–30º flexion	Tibialis anterior Quadriceps Gluteus maximus
Midstance	Single limb support	Ankle: from 15º plantarflexion to 15º dorsiflexion Knee: 5º flexion Hip: full extension	Gastrocnemius and soleus Gluteus maximus, gluteus medius minimus, and TFL
Terminal Stance	Single limb support Propulsion	Ankle: 15º dorsiflexion to 20º plantarflexion Knee: moves into full extension Hip: 10º extension	Gastrocnemius
Preswing	Propulsion	Ankle: 20º plantarflexion Knee: 40º flexion Hip: 10º extension	Gastrocnemius Hip adductors Rectus femoris
Initial Swing	Limb shortening for foot clearance	Ankle: to neutral dorsiflexion Knee: 40º–60º flexion Hip: from extension to 25°–30º flexion	Tibialis anterior Hamstrings Iliopsoas
Midswing	Limb shortening for foot clearance Generation of momentum	Ankle: neutral Knee: 60º flexion Hip: 25°–30º flexion	Tibialis anterior Iliopsoas
Terminal Swing	Limb advancement Preparation for initial contact Deceleration	Ankle: neutral Knee: to full extension Hip: 25°–30º flexion	Tibialis anterior Gluteus maximus and hamstrings

Adapted from: Bertoti DB. *Functional Neurorehabilitation through the Life Span.* Philadelphia; FA Davis Company, 2004.

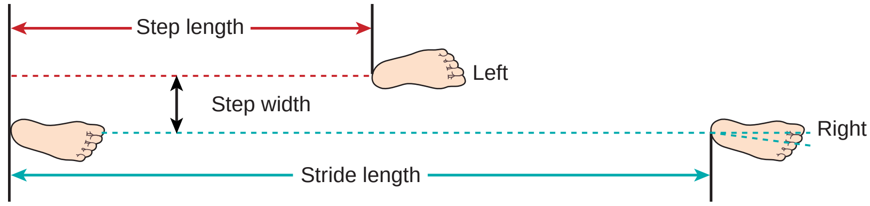


Figure 12.6 Spatial characteristics of gait: step length, stride length, step width, angle of progression.

ground (Fig. 12.6). **Stride length** is the distance between initial contact of one foot and initial contact of that same foot again. Stride length is synonymous with the combination of one right and one left step length. Typically, your step lengths are equal except during fast walking when the dominant leg has a little longer step because of its greater propulsive force.[25] In pathological conditions, step lengths may be significantly different between the involved and uninvolved extremities.[26, 27] **Step width** is the horizontal distance between the two feet, measured from the midpoint of one heel to the midpoint of the next heel contact. Step width measures typically between 2 to 4 inches (5 to 10 cm) for adults; again, this standard does not hold true in some pathological conditions. The **angle of progression** is the angle formed between the line of progression in a straight line and a line that bisects the foot at the heel's midpoint and runs between the second and third toes. Out-toeing of about 7° is typical in mature adults.[28]

Temporal characteristics are those variables that describe any characteristic that has to do with time, such as **velocity, step duration,** and **cadence. Velocity** is the distance covered over a unit of time such as meters per second or miles per hour. The number of steps completed per unit of time, usually given in steps per minute, is called **cadence**.[29] Normal walking velocity includes a wide latitude of speeds. Since there is such variation in walking speed, a description of an individual's gait pattern ordinarily includes velocity or cadence. Typical adult walking ranges from about 50 to 120–130 steps per minute. Calculated differently, average normal walking speed is about 80 m/min.[30] It is interesting to note that the optimal speed for most efficient walking individuals of average height is also at this speed.[30] Speeds lower or higher than this require more muscle effort and energy production.

Walking speed is important in a complete gait analysis since changes in speed impact other factors such as time and distance measurements, energy expenditure, and muscle activity. Normal subjects have the ability to alter their speed of walking from a stroll to a fast walk and into a run, thus making comparisons difficult. Each person, however, has a free or comfortable walking speed on a smooth, level surface that is most energy efficient for that individual. Part of the variability between individuals seen in walking speed is dependent on stride length, which is due to leg length. Free walking speed is often used in gait studies because it represents optimal efficiency for each individual, and the able-bodied subject reproduces the same values if the walking surface and the footwear remain the same.[30] In a study by Perry,[20] stride length averaged 1.4 m and the mean cadence was 113 steps per minute. The mean velocity of adults walking a free pace is 82 m/min, or approximately 3 miles per hour.[20] Men walked faster and had a longer stride length and a slower cadence than women (Table 12–3). Typical walking speed for men is 100 to 120 steps per minute; for women, it is 105 to 125 steps per minute.[20] Rates above or below these values are classified as fast or slow walking speeds.

Changes in walking speed are made by altering stride length or cadence, with the normal individual usually changing both parameters. Increased speed results in diminished duration of all of the component phases of the gait cycle: stance, swing, and double

TABLE 12–3 | MEAN STRIDE VALUES IN NORMAL ADULTS 20 TO 80 YEARS OF AGE WALKING AT FREE OR CUSTOMARY WALKING SPEED ON A SMOOTH LEVEL SURFACE[20]

	Males	Females	Total
Number of subjects	135	158	293
Velocity (meters per minute)	86	77	82*
Stride length (meters)	1.46	1.28	1.41*
Cadence (steps per minute)	111	117	113*

* Averages
Source: Data from Perry, J. *Gait Analysis: Normal and Pathological Function.* Thoroughfare, NJ: Slack, 1992.

PRACTICE POINT

One of the first questions active individuals ask their clinicians is, "When can I start running?" Although running is presented later in this chapter, it is important for the clinician to put the individual's condition in perspective. To do this, the clinician should know what normal motions are required for ambulation and realize that even greater motion is necessary for running activities. Therefore, if an individual has less than 60° of knee flexion, for example, it should be made clear to the individual that it is essential to first have enough motion to walk before considerations for running is possible.

face include inertia, gravity, and friction, and the internal forces include muscle forces and passive tension from connective tissue structures such as ligaments, tendons, and joint capsules.

Ground Reaction Forces

Forces imparted by and on the body abide by Newton's Third Law of Motion: For every action, there is an opposite and equal reaction (Chapter 2). When the body takes a step, it imparts a force to the ground and the ground produces an equal reactive force in the opposite direction. This is **ground reaction force (GRF).** As with other forces, GRF is a resultant force, so it has magnitude and direction. Since the body functions three dimensionally, forces are imparted in a three-dimensional manner. These three different directions are vertical, anterior-posterior, and medial-lateral. Since the foot is the point of contact with the ground, the GRF between the ground and foot impacts at this location, as illustrated in Figure 12.8. The largest of these components is the vertical force (Y) directed perpendicular to the floor toward the earth. This force represents an acceleration or deceleration force to the body's forward motion. It is greatest at two specific points of the stance phase: at initial contact as the supporting limb lands on the ground and at preswing when the body mass accelerates to propel the leg and body forward. This component force exceeds body weight. The decrease in force that occurs between these two peaks to below body weight at midstance is due to elevation of the COM; since the COM moves up during this time of stance, the downward forces diminish.

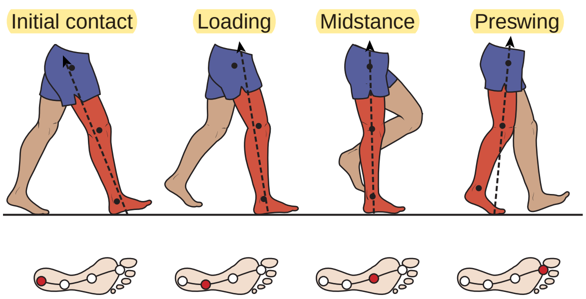


Figure 12.8 Relationship of the ground reaction force (GRF) and joint axes during stance phase. Note how the center of pressure (CoP) pathway moves from the heel at initial contact through the foot and to the great toe at the end of stance.

The Z-vector represents anterior-posterior forces directed at the foot during initial contact and preswing; these are shear forces. The anterior force of the foot occurring at initial contact is counteracted by the posterior force of the ground, producing friction to prevent the foot from slipping forward. The direction of these two forces switches at preswing so the foot produces a posterior force while the ground creates an anterior force; the friction created at this time provides the traction needed to advance the COM forward. In addition to allowing friction to secure a foothold, the AP force at initial contact primarily provides a deceleration of the limb, slowing the leg as it transitions from nonweight-bearing to weight-bearing. At the other end of the stance phase, the AP force becomes an accelerator of the limb as the force produced during preswing converts from friction to propulsion of the limb forward when it becomes nonweight-bearing. As one limb decelerates, the other accelerates, providing a smooth transition from one limb to the other throughout gait. During normal walking speeds, this anterior-posterior force is about 20% of the body's weight.[43] As the step length increases, the force magnitudes at initial contact and preswing also increase.

The X-force component is the medial-lateral shear between the foot and the ground. This force is the smallest of the three component forces making up ground reaction forces. This component is dependent upon the lateral movement of the body's COM as the body moves from one lower extremity to the other; since the amount of this lateral movement is variable and dependent upon factors such as the individual's size, weight, step width, and lateral hip muscle strength,

Glossary

A

Abduction *(Chapter 1, 11).* Position or frontal plane movement of the body segment away from the midline. In the foot, abduction occurs in a transverse plane around a vertical axis.

Acceleration *(Chapter 2).* A rate of increase in velocity.

Accessory motion *(Chapter 1).* Also known as component motions. Motions that take place at a joint as a natural smooth accompaniment to active range of motion.

Acetabular fossa *(Chapter 9).* Central area of acetabulum, devoid of hyaline cartilage, which houses fibroelastic fat pad and ligamentum teres.

Acetabulum *(Chapter 9).* The cup of the pelvis into which the head of the femur fits to form the hip joint, structurally comprised of portions from all three pelvic bones.

Actin *(Chapter 3, 4).* The thinner protein filament that contains troponin and tropomyosin, which control the binding between actin and myosin that occurs during muscle contraction.

Action potential *(Chapter 3).* Electrochemical signal propagated within nervous system whereby an excitable nerve or muscle cell is sufficiently depolarized then repolarized.

Active insufficiency *(Chapter 4).* When a muscle that crosses more than one joint is at its shortest position but the joint still has more motion available. The muscle's actin and myosin overlapping sites are used up, but the joint has not reached the end of its motion. This occurs in muscles that cross more than one joint; e.g., the hamstrings are used to fully extend the hip but are unable to fully flex the knee simultaneously.

Active tension *(Chapter 4).* Force produced by the muscle itself through crossbridge activation between the actin and myosin fibers of muscle tissue. Of all factors contributing to overall muscle force, active tension is the largest. See passive tension.

Adduction *(Chapter 1, 11).* Position or frontal plane movement of the body segment toward the midline. In the foot, adduction occurs in transverse plane around a vertical axis.

Adductor tubercle (*Chapter 9).* Projection proximal to the medial epicondyle at the distal femur, so named because the adductor magnus muscle attaches to it.

Aerobic metabolism *(Chapter 3).* Oxidative metabolism of fats, carbohydrates, and proteins for the production of energy within the muscle.

Afferent nerves *(Chapter 3).* Sensory nerves that send impulses into the central nervous system.

Agonist *(Chapter 4).* Muscle or muscle group that is primarily responsible for producing a motion.

Akinesia *(Chapter 3, 12).* Difficulty initiating movement. It is a condition that is seen typically in Parkinson's disease.

All-or-none law *(Chapter 3).* Principle in which all of the muscle fibers within a motor unit will contract maximally when the nerve is activated.

Alpha (α) motor neuron *(Chapter 3).* Large neuron that innervates skeletal muscle.

Ambulation *(Chapter 12).* Defined in a broad sense as a type of locomotion but is more often used in the clinical sense of describing whether or not someone can move about or walk freely or with the assistance of some device.

Amphiarthrosis *(Chapter 1).* Joint classification hallmarked by a cartilaginous structure with combinations of both fibrous and hyaline (or articular) cartilage and typically a disc between the bony partners, so that both a stability and mobility function can be achieved, such as seen at the intervertebral joints of the spine, the pubic symphysis, and the first sternocostal joint.

Anatomical position *(Chapter 1).* Reference position for the human body defined as standing erect with head, palms, and toes facing forward and the fingers extended.

Anaerobic metabolism *(Chapter 3).* Reactions that do not require the expenditure of oxygen as the energy source.

Angle of inclination *(Chapter 5, 8, 9).* The angle that is formed between either the humeral or femoral heads and their respective bony shafts. In the humerus, the angle of inclination is created by the lines running through the shaft of the humerus and the humeral head. Normal angle of inclination of the humerus is 130° to 150° with about 125° in the average adult. There is also an angle of inclination in the hip; this angle is formed between the shaft of the femur and the long axis of the femoral neck. The femoral angle of inclination is about 127°.

Angle of pelvic inclination *(Chapter 9).* The inclination in degrees of the amount of range of motion of anterior and posterior pelvic tilt, visualized by drawing a line representing an oblique plane through the PSIS and the foremost portion of the symphysis pubis, resulting in an angle of this plane with the transverse or horizontal plane.

Angle of progression *(Chapter 12).* This is the angle in gait that is formed between the line of progression in a straight line and a line that bisects the foot at the midpoint of the heel and runs between the second and third toes. An out-toeing of about 7° is typical in mature adults.

Angle of torsion *(Chapter 5, 9).* This is the angle formed between the plane of the humeral head and the plane of the humeral condyles. Normal angle of torsion is in 30° of retroversion. In the hip, it is the angle formed between the shaft and neck in the transverse plane, visualized by a line drawn bisecting the femoral head and neck and superimposing that line on a line running between the medial and lateral femoral condyles; this angle is reflective of the innate twist in the femur so that the head and neck are rotated anteriorly 13° to 15°.

Angular (rotary) motion *(Chapter 1).* Motion occurring around an axis or a pivot point. See rotary motion.

Ankle complex *(Chapter 11).* The talocrural joint and subtalar joints of the ankle and foot are often referred to as the ankle complex. Together, they function to provide mobility and adaptability of the foot and ankle, especially during closed chain activities.

Ankle strategy *(Chapter 12).* Posture control that is initiated from the ankles and feet.

Ankylosis *(Chapter 8).* Restriction of joint movement caused by pathology within the joint.

Annular ligament *(Chapter 6).* A fibrous ligament, lined with hyaline cartilage, which forms a ring around the head of the radius as a major support at the proximal radioulnar joint.

Antagonist *(Chapter 4).* Muscle or muscle group that is primarily responsible for producing motion that is directly opposite the desired or intended motion.

Antecubital *(Chapter 6).* The anterior aspect of the elbow; at the fold or bend of the elbow complex.

Anterior inferior iliac spine (AIIS) *(Chapter 9).* This is a landmark, not easily palpated, located inferior to the ASIS on the anterior aspect of the ilium of the pelvis.

Anterior radioulnar ligament *(Chapter 6).* Ligament that stabilizes the anterior aspect of the distal radioulnar joint.

Anterior superior iliac spine (ASIS) *(Chapter 9).* Easily palpable prominence is on the most anterior and superior aspect of the crest of the ilium of the pelvis.

Anterior tilting *(Chapter 5).* Rotation of the scapula around a medial-lateral axis so that the superior aspect of the scapula rotates forward or anteriorly. The motion occurs as the glenohumeral joint is hyperextended.

Anteversion *(Chapter 9).* An increase in the femoral angle of torsion, clinically presenting as intoeing, or "pigeon toes."

Antigravity muscles *(Chapters 3, 4, 12).* Postural muscles that maintain the body in an upright position against gravity. They have more type I muscle fibers than type II fibers. These muscles include primarily the neck and back extensors, hip and knee extensors, and to a lesser degree, the neck and trunk flexors and hip abductors and adductors.

Apophyseal plate *(Chapter 6).* The center of ossification or growth at the long end of a bone.

Apraxia *(Chapter 3).* Difficulty with planning a movement in which the individual's movements are typically slow and clumsy, with mild proximal weakness and loss of coordination around the proximal joints.

Areflexia *(Chapter 3).* Absent stretch reflexes; sign of a pathological condition.

Arthrokinematics *(Chapter 1).* Subdivision of kinematics, focused on a description of movement of the joint surfaces upon each other.

Arthrology *(Chapter 1).* (Gr. *arthron;* joint) The study of the classification, structure, and function of joints.

Association neuron *(Chapter 3).* Interneurons within the association cortexes of the CNS.

Ataxia *(Chapter 3).* Muscular incoordination that manifests when voluntary muscular movements are attempted, often seen as wide based movements; a common clinical symptom of cerebellar damage.

Athetosis *(Chapter 3).* Dystonic movement disturbance characterized by slow involuntary writhing or twisting, usually involving the upper extremities more than the lower extremities, whereby muscle tone appears to fluctuate in an unpredictable manner from low to high; most commonly manifested as a type of cerebral palsy.

Atrophy (*Chapter 4).* Decrease in a muscle's cell size, overall muscle girth, and strength secondary to injury, disuse, disease, or age.

Autogenic inhibition *(Chapter 3).* Mechanism of nonreciprocal inhibition mediated by GTO whereby activation of GTO by sufficient musculotendinous tension will cause inhibition of the agonist muscle and excitation of the antagonist (opposing) muscle.

Axial skeleton *(Chapter 8).* The part of the bony skeleton comprising vertebral column, skull, and ribs.

Axis *(Chapter 1, 2).* The point around which rotation occurs.

Axis of rotation *(Chapter 1, 2).* Pivot point for the angular motion at a joint, located within or near the surface of the joint.

B

Ball and socket joint *(Chapter 1).* Triaxial joint with a spherical type "ball" paired with a concave cup, such as seen at the hip and glenohumeral joint.

Base of support (BOS) *(Chapter 2).* The total surface area that supports a body or an object. It includes the area between and within the points of contact. The larger the base of support, the more stability the body or object it has.

Biaxial joint *(Chapter 1).* Joint that moves in two planes around two axes, having two degrees of freedom; includes three structural types: condyloid, ellipsoidal, and saddle.

Bipedal *(Chapter 12).* (L., *bi,* two, plus *pes,* foot) Walking on two extremities.

Biomechanics *(Chapter 1).* Application of the principles and analysis of mechanics to the living human body.

Bipennate *(Chapter 4).* Muscle fiber arrangement with two groups of parallel fibers running to the muscle's central tendon, similar to a feather's arrangement.

Bony (or hard) end feel *(Chapter 1).* Normal end feel felt when the motion is stopped by contact of bone on bone, as in elbow extension when the olecranon process of the ulna fits snugly into the olecranon fossa of the humerus.

Bradykinesia *(Chapter 3, 12).* Slowness or difficulty maintaining movement once it is initiated.

Bruxism *(Chapter 8).* Grinding of the teeth.

Bursa *(Chapter 1).* Fluid filled sac whose purpose is to decrease friction and offer some added protection or shock absorption between joint surfaces; can be natural or acquired.

C

Cadence *(Chapter 12).* A temporal characteristic of gait that is defined as the number of steps completed per unit of time such as steps per minute.

Capitulotrochlear groove *(Chapter 6).* A groove on the distal humerus between the capitulum and trochlea, within which the radius slides during elbow flexion.

Capitulum *(Chapter 6).* The distal bony prominence of humerus that articulates with the radius deep within elbow joint.

Capsular (firm or ligamentous) end feel *(Chapter 1).* A springy, normal end feel in which the limitation is from ligamentous, capsular, or muscle structures, such as in wrist flexion.

Cardinal planes *(Chapter 1).* Three-dimensional coordinate system used as frame of reference to describe and record location in space of human body and the motions at its joints.

Carrying angle *(Chapter 6).* This is anatomically known as the cubital angle, created between the humerus and forearm whereby the forearm deviates laterally in relation to the humerus because the axis for flexion and extension of the elbow is not fully perpendicular to the shaft of the humerus; this angle varies somewhat in individuals and is usually more pronounced in women than in men.

Catalyst *(Chapter 3).* A substance that acts to accelerate a chemical reaction but is not permanently changed by the chemical reaction.

Center of gravity (COG) *(Chapter 1, 2).* Center around which the mass is centered. It identifies the point at which gravity exerts its influence on an object or body's center of mass.

Center of mass (COM) *(Chapter 2).* The point around which the mass of an object or body is evenly distributed. Center of gravity for the human body, located just anterior to the second sacral vertebrae in humans. See center of gravity.

Center of pressure (COP) *(Chapter 12).* The location of the application point of the resultant ground reaction force within the foot.

Central nervous system (CNS) *(Chapter 3).* Composed of the brain and spinal cord.

Central pattern generators *(Chapter 3).* Complex patterns of muscle activation that produce purposeful movement through neural connections at a spinal level.

Cerebral Palsy *(Chapter 3).* A general term used to describe a group of motor disorders that generally results from damage to the developing brain.

Cerebral shock *(Chapter 3).* Time of profound depression of motor function in which all muscles of the affected body segments are involved, used to describe the temporary flaccid state in the muscles of the person following a brain injury when the nervous system is in a state of shock after a lesion of acute onset.

Chopart's joint *(Chapter 11).* This joint is the transverse tarsal joint, also known as the talonavicular joint of the midfoot. It is called Chopart's joint, named after French physician, François Chopart, who lived and practiced medicine in Paris during the 1700s.

Choreiform movements *(Chapter 3).* Type of dystonic movement characterized by quick, involuntary, jerky, rapid, or irregular movements whereby muscle tone appears to fluctuate in an unpredictable manner from low to high.

Circumduction *(Chapter 1, 7).* Movement performed during which the moving segment moves in a path similar to following the surface of a cone and the tip of the segment traces a circular path; typically seen in triaxial joints.

Clonus *(Chapter 3).* Spasmodic alterations of muscle contractions between antagonistic muscle groups, caused by hyperactive stretch reflexes; a symptom of CNS pathology.

Closed chain motion *(Chapter 1, 4).* When the distal portion of the segment is anchored or fixed, so movement of one part of the segment influences the other parts of the segment. These motions are typically used for force production rather than speed. Also referred to as closed kinematic chain.

Close-packed position (CKC) *(Chapter 1).* Joint position whereby the surfaces of the joint pairs match each other in maximum congruency (coinciding exactly) so that the maximum area of surface contact occurs, the attachments of the ligaments are farthest apart and under tension, the capsular structures are taut, and the joint is mechanically compressed and difficult to distract (separate).

Coactivation *(Chapter 6).* Muscle recruitment pattern whereby the agonist and antagonist both fire, often seen in new or unskilled movements.

Cogwheel rigidity *(Chapter 3).* Type of rigidity characterized by alternate episodes of resistance and relaxation, commonly seen in patients with Parkinson's disease.

Component vectors *(Chapter 2).* Forces whose combined magnitudes and directions produce a resultant vector.

Composition of forces *(Chapter 2).* Sum of all forces acting on a body or segment.

Concave-Convex principle *(Chapter 1).* Mechanical principle, but not a steadfast rule, that establishes that if the bone with the convex joint surface moves on the bone with the concavity, the convex joint surfaces move in the opposite direction to the bone segment, whereas if the bone with the concavity moves on the convex surface, the concave articular surface moves in the same direction as the bone segment.

Concurrent force system *(Chapter 2).* Two or more forces acting on a segment or body. The result of these forces creates a resultant force, and this resultant force is a combination of both original forces with its origin at the same site as the two original forces.

Concentric motion *(Chapter 4).* Muscle activation that produces shortening of the muscle as it moves the joint.

Conduction velocity *(Chapter 3).* Speed of transmission of an impulse along a nerve axon; related to the axon diameter and presence or absence of myelin.

Condyle *(Chapter 6).* Knob-like enlargements of long bones, such as the femur and humerus.

Condyloid joint *(Chapter 1).* Type of biaxial joint; a condyloid joint shape can be described as a spherical convex surface partnered with a shallow concave surface, as seen in the metacarpophalangeal joints of the hand (your knuckles) and foot.

Constraints *(Chapter 3).* Limitation or restriction imposed on the movement.

Contact pressure *(Chapter 10).* The ratio between the amount of joint reaction force and the area of contact. The larger the area of contact, the less stress applied to a structure.

Coronal (frontal) plane *(Chapter 1).* or XY plane, so named because it is parallel to the frontal bone along the coronal skull suture, dividing the body into front and back parts. It is the plane within which abduction and adduction movements occur.

Coronary ligament *(Chapter 10).* The ligament that connects the lateral rim of each meniscus to the tibia. This is a loose ligament that allows some movement of the menisci during knee motion. Also known at meniscotibial ligaments.

Coronoid fossa *(Chapter 6).* A cavity on the anterior aspect of distal humerus; receives coronoid process of ulna when elbow is in full flexion.

Coronoid process *(Chapter 6).* A distinctive bony process on anterior medial superior surface of the ulna.

Counternutation *(Chapter 8).* Movement of the sacrum by which the sacral promontory moves superiorly and posteriorly as the distal sacrum and coccyx move anteriorly. During counternutation, the iliac crests move apart and the ischial tuberosities move closer together.

Coupling motions *(Chapter 8).* Motions occurring in one plane that occurs with simultaneous motion(s) in another plane(s) because of the orientation of the planes of the joints. An example is lateral flexion of the spine and spinal rotation—it is not possible to isolate either lateral flexion or rotation of the spine.

Coxa valga *(Chapter 9).* A persisting increase in the neck-shaft angle whereby the angle of inclination is greater than 130°, resulting in several functional consequences: the limb will appear to be longer, placing the limb in an adducted position during weight-bearing, resulting in a functional increase of limb length.

Coxa vara *(Chapter 9).* A condition whereby the femoral neck-shaft angle is smaller than the typical 125° (approaching 90°), resulting in several functional consequences: a functional decrease in leg length; the limb appears to take on a more abducted position with a wide base of support.

Crawling *(Chapter 13).* The progression in the prone position in which the belly is in contact with the supporting surface, and the extremities are used in a reciprocal fashion to propel the body forward or backward.

Creep *(Chapter 4).* Elongation of tissue with the application of a low-level force over time.

Creeping *(Chapter 13).* A progression in quadruped in which the belly is lifted off of the supporting surface and the extremities move reciprocally to move the body forward or backward.

Crossbridges *(Chapter 3, 4).* Myosin "heads" extending from "arms" at angles from the myosin, whose function is to connect myosin to actin thereby providing muscle contraction.

Cubital *(Chapter 6).* (L., *cubitum*, elbow) Pertaining to the elbow or forearm.

Cubital angle *(Chapter 6).* The carrying angle. The angle created between the humerus and forearm with the elbow in full extension whereby the forearm deviates laterally in relation to the humerus because the axis for flexion and extension of the elbow is not fully perpendicular to the shaft of the humerus; this angle varies somewhat in individuals, usually being more pronounced in women than in men.

Curvilinear *(Chapter 1).* Subset of linear motion whereby the object travels in a curved path such as that seen when tossing a ball to a friend.

Cubitus valgus *(Chapter 6).* The lateral angulation of the forearm with respect to the humerus; also known as carrying angle when at about 15° or less. Term also can be used to signify excessive lateral angulation of the forearm with respect to the humerus.

Cubitus varus *(Chapter 6).* The medial angulation of the forearm with respect to the humerus.

D

Deceleration *(Chapter 2).* A rate of decrease in velocity.

Degrees of freedom *(Chapter 2, 3).* The number of planes through which a joint is able to move. For every degree of freedom, there is an axis of movement. In kinesiological terms, the number of independent planar movements permitted at a joint, functionally translate into how many movement options exist at that joint or body segment.

Delayed-onset muscle soreness (DOMS) *(Chapter 4).* Soreness that develops in muscles about 24 hours after exercise, especially eccentric activities.

Demifacet *(Chapter 8).* A notch on the superior and inferior posterior thoracic vertebral body (T1-T9) that articulates with the head of the rib.

Depolarization *(Chapter 3).* Rapid exchange of positive and negative ions across nerve or muscle cell membrane resulting in a movement of the membrane to a more positive charge.

Depression *(Chapter 5).* The scapular motion in which the scapula slides downward on the thorax relative to its resting position.

Diarthrosis *(Chapter 1).* Joints whose primary purpose is to provide mobility; structurally hallmarked by the presence of a synovial joint capsule; further subdivided into uniaxial, biaxial, and triaxial joints.

Dislocation (*Chapter 1).* The two bony partners at the joint are completely removed or disassociated from each other, usually meaning that some damage, even rupture of the capsule, has occurred.

Displacement *(Chapter 2).* When motion of a body or a body's segment occurs with application of a force.

Distal attachment *(Chapter 4).* The point at which a muscle inserts into bone. The distal attachment is also called the insertion (as opposed to its origin). This location is more distal from the body than the other end of the muscle attachment site. See proximal attachment.

Disuse atrophy *(Chapter 3).* Muscular atrophy, secondary to immobilization or bed rest.

Dorsal (posterior) radioulnar ligament *(Chapter 6).* Ligament that stabilizes posterior aspect of distal radioulnar joint.

Dorsiflexion *(Chapter 1, 11).* Near-sagittal plane flexion movement of the dorsum of the foot toward the anterior aspect of the tibia.

Double float phase *(Chapter 12).* The part of the gait cycle during running when neither lower limb is in contact with the ground. There are two double float phases, one at the beginning of initial swing and one at the end of terminal swing. Also called float phase.

Double-limb support *(Chapter 12).* The part of the gait cycle during walking in which both lower extremities are in contact with the ground. This occurs at the first and last 10% of each limb's stance phase.

Dynamic action system *(Chapter 3).* Any system that demonstrates change over time; used to describe the human motor control system.

Dynamic action system model *(Chapter 3).* Theoretical model that views movement as emerging from the dynamic cooperation of many subsystems in a task and environment specific context.

Dysmetria *(Chapter 3).* Inability to gauge distance in reaching or stepping; common clinical symptom of cerebellar damage.

Dystonia *(Chapter 3).* A syndrome dominated by sustained muscle contractions and disordered muscle tone, frequently causing abnormal postures, twisting, or writhing movements, and repetitive abnormal postures, often associated with basal ganglia disturbance.

E

Eccentric motion *(Chapter 4).* A muscle activation in which the muscle lengthens as it produces tension to control joint motion. Joint motion is produced by an outside force, and the muscle's force controls the rate of motion change.

Efferent nerves *(Chapter 3).* Nerves that send a response from the central nervous system to the muscles.

Elasticity *(Chapter 4).* The ability of tissue to succumb to an elongating force and then return to its normal length when the force is released.

Elevation *(Chapter 5).* The scapula slides upward on the thorax relative to its resting position.

Ellipsoidal joint *(Chapter 1).* Type of biaxial joint whereby the shape is spindle-like with one somewhat flattened convex surface articulating with a fairly deep concave surface such as seen at the radiocarpal joint at the wrist.

Electromyography (EMG) *(Chapter 8).* Used as a diagnostic tool in medicine or an investigative tool in research. It detects electrical activity of muscles and nerves. The three types of electrodes used to detect EMG include surface, wire, and needle. Needle electrodes are used in diagnostic techniques, whereas the surface and wire are more often used in research investigations to identify muscle activity.

Empty end feel *(Chapter 1).* A pathologic end feel denoting an abnormal absence of resistance on motion and sometimes, pain.

End feel *(Chapter 1).* Resistance to further motion felt by the examiner when a normal joint is moved passively to the end of its range of motion; also called the physiologic end feel; further clarified as firm (capsular or ligamentous) or hard (bony).

Endomysium *(Chapter 4).* The fascial layer surrounding individual muscle fibers.

Endoplasmic reticulum *(Chapter 3).* A system of interlaced tubes within the interior of a muscle fiber that plays a vital role in excitation and contraction comprised of the sarcoplasmic reticulum and the transverse tubules.

Endurance *(Chapter 3).* The ability to perform the same act repeatedly over a period of time. Loss of endurance may be a sign of cardiopulmonary, muscular, or neurological problems.

Epicondyle *(Chapter 6, 10).* A prominence or eminence superior to a condyle. The most noted ones are on the distal humerus and distal femur. They serve as locations for muscles and ligaments to attach.

Epimysium *(Chapter 4).* The fascial layer surrounding an entire muscle.

Eponym *(Chapter 11).* Something that is named after an individual, real or fictitious.

Equilibrium *(Chapter 2).* When a system is in balance, it is in equilibrium. One direction of forces equals the opposing direction of forces.

Eversion *(Chapter 1, 11).* Transverse plane motion at the subtalar joint of turning the foot outward.

Excitable *(Chapter 3).* A membrane or cell responding when a sufficient stimulus is applied to it.

Extensibility *(Chapter 4).* The ability to stretch, elongate, or expand.

Extension *(Chapter 1).* Straightening motion at a joint in which one bony partner moves away from the other and there is an increase in joint angle; occurring in the sagittal plane.

Extensor lag *(Chapter 10).* When a joint is unable to achieve full active extension but has full passive extension. It may be the result of weakness or pain.

Extensor mechanism *(Chapter 7).* The unique arrangement of the long extensor tendons of the digits and the attachments of the intrinsic muscles of the hand. Also known as extensor hood mechanism, extensor expansion, apparatus, aponeurosis, retinaculum, or hood.

External moment arm *(Chapter 2).* The perpendicular distance from the joint's axis to the external force.

External (lateral) rotation (Chapter 1). A transverse plane motion of turning toward the side or outward, sometimes used instead of lateral rotation; lateral rotation is the term preferred over external rotation since it more adequately indicates the motion.

Extrafusal muscle fibers *(Chapter 3).* Skeletal muscle fibers.

Extrapyramidal tract or system *(Chapter 3).* Efferent (UMN) tract containing axons that descend into the brainstem that synapse there outside of the medullary pyramids; distinctive from pyramidal or corticospinal tract.

Extrinsic muscles *(Chapter 7, 11).* Muscles of the hand or foot that originate more proximally on the limb and insert onto the hand or foot. These muscles are generally designed for power or force production. See intrinsic muscles.

F

Fascia *(Chapter 4).* Connective tissue, composed primarily of collagen, that surrounds tissue. It is a fibrous sheet that separates muscle cells, fascicles, and layers.

Fasciculus *(Chapter 3).* Term used to describe the organization of skeletal muscle fibers into bundles, each called a fasciculus.

Fast-twitch fiber *(Chapter 3).* Type II or phasic muscle fiber; uses a fast glycolytic metabolic process and fatigues easily.

Fatigue *(Chapter 3).* A failure to maintain the required or expected force of muscle contraction, due to any one of several physiologic mechanisms.

Fascicle *(Chapter 4).* A bundle of muscle fibers or a bundle of nerve fibers. If it is a muscle bundle, it is surrounded by perimysium. If it is a nerve bundle, it is surrounded by perineurium.

Feiss' line *(Chapter 11).* A line drawn from the apex of the medial malleolus to the plantar surface of the first MTP joint. If the medial longitudinal arch is normal, the navicular tubercle will fall on or close to this line.

Festinating gait *(Chapter 12).* A typical gait seen in Parkinson's patients that includes an acceleration of the shuffling gait with a shortening of the stride length.

Firm (or capsular or ligamentous) end feel *(Chapter 1).* A springy normal end feel in which the limitation is from ligamentous, capsular, or muscle structures, such as in wrist flexion.

First-order neuron *(Chapter 3).* Sensory neuron from the receptor which has an uninterrupted axon and enters the dorsal horn of the spinal cord; the main fiber usually ascends through the spinal cord to synapse on other neurons in the CNS.

Flaccid *(Chapter 3).* A complete loss of muscle tone with an absence of deep tendon reflexes. It may follow a lower motor neuron lesion or in the acute stage of an upper motor neuron lesion.

Flaccidity *(Chapter 3).* Pathological condition in which muscle tone is absent.

Float phase *(Chapter 12).* During running, at the beginning of initial swing and again at the end of terminal swing when neither limb is in contact with the ground; this provides more time during swing and less time during stance. Also called double-float.

Fusimotor neurons *(Chapter 3).* or gamma (γ) motor neurons; referred to as such because the neurons supply motor impulses to the intrafusal muscle spindle fibers.

Flexion *(Chapter 1).* Bending motion at a joint in which one bony partner moves toward the other and there is a decrease in joint angle; occurs in the sagittal plane.

Foramen of Weitbrecht *(Chapter 5).* Area between the middle and superior anterior glenohumeral ligaments that is a common site of anterior glenohumeral joint dislocations because of the capsule's weakness in the region.

Forefoot *(Chapter 11).* The forefoot is that part of the foot made up of all of the metatarsals and phalanges.

Force *(Chapter 2).* A push or pull that produces displacement. The mathematical formula for force is F = m x a, where F is the amount of force created, m is the mass of the object and a is the acceleration of the object.

Force arm *(Chapter 2).* Also called lever arm. The perpendicular distance from the force applied to produce motion to the axis of motion.

Force couple *(Chapter 5).* Rotation around an axis by two or more muscles that otherwise work opposite to one another.

Force feedback reflex *(Chapter 4).* This is an inhibitory reflex caused by muscle activity and occurs with activation of the Golgi tendon organs (GTO). Little is known about this reflex, but it is thought to play a role in coupling antigravity muscles that cross different joints during multijoint movements.

Force vector *(Chapter 2).* A force that is applied to a body has two dimensions—magnitude and direction.

Fovea *(Chapter 6, 7).* A concave depression at the base of the ulnar styloid process that provides attachment for the wrist's fibrocartilaginous disc. There is also a concave articulating fovea that serves as the articulating surface atop the radial head.

Free body diagram *(Chapter 2).* Simplified drawings of the body with the force vectors acting on the body or a segment.

Friction *(Chapter 2).* The resistance to movement between two surfaces or objects in contact with each other, typically in a horizontal direction.

Frontal (Coronal) plane: (XY plane) *(Chapter 1).* So named because it is parallel to the frontal bone along the coronal skull suture, dividing the body into front and back parts. It is the plane within which abduction and adduction movements occur.

Functional excursion (of a muscle) *(Chapter 4).* The distance a muscle is capable of shortening after it has been elongated as far as the joint(s) over which it passes allows.

Fundamental position *(Chapter 13).* This is similar to the anatomical position except the palms face the body; forearms are in neutral midposition.

Fusiform muscle *(Chapter 4).* Muscle fascicle arrangement that is parallel, creating a spindle-shaped muscle with tapered ends. Designed for speed of movement rather than force. Also known as strap muscle.

G

Gait *(Chapter 12).* The manner or style of walking.

Gait cycle *(Chapter 12).* The fundamental unit of human walking, described by studying the events associated with when the foot makes contact with the ground, swings through the air, and then makes contact with the ground again. The time from when one foot makes contact with the ground to the next time it makes contact again.

Gamma (γ) motor neurons *(Chapter 3).* Neurons that innervate the contractile element called the intrafusal (within the spindle) muscle fibers. Contractile element within the muscle spindle sensory receptor, composed of two types of fibers—nuclear bag and nuclear chain fibers.

Ganglia *(Chapter 3).* Aggregations of functionally and anatomically related neurons on the CNS; also called nuclei.

Genu valgus or genu valgum *(Chapter 10).* When the knee has an excessive Q angle and angles medially. Also called knock knee.

Genu Varus or genu varum *(Chapter 10).* or bowleg, when the knee has a diminished Q angle or the knee is laterally convex.

Gliding *(Chapter 1).* This term is synonymous with the basic joint motion of "sliding." See sliding.

Gluteus medius gait *(Chapter 9, 12).* or Trendelenburg gait, is a gait compensation seen in persons with significant hip abductor weakness might, demonstrated by lateral flexion of the trunk during the stance phase of gait over the stance limb. This maneuver will shift the center of gravity and the weight of HAT laterally over the hip joint axis, minimizing the torque demand on the weakened abductors.

Glycolysis *(Chapter 3).* Breakdown of glycogen from storage depots in muscles and liver for the purpose of supplying energy.

Golgi tendon organ (GTO) *(Chapter 3).* Sensory receptor located at musculotendinous junction that is receptive to tension stimulus.

Gomphosis joint *(Chapter 1).* The fit of a tooth in its socket; a type of synarthrodial joint.

Goniometer *(Chapter 1).* Measurement device which looks like a protractor with two arms hinged at a fulcrum. It is placed parallel to the two body segments to be measured and with the axis of the joint and the axis (fulcrum) of the goniometer superimposed so that the angle at the joint can be measured and recorded.

Goniometry *(Chapter 1).* An application of the coordinate system to a joint to measure the degrees of motion present in each plane of a joint.

Gunstock deformity *(Chapter 6).* Cubital varus, or a carrying angle of less than the normal 5° to 15° valgus angulation.

Gray matter *(Chapter 3).* Regions of CNS in which nerve cell bodies are concentrated; appears gray in color.

Greater sciatic notch *(Chapter 9).* An opening in the pelvic bone through which the sciatic nerve and piriformis muscle pass.

Greater trochanter *(Chapter 9).* Is easily palpated superior lateral prominence of the proximal femur; attachment site for the gluteus medius and lateral rotator muscles and an important landmark used in measuring leg length.

Ground reaction force (GRF) *(Chapter 12).* A resultant force comprised of reaction forces acting on the foot that occur in three different directions—vertical, anterior-posterior, and medial-lateral.

H

Hallux valgus *(Chapter 11).* A lateral deviation of the first MTP joint so the toe is at an angle toward the other toes. It is often a result occurring from excessive pronation.

Hard (or bony) end feel *(Chapter 1).* Normal end feel felt when the motion is stopped by contact of bone on bone, as in elbow extension when the olecranon process of the ulna fits snugly into the olecranon fossa of the humerus.

Head of the femur *(Chapter 9).* A large rounded proximal aspect of femur; articulates within the acetabulum as an articulating partner at the hip joint.

Head of the radius *(Chapter 6).* The superior prominence of the radius.

Heterarchy *(Chapter 3).* When the contributing systems are not arranged in a hierarchy; rather, all the contributing systems work parallel to each other.

Hierarchy *(Chapter 3).* When the contributing systems are arranged in a linear fashion, in which one is more important than the other and the lowest level is overseen by a higher level.

Hinge joint *(Chapter 1).* A type of uniaxial joint; e.g., the humeroulnar joint.

Hip strategy *(Chapter 12).* Control of posture that comes from adjustment movements produced at the hip, pelvis, and trunk.

Horizontal (Transverse) plane: (XZ plane) *(Chapter 1).* So named because it is parallel to the horizon and the floor, dividing the body into upper and lower parts, like a view from above. It is the plane within which rotational movements occur.

Hypermobile *(Chapter 1).* More joint motion than is expected or typical.

Hyperpolarization *(Chapter 3).* An increased negative potential (more negative than the resting potential) of the cell membrane.

Hyperreflexia (*Chapter 3).* Exaggerated stretch reflexes; sign of a pathological condition.

Hypertonia *(Chapter 3).* A motor disorder characterized by a velocity-dependent increase in the stretch reflex with exaggerated tendon jerks resulting from hyperexcitability. Common in upper motor neuron lesions.

Hypertrophy *(Chapter 4).* An increase in a muscle's cell size and overall muscle girth that accompanies gains in muscle strength.

Hypokinesis *(Chapter 3).* Decreased activity, often seen in the older adult.

Hypomobile *(Chapter 1).* Less joint motion than what is expected or typical.

Hyporeflexia *(Chapter 3).* Diminished stretch reflexes; a sign of a pathological condition.

Hypotonia *(Chapter 3).* A reduction of muscle stiffness characterized by low muscle tone, weakness, and a decreased ability to sustain muscle activation.

I

Iliac crest *(Chapter 9).* The very prominent and easily palpable superior bony border of the ilium of the pelvis, one on the right and one on the left side.

Iliac fossa *(Chapter 9).* A large concave well on the internal surface of the ilium, to which a portion of the large iliopsoas muscle attaches.

Ilium *(Chapter 9).* The more anterior and superior of the three pelvic bones; the bone that you feel when you "put your hands on your hips."

Impairments *(Chapter 3).* The typical consequences of disease or pathological processes indicated by signs and symptoms.

Inertia *(Chapter 2).* The reluctance of a body to change its current state of being, either stationary or in a uniform motion. Newton's First Law of Motion deals with this concept.

Inferior pubic ramus *(Chapter 9).* The bony aspect of inferior pubic bone; attachment site for most of the muscles that adduct the hip.

Initial contact *(Chapter 12).* The first subphase of the stance phase of gait during walking. During running, initial contact is not heel strike since most runners do not contact the ground with the heel first. Initial contact is when the foot makes contact with the ground. Also called heel strike.

Initial swing *(Chapter 12).* This is the first subphase of the swing phase of gait as the leg is off the ground and begins to swing forward. During this phase, the limb accelerates forward. Also called early swing.

Innervation ratio *(Chapter 3).* Average number of muscle fibers per motor unit in a given muscle.

Instant center of rotation (ICR) *(Chapter 10).* The theoretical axis of rotation of a joint that changes as the joint surface rolls and glides. Because of the joint's mechanics, the center of rotation, or its axis, changes as the joint moves through its range of motion.

Intention tremor *(Chapter 3).* Sometimes called an action tremor, a tremor evidenced upon purposeful movement of the body part, typically seen during reaching with the upper extremity, or stepping with the lower extremity, a symptom commonly seen in patients with cerebellar lesions.

Intercondylar fossa *(Chapter 10).* The distal femur's separation between the medial and lateral condyles that is evident at the bone's most distal aspect and posteriorly. This is the fossa through which the cruciate ligaments traverse between the tibia and femur.

Intercondylar groove *(Chapter 10).* A pulley-like furrow between the medial and lateral condyle of the distal femur. It is the femoral component of the patellofemoral joint. It is also known as the trochlear groove.

Internal moment arm *(Chapter 2).* The perpendicular distance from the joint's axis to the muscle.

Internal (medial) rotation *(Chapter 1).*Transverse plane movement of turning inward toward the midline, sometimes used instead of medial rotation; the more preferred term is medial rotation since it more accurately reflects the direction of motion.

Interneurons *(Chapter 3).* Neurons within the ventral horn and intermediate areas of the spinal cord that are essentially involved in the transmission to and regulation of movement via their action on alpha and gamma motor neurons.

Interosseous membrane *(Chapter 6, 11).* A strong, fibrous connective tissue located between the radius and ulna and between the tibia and fibula.

Intervertebral disc *(Chapter 8).* A fibrocartilaginous structure containing an annulus fibrosis outer section and a gelatinous-like nucleus pulposus. With the exception of the first and second cervical vertebrae and the sacrococcyx, an intervertebral disc sits between each vertebra of the spine. They allow motion and transfer weight between the vertebrae.

Intrafusal muscle fibers *(Chapter 3).* Literally means "within the fuse or spindle;" contractile element (two types—nuclear bag and nuclear chain fibers) within the muscle spindle sensory receptor, innervated by gamma (γ) motor neurons.

Intrinsic muscles *(Chapter 7, 11).* Muscles of the hand or foot that originate and insert on the hand or foot, respectively. They do not come from outside the hand or foot segment. These muscles are used for fine motions and stability of the hand or foot.

Inversion *(Chapter 1, 11).* Transverse plane motion at the subtalar joint of turning the foot inward.

In vivo *(Chapter 4).* Refers to the living body. This is usually contrasted with *in vitro* which is an experimental environment in which, for example, a muscle fiber, bone, or other tissue may be isolated and investigated in a lab without regard to its normal environment.

Irritable *(Chapter 3).* Capable of responding to a stimulus.

Ischial ramus *(Chapter 9).* A not easily palpable bony extension, medially connecting the body of the ischium to the ramus of the pubis; an attachment site for the adductor magnus and for some of the small lateral rotators of the hip.

Ischial tuberosity *(Chapter 9).* A notable large palpable feature on the most inferior aspect of the ischium of the pelvis; an important landmark because it is the weight-bearing prominence upon which you sit and serves as the common attachment for the hamstring muscles.

Isometric activation *(Chapter 4).* A muscle tenses, or produces force, without motion.

Isotonic activation *(Chapter 4).* A muscle produces force that produces the same tension throughout its motion. This occurs in the laboratory but not in the human body.

J

Joint play *(Chapter 1).* Amount of additional joint motion able to be discerned by the examiner; occurs only in response to external force. These slight passive translations that occur in most joints are described by defining the direction of the translation: anterior-posterior, medial-lateral, and superior-inferior.

Joint reaction force *(Chapter 2).* The amount of force either compressing or distracting the joint surfaces when forces such as muscle force and gravity are applied to a body segment. Also referred to as joint force.

Joint receptors *(Chapter 3).* Located within joint capsules and ligaments, they are afferent sensors; continually provide feedback to CNS by informing the nervous system of momentary angulation of joints and of the rate of movement of joints.

K

Kilograms *(Chapter 2).* Measurement of mass in the metric system; 1 kg = 0.031 slugs.

Kinematics *(Chapter 1).* Describing and measuring human movement by focusing on the type of motion, the direction, and the quantity of the motion without regard for the forces that may produce that movement; further subdivided into osteokinematics and arthrokinematics.

Kinematic chain *(Chapter 1).* Combination of several joints uniting successive segments, further clarified as open (distal segment free) or closed (distal segment fixed) kinematic chain.

Kinesthesia *(Chapter 3).* Awareness of dynamic joint motion.

Kinetics *(Chapter 1).* The science that deals with forces that produce, stop, or modify motion of bodies as a whole or of individual body segments. The study of forces acting on the body.

Krebs cycle *(Chapter 3).* Or tricarboxylic acid cycle is the process whereby the chemical energy reserves for muscle contraction are restored by oxidative metabolism of fats, carbohydrates, and proteins in the mitochondria of muscle fibers. Enzymes split the large molecules into smaller units that can be oxidized in a series of chemical reactions yielding reaction end products of carbon dioxide, water, and ATP, which are used for restoration and maintenance of energy stores or are released in respiration.

Kyphosis *(Chapter 8).* An exaggerated posterior convex curvature of the spine.

Kyphotic curve *(Chapter 12).* Considered functionally to be a *primary* curvature of the vertebral column because it is the first demonstrated curve of the column.

L

Lamina *(Chapter 8).* The part of a vertebra that is part of the neural arch and lies between the vertebra's transverse process and spinous process. This section of the vertebra is usually excised in a laminectomy.

Lateral epicondyles *(Chapter 6, 10).* A bony prominence that is superior to a lateral condyle and serves for a site of insertion for tendons and ligaments; e.g., there are lateral epicondyles in the elbow and knee.

Lateral femoral condyle *(Chapter 10).* A large knob-like lateral distal end of the femur, forming part of the femoral connection at the knee joint.

Lateral flexion *(Chapter 1).* Frontal plane motion of side-bending of the neck or trunk.

Lateral malleolus *(Chapter 11).* See malleolus.

Lateral (external) rotation *(Chapter 1).* A transverse plane motion of turning toward the side or outward. This term more accurately reflects the movement rather than the term "external rotation."

Lateral supracondylar ridge *(Chapter 6).* The bony ridge superior to the lateral epicondyle of the humerus; an attachment site for the brachioradialis muscle.

Lateral tilting *(Chapter 5).* Or lateral rotation of the scapula is the rotation of the scapula around a vertical axis to position the glenoid fossa away from the body. This motion occurs at the AC joint.

Lead pipe rigidity *(Chapter 3).* Type of rigidity characterized by a constant resistance to movement throughout the range of motion.

Length feedback reflex *(Chapter 4).* A reflex mechanism that is theorized to contribute to improved force output during plyometric activities. This reflex is triggered when a muscle is stretched and occurs at the same time of the muscle's stretch reflex. In addition to exciting the muscle to contract, it also excites the muscle's synergists while inhibiting the muscle's antagonists. This simultaneous excitation and inhibition is thought to improve the muscle's performance.

Lesser trochanter *(Chapter 9).* Prominence on proximal femur located medially and posteriorly to the greater trochanter, serving as an attachment site for the iliopsoas muscle.

Lever *(Chapter 2).* A simple machine consisting of a rigid bar that rotates around a fulcrum or axis.

Leverage factor *(Chapter 2).* A concept regarding muscle force production which states that the greater the perpendicular distance between the muscle's line of action and the joint's center (moment arm distance), the greater the rotational component produced by the muscle at that joint.

Ligamentum flavum *(Chapter 8).* A ligament primarily composed of elastic fibers that connects one lamina to the adjacent-level laminae throughout the spine.

Ligamentum interspinale *(Chapter 8).* The interspinous ligament. This ligament connects the spinous processes of adjacent vertebrae to each other.

Ligamentum intertransversarium *(Chapter 8).* The intertransverse ligament. This ligament connects the transverse processes of adjacent vertebrae to each other.

Ligamentum nuchae *(Chapter 8).* The nuchal ligament. A thick sagittal ligament band at the posterior neck that extends from the external occipital protuberance laterally to the posterior border of the foramen magnum and caudally to seventh cervical spinous process.

Ligamentum supraspinale *(Chapter 8).* The supraspinous ligament. This ligament is in the cervical region and attaches to the posterior edges of the spinous processes of the vertebrae in this area. It merges with the ligamentum flavum.

Linear (translatory) motion *(Chapter 1).* Motion whereby all points on the moving object travel the same distance, in the same direction with the same velocity and at the same time; further clarified as rectilinear if the movement is in a straight line or curvilinear if the motions travel in a curved path such as that seen when tossing a ball to a friend.

Linea aspera *(Chapter 9).* A prominent ridge running almost the entire length of the posterior femur; serves as an attachment for some of the adductor muscles.

Line of Gravity (LOG) *(Chapter 2).* The direction of pull of the force of gravity. It is perpendicular to the surface of the earth.

Lisfranc's joint *(Chapter 11).* The joints of the tarsometatarsals, named after French surgeon Jacques Lisfranc.

Lister's tubercle *(Chapter 7).* A tubercle on the distal dorsal surface of the radius that serves as a pulley to redirect the pull of the extensor pollicis longus.

Loading response *(Chapter 12).* Or flat foot is the second subphase of the stance phase of gait during walking. During this time the body absorbs the forces of impact and the foot is lowered to the ground.

Locomotion *(Chapter 12).* Moving from one place to another, including many forms of movement such as rolling, crawling and creeping, walking, running, hopping and skipping.

Loose-packed position (or open-packed) *(Chapter 1).* Joint position whereby the joint surfaces do not fit perfectly but are incongruent, the ligamentous and capsular structures are slack, and the joint surfaces may be distracted several millimeters.

Lordosis *(Chapter 8).* An anterior convexity (or posterior concavity) of the spine from a sagittal view. Normally seen in the lumbar and cervical vertebral regions. Lordosis may be either normal or excessive.

Lordotic curve *(Chapter 12).* Occurs first at the cervical spine as the baby develops head control in prone and then in the lumbar region as the infant sits and stands upright. These curves develop once the infant begins rolling and sitting. They are called secondary curves.

Lower motor neuron *(Chapter 3).* A motor (efferent) nerve whose cell body and axon originate in the ventral horn of the spinal cord and synapse directly onto skeletal muscle. This is often referred to as the *final common path* between the nervous system and the muscular system.

M

Malleolus *(Chapter 11).* The landmarks on the medial and lateral aspect of the ankle. The medial malleolus is formed by the distal projection of the tibia and the lateral malleolus is formed by the distal projection of the fibula.

Mass *(Chapter 2).* The amount of matter contained within an object. Measured in kilograms (kg) or slugs.

Medial epicondyle *(Chapter 6, 10).* A bony prominence that is superior to a medial condyle and serves for a site of insertion for tendons and ligaments; e.g. there are medial epicondyles in the elbow and knee.

Medial femoral condyle *(Chapter 10).* A large knob-like medial distal end of the femur, forming part of the femoral connection at the knee joint.

Medial femoral epicondyles *(Chapter 10).* A palpable superior aspect of medial femoral condyle.

Medial malleolus *(Chapter 11).* See malleolus.

Medial (internal) rotation *(Chapter 1).* Transverse plane movement of turning inward toward the midline. This term more accurately reflects the motion than does the term "internal rotation."

Medial tilting *(Chapter 5).* Rotation of the scapula around a vertical axis to rotate the glenoid fossa towards the midline of the body. Also called internal rotation of the scapula. This motion occurs at the AC joint.

Meniscotibial ligament *(Chapter 10).* See coronary ligament.

Meniscus *(Chapter 10).* A crescent-shaped fibrocartilaginous structure between the tibia and femur. The knee has a medial and lateral meniscus.

Metabolic equivalent (MET) *(Chapter 3).* The energy requirements of activities; based on the resting oxygen consumption of an individual whereby one MET is equal to 3.5 ml of oxygen per kilogram of body weight per minute.

Midfoot *(Chapter 11).* The midfoot is comprised of the navicular, cuboid, and three cuneiform bones.

Midstance *(Chapter 12).* The middle subphase of the stance phase of gait. During this time, the body's weight is entirely on the one limb. The COM is at its highest point.

Midswing *(Chapter 12).* The second and middle subphase of the swing phase of gait. It is the middle of the swing when the nonweight-bearing limb is moving under the trunk.

Mobility muscles *(Chapter 4).* Muscles with more fast-twitch fibers or type II fibers than type I fibers. They fatigue quickly but are able to produce force and power quickly. Also called nonpostural muscles.

Moment *(Chapter 2).* The shortened term for moment of force.

Moment arm *(Chapter 2).* The force arm, or lever arm, when discussing rotary forces. It is the perpendicular distance from the force vector to the axis of motion. See torque arm.

Moment of Force *(Chapter 2).* Torque created around an axis. It is the product of a force and its moment arm. In mathematical terms, a moment (M) is the product of this distance (d) and the force (F): $M = d \times F$.

Motion *(Chapter 2).* Displacement of a body or object from one place to another.

Motion segment *(Chapter 8).* This is most basic section of the spine that produces motion. One motion segment consists of two adjacent vertebrae, three intervertebral joints (the joint between the bodies of the vertebrae and the two facet joints), the soft tissues of the intervertebral disc, longitudinal and intersegmental ligaments, and the capsules of the facet joints.

Motor control *(Chapter 3).* A field of study directed at the study of movement as the result of a complex set of neurological, physical, and behavioral processes. Motor control is the ability of the individual to maintain and change posture and movement based on an interaction among the individual, task, and the environment.

Motor learning *(Chapter 3).* Area of study concerned mostly with how motor skills are acquired, made proficient, transferred, and retained.

Motor unit *(Chapter 3).* An individual motor neuron, together with its axon and all of the muscle fibers that are innervated by the motor neuron.

Movement system (*Chapter 3).* The functional interaction of several subsystems and structures that contribute to the act of moving. The contributing systems include the nervous, somatosensory, and musculoskeletal systems.

Multipennate muscles *(Chapter 4).* Muscles whose fibers have more than two pinnate groups attaching to more than one centralized tendon.

Muscle fibers *(Chapter 3).* Contractile tissue, made up of groups of myofibrils.

Muscle spindle *(Chapter 3).* A unique type of proprioceptor, located between the fibers of skeletal muscle, which has both sensory and motor properties. Detects change in muscle length (stretch) and rate of that change, and plays a role in setting resting muscle tone.

Muscle tone *(Chapter 3).* Steady state of alert or arousal of the muscular system for the task demands to be placed on it; determined by the level of excitability of the entire pool of motor neurons controlling a muscle, the intrinsic stiffness of the muscle itself, an intact CNS, and the level of sensitivity of many different reflexes.

Myofibril *(Chapter 4).* The contractile structures of skeletal muscle. It contains the myofilaments of actin and myosin.

Myofilaments *(Chapter 4).* The protein structures of skeletal muscle that provide muscle contraction. Myosin is the thicker protein filament that possesses the crossbridge heads (myosin heads) that connect to actin. Actin is the thinner protein filament that contains troponin and tropomyosin, which control the binding between actin and myosin which occurs during muscle contraction.

Myoneural junction (*Chapter 3).* Synaptic junction between nerve and muscle at motor end plate.

Myosin *(Chapter 3, 4).* This is the thicker protein filament that possesses the crossbridge heads (myosin heads) which connect to actin.

Myotatic reflex *(Chapter 3).* Or the stretch reflex is a monosynaptic simple reflex arc, mediated at the spinal cord level, whereby a change in muscle length (stretch) of a sufficient amount and at a sufficient rate, will activate the muscle spindle eliciting a reflex contraction of the agonist muscle undergoing the stretch.

N

Negative work *(Chapter 4).* See eccentric motion.

Neutral equilibrium *(Chapter 2).* When the center of gravity is displaced, it remains at the same level; i.e., it neither falls nor returns to its former position.

Neck of the femur *(Chapter 9).* Narrow area just inferior to the head of the femur, connecting to the femoral shaft.

Newton *(Chapter 2).* Force in the metric system. 9.8 N = 1 kilogram-force (kgf); 1 N = 0.225 lb.

Neural arch *(Chapter 8).* Sometimes called the posterior neural arch. It forms the vertebral canal through which the spinal cord travels.

Neurotransmitter *(Chapter 3).* Chemical released at a synapse.

Nonpostural muscles *(Chapter 4).* See mobility muscles.

Normal force vector *(Chapter 2).* In resultant vector configurations, this vector is the component that produces rotation around the axis of movement. At its greatest, it is applied 90° to the lever arm.

Nuclei *(Chapter 3).* Aggregations of functionally and anatomically related neurons on the CNS; also called ganglia.

Nutation *(Chapter 8).* Motion of the sacrum by which the sacral promontory moves inferiorly and anteriorly as the distal sacrum and coccyx move posteriorly. In this motion, the iliac crests move towards each other and the ischial tuberosities move apart.

O

Oblique cord *(Chapter 6).* A flat fascia band on ventral forearm running from radial notch of ulna to radial tuberosity; reinforces and stabilizes the proximal radioulnar joint.

Obturator foramen *(Chapter 9).* Opening in the pelvic bone through which several vessels and nerves pass toward the lower extremity.

Olecranon fossa *(Chapter 6).* A deep bony cavity on the posterior aspect of the distal humerus, providing a stable articulating surface for the superior ulna.

Olecranon process *(Chapter 6).* A distinctive bony prominence of the superior ulna on the posterior aspect.

On-guard position *(Chapter 12).* Posturing of the upper extremities during early walking in a high-, medium-, and then low-guard position.

Open kinematic chain (OKC) *(Chapter 1, 4).* Movement that occurs during nonweight-bearing when the distal portion of the segment is free to move and each part of the segment may move independently of the others. These motions are used for speed rather than force production. Also referred to as open chain motion.

Open-packed position. *(Chapter 1).* Or loose-packed position. Joint position whereby the joint surfaces do not fit perfectly but are incongruent, the ligamentous and capsular structures are slack, and the joint surfaces may be distracted several millimeters.

Opposition (Chapter 7). A rotation of the first metacarpal on the trapezium to place the pad of the thumb opposite the pads of the fingers.

Optimal sufficiency *(Chapter 4).* The result seen when an antagonist of a multijoint muscle or muscle group positions and stabilizes one joint to lengthen the multijoint muscle or group to allow improved function of the multijoint agonist at another joint; i.e., hip flexors position the hip in flexion (preventing hip extension) so the hamstrings can exert its force in knee flexion.

Osteokinematics *(Chapter 1).* A subdivision of kinematics, focused on a description of movement of the shafts of the bones on each other.

Osteophyte *(Chapter 8).* A bony growth that usually occurs around a joint.

Ovoid *(Chapter 1).* Egg-shaped joint surface type whereby the radius of curvature varies from point to point and the articular surfaces of the two bones form a convex-concave paired relationship, with this concave-convex joint relationship ranging from "nearly planar," as in the carpal and tarsal joints, to "nearly spheroid," as in the glenohumeral and hip joints.

P

Palmar radioulnar ligament *(Chapter 6).* Or anterior radioulnar ligament. The ligament that stabilizes the anterior aspect of distal radioulnar joint.

Parallel elastic component *(Chapter 4).* The connective tissues that surrounds or lies parallel to muscle.

Passive elastic component *(Chapter 4).* The fascia, or connective tissue, that surrounds muscle, from the entire muscle down to the smallest muscle component. When a muscle is stretched, the elastic component of the muscle's fascia provides additional muscle force as the muscle contracts.

Passive insufficiency *(Chapter 4).* When muscles become elongated over two or more joints simultaneously, they reach a length that does not allow further motion by the opposite muscle. This usually occurs in muscles crossing more than one joint and is the result of the muscle being stretched as far as possible but insufficiently to allow full motion of each joint it crosses; i.e., hamstrings are stretched in full knee extension, but the hip is unable to fully flex since the hamstrings have no more ability to lengthen.

Passive tension *(Chapter 4).* Tension developed in a muscle when it is elongated. This tension is the result of connective tissue surrounding the muscle (parallel elastic fibers) and the tendon (series elastic fibers) being stretched as slack is removed from the muscle during the stretch. See active tension.

Patellar groove *(Chapter 10).* A groove on the anterior distal femur between the two femoral condyles, providing a track for the underside of the patella at the patellar femoral joint.

Patellectomy *(Chapter 10).* Surgical removal of the patella.

Pathologic end feels *(Chapter 1).* These are normal end feels that occur at places in the range of motion or in joints other than what is expected, or it is an end feel that is not characteristic of the joint.

Pectineal line *(Chapter 9).* The small line located between the greater trochanter and the linea aspera on the posteromedial proximal femur so named because the pectineus muscle attached here.

Pedicle *(Chapter 8).* That part of the vertebrae that connects the transverse process to the body of the vertebrae.

Pelvic inclination *(Chapter 8).* Alignment of the pelvis when the ASIS and pubic symphysis do not align on the same vertical line. There is an increased, or forward, pelvic inclination when the ASIS are forward of the pubic symphysis and a posterior, or backward, pelvic inclination when the ASIS are backward of the pubic symphysis. In an anterior pelvic tilt, hip flexion increases; in posterior pelvic tilt, hip flexion decreases.

Pelvis *(Chapter 9).* Comprised of the two innominate bones, also called os coxae, formed by the fused ilium, ischium, and pubic bones, joined to the sacrum posteriorly.

Pennate muscle *(Chapter 4).* Muscle fascicle arrangement that is feather-like and oblique to the muscle's common tendon. More pennate muscles provide greater strength and fusiform muscles. Their pennate arrangement may be unipennate, bipennate, or multipennate. Designed for force rather than speed of motion.

Perimysium *(Chapter 4).* The fascial layer surrounding muscle fiber groups, or fascicles.

Peripheral nervous system *(Chapter 3).* Composed of receptors and effectors of the body, peripheral ganglia, and neuronal processes that connects the peripheral nervous system to the CNS.

Perseveration *(Chapter 3).* Repetitive speech or movement; symptom of a pathological condition.

Pes anserinus *(Chapter 9, 10).* The anterior proximal region of the medial tibia into which the sartorius, gracilis, and semitendinosus tendons insert. This region is called this because the insertion site appears similar to the foot of a goose.

Pes cavus *(Chapter 11).* A foot deformity that has a higher than normal medial longitudinal arch. This is usually a congenital condition. The foot joints are usually rigid, permitting little if any force absorption by the foot during weight-bearing activities. Known as club foot in its extreme condition.

Pes planus *(Chapter 11).* A foot deformity in which the joints of the foot are flexible and do not move into position as a rigid lever at the appropriate times during weight-bearing or during ambulation. This may be a congenital or acquired condition. Known as flat foot in its extreme condition.

Phasic *(Chapter 3).* Qualitative description given to a receptor or a muscle referring to the type of activity it generates; in this case, signifying a distinct stage or phase.

Pivot joint *(Chapter 1).* A type of uniaxial joint, such as the radioulnar joint.

Plafond *(Chapter 11).* Saddle-shaped structure on the inferior aspect of the tibia.

Plane of the scapula *(Chapter 5).* 30° to 45° forward of the frontal plane, so called because this is the angle at which the scapula lies on the posterior thorax when in its resting position. This is the plane in which the rotator cuff is best aligned to produce glenohumeral elevation.

Plantar aponeurosis *(Chapter 11).* Thick fascial covering of the plantar aspect of the foot. It consists of a series of fascial bands beginning about 2 to 3 cm proximal to the calcaneal tuberosity and ending distally on the toes. It provides the foot with a windlass mechanism that converts the tarsal and metatarsal bones of the foot to a rigid lever to permit rising on the toes. The arches are increased by this mechanism. This structure is also known as the plantar fascia.

Plantarflexion (*Chapter 1, 11).* Near-sagittal plane motion of the ankle in which the dorsum of the foot moves away from the anterior leg.

Plica *(Chapter 10).* Folds or seams in the synovial membrane.

Plumb line *(Chapter 12).* A vertical line used as a reference to assess posture. It is usually a string or cord with a weight at the bottom so the string is taut as it hangs freely.

Plyometrics or Plyometric exercise *(Chapter 4).* See stretch-shortening cycle.

Popliteal fossa *(Chapter 10).* The posterior region of the posterior knee. The fossa contains the popliteal artery, vein, and nerve.

Position sense *(Chapter 3).* The awareness of static position of one's joints.

Positive work *(Chapter 4).* See concentric motion.

Posterior inferior iliac spine (PIIS) *(Chapter 9).* Landmark, not easily palpated, located inferior to the PSIS on the posterior aspect of the ilium of the pelvis.

Posterior radioulnar ligament *(Chapter 6).* Also called the dorsal radioulnar ligament. A ligament that stabilizes posterior aspect of distal radioulnar joint.

Posterior superior iliac spine (PSIS) *(Chapter 9).* Prominence on the most posterior and superior aspect of the crest of the ilium of the pelvis.

Posterior tilting *(Chapter 5).* Rotation of the scapula around a medial-lateral axis so that the superior scapula rotates backward or posteriorly. The motion occurs as the scapula returns to the resting position from an anteriorly tilted position.

Postural muscles *(Chapter 4).* See antigravity muscles.

Postural tone *(Chapter 3).* Development of muscular tension, in particular muscles that are actively engaged in holding different parts of the skeleton in proper relationships to maintain particular postures.

Postural sway *(Chapter 12).* Small, automatic motions required as we continually seek and re-establish equilibrium because of body motions occurring secondary to respiration, heart beat, and metabolic functions.

Posture *(Chapter 12).* General term that is an alignment of body segments, a position or attitude of the body, the relative arrangement of body parts for a specific activity, or a characteristic manner of bearing one's body.

Pound *(Chapter 2).* Measurement of force in the US system. 1 pound = 4.448 N.

Power *(Chapter 3).* The rate at which physical work is performed.

Preswing *(Chapter 12).* The final subphase of the stance phase of gait. It is during this time that the foot moves from the lifted heel (terminal stance) to lifting the foot off the ground. Also called toe-off.

Pretibial muscles *(Chapter 11).* Muscles of the anterior leg (tibialis anterior, extensor digitorum longus, extensor hallucis longus, and peroneus tertius) are collectively referred to as pretibial muscles because of their position relative to the tibia.

Prime mover *(Chapter 4).* See agonist.

Promontory *(Chapter 8).* A ridge or protrusion. On the sacrum, it is the top of the body of the sacrum that is in contact with the lowest lumbar vertebra. It juts out anteriorly and serves as an important obstetrical landmark.

Pronation *(Chapter 1, 11).* Triplanar motion of the foot and ankle that occurs differently in the open kinetic chain than it does in the closed kinetic chain. In the open kinetic chain, the combined motions include eversion, abduction, and dorsiflexion. In the closed kinetic chain, the motions include plantarflexion, adduction, and eversion.

Proprioception *(Chapter 3).* Refers to the use of sensory input from receptors in muscle spindles, tendons, and joints to discriminate joint position and joint movement, including direction, amplitude, and speed, as well as relative tension within tendons.

Proprioceptors *(Chapter 3).* Class of receptors that gives sensory input about joint position, joint movement, and muscle length and tension; includes golgi tendon organs (GTO), several different types of joint receptors, and muscle spindles.

Propulsive gait *(Chapter 12).* A gait that takes on an accelerating characteristic, sometimes requiring that the patient come in contact with an object or a wall in order to stop.

Protraction *(Chapter 1, 5).* The lateral end of the clavicle and the scapula move anteriorly around the rib cage in curvilinear fashion, with the medial borders of the scapula moving away from the midline 5 to 6 inches (13 to 15 cm). This motion is also referred to as abduction of the scapula.

Proximal attachment *(Chapter 4).* The location at which one end of a muscle inserts into the bone. The proximal attachment site is the location closest to the center of the body. Formerly known as the muscle's origin. See distal attachment.

Pubic tubercle *(Chapter 9).* Small prominence on the most medial and superior aspect of the superior ramus of the pubis to which the inguinal ligament attaches.

Pyramidal tract *(Chapter 3).* Anatomically known as the corticospinal tract; referred to as such because many of the cell bodies located in the motor cortex are triangular in shape and have the appearance of small pyramids when a section of cortex is stained and viewed under a light microscope. Most of the corticospinal axons cross to the opposite side in the brainstem within the pyramid of the medulla.

Q

Quadrate ligament *(Chapter 6).* The ligament that arises from radial notch of ulna to neck of radius; it reinforces joint capsule and stabilizes the proximal radioulnar joint.

Qualitative analysis *(Chapter 15).* An analysis of a movement that breaks down the movement into segments and assesses the segments for its muscle and joint activity without quantifying the segments.

Q angle *(Chapter 10).* Quadriceps angle. The angle formed by the intersection of the line from the anterior superior iliac spine (ASIS) to the center of the patella and the line from the tibial tuberosity to the center of the patella. Normal is 170°.

R

Radial abduction *(Chapter 1, 7).* In the anatomic position, wrist movement in the frontal plane through an anterior-posterior axis that moves the hand away from the side of the body toward the thumb. Also known as radial flexion or radial deviation.

Radial collateral ligament *(Chapter 6).* The three-part stabilizing ligament located on the lateral side of the elbow region; contributes some stability in the frontal plane. Also called the lateral collateral ligament of the elbow.

Radial deviation *(Chapter 1, 7).* See radial abduction.

Radial fossa *(Chapter 6).* Cavity on distal anterior humerus superior to the capitulum; receives the radial head at full elbow flexion.

Radial fovea *(Chapter 6).* A deep concavity atop the radial head; articulates with the humeral capitulum.

Radial head *(Chapter 6).* Superior aspect of radius, just below the head.

Radial neck *(Chapter 6).* Narrowed area just inferior to radial head.

Radial notch *(Chapter 6).* Concave bony landmark on proximal lateral ulna, articulation between ulna and radius at proximal radioulnar joint.

Radial styloid process *(Chapter 7).* The distal process of the radius that extends somewhat more distally than the corresponding process of the ulna. The radial styloid process serves as the attachment site for the radial carpal collateral ligament and the brachioradialis muscle.

Radial tuberosity *(Chapter 6).* Bony landmark on anterior proximal radius just distal to radial head and neck; attachment site for biceps brachii muscle.

Range of movement or range of motion (ROM) *(Chapter 3).* Excursion of a joint through its arc of motion.

Ray *(Chapter 11).* A toe unit that is anterior to the midfoot and incorporates the cuneiform with its corresponding metatarsal in the case of the three medial rays and only the metatarsals in the case of the lateral two rays.

Reaching strategy *(Chapter 12).* See stepping or reaching strategy.

Reafference *(Chapter 3).* Property of the cerebellum giving it the ability to receive sensory feedback from receptors about the movements as the movement is occurring.

Rearfoot *(Chapter 11).* That part of the foot made up of the calcaneus and talus. The rearfoot guides the rest of the foot.

Reciprocal arm swing *(Chapter 12).* The manner of swinging the upper extremity rhythmically with the contralateral lower extremity during walking; e.g., the RUE swings forward into shoulder flexion when the LLE steps forward at initial contact.

Reciprocal innervation *(Chapter 3).* Spinal mechanism whereby antagonist muscles relax when agonist muscles are activated; allows for fluidity of human movement.

Recruitment *(Chapter 3).* Process whereby strength of muscle contraction occurs by increasing the number of motor units activated simultaneously.

Repolarization *(Chapter 3).* An active process of an excitable cell membrane, occurring immediately after depolarization, to re-establish the resting membrane potential.

Rectilinear *(Chapter 1).* A subset of linear motion whereby movement is in a straight line.

Reposition *(Chapter 7).* The opposite of thumb opposition or returning the thumb back into anatomical position from a position of opposition.

Resistance arm *(Chapter 2).* The perpendicular distance from the resistance force applied to a segment to the axis of motion.

Resting length *(Chapter 4).* A muscle's resting length is the point at which there are the most available actin-myosin crossbridges.

Resting position *(Chapter 1).* A position of a joint at which there is the least congruency and the most slack in the capsule and ligaments; this position is often near the joint's midrange.

Resting potential *(Chapter 3).* Charge across nerve or muscle membrane at equilibrium; ranges from −60 to −90 mV.

Resting tremor *(Chapter 3).* A tremor occurring in a body part that is not being voluntarily activated and is supported against gravity; a symptom of Parkinson's disease, secondary to basal ganglia dysfunction.

Resultant vector *(Chapter 2).* When two or more forces are applied to an object or body segment, a resultant force is created as a combination of these forces. The resultant force will have a direction and magnitude that reflects the combination of these forces and is the resultant vector.

Retinacular system *(Chapter 7).* This is a complex fascial and ligamentous arrangement that provide functions on both the palmar and dorsal hand. These functions include enclosing, compartmentalizing, and restraining the joints and tendons as well as the nerves, blood vessels, and skin.

Retraction *(Chapter 1, 5).* The lateral end of the clavicle and the scapula move posteriorly in a curvilinear fashion, and the medial borders of the scapula approach the midline. This motion is also called scapular adduction. At the sternoclavicular joint, the total range for protraction and retraction is approximately 25°.

Retroversion *(Chapter 5, 9).* Posterior rotation or a backward rotation. In the hip, it may clinically present as out-toeing (lateral rotation) during standing and walking.

Rigidity *(Chapter 3).* Heightened resistance to passive movement, but independent of the velocity of a stretch or movement. Associated with lesions of the basal ganglia, and appears to be the result of excessive supraspinal drive acting upon a normal spinal reflex mechanism. There are two types of rigidity, lead pipe and cogwheel. A constant resistance to movement throughout the range characterizes **lead pipe rigidity**, whereas **cogwheel rigidity** is characterized by alternate episodes of resistance and relaxation. Rigidity is frequently associated with lesions of the basal ganglia, commonly seen in Parkinson's disease.

Rocking *(Chapter 1).* A synonym for basic joint motion of "rolling." See rolling.

Rolling *(Chapter 1, 13).* When discussing joints, it is a rotary or angular type of basic joint motion whereby each subsequent point on one articulating surface contacts a new point on the other surface, such as in "rolling" a ball across the floor. Also called rocking. When discussing body movement, it is moving the body from supine to prone, or from prone to supine, usually involving some amount of trunk rotation.

Rotary motion *(Chapter 2).* Movement around an axis which occurs in an arc or circular movement. Also called angular displacement or angular motion. Joint movement is rotary motion.

Rotation *(Chapter 1).* Angular motion of a bony lever around an axis.

Running *(Chapter 12).* A gait wherein the swing phase is longer than the stance phase and there are two periods within one gait cycle when neither lower limb is in contact with the ground.

S

Saddle joint *(Chapter 1).* A type of biaxial joint in which each bony partner has a concave and convex surface oriented perpendicular to each other; like a rider in a saddle; such as seen in the carpometacarpal joint of the thumb.

Sagittal plane *(Chapter 1).* Or YZ plane, so named because it is parallel to the sagittal suture of the skull, dividing the body into right and left sides. It is the plane within which flexion and extension movements occur.

Sarcolemma *(Chapter 4).* Cell membrane surrounding a muscle fiber.

Sarcomere *(Chapter 3, 4).* Contractile unit of muscle fiber; made up of actin and myosin myofilaments.

Sarcoplasmic reticulum *(Chapter 3, 4).* A component of the endoplasmic reticulum of a muscle cell; involved in the storage and release of calcium ions during contractile process.

Scalar quantities *(Chapter 2).* Items that have only one dimension. It has magnitude but no direction; e.g., 5 horses, 3 shoes, 1 mile.

Scaption *(Chapter 5).* Shoulder elevation in the scapular plane. This term was first coined by Dr. J. Perry and has become a universally accepted term for this motion.

Scapulohumeral rhythm *(Chapter 5).* The synchronous motion between the scapula and humerus during glenohumeral elevation. Although not consistent throughout, there is roughly a 2:1 ratio of glenohumeral motion to scapular motion.

Scoliosis *(Chapter 8).* A postural deviation such that there is a lateral curvature of the vertebral column.

Screw home mechanism *(Chapter 10).* The terminal lateral rotation of the tibia on the femur that occurs in nonweight bearing because the lateral femoral condyle has completed its motion but the medial femoral condyle has not so the lateral condyles rotate as the medial condyles complete their motion. The motion in weight bearing is medial rotation of the femur on the tibia. Also called terminal rotation of the knee.

Second order neurons *(Chapter 3).* Sensory neurons that receive synaptic input from a peripheral sensory neuron (from a first order neuron) and conduct action potentials from the spinal cord or brainstem to sensory centers in the CNS.

Sellar joint *(Chapter 1).* Joint surface type so named because the surfaces resemble the matching of a rider in a saddle, both surfaces having convex and concave surfaces perpendicular to each other, such as seen in the carpometacarpal joint of the thumb and the ankle (talocrural joint).

Semilunar notch *(Chapter 6).* Also called the trochlear notch. Concave surface, shaped like a half moon, on proximal ulna that articulates with the trochlea of the humerus at the elbow joint.

Series elastic component *(Chapter 4).* The term given to a muscle's tendons because of the alignment of tendon–muscle–tendon. Force transmission is provided in series from the muscle to the tendon to the bone.

Sesamoid bone *(Chapter 10).* A small bone that lies within a tendon. It serves to protect the tendon and change the angle of pull of the tendon.

Shaft of the femur *(Chapter 9).* Bony body of the femoral bone.

Shoulder complex *(Chapter 5).* See shoulder girdle.

Shoulder girdle *(Chapter 5).* Combination of the scapula, clavicle, and manubrium, together with left and right components that form a girdle around the upper thorax.

Shoulder joint *(Chapter 5).* Connection between the glenoid fossa and the humeral head.

Sigma (Σ) *(Chapter 2).* Greek symbol used in formulas to signify sum or addition total.

Sigmoid notch *(Chapter 7).* See ulnar notch.

Single-limb support *(Chapter 12).* When only one lower extremity is in stance phase. This occurs during the middle 40% of the stance cycle.

Sinus tarsi *(Chapter 11).* Channel that runs between the articulations of the talus and the calcaneus, housing proprioceptors; it may be palpated slightly distal and lateral to the talar dome.

Sliding *(Chapter 1).* A translatory or linear type of basic joint motion whereby one point of reference contacts new points across the adjacent surface and the movement of one joint surface is parallel to the plane of the adjoining joint surface, such as when a figure skater "glides" across the ice. Also referred to as gliding.

Sliding filament theory *(Chapter 3).* Theoretical concept that actin and myosin filaments slide past each other during muscle contraction.

Slow-twitch fiber *(Chapter 3).* Type I or tonic muscle fibers; use a slow oxidative metabolic process and are resistant to fatigue.

Slug *(Chapter 2).* Term for mass in the US system. 1 slug = 14.59 kg. 1 pound = 0.031 slugs.

Soft end feel *(Chapter 1).* A feeling that is felt at the end of joint range when soft tissue, typically fleshy muscular bulk, approximates and stops further motion.

Somatosensory *(Chapter 3).* Pertaining to sensation.

Space diagram *(Chapter 2).* See free body diagram.

Spasticity *(Chapter 3).* A condition of increased muscular tone which produces involuntary and rapid contractions and relaxations and an associated hyperreflex response. See hypertonicity.

Spatial characteristics *(Chapter 12).* Those variables that are defined in terms of length, width, or depth. They identify characteristics that include space. In gait, they include items such as step width, step length, and stride length.

Speed *(Chapter 4).* The rate of motion.

Spinal shock *(Chapter 3).* Time of profound depression of motor function in which all muscles of the affected body segments are involved; used to describe the temporary flaccid state in the person with a spinal cord injury when the nervous system is in a state of shock after a lesion or acute onset.

Spinous process *(Chapter 8).* A process on the posterior aspect of vertebra that form the neural arch of the vertebra. The transverse processes are the other two processes along with the laminae that form the neural arch.

Spinning *(Chapter 1).* A rotary or angular basic joint motion whereby one point of contact on each surface remains in constant contact with a fixed location on the other surface, such as in "spinning" a top.

Spondylolisthesis *(Chapter 8).* A pathological condition usually seen in the lumbar spine in which the vertebral body of one segment slips forward of the one below it.

Sprinting *(Chapter 12).* Running as fast a possible for short distances.

Stable equilibrium *(Chapter 2).* When the center of gravity of a body is disturbed slightly and the body tends to return the center of gravity to its former position.

Stance phase *(Chapter 12).* The period of the gait cycle when the foot is in contact with the ground.

Step duration *(Chapter 12).* A temporal characteristic of gait defined as the amount of time the foot is in contact with the ground.

Step length *(Chapter 12).* The distance between the initial contact of one foot to the initial contact of the opposite foot.

Stepping or reaching strategies *(Chapter 12).* The use of steps, hops, or reaches to maintain the center of mass within the base of support. This strategy is usually used during fast changes of line of gravity and requires an adjustment of the COM position.

Step width *(Chapter 12).* The horizontal distance between the two feet measured from the midpoint of one heel to the midpoint of the next heel contact, typically from 2 to 4 inches (7–9 cm) for adults.

Stiff-leg gait *(Chapter 12).* Characterized by extension at the trunk, posterior tilt of the pelvis, and excessive hip and knee extension usually in combination with medial rotation and adduction of the hips.

Stiffness *(Chapter 3).* A change in the viscoelastic physical properties of the muscle accompanying hypertonicity, which contributes to the increased resistance to passive stretch.

Strain *(Chapter 4).* The body, segment, or muscle's ability to withstand a stress that is applied to it. The amount of deformation it is able to tolerate before it succumbs to the stress.

Stratum fibrosum *(Chapter 1).* Thick outer layer of joint capsule primarily comprised of dense irregular fibrous tissue, laden with joint receptors.

Stratum synovium *(Chapter 1).* The inner, highly vascular layer of the joint capsule; it produces and secretes synovial fluid.

Strength *(Chapter 4).* The ability of a muscle to develop or produce force or generate active tension.

Stress *(Chapter 4).* A load or force applied to a body, segment, or muscle.

Stress fracture *(Chapter 4).* Application of a repetitive force on a bone that causes breakdown of that bone; application of the stress-strain principle to bone.

Stress-strain curve *(Chapter 4).* The relationship between a structure's ability to absorb the forces applied to it. Every structure has its unique strain quality to deform as a stress is progressively applied to it, and every structure also has its breaking point at which no further stress is tolerated. Also referred to as stress-strain principle.

Stretch reflex *(Chapter 3).* Or myotatic reflex is a monosynaptic simple reflex arc, mediated at the spinal cord level whereby a change in muscle length (stretch) of a sufficient amount and at a sufficient rate, will activate the muscle spindle eliciting a reflex contraction of the agonist muscle undergoing the stretch.

Stretch-shortening cycle *(Chapter 4).* A type of activity that uses a rapid eccentric activity of a muscle followed quickly by a sudden and forceful concentric activity of the same muscle. It is also more commonly referred to as plyometrics or plyometric exercises and is used in many sports activities.

Stride length *(Chapter 12).* The distance between initial contact of one foot to initial contact of that same foot again; equivalent to one gait cycle.

Structure fatigue *(Chapter 4).* Fatigue of a structure that occurs with the application of repeated stresses so the accumulation of stresses causes failure of the structure.

Subluxation *(Chapter 1).* Abnormal condition that occurs when there is a separation of the two bony partners and the joint partners are partially disassociated from each other, but usually there is no rupture of the connecting tissue.

Superior pubic ramus *(Chapter 9).* Bony aspect of superior pubic bone; attachment site for most of the muscles that adduct the hip.

Supination *(Chapter 1, 11).* Triplanar motion of the foot and ankle that occurs differently in the open kinetic chain than it does in the closed kinetic chain. In the open kinetic chain, the combined motions include inversion, adduction, and plantarflexion. In the closed kinetic chain, the motions include dorsiflexion, abduction, and inversion.

Suprapatellar pouch *(Chapter 10).* A pouch formed by the proximal expansion of the synovial lining of the knee. It extends proximal to the patella and lies between the femur and quadriceps muscle. It provides an area within which the patella moves during knee flexion to ultimately provide an increased ability to flex the knee.

Supraspinatus outlet *(Chapter 5).* The area under the coracoacromial arch.

Sustentaculum tali *(Chapter 11).* A portion of the middle calcaneus that projects medially to serve as a shelf on which the talus sits.

Swing phase *(Chapter 12).* The period of the gait cycle when the foot is not in contact with the ground.

Symphysis *(Chapter 8).* The point of contact between two bones that is separated in early development or early life but becomes fused later in life.

Symphysis pubis *(Chapter 9).* Amphiarthrodial connection between the two pubic bones anteriorly.

Synarthrosis *(Chapter 1).* Joints whose primary purpose is to offer stability and are therefore largely fibrous in structure, such as seen in the sutures of the skull or the syndesmosis at the tibiofibular articulation.

Syndesmosis *(Chapter 1).* A subtype of synarthrodial joint, such as found longitudinally between the radius and ulna and between the tibia and fibula, where these pairs of bones are joined by a strong interosseous membrane in order to maintain a close relationship of the bones next to each with little or no mobility allowed.

Synergist *(Chapter 4).* The muscle or muscle group that assists the agonist to produce the desired motion.

Synergy *(Chapter 3).* Functional muscle groups that work together to produce motor behavior. In pathological conditions, synergy is also used to describe impaired motor control whereby muscles are activated as a bound unit.

Synovial fluid *(Chapter 1).* A pale, viscous fluid secreted by the capsule into the joint space, constantly nourishing and lubricating the joint surfaces.

Synovial joint *(Chapter 1).* A term used interchangeably with diarthrodial joint.

T

Tangential force vector *(Chapter 2).* In resultant vector configurations, this vector is the component that produces either a compressive or a distraction force to a segment moving around its axis. When the force vector is parallel to the lever arm, all of the force is either compressing or distracting the joint.

Temporal characteristics *(Chapter 12).* Variables that are defined by time; examples include velocity, acceleration, power, and cadence.

Tendinopathy *(Chapter 4).* Application of the stress-strain curve to a tendon; repetitive stress applied to a tendon that does not allow recovery sufficiently to restore tendon strength causes break down of that tendon.

Tenodesis *(Chapter 4, 7).* When passive tension of tendons produce movements of joints as the muscle is elongated over two or more joints. For example, extending the wrist places passive tension on the long finger flexors, allowing the fingers to grasp an object even though active finger flexion does not occur.

Terminal rotation of the knee *(Chapter 10).* See screw home mechanism.

Terminal stance *(Chapter 12).* The fourth subphase of the stance phase of gait. It is during this time that the heel is lifted off the ground.

Terminal swing *(Chapter 12).* Third and final subphase of the swing phase of gait. The extremity prepares to impact the ground.

Thoracic outlet syndrome *(Chapter 8).* Pathological condition producing pain and dysfunction. In this condition, the ventral nerve roots of cervical nerves and/or blood vessels become compressed secondary to anatomical anomalies, hypertrophy, spasm, or poor posture.

Tibial torsion *(Chapter 11).* Angle created between the alignment of the knee and the alignment of the ankle. It is caused by the tibia's longitudinal lateral rotation. Normal measurements are 15° to 40° in the adult.

Tonic *(Chapter 3).* Qualitative description given to a receptor or a muscle, referring to the type of activity it generates; in this case, signifying continuous activity.

Tract *(Chapter 3).* Axonal bundles of upper motor neurons with common origin, function, and termination.

Torque *(Chapter 2).* Force applied to produce rotation. It is the product of the force times the perpendicular distance from its line of action to the axis of motion. It is symbolized in formulas as τ.

Torque arm *(Chapter 2).* Moment arm (lever arm) of a rotational force.

Transfer *(Chapter 13).* Movement of the body from one surface or position to another. It may be accomplished independently, with assistance, or with supervision.

Translatory motion *(Chapter 2).* Motion in which all points on the moving object travel the same distance, in the same direction with the same velocity and at the same time; further clarified as being rectilinear if the movement is in a straight line or curvilinear in which motions travel in a curved path such as that seen when tossing a ball to a friend. Also called linear motion.

Transverse plane *(Chapter 1).* A plane of motion so named because it is parallel to the horizon and the floor, dividing the body into upper and lower parts, like a view from above. It is the plane within which rotational movements occur. Also called the XZ plane or the horizontal plane.

Transverse process *(Chapter 8).* There are two on each vertebra. They sit on either side of the spinous process, and with the spinous process and laminae, form the vertebral arch.

Transverse tubular system *(Chapter 3).* "T" system; a component of the endoplasmic reticulum of a muscle cell which speeds the transmission of a muscle action potential to all portions of the muscle fiber.

Tremor *(Chapter 3).* A rhythmical, involuntary, oscillatory movement of a body part, symptomatic of damage to the CNS.

Trendelenburg gait *(Chapter 9, 12).* Pathological gait caused by weakness of the gluteus medius. During stance phase, the contralateral hip drops since the gluteus medius is unable to hold the pelvis level.

Trendelenburg sign *(Chapter 9).* Clinical sign characterized by dropping of the pelvis on the unweighted side during unilateral stance; associated with a severely weakened or paralyzed gluteus medius on the stance limb.

Triangular fibrocartilage (TFCC) *(Chapter 7).* Name given to articular disc at the distal or inferior radioulnar joint, so named because of its shape.

Triaxial joint *(Chapter 1).* A joint that moves in three planes around three axes having three degrees of freedom, such as seen at the hip and glenohumeral joint.

Triceps surae *(Chapter 11).* The superficial posterior calf muscles of the medial and lateral gastrocnemius along with the soleus are called the triceps surae.

Triplanar axis *(Chapter 11).* A joint axis that is not perpendicular to the cardinal planes but intersects all three planes.

Trochlea *(Chapter 6).* Bony prominence that usually articulates with a concave surface such as a groove or notch. The distal humerus is an example of a trochlea.

Trochlear groove *(Chapter 11).* Groove that separates portions of the trochlea of the humerus. See intercondylar groove.

Trochlear notch *(Chapter 6).* Concave surface that interfaces with a trochlear notch. An example is the semilunar notch of the proximal ulna articulating with the trochlea of the humerus at the elbow joint.

Trochlear ridge *(Chapter 6).* Ridge that runs between trochlea. This is seen when a bone such as the humerus articulates with more than one bone—the radius and ulna—at its distal joint.

Type I fiber *(Chapter 3).* Also referred to as slow-twitch or slow-oxidative; contains large number of mitochondria and high concentration of myoglobin, uses oxidative enzymes and aerobic metabolism, and is fatigue-resistant.

Type II fiber *(Chapter 3).* Also referred to as fast-twitch or fast-glycolytic; contains few mitochondria and little myoglobin, uses glycolytic enzymes and anaerobic metabolism, and fatigues quickly.

U

Ulnar abduction *(Chapter 1, 7).* In the anatomic position, wrist movement in the frontal plane through an anterior-posterior axis that moves the hand toward the side of the body and the little finger. Also known as ulnar flexion or ulnar deviation.

Ulnar collateral ligament *(Chapter 6).* The three part stabilizing ligament located on the medial side of the elbow. It contributes the primary stability in the frontal plane. Also referred to as the medial collateral ligament of the elbow.

Ulnar deviation *(Chapter 1, 7).* See ulnar abduction.

Ulnar notch *(Chapter 7).* The distal ulnar notch on the radius that serves as the articulating surface for the distal radioulnar joint. Also called the sigmoid notch.

Ulnar styloid process *(Chapter 7).* Bony projection palpated, when the forearm is pronated, on the ulnar side of the wrist. It is the distal end of the ulna.

Ulnar tuberosity *(Chapter 6).* The bony landmark located on the anterior proximal ulna, inferior to the coronoid process; an attachment site for the brachialis muscle.

Uniaxial joint *(Chapter 1).* Joint that moves in one plane around one axis having one degree of freedom; including two types—hinge or pivot.

Unipennate muscles *(Chapter 4).* Muscles whose fibers have one parallel fiber arrangement.

Unstable equilibrium *(Chapter 2).* Center of gravity of a body is disturbed and the body does not to return the center of gravity to its former position and falls.

Upper motor neurons *(Chapter 3).* Neurons located within the CNS.

V

Valgus *(Chapter 10).* A condition in which the distal portion of a joint segment is positioned outward or away from the midline of the body. Also referred to as valgum.

Varus *(Chapter 10).* A condition in which the distal portion of a joint segment is positioned inward or towards the midline of the body. Also referred to as varum.

Vector quantity *(Chapter 2).* Physical quantity that has two dimensions—magnitude and direction. Forces are directional quantities.

Velocity *(Chapter 2, 12).* A temporal characteristic; the rate of motion in a specific direction. In gait, it is the distance covered in a unit of time such as meters per second or miles per hour.

Viscoelasticity *(Chapter 4).* A structure that has the characteristics of both viscosity and elasticity. Most tissue is viscoelastic; viscoelastic tissue has the ability to withstand forces or loads to resist changing shape, but if the force is sufficient, the structure's shape changes and does not return to its original shape.

Viscosity *(Chapter 4).* Resistance a structure has to an external force or load that causes a permanent deformation of the structure.

W

Walking *(Chapter 12).* Particular form of gait; the most common of human locomotor patterns.

Weakness *(Chapter 3).* Inability to generate normal levels of muscular force.

Weight *(Chapter 2).* Force of gravity acting on a mass; measured in pounds (lb) or Newtons (N).

White matter *(Chapter 3).* Term used to describe areas of CNS that contain predominantly nerve tracts and axons, covered in myelin.

Z

Zygapophyseal joints *(Chapter 8).* Also called facet joints or apophyseal joints. These joints are formed by the inferior articular processes of a superior vertebra and the superior articular processes of the immediately adjacent inferior vertebra. There is one inferior process and one superior process forming two zygapophyseal joints with its inferior and superior vertebrae on each side of the vertebra, respectively. Zygapophyseal joints are synovial joints.