Chapter 1

Functional Anatomy

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Knowledge of functional anatomy is critical to the success of the personal trainer. Because voluntary movement stems from the application of force produced by the muscle on the attached bone, having clear comprehension of the musculoskeletal structures and their function is fundamental to understanding human movement. Employing knowledge of the body’s structures and how they work in a coordinated manner allows personal trainers to use appropriate decision-making criteria for individual exercise prescription.

**Composition of Bones**

The human skeletal system is uniquely designed to resist stress, providing shape and support to the body. The skeleton has a mineral component which provides rigidity, and a protein component that makes bone resistant to tension. The organic compounds or protein, mainly in the form of collagen fiber, represent 33% of bone, while the mineral component represents the other 67% (1). The resilience of the bony tissue makes the body capable of managing force, while the connective tissues provide for the application of force. Together, the tissues function to systematically produce and control motor function.

Bone tissue is hardened by calcium salts which represent approximately 98% of the calcium storage in the body. Although it is the most significant location of calcium in the body, bone is not simply mineral composite; it is actually very dynamic, with a fairly complex vascular system, which acts as a reservoir of calcium usable in the maintenance of extracellular calcium concentrations. When extracellular calcium levels fall too low, calcium is recruited from bone storage and mobilized to alternate physiological destinations based on the need of the internal environment. This process is a normal interchange by the body to maintain homeostasis. When daily calcium intake is insufficient for prolonged periods of time, bone stores of calcium become compromised as the mineral density declines. A significant reduction in bone mineral density causes a predisease condition called **osteopenia**, before progressing to the disease state called **osteoporosis**.

The skeleton is actually a system of levers, support structures, and struts which allow the body to maintain erect postural equilibrium, perform movement, and protectively house vital organs. The skeleton consists of two segments: 1) the axial skeleton which consists of the skull, hyoid bone, vertebral column, and rib cage; and 2) appendicular skeleton consisting of the limbs and their respective girdles. For the most part, the axial skeleton serves a protective role for the central nervous system, heart and lungs, and is the structural segment for erect posture, while the appendicular skeleton supports locomotion and everyday movements. Each segment is comprised of various bones to support its respective role and function.

The shape of a bone is specific to its purpose. Bones come in several shapes and sizes, which also define how they are classified. The bones of the arms and legs are long bones; in the hands and feet they are called short bones; the unique shape of the vertebra are called  **collagen 30%**  **magnesium 1%**  **sodium 1%**  **potassium 1%**  **carbonate 10%**  **phosphate 17%**  **calcium 37%**

**~Key Terms~**

**Osteopenia** - Refers to bone mineral density (BMD) that is lower than normal peak BMD but not low enough to be classified as osteoporosis.

**Osteoporosis** - Irreversible decrease in mineralized bony tissue.
irregular bones, while bones with a broad connective surface, like that of the scapulae, are called flat bones. As stated, each bone’s shape has distinctions which support its function. Long bones, for instance, serve as levers that allow for bipedal movement and include an elongated diaphysis (shaft) which contains a significant marrow cavity where 2.5 million red blood cells are formed every second. Short bones make up the intricate formations of the hands (providing for dexterity) and feet (serving as a platform for postural balance). The flat bones allow for broad muscular attachments, which are often used to support significant force requirements, as seen with the insertion sites of the rhomboids on the scapula and pectoralis major on the sternum. Irregular bones are intended to manage uniquely designed muscle arrangements, as seen with the spiny process of the vertebrae. These bones support the numerous muscular attachments to the spine and function to accommodate the specific action capabilities of the trunk.

**Bone Growth**

The skeleton begins as a cartilaginous structure and is replaced by bone through a maturation process called ossification. Increases in bone mass (width or diameter) occur from the formation of new bone on the surface of existing bone tissue called appositional growth. During normal maturation, the bone increases in size and is remodeled by the removal and replacement of bone. Bone length is attributed to endochondral growth, where cartilage is ossified in the epiphyseal plates of long bones. As humans age, new cartilage is formed to promote growth that eventually turns to bone. Vertical growth ceases when no further cartilage is formed and the present cartilage becomes ossified. In most humans, 90% of bone mass is reached by age 18 (2). The integrity of bone is often measured by mass and density. Bone mass represents the surface area of bone, while bone mineral density reflects the concentration of minerals within bone.

To promote bone development, it is critical that children consume adequate vitamin D and calcium and participate in regular physical activities. Once bone mass has reached maturity, the mineral density is still subject to variations based upon diet and activity. Improvements in bone mineral density can be attained until approximately age thirty, at which time, genetics, behavior, and lifestyle become the primary factors dictating the rate of decline (2). One key factor in maintaining healthy bones is the application of resisted movement activities. There is a correlation between bone mineral density and the strength of the attached musculature, which suggests that resistance training can be an important activity used to maintain bone health (3). This holds true for all populations and age ranges. It is believed that skeletal benefits can be attained by even older adults and children via routine age-appropriate strengthening activities (2).

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**Quick Insight**

Calcium ion concentration requires close management by the body to prevent dysfunction. Even small variations in calcium concentration can disrupt physiological function. For example, hypocalcemia (low blood calcium) can lead to neuromuscular excitability, muscle spasms and tetany, while hypercalcemia (high blood calcium) can cause abnormally high deposits of calcium phosphate in tissues leading to organ dysfunction and failure. Due to the key role calcium plays in motor neuron activities, calcium deficiency within the body can cause muscles to lose normal function, becoming unresponsive. This can be life threatening when cardiac muscle activity is altered. Fortunately, the calcium levels of the extracellular fluid are closely regulated by the endocrine system. During hypocalcemia, parathyroid hormone will cause increased intestinal absorption of calcium via activation of Vitamin D, tubular reabsorption of calcium from the kidneys, and release of calcium and phosphate from bone tissue. In contrast, hypercalcemia suppresses parathyroid hormone activity and leads to the secretion of calcitonin, which reduces urinary excretion of calcium and inhibits calcium loss from the bone. Therefore, prolonged dietary deficiency causes the calcium needs of the body to be met by the bone calcium stores, which reduces bone mineral density. When this activity parallels the natural loss of bone mass that occurs after age 30, the risk for bone disease is dramatically increased. Women will lose approximately 8% of bone mass (men 3%) naturally per decade from the aging process (2). Sex hormones are key endocrine factors in the maintenance of bone mineral density. Lower levels of circulatory estrogen increase the risk for developing osteoporosis, which is of particular concern for menopausal females. Males lose far less bone because of the relatively high amounts of androgens produced later in life (2). The bone disease osteoporosis occurs when bone function is compromised due to excessive bone loss. Commonly, the epiphyses (ends) of long bones, the vertebral column, hip, and jaw experience the greatest decline, placing these areas at high risk for fracture. Osteoporosis is linked to premature death due to functional decline. One out of two women and one out of four men will suffer from an osteoporotic fracture after age 50 (4). Approximately one out of four hip fracture patients die within one year after the hip fracture, commonly from pulmonary thrombosis due to the significant reduction in movement. It is estimated that the public health cost attributed to osteoporotic fractures is in excess of $17 billion annually, and approximately 90% of women and 50% of men will have osteoporosis before they die (5).
Resistance training activities performed by children and adolescents have raised concerns due to the potential risk of damage or premature ossification of the epiphyseal (growth) plates of long bones (6). The risk of epiphyseal fracture in children performing resistance exercise is equivocal as no clinical trials have demonstrated an adverse effect. However, due to the developmental stage of the bone and the stress associated with resisted movement it is believed there may be some increased vulnerability. Premature cessation of bone growth may be another potential adverse event associated with intense resistance training in children. The epiphyseal plates close naturally in response to high levels of sex hormones that exist during post-pubescence. Some theorize that the increased androgenic hormones produced in response to intense resistance training may promote a premature ossification of the epiphyseal plates, attenuating natural bone growth. Nevertheless, there is no clear evidence to support this notion. In fact, most physicians will encourage age-appropriate resistance activity when performed under supervision of a prudent professional. No clinical trial to date has indicated that appropriately applied resisted movement damages the epiphyseal plates of long bones. Analysis of bone stress during play, where jumping and landing activities are engaged in, shows that stress from daily activities supersedes that of controlled resisted activities such as squatting and pressing when performed with 10 RM resistance (7). Children and adolescents have greater risks to bone health from malnutrition, disease, and trauma.

Contrary to popular belief, bone is not static or inert. In fact, bone is extremely active, continually recycling and renewing the organic and mineral components in the process of remodeling. To remodel the bone matrix without weakening the bone, an interplay of supporting activities must occur between the bone cells: osteocytes, osteoblasts, and osteoclasts. In adult bones, the osteocytes are constantly removing and replacing the calcium salts, while the osteoblasts and osteoclasts manage the balance of forming new bone, while destroying old bone. In young adults, the annual turnover rate is about 20% of the skeleton (1). The bone remodeling occurs at selected areas within the bone, identifying areas for greater formation activity and areas where bone turnover is more suppressed. This ability to turn over bone and manage the component salts allows the body to adapt to new stress. The theory supporting bone’s ability to identify stress suggests osteoblasts are sensitive to electrical variations. When the bone is stressed, the electrical fields communicate to the osteoblasts to form more bone. This explains why a person performing weight training experiences bone enlargement at the site of the attachment to accommodate tissue hypertrophy and strength. Bones that experience heavy stress become thicker and stronger, whereas bones that do not experience stress weaken and become brittle. Recent evidence has demonstrated significant increases in bone stiffness and strength, as well as increased quantity and quality of trabecular bone in response to low-level, high frequency skeletal vibration (9,10). This experimental evidence supports the association between physical activity and bone cell activity. Moreover, vibratory stimulus may be a useful intervention in the future to treat osteoporosis or ameliorate bone loss in post-menopausal women (10).

Notable amounts of degenerative changes occur in a relatively short period of time when the body is inactive. In fact, an individual loses approximately a year of bone mass in one week of bed confinement (11). This explains why astronauts have a high risk for osteoporosis. Fortunately, bones regenerate about as quickly as they degenerate in response to acute changes in physical activity and weight-bearing or resisted movements. This again reinforces the need for daily physical activity and strength training exercise.
~Key Terms~

**Appositional growth** - Growth by the addition of new layers on those previously formed. Characteristic of tissue formed of rigid materials.

**Endochondral growth** - Process of bone formation whereby a cartilage model is replaced by bone.

**Epiphyseal plates** - Transverse cartilage plate near the end of a child’s bone responsible for growth in length of the bone.

**Bone mass** - The volume of bone in the body measured by mineral content.

**Bone mineral density** - The mineral content in a given volume of bone, used as a measure of bony health and in the diagnosis of osteoporosis.

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**Human Skeletal Structure**

Anterior

Posterior

- Skull
  - Cranium
  - Maxilla
  - Mandible

- Clavicle
- Sternum
- Humerus
- Rib
- Radius
- Ulna
- Pelvis
- Carpal
- Metacarpal
- Phalanges
- Femur
- Patella
- Fibula
- Tibia
- Metatarsal
- Tarsal
- Phalanges

- Cervical Vertebrae (first 7 vertebrae)
- Scapula
- Thoracic Vertebrae (next 12 vertebrae)
- Lumbar Vertebrae (last 5 vertebrae)
- Sacrum & Coccyx
- Calcaneus
Joint Classifications
The intersection of two bones is called an articulation or a joint. Depending on the role of the joint, its movement may have a broad range, such as the shoulder’s glenohumeral joint, or it may be limited for structural purposes, such as the acromioclavicular joint. The structure of a joint relates to its movement capabilities. The more movement that is afforded to a joint, the more it is able to reduce friction.

The three major classifications of joints are fibrous, cartilaginous, and synovial. The connective tissue characteristics determine how they are classified. Fibrous joints are not intended to move, or exhibit very little movement, so they are tightly connected by fibrous tissue and do not possess a joint cavity. Cartilaginous joints unite articular surfaces with hyaline cartilage which allows for very slight movement, or fibrocartilage which has slightly greater movement capabilities due to the tissue’s flexible nature. The primary role of the aforementioned joints is to support the structural integrity of the skeletal system or serve as connectors for growth. In contrast, synovial joints are designed to manage movement. To allow for the considerable movement range between articulating joints, synovial joints are more complex anatomically than fibrous and cartilaginous joints.

Synovial Joints
The joints of the appendicular skeleton are predominantly synovial to accommodate the movements required for locomotion and daily activity. Synovial joints rely on several mechanisms to reduce friction and maintain the joints’ integrity when forces are applied. The articular surfaces are covered with hyaline cartilage which provides for a smooth surface at the site where the bones meet. In areas where compressive or shock forces are often applied, the surfaces are additionally supported by fibrocartilage and fat pads. The fibrocartilage forms articular discs which provide added strength and support to the joint, as for example the meniscus in the knee. The fat pads are often found around the edges of joints to provide protection for the cartilage. Each joint is enclosed by a dual layer joint capsule. The articular capsule is made up of fibrous tissue extending from the periosteum that covers the bone. The fibrous capsule may have thickened regions which provide ligamentous support to the joint. Ligaments and tendons may further add structural support to strengthen the joint. Lining the joint capsule is a synovial membrane. This inner lining secretes synovial fluid to form a thin lubricating film which covers the articular surfaces to further reduce the frictional coefficient created by movement. In some synovial joints the lining extends to form a pocket or sac called a bursa, which serves as a fluid-filled cushion between surfaces to prevent contact or the rubbing of connective tissues during movement.

~Key Terms~

Joint- A point of articulation between two or more bones, especially such a connection that allows motion.

Fibrous joints- Consist of two bones that are united by fibrous tissue and exhibit little or no movement.

Cartilaginous joint- Unites two bones by means of either hyaline cartilage or fibrocartilage.

Synovial joints- Contain synovial fluid and allow for considerable movement between articulating bones.

Hyaline cartilage- A tough, elastic, fibrous connective tissue found in various parts of the body, such as the joints, outer ear, and larynx.

Fibrocartilage- Cartilage that allows for greater movement capabilities due to its flexible nature.

Articular discs- A plate or ring of fibrocartilage attached to the joint capsule and separating the articular surfaces of the bones.

Joint capsule- A sac enclosing a joint, formed by an outer fibrous membrane and an inner synovial membrane.

Periosteum- The dense fibrous membrane covering the surface of bones except at the joints and serving as an attachment for muscles and tendons.
Types of Synovial Joints

There are several types of synovial joints which are classified according to the shape of the adjoining articular surfaces. The six types of synovial joints include: Ball and Socket joints, which consist of a rounded articular surface of one bone that fits into the socket (cup-shaped depression) of the corresponding bone, allowing for complementary movements (shoulder and hip); Plane or Gliding joints, consisting of two opposed flat surfaces that are relatively equal in size and may glide across or twist slightly over each other (spinal vertebrae); Hinge joints, which work by fitting a convex cylinder inside a concave articular surface, allowing for movement in a single plane (elbow and knee); Pivot joints, which restrict movement to rotation around a single axis (radius/ulna); Saddle joints, which have similarly shaped (saddle) articular surfaces which fit into one another, allowing for two planes of movement (thumb); and condyloid joints which are uniquely structured shallow ball and sockets with limited movement range similarly to a hinge (wrist).

The ability of the joint to move depends upon the muscular attachment location called the insertion site, the type of joint, and the shape of the articular surface. The joints that have the greatest mobility have the least stability and are often considered to be weak when compared to limited moving synovial or non-moving fibrous and cartilaginous joints. The shoulder or glenohumeral joint is a good example. Although freely moving, the shoulder joint loses stability when fully abucted, flexed, or externally rotated. The body has put defense mechanisms in place to help manage the risk for injury in highly moveable joints by attempting to limit movement range. This is accomplished by the location of fibrous connective fibers in and around the joint capsule, the particular shape of the articulating surface in relation to the muscle attachment sites, the presence of other structures including disks and fat pads, and the activity of proprioceptors that manage muscle and tendon tension. When these mechanisms can not manage an external force, a joint may dislocate, causing the articular surfaces to come apart. This may damage the joint capsule, articular cartilage, and ligaments. Individuals with extremely flexible joints are often referred to as having joint laxity or hypermobility and should strengthen the surrounding tissues to encourage stability and be cautious during high force activities (8).

~Key Terms~

Ligaments- Tough fibrous band of connective tissue that supports internal organs and holds bones together properly in joints.

Tendons- A tough band of fibrous connective tissue that connects muscles to bones.

Synovial membrane- A layer of connective tissue which lines the joint and produces synovial fluid.

Bursa- A bursa is a tiny fluid-filled sac that functions as a gliding surface to reduce friction between tissues of the body.

Hypermobility- Describes joints that stretch further than is normal.
How Joints Work

Joints move when internal forces or external forces are applied to the skeleton. Voluntary movements require muscles to contract in a coordinated manner to produce internal forces which act on the bone. Muscle connects to bone by tendons which extend from the musculotendinous junction at the muscles end to the periosteum, a fibrous connective tissue which makes up the outer surface of the bone. The periosteum isolates the bone from surrounding tissues and encases a network of nerves and vessels which provides nutrients and participates in bone remodeling. Near joints, the periosteum becomes continuous with connective tissue to hold bones together and form the joint capsule. The fibers of the periosteum are also interwoven with the tendons that attach to the bone. The connective tissues are further secured to the bone by collagen fibers, which provide for an extremely strong attachment. So strong that an exertion of force beyond the tissue’s strength will most often break a bone before snapping the collagen fibers at the bone’s surface. This tension is monitored by special neuronal cells (golgi tendon organs) which send reflexive signals back to the spinal cord. These signals are part of a protective mechanism involving inhibitory signals to the contracting muscle when the tension on the bone reaches a critical threshold prior to damage (see Chapter 4 for more detail).

On the other end of the tendon, connective tissue is structured in a way that produces and manages efficient force development. The muscle anatomy that causes movement is arranged to serve several purposes. The obvious first role of skeletal muscle is to pull on the tendons attached to the skeleton for movement. The skeletal muscles also must produce tension to maintain posture and sustain body positions. In addition, skeletal muscles serve to support soft tissues, such as the visceral organs, guard entrances and exits, including the digestive and urinary tracts for swallowing, defecation, and urination, as well as assist the maintenance of body temperature by releasing heat.

Skeletal Muscle Architecture

Skeletal muscles are organized into several layers. The outer layer is the muscle fascia, which is a fibrous connective tissue that separates individual muscles, and in some cases muscle groups, providing shape to the arranged fibers it contains and maintaining intramuscular tension. Just beneath the fascia is the epimysium, which is a dense collection of collagen fibers covering the entire surface of the muscle. Inside the epimysium lie bundles of fibers enclosed by the perimysium. Each bundle is called a fasciculus, which contains packages of muscle fibers called myofibrils.

Myofibrils are made up of long cylinder-like muscle fibers (muscle cells). The individual muscle fibers are encompassed by the endomysium. The muscle fibers are further encased by sarcolemma, a delicate external lamina of reticular fibers which serves as an extension of the muscle fiber for connective purposes. The individual muscle fibers themselves can be further broken down to their constituent parts, called myofibrils. The myofibrils are comprised of proteins called myofilaments, which set the actions of the muscle into motion. The thick myofilaments are myosin, and the thin filaments are actin. Together, actin and myosin are arranged in functional sequence along the myofibril and are used to create tension inside the muscle tissue.

Each subsequent layer of muscle tissue maintains an intricate network of nerve and circulatory branches to fuel and run the muscle cell operations. This enables the muscle tissue to efficiently manage neural information while satisfying energy and oxygen requirements of the working tissue. When tissue is trained, it responds with cellular enhancements to allow the body to adapt to the demands of the stress. By now, it should be fairly clear that there is a close-knit relationship between the tissues within a system.
Spatial and Directional Terminology

When the musculoskeletal system is put into action, the outcome is often dynamic. Contractile forces extending from the myofilaments make their way through the muscle fibers to the muscle’s epimysium and fascia, pulling on the tendon. This in turn, pulls on the bone to put action into a joint. When voluntary movement occurs at a given joint, the movement will be specific to the location of the contractile force, the shape of the joint, and the structures that act on the joint. In most cases, anatomical movement either occurs to move a body segment away from the body or back to the body. Although this is well illustrated when viewed with regard to basic anatomical positions, there are occasional exceptions.

Describing the actions or motions of synovial joints requires anatomical terminology. For instance, lifting the arm could apply to abduction, flexion, extension, and even rotation depending on the start position and the plane of movement where the action occurs. These directional terms are applied to anatomical structures and function.

Describing movement anatomically requires both the starting position, axis of joint rotation and the plane in which the movement occurs. Anatomical position is the standard reference position for the body when describing locations, positions, and movements of limbs or other anatomical structures. Anatomical position is assumed when the body is standing with erect posture, facing forward with both feet aligned parallel and the toes forward, the arms and hands hanging below the shoulders at the side with the elbows and fingers extended, palms facing forward. From this reference position, spatial and direction terms can be easily applied.

Positional Lines and Movement Planes

Spatial term comprehension and accuracy can be further enhanced by the defined lines of origin along the anatomical position. These lines correspond with the planes of movement. The line that dissect the body down the center, splitting it into side by side halves, is called the Midline, which lies along the Sagittal Plane. When that line is shifted over to align with the crease of the arm it is referred to as the Anterior Axillary Line. If the line dissected the body into front and back halves, it would be called the Midaxillary Line, which runs along the Frontal Plane. The last plane is called the Transverse Plane. It runs side to side and anterior to posterior, dissecting the body into superior (top) and inferior (bottom) parts. Sometimes the word cardinal, or cross, is attached to planes to identify the center of gravity of the body. Planes will be further reviewed under movement terminology.
Spatial Terms

When spatial terms are used they may be referencing location or direction. They describe the area of space relative to the body’s anatomical position. For instance, if something is in front of the body or the body segment moves forward, the space descriptor for the movement or location would be anterior. If the location of space is behind the body or a segment of the body is moved backward, the space location would be posterior. In some cases, other words can be used to describe the same area of space. For instance, anterior is synonymous with ventral and posterior is synonymous with dorsal. This may also occur when spatial terms are used as directional movement terms, as is the case with medial, internal, and inward rotation, or lateral, external, and outward rotation. When applied to rotation, these terms have a synonymous relationship. Medial refers to the direction or location toward, or closer to, the midline, while lateral refers to a position or movement away from, or farther from, the midline of the body.

When locating a point or direction along a limb, the terms proximal and distal are used. Proximal refers to the direction or location close to where the limb attaches to the body. Distal refers to the point toward the end of the limb or location farthest away from the limb’s attachment site. When the limbs are viewed from a particular side, they are often referenced by the terms ipsilateral (same side) and contralateral (opposite side) rather than left or right side. The terms superficial and deep also refer to locations on (or within) the body. The location descriptors refer to positions relative to the exterior surface of the body. The superficial layers of tissue, for instance, lie just below the skin, while deep tissues are more internally located in reference to the skin layer. So, one might refer to the deep muscles of the spine or identify the trapezius as superficial to the rhomboids. Another way to view it is a superficial or surface wound, compared to a deep wound.

When the terms are applied to movement, the planes and axes of motion are applied to the anatomical positions and often reference spatial descriptors to add conciseness to the movement description. The three movement planes dissect the body, each with a corresponding axis that passes perpendicularly through the plane. The sagittal plane is probably the most referenced due to the number of activities and movements the body performs in the plane. The two dimensional surface connects anterior to posterior and superior to inferior, in layman’s terms it runs front to back and top to bottom. The axis that corresponds with the sagittal plane is the transverse axis. The frontal, or coronal, plane dissects the body into front and back. It runs side to side and superior to inferior (top to bottom). The respective plane of movement is the anteroposterior axis. The transverse plane runs perpendicular to the sagittal plane, splitting the body into top and bottom. The axis of rotation for the transverse plane is called the longitudinal axis.

With the planes and axes of rotation defined, the application of movements can be described accurately. The movements can be categorized by the plane that they occur in. Movements around the transverse axis (sagittal plane) include flexion, extension, hyperextension, plantar flexion, and dorsi flexion. The joint movements that occur around the anteroposterior axis (frontal plane) include abduction, adduction, lateral flexion (right and left), inversion, eversion, radial deviation, and ulnar deviation. The longitudinal axis (transverse plane) perpetuates different types of rotational movements. These include internal and external rotation, supination, pronation, horizontal abduction, and horizontal adduction.
Positional Terms

**Anatomical Position** - A reference posture used in anatomical description in which the subject stands erect with feet parallel and arms adducted and supinated, with palms facing forward.

**Midline** - The median plane of the body.

**Anterior Axillary Line** - Crease of the axilla (underarm).

**Midaxillary Line** - A perpendicular line drawn downward from the apex of the axilla.

**Anterior** - Placed before or in front.

**Posterior** - Located behind a part or toward the rear of a structure.

**Proximal** - Situated nearest to point of attachment or origin.

**Distal** - Situated farthest from point of attachment or origin, as of a limb or bone.

**Medial** - At, in, near, or being the center; dividing a person into right and left halves.

**Lateral** - Situated or extending away from the medial plane of the body.

**Ipsilateral** - On, or relating to, the same side of the body.

**Contralateral** - On, or relating to, the opposite side of the body.

**Superficial** - Shallow proximity in relation to a surface.

**Deep** - Extending inward in relation to a surface layer.

Movement Definitions

**Flexion** - To bend; in hinge joints, the articulating bones move closer together; in ball and socket joints, the limb moves anterior to the midaxillary line.

**Extension** - To straighten or extend; in hinge joints the articulating bones move away from each other; in ball and socket joints, the limb moves posterior to the midaxillary line.

**Lateral Flexion** - Spinal movement to the left or right occurs at the neck and trunk.

**Protraction** - Movement of a structure toward the anterior surface in a straight horizontal line.

**Retraction** - Movement back to the anatomical position or additionally, posterior to functional range of motion.

**Dorsi Flexion** - Movement of the ball of the foot towards the shin.

**Plantar Flexion** - Foot movement towards the plantar surface.

**Pronation** - Unique rotation of the forearm which crosses the radius and ulna. The palm faces posterior. (Prone means lying face down.)

**Supination** - Unique rotation of the forearm where the radius and ulna uncross. The palms face anteriorly. (Supine means lying face up.)

**Inversion** - Confined to the ankle; consists of turning the ankle so the plantar surface of the foot faces medially.

**Eversion** - Confined to the ankle; consists of turning the ankle so the plantar surface of the foot faces laterally.

**Abduction** - Movement away from the midline.

**Adduction** - Movement toward the midline.
Anatomical Movements

Trunk & Neck
Shoulder

- Abduction
- Adduction
- Flexion
- Extension
- Hyperextension
- External Rotation
- Internal Rotation
- Horizontal abduction
- Horizontal adduction
Elbow & Wrist

- Pronation
- Supination
- Flexion
- Extension
- Radial deviation
- Ulnar deviation

Hip

- External rotation
- Internal rotation
- Flexion
- Hyperextension
- Extension
- Abduction
- Adduction
As previously stated, joint function is dictated by its architecture and the surrounding connective tissue. The joint’s actions are largely determined, both in direction and range, by the articulating surfaces of the intersecting bone. The ball and socket joints, for instance, allow for significant movement, whereas a hinge joint has restrictions in both direction and range to prevent injury to the connective tissue. Bone impingement, ligament attachment sites, and elasticity are the primary contributors to joint range of motion. Muscle and tendon tissue are secondary contributors. The extent and frequency of joint use will determine the motion range of these structures. The muscle and fascia are considered to have a visco-elastic property (12). That is, the tissue can be stretched and lengthened and then can return to its original length again. But instead of being simply elastic with rapid changes in length, it is a more gradual viscous process; like a thick fluid (ketchup) changing length gradually and slowly.

The appendicular skeletal muscles are the most commonly targeted in resistance exercise prescriptions. For example, muscles of the shoulder joint, shoulder girdle, the elbow, and wrist as well as the pelvis, hip, knee, and ankle are commonly the only muscles included in a selectorized weight training circuit. In contrast, the axial skeletal joint movements predominantly come from the spine. Since spinal position will affect the movement capabilities of the appendicular joints, it will be discussed first.

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**Movement Definitions**

- **Ulnar deviation** – Joint action at the wrist that causes the hand to move medially toward the little finger in the frontal plane.

- **External rotation** – Action at the shoulder and hip joint where the articulating bone is rotated away from the body from anatomical position.

- **Internal rotation** – Action at the shoulder and hip joint where the articulating bone is rotated toward the body from anatomical position.

- **Circumduction** – Multiple-axis joint action where flexion is combined with abduction, and then adduction or extension and hyperextension are combined with abduction and then adduction.

- **Elevation** – Superior movement of the bone.

- **Depression** – Inferior movement of the bone.

- **Horizontal abduction** – Movement away from the midline in the transverse plane.

- **Horizontal adduction** – Movement toward the midline in the transverse plane.

- **Rotation** – The turning of a structure around its long axis.

- **Radial deviation** – Joint action at the wrist that causes the hand to move laterally toward the thumb in the frontal plane.
Spine and Neck
The vertebral column is composed of five regions serving a variety of functions, including support and movement of the head and trunk, protection for the spinal cord, allowing nerve outlets from the spinal cord, and providing sites for muscle attachment. The five segments include seven (7) cervical vertebrae, twelve (12) thoracic vertebrae, five (5) lumbar vertebrae, one (1) sacral bone (5 fused vertebrae) and one (1) coccygeal bone (4 or 5 fused vertebrae). In addition to the regions, the vertebral column has four major curvatures that assist in shock absorption and movement. The cervical and lumbar regions have lordotic curvature, represented by a natural concavity. If the forward curvature is exaggerated in an undesirable manner, it is termed lordosis. The curvature of the thoracic and sacral spine is convex or kyphotic. When the thoracic spine experiences an exaggerated curvature, it is referred to as being in a state of kyphosis, as is commonly seen in elderly populations. The exaggerated curves are detrimental to the function of the articulations within the area as well as those joints that depend on spinal position for proper function. For instance, a person with a structural kyphosis will lose range of motion in the shoulder complex and shoulder joint. Try rounding your back and externally rotating your arm. Range of motion capabilities of the shoulder will significantly decline. When the term neutral spine is applied, it refers to the state of functional curvature seen in an erect posture.

The joints of the spine are separated by a fibrocartilage intervertebral disc which provides support and prevents the bone surfaces from making contact. The discs are comprised of an outer annulus, which encases the gelatinous disc nucleus-pulposus, looking much like a fried egg. With age, the discs become more compressed and gradually lose water, which decreases the cushioning capabilities and explains the shortening phenomenon that occurs as a person gets older (13). If the disc is compressed from repetitive microtrauma or blunt trauma it may bulge or herniate. This often causes a partial or complete release of the nucleus pulposus. The bulging or herniated portion may impinge upon the spinal nerves compromising their function and causing pain. The design of the motion segments of the spine allows the spine to perform several movements. The spine is capable of flexion and extension (hyperextension) of the trunk, lateral flexion of the neck and trunk, as well as rotation of the trunk and head. In many cases, the spinal movements are enjoined with movements of the appendicular skeleton to allow for the completion of everyday movements, as well as those engaged in during sports and other physical activities. Limitations in the movement of these articulations often lead to premature functional decline (13). With age, the ability to extend and rotate the spine is often reduced due to lack of use.
Disc damage and injury can lead to physical debilitation. A disc does not always become damaged from a single dose of excessive force. In fact, most disc-related injuries occur from repetitive microtrauma (13, 14). If a heavy object is suspended in the air from a thick rope, and the rope is hit by something as blunt as a butter knife, the thickness of the rope will prevent the object from falling. But if the rope is struck with the object in the same place everyday for a year, its integrity will eventually become compromised to the point that it can no longer hold the weight of the object, and it will break. This is analogous to what happens with people who experience back pain and disc problems. The daily stress from poor movement biomechanics, poor posture, muscle weakness and tightness, and poor lifting techniques eventually wear down the ligaments and supporting structures so that when a single high force event occurs, the disc is damaged.

In most cases, the discs at the greatest risk are in the lordotic curvatures of the spine, specifically between C5-C6, L4-L5, and most commonly L5-S1. The reason for the frequent occurrence of injury in these areas is that these are the vertebral segments with the greatest movement capabilities (2, 14). They often experience anterior, posterior, and/or lateral compressive forces from the aforementioned contributing factors. When the disc is damaged and the nucleus pulposus breaks through the annulus fibrosus, it penetrates the vertebral canal distorting sensory nerves and affects sensory function. Additionally, the protruding section compresses the nerve roots, causing severe pain often leading to abnormal posture and radiating sensation through the lower back and limbs. In some cases, the compressed nerve loses its ability to properly innervate muscle tissue, and a partial loss of muscle control is experienced (15).

The radiating sensations often identify the area of injury. A herniation between L5-S1 is most often felt in the posterior aspects of the buttocks, upper leg, calf, and the bottom of the foot (15). A herniation between L4-L5 tends to cause more laterally experienced discomfort, including the lateral hip and lateral posterior portion of the leg, lateral surface of the calf, and top of the foot. Most therapies for lumbar disc herniation include pain medication, rest, braces, and physical therapy. Only about 10% of the disc herniations are treated with surgery to repair the damaged area (15).
Spinal & Trunk Musculature

Cross Sectional View

Anterior View

Posterior View

<table>
<thead>
<tr>
<th>Trunk Muscles</th>
<th>Movement Function</th>
<th>Example Exercise</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rectus Abdominis</td>
<td>Trunk Flexion</td>
<td>Ab curl-up</td>
</tr>
<tr>
<td>External Oblique</td>
<td>Flexes and rotates vertebral column</td>
<td>Diagonal chop</td>
</tr>
<tr>
<td>Internal Oblique</td>
<td>Flexes and rotates vertebral column</td>
<td>Cable torso twist</td>
</tr>
<tr>
<td>Transverse Abdominis</td>
<td>Compresses abdomen</td>
<td>Draw in</td>
</tr>
<tr>
<td>Erector Spinae Group</td>
<td>Extends vertebral column</td>
<td>Good morning</td>
</tr>
<tr>
<td>Quadratus Lumborum</td>
<td>Abducts vertebral column</td>
<td>Lateral flexion</td>
</tr>
</tbody>
</table>
Pelvic Positioning

The pelvis has a relationship with the spine, based on the movements that occur, mainly at the lumbosacral joint, which is formed by the pelvis and lowest lumbar vertebrae. When the spine of the ilium is rotated forward, the movement is termed an anterior pelvic tilt. When the same anatomy is rotated backward, the pelvis is considered to be in a posterior pelvic tilt. When these movements are performed, they change the curvature of the spine. An anterior pelvic tilt increases the convexity (lordosis) of the lumbar spine which, consequently, may place excessive stress on the posterior aspect of the discs in the region. A posterior pelvic tilt reduces the convexity, flattening the lumbar spine. This interaction of the pelvis and spine points to the need to properly control the pelvis when lifting resistance or maintaining posture for prolonged periods of time. Weakness or tightness in the muscles that attach to the pelvis and spine can lead to pelvic instability, often manifesting into low back pain.

Shoulder

The glenohumeral joint is a ball and socket joint which allows for the most movement of any joint. As previously mentioned, the shallow glenoid fossa allows for substantial movement capabilities by the humerus. In the hip, these same movements are more closely limited by the articulating surfaces of the joint, causing it to be more stable. For instance, abduction at the shoulder joint far surpasses the 45 degrees attainable at the hip. In humeral or shoulder flexion, the arm can be raised far above the shoulder when the hand is held in neutral position. Additionally, the joint allows for movement in all planes including flexion, extension, hyperextension, abduction, adduction, horizontal adduction, horizontal abduction, internal and external rotation, and circumduction. The vast movement capabilities decrease the stability due to a reduced contact area. To counteract the lack of stability, the body uses three sets of ligaments and four muscles, which collectively make up the rotator cuff. The rotator cuff, which is comprised of the supraspinatus, infraspinatus, teres minor, and subscapularis, also serve to assist movement at the shoulder. The teres minor and infraspinatus extend and externally rotate the humerus, while the subscapularis laterally extends and internally rotates the humerus.

~Quick Insight~

Due to the importance of pelvic control, it is important to maintain a healthy balance in the muscles that act on the articulating bones. Tightness in the hip flexors (iliopsoas muscle group) often pulls the pelvis forward and increases lumbar convexity due to the insertions of the psoas major and iliacus. The gluteus maximus muscle, if tight, may pull the pelvis into a posterior tilt particularly in conjunction with hip flexion. If this muscle is weak, the pelvis may gravitate forward, contributing to anterior tilt. Likewise, the quadratus lumborum, which attaches the pelvis and lumbar vertebrae laterally, may pull on the pelvis, reducing the stability in the frontal plane.

~Key Terms~

**Anterior pelvic tilt**- Anterior pelvic movement, originating from the lumbosacral joint and affecting the curvature of the spine.

**Posterior pelvic tilt**- A posterior pelvic movement, originating from the lumbosacral joint and affecting the curvature of the spine.
Shoulder Musculature

Anterior View

Posterior View

Rotator Cuff
Posterior View

Rotator Cuff
Anterior View
The rotator cuff muscle group is very important to the health and integrity of the shoulder joint. Injuries to the rotator cuff are common in both the sedentary population and active population, which suggest the tissue often has deficiencies. Additional concerns arise when the external accelerators and decelerators are imbalanced or are considerably stronger than the appropriate strength balance between the stabilizers and prime movers of a joint. Rotator exercises should be included in any comprehensive exercise program to prevent these imbalances and associated pain, instability, and injury.

~Quick Insight~

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Shoulder Girdle
The movements of the shoulder girdle complement the actions of the glenohumeral joint. Rather than a single joint, the shoulder girdle is a joint complex that includes the articulations between the sternum and clavicle and the clavicle and the scapula. The movements, defined by scapular action, can be performed without shoulder joint movement but most often are employed to enhance the movements of the shoulder. Although gliding movements occur at the respective articulations of the sternoclavicular (sternum and clavicle) and acromioclavicular (scapula and clavicle) joints, the actual movement terms are applied to actions of the scapula. The scapula can be elevated and depressed, abducted (protracted) and adducted (retracted), and rotated upward and downward. As mentioned, these movements are often combined with shoulder movements. For instance, the scapula may be adducted while the humerus is hyperextended to allow for the action of a seated row, or the scapula may be depressed and rotated downward while the arm is adducted to allow for the movements of the lat pulldown. These movements should be taught for correct exercise performance.
Elbow

The elbow joint, like the knee, is a hinge joint which allows for flexion and extension of the arm. The bicep muscle crosses the elbow and attaches to the radius to allow for arm flexion. The triceps muscle crosses the elbow and attaches to the ulna to straighten or extend the arm. The elbow is very stable because the surface of the humerus and ulna interlock; if a person can hyperextend their arm it is due to the irregular shape of their articulating surfaces. The elbow is most at risk when a person falls and uses the arm to brace the impact.
Radioulnar Joint
The radius and ulna of the forearm come together to form a pivot joint which allows the bone to cross and uncross so the hand is supinated (facing forward) or pronated (facing backward). When supinated, the radius and ulna are parallel; when pronated, the radius lies across the top of the ulna. Hand position variations when lifting will change the resistive load application to different structures. For instance, if the arm is flexed and hand pronated, the brachioradialis performs more work. If the hand is supinated during arm flexion (bicep curl) the bicep brachii experiences greater resistive force.

Wrist
The movements of the wrist generally occur in two planes, which allow for radial and ulnar deviation, also called abduction and adduction, in the frontal plane, and flexion and extension in the sagittal plane from the anatomical position. The wrist has the ability to hyperextend, which occurs as the back of the hand moves closer to the top of the forearm from a neutral wrist position. Forceful extension of the wrist over time can result in wrist extensor inflammation called tennis elbow (16).
Hip

Movements of the hip occur at the articular surface of the acetabulum and femoral head. Due to its connective make-up, the joint capsule of the hip is very dense, providing for strength and stability. The shape of the joint, organization of the articular capsule, and four broad ligament attachments supporting the ball and socket joint ensure the femoral head stays securely inside the acetabulum. The hip joint allows for similar movements as the shoulder joint. The hip can flex, extend, hyperextend, abduct, adduct, and internally and externally rotate. It has greater limitations to its specific range of motion in some movements due to the deeper socket and supportive connective structures. For instance, bone impingement limits true hip abduction to about 45 degrees and hyperextension of the hip is limited in range compared to that of the shoulder. In young adults, the hip is injured less frequently than the shoulder because the comparable decrease in mobility encourages greater stability (16).
Knee

The relationship between the shoulder and hip is similar to that of the knee and the elbow. The elbow and knee are both hinge joints and perform flexion and extension, but the knee is far more complex than the elbow joint. The femoral condyles actually allow for variations in contact with the tibia, which change during movement, and the patella-femur relationship adds to the differences seen between the joints. Additionally, the knee does not have a unified capsule or common synovial cavity. The knee uses fibrocartilage discs called menisci for cushioning, shape, and lateral stability, as well as fat pads to reduce friction. In addition, a fairly complex organization of ligaments aids in stability. Due to the nature of movements encouraged by physical activity these ligaments and menisci are subject to injury. In activities that use resistance, the risk of ligament injury is decreased compared to sport participation because the movements are slower and more controlled. Risk still exists however, when the knee does not follow proper biomechanics of movement. When the knee passes the plane of the toe during flexion, the action forces undesirable movement of the tibia called tibial translation, which disrupts the patella tracking. When this occurs frequently the patellar ligament is subject to inflammation termed chondromalacia patellae, often referred to as “jumper’s knee,” or “runner’s knee.” The knee joint also has the ability to lock in place to allow for prolonged periods of standing without contracting the knee extensors. This action is undesirable during lifting activities because the mechanism requires the meniscus to be compressed between the tibia and femur to maintain the position. Under load, the risk for damage is dramatically increased compared to unloaded standing with the knee in the same position (16).
### Knee Muscles

<table>
<thead>
<tr>
<th>Muscles</th>
<th>Movement Function</th>
<th>Example Exercise</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rectus Femoris</td>
<td>Extends leg, flexes thigh (hip)</td>
<td>Front squat</td>
</tr>
<tr>
<td>Vastus Lateralis</td>
<td>Extends leg</td>
<td>Lunge</td>
</tr>
<tr>
<td>Vastus Intermedius</td>
<td>Extends leg</td>
<td>Leg press</td>
</tr>
<tr>
<td>Vastus Medialis</td>
<td>Extends leg</td>
<td>Leg extension</td>
</tr>
<tr>
<td>Sartorius</td>
<td>Flexes hip and leg, rotates leg medially and thigh laterally</td>
<td>Lateral step up</td>
</tr>
<tr>
<td>Biceps Femoris</td>
<td>Extends thigh (hip); flexes and laterally rotates leg</td>
<td>Romanian deadlift</td>
</tr>
<tr>
<td>Semitendinosus</td>
<td>Extends thigh (hip); flexes and medially rotates leg</td>
<td>Supine leg curl</td>
</tr>
<tr>
<td>Semimembranosus</td>
<td>Extends thigh (hip); flexes and medially rotates leg</td>
<td>Standing leg curl</td>
</tr>
<tr>
<td>Adductor Brevis</td>
<td>Adducts, flexes, and laterally rotates thigh</td>
<td>Lateral lunge</td>
</tr>
<tr>
<td>Adductor Longus</td>
<td>Adducts, flexes, and laterally rotates thigh</td>
<td>Side step ups</td>
</tr>
<tr>
<td>Adductor Magnus</td>
<td>Adducts, extends, and laterally rotates thigh</td>
<td>Seated adduction</td>
</tr>
<tr>
<td>Pectineus</td>
<td>Adducts and flexes thigh</td>
<td>Cable adduction</td>
</tr>
</tbody>
</table>
Ankle

The ankle joint is also a hinge joint which allows for two primary movements: plantar flexion (extended ankle) and dorsi flexion (flexed ankle). The foot can also be inverted and everted through a limited range at the intertarsal joints (gliding joints). Injuries can occur when the foot is inverted or everted under load. This commonly occurs during jumping or running activities when body weight is applied to an uneven surface, such as landing on a person’s foot during a rebound in a basketball game or stepping in a divot when running.

~Quick Insight~

A common injury experienced by runners is shin splints. The term could apply to any of four injuries associated with anterior pain of the lower leg. In most cases, the injuries are caused by muscle imbalance, limited acclimation to the exercise stress, overuse, uneven running surfaces, the wrong foot wear, or improper technique. Shin splints are commonly attributed to overstressing the posterior tibialis, inflammation of the tibial periosteum (tibialis periosteum), anterior compartment syndrome where compressed nerves and vessels cause pain due to excessive blood flow to the anterior compartment muscles with concurrent tightness in the overlying fascia, and stress fractures of the tibia. Rest and ice often help to treat these ailments along with changing footwear and running surface (16).
CHAPTER ONE REFERENCES


