CHAPTER 3

Anatomical Description and Its Limitations

In order to understand the origins of human movement, it is essential to understand anatomy. **Anatomy** is the study of the structure of the human body. Anatomy provides essential labels for musculoskeletal structures and joint motions relevant to human movement. Knowledge of anatomy also provides a common "language" of the human body and motions for kinesiology and medical professionals. Anatomy is an important prerequisite for kinesiology professionals trying to improve movement, prevent or treat injury. Anatomy is primarily a descriptive field of study and is not, by itself, enough to *explain the function* of the musculoskeletal system in movement. Knowledge of anatomy must be combined with biomechanics to accurately determine the musculoskeletal causes or the "how" human movement is created. This chapter reviews key anatomical concepts, shows how functional anatomy traditionally classifies muscle actions, shows how biomechanics is needed to determine muscle function in movement, and discusses the first two of the nine principles of biomechanics: **Range of Motion** and **Force–Motion**.

REVIEW OF KEY ANATOMICAL CONCEPTS

This section reviews several key concepts from human anatomy. A course in gross anatomy (macroscopic structures) is a typical prerequisite for the introductory biomechanics course. This section does not review all the bones, muscle, joints, and terms. Students and kinesiology professionals must continuously review and refresh their knowledge of anatomy. Anatomy describes the human body relative to the *anatomical position*. The anatomical position is approximated in Figure 3.1. The three spatial dimensions of the body correspond to the three anatomical planes: frontal, sagittal, and transverse. Recall that a plane of motion is a particular spatial direction or dimension of motion, and an axis is an imaginary line about which a body rotates. The anatomical axes associated with motion in each of these planes are the antero-posterior, medio-lateral, and longitudinal axes. Knowing these planes and axes is important to understanding medical descriptions of motion or movements. Even more important may be the functional implications of the orientation of these axes to the planes of motion they create. Note that motion in a particular plane (for example, sagittal) occurs by rotation about an axis oriented 90° (medio-lateral axis) to that plane. A person supinating their forearm to illustrate the anatomical position is creating motion in a transverse plane about a longitudinal axis roughly along the forearm. Functional anatomy applies knowledge of joint axes of rotation and muscle positions to hypothesize which muscles contribute to motion in an anatomical plane.

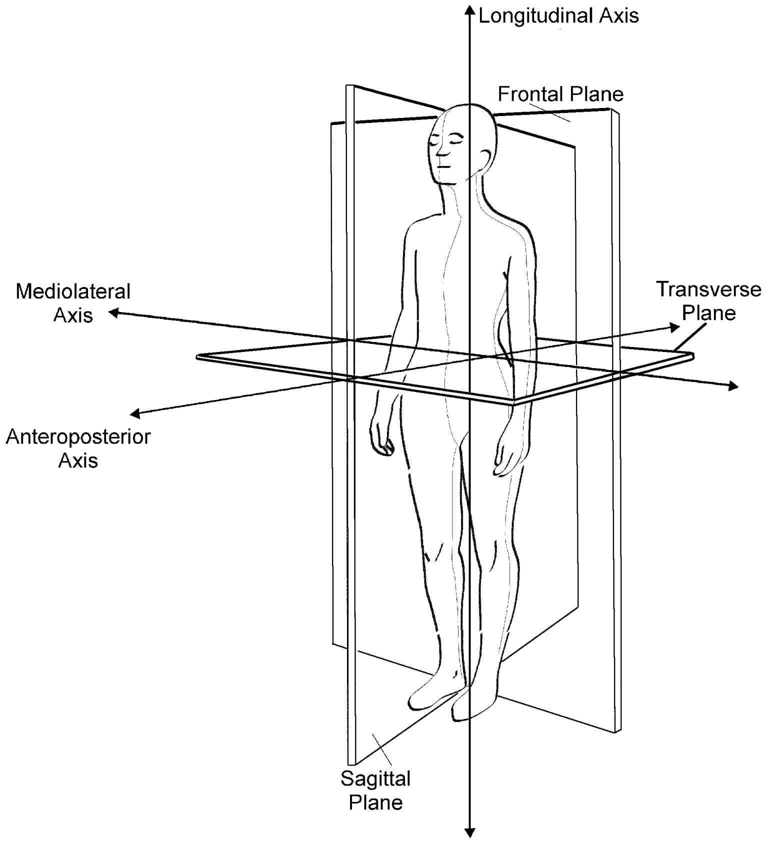

Figure 3.1. The major anatomical planes of motion, and axes of rotation.

Directional Terms

In addition to planes and axes, anatomy uses several directional terms to help describe the position of structures relative to the anatomical position. Toward the head is called superior, while toward the feet is inferior. Body parts toward the front of the body are anterior and objects to the back are in the posterior direction. Parts or motion toward the midline of the body are said to be medial, while motion or position toward the sides of the body are lateral. There are many other anatomical terms that have similar meanings as these but retain the original Latin or Greek form of classical anatomy. For example, superior is synonymous with cephalic, while inferior is the same a caudal. This book will use the more familiar English anatomical terms whenever possible.

Students with interests in sports medicine careers would do well to keep a medical dictionary handy and become familiar with the variety of classical anatomical terms used in medicine. Careful use of terminology is important in science and professions to prevent confusion. One example of the confusion that can occur with using unfamiliar Greek or Latin terms is the debate over the directional terms *valgus* and *varus*. The original Greek meanings of these terms (valgus [bowlegged] and varus [knock-kneed]) can be at odds with their typical use in orthopaedic medicine. Medicine usually defines genu (knee) valgus as an inward deviation of the knee joint, resulting in a knock-kneed appearance (Figure 3.2). Genu varus or varum usually corresponds to an outward deviating knee, which results in a bowlegged appearance. This leads to considerable confusion in describing anatomical abnormalities, and some have suggested that these terms be dropped or at least defined every time they are used (Houston & Swischuk, 1980). Some would look at Figure 3.2 and say the knee deviates medially, while others would say the lower leg deviates laterally. We will see that this little problem of anatomical description is very similar to the multiple kinematic frames of reference (chapter 5) that are all correct descriptions of a single motion and the different units of measurement that can be used. Mechanics and anatomy both share the minor problem that there are several standards that have grown up with these sciences since people all over the world have been working on these same problems. Students should strive to read and write with special attention to the meaning of professional/scholarly terminology.

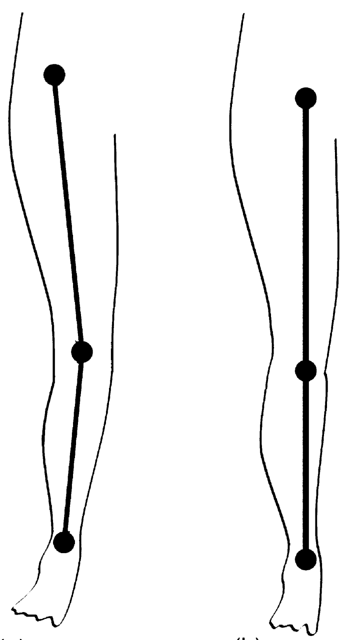

Figure 3.2. Orthopedic and pediatric medicine often calls the lower extremity deviation in (a) genu (knee) valgus because the distal segment (lower leg) deviates laterally from the midline of the body. Normal leg orientation in the frontal plane is illustrated in (b). The use of valgus and varus terminology is often inconsistent in the literature and should be clearly defined when used (Houston & Swischuk, 1980).

Joint Motions

Anatomy also has specific terminology describing the major rotations of bones at joints. "Flexion" refers to a decrease in joint angle in the sagittal plane, while "extension" is motion increasing joint angle (Figure 3.3a). Motion into the extremes of the range of motion are often noted as "hyper," as in hyperextension. Motion of a segment away from the midline in the frontal plane is "abduction," while movement back toward the midline is called "adduction" (Figure 3.3b). Joint motions in the transverse plane are usually called inward rotation (rotation of the anterior aspect of the segment toward the midline) and outward rotation (Figure 3.4). Some examples of special joint motion terms are "pronation," which refers to internal rotation of the forearm at the radioulnar joint, or "horizontal adduction," which is drawing the shoulder (glenohumeral joint) toward the midline in a transverse plane. Like the directional terms, anatomical terminology related to the rotations of joints is also used incorrectly. It is incorrect to say "a person is flexing a muscle" because flexion is a joint movement. It is important for kinesiology majors to use anatomical terms correctly. Refer to your anatomy book frequently to keep all

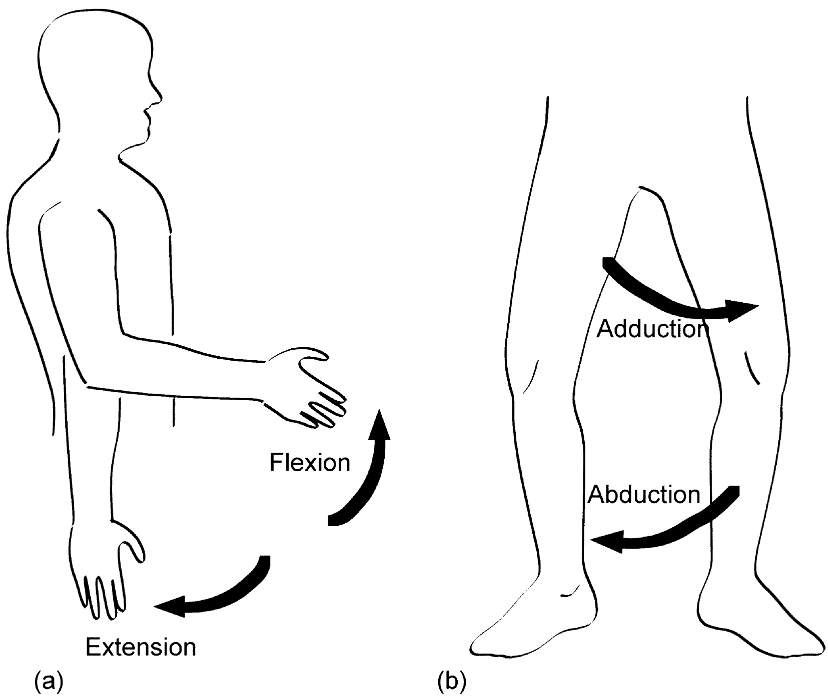

Figure 3.3. (a) Flexion and extension movements occur in a sagittal plane about a mediolateral axis; (b) adduction/abduction of the hip joint occurs in a frontal plane about an anteroposterior axis.

the joint motion terminology (this section does not review them all) fresh in your mind.

While there are attempts to standardize anatomical description throughout the world (Federative Committee on Anatomical Terminology, 1998; Greathouse *et al.*, 2004), there remain regional inconsistencies in terminology. For example, some refer to the frontal plane as the "coronal" plane. Applied sciences such as medicine often develop specialized terms that are borrowed from anatomy, but that go against anatomical convention. A good example is related to how the foot acts during the stance phase of running. Medical and biomechanical studies have adopted the terms "pronation" and "supination" to refer to the complex triplanar actions of the subtalar joint. In normal running the foot strikes the ground on the lateral aspect of the foot; the combined anatomical actions of eversion, plantar flexion, and abduction in the first part of stance is called pronation. This pronation serves to absorb the shock of the collision of the foot with the ground (Figure 3.5). The opposite motion (supination) stiffens the foot for the push off phase of stance. Here is another example of how anatomical terms are not always used in a consistent way. In your studies of biomechanics and other kinesiology disciplines, remember that adaptations and variations in anatomical terminology make it important to read carefully and often check background information. Modern biomechanical studies often assume quite a bit about reader expertise in the area and may not cite sources giving necessary terminology and background information. This saves

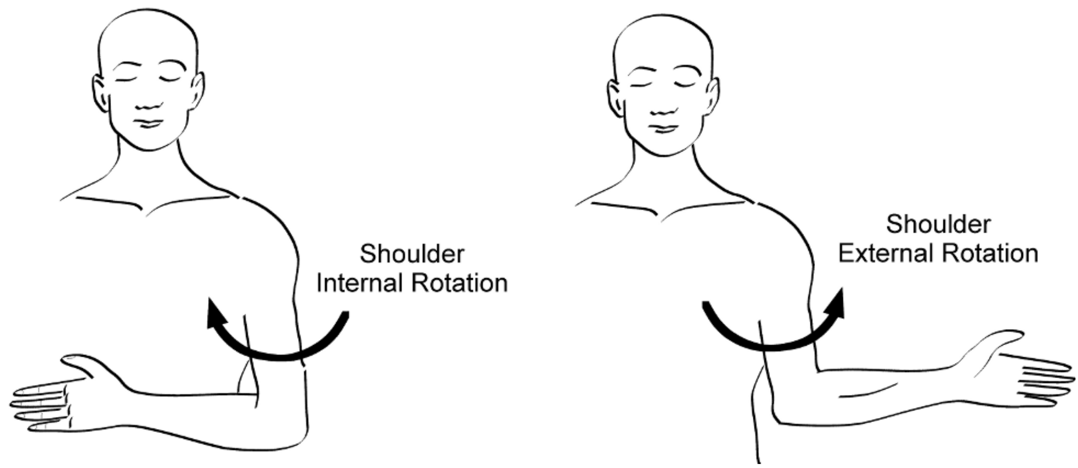

Figure 3.4. Inward and outward rotation of the shoulder joint occurs in a transverse plane about a longitudinal axis.

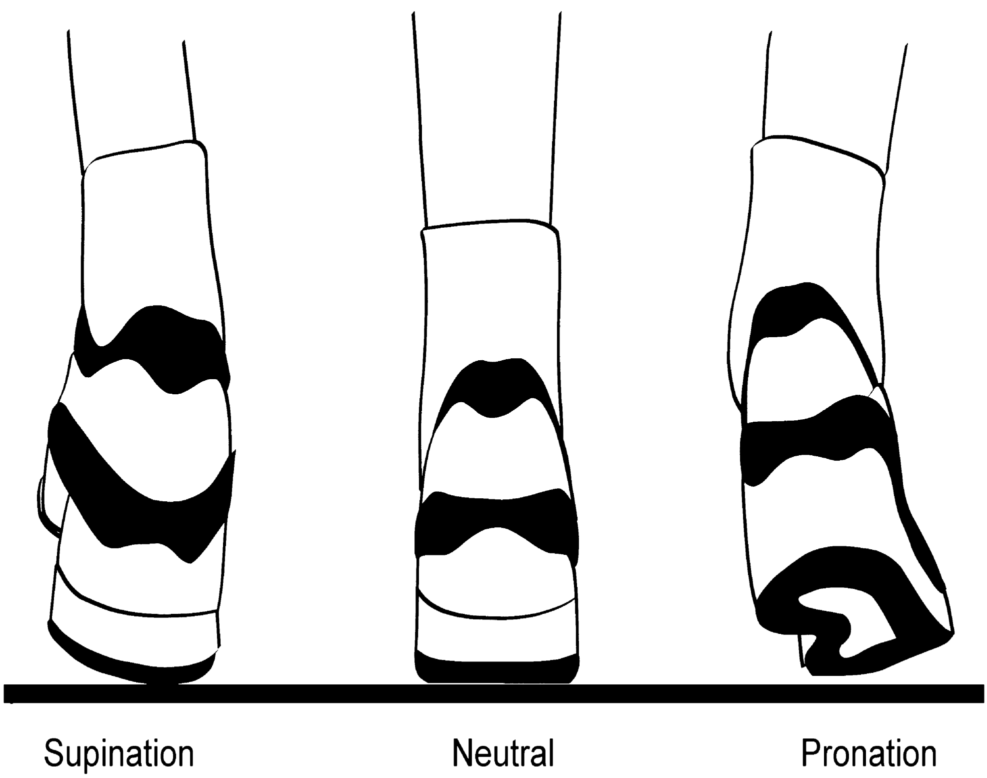

Figure 3.5. Frontal plane view of rear-foot motion in the first half of the stance phase of running. The foot lands in a supinated position. The motion of the foot and ankle to accommodate to the surface and absorb shock is called *pronation*.

journal space but places a burden on the kinesiology professional to be knowledgeable about variations in descriptive terminology.

Review of Muscle Structure

The anatomical structure and microstructure of skeletal muscle has considerable functional importance. We will see later that the function of the complex structures of skeletal muscle can be easily modeled as coming from active and passive sources. This section will review a few of the structural components of skeletal muscle that are believed to be important in these active and passive tissue properties.

Careful dissection of skeletal muscle shows that muscles are composed of many distinct bundles of muscle fibers called *fascicles*. In cutting across a piece of beef or chicken you may have noticed the tissue is in small bundles. The connective tissue sheath that surrounds the whole muscle, bundling the fascicles together, is called *epimysium* (meaning over/above the muscle). Each fascicle is covered by connective tissue called *perimysium*, meaning "around the muscle." There are hundreds of muscle fibers within a fascicle, and an individual fiber is essentially a muscle cell. Muscle fibers are also covered with connective tissue called *endomysium* (within the muscle). The gradual blending of these connective tissue components of muscle forms a distinct tendon or fuses with the calcified connective tissue, the periosteum of bones. A schematic of the macrostructure of skeletal muscle is shown in Figure 3.6.

The specific arrangement of fascicles has a dramatic effect on the force and range-of-motion capability of the muscle

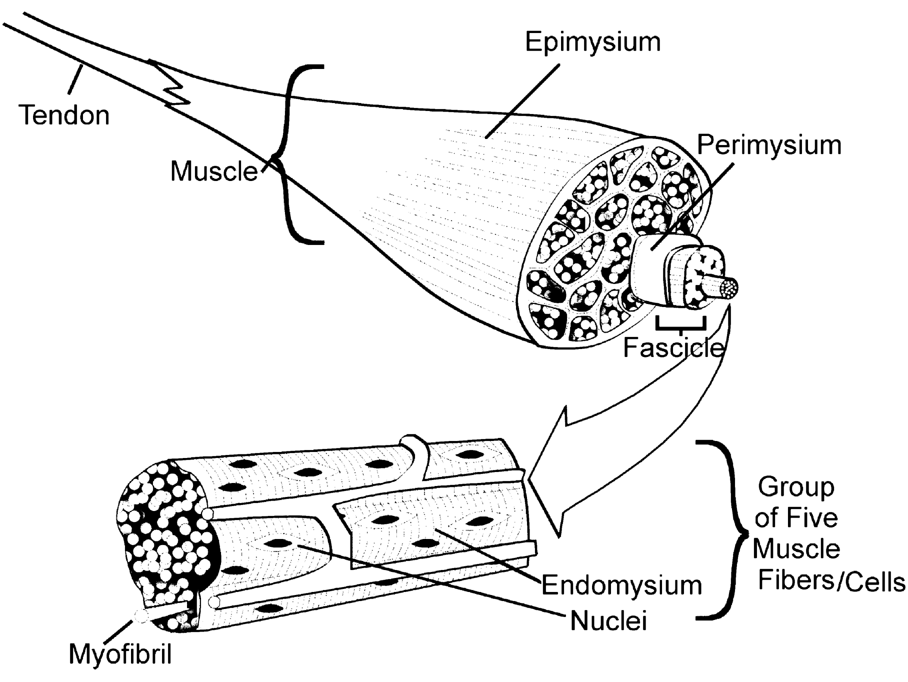

Figure 3.6. The macroscopic structure of muscle includes several layers of connective tissue and bundles of muscle fibers called fascicles. Muscle fibers (cells) are multinucleated and composed of many myofibrils.

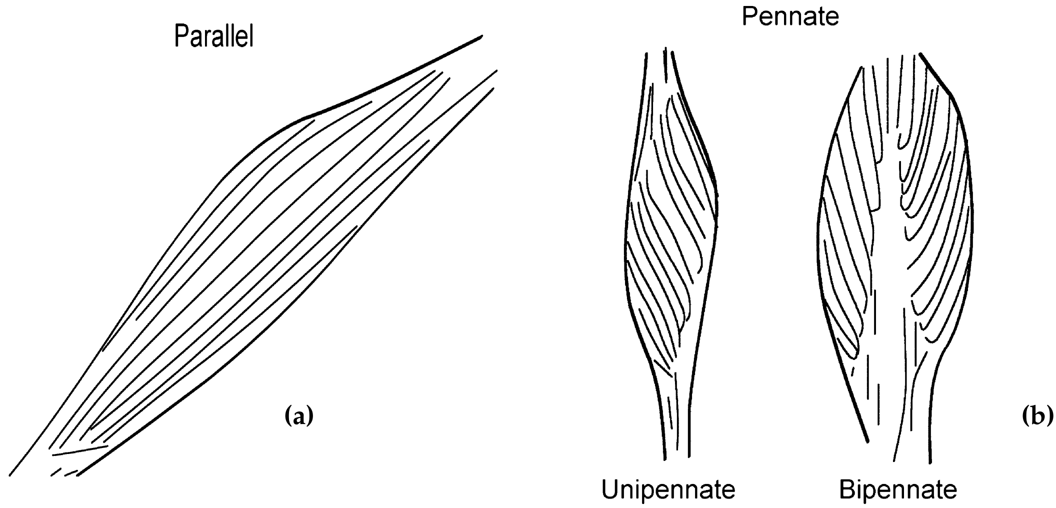

Figure 3.7. (a) Parallel arrangement of muscle fibers with the tendon favors range of motion over force. (b) Pennate arrangement of fibers are angled into the tendon and create greater force but less range of motion.

(Lieber & Friden, 2000). Anatomically, this fiber arrangement has been classified as either **parallel** or **pennate**. A **parallel** arrangement means that the muscle fascicles are aligned parallel to the long axis or line of pull of the muscle. Muscles like the rectus abdominis, sartorius, and biceps brachii have predominantly a parallel architecture (Figure 3.7a). **Pennate** muscles have fibers aligned at a small angle (usually less than 15º) to a tendon or **aponeurosis** running along the long axis of the muscle. An **aponeurosis** is a distinct connective tissue band within a muscle. This arrangement is called pennate because of the feathered appearance. The tibialis posterior and semimembranosus are primarily unipennate, while rectus femoris and gastrocnemius are bipennate (Figure 3.7b). An example of a multipennate muscle is the deltoid.

Muscles with parallel architecture favor range of motion over force development. The greater muscle excursion and velocity of parallel muscles comes from the greater number of sarcomeres aligned in series. The rectus abdominis can shorten from 1/3 to 1/2 of its length because of the parallel arrangement of fibers and fascicles. Small muscles may have a simple parallel design with fibers that run the length of the muscle, while larger parallel muscles have fibers aligned in series or end to end. These end-to-end connections and transverse connections within muscles make force transmission in muscle quite complex (Patel & Lieber, 1997; Sheard, 2000). Fiber architecture also interacts with the connective tissue within muscle to affect force or fiber shortening. The fibers in the center of the biceps do not shorten uniformly due to differences in the distal and proximal aponeurosis (Pappas, Asakawa, Delp, Zajac, & Draceet, 2002). The amount of tendon a muscle has and the ratio of tendon to fibers also affects the force and range-of-motion potential of a muscle.

In essence, pennate muscles can create a greater tension because of a greater physiological cross-sectional area per anatomical cross-sectional area, but have less range of shortening than a muscle with a parallel architecture. Physiological cross-sectional area is the total area of the muscle at right angles to the muscle fibers.

Muscle fibers are some of the largest cells in the body and are long cylindrical structures with multiple nuclei. A typical muscle cell is between 10 and 100 µm in diameter. The lengths of muscle fibers varies widely from a few centimeters to 30 cm long. Besides many nuclei there are hundreds to thousands of smaller protein filaments called **myofibrils** in every muscle fiber. If a muscle cell were to be imagined as a cylindrical straw dispenser, the myofibrils would be like the straws packed in this dispenser. Figure 3.8 illustrates the microstructure of a muscle fiber.

The microstructure of a muscle becomes even more fascinating and complex as you pull out a straw (myofibril), only to notice that there are even smaller threads or cylindrical structures within a myofibril. These many smaller fibers within each myofibril are all well organized and aligned with other adjacent myofibrils in a fiber. This is why looking at skeletal muscle under a light microscope gives the appearance of a consistent pattern of dark and light bands. This is how skeletal muscle came to be called *striated muscle* (Figure 3.8). These small sections of a myofibril between two Z lines (thin dark band) are called **sarcomeres**. Sarcomeres are the basic contractile structures of muscle.

Biomechanists model the active tension of whole muscles based on the behavior of the interaction of two contractile proteins in sarcomeres: **actin** and **myosin**. Actin is the thin protein filaments within the sarcomeres of a myofibril, and myosin the thicker protein filaments. Cross-bridges between myosin and actin are attached and detached with the chemical energy stored in adenosine triphosphate (ATP). You may be familiar with the names of the various zones (Z line, A band, and I band) and other substructures of a sarcomere.

While most biomechanists use simple models of the active tension of whole muscles, some biomechanists are interested in researching the mechanical behavior of the microstructures of myofibrils to increase our understanding of where active and passive forces originate. Considerable research is being done to understand muscle actions

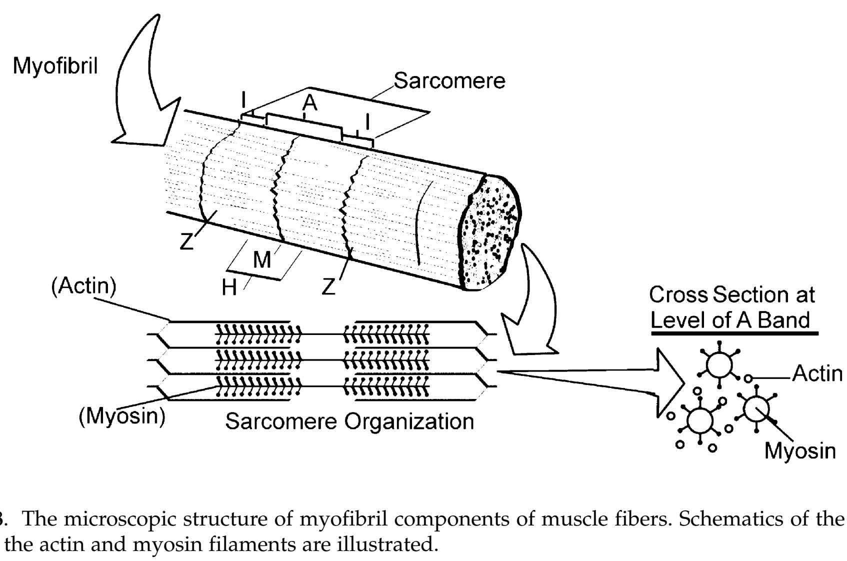

Figure 3.8. The microscopic structure of myofibril components of muscle fibers. Schematics of the sarcomere, as well as of the actin and myosin filaments are illustrated.

at this microscopic level from variations in myosin isoforms (Lutz & Lieber, 1999) to force transmission throughout the muscle fiber and muscle (Patel & Lieber, 1997; Sheard, 2000). Some muscle injuries could be due to this complex force production behavior and to nonuniform stresses in the sarcomeres of fibers (Morgan, Whitehead, Wise, Gregory, & Proske, 2000; Talbot & Morgan, 1996).

Many kinesiology students are familiar with muscular **hypertrophy** (increased muscle fiber diameter as a result of training), but they are unaware that chronic elongation of muscles (like in stretching) increases the number of sarcomeres in series within muscle fibers to increase their functional range of motion (Cox *et al.*, 2000; Williams & Goldspink, 1978). The number of sarcomeres and muscle fiber length are adaptable and strongly related to muscle performance (Burkholder, Fingado, Baron, & Lieber, 1994).

It is clear that biomechanics plays a role in understanding the functional significance of the gross and microstructural factors of the muscletendon unit. Most general concepts related to human movement, like muscular strength or range of motion, have many biomechanical factors and levels of structure that interact to determine how the concept actually affects movement. This is our first example of the paradox of learning: the more you know, the more you know what you don't know. Now that we have reviewed some of the major structural factors that affect muscle force and range of motion, let's define the kinds of actions muscles have.

MUSCLE ACTIONS

Muscle forces are the main internal motors and brakes for human movement. While gravity and other external forces can be used to help us move, it is the torques created by skeletal muscles that are coordinated with the torques from external forces to obtain the human motion of interest. While some biomechanists are interested in the forces and motions created by smooth (visceral) or cardiac (heart) muscle, this text will focus on the actions of skeletal muscle that create human movement.

The activation of skeletal muscle has traditionally been called *contraction*. I will avoid this term because there are several good reasons why it is often inappropriate for describing what muscles actually do during movement (Cavanagh, 1988; Faulkner, 2003). Contraction implies shortening, which may only be accurate in describing the general interaction of actin and myosin in activated muscle. Contraction also conflicts with the many actions of muscles beyond shortening to overcome a resistance. Saying "eccentric contraction" is essentially saying "lengthening shortening"! Cavanagh suggests that the term "action" is most appropriate, and this book adopts this terminology. **Muscle action** is the neuromuscular activation of muscles that contributes to movement or stabilization of the musculoskeletal system. We will see that muscles have three major actions (eccentric, isometric, concentric) resulting from both active and passive components of muscle tension. It could also be said that a fourth action of muscle is inaction, not being activated because their activation at that time would be inefficient or counterproductive to the task at hand.

Mechanically, the three kinds of actions are based on the balance of the forces and torques present at any given instant (Figure 3.9). If the torque the activated muscles creates is exactly equal to the torque of the resistance, an isometric action results. A bodybuilder's pose is a good example of **isometric** muscle actions of opposing muscle groups. Recall that isometric literally means "same length."

A **concentric** action occurs when the torque the muscle group makes is larger

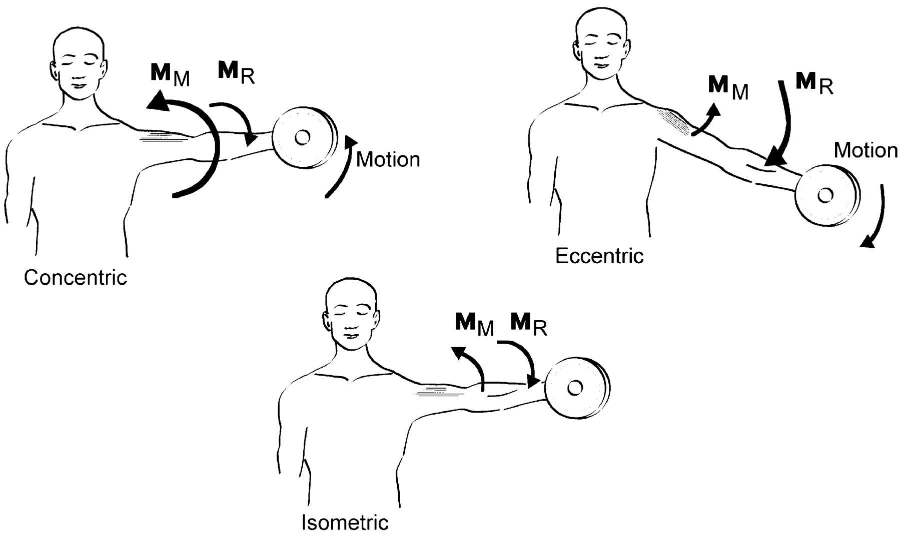

Figure 3.9. The three kinds of muscle action are determined by the balance of torques (moments of force: **M**). In concentric action the torque of the abductors ($\mathbf{M}_M$) is greater than the torque of the resistance ($\mathbf{M}_R$), so the arm rises. In isometric conditions the joint angle does not change because $\mathbf{M}_M$ and $\mathbf{M}_R$ are equal. In eccentric action $\mathbf{M}_M$ is less than $\mathbf{M}_R$, so the arm is lowered.

than the torque of a resistance, resulting in muscle shortening. The upward lift of a dumbbell in an arm curl is the concentric phase of the exercise. In essence a concentric action occurs when a muscle activation results in shortening of the muscle-tendon unit. When the lifter gradually lowers the weight in an arm curl, the torque the muscle group makes is less than the torque of the resistance. This lowering of the dumbbell is an **eccentric** muscle action or the lengthening of an activated muscle. In eccentric actions muscles are used as brakes on external forces or motion like the brakes of your car.

The importance of these different muscle actions cannot be overemphasized. Functional anatomical analysis and most people tend to focus primarily on the concentric actions of muscles. This overemphasis of what is usually in the minority of muscle actions for most movements gives a false impression of how muscles create human movement. The following section on the limits of functional anatomy will expand on this idea by showing that muscles create movement in a variety of ways using all three muscle actions, not just concentric action.

Application: Eccentric Actions and Muscle Injury

Eccentric actions are common to all muscles and virtually every human movement. Eccentric actions of high intensity, repetitive nature, or during fatigue are associated with muscle injury. When eccentrically active muscles are rapidly overcome by external forces, a *muscle strain* injury can occur. When people perform physical activity beyond typical levels, especially eccentric muscle actions, the result is usually *delayed-onset muscle soreness*. This is why it is important in conditioning to include both eccentric and concentric phases of exercises. Some athletic events would benefit from emphasis on eccentric training. For example, long jumpers and javelin throwers need strong eccentric strength in the takeoff and plant leg.

Active and Passive Tension of Muscle

Activated muscles create forces by pulling about equally on all their attachments. This tensile force really has two sources: active and passive tension.

Active tension refers to the forces created between actin and myosin fibers in the sarcomeres of activated motor units. So active tension is the force created by the contractile proteins (actin and myosin) using chemical energy stored in ATP. This ability of muscles to create active tensile forces is unique compared to the connective tissue components (ligaments, tendons, bone) of the musculoskeletal system. The shape of this active tension potential of skeletal muscle is called the force–velocity relationship of muscle and is summarized in chapter 4.

Passive tension is the force that comes from an elongation of the connective tissue components of the muscletendon unit. When a person does a stretching exercise, the tension she feels in the muscles is the internal resistance of the muscletendon unit to the elongation of the stretch. This passive tension in stretching exercises can be quite large and may be responsible for the muscular weakness seen in muscles following stretching (Knudson, McHugh, & Magnusson, 2000). In the midranges of joint motion, passive tension does not significantly contribute to muscle forces in normal movement (Siegler & Moskowitz, 1984); however, it is more a factor in low-force movements (Muraoka et al., 2005) and in various neuromuscular disorders (Lamontagne, Malouin, & Richards, 2000). Muscle passive tension is a significant factor affecting movement at the extremities of joint range of motion. The increase in passive tension limiting range of joint motion is quite apparent in multiarticular muscles and is called **passive insufficiency**. We will see in the following chapter that passive tension is an important component of the force–length relationship of muscle. The passive insufficiency of poor hamstring flexibility could lead to poor performance or risk of injury in activities that require combined hip flexion and knee extension, such as in a karate front kick (Figure 3.10). The passive tension in the hamstring muscles is high in Figure 3.10 because the muscle is simultaneously stretched across the hip and knee joint. We will learn later on in this chapter that the concept of range of motion is a complicated phenomenon that involves several mechanical variables.

Hill Muscle Model

One of the most widely used mechanical models of muscle that takes into account

Figure 3.10. The combined hip flexion and knee extension of a karate front kick may be limited by the passive insufficiency of the hamstring muscles. This technique requires excellent static and dynamic hamstring flexibility. Image courtesy of Master Steven J. Frey, 4th-Degree Black Belt.

Activity: Passive Tension

The effect of passive tension on joint motions can be felt easily in multi-joint muscles when the muscles are stretched across multiple joints. This phenomenon is called *passive insufficiency*. Lie down in a supine (face upwards) position and note the difference in hip flexion range of motion when the knee is flexed and extended. The hamstring muscle group limits hip flexion when the knee is extended because these muscles cross both the hip and the knee joints. Clinical tests like the straight-leg raise (Eksstrand, Wiktorsson, Oberg, & Gillquist, 1982), active knee extension (Gajdosik & Lusin, 1983), and the sit-and-reach (Wells & Dillon, 1952) all use passive insufficiency to evaluate hamstring static flexibility. Careful body positioning is required in flexibility tests because of passive insufficiency and other mechanical factors across several joints. Some aspects of this issue are explored in Lab Activity 3.

both the active and passive components of muscle tension is the three-component model developed by A. V. Hill in 1938 (Hill, 1970). Hill was an English physiologist who made substantial contributions to the understanding of the energetics (heat and force production) of isolated muscle actions. Hill was also interested in muscular work in athletics, and some of his experimental techniques represent ingenious early work in biomechanics (Hill, 1926, 1927). The **Hill muscle model** has two elements in series and one element in parallel (Figure 3.11). The contractile component (CC) represents the active tension of skeletal muscle, while the parallel elastic component (PEC) and series elastic component (SEC) represent two key sources of passive tension in muscle. The Hill muscle model has been the dominant theoretical model for understanding muscle mechanics and is usually used in biomechanical computer models employed to simulate human movement.

We can make several functional generalizations about the mechanical behavior of muscle based on Figure 3.11. First, there is elasticity (connective tissue) in the production of active muscle tension modeled by the series elastic component. The source of this series elasticity is likely a mixture of the actin/myosin filaments, cross bridge stiffness, sarcomere nonuniformity, and other sarcomere connective tissue components. Second, the passive tension of relaxed muscle that is easily felt in stretching exercises or in passive insufficiency affects motion at the extremes of joint range of motion. The "p" in the parallel elastic component is a key for students to remember this as the primary source of passive tension in the Hill muscle model. Third, muscle tension results from a complex interaction of active and passive sources of tension. This third point can be generalized beyond the simple Hill muscle model as a result of recent research that has focused on the complex transmission of force within the connective tissue components of muscle (Patel & Lieber, 1997). Muscles may not create equal forces at their attachments because of force transmitted to extramuscular connective tissues (Huijing & Baan, 2001).

The separation of the passive tension into series and parallel components in the Hill model and the exact equations used to represent the elastic (springs) and contractile components are controversial issues. Whatever the eventual source and complexity of elastic tension, it is important to remember that the stretch and recoil of elastic structures are an integral part of all muscle actions. It is likely that future research will increase our understanding of the interaction of active and passive components

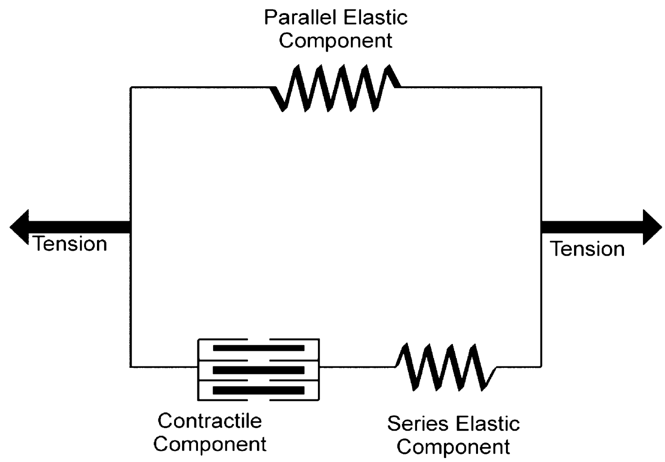

Figure 3.11. The Hill model of muscle describes the active and passive tension created by the MTU. Active tension is modeled by the contractile component, while passive tension is modeled by the series and parallel elastic components.

of muscle tension in creating human movement. There are many other complexities in how muscles create movement. The next section will briefly review the logic of functional anatomical analysis and how biomechanics must be combined with anatomy to understand how muscles create movement.

THE LIMITATIONS OF FUNCTIONAL ANATOMICAL ANALYSIS

Anatomy classifies muscles into functional groups (flexors/extensors, abductors/adductors, etc.) based on hypothesized actions. These muscle groups are useful general classifications and are commonly used in fitness education, weight training, and rehabilitation. These hypothesized muscle actions in movements and exercises are used to judge the relevance of various exercise training or rehabilitation programs. This section will show that such qualitative estimations of muscle actions are often incorrect. Similarly, many of the muscle actions hypothesized by coaches and therapists from subjective observation of movement are not correct (Bartlett, 1999; Herbert, Moore, Moseley, Schurr, & Wales, 1993). Kinesiology professionals can only determine the true actions of muscle by examining several kinds of biomechanical studies that build on anatomical information.

Mechanical Method of Muscle Action Analysis

Functional anatomy, while not an oxymoron, is certainly a phrase that stretches the truth. Functional anatomy classifies muscles actions based on the mechanical method of muscle action analysis. This method essentially examines one muscle's line of action relative to one joint axis of rotation, and infers a joint action based on orientation and pulls of the muscle in the anatomical position (Figure 3.12). In the sagittal plane, the biceps brachii is classified as an elbow flexor because it is assumed that (1) the origins are at the shoulder joint, (2) the insertion is on the radial tuberosity, and (3) the anterior orientation

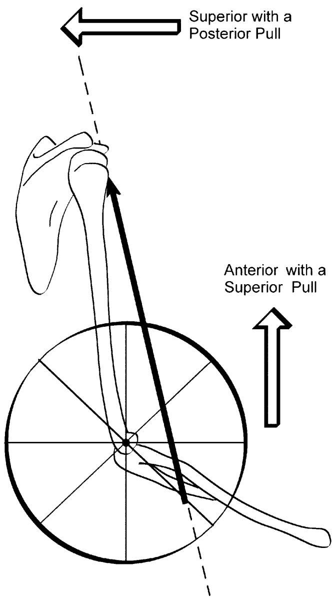

Figure 3.12. The mechanical method of muscle action analysis applied to biceps and elbow flexion in the sagittal plane. It is assumed that in the anatomical position the biceps pulls upward toward its anatomical origin from its anatomical insertion (radial tuberosity). The motion can be visualized using a bicycle wheel with the axle aligned on the joint axis. If the the muscle were pulling on the wheel from its illustrated direction and orientations relative to that joint axis (visualize where the line of action crosses the medial-lateral and superior-inferior axes of the sagittal plane), the wheel would rotate to the left, corresponding to elbow flexion. Unfortunately, the actions of other muscles, external forces, or other body positions are not accounted for in these analyses. More thorough and mathematical biomechanical analyses of the whole body are required to determine the true actions of muscles.

and superior pull, as well as the superior orientation and posterior pull, would create elbow flexion. When a muscle is activated, however, it pulls both attachments approximately equally so that which end moves (if one does at all) depends on many biomechanical factors. Recall that there are three kinds of muscle actions, so that what the biceps brachii muscle does at the elbow in a particular situation depends on many biomechanical factors this book will explore. Notice that the tension at both ends of a muscle often might not be the same because of the force transmitted to nearby muscles and extramuscular connective tissue (Huijing, 1999; Maas *et al.*, 2004).

While the biceps is clearly an elbow flexor, this analysis assumes quite a bit and does not take into consideration other muscles, other external forces, and the biarticular nature of the biceps. The long head of the biceps brachii crosses the shoulder joint. What if the movement of interest was the eccentric phase of the pull-over exercise (Figure 3.13), where the shoulder was the origin because the elbow angle essentially did not change while shoulder flexion and extension were occurring? It is not entirely clear if the long head of the biceps is in isometric or concentric action in this pull-over exercise example. Biomechanical data and analysis are necessary to determine the actual actions of muscles in movement. There are even cases where muscles accelerate a

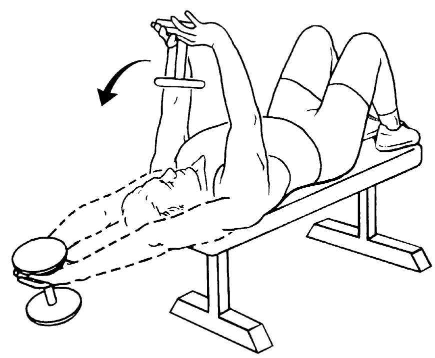

Figure 3.13. In the eccentric phase of the pullover exercise, the motion primarily occurs at the shoulder joint, with the elbow angle remaining unchanged. The isolated mechanical method of muscle action does not help in this situation to determine if the long head biceps (crossing both the elbow and shoulder joints) is isometrically active, concentrically active, or inactive. Do you think a biarticular muscle like the biceps can be doing two kinds of muscle actions at once? We will see later that extensive kinetic biomechanical models and EMG research must be combined to determine the actual action of muscles in many movements. Image courtesy of VHI Kits, Tacoma, WA.

joint in the opposite direction to that inferred by functional anatomy (Zajac, 1991; Zajac & Gordon, 1989).

Rather invasive biomechanical measurements are usually required to determine exactly what muscle actions are occurring in normal movement. Many studies conducted on animals have shown that muscles often have surprising and complex actions (see Biewener, 1998; Herzog, 1996a,b). One such study of the turkey (Roberts *et al.*, 1997) gastrocnemius (plantar flexor) found the muscle acted in essentially an isometric fashion in the stance phase of level running (Figure 3.14A), while concentric actions were used running uphill (Figure 3.14B). The invasive nature of these kinds of measurements and the interesting variations in the musculoskeletal structure of animals (fish, kangaroo rats, wallabies; Biewener, 1998; Griffiths, 1989; Shadwick, Steffensen, Katz, & Knower, 1998) makes animal studies a major area of interest for the biomechanics of muscle function.

Similar complex behavior of muscle actions has been observed in humans using

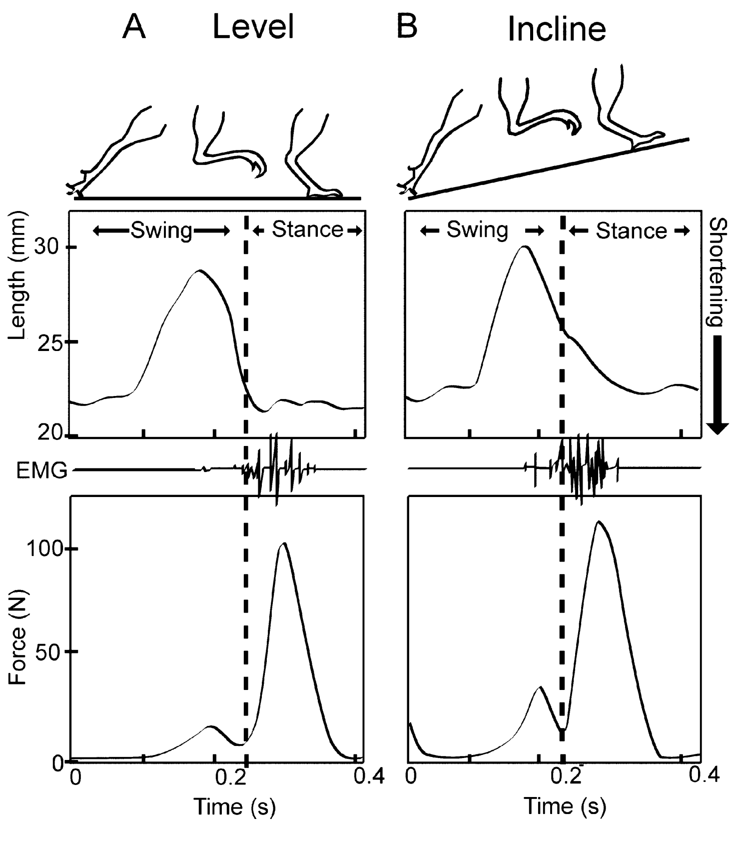

Figure 3.14. Simultaneous muscle force, length, and activation (EMG) measurements of the gastrocnemius of running turkeys. (A) Note that in level running the muscle creates considerable force but the fibers do not shorten, so the muscle is in isometric action and length changes are in the stretching and recoiling of the tendon. (B) in the stance phase of uphill running, the muscle fibers shorten (concentric action), doing mechanical work to lift the turkey's body. Reprinted with permission from Roberts *et al.* (1997). Copyright © 1997 American Association for the Advancement of Science.

recent improvements in ultrasound imaging (Finni, Komi, & Lepola, 2000; Finni *et al.*, 2001: Fukunaga, Ichinose, Ito, Kawakami, & Fukashiro, 1997; Fukunaga, Kawakami, Kubo, & Keneshisa, 2002; Kubo, Kawakami, & Fukunaga, 1999) and implantable fiberoptic force sensors (Komi, Belli, Huttunen, Bonnefoy, Geyssant, & Lacour, 1996). Recent studies of the human tibialis anterior have also documented nonlinear and nonisometric behavior of the muscle (lengthening of tendon and aponeurosis while fibers shorten) in isometric actions (Maganaris & Paul, 2000; Ito *et al.*, 1998). This is an area of intense research in biomechanics because the lengthening and shortening of muscle fibers, aponeurosis, and tendon from several different muscles can all be documented *in vivo* during human movements (Finni, 2006; Fukashiro *et al.*, 2006; Kawakami & Fukunaga, 2006). It is clear now that muscle actions in animal movements are more complicated than can be predicted by the concentric, single-joint analysis of functional anatomy.

Given these many examples of the complexity of muscle actions at the macro and microscopic levels, the hypothesized muscle actions from functional anatomy in many human movements should be interpreted with caution. Seemingly simple questions of what muscles contribute most to walking, jumping, or any movement represent surprisingly complex biomechanical issues. For example, should the word "eccentric" be used as an adjective to describe phases in weight training exercise (eccentric phase), when all the active muscles are clearly not in eccentric actions in the movement? If the active muscle group, body position, and resistance are well defined, this terminology is likely accurate. When the lifter "cheats" with other muscles in the exercise, modifies exercise technique, or performs a similar sporting movement, the eccentric adjective may not be accurate. The actions of other muscles, external forces like gravity, and the complexity of the musculoskeletal system can make the isolated analyses of functional anatomy in the anatomical position inaccurate for dynamic movement. Some biomechanical issues that illustrate this point are summarized here and developed throughout the book.

Interdisciplinary Issue: Anthropometry

Anthropometry is the science concerned with measurement of the physical properties (length, mass, density, moment of inertia, etc.) of a human body. Kinanthropometry is an area within kinesiology that studies how differences in anthropometry affect sport performance (see chapters 5 and 7 in Bloomfield, Ackland, & Elliott, 1994). The main organization in this area is the International Society for the Advancement of Kinanthropometry (ISAK). Since humans move in a wide variety of activities, many professionals use anthropometric data. Engineers use these measurements to design tools and workstations that fit most people and decrease risk of overuse injuries. Prosthetic and orthotic manufacturers often make anthropometric measurements on individuals to customize the device to the individual. Motor development scholars track the changes in anthropometric characteristics with growth and development. While people seem to have a wide variety of shapes and sizes, the relative (scaled to size) size of many anthropometric variables is more consistent. Biomechanists use many of these average physical measurements to make quite accurate kinetic or center-of-gravity calculations.

The Need for Biomechanics to Understand Muscle Actions

The traditional "kinesiological" analysis of movements of the early twentieth century essentially hypothesized how muscles contributed to motion in each phase of the skill by noting anatomical joint rotations and assuming muscles that create that joint rotation are active. Muscle actions in human movements, however, are not as simple as functional anatomy assumes (Bartlett, 1999). Several kinds of biomechanical research bear this out, and show that the combination of several kinds of quantitative biomechanical analysis are necessary to understand the functions of muscles in movements.

First, **electromyographic** (**EMG**) studies have documented general trends in activation of muscles in a particular muscle group, but with considerable potential variation in that trend or in activation between subjects (Basmajian & De Luca, 1985). The primary source of this variation may be the considerable redundancy (muscles with the same joint actions) of the muscular system. Nearly identical movements can be created by widely varying muscular forces or joint torques (Hatze, 2000; Patla, 1987; Winter, 1984).

EMG studies show that the activation patterns of individual muscles are not representative of all muscles in the same functional group (Arndt, Komi, Bruggemann, & Lukkariniemi, 1998; Bouisset, 1973), and there are differences in how muscles within a muscle group respond to training (Rabita *et al*., 2000). Even individual muscles are quite sophisticated, with different motor unit activation depending on the task or muscle action (Babault, Pousson, Ballay, & Van Hoecke, 2001; Enoka, 1996; Gandevia, 1999; Gielen, 1999). Muscles within a muscle group can alternate periods of activity in low-level activities to minimize fatigue (Kouzaki, Shinohara, Masani, Kanehisa, & Fukunaga, 2002). Muscle activation can vary because of differences in joint angle, muscle action (Kasprisin & Grabiner, 2000; Nakazawa, Kawakami, Fukunaga, Yano, & Miyashita, 1993) or the degree of stabilization required in the task (Kornecki, Kebel, & Siemienski, 2001). For example, a manual muscle test for the biceps used by physical therapists uses isometric elbow flexion with the forearm in supination to minimize brachioradialis activity and maximize biceps activity (Basmajian and De Luca, 1985). Recent EMG studies, however, have also demonstrated that some of these procedures used to isolate specific muscles in physical therapy do not always isolate the muscle hypothesized as being tested (see Kelly, Kadrmas, & Speer, 1996; Rowlands, Wertsch, Primack, Spreitzer, Roberts, Spreitzer, & Roberts, 1995).

The activation of many muscles to create a specific force or action is called a muscle **synergy**. A muscle **synergy** is a combination of muscle actions that serves to optimally achieve a motor task. There is considerable recognition of the importance of muscle synergies and force sharing of muscles in biomechanical research (Arndt *et al.*, 1998; Herzog, 1996b, 2000) and in current rehabilitation and conditioning trends (see Interdisciplinary Issue on training muscles versus movements). How individual muscles share the load is complicated, depending on fiber type, contractile properties, cross-sectional area, moment arm, and antagonism (Ait-Haddou, Binding, & Herzog, 2000). Motor control uses the term *synergy* to refer to underlying rules of the neuromuscular system for using muscles to coordinate or create movements (Aruin, 2001; Bernstein, 1967).

Activity: Muscle Synergy

Make a tight fist in your dominant hand as forcefully and quickly as you can. Observe the actions of the superficial muscles of your arm. Why do you think biceps and triceps are isometrically activated in a power grip muscle synergy?

Recent EMG research has in addition begun to focus on different activation of intramuscular sections within a muscle beyond the traditional gross segmentation in classical anatomy (Brown, *et al.*, 2007; Mirka, Kelaher, Baker, Harrison, & Davis, 1997; Paton & Brown, 1994; Wickham & Brown, 1998; Wickham *et al.*, 2004). Wickham and Brown (1998) have confirmed different activation of seven distinct segments of the deltoid muscle, rather than the typical three sections (anterior, intermediate, posterior) of muscle fibers usually identified in anatomy. This line of research supports the EMG studies mentioned earlier which indicate that activation of muscles is much more complex than had been previously thought. Further microanatomy and EMG research on muscles, particularly those with large attachments, will most likely increase our understanding of how parts of the muscles are activated differently to create movement.

Second, the descriptions of musculoskeletal anatomy often do not account for variations in muscle attachment sites across individuals. The numbers and sites of attachments for the rhomboid and scalene muscles vary (Kamibayashi & Richmond, 1998). A person born with missing middle and lower fibers of trapezius on one side of their body must primarily rely on rhomboids for scapular retraction. Variations in skeletal structure are also hypothesized to contribute to risk of injury. For example, the shape of the acromion process of the scapula is believed to be related to a risk of impingement syndrome (Whiting & Zernicke, 1998). The role of anatomical variation in gross anatomy or in muscle architecture (Richmond, 1998) and their biomechanical effects of muscles actions and injury risk remain an important area of study.

Third, the linked nature of the human body makes the isolated functional anatomical analysis incomplete. This linking of body segments means that muscle actions have dramatic effects on adjacent and other joints quite distant from the ones the muscles cross (Zajac, 1991; Zajac & Gordon, 1989). This redistribution of mechanical energy at distant joints may be more important to some movements than the traditional joint action hypothesized by functional anatomy (Zajac, Neptune, & Kautz, 2002). Zajac and Gordon (1989), for example, showed how soleus activity in a sit-to-stand movement tends to extend the knee joint more than it plantar flexes the ankle joint. Physical therapists know that the pectoralis major muscle can be used to extend the elbow in closed kinetic chain (see chapter 6) situations for patients with triceps paralysis (Smith, Weiss, & Lehmkuhl, 1996). Functional anatomy does not analyze how forces and torques created by a muscle are distributed throughout all the joints of the skeletal system or how these loads interact between segments. Zajac and Gordon (1989) have provided a convincing argument that the classification of muscles as **agonists** or **antagonists** should be based on biomechanical models and joint accelerations, rather than torques the muscles create.

Dramatic examples of this wide variety of effects of muscles can be seen in multiarticular muscles (van Ingen Schenau *et al.*, 1989; Zajac, 1991). There is considerable interest in the topic of biarticular or multiarticular muscles, and it is known that they have different roles compared to similar monoarticular muscles (Hof, 2001; Prilutsky & Zatsiorsky, 1994; van Ingen Schenau *et al.*, 1995). Another example of the complexity of movement is how small differences in foot placement (angle of ankle plantar/dorsiflexion) dramatically affects which joint torques are used to cushion the shock in landing (DeVita & Skelly, 1992; Kovacs, Tihanyi, DeVita, Racz, Barrier, & Hortobagyi, 1999). A flat-footed landing minimizes a plantar flexor's ability to absorb shock, increasing the torque output of the hip and knee extensors. Small differences in foot angle in walking also affect the flexor or extensor dominance of the knee torque

Interdisciplinary Issue:
Training Muscles vs. Movements

In the strength and conditioning field an area of philosophical debate is related to a greater emphasis on training functional movements rather than training specific muscle groups (Gambetta, 1995, 1997). This debate is quite similar to the debate about the relative benefits of training with free weights or with machines. Training with free weights can more easily simulate the balance and stabilizing muscle actions in normal and sport movements. The advantage of machines is that they provide more muscle group-specific training with resistance that is not as dependent on position relative to gravity as free weights are. How might rehabilitation and conditioning professionals use biomechanics and EMG research to help match training to the demands of normal movement?

(Simonsen, Dyhre-Poulsen, Voigt, Aagaard, & Fallentin, 1997), and the frontal plane knee torques that may be related to knee injury (Gregersen, Hull, & Hakansson, 2006; Teichtahl *et al.*, 2006). The kinematics and kinetics chapters (5 and 6 & 7, respectively) will expand on the effects of the joints and segment actions in human movement.

The fourth line of biomechanical research documenting the complexity of muscular actions creating movement are **modeling** and **simulation**. **Modeling** involves the development of a mathematical representation of the biomechanical system, while **simulation** uses biomechanical models to examine how changes in various techniques and parameters affect the movement or body. Biomechanical models of the human body can be used to simulate the effects of changes in any of the parameters of the model. The more simple the model, the easier the interpretation and application of results. For example, models of the motion of body segments in airborne skills in gymnastics and diving are quite effective in determining their effect on flight and rotation (Yeadon, 1998). As biomechanics models get more complicated and include more elements of the musculoskeletal system, the more difficult it is to validate the model. Interpretation is even complicated because of the many interrelated factors and variations in model parameters across subjects (Chow, Darling, & Ehrhardt, 1999; Hubbard, 1993).

Despite the many controversial issues in biomechanical modeling, these kinds of studies show that the actions of muscles in movements are quite complex and are related to segment and muscle geometry (Bobbert & van Ingen Schenau, 1988; Doorenbosch, Veeger, van Zandwij, & van Ingen Schenau, 1997), muscle elasticity (Anderson & Pandy, 1993), coordination (Bobbert & van Soest, 1994; Hatze, 1974; Nagano & Gerritsen, 2001), and accuracy or injury (Fujii & Hubbard, 2002; Thelen *et al.*, 2006). One simulation found that non-extensor muscles of the legs could be used to improve jumping performance (Nagano *et al.*, 2005), and it is also possible that coordination in a movement even varies slightly across people because of differences in muscle mechanics (Chowdhary & Challis, 2001). Here we have the paradox of learning again. What muscles do to create movement is quite complex, so kinesiology scholars and professionals must decide what level of biomechanical system to study to best understand movement. The strength and conditioning field commonly groups muscles into functional groups like the knee extensors (quadriceps) or knee flexors (hamstrings). Whatever movements or level of analysis a kinesiology professional chooses, biomechanics needs to be added to anatomical knowledge to make valid inferences about human movement. The next section briefly shows how the sports medicine professions have integrated more biomechanical information into their professional practice.

Application: Muscle Groups

If muscles create movement in complex synergies that are adaptable, should kinesiology professionals abandon the common practice of naming muscle groups according to anatomical function (quads [knee extensors] or calf [ankle plantar flexors])? Such an extreme reaction to the complexity of biomechanics is not necessary. This common terminology is likely appropriate for prescribing general strength and conditioning exercises. It may even be an appropriate way to communicate anatomical areas and movements in working with athletes knowledgeable and interested in performance. Kinesiology professionals do need to qualitatively analyze movements at a deeper level than their clients, and remember that this simplified terminology does not always give an accurate picture of how muscles really act in human movement. Biomechanical and other kinesiology research must be integrated with professional experience in qualitatively analyzing movement.

Sports Medicine and Rehabilitation Applications

Musculoskeletal anatomy and its motion terminology are important in kinesiology and sports medicine, but it cannot be the sole basis for determining the function of muscles in human movement. Medical doctors specializing in sports medicine found that their extensive training in anatomy was not enough to understand injuries and musculoskeletal function in the athletes they treated (McGregor & Devereux, 1982). This recognition by MDs that their strong knowledge of anatomy was incomplete to understand function and that they needed the sciences of kinesiology was a factor in the fusion of medical and kinesiology professionals that formed the American College of Sports Medicine (ACSM).

Today, many kinesiology students prepare for careers in medicine- and sports medicine-related careers (athletic training, physical therapy, orthotics, prosthetics, strength & conditioning). These professions are concerned with analyzing the actions of muscles in movement. Where can sports medicine professionals (athletic trainers, physical therapists, physical medicine, strength and conditioning) get the most accurate information on the biomechanical function of specific areas of the human body? Fortunately, there are several sources that strive to weigh the anatomical/clinical observations with biomechanical research. These sources focus on both normal and pathomechanical function of the human body. The following sources are recommended since they represent this balanced treatment of the subject, not relying solely on experience or research (Basmajian & Wolf, 1990; Kendall, McCreary, & Provance, 1993; Smith, Weiss, & Lehmkuhl, 1996).

It is important to remember that biomechanics is an indispensable tool for all kinesiology professionals trying to understand how muscles create movement, how to improve movement, and how problems in the musculoskeletal system can be compensated for. The last two sections of this chapter illustrate how biomechanical principles can be used to understand and improve human movement.

RANGE-OF-MOTION PRINCIPLE

One area where anatomical description is quite effective is in the area of the range of motion used in movement. Movement can be accurately described as combinations of joint angular motions. Remember that the biomechanical principle of range of motion, however, can be more generally defined as any motion (both linear or angular) of the body to achieve a certain movement goal. Specific joint motions can be of interest, but so too can the overall linear motions of the whole body or an extremity. Coaches can speak of the range of motion of a "stride" in running or an "approach" in the high jump. Therapists can talk about the range of motion for a joint in the transverse plane.

In human movement the performer can modify the number of joints, specific anatomical joint rotations, and amount of those rotations to tailor range of motion. Range of motion in movement can be imagined on a continuum from negligible motion to 100% of the physically possible motion. The **Range-of-Motion Principle** states that less range of motion is most effective for low-effort (force and speed) and high-accuracy movements, while greater range of motion favors maximum efforts related to speed and overall force production (Hudson, 1989). A person playing darts "freezes" or stabilizes most of the joints of the body with isometric muscle actions, and limits the dart throw to a small range of motion focused on elbow and wrist. The javelin thrower uses a long running approach and total body action to use considerable range of motion to maximize the speed of javelin release. The great accuracy required in golf putting favors limiting range of motion by using very few segments and limiting their motion to only what is needed to move the ball near the hole (Figure 3.15).

The application of the range-of-motion principle is more complicated when the effort of the movement is not maximal and when the load cannot be easily classified at the extremes of the continuum. A baseball or softball seems pretty light, but where on the range-of-motion continuum are these intermediate load activities? How much range of motion should you use when the load is a javelin, a shot, or your bodyweight (vertical jump)? Biomechanical studies can help kinesiology professionals decide how much range of motion is "about right." In the qualitative analysis of movement, this approach of identifying a range of correctness (like in range of motion) is quite useful because the professional can either reinforce the performer's good performance, or suggest less or more range of motion be used (Knudson & Morrison, 2002). The continuum of range of motion can also be qualitatively evaluated as a sliding scale (Knudson, 1999c) or volume knob (Hudson, 1995) where the performer can be told to fine tune range of motion by feedback (Figure 3.16). Let's look at how biomechanical research can help professionals evaluate the range of motion in a vertical jump.

Figure 3.15. Very accurate movements like putting in golf limit range of motion by freezing most segments and using only a few segments. Photo courtesy of Getty Images.

The amount and speed of countermovement in a vertical jump is essential to a high jump. This range-of-motion variable

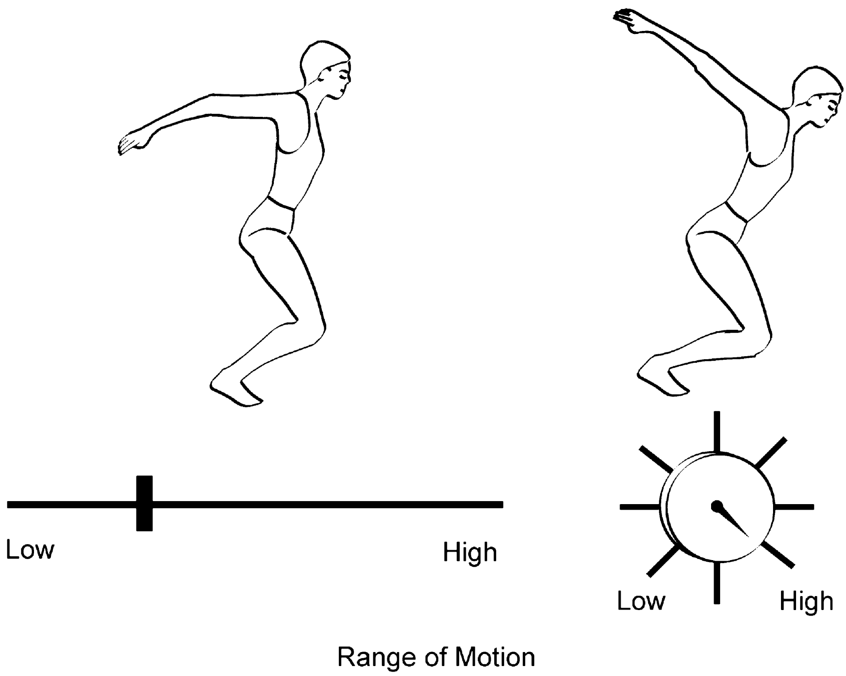

Figure 3.16. Range of motion can be evaluated and pictured as an analog scale or a volume knob. If a change in range of motion is appropriate, the performer can be instructed to "increase" or "decrease" the range of motion in their movement.

can be expressed as a linear distance (drop in center of mass as percentage of height) or as body configuration, like minimum knee angle. We use the knee angle in this example because it is independent of a subject's height. One can hypothesize that maximizing the drop (range of motion) with a small knee angle in the countermovement would increase the height of the jump; however, this is not the case. Skilled jumpers tend to have minimum knee angles between 90 and 110° (Ross & Hudson, 1997). The potential benefits of range of motion beyond this point seems to be lost because of poorer muscular leverage, change in coordination, or diminishing benefits of extra time to apply force. The exact amount of countermovement will depend on the strength and skill of the jumper, but coaches can generally expect the knee angles in this range.

Another example of the complexity of applying the range-of-motion principle would be the overarm throw. In overarm throwing the athlete uses range of motion from virtually the entire body to transfer energy from the ground, through the body and to the ball. The range of motion (kinematics) of skilled overarm throwing has been extensively studied. Early motor development studies show that one range-of-motion variable (the length of the forward stride is usually greater than 50% of height) is important in a mature and forceful overarm throw (Roberton & Halverson, 1984). Stride length in throwing is the horizontal distance from the rear (push-off) foot to the front foot. This linear range of motion from leg drive tends to contribute 10 to 20% of the ball speed in skilled throwers (Miller, 1980). The skill of baseball pitching uses more stride range of motion, usually between 75 and 90% of standing height, and has been shown to significantly affect pitch speed (Montgomery & Knudson, 2002).

The axial rotations of the hips and trunk are the range-of-motion links between stride and arm action. The differentiation of hip and trunk rotation is believed to be an important milestone in mature throwing (Roberton & Halverson, 1984), and these movements contribute about 40 to 50% of ball speed in skilled throwers. In coaching high-speed throwing, coaches should look for hip and trunk opposition (turning the non-throwing side toward the target) in preparation for the throw. The optimal use of this range of motion is a coordination and segmental interaction issue that will be discussed later. Students interested in the skilled pattern of hip and trunk range of motion should look at the research on skilled pitchers (Fleisig, Barrentine, Zheng, Escamilla, & Andrews, 1999; Hong & Roberts, 1993; Stodden *et al.*, 2005).

Arm action is the final contributor to the range of motion used in overarm throwing. The complex joint actions of throwing contribute significantly (30–50% of ball velocity) to skilled throwing (Miller, 1980). To take advantage of the trunk rotation, the shoulder stays at roughly 90° of abduction to the spine (Atwater, 1979) and has been called the strong throwing position (Plagenhoef, 1971). With initiation of the stride, the elbow angle stays near 90° to minimize resistance to rotating the arm, so the major increase in ball speed is delayed until the last 75 ms (a millisecond [ms] is a thousandth of a second) before release (Roberts, 1991). Contrary to most coaching cues to "extend the arm at release," the elbow is typically 20° short of complete extension at release to prevent injury (Fleisig *et al.*, 1999). Inward rotation of the humerus, radioulnar pronation, and wrist flexion also contribute to the propulsion of the ball (Roberts, 1991), but the fingers usually do not flex to add additional speed to the ball (Hore, Watts, & Martin, 1996).

In overarm throwing it appears that the range-of-motion principle can be easily applied in some motions like stride length using biomechanical research as benchmarks; however, it is much more difficult to define *optimal* amounts of joint motions or body actions in complex movements like overarm throwing. How range of motion might be changed to accommodate different level of effort throws, more specific tasks/techniques (e.g., curveball, slider), or individual differences is not clear. Currently, professionals can only use biomechanical studies of elite and skilled performers as a guide for defining desirable ranges of motion for movements. More data on a variety of performers and advances in modeling or simulation of movement are needed to make better recommendations on how modifications of range of motion may affect movement.

FORCE–MOTION PRINCIPLE

Another way to modify human movement is to change the application of forces. The **Force–Motion Principle** states that it takes unbalanced forces (and the subsequent torques they induce) to create or modify our motion. To know what size and direction of force to change, recall that a **free-body diagram** of the biomechanical system is usually employed. A major limitation of functional anatomical analysis was the limited nature of the forces and structures being considered. We are not in a position to perform quantitative calculations to determine the exact motion created at this point in the text, but this section will provide examples of the qualitative application of the Force–Motion Principle in improving human movement. Later on, in chapters 6 and 7, we will explore Newton's laws of motion and the major quantitative methods used in biomechanics to explore the forces that create human movement.

Kinesiology professionals often work in the area of physical conditioning to improve function. Function can be high-level sport performance or remediation of the effects of an injury, disuse, or aging. If muscle forces are the primary motors (hip extensors in running faster) and brakes (plantar flexors in landing from a jump), the Force–Motion Principle suggests that muscle groups that primarily contribute to the motion of interest should be trained. Remember that this can be a more complex task than consulting your anatomy book. How can we know what exercises, technique (speed, body position), or load to prescribe?

Imagine a physical education teacher working with students on their upper body muscular strength. A particular student is working toward improving his score on a pull-up test in the fitness unit. The forces in a pull-up exercise can be simplified into two vertical forces: the downward gravitation force of bodyweight and an upward force created by concentric muscle actions at the elbows, shoulders, and back. The considerable isometric actions of the grip, shoulder girdle, and trunk do not appear to limit this youngster's performance. You note that this student's bodyweight is not excessive, so losing weight is not an appropriate choice. The teacher decides to work on exercises that train the elbow flexors, as well as the shoulder adductors and extensors. The teacher will likely prescribe exercises like lat pulls, arm curls, and rowing to increase the student's ability to pull downward with a force larger than his bodyweight.

Suppose a coach is interested in helping a young gymnast improve her "splits" position in a cartwheel or other arm support stunt (Figure 3.17). The gymnast can easily overcome the passive muscular tension in the hip adductors to create a split in

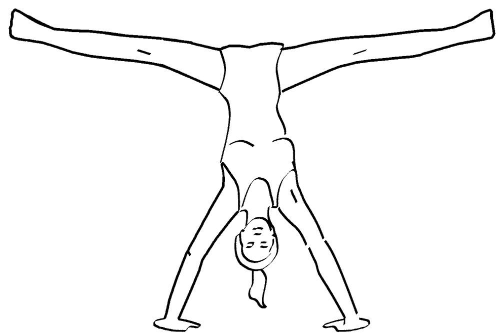

Figure 3.17. The Force–Motion Principle can be applied in a situation where a gymnast is having difficulty in performing inverted splits. The two forces that may limit the split are the passive tension resistance of the hip muscles or inadequate strength of the hip abductors. The coach must decide which forces limit this athlete's performance.

a seated position, but the downward force creating this static position is large (weight of the upper body) compared to the weight of the leg that assists the split in the inverted body position. The Force–Motion Principle suggests that the balance of forces at the hips must be downward to create the split in the dynamic action of the stunt. In other words, the forces of gravity and hip abductors must create a torque equal to the upward torque created by the passive tension in the hip adductors. If the gymnast is having trouble with this stunt, the two biomechanical solutions that could be considered are stretching the hip adductors (to decrease passive muscle tension resistance) and increase the muscular strength or activation of the hip abductors.

The examples of the Force–Motion Principle have been kept simple for several reasons. First, we are only beginning our journey to an understanding of biomechanics. Second, the Force–Motion Principle deals with a complex and deeper level of mechanics (kinetics) that explains the causes of motion. Third, as we saw in this chapter, the complexity of the biomechanical

Interdisciplinary Issue: Variability

Scientists from a variety of disciplines have been interested in the variability of human movement performance. Biomechanical studies have often documented variability of kinematic and kinetic variables to determine the number of trials that must be analyzed to obtain reliable data (Bates, Osternig, Sawhill, & Janes, 1983; Rodano & Squadrone, 2002; Winter, 1984). Motor learning studies have focused on variability as a measure of neuromuscular control (Davids *et al.*, 2003; Slifkin & Newell, 2000). The study of variability has also indicated that variability may play a role in potential injury (James, Dufek, & Bates, 2000). Multiple biomechanical measurements of kinematics and kinetics may provide important contributions to interdisciplinary studies of human movement variability.

and neuromuscular system makes inference of muscle actions complicated. The variability in the forces and kinematics of human movement, therefore, have been of interest to a variety of scholars (see the Interdisciplinary Issue on Variability). The rest of the book will provide challenges to the perception that the causes of and solutions to human movement problems are simple and introduce you to the main areas of biomechanics that are used to answer questions about the causes of movement.

SUMMARY

Anatomy is the descriptive study of the structure of the human body. This structural knowledge is an important prerequisite for the study of human movement, but must be combined with biomechanical knowledge to determine how muscles create human movement. Kinesiology professionals and students of biomechanics need to continually review their knowledge of musculoskeletal anatomy. Muscles tend to be activated in synergies to cooperate or coordinate with other forces to achieve movement goals. Muscle tension is created from active or passive components, and the action muscles create are either eccentric, concentric, or isometric. Biomechanical research has shown that the actions of muscles in normal movement are more complicated than what is hypothesized by functional anatomy. The Range-of-Motion Principle of biomechanics can be used to improve human movement. Modifying range of motion in the countermovement of the vertical jump, as well as the stride and body rotations in the overarm throw, were

Application: Decline Squats

Rehabilitation and conditioning professionals often used incline and decline support surfaces to modify exercises for clients. People with limited ankle dorsiflexion range of motion often do squats with support under their heels. In rehabilitation, similar squat exercises emphasizing the eccentric phase on decline surfaces are used in treating patellar tendinopathy (Kongsgaard *et al.*, 2006). Apply the force-motion and range of motion principles to study the external resistance relative to the body position squatting on two different incline surfaces. How does the different orientation of body to gravity and the joint angles compare to a regular squat exercise? What other data or knowledge would help you in making this comparison or understanding the influence of variations in the squat exercise?

examples discussed. The Force–Motion Principle was applied to exercise training and how passive tension affects gymnastic performance.

REVIEW QUESTIONS

1. What are the major anatomical terms used in kinesiology and medicine to describe the position and motion of the body?
2. What structural and functional properties of muscle cells are different from other body cells?
3. How do fiber properties and arrangement affect force and range-of-motion potential of a muscle?
4. Name and define the three kinds of muscle actions.
5. What are the two major sources of muscle tension, and where in the range of motion are they most influential?
6. Explain the Hill three-component model of muscle and how the components relate to the sources of muscle tension.
7. What is an example of the Force– Motion Principle in human movement?
8. Why is the mechanical method of muscle action analysis used in functional anatomy inadequate to determine the actions of muscles in human movement?
9. How does biomechanics help kinesiology professionals understand the causes and potential improvement of human movement?
10. What factors should a kinesiologist consider when defining the appropriate range of motion for a particular movement?

KEY TERMS

active tension
agonist
antagonist
anatomy
anthropometry
actin
concentric
contractile component
eccentric
fascicle
Hill muscle model
hypertrophy
isometric
modeling
muscle action
myofibril
myosin
parallel elastic component
passive insufficiency
passive tension
pennation
sarcomere
series elastic component
simulation
synergy

SUGGESTED READING

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WEB LINKS

Hypermuscle: Review of anatomical joint motion terminology from the University of Michigan.
http://www.med.umich.edu/lrc/Hypermuscle/Hyper.html

PT Central Muscle Page: Comprehensive web muscle tables
http://www.ptcentral.com/muscles/

Martindale's “Virtual” Medical Center-An electronic medical/anatomical library hosted by UC-Irvine.
http://www.martindalecenter.com/MedicalAnatomy.html

Body Worlds—von Hagens’ plastic-preserved human bodies.
http://www.koerperwelten.de/en/pages/home.asp

Tour of Visible Human Project—Simple review of anatomical planes and structures using images from the NIH visible human project.
http://www.madsci.org/~lynn/VH/