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Imaging the Extremities

Approved for 12 Category A Continuing Education Credits

American Society of Radiologic Technologists
Approved for 12 Category A CE Credit
Course Approval Start Date 06/01/2011
Course Approval End Date 07/01/2017

Florida Radiologic Technology Program FLDOH-BRC
Category (A) 00-Technical CE Credits
Course Approval Start Date 05/04/2011
Course Approval End Date 01/31/2017

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A Continuing Education Course for Radiation Operators

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Updated March 2015

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Imaging the Extremities

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Course Description

Conventional non-contrast radiography examinations of bones, joints, and soft tissues are among the most common imaging procedures requested. Since conventional radiography images contribute to information concerning pathology and trauma, the radiographer must control factors that might otherwise distort the image. Such factors include patient cooperation, correct positioning, photographic and geometric factors, and the proper selection of exposure factors. Subtle changes in skeletal structures can be obscured by a slight shift of the patient's body or inaccurate exposure factors. This course provides the radiographer with a thorough review of the conventional non-contrast radiography imaging of the appendicular skeleton. Basic information about adjunct imaging modalities such as magnetic resonance imaging, computed tomography, ultrasonography, bone densitometry, nuclear medicine, and interventional examinations are also included.

Course Objectives: Upon completion of this course, the participant will be able to:

1. Review and recall facts about the appendicular skeleton.
2. Identify appropriate patient care practices during imaging examinations.
3. Recall technical factors related to conventional radiography positioning protocols of the appendicular skeleton.
4. Select the correct response regarding signs and symptoms of trauma and injury to the appendicular skeleton.
5. Recall facts about radiation protection.

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The Imaging the Extremities course contains the following 7 chapters:

Chapter 1 The Appendicular Skeleton: A Review

"Parents are the bones on which children cut their teeth."
Peter Ustinov

Introduction

Ancient skeletal fossils are a reminder that bone is one of the most durable of all human tissues. The bony skeleton serves a structural function providing mobility, support, and protection for the body. The skeletal armor however is not impervious to disease and traumatic injury. This is evident by the number of imaging examinations performed each day that involve some aspect of the skeletal system. Imaging examinations play a major role in the accurate diagnosis and treatment of disease and trauma of the musculoskeletal anatomy. To produce high quality images, radiographers must have a thorough knowledge of each aspect of the skeletal system. This chapter provides a review of the skeletal system with emphasis on the appendicular skeleton.

The Bony Skeleton

The bony skeleton serves a structural function providing mobility, support, and protection for the body and acts as a reserve, storing up essential minerals.[1] Many assume that the adult skeleton is an inert framework, a sort of stone-like foundation for the living flesh of our bodies. This assumption is false, however, since bone is living tissue, and from birth to death is in a constant state of flux.

Bone health is difficult to maintain because the skeleton is simultaneously serving two different functions that are in competition with each other.[1] First, bone must be responsive to changes in mechanical loading or weight bearing activities, which requires ample supplies of calcium and phosphorus. Yet when these elements are in short supply elsewhere, regulating hormones siphon them out of the bones to serve vital functions in other body systems.[1] The skeleton can be compared to a bank where calcium or phosphorus is deposited and then later withdrawn in times of need.[1] Too many withdrawals weaken the bone and can lead to the most common bone disorder, fracture.[1]

The amount of bone and its architecture or shape are determined by the mechanical forces that act on the skeleton.[1] Both genes and the environment contribute to bone health. Genes generally determine elements of bone health like size and shape of the skeleton, and errors in signaling on the part of these genes can result in birth defects.[1] External factors, such as diet and physical activity, are critically important to bone health throughout life and can be easily modified for better health.[1]

To respond to the dual roles of physically supporting the body and regulating the amounts of calcium and phosphorus within it, bone is constantly changing. Osteoporosis and many related bone diseases cause bones to become porous, gradually making them weaker and more brittle.[2] The word osteoporosis literally means porous bones.

Skeletal Anatomy and Physiology

Bone consists of approximately 25% organic substances and 75% inorganic substances, and is the supporting framework of the body. The major organic component of bone is collagen, a strong and flexible protein. Calcium and phosphate in the form of calcium phosphate crystals are the primary inorganic substances found in bone. Together, the combination of organic and inorganic substances makes bone both flexible and able to withstand weight-bearing stresses.

Microscopically, bone consists of a mixture of connective tissue, blood vessels, specialized cells, and crystals of calcium and phosphate. The skeleton contains 99% of the body's total calcium, but being rich in calcium is not enough to make bones resistant to fracture. Bones can be dense yet brittle, lacking flexibility, which will cause them to break easily. The collagen protein content is crucial for maintaining flexibility. It is thought that the quality and quantity of collagen protein in bones may be more essential to preventing fractures than the calcium content. In addition to calcium, bones are a reservoir of numerous other minerals that the body requires for day-to-day function. The bones act as a bank for nutrients, with a constant flow of deposits and withdrawals. Calcium, phosphorus, sodium, magnesium, and collagen protein enter and leave bone during the resorption and remodeling process.

Humans obtain these nutrients from the foods they ingest. Food is broken down in the stomach and duodenum, where nutrients are absorbed through the walls of the small intestine and enter the bloodstream. Once in the blood, calcium migrates to the bones, and is deposited and stored. Bone resorption takes place as needed, liberating calcium for necessary functions in the blood, muscles, nerves, and elsewhere. The kidneys excrete excess calcium that is not absorbed. Deposition of calcium in the bones is increased by the influence of gravity, which occurs when the human body is in motion, for example when walking. A sedentary lifestyle contributes to the loss of bone mass by preventing deposition of calcium, so that the process of mineral resorption slowly uses up the available bone mass.

Bone is classified as a connective tissue and contains three basic parts: cells (osteocytes, osteoblasts, and osteoclasts), the matrix, and inorganic calcium salts. These cells react to hormones, physical stress, and calcium blood levels, and bone repair demands. The osteoblasts, or bone-producing cells, produce the organic bone matrix components that later become mineralized through a process that is not well understood. The osteoclasts are responsible for bone remodeling and have large multinucleated cells that contain and secrete calcium-dissolving acids. Excessive bone breakdown by osteoclasts is an important cause of bone fragility. This process occurs not only in osteoporosis but also in other bone disease such as hyperparathyroidism and Paget's disease.[1] Inhibitors of osteoclastic bone breakdown have been developed to treat these disorders.

The balance of the calcium moving in and out of bone forms the basis for bone remodeling. Calcium in the blood moves into bone as osteoblasts make new bone and returns into the blood when the osteoclasts break bone down. Osteoclasts are sensitive to blood calcium levels and respond by increasing or decreasing activity levels. Other factors, whether physiological, environmental, or behavioral, can also alter the delicate balance between osteoblast and osteoclast equilibrium. Some of these factors include low estrogen and testosterone levels, calcium and vitamin D deficient diets, and a sedentary lifestyle.

There are two major bone classifications: cortical (compact) bone and trabecular (spongy) bone. Cortical bone consists of dense, tightly aligned lamellar osteons (tubules) and is found in locations where bone compresses in a limited number of directions. Cortical bone may be found in the skull and femur shafts. Cortical bone is organized into units called haversian systems, each containing osteocytes and an intracellular matrix arranged in circular layers around central haversian canals.

Trabecular bone has a honeycomb appearance, with a partitioned internal design and weighs less than cortical bone, thus reducing skeletal weight. Trabecular bone is found in locations that receive either low mechanical stresses or multi-directional stresses. The femoral head, calcaneus, and spine are all examples of predominately trabecular bone. Trabecular bone is more metabolically active than cortical bone and responds quickly to factors that affect the skeleton. The differentiation of bone as either cortical or trabecular is important in imaging examinations involving bone densitometry because certain diseases show a preference for one type of bone over another. The radiographer should be knowledgeable about the differences between cortical and trabecular bone and about how various disease conditions and drug therapies affect each type.

In addition to describing skeletal bones as predominantly cortical or trabecular, there are 3 other ways to characterize skeletal sites:

- Weight-bearing or non-weight bearing
- Axial or appendicular
- Central or peripheral

Weight-bearing sites include the lower extremities, the cervical, thoracic, and lumbar spines, and the calcaneus, with all other bones being non weight-bearing. The axial skeleton includes the skull, ribs, sternum, and spine; and the appendicular skeleton includes the extremities. The thoracic and lumbar spines and the proximal femur are central skeletal sites. Peripheral skeletal sites are non-central sites, and include the calaneus, tibia, and forearm.

The mature skeleton gradually increases in mass during early adult life. Peak bone mass is achieved between 30 and 35 years of age. Peak bone mass is affected by genetics, mechanical loading, and hormonal and nutritional levels, and is approximately 30% higher in men than in women. After the skeleton reaches its peak bone mass, the bone mass declines throughout life due to an imbalance in remodeling. In women, bone mass decreases rapidly for three to seven years after menopause. Estrogen produced by the female ovaries, plus other hormones, regulate the absorption and release of calcium in the bones. After menopause, the ovaries no longer produce estrogen, and bone loss accelerates, finally slowing down at about age 65. Bone loss may also be accelerated by a variety of diseases and drugs. In males, testosterone affects bone mass.[3] Recent research in the U.S. and Germany demonstrates that testosterone replacement therapy for men with deficient hormone levels has helped to increase both cortical and trabecular bone density.[3-5]

As humans age, bone formation does not keep pace with bone loss. The rate of bone loss increases with advancing age. When the long-term rate of bone dissolution is greater than the rate of replacement, mineral content slowly decreases, and the bones become thin, brittle, and easily broken. This cycle is called the process of destruction, or resorption, and renewal formation, known as remodeling. In the mature adult, approximately 25% of trabecular bone and about 3% of cortical bone is renewed on an annual basis.[6]

The remodeling cycle consists of two distinct stages referred to as resorption and formation. The resorption stage begins when osteoclasts become active on the surface of bones and creates small cavities. The resorption process forms hollows in trabecular bone and cylindrical cavities in cortical bone. The resorption stage is followed by bone formation, during which bone-building osteoblasts fill the cavities with new bone. After formation, the bone returns to a resting state that is referred to as quiescence. About 90% of bone surfaces are normally at rest.[6]

Resorption is more rapid than formation, and by age 40 the entire resorption stage may last one month, while the formation stage may take up to 3 months.[5] By age 65, the entire process of resorption and formation may take up to 5 months.[5] Modeling and remodeling continues throughout life, so that most of the adult skeleton is replaced about every 10 years, Figure 1-1.[6]

Osteoclasts attach to bone surface	Osteoclasts attach to bone surface
Osteoclasts resorb bone	Osteoclasts resorb more bone tissue and leave a deeper resorption cavity
Osteoblasts enter cavity and build new bone	Osteoblasts build less bone than the amount resorbed
Amount of bone formed is equal to the amount of bone resorbed so that bone mass/strength are maintained	Bone resorption exceeds bone formation, leading to a progressive decline in bone mass, weakening bones and increasing risk of fractures

Fig 1-1. Steps in normal and abnormal bone regeneration.

Bone Metabolism

Alkaline phosphatase, which raises calcium and phosphate levels, is thought to play a role in bone mineralization. However, many factors influence the bone metabolism and remodeling process by direct action on the osteoblasts and osteoclasts. The most critical systemic hormones regulating bone growth include:

- **Calcium-regulating hormones;**

    Parathyroid hormone (PTH)

    Calcitriol (active vitamin D)

    Calcitonin

- **Sex hormones;**

    Estrogen

    Testosterone

- **Other systemic hormones**

    Growth hormone/insulin-like hormone

    Growth factor

    Thyroid hormone

    Cortisol

The parathyroids are four small glands located adjacent to the thyroid gland and produce parathyroid hormone (PTH). These glands control the level of calcium in the blood, and are sensitive to small changes in calcium concentration. PTH acts on the kidneys to conserve calcium and stimulate calcitriol production, which increases intestinal absorption of calcium. PTH stimulates bone formation as well as absorption by increasing movement of calcium from bone to blood. Excessive production of PTH, called hyperparathyroidism, is sometimes due to a small tumor of the parathyroid glands. Overproduction of PTH can lead to bone loss.

Recently a second hormone has been discovered, parathyroid hormone-related protein (PTHrP) that serves to regulate cartilage and bone development in the fetus.[1] The hormone may be overproduced in individuals with certain types of cancer. PTHrP acts like PTH, causing excessive bone breakdown and abnormally high blood calcium levels, a condition called hypercalcemia of malignancy.[1]

Calcitriol, 1,25 dihydroxycholecalciferol, is a hormone formed in the liver and kidneys by the action of enzymes. Calcitriol acts on many different tissues, but its most important action is to increase intestinal absorption of calcium and phosphorus. Vitamin D can be made in the skin through the action of ultraviolet light from the sun on cholesterol. Many people need vitamin D in their diet because they do not derive adequate levels of it from exposure to the sun. Vitamin D deficiency leads to a disease of defective mineralization called rickets in children and osteomalacia in adults. These conditions can cause bone pain, bowing and deformities of the legs, and fractures. Treatment with vitamin D can restore calcium supplies and reduce bone loss.

Calcitonin is a calcium-regulating hormone produced by cells of the thyroid gland. Calcitonin is thought to be more important for maintaining bone development and normal blood calcium levels in early life. In adults, excesses or deficiencies of calcitonin does not interfere with maintaining calcium concentration or the strength of bone. Calcitonin is used as a drug for treating various bone diseases.

Sex hormones, along with calcium-regulating hormones, are extremely important in regulating the growth of the skeleton and maintaining the mass and strength of bone.[7-8] Estrogen and testosterone influence bone mass and strength in both men and women.[7-8] In females, estrogen acts on the osteoclasts and osteoblasts to inhibit bone breakdown at all stages of life.[9] In males, testosterone is important for skeletal growth because of its direct effects on bone and its ability to stimulate muscle growth.[7-8] Growth hormone from the pituitary gland is also an important regulator of skeletal growth. It acts by stimulating the production of another hormone, called insulin-like growth factor (IGF-1), which is produced in large amounts in the liver and released into the blood circulation. IGF-1 is produced locally in other tissues, particularly in bone, also under the control of growth hormone.

Thyroid hormones increase the energy production of all body cells, including bone cells. Thyroid hormones increase the rates of both bone formation and resorption. Thyrotropin (TSH), a pituitary hormone that controls the thyroid gland, may have a direct effect on bone.

Cortisol, the major hormone of the adrenal gland, is a critical regulator of metabolism, and is important to the body's ability to respond to stress and injury. Small amounts are necessary for normal bone development, but large amounts block bone growth. Synthetic forms of cortisol, called glucocorticoids, are used to treat many diseases such as asthma and arthritis. The use of glucocorticoids can cause bone loss due to a decrease in bone formation and an increase in bone breakdown, both of which lead to increased risk of fracture.[1]

Bone Strength

Bone fractures, especially vertebral compression fractures, present serious consequences following trauma and non-trauma occurrences such as those experienced by those with osteopenia, osteoporosis, and other bone diseases. The ability of bone to resist fracture depends on the amount of bone (i.e., mass), the spatial distribution of the bone mass (i.e., shape and microarchitecture), and the intrinsic properties of the materials that comprise the bone.

Diseases and drugs that influence bone remodeling will affect bone's resistance to fracture. Living bone tissue is continually changing under the influences of mechanical and hormonal impacts and in response to increased mechanical loading, and may adapt by altering its size, shape, and/or matrix properties. The properties that influence bone strength are related to microarchitectural and macroarchitectural at the cellular and matrix levels.

In daily life, the skeleton must withstand a combination of compression or tension forces with bending and twisting motions. The highest stress impacts occur to the vertebral spine due to compression loading. Research has proven that the best bone design to withstand bending loads is when the axis is near the center of the bone. This area is referred to as the area moment of inertia.

> ***Area moment of inertia*** *is a geometric property that describes the distribution of mass around the neutral bending axis of an object (i.e., bone).*

In essence this means that as the external diameter of a long bone increases, the bone assumes more resistance to bending and twisting loads applied to it, thus reducing potential fractures. The material properties of bone tissue declines with age and is accompanied by a redistribution of cortical and trabecular bone. This decline is greater in the appendicular skeleton, which involves endosteal resorption with bone along with periosteal apposition on the bone's exterior surface. The process results in an age-related increase in the diameter of long bones with a decrease in cortical thickness.[16] This process was once thought to occur to a greater degree in women; however, research data has demonstrated that both men and women undergo these geometric bone changes with aging.

Microarchitecture has an important role in bone strength. Newer imaging modalities such as high-resolution microcomputed tomography (mCT) and magnetic resonance imaging (MRI) that provides three-dimensional evaluation of trabecular bone have been able to show altered trabecular microarchitecture associated with vertebral fracture.[10]

Bone matrix properties of mineralization, collagen characteristics, and microdamage also affect the mechanical properties of bone. The quantity and quality of bone matrix content relates directly to stiffness and strength of bone. When bone matrix is undermineralized or decreases due to a disease state, the ability of the bone to withstand energy impacts decreases.[10]

The quality and quantity of collagen has an important role in bone strength. Bone is primarily composed of minerals and collagen which gives bone the ability to withstand energy impacts (i.e., reduces fracturing). Along with adequate bone matrix and collagen, the ability of bone to withstand energy impacts is also dependent upon microdamage. Microdamage or fatigue to bone occurs from the daily physiologic loading to the skeleton. The concept of fatigue microdamage to bone may be related to both age-related fragility bone fractures and certain diseases and conditions.[10]

Divisions and Classification of Bones

The adult human skeleton consists of 206 bones. Of these, 80 bones comprise the axial skeleton, which includes all of the bones that lie on or near the central axis of the body. The adult axial skeleton includes bones in the skull, vertebral column, ribs, and sternum. The adult human appendicular skeleton consists of 126 bones, which are located in the upper and lower limbs and the shoulder and pelvic girdles. Each of the 206 bones of the human body can be classified according to shape such as a long bone, short bone, flat, or irregular.

Long bones consist of a body (i.e., shaft or diaphysis) and two ends covered with hyaline cartilage. Long bones are found only in the appendicular skeleton. Short bones are cuboidal in shape and are found only in the wrists and ankles. There are eight cubodial shaped bones in the wrist (i.e., carpal bones) and seven cubodial shaped bones in the ankle (i.e., tarsal bones). Flat bones consist of two plates of compact bone with cancellous bone and marrow between them. The calvarium (i.e., skullcap), sternum, ribs, and scapulae are examples of flat bones. The narrow space between the inner and outer table of flat bones in the cranium is known as diploe. Flat bones provide either protection or broad surfaces for muscle attachment.

A final category is the irregular bones, which have peculiar shape and are found in the vertebrae, facial bones, bones of the base of the cranium, and bones of the pelvis. In adults red blood cells are produced by the red bone marrow of flat and irregular bones such as the sternum, ribs, vertebrae, and pelvis.

Arthrology

Arthrology is the study of joints or articulations. Movement does not occur in all joints and as such joints are classified according to their function and mobility or lack thereof. The three common functional classifications of joints are synarthrosis (immovable joint), amphiarthrosis (limited movement), and diarthrosis (freely movable joint). Sometimes all joints of the body are grouped according to a structural classification based on the type of tissue that separates the ends of the bone.

The three structural categories of joints are fibrous, cartilaginous, and synovial. Fibrous joints lack a joint cavity and adjoining bones are held together by fibrous connective tissue. An example of a fibrous joint would be the sutures of the cranium. Cranial sutures are immovable or synarthrodial joints. Cartilaginous joints also lack a joint cavity and are only slightly moveable. The bones that articulate with this type of joint are held tightly together by cartilage. Examples of these joints would be the symphysis pubis in the pelvic cavity and the epiphyseal plates between the epiphysis and the body of long bones. Synovial joints are freely movable and are characterized by a fibrous capsule containing synovial fluid.

Synovial joints, also known as diarthrosis joints, and are the most common and most movable of all types of joints. As with most other joints, synovial joints achieve movement at the point of contact of the articulating bones. Structural and functional differences distinguish synovial joints from cartilaginous joints and fibrous joints. The main structural differences between synovial and fibrous joints are the existence of capsules surrounding the articulating surfaces of a synovial joint and the presence of lubricating synovial fluid within the capsule. Synovial fluid is a clear viscous liquid and it provides lubrication of the joint and facilitates joint movement. The synovial fluid and surrounding specialized articular surfaces and intra-articular structures such as the menisci, discs, and fat pads, allow for almost unrestricted movement of the joint surfaces. The synovial joint capsule contains fibers arranged in irregular bundles and nerve endings so that any tension or trauma to the joint is transmitted to the spinal cord and brain and registers as pain. The synovial joints are classified according to the movement of the joint and includes gliding joints, hinge joints, pivot joints, condyloid (i.e., ellipsoidal) joints, saddle joints, ball and socket joints, and compound joints, Figure 1-2.

Gliding joints are located in the articular processes of the vertebral spine and allow a sliding of one surface on the other. The surrounding ligaments and structures limit the range motion of a gliding joint. The knee joint is one example of a hinge joint. A hinge joint allows movement in only one plane such as either flexion or extension.

A pivot joint allows rotational movement around a fixed point such as the movement of the radial head. The wrist joint obtains its movement via an ellipsoidal or condylar joint. When an oval head or condyle articulates with an elliptic cavity, movement such as flexion, extension adduction, abduction, and circumduction is possible. An ellipsoidal joint does not allow axial rotation type motion. The movement of the thumb is provided by a saddle joint which is similar to an ellipsoidal or condyloid joint in its range of motion. A ball-and-socket type joint provides the movement of the hip joint. The hip has movement in three axes that include flexion, extension, adduction, abduction, and rotation.

Part	**Bones**	**Type**	**Movement**
Hand	Proximal end of 1^{st} metacarpal with the trapezium	Saddle	Flexion, extension, abduction, adduction, and circumduction of the thumb
Wrist	Scaphoid, lunate, and triquetral bones articulate with the radius and articular disk	Condyloid	Flexion, extension, abduction, and adduction of the hand
Elbow	Trochlea of the humerus with the semilunar notch of the ulna; head of the radius with the capitulum of the humerus and head of the radius in the radial notch of the ulna	Hinge type	Flexion and extension
Shoulder	The head of the humerus in the glenoid cavity of the scapula	Ball-and-socket	Flexion, extension, abduction, adduction, rotation, and circumduction of the upper arm
Foot	Between the tarsals Between the metatarsals and phalanges Between the phalanges	Gliding Hinge Hinge	Gliding; inversion and eversion Flexion, extension, slight abduction, and adduction Flexion and extension
Ankle	The distal ends of the tibia and fibula with the talus	Gliding	Flexion and extension
Knee	Between the distal end of the femur and proximal end of the tibia. Constitute the largest joint in the body	Hinge	Flexion and extension with slight rotation of the tibia
Hip	Head of the femur in the acetabulum	Ball-and-socket	Flexion, extension, abduction, adduction, rotation

Fig. 1-2. Individual joints of the upper and lower extremity.

The joints within the human skeleton do not come with a lifetime guarantee. The mechanics of constant movement along with factors associated with aging, genetics, and environmental impacts all contribute to destruction of the hyaline articular cartilage within the joint capsule.

Terminology Associated with Bony Parts and Prominences

The production of high quality radiography images requires that the radiographer perform many tasks properly. One of the most important tasks that the radiographer must perform is proper placement and positioning of the anatomic structure being examined. To do so requires that radiographers be intimately familiar with the terminology used to describe or name various bony parts and prominences located on each of the 206 bones in the human skeleton. These structures are referred to as anatomical landmarks and are commonly used by radiographers in positioning for various imaging examinations.

Ala, Body, Crest, Spine, and Process

The ilium, a bone in the pelvic girdle, has 3 descriptive anatomic landmarks. The ala or wing is the upper flat curved part of the body or main portion of the ilium. The term body is also used when referring to the main portion of the body of the scapula. A crest refers to the upper border of an ala or wing such as the crest of the ilium. A pointed process on a bone is referred to as a spine and the term is often used when referring to a portion of the ischium (i.e., the ischial spine). A process is a projection or outgrowth of bone or tissue.

Condyle, Epicondyle, Head, Capitulum, Neck and Capitellum

The term condyle is used to describe a rounded projection on a bone. A condyle helps to form an articulation such as the ones located on the distal ends of the femur, helping to form the knee joint, and the condyle at the distal end of the humerus, helping to form the elbow joint. An epicondyle is a rounded projection on a bone and is located above its companion condyle. An epicondyle usually has a roughened surface to allow for the attachment of muscles and ligaments.

The term that is often used to describe the rounded upper end of a bone is the head (i.e., the head of the humerus or the head of the femur). When the term neck is used in relationship to a bony landmark it means the elongated portion. A capitulum is a small rounded portion located on the articular end of a bone. The term capitellum refers to a rounded eminence such as the one at the lower end of the humerus.

Foramen, Fossa, Sulcus, Lumen, and Meatus

A fissure is a groove or natural division, cleft, or slit in a bone and the term used to describe an ulcer or cleft-like sore. A foramen is a perforation or opening (usually in a bone) through which nerves or blood vessels pass. An example of a foramen within a bone is the foramen magnum located within the occipital bone of the cranium. Another example of a foramen is the large opening in the lower part of the innominate bone, which is the largest foramen in the human skeleton. A fossa refers to a pit or depression in bone and the term sulcus is used to describe a furrow, groove, or slight depression.

A lumen is a space within an artery, vein, intestine or tube and the term meatus is used when describing a passage or opening such as the external auditory meatus.

Sesamoid bone, Symphysis, and Trochanter

A sesamoid bone is an oval nodule of bone or fibrocartilage located within a tendon playing over a bony surface. The patella is the largest sesamoid bone in the human body. The term symphysis refers to a slightly movable joint that is located between two bones. The joint between the two pubic bones is referred to as the symphysis pubis. A trochanter is a rounded prominence on the outer or lateral border of a bone such as the greater trochanter of the femur. A tubercle is a small rounded elevation or eminence of bone such as the greater and lesser tubercles of the humerus.

Terminology related to Skeletal Anomalies of the Hand and Foot

The term syndactyly refers to a failure of the fingers or toes to separate during fetal development. Syndactyly is a webbed appearance of the toes or fingers. When extra digits (fingers or toes) are present, the condition is referred to as polydactyly. Clubfoot (talipes) is a congenital malformation of the foot that prevents normal weight-bearing activities. Congenital hip dislocation is a malformation of the acetabulum in which the acetabulum does not completely form. Congenital hip dislocation causes the head of the femur to be displaced superiorly and posteriorly.

Anatomy of the Upper Limb

The upper extremity or limb includes the fingers, hand, wrist, elbow, forearm, humerus, shoulder, clavicle, scapula, and acromioclavicular joints. Figure 1-3 lists the number of bones found in each anatomic area per one limb.

Anatomic Area	**Number of Bones per side**
Hand (phalanges, metacarpals, carpals)	27
Phalanges (fingers and thumb)	14
Metacarpals (palm)	5
Carpals (wrist)	8
Forearm (radius and ulna)	2
Elbow joint	
Humerus	1
Shoulder	
Clavicle	1
Scapula	1

Fig. 1-3. Number of bones found in each anatomic area per one limb.

The Hand

The hand includes the bones of the wrist or carpus, palm or metacarpals, and digits or phalanges, Figures 1-4 and 1-5. Each finger and thumb is called a digit. Each digit consists of two or three separate small bones called phalanges (plural) or phalanx (singular). The digits are numbered, starting with the thumb as the first digit and ending with the little finger as the fifth digit. Each of the four fingers (digits two through five) consists of three phalanges, individually identified as proximal, middle, and distal. The thumb has only two phalanges, proximal and distal.

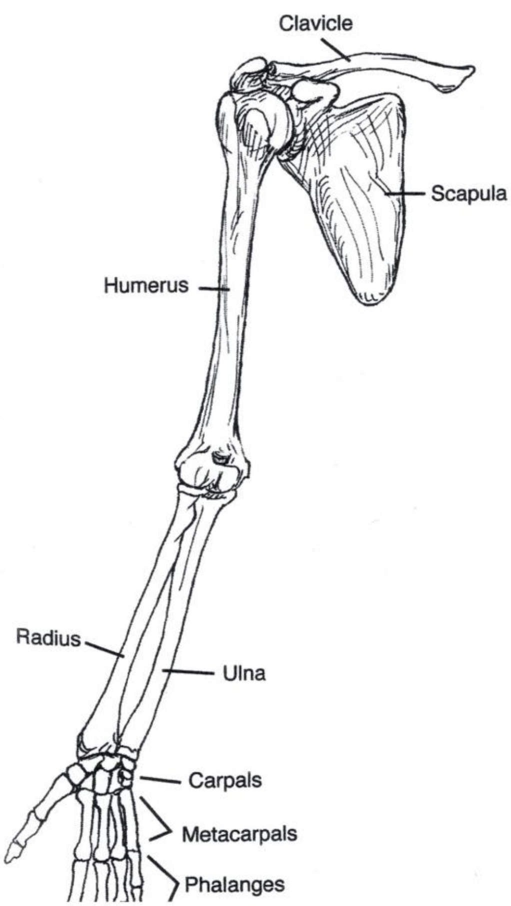


Fig. 1-4. Bones of the upper extremity. From Greathouse. *Delmar's Radiographic Positioning Volume 1,* 1E © 1998 Delmar Learning, a part of Cengage Learning, Inc. Reproduced by permission. www.cengage.com/permissions.

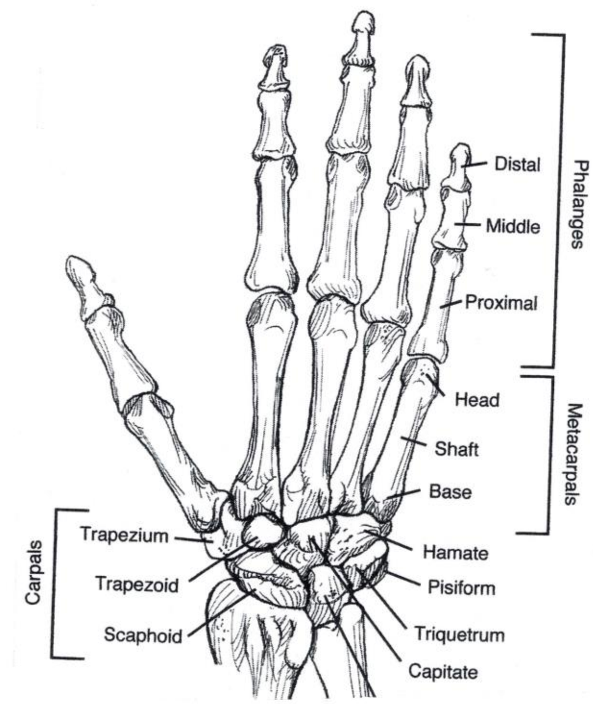


Fig. 1-5. Bones of the hand. From Greathouse. *Delmar's Radiographic Positioning Volume 1,* 1E © 1998 Delmar Learning, a part of Cengage Learning, Inc. Reproduced by permission. www.cengage.com/permissions.

The metacarpals have two ossification centers; one for the body, which ossifies at 8 weeks of fetal life, and one at the neck, which appears before three years of age. The phalanges all have secondary ossification centers at their bases. The joints and articulations of the hand are found between the individual bones. These articulations are important in radiography since small chip fractures may occur near the joint spaces. The thumb has two phalanges with one joint between them called the interphalangeal (IP) joint. The joint between the first metacarpal and the proximal phalanx of the thumb is called the first metacarpophalangeal (MP) joint. For radiography purposes, the first metacarpal is considered to be part of the thumb and must be included in its entirety on images of the thumb

The second through the fifth digits each have three phalanges with three joints. From the most distal portion of each digit, the joints are called the distal interphalangeal (DIP) joint, followed by the proximal interphalangeal (PIP) joint, and the most proximal being the metacarpophalangeal (MP) joint. The 5 metacarpals articulate with specific carpals as follows:

1st metacarpal…Trapezium 2nd metacarpal…Trapezoid
3rd metacarpal…Capitate 4th & 5th metacarpal…Hamate

Carpals

There are eight carpal bones, which are best remembered by dividing them into two rows consisting of four each, Figure 1-6.

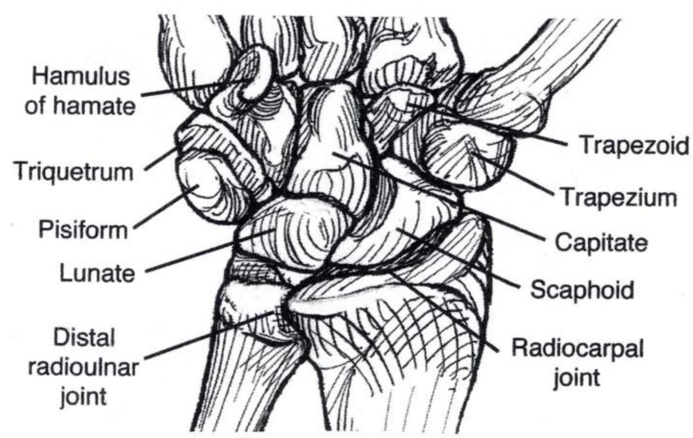


Fig. 1-6. Bones of the wrist. From Greathouse. Delmar's Radiographic Positioning Volume 1, 1E © 1998 Delmar Learning, a part of Cengage Learning, Inc. Reproduced by permission. www.cengage.com/permissions.

A memory mnemonic for the carpal bones is *Send Letter (to) Paul to Tell (him to) Come Home*. Figure 1-7 provides a chart of the memory aid that may be used to remember the names of the carpal bones.

Memory Tips		
Memory Mnemonic	**Carpal Bone & Location**	**Other Tidbits**
S Send	Scaphoid Proximal row	Lateral side by thumb. Also called navicular but since there is a navicular bone in the foot, the term scaphoid is used for the wrist. The largest bone in the proximal row and the most frequently fractured carpal bone.
L Letter	Lunate Proximal row	Moon-shaped and articulates with the radius.
P Paul	Pisiform Proximal row	Pea-shaped and the smallest of the carpal bones.
T To	Trapezium Distal row	Located on the lateral side by thumb and is four sided and has an irregular shape.
T Tell	Trapezoid Distal row	Wedge shaped and smallest in the distal row.
C Come	Capitate Distal row	Also called os magnus, meaning large bone
H Home	Hamate Distal row	Has a hooked-like process, the hamulus.

Fig. 1-7. A memory mnemonic for the carpal bones.

Ossification begins at the capitate (usually present at one year of age) and proceeds in a counterclockwise direction. The hamate is the second carpus to ossify (by one to two years of age), followed by the triquetrum (by three years of age), lunate (by four to five years of age), scaphoid (by five years of age), trapezium (by six years of age), and trapezoid (by seven years of age). The pisiform is a large sesamoid bone and is the last to ossify (by nine years of age).

The radiocarpal articulation is an ellipsoid type joint and is made up of the distal radius, scaphoid, lunate, triquetrum, and ligamentous structures.

Carpal Sulcus (Canal or Tunnel)

If the carpals were viewed tangentially downward from the wrist and arm from the palm side of a hyperextended wrist, the view would demonstrate the carpal sulcus formed by the concave anterior or palmar aspect of the carpals. The pisiform and hamulus process of the hamate is best visualized on the canal or tunnel projection.

Forearm

The radius and ulna are the two forearm bones. The radius and ulna articulate with each other at the proximal radioulnar joint and at the distal radioulnar joint. With the forearm in the true anatomic position, the radius is on the outer or lateral side, and the ulna on the inner or medial side. To remember the position of the radius and ulna is to recall where the radial pulse is counted. Two small conical projections called the styloid processes are located at the extreme distal ends of both the radius and the ulna.

The radius is the shorter of the two bones of the forearm and is the only one of the two forearm bones directly involved in the wrist joint. The proximal radius is composed of a head, neck, and proximal medial radial tuberosity. The radius has a gradual bend and increases in size distally. The radius and ulna articulate proximally at the elbow joint and distally at the wrist. The ulna is the longer of the two forearm bones and is primarily involved in the formation of the elbow joint. The proximal ulna has two beak-like processes, the olecranon and coronoid process.

The nerves of the upper arm continue into the forearm (i.e., radial nerve, median nerve, and ulnar nerve). Blood is supplied to the forearm at the elbow where the brachial artery enters the cubital fossa and branches into the radial artery and ulnar artery.

Elbow Joint

The humerus, radius, and ulna combine to form the elbow joint, Figure 1-8.

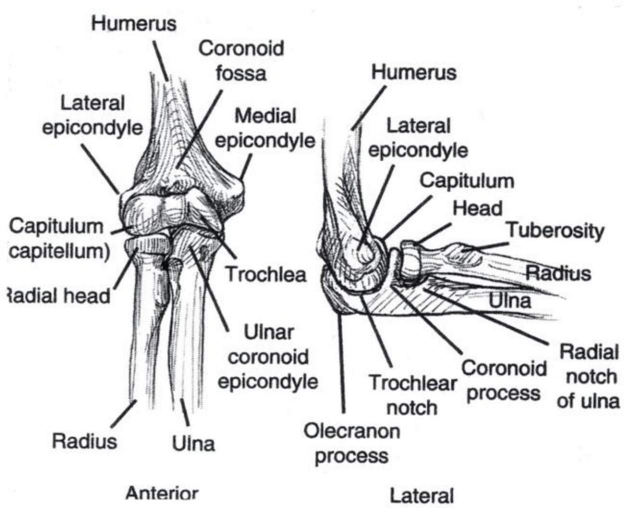


Fig. 1-8. Elbow joint, anterior and lateral views. From Greathouse. Delmar's Radiographic Positioning Volume 1, 1E © 1998 Delmar Learning, a part of Cengage Learning, Inc. Reproduced by permission. www.cengage.com/permissions.

The elbow is a type of diarthrodial joint, which allows only flexion and extension. The elbow joint is very stable because it receives support from long ligaments and a tough capsule. Fat pads and several bursas containing synovial fluid surround the elbow joint.

The lateral ulnar collateral ligament is an essential elbow stabilizer and runs from the lateral epicondyle to the ulna crista supinatoris. There are four muscles of the arm.

The muscles controlling elbow motion include the flexors and extensors. Tennis elbow (i.e., lateral epicondylitis) primarily involves the extensor carpi radialis brevis.

Humerus

The humerus is the single bone of the upper arm and it is the largest and longest bone of the upper extremity. It is composed of a shaft (i.e., the body or midportion) and two articular extremities. The humerus articulates with the scapula on its upper end, forming the glenohumeral joint, and with the radius and ulna on its lower end, forming the elbow joint. The expanded distal end of the humerus is the humeral condyle divided into two parts, the trochlea and the capitulum, Figure 1-9.

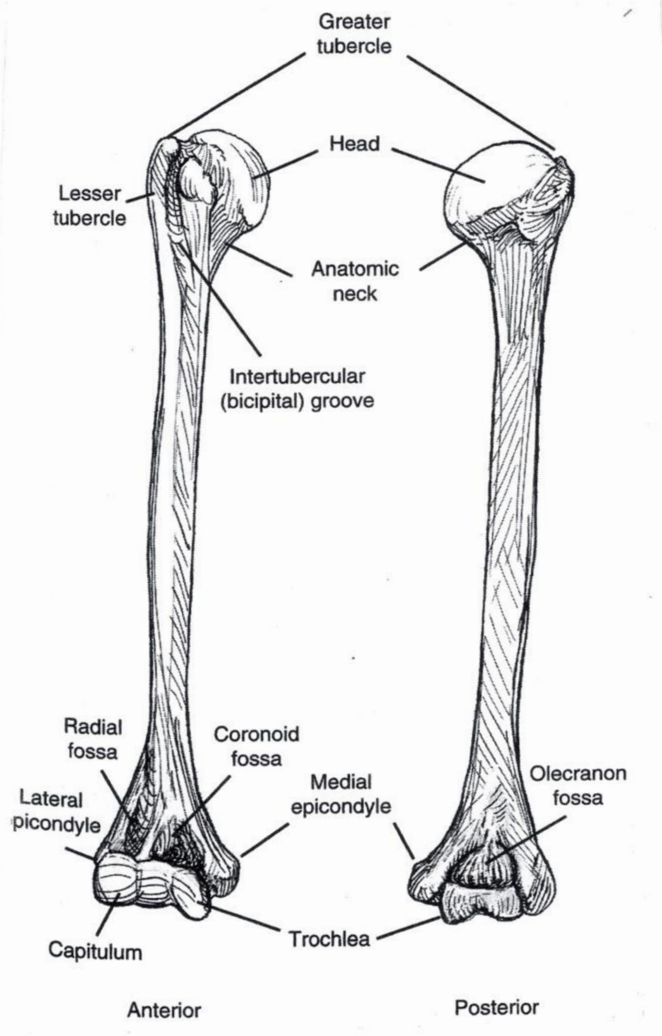


Fig. 1-9. Humerus, anterior and posterior views. From Greathouse. Delmar's Radiographic Positioning Volume 1, 1E © 1998 Delmar Learning, a part of Cengage Learning, Inc. Reproduced by permission. www.cengage.com/permissions.

The anatomic neck, directly below the head, serves as an attachment for the shoulder capsule. The surgical neck is lower than the anatomic neck and is frequently involved in fractures. The greater tuberosity, which is situated lateral to the head, serves as the attachment for the supraspinatus, infraspinatus, and teres minor muscles. The lesser tuberosity, located anteriorly, has only one muscular insertion. Distally, the humerus flares into medial and lateral epicondlyes and forms half of the elbow joint with a medial spool-shaped trochlea. The trochea articulates with the olecranon of the ulna.

There are four major nerves that traverse the arm with the brachial artery and its bifurcations into the radial and ulnar arteries serving the extremity.

Shoulder Girdle

The shoulder (i.e., glenohumeral) joint is the attachment of the upper humerus to the shoulder girdle. The scapula spans the second through the seventh ribs and serves as an attachment for seventeen muscles and four ligaments. The scapula forms the posterior part of the shoulder girdle and is a flat triangular bone with three borders, three angles, and two surfaces. The three corners of the triangular shaped bone are called angles. The lateral angle is the thickest part and ends laterally in a shallow depression called the glenoid cavity or fossa. The humeral head articulates with the glenoid cavity of the scapula to form the scapulohumeral joint or shoulder joint. The constricted area between the head and the body is called the neck. The acromion is a long curved process extending laterally over the head of the humerus. The coracoid process is the thick, beak-like process projecting anteriorly beneath the clavicle.

The scapula has several processes that include the scapular spine, coracoid, and acromion. Attachments to the coracoid process include the coracoacromial ligament, coracoclavicular ligaments, conjoined tendon, and pectoralis minor. The suprascapular notch has the superior transverse scapular ligament separating the suprascapular artery from the suprascapular nerve.

The shoulder area has one major articulation and several minor articulations. The glenohumeral articulation is a spheroidal (ball-and-socket) joint and has the greatest range of motion of any joint. The shoulder joint motion is at the expense of stability because there are static and dynamic restraints of shoulder motion. The static restraints include the articular anatomy, glenoid labrum, capsule, and ligaments. The dynamic restraints include the rotator cuff, biceps tendon, and scapulothoracic motion.

The acromioclavicular articulation is a plane/gliding type joint containing a fibrocartilaginous disc. The ligaments of the joint prevent anteroposterior displacement of the distal clavicle. The scapulothoracic joint is not a true joint but allows scapular movement against the posterior rib cage. The muscles connecting the upper limb to the vertebral column include the trapezius, latissimus, both rhomboids, and levator scapulae. The muscles connecting the upper limb to the thoracic wall include the pectoralis muscles, subclavius, and serratus anterior. Muscles acting on the shoulder joint itself are the deltoid, teres major, and four rotator cuff muscles. The rotator cuff muscles depress and stabilize the humeral head against the glenoid. The greater tuberosity of the humerus serves as an attachment for three of the rotator cuff muscles. The subclavian artery arises either directly from the aorta or from the brachicephalic trunk and then emerges between the scalenus anterior and medius muscles and becomes the axillary artery at the outer border of the first rib. The axillary artery branches off into 3 main portions. The brachial plexus nerves (i.e., and its branches) serves the upper extremity.

Clavicle

The clavicle is a long bone having a double curvature, an acromial end, and a sternal end. The lateral end or acromial end of the clavicle articulates with the acromion of the scapula and forms an articulation called the acromioclavicular joint. The medial or sternal end of the clavicle ends in an articulation called the sternoclavicular joint and has an important positioning landmark called the jugular notch. In females, the clavicle is usually shorter and less curved than the clavicle in males, which is due to the variance in muscle mass between females and males. Because of the curve of the clavicle, an anteroposterior (AP) with no tube angle and an AP axial with a 15 to 30 degree cephalic x-ray tube angle may be requested. Posteroanterior (AP) axial projections may also be taken but would require a 15 to 20 degree caudal angle on the x-ray tube.

Overview of Anatomy of the Lower Limb

The lower extremity includes the foot, ankle, leg, knee, femur, and hip, Figure 1-10 below.

The Foot

There are 26 bones of the foot. These consist of seven tarsal bones, five metatarsals, and fourteen phalanges. The foot is divided into the hindfoot (the talus and calcaneus), midfoot (the navicular, cuboid, and three cuneiform bones), and forefoot (the metatarsals and phalanges). The most distal bones of the foot are the phalanges also referred to as the toes or digits.

Anatomic Area	**Number of bones per extremity**
Foot (phalanges, metacarpals, carpals)	26
Phalanges (toes or digits)	14
Metatarsals (instep)	5
Tarsals (ankle)	7
Leg (tibia and fibula)	2
Ankle joint	
Knee joint	
Femur	1

Fig. 1-10. Anatomic areas of the lower extremity.

The five digits of each foot are numbered one through five starting with the big toe located on the medial aspect of the foot. The large toe or first digit has only two phalanges, which is similar to that of the thumb with a proximal and distal phalanx. The second through fifth digits have a proximal, middle, and distal phalanx. The phalanges in the foot are smaller than those of the hand and have limited movement, Figure 1-11.

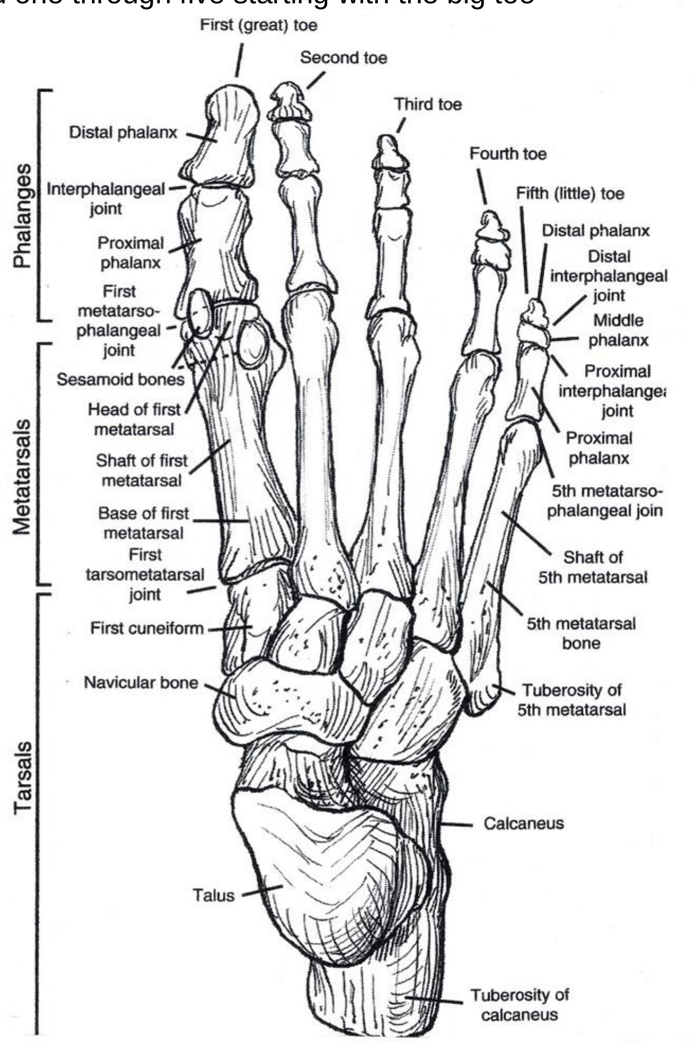


Fig. 1-11. Foot, superior aspect. From Greathouse. Delmar's Radiographic Positioning Volume 1, 1E © 1998 Delmar Learning, a part of Cengage Learning, Inc. Reproduced by permission. www.cengage.com/permissions.

The arch or instep of the foot consists of metatarsal bones. The metatarsals are five bones that number from a medial to lateral direction and span the distance between the tarsal bones and phalanges, Figure 1-12.

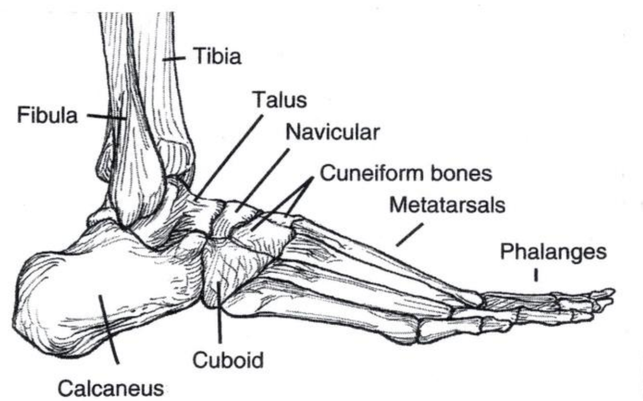


Fig. 1-12. Foot,lateral aspect. From Greathouse. Delmar's Radiographic Positioning Volume 1, 1E © 1998 Delmar Learning, a part of Cengage Learning, Inc. Reproduced by permission. www.cengage.com/permissions.

Each metatarsal is composed of three parts, the head, body, and base. The joints are named from the two bones on either side of that joint. The second through fifth digits have three bones and two joints. The joint between the middle and distal phalanges is called the distal interphalangeal joint (DIP) and the joint between the proximal and middle phalanges is referred to as the proximal interphalangeal joint (PIP) joint. Each joint at the head of the metatarsal is referred to as a metatarsophalangeal (MP) joint. The joint at the metatarsal base is a called the tarsometatarsal joint (TM) joint. When describing joints of the foot, it is important to state the name of the joint first, then include which digit or metatarsal and specify either right or left.

The joints of the phalanges and metatarsals are important since fractures may occur at the joint surface. The proximal area of the fifth metatarsal is a common site for injury. The first metatarsal bears approximately one third of the body's weight. Stress fracture of the second metatarsal is the most common. Fracture of the fifth metatarsal represents a unique subset of forefoot injuries, often referred to as "Jones fractures". The second through fifth metatarsals have two ossification centers: a primary center in the shaft and a secondary center for the head, which appears from five to eight years of age. The phalanges and first metatarsal have secondary centers of ossification at their bases that appear during the third or fourth year proximally and distally during the sixth or seventh years of life.

The tarsals are a network of bones that includes the talus, calcaneus, cuboid, navicular, and three cuneiform. There are seven tarsal bones. Figure 1-13 illustrates the memory mnemonic for the tarsal bones: *Come to Columbus (the) Next (three) Christmases*. Each tarsal bone has a single ossification center except for the calcaneus, which has a secondary ossification center located posteriorly. The calcaneus, talus and usually the cuboid are present at birth. The lateral cuneiform appears during the first year of life; and the medial cuneiform appears during the second year of life and the intermediate cuneiform and navicular during the third year of life.

Memory Mnemonic	**Tarsal & Tidbits**
C **Come**	**Calcaneus (Os Calcis)** The largest bone of the foot. The Calcaneus articulates with the cuboid and the talus anteriorly and the talus superiorly. The calcaneus and the talus form the subtalar or talocalcaneal joint.
T **To**	**Talus (Astragalus)** Second largest tarsal bone located between lower leg and calcaneus. The weight of the body is transmitted through this bone via the ankle and talocalcaneal joint.
C **Columbus**	**Cuboid** Located on the lateral aspect of the foot, distal to calcaneus and proximal to 4^{th} & 5^{th} metatarsals. The cuboid articulates with 4 bones, calcaneus, lateral cuneiform, and 4^{th} & 5^{th} metatarsals.
N **Next**	**Navicular** A flattened, oval shaped bone on medial side of foot between talus & 3 cuneiform.
C **Christmases**	**Cuneiform** Three wedge shaped bones on the medial & mid aspects of the foot

Fig.1-13. **A memory mnemonic for the tarsal bones is Come to Columbus (the) Next (three) Christmases**

The talus articulates with the tibia and fibula in the ankle mortise and with the calcaneus and navicular distally. The talus is made up of a body that is wider anteriorly with three articular surfaces (the trochlea and posterior and middle calcaneal facets) and a posterior process (the posterior tabofibular ligaments). The neck of the talus connects with the head, which articulates with the navicular distally and the calcaneus inferiorly. The talus has no muscular attachments but has a groove posteriorly for the flexor hallucis longus (FHL) tendon. Two-thirds of the talus is covered with cartilage served by the posterior tibial artery and other accessory vessels.

The calcaneus is the largest and strongest bone of the foot, having three surfaces that articulate with the talus. The distal aspect of the calcaneus has an articular surface that receives the cuboid bone. The cuboid bone located on the lateral aspect of the foot and has a grooved plantar surface for articulation with the calcaneus, the lateral cuneiform, and the fourth and fifth metatarsals.

The navicular is the most medial tarsal bone and lies between the talus and the cuneiforms. The cuneiforms are three bones (medial, intermediate, and lateral) that articulate with the navicular and posterior cuboid (lateral cuneiform) and the first three metatarsals. Injuries to the cuboid are often associated with other midfoot or Lisfranc fractures/dislocations.

The bones of the foot are arranged in longitudinal and transverse arches, which provide a strong, shock absorbing support for the weight of the body. The arrangement of muscles and tendons in the foot are best described as layers. The nerves of the ankle and foot are the branches of the proximal nerves. The two main arteries that supply the ankle and foot are the dorsalis pedis artery, a continuation of the anterior tibial artery of the leg, and the posterior tibial artery. Sesamoid bones are small-detached bones commonly found in the feet and hands. These are extra bones embedded in tendons and usually near a joint.

Ankle Joint

Three bones form the ankle joint: two long bones of the lower leg, the tibia and fibula, and one tarsal bone, the talus. The lateral malleolus is the expanded distal end of the fibula and the medial malleolus is the elongated process of the tibia. The inferior portions of the tibia and fibula form a deep socket or three-sided opening called a mortise into which the upper talus fits. The ankle is a synovial hinge type joint having flexion and extension movements only. Lateral stress on the joint can result in a sprained ankle with stretched or torn collateral ligaments.

Leg (Tibia and Fibula)

The leg consists of the tibia and the fibula. The tibia is a large bone having weight bearing capacity. It can easily be felt through the skin on the anteromedial part of the leg. The tibia articulates with the distal femur by means of proximal medial facet (oval and concave) and lateral facet (circular and convex). The tibial shaft is triangular and tapers to its thinnest point at the junction of the middle and distal thirds before widening again to form the tibial plafond. Distally, the tibia's quadrilaterals provide a surface for articulation with the talus and the pyramid-shaped medial malleolus. The proximal end of the tibia has two large processes called the medial and lateral condyles. The intercondylar eminence, often called the tibial spine, includes two small pointed prominences, the medial and lateral intercondylar tubercles. The tibial tuberosity is located on the proximal end of the tibia and has a rough textured prominence, which provides for attachments of the patellar tendon and the large muscle of the anterior thigh. Osgood-Schlatter's disease is an inflammatory condition of the tibial tuberosity.

The fibula is the smaller of the two leg bones and is located laterally and posteriorly to the larger tibia. The fibula articulates with the tibia proximally. The enlarged distal end of the fibula has a bump on the lateral aspect of the ankle joint and is called the lateral malleolus. The styloid process of the fibular head serves as the attachment for the fibular collateral ligament and the biceps tendon. A groove just below the fibula head provides space for the peroneal nerve. The expanded distal fibular is referred to as the lateral malleolus and extends beyond the distal margin of the medial malleolus. Together with the inferior distal surface of the tibia, these structures comprise the ankle mortise.

Knee Joint

The knee is a compound joint consisting of two condyloid joints and one sellar joint (i.e., the patellofemoral articulation), Figure 1-14.

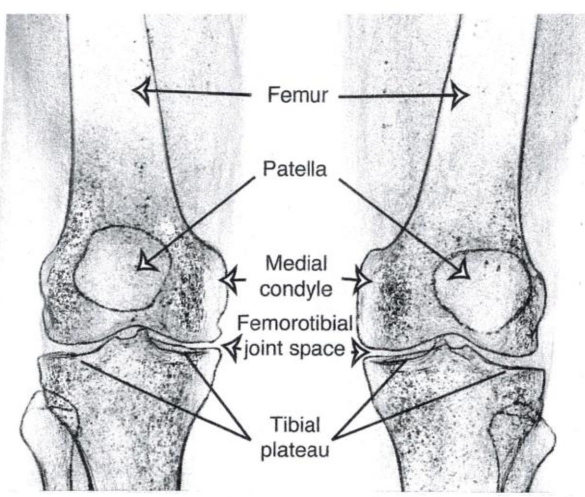


Fig. 1-14. AP, weight-bearing knee. From Greathouse. Delmar's Radiographic Positioning Volume 1, 1E © 1998 Delmar Learning, a part of Cengage Learning, Inc. Reproduced by permission. www.cengage.com/permissions.

The joint cavity of the knee is the largest joint space in the human body. The knee is a synovial type joint, which is enclosed in a capsule that has posteromedial and posterolateral recesses extending 15 millimeters (mm) distal to the subchondral surface of the tibial plateau. The medial and lateral femoral condyles articulate with the corresponding tibia facets.

Intervening menisci serve to deepen the concavity of the facets, help protect the articular surface, and assist in rotation of the knee. The medial and lateral menisci are fibrocartilage discs between the articular facets of the tibia and the femoral condyles and serve as shock absorbers for direct impact to the knee joint. The medial meniscus tears three times more often than the more mobile lateral meniscus. The lateral meniscus is also associated with meniscal cysts and the dicoid menisci are the frequent site of tears in acute injuries to the anterior cruciate ligament (ACL).

The patella is the largest sesamoid bone in the human body and serves three functions. It is a fulcrum for the quadriceps, protects the knee joint, and enhances lubrication of the knee. The stability of the knee is enhanced by a complex arrangement of ligaments. The cruciate ligaments are crucial to anteroposterior stability and the collateral ligaments provide varus/valgus stability. Each cruciate ligament is made up of two bundles. The anterior bundle of the ACL and posterior cruciate ligament (PCL) is tight in flexion. The PCL has an anterolateral portion that is tight in flexion and a posteromedial portion that is tight in extension.

Several muscles and tendons traverse the knee, giving it dynamic stability. The muscles of the leg are divided into groups based on compartments. The posterior compartments are supplied by the tibial nerve and contain preaxial muscles. The anterior and lateral compartments are supplied by the common peroneal nerve and contain postaxial muscles. The gastrocnemius muscles, semi-membranousus, and biceps border the popliteal fossa. The branches of the popliteal artery (i.e., the continuation of the femoral artery) supply the leg.

Femur

The femur is the longest and strongest bone in the entire body and its anatomic boundaries includes the knee and hip joint. The patella has a depression called the intercondylar sulcus. The distal femur has two large rounded condyles that are joined anteriorly but separated distally and posteriorly by a deep intercondylar fossa or notch. The area behind the knee joint is called the popliteal region. The centers of ossification in the femur are the head and distal portions. The muscles of the thigh are classified as anterior, medial and posterior.

Hip

The hip is a ball-and-socket, diarthrodial type joint. The inferior surface of the ilium contains the acetabular notch and is deepened by the fibrocartilaginous labrum. The primary muscles of the hip joint are the iliopsoas, rectur femoris, and sartorius. The hip extensor muscles are the gluteus maximus and hamstrings. Hip abduction results from the actions of the gluteus medius and minimus.

Chapter 2 Patient Care and Management

"Never go to a doctor whose office plants have died"
Erma Bombeck

Introduction

Radiographers are encouraged to adopt a customer-focused approach to imaging procedures to increase patient satisfaction. The services provided by radiographers and staff and the overall environment of a medical facility often determines a patient's (i.e., the customer), perception about quality of care. This perception, whether true or not, determines if the patient will return to use a facility's services and what kind of recommendations they will make to others.[1]

Establishing a positive relationship with the patient from the moment they enter the facility until they depart is very important. This requires that the staff projects a cheerful, positive reception and that the patient be informed as they progress through the imaging examination. For example, if there has been an unexpected delay that requires the patient to wait longer than expected, a simple explanation from the radiographer goes a long way in showing courtesy and placing value on the patient's time.

Patient advocacy involves treating patients as individuals, protecting their dignity and privacy, and respecting their choices.[2] Radiographers perform advocacy duties when they ensure that proper radiation protection is used during every imaging examination and that established quality control procedures are used consistently. Consistent implementation of effective quality control measures improves image quality and allows the clinician to accurately diagnose and deliver appropriate treatment in a timely manner.

As a representative of the medical facility, a radiographer has less than 30 seconds to make a good impression when the patient arrives.[3] It is important for radiographers to understand that the patient is a consumer of services and that they are customers. The five most important needs of patients, as customers of health care services, are reliability, responsiveness, assurance, empathy, and tangibles.[3] Reliability means that patients receive what has been promised to them. For health care institutions to remain in business they must be viewed as reliable or else patients will go elsewhere for care. Responsive service is delivered when radiographers promptly respond to patients' questions or requests.

In addition to providing reliable and responsive attention, radiographers must provide services that are delivered in such a manner as to assure the customer that everything will be all right while they are receiving care. This equates to a safe, non-threatening environment. Patients also want services delivered by providers who give care and services in an empathetic manner. Tangible expectations include such things as an attractive and hygienic environment and fully functioning and well-maintained equipment.

During any given day, radiographers provide care to a number of patients, each with specific and unique imaging examination needs. To complete the imaging examination, the radiographer may need to provide assistance to the patient in meeting general as well as personal needs. The radiographer must remember that a person's sense of belonging and feelings of well-being, security and self-control may be compromised because of illness and trauma. Radiographers can show concern by such simple things as being friendly and courteous. The following are suggestions that radiographers may be able to use when relating to patients.

Showing concern

The radiographer should provide a welcome environment and should not hurry the patient or appear rushed to get to the next patient. Caring is demonstrated when the radiographer listens to, provides information for, helps, communicates with, shows respect towards, touches, and protects the patient.[4]

Showing respect

The radiographer can show respect to others by creating a welcoming "we care" environment in the imaging area. All sexes, races, religions, and socioeconomic levels are represented in any patient population. Respect can be verbalized in the way one talks to patients; such interactions may be communicated by the choice of words and the body language used by the radiographer. Adopting the motto "treat others as you would want to be treated" is helpful in showing respect. Treating all patients equally is a very critical aspect of every examination. Children are people too and should be given every courtesy afforded adults. The radiographer should react and respond in a professional manner to what is observed and heard while providing care.

Cultural Diversity

A person's needs and perceptions can influence the outcome of relationships and communications in the medical environment. Radiographers must often overcome patients' preconceived ideas about the medical environment and overcome a patient's bad experience with prior healthcare providers. The patient's cooperation is vital to a successful outcome and generally necessary to produce images possessing diagnostic value. To reach this goal, radiographers must communicate effectively to patients and staff.

Radiographers, co-workers, and patients represent a diverse population from a variety of cultures, religions, races, and ethnic characteristics. Cultural differences can become barriers when they are not acknowledged and adaptations made to respect them. Such differences can interfere with the patient's ability or willingness to help and this may lead to inaccurate images and medical errors.[5, 6]

Recognizing other accepted cultural differences such as body language, facial gestures, and attire are also important for incorporating cultural diversity equality into everyday action. In certain societies it is considered disrespectful to look directly into the eyes of the other person during a conversation. Also in some cultures, repeated head nods may indicate respect rather than agreement with what is being said. Pointing directly at an individual may be considered an insult in some cultures as well as invading a person's space by standing too close.

Clothing or adornment is often based on cultural and ethnic traditions. In some societies, women must keep their bodies completely covered with clothing, allowing only the eyes to be seen. Yet, in other societies, it is acceptable to wear revealing clothing. These traditions may influence a person's need for privacy and their willingness to disrobe for imaging procedures.

Touching is another act that may be different among cultures. The radiographer needs to be aware that in some cultures touching of any kind is an intimate act and the patients may find any touching offensive. To avoid unintentionally offending a patient during positioning, the radiographer should tell the patient in advance what they are about to do.

Everyone harbors reactions, habits, and traditions common to their ethnic and socioeconomic background. Radiographers are no exception and these personal feelings are sometimes difficult to ignore; however, radiographers must not let personal feelings affect the care they deliver.[5,6] Every society has written and unwritten codes of conduct that govern everyday life. For effective communication and cooperation to occur between the radiographer and others, these differences should not become barriers. Radiographers should be aware of these differences, acknowledge them, and respect others when providing imaging services. Awareness, acknowledgment, and respect does not imply personal acceptance (i.e., certain cultural, religious, political beliefs) but represents professional acceptance so that effective communication can occur during imaging examinations.[5,6]

Language differences pose a substantial risk for miscommunication between the radiographer and the patient. Large hospitals and clinics may employ an interpreter or arrange for one as needed. In areas of the U.S. where languages other than English are used, signs may be posted in the most common languages advising patients of the availability of interpreters. English speaking family members, friends, or an advocate may accompany some non-English speaking patients. Radiographers should be aware that there is a subtle difference between a family interpreter and a certified interpreter. A certified interpreter is trained to translate only what has been said, both by the patient and healthcare provider. A non-certified interpreter may attempt to explain or edit the information. Also, a non-certified interpreter who is a family member or a close friend may be tempted to add their own observations to the conversation.

Some suggestions for effectively communicating through an interpreter include:

- Look directly at the patient and speak as though the patient were able to understand;
- After speaking, allow the interpreter to translate what has just been said; and,
- Use available telephone translation services through various telephone communication companies.

Radiographers may want to develop their own tool kit to effectively communicate with non-English speaking patients. A tool kit may contain flash cards in the most common languages, which will help the radiographer communicate simple words and phrases. The flash cards may contain such phrases as “Please hold very still”, “Please get on the table”, “Please hold your breath” and “Point to where it hurts”. The tool kit may also contain sketches that show the non-English speaking patient how they need to stand, sit, or recline on the radiographic table and may also be helpful in communicating what needs to happen to prepare for the examination.

Communication with patients who have low literacy levels may also interfere with providing imaging services. Radiographers should carefully screen patients for their literacy level before just handing them written instructions. Radiographers can usually detect if the patient experiences difficulties in grasping or retaining information by eliciting patient feedback. By verifying the patient's comprehension of the information presented, the radiographer can improve communications with those who have low literacy levels.

The Medical Record

Results from clinical examinations, imaging procedures and prescribed treatment for bone injuries and diseases require accurate documentation and often inter-communication between several medical specialties. The medical record, health record, or medical chart is a systematic documentation of a patient's medical history and care.[7] Medical records are uniquely personal documents and there are many ethical and legal issues surrounding them, such as who has access to them and the proper storage and disposal of the records.[8] The medical record allows communication among health care providers and contains critical evidence of the type and quality of care provided to the patient.[8] The three most recognized reasons for the medical record are:

- To document the patient's diagnosis, treatment and progress of the patient;
- For business purposes and financial documentation; and,
- For use as a legal document.

According to a recent article in *Mayo Clinic Women's HealthSource,* electronic personal health records are likely to replace handwritten notes.[9] The U.S. President has stated that he will make electronic medical records a priority.[9] One of the major roadblocks is finding the right technology to handle the transition to paperless medical records. Among the many challenges are the storing, accessing, and updating of records so that the patient's privacy is maintained yet the information is accessible across a wide network of medical providers.

The medical record serves as the basis of the quality and timeliness of the care provided to the patient. The record also serves as a legal document and is often cited in malpractice litigation. In the first two-thirds of the 20th century, the most common reasons for malpractice were negligent acts of commission (i.e., physicians did something wrong).[10] Medical care providers were often charged with the failure to order imaging studies in a timely manner. The litigation involved what is referred to as "omission of care." Defensive medicine, in which medical care providers ordered tests and procedures that were not indicated medically, but if absent might render the physician vulnerable in malpractice litigation, became the norm.[11] The annual cost to the nation for defensive medicine has been estimated to range from $25 billion to $126 billion.[10]

Radiologists are subject to litigation for "failure to diagnose" and "failure to follow-up" or failure to obtain additional diagnostic studies to clarify or confirm the impression when appropriate.[10] It is anticipated that as the sophistication of radiologic and nonradiologic procedures and tests continues to expand, the errors caused by physicians' omission in ordering or using this technology will increase.[10] Radiologists can expect to be increasingly sued not only for failure to recommend imaging tests, but also for failure to recommend other diagnostic procedures as well.[10] One may also speculate that in the not-so-distant future, radiologists will likely be subject to litigation for errors in omitting the use of technology that is not yet the standard of care, such as computer-assisted detection (CAD) and teleradiology to obtain expert consultations.[10] Conscientious review of the patient's medical history and clinical findings in conjunction with the imaging examination request is a first step in providing quality patient care, and hopefully reducing future litigation.

The radiographer plays a critical role in reviewing the patient's medical history and clinical symptoms prior to performing an imaging examination. The radiographer documents information in the patient's medical record and serves as a liaison between the patient and the radiologist. Radiologists have a duty to acquaint themselves with the pertinent clinical information concerning patients whose images they will be interpreting.

In many imaging centers, it is the radiographer who questions the patient and completes a preprinted questionnaire form.[11] If this is the procedure used, the radiographer should have the patient or their advocate review, sign, and date the questionnaire form. Risk management experts recommend that a written form on which the patient must provide (i.e., write) pertinent clinical information is the most reliable source document.[10,11] Although it is acceptable practice for the radiographer to complete the information on the questionnaire form, there may be less likelihood of misunderstanding if the patient herself/himself fills out the form.[10] The radiographer can then go over the completed form and obtain additional verbal confirmation from the patient. If the patient fills out the form, the radiographer should document that the completed questionnaire was reviewed and the answers confirmed by the patient. Such notations in the record should be signed and dated.

A system that ensures that every patient undergoing imaging procedures provides a complete medical history, possible symptoms, and clinical signs is critical to obtaining high quality images. Risk management experts also suggest that the questionnaire form have a question about the patient's understanding of why she/he is having the imaging procedure. By asking these pertinent questions, the radiographer is able to determine if the imaging request properly matches the patient's clinical signs and symptoms. When taking the patient's medical history or confirming what the patient has written, the radiographer should be able to use the information about risk factors, and the "red-flag" indicators or disease processes to further question the patient.

Communication & Examination Preparation

Communication between radiography staff and the patient is vital for ensuring the successful outcome of imaging procedures. Also, radiographers have a professional and ethical obligation to accurately explain radiation protection principles to patients and the public so that the risks and benefits of using ionizing radiation in medical imaging can be understood. The American Society of Radiologic Technologists (ASRT) refers to the radiographer's responsibility to educate in Practice Standard 3, which states that the "…radiographer educates the patient, public, and other health care providers about procedures, along with the biological effects of radiation, sound waves, or magnetic fields, and protection."[12] Patients present for imaging procedures with various levels of apprehension and knowledge, or lack thereof. Patients have the right to know the details of their imaging procedure, and have the legal right to be informed about the potential risks and benefits. Most facilities providing diagnostic imaging services will require that the patient or his/her legal guardian complete an informed consent form. Patients have a right to know about the imaging procedure, and if adequately informed may be more at ease and cooperative. If the imaging procedure requires that the patient disrobe, clear directions and privacy are important. Retake examinations often result when the patient has not properly disrobed, or has failed to remove jewelry, zippers, hairpins, etc. Any radiopaque object in the area of interest can compromise the diagnostic quality of the images. One common area of miscommunication occurs when patients are asked to undress and remove jewelry. For various reasons, the patient may not have heard or even understood the full intent of this request. To prevent retakes, the radiographer should double-check before the imaging examination begins to confirm that the patient followed all disrobing directions.

The Geriatric Patient

Advances in medicine have led to the eradication of many contagious diseases. The strides that have been made in early detection and treatment of disease have resulted in increased longevity. Life expectancy in 1900 for women was age 48 and for men was age 46.[12] Today, the life expectancy for women is age 79 and for men age 72.[12] The "boomers" are coming of age and are expected to change the demographic landscape of the U.S. Beginning in 2011 boomers will turn 65 at a rate of 8,000 a day. Because of this rapid rise in the geriatric population new fields of medicine are emerging and hospitals and medical care facilities are opening specialty clinics that will serve patients age 65 and over.[12]

Gerontology is the study of all aspects of aging and geriatric medicine deals with diseases and medical problems of aging. A distinct difference between the two is that geriatric medical care providers actually deliver care to the elderly population.
Elderly patients have special needs that require different care than younger patients. Radiographers should be aware of the biological changes that accompany aging and use that knowledge to adapt the imaging routines as necessary. Although there are individual variations in the aging process, there are predictable chronic and acute medical conditions that require radiography examinations.[14] The radiographer should be aware that in the elderly population, the patient's chief complaint or primary diagnosis indicates only one of many potential medical complications. It is the radiographer's responsibility to assess each patient's cognitive and physical ability prior to beginning an imaging examination. A few of the biologic changes that accompany aging include:

- Decreased depth perception that may cause a loss of judgment when stepping on and off the examination or radiography table;
- Visual loss may impair the older patient's ability to navigate between the examination room and the dressing room or bathroom. Visual loss may also interfere with the older patient's ability to read examination instructions and to complete medical information questionnaires;
- Hearing loss may interfere with the older patient's ability to hear instructions. This is particularly evident when the older person is unable to follow breathing or motion control instructions;

- A decrease in muscle mass results in poor mobility and poor balance. The older patient is also more likely to suffer from osteopenia and osteoporosis making them more susceptible to bone fractures; and,
- A decrease in fat pads can make it more painful for an older patient to lie on the examination table. Also, the older patient may have fragile skin, which is more susceptible to cuts and scrapes during the imaging examination. Care should be taken when moving or assisting the older patient to avoid skin injuries.[14]

On a pyschosocial level the older patient is more likely to have concerns and fears about death. The radiographer may feel uncomfortable when talking about death or even attending to the dying patient. It has been suggested that radiographers should seek out information on the topic of death.[14] Exploring one's feelings about death is a first step in being able to provide quality care to older patients.

The radiographer may also harbor ideas about older patients as being weak, incompetent, and mentally unstable. The general cultural attitude in the U.S. is directed toward youth and retaining a youthful appearance and agility, which is not always realistic considering the biologic changes that accompany aging and the changes resulting from certain diseases, illnesses, and medical treatments. As with the topic of death, everyone who provides health care should be knowledgeable about the biologic changes that accompany aging but should also learn as much about the aging process as possible. After all, everyone ages, and this reality should prompt the radiographer to learn as much about the aging process as possible in order to be able to provide quality patient care.

One of the most important aspects of dealing with the older patient is communication. When the radiographer calls the patient by name, smiling, and having a brief conversation, it helps to create a welcoming environment. This also allows the radiographer to determine the patient's ability to hear and comprehend information about the imaging examination. The elderly often exhibit reduced strength and endurance, which results in increased risk of injury. To accommodate the needs of the older patient, the radiographer should walk through the facility and evaluate each area including the waiting or reception area, dressing room, bathroom, and imaging suite. In performing the evaluation, the radiographer should consider each area from the older patient's perspective. For example are there signs that direct the patient in case they should become disoriented? Is the signage legible, accessible, consistent, bilingual and in

Braille? Is the facility well-lit and free of clutter that may cause an accident? Are there places for patients to stop and rest, or to call for help in long stretches of hallways? The following are suggestions that radiographers may be able to use when working with older patients.

- Clear the imaging room of all unnecessary items. Provide a chair or stool for the patient. Providing a place for the patient to sit helps to reduce the patient's muscle fatigue and the likelihood they will become weak, dizzy, and fall.
- Simplify the imaging routine by preparing the room and obtaining all necessary supplies prior to requiring the patient to move into the required radiography position(s).
- When assisting the patient to change positions, provide time to allow for the patient's blood pressure to stabilize. This is very important when assisting the patient from a recumbent to an upright position.
- Provide shoe covers with a non-slip surface or provide slip-on socks with rubberized soles.
- Provide gowns with front-closure openings.
- If tape is necessary for immobilization, use low-stick tape instead of adhesive tape to prevent skin tears.
- Provide a blanket or a wrap for patients. Because of reduced body fat and poor circulation, the older patient may be cold even though the room is at a normal warm temperature.

The older patient often requires special accommodations during the preliminary stages of an imaging examination. The radiographer should keep in mind that the anatomy requested should appear on the final image, while considering the limitations imposed by the musculoskeletal structures of the older patient. For example, radiography examinations of the fingers, hands, wrists, elbows, and distal humerus may be obtained without moving the patient from a chair or requiring the patient to stretch over the end of the imaging table. Some facilities may have an image receptor support, such as a lightweight piece of wood or plexiglass that can rest on the arms of the wheelchair. This provides an ideal method of obtaining upper extremity images when the patient is wheelchair bound.

A similar type of image receptor support bench can be used to obtain radiography images of the toes, feet, ankles, lower legs, knees and the distal femur.

The image receptor (IR) can also be placed on a footrest; foot stool or even on the floor to obtain radiography images of the lower extremity of a patient confined to a wheelchair. There are several radiography findings that are consistent with aging, chronic pathology, and the lifestyle choices of many elderly patients. In chest radiography of the elderly, the images may be expected to have calcifications of the great vessels. Radiography images may also demonstrate cardiomegaly, chronic obstructive pulmonary disease (COPD), a pacemaker or other evidence of previous cardiac surgery. In radiography images of the spine and pelvis, compression fractures, osteoporosis and osteoarthritis are likely to be evident. Extremity radiography images of geriatric patients are likely to exhibit evidence of gout, osteoporosis, rheumatoid arthritis, and degenerative joint disease.

The Patient with Dementia or Alzheimer's Disease

More than 4 million Americans are affected by some form of dementia or have a confirmed diagnosis of Alzheimer's disease (AD).[16] Obtaining diagnostic quality radiographic images of the Alzheimer's patient can be challenging. Patients with any form of dementia may have difficulty following directions. They may forget what was asked of them before they can follow the radiographer's directions.

The Alzheimer's Association has identified communication difficulties in each of recognized stages of the disease and the information can be applied to anyone presenting with the symptoms of dementia.[16] Individuals in the early stages of Alzheimer's, may have trouble finding the right word, most often a noun, or understanding abstract ideas, such as "a stitch in time saves nine."[16] Those afflicted have diminished cognitive and language processing skills as their disease progresses. The degree to which people realize that they have memory problems varies greatly from person to person. Some people forget that they are forgetting, while others are extremely aware of their cognitive losses and become depressed.

In the second stage of Alzheimer's disease, the loss of communication skills becomes more pronounced. In this stage, the individual may forget what they are talking about in the middle of a sentence. They may ask the same question several times, mixing up words, and speak in an unorganized, garbled way. The third stage of the disease is often recognized when the individual no longer utters words, except when answering direct questions. In the final stage of Alzheimer's disease, the affected individual rarely speaks.

People with dementia often become fearful and show signs of distress when confronted with unfamiliar surroundings. The radiography-imaging environment poses such a threat because the size of the equipment may appear as a monstrous beast. The radiographer should remember that individuals with dementia are adults who simply have severe memory problems. Radiographers may be able to apply the following information when attempting to obtain quality radiography images on patients with a memory disability.

Respect is the first rule in initiating communication with patients during radiography examinations. During the initial introductions, the radiographer respects the individual when using appropriate courtesy titles such as Mr. or Mrs. or a professional title. The radiographer should realize that repeating directions is necessary when the individual has dementia or some type of memory disorder. The first introduction sets the stage, as the radiographer states, who they are and what they intend to do. The radiographer's tone of voice and body language often communicate more to someone with dementia than the actual words can convey. Individuals with dementia have a short-term memory that may last no longer than 1 to 3 minutes without any distractions or interruptions. The radiographer can create a non-threatening environment by using a calm and easy going manner when having to repeat directions or questions to affected individuals. The radiographer should expect to have to reintroduce him or herself and remind the patient about what is happening. Using short sentences that convey one thought at a time and waiting for an answer before asking the next question is essential to communicating with someone with dementia or memory impairment. Communication skills used with the dementia patient are similar to those used when imaging children.

The Pediatric Patient

Children may associate doctors and hospitals with pain and discomfort; so the radiographer's first task when approaching a child is to create an atmosphere of trust and safety. Being honest and telling the child that you are only going to take a "picture" and that it will not hurt is an important part of the initial introduction. Some specific ways to develop trust include:

- Use a demonstration doll or animal to show what will happen and how the exam will take place.
- Have an arsenal of funny items to wear when taking radiographs of children. Floppy hats and colorful jackets may help to avoid a child's "white coat" fear.

- Toys that are appropriate and can withstand regular cleaning also help to distract the child's attention. Also the radiographer may sing a familiar song and talk in a low, calm voice to assure the child.[17]

As always, the radiographer should be equipped with the accessory tools and skills necessary to accommodate pediatric radiography imaging examinations. Preparation for pediatric patients include having age appropriate immobilization devices ready if needed and generally attending to as many tasks as possible before bringing the pediatric patient into the imaging examination room.

Immobilization and sedation are two methods commonly used when performing radiography imaging examinations on young children. Immobilization is the preferred method since sedation involves risks. Sedation is more frequently used during CT and MR imaging examinations and in certain interventional procedures.

Immobilization of children poses many challenges to the radiographer. The most common challenge to the radiographer is responding to the parent or caregiver's reaction when they learn of or see their child restrained. Traditionally, immobilization of children has been managed with simple pieces of cloth to hold the child's arms and feet in place often referred to as "arm bands". Today commercially available immobilization devices such as the Papoose Board™, the Posi-Tot®, or the Pigg-O-Stat® are used.

The Imaging Routine

An organized approach to completing patient care tasks is critical to providing quality services. Most radiographers establish a personalized routine to avoid omitting an important step or steps. Each radiographer adapts the routine to fit the work area, the examination request, and the patient. The following is a brief review of the essential tasks performed in a basic radiography examination.

- Obtain the imaging request;
- Interpret what procedures/examinations need to be completed.
- Review the reason for the examination and any available patient history;
- Check for the patient's location and ambulatory status (walking, assistance with a walker, cane, crutches, wheelchair, stretcher, etc.). Also, the radiographer should check to determine whether there are any restrictions about the patient being in an upright position;
- Prepare the radiographic room.

- Clean the table and obtain a clean gown and linen.
- Obtain correct size and number of cassettes.
- Obtain necessary supplies, immobilization and positioning aids;
- Place the cassette or IR in the proper location with a correct identification marker;
- Select and pre-set exposure factors on the control console;
- Identify and transport the patient;
- Greet the patient and confirm their identity.
- Evaluate the patient's ability to cooperate and communicate.
- Provide instructions for disrobing and assist the patient as necessary. Check to determine that all radiopaque objects have been removed from the area to be evaluated.
- Review the patient's history; gather additional information as necessary, including pregnancy status.
- Explain the examination to the patient and ask for their cooperation during the examination.
- Perform the radiography imaging examination;
- Assist the patient into the initial position and determine approximate exposure factors. Note if adjustments in the exposure factors are required;
- Move the patient and/or part into final position.
- Place the central ray (CR) and x-ray tube into correct position;
- Collimate the primary beam and apply gonadal shielding, as appropriate;
- Make final adjustments to the technical exposure factors;
- Give the patient final breathing instructions and motion control directions;
- After the exposure, while still at the control console, make necessary adjustments to the exposure factors for the next image in the series;
- Return to the patient, exchange cassettes or IRs, reposition the patient and repeat the steps to complete all steps in the examination;
- Continue to talk to the patient about matters concerning the radiographic procedure;
- Observe all safety guidelines and standard precautions during transport and the imaging examination;
- Finish the procedure;
- Assist the patient from the examination table and to return to the waiting or discharge location or to the transport area;

- Process the images;
- Evaluate the finished radiographs or images;
- If appropriate, dismiss the patient; and,
- Complete all final tasks related to cleaning the examination room and forwarding the images for interpretation.

It is important for the radiographer to engage the patient in conversation during all aspects of the radiography examination. Appropriate conversation includes talking about the reasons for using immobilization and about the reason for breathing and motion control directions that will be given during the examination.

Ergonomics

Radiographers often suffer chronic aches and pains from lifting and positioning patients. Shoulder, wrist, and elbow injuries are common among radiographers who use their hands, arms, and shoulders in positioning the patient. Ergonomics is the study of the physiological and psychological relationship between the worker and the workplace, making for a healthier, safer environment.[19, 20] The following are simple tips that the radiographer may use to avoid musculoskeletal injury while using a computer or keyboard.

- If standing at a computer, keep one foot on the floor while placing the other on a box or shelf, and switch legs often. This reduces stress on the lower back; and,
- If sitting at the a computer, sit in a cushioned, comfortable chair, keeping your back straight, feet on the floor, keyboard at elbow level and the monitor at eye level.[19, 20]

Radiographers are at high risk for a variety of musculoskeletal injuries, especially injuries of the back, neck, and shoulder, when they repeatedly lift and move patients during imaging examinations. National surveys conducted to document healthcare worker safety concerning lifting patients is one of the most frequently mentioned causes of on-the-job-injury.[21] Many healthcare workers have indicated in various surveys that they were required to lift or move patients by themselves because of personnel shortages.[21] In radiology, the workers at the greatest risk of injury were radiographers who work in emergency care facilities, mobile radiography, and general radiography.[21]

On January 1, 2006, new legislation took effect in Texas that aims to protect nurses from the hazards of lifting and transferring patients.[22] Although radiographers are not mentioned in the Texas law, several states are considering similar legislation and this might be the first step toward expanding the lifting policies for all health care providers.[22] In the 1990s, the United Kingdom and Australia implemented safer patient-lifting laws, and the American Nurses Association has advocated eliminating manual patient handling since 2003.[22]

In 2003, several hospitals in Iowa implemented a minimal lifting policy.[22] After considering recommendations from a task force, the hospitals and clinics bought more than 600 pieces of new patient transfer equipment, including slides, belts, and overhead lifting systems. Staff members were trained to use the equipment and results were dramatic in reducing injuries. The Iowa facilities reported that the number of workdays lost to injuries decreased by 82% and workers' compensation costs dropped 85%.[22]

If this equipment is not available, an alternative is to have designated "lift teams" on staff.[22] The lift team staff are specially trained in safe patient-lifting and transfer techniques and are available on call throughout the facility.[22]

One of the keys to preventing back injuries is to strengthen the back and abdominal muscles. Stomach crunches are effective for strengthening the abdominal muscles. Also the pelvic tilt helps to strengthen the muscles used in moving, lifting, and positioning patients. Radiographers are advised to refer to an exercise manual for specifics about toning and strength building exercises.

Medical Errors

Easily preventable medical errors kill as many as 195,000 people per year in U.S. hospitals, according to a study by HealthGrades, Inc. and reported by Reuters.[23] The report identified approximately 1.14 million "patient safety incidents" among 37 million hospitalizations.[23] Preventing errors in the imaging arena requires that the radiographer is constantly vigilant and aware that Hippocrates said, "do no harm". To "do no harm", the radiographer can first check and recheck all the steps required to accomplish a specific imaging examination.

A major factor in limiting errors in imaging examinations is effective communication between radiographers, patients, and staff. Many examinations using specialty imaging modalities require staff to adhere to the Joint Commission's Universal Protocol for Preventing Wrong Site, Wrong Procedure, Wrong Person Surgery™ for procedures performed in non-operating room settings, including bedside procedures.[24] "Time-out" must be conducted in the location where the procedure will be done, just before starting the procedure.[24] The organization should have processes and systems in place for reconciling differences in staff responses during the "time out".[24]

It is the radiographer's responsibility to check and confirm each person's identity before proceeding with the imaging examination. The radiographer can also prevent errors in imaging examinations by following the established protocols and procedures for a particular medical facility. Individual patient circumstances often require that the radiographer adapts the routine procedure for a particular examination but any extreme variation should be explained in the examination documentation. In today's fast paced, competitive health industry, radiographers are increasingly required to assume greater workloads yet be efficient and effective. One should never become so overwhelmed that there is no time to check technical factors, patient positioning, or adhere to standard radiation safety measures. Although time is of the essence during imaging examinations, especially trauma care, the radiographer should remember that the time spent on "doing the work right, the first time", will more likely result in the production of diagnostic quality images. A simple yet effective way to limit errors in imaging examinations is to maintain communication between co-workers, patients, physicians, and all support staff. To summarize the importance of preventing errors in imaging examinations, the radiographer should:

- Review and check all paperwork related to a imaging examination just finished to determine that all documentation is complete before moving on to another patient;
- Concentrate on the task at hand by focusing on one patient at a time;
- Read each imaging request thoroughly before preparing for the imaging examination;
- Develop a routine approach to preparing for each imaging examination; and
- Review the images to determine if the required facility standards for quality have been met.

Obligations to Protect

The radiographer has moral, ethical, and legal obligations to protect the public, patients, co-workers, staff, and self from harm while in the service of providing imaging services. "From harm" is an all-encompassing concept that sometimes may seem overwhelming to the individual radiographer; however, when put into perspective, one realizes that he/she is part of a healthcare team, where each member shares a portion of the burden of safety. Radiographers are provided guidelines about safe practices, professional behavior, and the scope of imaging practice by the American Registry of

Radiologic Technologists (ARRT), American Society of Radiologic Technologists (ASRT), and American College of Radiology (ACR). All personnel must follow recognized universal practices when participating in or performing imaging examinations.[25]

The ACR has issued detailed universal practice guidelines that support personnel actions during imaging procedures.[25] The ultimate goal of the practice guidelines is to minimize radiation exposure to patients, staff, and the public while delivering high quality diagnostic images. Additional information about the ACR guidelines will be discussed in later chapters of this course.

Infection Control

Hospitals, clinics, doctor's offices, and other medical facilities provide services to many people. Infection control (i.e., the prevention of the spread of infectious conditions and diseases) is an important responsibility and goal for everyone. There are unlimited contacts for disease transmission and cross infection among the many people who enter a medical facility. Infection can spread from a single focal point or person of contamination to many other parts of the medical care chain and the general public. Nosocomial infections, often called opportunistic infections, are a group of disease causing organisms that are often drug resistant and extremely pathogenic organisms. These occur primarily in hospitals and medical care settings and result from infections in wounds and in the urinary and upper respiratory tracts.

Radiographers are responsible for preventing the spread of microorganisms to others and for protecting themselves from contamination. The total number of infectious organisms can be reduced or diluted to a harmless level by such tasks as hand washing before and after attending each patient, proper disposal of contaminated items, and routine cleaning of imaging equipment and accessories. Radiographers should also practice infection control and follow standard precautions at all times.

Medical Equipment

As has been mentioned previously, imaging examinations of musculoskeletal structures represents a major percentage of the daily workload in imaging facilities. Because of advances in medical care, the number of the very ill has greatly increased the reliance on mobile imaging at the patient's bedside. It is important for the radiographer to recognize common life support and other essential medical equipment that may be within the patient or somehow attached to the patient and must be dealt with during mobile bedside imaging examinations.

Tubes, lines, and catheters are essential in treatment of various conditions of the respiratory and circulatory systems. Most life-support devices are within the patient's heart, blood vessels, lungs or pleura. External apparatus such as tubing, clamps, and syringes often lie on or under the patient and the radiographer must use care when positioning the patient to ensure that these are excluded from the images. The patient may have ventilator support tubing, temperature and humidity sensors, or electrocardiogram electrodes and the radiographer should not disturb these during the imaging examination.

Pleural devices such as thoracotomy (chest) tubes allow drainage of air (higher chest placement) or fluid (lower chest placement) from the thoracic cavity and allow the lungs to inflate. Such devices consist of a large plastic tube, which is inserted through the chest wall between the ribs. The normally positioned tube lies on the surface of the expanded lung, between the visceral and parietal pleurae.

Endotracheal intubation is a lifesaving procedure but can also be life threatening if the tube is incorrectly positioned. An endotracheal (ET) tube provides for airway management by allowing frequent suctioning and mechanical ventilation. It consists of a large plastic tube, which is inserted through the patient's nose or mouth into the trachea. In adults, the tip of the tube should be situated approximately 5 cm above the tracheal carina. When advanced too far, the endotracheal tube usually enters the right main bronchus, causing various combinations of hyperinflation and atelectasis of the lungs. Radiographers should be aware that movement of a patient with an ET tube should be done with great caution since disruption of the tube may block the patient's airflow. Nasogastric tubes and feeding tubes pass though the mediastinum on their route to the stomach and intestines and are usually visible on radiography images.

Vascular catheters and various apparatus are now routinely used for monitoring hemodynamic function; for performing hemodialysis; and for administering fluids, medications, and nutrition. Central venous pressure (CVP) lines provide an alternative injection site to compensate for loss of peripheral infusion sites or to allow for infusion of massive volumes of fluids.[8] A CVP line is usually inserted in the subclavian vein but may also be inserted in the jugular vein, antecubital vein, or femoral vein. Chest radiographs may be requested shortly after initial insertion to determine proper placement and for the presence of a pneumothorax or hemothorax.

A pulmonary artery catheter is a multilumen catheter that measures cardiac function. It is usually inserted into the subclavian vein but can also be inserted into the same veins as the CVP line. Ventricular pacing electrodes are used to provide electrical pacing of the heart, in cases of a very slow heart rate, and after open-heart surgery.

Implantable access devices (subcutaneous ports) are designed for easy, long-term access to the vascular system or peritoneal cavity. A central venous catheter is used for monitoring pressure of infusion of medication and nutrition. Such devices, over time, can migrate and cause vessel injury and pulmonary infarction.

Cardiac devices are used in the treatment of heart disease and include cardiac pacemakers, valve prostheses, and artificial hearts. Heart valve prostheses have been used successfully since the 1960s and consist of either a mechanical or biologic type.

Cardiac pacemakers are as common as prosthetic cardiac valves and may be found in people of all ages, but are more commonly found in older adults. The purpose of cardiac pacemakers is to improve cardiac function, reduce the severity of clinical symptoms, and reduce mortality and morbidity.[14] Cardiac resynchronization therapy (CRT) is used to treat patients with severe chronic congestive heart failure. There are different methods used to place the CRT wiring; and, some wiring leads go directly to the surface of the left ventricle while another option is to introduce the wiring leads through the coronary sinus into a left ventricular vein.

Aortocoronary saphenous vein bypass grafts for direct myocardial revascularization have been used since 1967. These techniques include surgery, coronary artery angioplasty, and coronary artery stent placement. Since sternotomy is the usual surgical approach for surgery, sternal wires fixing the two sternal segments will be seen on chest radiographs. Vascular clips are also used to occlude veins and arteries and will also be visible on chest images.

Miscellaneous items that may be visualized in appendicular skeletal images include replacement joint apparatus and fixation devices such as nails, screws, plates, rods, etc. When such items are present, the radiographer is advised to include the entire device on the radiography image.

Each year thousands of patients with central venous access devices (CVADs) die of catheter-related bloodstream infections. Preventing catheter-related bloodstream infections begins with understanding the risk and one’s role in transmitting microorganisms. Once a CVAD or any indwelling device has been inserted through the skin and remains in place, the puncture site becomes a potential entry for organisms into the tract. When preparing the patient for musculoskeletal imaging examinations, the radiographer should use caution because catheter movement can introduce skin organisms into the catheter tract and the bloodstream. The radiographer should not touch the insertion site or surrounding skin and should report to nursing personnel on duty if the dressing over the site is loose or the insertion site is exposed. Central lines and catheters may be easily displaced because of tension on the catheter or tubing, so the radiographer should use caution when positioning and moving the patient during radiography examinations.

Child Abuse

It is estimated per year in the U.S. that more than 1 million children are seriously injured and 5,000 killed secondary to abuse.[26] Most abused children are younger than one year old, and almost all are younger than six years old. Authorities believe that this number represents only half of the number of actual reported or discovered cases. Why so many cases go unreported is a topic of concern; however, many children are too afraid to report abuse for fear of their safety or their siblings' or other family members' safety. Child abuse in most states is chargeable under general felony and misdemeanor criminal statutes such as murder, mayhem or assault with intent to maim, assault and battery by means of a dangerous weapon, and assault and battery.

Child abuse takes many forms: physical, sexual, and emotional. All types are damaging to the child's sense of security, trust, and overall well-being. Children who are abused or exposed to abuse are at an increased risk of developing stuttering, bed-wetting, insomnia, impaired concentration, aggression, and separation anxiety. It is well documented that children who are abused or exposed to abuse are more likely to become an abuser. Most medical facilities have developed policies and procedures for reporting suspected child abuse. In the past, the term used for child abuse was battered child syndrome (BCS). Today the acceptable term is non-accidental trauma (NAT). The radiographer should be aware of their responsibilities concerning NAT in the state in which they are working. For purposes of the following discussion, the term child abuse will be used.

The radiologist, referring physician, radiographer, and all medical staff members are critical watchdogs for the signs and symptoms of child abuse. The importance that radiology imaging professionals play in diagnosing child abuse cannot be overstated. Radiological professionals involved in the detection of child abuse and neglect must be familiar with current laws about reporting. Common questions about reporting involve obtaining consent for assessments, documentation in the medical record; filing mandated child abuse reports with state agencies, civil and criminal court actions, privilege, and confidentiality of the information. Radiological professionals often must work closely with police departments, district attorneys' offices, courts, and protective service agencies. Three basic issues arise concerning these questions:

1. When should the state intervene in family life?
2. How should the state intervene?
3. What procedural requirements exist to fulfill professional responsibility to patients and the state?

A minor child cannot usually consent to medical treatment; only the child's parents or legal guardians have this authority. In most states, however, there are statutory exceptions to this general rule. Among the common exceptions are the following:

- When an emergency arises and a child is taken to the hospital by police ambulance, the attending physicians may take whatever medical steps are necessary to diagnose and treat the patient, even if the legal guardians are unavailable. If time permits staff should make every reasonable effort to contact the child's legal guardian to obtain consent.
- When an emancipated minor is married, has children, is a member of the armed forces, or is financially independent and living separate and apart from the parents, the child can often consent to medical intervention. As the minor approaches the age of maturity, greater legal respect is accorded the child's wishes concerning medical intervention; that is, the legal guardian may have less decision-making authority over an older teenager than they do over a toddler.
- Specific medical issues for which states permit a minor who is pregnant, or a child who has suffered abuse/neglect, to be treated without parental consent.

Medical intervention requires the consent of only one parent or guardian, but if there is conflict between parents or guardians, radiological professionals should obtain legal consultation. All 50 states have child abuse reporting statutes. These statutes have as their primary purpose the identification of child abuse and neglect and, secondarily, the protection of children through state monitoring of families and the provision of services. Many medical facilities have operating guidelines for handling child and elder maltreatment cases. Also, some medical centers may have an interdisciplinary diagnostic team composed of a primary care physician, nurse, social worker, psychiatrist, and radiologists to review and evaluate suspected or confirmed cases of both child and elder abuse.

Statutes usually begin by defining groups of mandated reporters; those professionals who must report suspected abuse/neglect to departments of social service. Common mandated groups are teachers, psychologists, social workers, guidance counselors, physicians and nurses, and law enforcement personnel.

The basis for notification of state authorities is not knowledge but reasonable suspicion or belief. That is, a person does not need to know that abuse or neglect exists in order to report. A mandated reporter must report if the given medical or social data indicates abuse or neglect. In many states, if a mandated reporter fails to report child abuse when a filing is required, the professional risks imposition of a fine or criminal sanction. Legally, it is always better for a mandated reporter to file an abuse/neglect report, even if the allegation later proves erroneous, than to fail to file. If medical personnel observe a relatively minor injury that is not medically serious but reasonably reflects abuse or neglect, the filing requirement still remains. All states have an immunity provision in the reporting statute, holding the professional free from civil or criminal liability should a filed report not be substantiated.

The role of the radiologist and radiographer in cases of suspected abuse is usually that of a consultant acting with limited clinical and laboratory information. When radiological findings indicate the possibility of abuse, the radiologist or film-reading physician has the responsibility to indicate this in the written report as well as in direct verbal communication to the referring physician or physician representative. If after these discussions, the referring or attending physician is unwilling to file a report, the radiologist or film-reading physician has the legal responsibility to do so. Radiographers are also held accountable to report suspected or confirmed child abuse. In this situation, the radiographer should prepare a written documentation of any such communication to the supervising physician. This is an important step in the legal chain in order to protect oneself from a legal charge of failure to report.

Mandated reporters are required to report many different types of abuse and neglect. “Abuse” includes physical, emotional, and sexual injury or exploitation. “Neglect” covers physical harm (such as failure by caretakers to feed, clothe, or shelter a child), emotional deprivation (failure to nurture or attend to psychological needs), a lack of monitoring (e.g. allowing a child to roam outside freely, and medical or educational neglect.

Skeletal injuries are the most common physical injuries observed in the radiology setting. The most common fractures in abused children involve the skull, long bones, and ribs. Extra skeletal trauma (visceral and intracranial injuries) accounts for most of all fatalities in children. Miscellaneous forms of abuse and neglect includes abuse of the disabled child, neglect, poisoning, Munchausen's syndrome by proxy, unusual signs of physical injury, and sexual abuse.

Substantial clinical data exists to indicate that disabled children are at increased risk for abuse and neglect. Children at the greatest risk for abuse are low-birth-weight and premature infants, children with neurologic disabilities (especially cerebral palsy), and children with impaired communication skills. Male children tend to be at greater risk for abuse than female children are.

Neglect in the young child generally manifests as nonorganic failure to thrive or lack of normal growth and development. In elder neglect, significant loss of weight is also an important indicator of abuse. Other signs of neglect include gastric distention accompanied by profound nutritional deficiency diseases (rickets/marasmus).

Munchausen's syndrome by proxy is a condition in which a parent or caretaker alleges or causes an illness in the child for which repeated medical attention is sought. Most frequently infants and toddlers are intentionally made ill by a parent or caretaker and often undergo extensive medical examinations that frequently involve diagnostic imaging studies. Failure to diagnose Munchausen's syndrome by proxy may result in death, with mortality suggested as high as 33%.

Unusual signs of abuse include impalement (i.e., insertion of needles and other sharp objects), hair pulling, poisoning, and drowning. Sexual abuse is considered one of the most serious and common forms of child mistreatment. Diagnosis is generally based on history and physical examination with supporting laboratory studies. Those involved with radiography imaging examinations should be aware that sexual abuse is frequently associated with physical abuse. As in Munchausen's syndrome by proxy, sexually abused children often present with a variety of symptoms that may not be easily diagnosed.

When clinical or imaging findings are suspicious for potential abuse, a skeletal survey is obtained. The purpose of the skeletal survey is to document the presence of findings of abuse for legal reasons so that the child can be removed from exposure to the abuser. Additional tests are sometimes used to look for healing injuries not seen on the initial skeletal survey; such as, repeat skeletal survey (2 weeks after initial survey), skeletal scintigraphy, abdominal computed tomography (CT), and magnetic resonance imaging (MRI) of the brain. In a policy statement issued by the American Academy of Pediatrics (AAP), the role of diagnostic imaging of child abuse is succinctly detailed in the following statement.

> *"The role of imaging in cases of child abuse is to identify the extent of physical injury when abuse is present and to elucidate all imaging findings that point to alternative diagnoses. Effective diagnostic imaging of child abuse rests on high-quality technology as well as a full appreciation of the clinical and pathologic alterations occurring in abused children."*[27]

The AAP states that, " in general, the radiographic skeletal survey is the method of choice for global skeletal imaging in cases of suspected abuse." The AAP concurs with the ACR that a complete skeletal survey should include the following:

- **Appendicular skeleton**
  - arms (AP)
  - forearms (AP)
  - hands (PA)
  - Thighs (AP)
  - Legs (AP)
  - Feet (PA or AP)
- **Axial skeleton**
  - Thorax (AP and lateral) to include the thoracic spine and ribs
  - AP abdomen, lumbosacral spine, and bony pelvis
  - Cervical spine (AP and lateral)
  - Skull (frontal and lateral)

Skeletal surveys and CT scans are also recommended as part of an autopsy for children who die from injuries sustained in child abuse. The most common radiography imaging findings in physically abused children include fractures of long bones, ribs, skull and damage to organs in the major body cavities.

The radiographer is a key player in the detection of child abuse and neglect and it is important that signs and symptoms be recognized. It is important for radiographers to remember that child abuse knows no bias of gender, race or socioeconomic background and the abuser is usually **not** a stranger to the child. Often, the abuser is the child's caregiver, parent, sibling or a family friend or relative.

A few of the warning signs of physical abuse are fairly easy to recognize and include unexplained bruising, burns, black eyes, fractures, sprains, dislocated joints and other injuries. A radiographer should notice injuries that seem unusual for a child to have suffered under normal circumstances. The parent or guardian may try to explain how the child's injury occurred. The radiographer should be alert to these explanations, especially those that seem implausible or impractical. An example of an implausible explanation might be that an infant accidentally rolled off a bed, couch, etc. or down a flight of stairs. Any unusual trauma marks, bruises, and cigarette burns should alert the radiographer to possible child abuse. The young child who is a victim of sexual or emotional abuse may exhibit a variety of symptoms such as headaches, nausea, stomach aches, and vomiting. Chronic urinary tract symptoms, infections, and vaginal discharge may be indicative of sexual abuse.

Radiographers are encouraged to get involved if abuse of an individual is suspected. Radiographers should notify their supervisor and the local police department should be notified. Radiographers may also call the National Child Abuse Hotline (Child Help USA) at 800-422-4453.

Adult and Elder Abuse

Radiographers should be alert to signs of adult and elder abuse. The radiographer is in a unique position to observe the patient's upper chest, neck, and face for unusual signs that may indicate physical abuse. According to the best available estimates between 1 and 2 million Americans age 65 or older have been injured, exploited, or otherwise mistreated by someone on whom they depended for care or protection.[26]

Every year, an estimated 2.1 million older Americans are victims of physical, psychological, and other forms of abuse and neglect.[26] Approximately 1 out of every 14 cases of elder abuse is reported to authorities; typically the victims are 50 years of age and older and primarily women.[26] The perpetrators can be spouses, partners, adult children and grandchildren, other family members, caregivers or other individuals with ongoing, lasting relationships with the victim.[28] Studies show that up to 10% of the elderly population have been abused and the percentage of those abused increases as the age of the victim rises.[28] About 48% of substantiated cases of abuse involve older adults who are not physically able to care for themselves.[28]

Individuals suffering from dementia often experience poor judgment and impaired communication skills and may be more vulnerable to abuse and neglect. Neglect is the most common form of elder maltreatment in domestic settings. Elder abuse is an umbrella term referring to any knowing, intentional, or negligent act by a caregiver or any other person that causes harm or a serious risk to a vulnerable adult.[29] The following is a brief list of generally accepted facts related to elder abuse.[29]

- Physical abuse is inflicting, or threatening to inflict, physical pain or injury on a vulnerable elder, or depriving them of a basic need.
- Sexual abuse is the infliction of non-consensual sexual contact of any kind.
- Emotional or psychological abuse is the infliction of mental or emotional anguish or distress on an elder person through verbal or nonverbal acts.
- Financial or material exploitation is the illegal taking, misuse, or concealment of funds, property, or assets of a vulnerable elder.
- Neglect is the refusal or failure by those responsible to provide food, shelter, health care, or protection for a vulnerable elder.
- Self-neglect is characterized as the behavior of an elderly person that threatens his/her own health or safety.
- Abandonment is the desertion of a vulnerable elder by anyone who has assumed the responsibility for care or custody of that person.[29]

Federal laws exist on child abuse and domestic violence which fund services and shelters for victims but there is no comparable federal law on elder abuse.[29] The Federal Older Americans Act does provide definitions of elder abuse and authorizes the use of federal funds for the National Center on Elder Abuse (NCEA) and for certain elder abuse awareness and coordination activities in states and local communities, but it does not fund adult protective services or shelters for abused older persons.[29]

Legislatures in all 50 states have passed some form of elder abuse prevention laws. Laws and definitions of terms vary considerably from one state to another, but all states have set up reporting systems and generally, adult protective services agencies receive and investigate reports of suspected elder abuse. In 42 states, certain types of professionals are designated as mandatory reporters of domestic elder abuse.[29] They are required by law to report suspected cases of abuse, neglect, and exploitation. In gathering information for this course most sources stated that the greatest percentage of all domestic elder abuse reports originates from healthcare providers while service providers (i.e., staff of agencies providing services to the elderly) ranked second in reporting. Additionally, family members and relatives of victims were frequently cited as the source of reported cases of domestic elder abuse. Friends and neighbors, law enforcement personnel, clergy, banks/business institutions, and elder abuse victims also are cited as reporters of domestic elder abuse.[29]

With current medical advances and the adoption of healthier lifestyles, people are living longer. Older Americans now comprise the fastest growing segment of the U.S. population.[29] As a result of the sheer number of older Americans, the number of elder abuse cases will increase, and the impact of elder abuse as a public health issue will grow.[29] Victims of violence have twice as many medical visits compared with the general U.S. population, allowing opportunities for discovery and intervention.[29] Emergency physicians, radiologists, and radiographers are in a unique position to affect diagnosis and management of this vulnerable population.[29] The American Medical Association (AMA) recommends that doctors routinely ask geriatric patients about abuse, even if signs are absent. Substantial evidence exists for the following risk factors of elder abuse:

- Shared living situation with abuser, likely due to an increased opportunity for contact;
- Dementia;
- Social isolation; and,
- Pathologic characteristics of perpetrators such as mental illness and alcohol misuse.[29]

Theories of the origin of mistreatment of elders can be divided into four major categories, as follows: physical and mental impairment of the patient, caregiver stress, trans-generational violence, and psychopathology in the abuser. Recent studies have failed to show direct correlation between patient frailty and abuse, even though it had been assumed that frailty itself was a risk factor of abuse.[29] Physical and mental impairment has been shown to play an indirect role in elder abuse, decreasing seniors' ability to defend themselves or to escape, thus increasing vulnerability.[29]

Caregiver stress is considered more as a trigger for abuse rather than as a cause.[16] Trans-generational violence is considered to be family violence that is a learned behavior that is passed down from generation to generation. The child who was once abused by the patient continues the cycle of violence when both are older. Family members who have psychopathologic tendencies many times become the caregiver because they may be home because of lack of employment or poor social skills. Drug and alcohol addiction, personality disorders, intellectual and developmental disorders, dementia, and other conditions can increase the likelihood of elder abuse.[29]

Radiographers should keep these “red flags” in mind in all interactions with elder patients. Some general recommendations when evaluating a patient for possible elder abuse include keeping questions direct and simple and asking in a nonjudgmental or nonthreatening manner. It is also helpful to interview the patient and caregiver together and separately to detect disparities offering clues to the diagnosis or abuse.[29] Accurate and objective documentation of the interview is essential since all findings may be entered as evidence in criminal trials or in guardianship hearings.

During the physical examination, the patient should thoroughly disrobe and should be evaluated for unexpected injuries. The size, shape, and location of all injuries should be documented, including photographing the injuries if possible.[29] Certain clinical findings and observations are strong indicators for elder abuse, including:

- Several injuries in various stages of evolution;
- Unexplained injuries;
- Delay in seeking treatment;
- Injuries inconsistent with history;
- Contradictory explanations given by the patient and caregiver;
- Laboratory findings indicating under dosage or over dosage of medications;
- Bruises, welts, lacerations, rope marks, burns;
- Venereal disease or genital infections;
- Dehydration, malnutrition, decubitus ulcers, poor hygiene; and, signs of withdrawal, depression, agitation, or infantile behavior.[29]

For additional information on the subject of elder abuse contact the National Center on Elder Abuse at 1-202-898-2586 or visit www.elderabusecenter.org.

Conclusion

The radiographer serves a vital role in providing quality patient care and in serving as an advocate to patients. While the radiographer's primary role is to obtain high quality images, the patient also is a customer-service representative of the medical facility where they work and, on a grander scale, the profession of radiologic technology. As such, the radiographer has a demanding role and presence in the delivery of excellent patient care and imaging services.

Chapter 3 Conventional Radiography & Positioning Protocols

"I am opposed to millionaires, but it would be dangerous to offer me the position." Mark Twain

Introduction

Conventional non-contrast radiographic examinations of bones, joints, and soft tissues are among the most common imaging procedures requested. Since conventional radiography images contribute to information concerning pathology and trauma, the radiographer must control factors that might otherwise distort the image. Such factors include patient cooperation, correct positioning, photographic and geometric factors, and the proper selection of exposure factors. Subtle changes in skeletal structures can be obscured by a slight shift of the patient's body or inaccurate exposure factors. The recommended source-to-image distance (SID) for conventional extremity radiography is 40 inches; anything less will cause magnification of the structures on the radiographic image, thus leading to a possible erroneous diagnosis.

The American College of Radiology (ACR), Society for Pediatric Radiology (SPR), and the Society for Skeletal Radiology (SSR) provide recommendations concerning the number of images for various patient situations.[1] The guidance generally recommends at a minimum that the projections include an anteroposterior (AP), oblique, and lateral, which may be obtained in either a recumbent or upright position.[1] According to the ACR and others the goal of radiography examinations of musculoskeletal structures is to help establish the presence or absence of disease processes, to monitor progression of conditions, and to evaluate the effects of treatment.[1] The ultimate judgment regarding any specific examination or course of action must be made by the requesting physician in consultation with the radiologist; however, the ACR provides suggested guidelines in the document titled *ACR-SPR-SSR Practice Guidelines for the Performance of Radiography of the Extremities in Adults and Children.* In this document, the ACR lists indications and contraindications for radiography of the extremities to include:

- Trauma;
- Pain;
- Suspected physical abuse such as in infants, young children, and the elderly;

- Metabolic diseases, nutritional deficiencies, and skeletal changes from systemic disease;
- Benign and malignant neoplasms;
- Primary non-neoplastic bone pathology;
- Arthropathies;
- Infections;
- Preoperative or postoperative evaluation and/or follow-up;
- Congenital syndromes and developmental disorders;
- Vascular lesions;
- Evaluation of soft tissues in an extremity; and,
- Correlation of abnormal skeletal findings on other imaging studies.[1]

The ACR and others highly recommend that extremity radiography be performed in the imaging department whenever the patient's condition allows so that high quality images may be obtained. Portable radiography is the modality of choice for imaging patients under certain circumstances and in select patient populations (e.g., critically ill, postoperative, newborn).[1]

Conventional non-contrast radiography of the musculoskeletal structures are some of the most routine radiography procedures performed in imaging centers and provide substantial diagnostic information. Conventional radiography does have certain limitations and adjunct imaging modalities such as computed tomography (CT), magnetic resonance imaging (MRI), ultrasonography (US), and nuclear medicine are used, when necessary.[1]

To help lessen questions about the appropriate imaging modality to use for evaluation of diseases and injuries to musculoskeletal structures, the ACR and its expert panels have developed criteria for determining appropriate imaging examinations for the diagnosis of specific medical condition(s).[4] The criteria are intended to guide radiologists, radiation oncologists, and referring physicians in making decisions regarding proper selection of imaging examinations.[4] A relative radiation level is also assigned to each suggested imaging modality, with the radiation exposure listed as low, medium, or high. The ACR has developed criteria for imaging many clinical conditions but the ones specific to the appendicular skeleton include the following:

- Chronic pain;
- Athletic injury;

- Fracture;
- Evaluation for inflammatory conditions; and,
- Initial radiographs normal but condition warrants further investigation.[1]

Appropriateness Criteria

During the 1990s, the ACR recognized the need to define national guidelines for appropriate use of imaging technologies. These guidelines became known as the ACR Appropriateness Criteria® (ACR AC).[2] In 1993, K.K. Wallace, MD formally introduced the ACR AC during testimony to the U.S. House Ways and Means Committee.[2] Dr. Wallace stated that the ACR was ready to create guidelines for radiology to eliminate inappropriate utilization of radiological services.[2] Currently the ACR AC provides the most comprehensive evidence based guidelines for diagnostic imaging selection, radiotherapy protocols, and image guided interventional procedures available.[2] They embody the best, current evidence for selecting appropriate diagnostic imaging and interventional procedures for numerous clinical conditions.

The ACR guidelines suggest various imaging examination procedures for certain specific chief complaints. Each of these are assigned an appropriateness rating from one to nine, with one being least appropriate and nine being most appropriate for the specific condition.[2] A relative radiation level is also assigned to each imaging examination.

Potential adverse health effects associated with radiation exposure are an important factor to consider when selecting the appropriate imaging procedure. Because there is a wide range of radiation exposures associated with different diagnostic procedures, a relative radiation level (RRL) indication has been included for each imaging examination. The RRLs are based on effective dose, which is a radiation dose quantity that is used to estimate population total radiation risk associated with an imaging procedure. Patients in the pediatric age group are at inherently higher risk from exposure, both because of organ sensitivity and longer life expectancy (relevant to the long latency that appears to accompany radiation exposure). For these reasons, the RRL dose estimate ranges for pediatric examinations are lower as compared to those specified for adults. Additional information regarding radiation dose assessment for imaging examinations found in the ACR AC may be found in the ACR's Radiation Dose Assessment Introduction.[2] Figure 3-1 illustrates some of the imaging examinations receiving various ratings for specific conditions of the extremities.

Chronic foot pain and to rule out tarsal coalition		
Radiologic Exam	9 rating 9 rating	X-ray of the foot (AP, lateral, oblique, and Harris-Beath views) CT of the foot without contrast. This is a secondary but complementary study. Recommended if x-ray is unremarkable or equivocal and clinical concern warrants.
Athlete with pain and tenderness over tarsal navicular; initial radiographs are unremarkable		
Radiologic Exam	9 rating	MRI of the foot without contrast.
Chronic ankle pain of any origin		
Radiologic Exam	9 rating	X-ray of the ankle
Avascular necrosis (AVN) of the hip		
Radiologic Exam	9 rating	X-ray of the pelvis for initial evaluation in patients at risk for AVN who present with hip pain
Chronic elbow pain with initial radiographs nondiagnostic		
Radiologic Exam	9 rating 8 rating	MRI without contrast Ultrasound of the elbow if MRI expertise is not available
Acute trauma to the knee		
Radiologic Exam	9 rating 9 rating	X-ray of the knee; initial examination to assess overall injury MRI knee without contrast to evaluate extent of damage to ligament and other support structure

Fig. 3-1 Adapted from the ACR Appropriateness Criteria® Retrieved from www.acr.org on September 2010.[2]

The ACR AC topics are posted on the National Guideline Clearinghouse's website http://www.guidelines.gov.

Technical Specifications of Conventional Radiography

Densities on Radiography Images

The anatomic structures within the appendicular skeleton are composed of four inherent densities: air, fat, soft tissue, and bone. A fifth density has been attributed to extrinsic metal that may be implanted in the patient (i.e., clips, plates, screws, and joint replacements). Anatomic structures are often described as being either radiopaque or radiolucent.

> ***Radiopaque*** *refers to tissue or material that attenuates (i.e., absorbs) x-rays and appears bright on a radiograph. In the appendicular skeleton, the bones will appear radiopaque.*

***Radiolucent** refers to tissue or material that permits x-rays to easily pass through, thus appearing dark on a radiograph. In the appendicular skeleton, soft tissue appears more radiolucent than bones.*

Listed below are densities, from the most radiolucent to the least radiolucent:

- Air;
- Fat;
- Soft tissue;
- Bone; and,
- Metal.

Air, fat, and soft tissues are radiolucent; their shading on radiography images will range from black (i.e., air-filled lungs) to various shades of gray (i.e., fat and soft tissue). Bones are composed primarily of calcium, consisting of organic material having a high atomic number, thus they attenuate the x-ray beam and reduce the amount of radiation reaching the image receptor (IR). The actual composition of bone depends on the area of the body, age, and health status of the patient thus bones appear in various shades of white on the radiography image. Certain orthopedic devices implanted in the patient attenuate more radiation than any of the other densities and will appear white on the radiography image. Depending on the composition, cloth bandages, elastic type bindings, and casting materials will attenuate the radiation beam to various degrees and thus their final appearance on the image will range from vary light to gray tone densities.

Diseases and conditions that cause the affected body tissue to decrease in composition are referred to as destructive diseases or conditions. These conditions reduce attenuation (absorption) of the x-ray beam. If a destructive disease or condition exists in the anatomic area being examined, the radiographer may need to decrease the x-ray exposure factors; otherwise, the radiography image will appear too dark (overexposed and exhibit too much photographic density).

***Additive diseases** result in increased attenuation of the x-ray beam and requires that the x-ray exposure factors be increased.*

Destructive diseases *result in decreased attenuation of the x-ray beam and require that the x-ray exposure factors be decreased.*

Figure 3-2 provides a partial list of the most common additive and destructive diseases affecting musculoskeletal structures.

Additive (Increased attenuation)
Acromegaly
Callus
Charcot joint
Chronic osteomyelitis (healed stage)
Exostosis
Osteochondroma
Osteoma
Paget's disease
Sclerosis
Destructive (Decreased attenuation)
Active osteomyelitis
Active tuberculosis
Atrophy
Degenerative arthritis
Gout
Multiple myeloma
Osteoporosis/Osteomalacia
Radiation necrosis

Fig. 3-2. Additive and destructive diseases and conditions of the skeletal system.

To review, an additive condition generally requires an increase in kilovoltage (kVp) to adequately penetrate the part and a destructive condition requires a decrease in kVp. The 15% kVp rule may be applied when the radiographer has information (i.e., from the imaging request), that indicates an additive or destructive condition may exist. The 15% rule states that an increase in kVp by 15% is equivalent to doubling the milliamperage-seconds (mAs). Likewise, a 15% reduction in the kVp is equivalent to reducing the mAs by half.

An important step prior to commencing the actual examination is for the radiographer to review the imaging request to glean information that may be used to determine the best combination of technical x-ray exposure factors. Also, the radiographer may gain information about the patient's chief complaint and the reason for the examination. This information may allow the radiographer to make adaptations and adjustments to the basic imaging protocol and may prevent unnecessary retake examinations due to technical errors. With this type of information, the radiographer will use their knowledge and judgment in selecting the proper technical exposure factors for the examination and in adapting the basic protocol, as necessary, to accommodate each patient.

> *As* ***a general guide*** *when an increase in the x-ray exposure factors is needed, the radiographer should increase the kVp. This is the preferred method since kVp controls the penetrability of the primary x-ray beam and also controls the visible scale of contrast.*

To review, the 15% rule generally applies to x-ray examinations of smaller anatomic areas such as the extremities. Unless the radiographer has access to previous radiographs with recorded exposure factors; the initial x-ray exposure factors should be determined by using a standardized protocol. An exception to this statement is when the patient's medical history indicates that an additive or destructive disease process is present. In this situation, it is best for the radiographer to start with the exposure factors listed on a standardized technique chart and make alterations as necessary to the x-ray exposure factors. The use of automatic exposure control (AEC) facilitates consistent x-ray exposures. The use of an AEC requires that the radiographer carefully review the clinical history to determine the type and location of disease in order to produce optimal diagnostic-quality radiographs.

Equipment Specifications

The *ACR-SPR-SSR Practice Guideline for the Performance of Radiography of the Extremities in Adults and Children* provides suggestions about the minimum radiography equipment standards. Their suggestions for equipment standards include:

- *A diagnostic unit with a rotating anode tube and tube filtration sufficient to achieve a half-value layer (HVL) greater than 3 mm of aluminum at 100 kVp;*
- *A grid consisting of at least 10:1 (preferable 12:1) ratio with a minimum of 103 lines per inch (stationary) or 80 lines per inch (reciprocating);*
- *Equipment having a beam-limiting device that provides rectangular collimation;*
- *A nominal source (focal spot) size that does not exceed 2.0 mm (0.6-1.2mm is the recommended range);*
- *Intensifying screens with a film-screen combination of at least 200 speed;*

- *Automatic processing with carefully controlled temperature and maintenance (if manual processing is employed, a constant time and temperature shall be employed); and,*
- *Careful quality control, if photostimulable phosphor plates or digital imaging techniques are used, instead of film-screen radiography.*[3]

Positioning Basics

The true anatomical position is considered the “home” or starting point for radiography positioning. The true anatomical position refers to when the patient is erect with the arms and legs extended and the face, arms, hands, legs, and feet placed in an anteroposterior (AP) projection.

During imaging examinations, the position of the patient’s body may be either upright (erect) or lying down (recumbent). The upright position is used when the radiographic study is being performed to determine levels of bodily fluids, gas, or air. The upright position is also used for certain weight bearing examinations of the feet, ankles, knees, hips, and vertebral spine. Routine radiography imaging of musculoskeletal structures may be performed with the patient sitting on a stool, lying on the radiographic table, and with the patient in the upright position. Conventional radiography examinations may also be performed in the emergency room, a specialized examination room, or at the patient’s bedside. In radiography examinations, certain positioning terminology has been adopted as standard and these include:

- **Projection** describes the path of the x-ray beam as it travels from the x-ray tube, through the patient, and onto the cassette or image receptor (IR). Projections are either posterior-anterior (PA) or anterior-posterior (AP);
- **View** refers to the representation of an image as seen from the position of the cassette or IR. When looking at an AP or PA image, the anatomy closest to the film or the IR is considered the view. When viewing an AP projection, the anatomy closest to the cassette or IR was the posterior surface; thus, it is referred to as a posterior view. When a viewing a PA projection, the anatomy closet to the cassette or IR was the anterior surface, thus it is referred to as an anterior view;
- **Position** is the term used to describe a general body position. A lateral position is obtained when the patient’s body or anatomic part is positioned at a right angle or laterally to the cassette or IR. A lateral extremity image should be marked as either a right (R) or a left (L) to properly identify the extremity being examined. A lateral

radiograph provides depth or a dimensional view when compared to the AP or PA projection;

- **Oblique** refers to a position of the body or a part (i.e., hand or foot) that is rotated and angled and is neither in the AP, PA projection, or lateral position. An oblique position refers to one in which the patient or a specific anatomic part is rotated (slanted) at an angle that is somewhere between a frontal and a lateral position. The side and surface closest to the image receptor is used to identify oblique body positions; and,
- **Decubitus** position refers to when the patient is lying down (recumbent) with the central ray of the x-ray tube directed horizontally. The dependent side (side down) identifies the position.

Figure 3-3 provides information about some of the accessory methods that may be considered when the patient cannot assume the required position.

Radiographic Projections/Positions	**Pathology Indications**
Transthoracic	Suspected fracture of the shoulder/humerus
Cross Table Lateral	Suspected fracture of the hip, femur, knee
Bilateral images	Comparison, typically of a joint such as the carpal, knees, etc.
Axial/Transaxial	Suspected injury requires that the specific anatomic area not be moved

Fig. 3-3. An accessory method when the patient cannot assume the standard basic positioning protocols.

Additional Positioning Terminology

The term *axial* refers to the long axis of a structure or anatomic part. Superoinferior or cephalocaudad describes a true axial projection where the CR is directed along the long axis or centerline of the body from the head to the feet and is used to describe any angle of the CR that is more than 10 degrees along the long axis of the body.[8] Inferosuperior and superoinferior axial projections are often used when performing radiography examinations of the shoulder, hip, and skull where the CR enters below or inferiorly and exits above or superiorly.

The transthoracic lateral projection is a lateral projection through the thorax and is further identified as either a right or left lateral. The transthoracic lateral projection is used as the initial method of choice when imaging suspected fracture or trauma of the humerus and shoulder area.

Dorsoplantar and plantodorsal projections of the foot are often used in podiatric radiography to replace terminology associated with the AP or PA projection. Also the term dorsiflexion, the act of moving the toes and forefoot upward, is often used in positioning directions. Plantar flexion refers to the act of moving the toes and forefoot downward. Other terms used in positioning the foot include eversion and inversion. Eversion is the act of turning the plantar foot surface as far laterally as the ankle will allow; and, inversion is the act of turning the plantar foot surface as far medially as the ankle will allow. A tangential view is produced when the CR skims a body part in order to demonstrate it in profile, free of superimposition of any anatomy that may lie above or below the area to be visualized.

Radiographers must be familiar with relationship terms when performing imaging examinations of musculoskeletal structures. Medial refers to a direction toward the median plane of the body and lateral refers to a direction away from the median plane of the body. Proximal refers to a point of reference near the source of attachment (i.e., usually a joint); and distal refers to a point of reference away from the source of attachment. Cephalad refers to a direction toward the head and caudad refers to a direction away from the head or toward the feet. Superior refers to a direction toward the head or vertex; and, inferior refers to a direction away from the head or vertex.

Terms that are used specifically with the extremities include movement directions. For example when the positioning directions require that the extremity is moved outward, away from the torso, the term *abduct* is used. The term *adduct* is used when the extremity is moved toward the torso. In the directions for various basic and accessory examinations of the extremities, the radiographer is often told to align or bring into alignment the entire limb. For example, when positioning the patient for an AP ankle image, the entire limb must be aligned to avoid possible rotation of the part being examined. To obtain a true lateral image of the extremities, the radiographer is directed to superimpose certain anatomy. The term superimposes means to move the anatomical structures or objects in such a way as to cause them to lie over or above another structure.

The terms internal (medial) and external (lateral) rotation are also frequently used terms that refer to the act of turning the anterior surface of an extremity either inward or outward from the patient’s torso midline. The terms pronate and supinate are frequently used when referring to positioning of the hand and upper limb. The term pronate refers to the rotation or turning of the upper extremity medially until the hand's palmar surface is facing downward or posteriorly. The term supinate is just the opposite movement that requires rotating or turning the upper extremity laterally until the hand's palmar surface is facing upwardly or anteriorly. When the radiographer is instructed to retract a particular anatomic structure, it means to move a structure backward or posteriorly. For example, to retract the shoulder means to move it backwards in order to achieve a certain radiography position.

Image Identification

The radiograph or image should be permanently marked with the patient's name, identification number, right or left side, patient position, and the date and time of the examination. Labeling the image with the patient's date of birth is strongly recommended by the ACR.[2] In conventional film screen radiography this information should be permanently affixed by the photo-flashed lead blocker method. The radiograph should also contain the side marker, either right (R) or left (L) and any alteration from the normal procedure. It is important for the radiographer to know the position of the lead blocker in conventional film-screen cassettes to avoid obscuring any requested anatomic structures. Digital imaging systems allows the radiographer to add an R or L maker during post processing if it was partially positioned outside the collimated light field during the exposure. Radiographers are advised to not cover up the original information, although it may be incomplete.

To avoid mislabeled images, the radiographer should always ensure that the marker is visualized within the collimated fields and does not obscure areas of interest. The marker should also be positioned in the best possible location for the projection or position. When taking a series of images of the toes, fingers, wrist, ankle, etc., on the same cassette or image receptor, it is necessary to mark only one of the positions as long as they are all of the same anatomical structure. For radiography images of the hips and shoulder, the identification marker should identify the side of the patient being imaged. As a general rule, for the AP/PA projections and the oblique positions of the hip and shoulder, the marker is placed on the lateral side of the structure. For lateral cross-table images (i.e., hip or shoulder), the identification marker contain either a R or L and should be positioned anteriorly to prevent it from being superimposed over structures situated along the posterior edge of the cassette or image receptor.

Introduction to Image Quality

Image quality on conventional radiographs often suffers if the patient is overweight or obese due to limited penetrability and attenuation of the primary radiation beam. Excessive scatter radiation, which degrades the image, is also of primary concern. Inadequate image quality radiographs may also be compromised in those who are obtund (i.e., less than full mental capacity, as a result of a medical condition or trauma), uncooperative, unconscious, and those receiving life support. Often, the clinician selects a particular imaging modality based on the suspected disease process or injuries. Decisions regarding the appropriate selection of imaging modalities for trauma patients with possible injuries are quite controversial. Currently, the debate centers on the question of whether CT should be an integral part of the initial imaging examination of trauma victims.

The fact that CT imaging provides greater detection of fractures when compared with conventional radiography has been well documented. Decisions regarding the choice of which imaging modality to use in general diagnosis of bone diseases and trauma care are often dictated by institutional polices and often restricted by availability of various equipment and the patient status, etc. In any case, radiography examinations of individuals with bone conditions and fractures should demonstrate the portion(s) or the area of clinical interest requested and should be repeated if the image quality is insufficient. Any prior imaging studies including CT, MRI, or nuclear medicine should be obtained, if possible, to provide additional correlation information for the radiologist.

The ultimate goal of any radiography examination is to provide diagnostic quality images for prompt and accurate interpretation. To accomplish this goal, the selection of technical factors selected must provide proper penetration of the anatomic area. The following provides a review of the general considerations in providing high quality images.

General Considerations

The primary x-ray beam, also referred to as useful radiation or primary radiation, consists of the radiation emerging from the x-ray tube that has not interacted with an object. As the primary x-ray beam passes through anatomic tissue, it will lose some of its energy. This reduction in the energy of the primary x-ray beam is known as attenuation. When the primary x-ray beam interacts with anatomic tissues; absorption, scattering, and transmission occur. Less than 5% of the primary x-ray beam interacting with the anatomic tissue actually reaches the cassette or image receptor (IR).[4]

The central ray (CR) is representative of the radiation emerging off of the x-ray tube target at a right angle. The CR is intended to be projected perpendicular to both the anatomical part and the IR. Whenever the CR is not perpendicular, some degree of shape distortion will be evident on the radiographic image.

Scatter radiation occurs during attenuation of the x-ray beam. Some of the photons in the primary x-ray beam are not absorbed, but instead lose energy during interactions with atoms in the anatomic tissue. This process is simply referred to as "scatter". Scattered radiation provides no useful diagnostic information and needlessly increases the radiation exposure of both patient and staff and places an undesirable fog over the radiographic image. Scatter radiation can be minimized by limiting the primary x-ray beam field size to the size to the smallest area possible; thus, reducing the amount of tissue with which the x-rays interact and producing fewer scattered x-rays. Leakage radiation refers to x-rays that escape from the protective x-ray tube housing. The amount of permissible leakage radiation is usually dictated by state law and is a parameter that is measured during equipment safety inspections.

The construction properties of the x-ray tube, such as beam filtration, line focus principle, and anode heel effect, also have an impact on the quantity and quality of the x-ray beam. Filtration affects both quality and the quantity of radiation in the primary x-ray beam. The x-rays that exit the x-ray tube are heterogeneous or polyenergetic, consisting of low, medium, and high energy x-rays. Low x-ray energies are not strong enough to penetrate the anatomic part and are not useful in forming the image. Low energy x-rays only contribute to the patient radiation dose. Filtration installed within the x-ray tube attenuates or absorbs the low energy x-rays. Additional filtration may be added to increase the attenuation and absorption. Various components within the x-ray tube assembly (i.e., metal housing, oil insulation, etc.) also contribute to the attenuation of low-energy x-rays. The amount of total filtration that must be present in a diagnostic radiography tube is set by the U.S. government to ensure that patients receive minimum doses of radiation. Special filters, called compensating filters, can be added to the primary x-ray beam to alter its intensity. Such filters are usually employed when imaging anatomic areas that are non-uniform in composition and/or size. Use of a compensating filter may be useful in obtaining uniform density along the vertebral column and in imaging examinations of the foot.

The line focus principle describes the relationship between the actual and effective focal spots in the x-ray tube. The actual focal spot size refers to the size of the area on the anode target that is struck by the electrons from the tube current. The actual focal spot is determined by the size of the filament producing the tube current (i.e., electron stream). The effective focal spot size refers to focal spot size as measured directly under the anode target. A large focal spot has the advantage over a small focal spot by being able to withstand the heat generated by higher x-ray exposure ranges. However, a small focal spot produces an image that has the greatest geometric sharpness. To overcome this disadvantage, manufacturers have developed x-ray tubes having specific anode angles, typically ranging from 6 to 20 degrees. Based on the line focus principle, the amount of the anode angle determines the size of the effective focal spot. The smaller the anode angle, the smaller the effective focal spot, thus greater geometric sharpness on the image.

The anode heel effect is a phenomenon that occurs due to the angle of the x-ray tube target. Because the x-ray tube target is angled, the emerging x-ray beam has greater intensity (number of x-rays) on the cathode side of the x-ray tube, with the intensity diminishing toward the anode side of the x-ray tube. The anode heel effect has a practical application when imaging anatomic areas that present different ranges in centimeter thickness. One such application may be used when imaging the lower leg, which is thinner at the ankle portion and gets thicker toward the knee portion. Using the leg as an example, the ankle is placed at the anode end of the x-ray tube and the knee at the cathode end of the x-ray tube. Figure 3-4 provides suggested guidelines for incorporating the anode-heel effect in extremity radiography.

Projections	**Part placed at anode end of the x-ray tube**	**Part placed at cathode end of the x-ray tube**
AP & lateral leg	Ankle	Knee
AP & lateral femur	Knee	Hip
AP & lateral forearm	Wrist	Elbow
AP & lateral humerus	Elbow	Shoulder

Fig. 3-4. Suggested guidelines for incorporating the anode-heel effect in extremity radiography.

Photographic and Geometric Properties

Diagnostic quality radiography images exhibit adequate photographic and geometric properties. The photographic properties of a radiograph are radiographic density and contrast and the geometric properties are recorded detail and distortion. The correct balance of these properties determines visibility of detail on the recorded image and overall image quality. The following is a brief review of these properties.

Radiographic density is the amount of overall image blackness after processing. The controlling factors of density are milliamperage (mA) and exposure time. Milliamperage and exposure time control the quantity of radiation reaching the image receptor. There are many influencing factors and these include kilovoltage, source to image distance (SID), grids, screen-film speed, collimation, anatomic part, anode heel effect, reciprocity law, generator output, filtration, and the type of processing system used. Milliamperage (mA) is the unit of measurement for x-ray tube current. Tube current is the number of electrons flowing per unit of time between the cathode and anode. The quantity of electrons in the tube current is directly proportional to the mA. If the mA increases, the quantity of electrons increases and the production of x-rays increase proportionally. The mA does not affect the quality, or energy of the x-rays produced rather affects only the quantity. The quantity of radiation produced is proportional to the amount of mA selected on the control console. For example, if the mA is doubled, the quantity of radiation is doubled or increased by a factor of two.

Exposure time determines the length of time that the x-ray tube produces x-rays. Selection of the exposure time is under the direct control of the radiographer. The exposure time determines the length of time that the tube current is allowed to flow from the cathode to anode. When the factors of milliamperage and time are multiplied the product is referred to as milliamperage-seconds (mAs). Higher mAs result in more electrons flowing in the x-ray tube current from cathode to anode. The more electrons in the tube current, the more x-rays produced. The amount of mAs affects only the quantity of x-rays produced and has no effect on the quality of the x-rays produced.

Radiographic contrast is a major factor affecting visibility of recorded detail. Contrast is the degree of difference between adjacent densities and can be classified as either high or low. High contrast means that there are few densities in the image but great differences or shades among them. High contrast is also referred to as short-scale contrast. Low contrast means that there are a large number of densities in the image but little differences among them. Low contrast is also referred to as long-scale contrast.

The controlling factor of contrast is kilovoltage. There are many influencing factors affecting contrast and these are grids, collimation, object to image-receptor distance (OID), anatomic part, contrast media, and processing.

A grid is a device that is placed between the patient and the cassette or image receptor (IR) to absorb scatter radiation exiting from the patient. A collimator is used to limit the primary x-ray beam to the area of clinical interest. Collimation of the primary radiation field size ultimately reduces the amount of scatter radiation. Whenever the quantity of scatter radiation can be reduced, the image quality improves. Scatter radiation is detrimental to the radiographic image quality because excessive scatter radiation results in additional unwanted density and reduces contrast (brightness). By using a grid to absorb scatter radiation before it reaches the cassette or IP, damaging effects of scatter radiation on image quality can be minimized. The amount of scatter that exits from the patient increases as kVp increases. Restriction of the primary x-ray beam limits the size of the area exposed and ultimately reduces the amount of scatter radiation produced.

Kilovoltage (kVp) is under the direct control of the radiographer. The penetrability and quality of the primary x-ray beam is controlled by the selection of the kVp range. The higher the kVp, the greater the penetrating ability of the primary x-ray beam. The intensity of the primary x-ray beam is directly proportional to the kVp selected on the control console. If the kVp is doubled, the intensity increases by a factor of 4. This means that by increasing the kVp, the quantity of radiation can be increased. Increasing kVp by 15% (i.e., the 15% rule), is comparable to doubling the mAs and may be used as a guideline when kVp adjustments are required. Higher kVp ranges result in a decrease in the patient’s radiation dose.

Source to image distance (SID) is under the direct control of the radiographer. The universal recognized SID used for extremity radiography is 40 inches. The quantity of radiation is affected by the inverse square law, which states that the intensity (quantity) is inversely proportional to the square of the distance. The SID selected has a direct influence on both the photographic and geometric properties of an image. The ultimate goal of any radiographic examination is to produce diagnostic quality radiography images, which accurately projects the anatomy on the image. Geometric properties are those factors that affect recorded detail and distortion.

Recorded detail refers to the sharpness of the structural lines that make up the recorded detail. During the x-ray exposure, any motion of the x-ray tube, patient, part, or image receptor decreases recorded detail. Factors controlling recorded detail include penumbra (geometric unsharpness), image receptor system speed, and motion unsharpness. Factors influencing recorded detail include focal spot size, SID, OID, screen phosphor crystal size and phosphor layer thickness, screen reflective layer, film emulsion crystal size, crossover, screen-film contact and motion.

Distortion refers to the radiographic misrepresentation of either the size (magnification) or shape of the anatomic part. When the image is distorted, recorded detail is also reduced. As SID increases, size distortion (magnification) decreases; as SID decreases, size distortion increases. Elongation and foreshortening are shape distortions, which can be minimized by the proper central ray (CR) alignment (i.e., x-ray tube, part, image receptor, and CR entry or exit point).

Standardized Technique Charts

Standardized technique charts accompany each imaging unit and provide a baseline for the selection of technical x-ray exposure factors. The design of technique charts must take into consideration many factors including:

- Centimeter measurement and size of the anatomic area or part of clinical interest;
- Pathology and atomic composition of the tissues to be imaged;
- Film-screen combination or other types of image receptor (IR) systems;
- Source to image distance;
- Type and quantity of x-ray tube filtration;
- Type of x-ray generator used;
- Scale of radiographic contrast desired, level of optical density; and,
- Type of imaging system(s).[4]

For a standardized technique chart system to be effective, the x-ray system on which it is based must be calibrated by a medical physicist and the processing system must be evaluated. The type and amount of total x-ray tube filtration, and the type of grid(s) and collimation methods must also be considered when developing a standardized technique chart.[4]

The primary technical exposure factors are kVp, mA, exposure time and SID. The radiographer is responsible for selecting and manipulating these factors to produce a diagnostic image containing adequate optical density, radiographic contrast, image detail, and no distortion. The four commonly recognized variations of radiographic exposure technique charts are:

- Variable kilovoltage;
- Fixed kilovoltage;
- High kilovoltage; and,
- Automatic exposure control.

Most imaging centers will select a particular radiographic exposure system for each examination room. Although many factors determine the system selected, the final decision often depends upon the preferences of the imaging center director, staff radiologists, and medical physicists. In computed radiography systems, normalization (i.e., automatic scaling), is provided. Normalization is a process by which the computed radiography system automatically corrects for manually set and automatic exposure errors and allows for consistently optimized images.

The variable kVp technique chart method is based on a fixed mAs value and kVp that varies according to the centimeter thickness of the anatomic part. This method generally uses lower kVp than the other methods and produces images with short-scale contrast. Short-scale contrast images exhibit black and white tones without various shading levels in between. This method results in a higher radiation dose to the patient and a short-scale or “high-contrast” image.

The fixed kVp radiographic technique chart is the most commonly used x-ray exposure method used for large body areas such as the chest. This method results in images with a long-scale contrast. As opposed to the variable kVp method, which generally uses kVp ranges near the minimum kVp latitude range for a given part, the fixed kVp method provides the optimum kVp (i.e., near the maximum latitude range) for the particular part.

A fixed kVp level is set for each type of examination and does not vary according to the centimeter size of the part. For each imaging examination, the mAs value is changed according to the centimeter size of the part and to produce the optimum optical density required. Often, instead of measuring the exact centimeter size, the variable kVp exposure method is based on small, medium, or large size ranges.

The high kVp method employs kVp in ranges that usually exceed 100 kVp. The use of higher kVp is ideal for chest radiography where detailed imaging of the pulmonary and mediastinal structures is required. All exposures for a specific body part use the same kVp, and the mAs value would be adjusted. One concern with this method is that as the kVp increases and the mAs decreases, radiographic contrast is reduced. A reduction in radiographic contrast may be associated with a loss of useful information in the recorded image.

Exposure Control

There are many factors that influence the amount of radiation that the patient receives. Of these, there are only a few within the radiographer's control. The correct selection of exposure factors is under the direct control of the radiographer, and if performed consistently can reduce their occupational radiation exposure as well as that received by patients. There are various systems available for the selection of technical exposure factors; and these include both manual and automatic variables on computed and direct radiography equipment. Automatic exposure control (AEC) systems limit the length of the exposure, and thereby have some impact on overall radiation dose. AEC devices are also referred to as phototimers, and are programmed to terminate the radiographic exposure time at a predetermined value.

Today, most AEC systems consist of an ionization chamber that allows the x-ray exposure to continue until a satisfactory preset value has been achieved. Most AEC systems provide a way to manually set a backup timer. A backup timer should not be set to exceed the tube limit, and should be set at 150% of the anticipated manual mAs exposure.[5] The AEC system is not perfect, so there is a reaction or response time that must be considered in calibration of the unit. With both manual and AEC controlled x-ray exposure time, the radiographer must consider the patient's unique body size and shape, pathology, etc.

There is conflicting information about the proper selection of AEC chambers, and the correct positioning of the area of interest over the selected AEC chamber(s).[5] Both proper selection of the AEC chamber(s) and correct positioning of the patient are important. In conventional film-screen systems, once the exposure has been made, if the radiographer has not properly selected the technical factors, no corrections can be made. When computed or digital radiography is used, the radiographer may have an opportunity to make post-exposure image adjustments. This may provide an adequate image, but sometimes, in the case of an over exposure, may also deliver unnecessary radiation exposure to the patient.

Some AEC systems are designed in the form of anatomically programmed radiography (APR) systems.[5] With an APR system, the radiographer can select a particular anatomic part and position on the control panel, and the optimum milliampere-seconds (mAs) and kVp exposure factors are set by the system. Once displayed on the control panel, the radiographer may have controls that permit further adjustment. Some imaging systems provide both AEC and APR technical exposure controls. In this case, the radiographer may use the APR to set optimum kVp and mA, and the AEC to determine the exposure time. Radiographers are advised to continually review current technical and positioning references in regard to proper selection of AEC chamber(s), and positioning when using AEC chamber(s).

Adjustments to the Technical Exposure Factors

Conventional radiography of the musculoskeletal structures is generally required to determine if disease or injury is present. After initial examination, a patient may present for follow-up radiography that includes immobilization and stabilization devices such as casts and splints. Figure 3-5 provides some general suggestions for adjusting the technical exposure factors when such devices are involved; however, radiographers are advised to follow the protocols established for their imaging facility.

Device or Condition	KVp adjustment	mAs adjustment
Soft tissue injury with suspected foreign body	(minus) 15%-20% kVp	
Fluid in the joint area		(add) 35% mAs
Small-Medium plaster cast	(add) 5-7 kVp	(add) 50%-60% mAs
Large plaster cast	(add) 8-10 kVp	(add) 100% mAs
Fiberglass cast	(add) 3-4 kVp	(add) 25%-30% mAs

Fig. 3-5. Adjustments to the technical exposure factors.

Digital Radiography

"Increasingly, medical imaging and patient information are being managed utilizing digital data during acquisition, transmission, storage, display, interpretation, and consultation. The management of these data during each of these operations may have an impact on the quality of patient care."[6] The ACR *Practice Guideline for Digital Radiography* lists motivations for using digital radiography and several of these can be used to advantage in imaging the vertebral column.[6] The ACR list of motivations includes:

- *Significantly larger range of x-ray intensities that can be imaged by digital receptors compared to analog systems;*
- *Independence of displayed contrast from kVp setting through adjustment of the display window width;*
- *Independence of displayed brightness from mAs setting through adjustment of the display window level;*
- *The availability of image processing and computer aided detection (CAD) and diagnosis algorithms for image enhancement and analysis;*
- *Easier and more reliable generation of accurately labeled and identified image data;*
- *The ability to electronically transmit data to an appropriate storage medium from which it can be electronically retrieved for display for formal interpretation, review, and consultation; and,*
- *The ability to transmit data to remote sites for consultation, review, or formal interpretation.*[6]

The ACR states that the components necessary for the performance of high-quality digital radiography should include, but are not limited to:

- *Development of validated imaging protocols so that consistency of image quality and radiation dose can be established and maintained between rooms and between sites;*
- *Utilization of appropriate compression of image data to facilitate transmission or storage, without loss of clinically significant information;*
- *Archiving of data to maintain accurate patient medical records in a form that may be retrieved in a timely fashion;*
- *The ability to retrieve data from available prior imaging studies to be displayed for comparison with a current study;*
- *The ability to apply image processing for better display of acquired information;*
- *Adherence to applicable facility, state, and federal regulations;*
- *Maintenance of patient confidentiality;*
- *Minimization of the occurrence of poor image quality;*

- *Minimization of the delivery of inappropriate ionizing radiation dose to the patient; and,*
- *Promotion of clinical efficiency and continuous quality improvement.*[6]

The greatest advantage of digital radiography is that the steps of recording, displaying, and archiving an image are decoupled, providing the radiologist and radiographer the opportunity to optimize each task independently. In addition, the ability to display, archive, and transmit digital images may facilitate:

- Tele-radiology: Transmission of digital images to remote sites for purposes of off-site monitoring of diagnostic work-ups, interpretation, consultation, and conferencing;
- Computer-aided detection and diagnostic assistance to radiologists;
- Reduction in the number of repeats for technical reasons;
- More efficient storage and retrieval of images; and,
- Interventional techniques.

Teleradiology

Teleradiology consists of one or more digital imaging units linked by a network or common line to one or more remote display workstations. Provisions such as data encryption and authentication must be provided to ensure confidentiality. Transmission time can be reduced by image compression and may not be the only bottleneck in the teleradiology system.

Teleradiology has been credited with allowing interpretation of images by radiologists with the greatest expertise. This is an especially important benefit of teleradiology particularly in under-served rural areas where an experienced radiologist may be not available. The process has also proven beneficial when a second reader's opinion is required on certain cases. Consultation on difficult cases with experts anywhere in the world or within an organization allows improved and efficient communication among radiologists, surgeons, and oncologists.

There are dramatic differences among digital systems in the areas of imaging performance, patient radiation dose, workflow, and long-term costs. These and other advantages have been promoted as being superior in comparison to screen film imaging. Digital imaging has overcome the negative criticism of early skeptics and may prove to be a powerful tool in the battle to provide early diagnosis and treatment of diseases. As with any new technology, the advantages and disadvantages and any shortcomings will have to be considered and addressed before imaging facilities transition to digital imaging.

Computer Aided Diagnosis (CAD)

Early and accurate evaluation of musculoskeletal conditions and fractures is important for optimizing therapy and improving prognosis.[7] Computer aided diagnosis (CAD) or second reader is currently available in applications such as CT and conventional radiography; however development of CAD for MR imaging has proven to be a more complicated process than that of CT because of intensity inhomogeneity problems and higher noise levels.

CAD is defined as a diagnosis made by a radiologist who considers the output of a computer analysis of the image when making an interpretation. With CAD, radiologists use the computer output as a “second opinion” but make the final decision.[7] CAD is a concept established by taking into account equally the roles of physicians, whereas automated computer diagnosis is a concept based on computer algorithms only.[7] CAD is a technical method for the automated detection of lesions and various pathologies. With CAD, the performance by computers does not have to be comparable to or better than that by physicians, but needs to be complementary to that by physicians.[7] CAD has the potential to increase detection of cancer; however, it is the radiologist’s knowledge and interpretive skill that determines the final decision.[7]

Procedural and Positioning Considerations

Breathing and Motion Control

Certain imaging examinations require that the patient comply with either holding their breath or breathing in a certain manner (i.e., full inspiration, full expiration, or shallow breathing method). When giving breathing directions to the patient for certain radiography examinations of the hip, shoulder, clavicle, scapula, etc., the radiographer should take time to thoroughly instruct the patient. For example, when the shallow breathing method is used it is best that the radiographer explain what is being requested while demonstrating the maneuver. The radiographer should always take time to give clear directions to the patient, ask for their help and cooperation, and evaluate each patient as to their level of understanding and ability to cooperate.

The radiographer must recognize that breath and motion control during radiography, especially in the pediatric population, is critical to producing a diagnostic image. Adapting the exposure control factors to allow for the use of very short exposure times is one method used to help control motion in those unable to do so. However, use of effective immobilization devices that are available to hold the pediatric patient securely and safely in the required position is the gold standard in pediatric imaging.[17]

In an ideal situation, mechanical immobilization devices would be sufficient to assist the patient. Infants, young children, elderly, and critically ill or injured patients may require additional assistance. These patients are often unable to hold still during the exposure and may be unable to remain by themselves on the radiographic table or in an upright position. In these circumstances, someone must remain with the patient during the radiographic exposure. Radiographers should never stand in the path of the primary x-ray beam to restrain a patient during a radiographic exposure. The person chosen should **not** be pregnant or be concerned about the possibility of an undetected pregnancy.

The non-occupationally exposed person chosen to assist in holding a patient during a radiography examination should be provided with appropriate protective apparel. The most common available protective devices are impregnated with lead (i.e. aprons and gloves, glasses, and thyroid shields). Protective aprons and gloves are usually made of lead impregnated vinyl within the range of 0.25-1.0 mm of lead equivalency.[5] For x-ray exposures with a peak energy of 100 kVp, protective aprons must possess a minimum of 0.5 mm lead equivalency.[5] Additionally the radiographer should instruct the person as to how to assist in holding the patient and should also position the person so as to minimize their exposure to the primary x-ray beam. The radiographer should also make certain that the radiography room doors are closed when making x-ray exposures. This practice provides a substantial degree of protection for patients and staff who may be walking past the radiographic room.

Imaging the Upper & Lower Extremities

Introduction

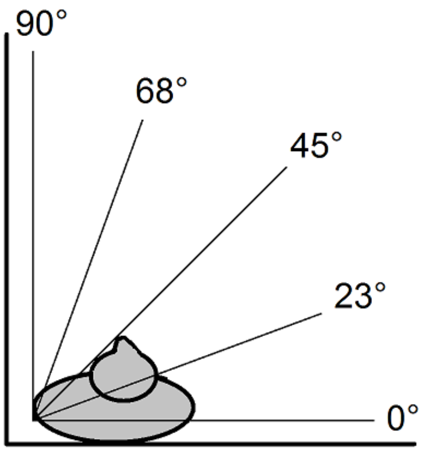
Initial radiography imaging protocols for imaging the musculoskeletal structures vary among facilities and there are numerous positioning references used by radiographers. Following a routine in preparing for radiography imaging examinations can help prevent unnecessary mistakes or omissions that may require a retake examination. Each radiographer often adapts the routine procedure to fit individual patient circumstances. The *Textbook of Radiographic Positioning and Related Anatomy,* *7th edition by* Kenneth L. Bontrager and John P. Lampignano has been used as a baseline for the basic radiography imaging protocols; however additional references have influenced the content of this section.[8-10]

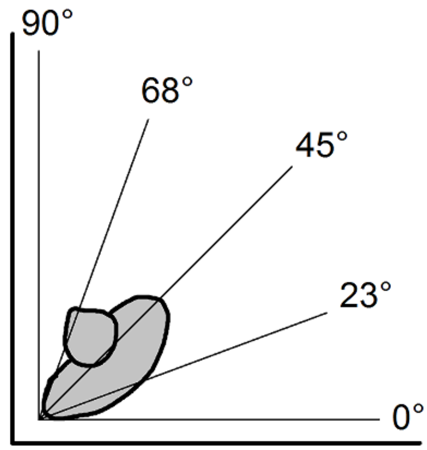
Bontrager and Lampignano lists standard imaging protocols of the extremities and also describes additional accessory images that may be used to demonstrate a particular structure or to alter the basic protocols to accommodate certain patient conditions.[8] As necessary, additional radiographic anatomy and positioning textbooks and references were used in this course and are cited as indicated.[9,10] The following provides an overview of the basic and accessory radiography imaging protocols for the musculoskeletal structures of the upper and lower extremities. Radiographers are advised to follow the imaging protocols posted by their employer and to consult current positioning references for additional information as needed or whenever questions arise about a specific imaging protocol.

Determining obliquity

One area that concerns all radiographers is determining the correct degree of obliquity required for specific positions and projections. Radiographers generally do not have a protractor available in the clinical setting so must rely on proven concepts to know when the correct obliquity is achieved. The first thing that radiographers should remember is that when the patient is in an AP/PA projection, the reference line is aligned parallel or zero degrees with the IR or radiography table. When the patient is positioned in a true lateral to the IR or radiography table, the reference line is at a 90 degree angle, Figure 3-6. For a 45 degree-oblique position, the anatomic part or the entire torso is positioned halfway between the AP/PA projection and the lateral position, Figure 3-7. For a 35 degree-oblique position from the IR or examination table, the anatomic part or the entire torso is positioned 10 degrees less from the 45 degree oblique position.

Radiography examinations of the extremities involve imaging the joints and often require precise flexion or extension for certain positions and projections. To accomplish this, radiographers need some reference point from which to work and just like determining the degree of obliquity, certain basic concepts can be applied. Radiographers are advised to start from the point when the extremity is in full extension and the degree of flexion is zero. When the two adjoining limbs are aligned perpendicular to each other, the degree of flexion is 90 degrees. When the anatomic part or limb is flexed halfway between zero and 90 degrees, a 45 degree flexion is achieved. A flexion of 68 degrees may be acquired when the anatomic part or limb is flexed halfway between 45 degrees and 90 degrees; a 23 degree flexion is halfway between full extension and the 45 degree position. Figure 3-8 provides a visualization of this concept.





Figs. 3-6 and 3-7. Estimating the degree of obliquity on the torso. Adapted from Figure 1.22:14. From Martensen. Radiographic Imaging Analysis. 2E. 2006. Elsevier Saunders. St. Louis, MO.

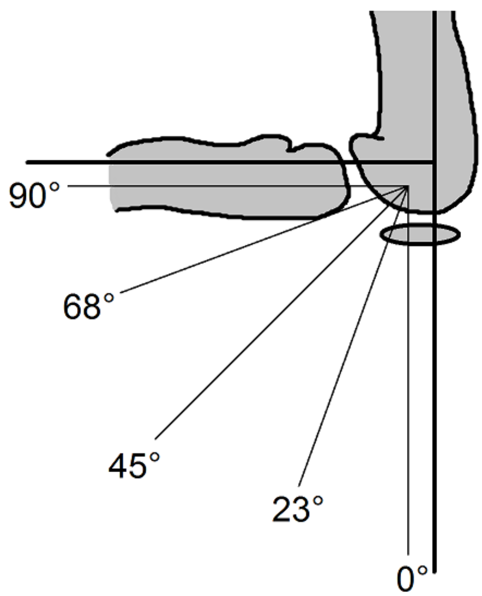


Fig. 3-8. Estimating the degree of obliquity on the knee joint. Adapted from Figure 1.22:14. From Martensen. Radiographic Imaging Analysis 2E. 2006. Elsevier Saunders. St. Louis, MO.

As a final note, all conventional radiography examinations of the extremities use the universal standard SID of 40 inches, unless otherwise stated. Collimation should be visible on all images and additional radiation protection measures should be used whenever possible. The radiographer should also take all necessary pre-exposure precautions to reduce patient movement during the exposure.

Fingers & Thumb

The basic radiography imaging protocol for fingers two through five include several projections (i.e., PA, PA oblique, and lateral) using a tabletop method. The anatomic structures demonstrated by the basic images are the distal, middle, and proximal phalanges; distal metacarpal; and associated joints. The ideal method of positioning the patient for the basic images of both the fingers and thumb is to seat the patient at the end of the radiography table, with the elbow flexed about 90 degrees and with the hand and forearm resting on the radiography table. Whenever possible the hand should be pronated with the fingers fully extended for all basic positions of the fingers. To aid in positioning a finger for the oblique position, the radiographer may use a 45 degree foam wedge block or step wedge to obtain the desired position and to help the patient "hold still". The oblique position should demonstrate the interphalangeal (IP) and the metacarpal phalangeal (MCP) joint spaces as open and without superimposition from adjacent fingers. A sponge or support block may also be used to obtain a true lateral position.

The central ray (CR) should be directed perpendicular to the image receptor (IR) at the location of the proximal interphalangeal (PIP) joint. Usually all three images of a finger can be taken on one image receptor; however, several radiographic positioning references suggest that a PA projection of the entire hand be acquired and then an oblique and lateral position of the injured digit be acquired on another film holder. On all images the radiographer should collimate the primary beam to within the four sides of the affected finger and for added protection a lead apron may be placed across the patient's lap.

The basic radiography imaging protocol for the thumb is an AP projection and a PA oblique, and a lateral position. For all three images of the thumb the CR is directed perpendicular to the IR, to the first metacarpal phalangeal joint (MCP).

Positioning for the AP thumb is awkward for most people and it is helpful if the radiographer uses their own hand to demonstrate the position to the patient. In some cases, the patient may be unable to execute the maneuver required to obtain an AP of the thumb and a PA projection may be acquired as an exception to the basic protocol. If the PA thumb projection is to be used a sponge support block will be needed to support the digit. The PA thumb projection is less than ideal because use of support block raises the thumb off of the image receptor, thus increasing the object to image receptor distance (OID) and resulting in loss of anatomic definition.

For the PA oblique projection of the thumb, the radiographer should gently abduct the thumb while maintaining the palmar surface of the hand in contact with the IR. For the lateral position of the thumb, the radiographer should first place the patient's hand in a pronated position with the thumb abducted, the radiographer should gently rotate the hand until the thumb is in a true lateral position.

Bontrager and Lampignano suggest a special projection (i.e., PA stress "skier's thumb") to demonstrate sprain or tearing of the ulnar collateral ligament of the thumb at the MCP joint, resulting from acute hyperextension of the thumb.[8] The projection may also be referred to as the Folio method and is obtained by having the patient control stress on the thumb during the examination. Supplies needed for the projection include a round spacer, such as a roll of tape and short rubber band. To obtain the PA stress image, the patient should be seated at the end of the radiography table with both hands extended and pronated on the IR. Prior to commencing the examination, the radiographer should explain to the patient that a rubber band will be placed around the thumbs and they will be asked to pull the thumbs apart (i.e. stress). Further, the patient should be told that they should try to exert the pulling pressure with as little movement as possible.

To begin the PA stress examination the patient should be asked to place both hands side by side to the center of the IR and rotated to such a degree as to acquire a true PA projection of both thumbs. The radiographer should place the round spacer between the proximal thumb regions and wrap the rubber band around the distal thumbs. The image should demonstrate the MCP and IP joints in an open position and there should be no rotation of the thumbs without obvious motion evident.

A special projection of the thumb (i.e., Modified Robert's method) may also be used to demonstrate fractures and/or dislocations of the first carpometacarpal (CMC) joint. Also the modified Robert's method may be used to image the base of the first metacarpal for evaluating Bennett's' fracture. The thumb is positioned in an AP projection with the fingers extended in such a manner that the soft tissue does not superimpose the first CMC joint. The radiographer should instruct the patient to hold the fingers aside with the other hand. The CR is directed 15 degrees toward the wrist, entering at the first CMC joint. The modified Robert's method should produce an AP image of the thumb and first CMC joint without superimposition of adjacent structures.

Hand

The basic radiography imaging protocol for the hand includes a PA projection, PA oblique, and a "fan" lateral position. Bontrager and Lampignano offer an alternative method of a lateral hand in extension and flexion when a patient's condition does not accommodate positioning for a "fan" lateral.[8]

The PA projection of the hand demonstrates the entire hand and wrists and about one inch of the distal forearm. For both the PA projection and the PA oblique position, the CR is directed perpendicular to the IR at to the 3rd MCP joint. A 45 degree wedge support or step block may be used to obtain an acceptable degree of obliquity of the hand. For the "fan" lateral, the hand and wrist are rotated into a lateral position with the thumb side up. The patient should be instructed to spread the fingers and thumb into a "fan" position. If a sponge-positioning block is available, it makes it easier for the patient to maintain the "fan" position without movement. The CR is directed perpendicular to the IR at the second MCP joint. When evaluating a "fan" lateral, the entire hand and wrist should be visible and the fingers should appear equally separated, with the phalanges in the lateral position and the joint spaces open.

An alternative to the "fan" lateral is a lateral hand in extension and flexion. Both the "fan" lateral and its alternative are ideal for localization of foreign objects in the hand and fingers and also for demonstrating anterior or posterior displaced fractures of the metacarpals. To accomplish the "fan" alternative, the hand is placed in a true lateral position. For the extension image, the fingers and thumb are extended and for the flexion image, the patient is asked to flex the fingers into a natural flexed position with the thumb touching the first finger. A special examination, the Norgaard method, sometimes referred to as "Ball Catcher's Position" may also be used to evaluate for early evidence of rheumatoid arthritis at the second through the fifth proximal phalanges and MCP joints, Figure 3-9.

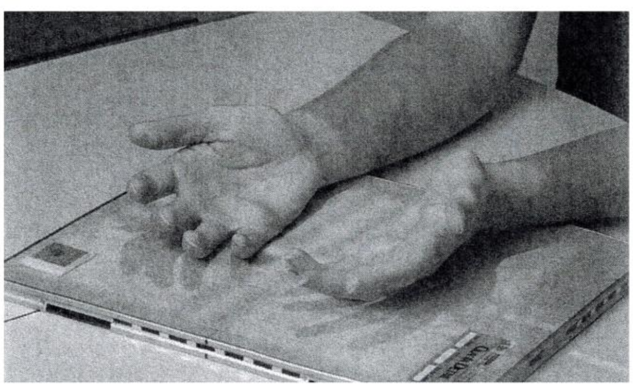


Fig. 3-9. Norgaard hand. From Greathouse. Delmar's Radiographic Positioning Volume 1, 1E © 1998 Delmar Learning, a part of Cengage Learning, Inc. Reproduced by permission. www.cengage.com/permissions.

Wrist

The basic radiography imaging protocol for the wrist includes a PA projection, PA oblique, and lateral position. Because the wrist is commonly the site of injury there are several special or accessory projections and positions available in the imaging arsenal.

For basic projections of the wrist, the patient is positioned at the end of the radiographic table with the elbow of the affected side flexed 90 degrees and the hand and wrist resting on the IR with the palm down. The patient should be asked to slightly lower the shoulder on the affected side to allow the shoulder, elbow, and wrist to rest at about the same horizontal level. Further, the radiographer should check that the wrist and carpal area are in close contact with the IR.

For the PA oblique image, the hand and wrist should be gently rotated 45 degrees laterally. A 45 degree sponge block may be used under the hand and wrist to support the wrist and aid in immobilization during the examination. A true lateral position is part of the basic imaging protocol for the wrist. The purpose of a true lateral is to assist in visualization of fractures and dislocations specifically in the wrist. The lateral image also provides information about anteroposterior dislocations of Barton's, Colle's, or Smith's fractures. A true lateral wrist image illustrates the ulnar head superimposed over the distal radius.

Of all the carpal bones, the scaphoid is the most frequently fractured, accounting for 60-70% of all carpal fractures. So, many of the special or accessory imaging examinations of the wrist are to provide visualization of the scaphoid bone. Two such special imaging examinations include the PA axial scaphoid with ulnar deviation and the modified Stecher method. To assist in the diagnosis of carpal tunnel syndrome, several special imaging examinations are available and include a tangential, inferosuperior projection (i.e., carpal canal or tunnel) and a tangential projection or carpal bridge projection.

Radiographers are usually cautioned not to attempt any manipulation like that required in the PA axial scaphoid with ulnar deviation if a wrist fracture is suspected. Before any special or accessory imaging examinations of the wrist are attempted, the usual procedure is to obtain the basic images first. For the PA axial scaphoid with ulnar deviation the patient is prepared as for a basic PA projection of the wrist. The radiographer should then gently evert the patient's hand without moving their forearm. The CR is angled 10 to 15 degrees proximally toward the elbow. The CR should be centered over the scaphoid bone. This imaging method allows the scaphoid to be demonstrated clearly and without foreshortening, Figure 3-10.

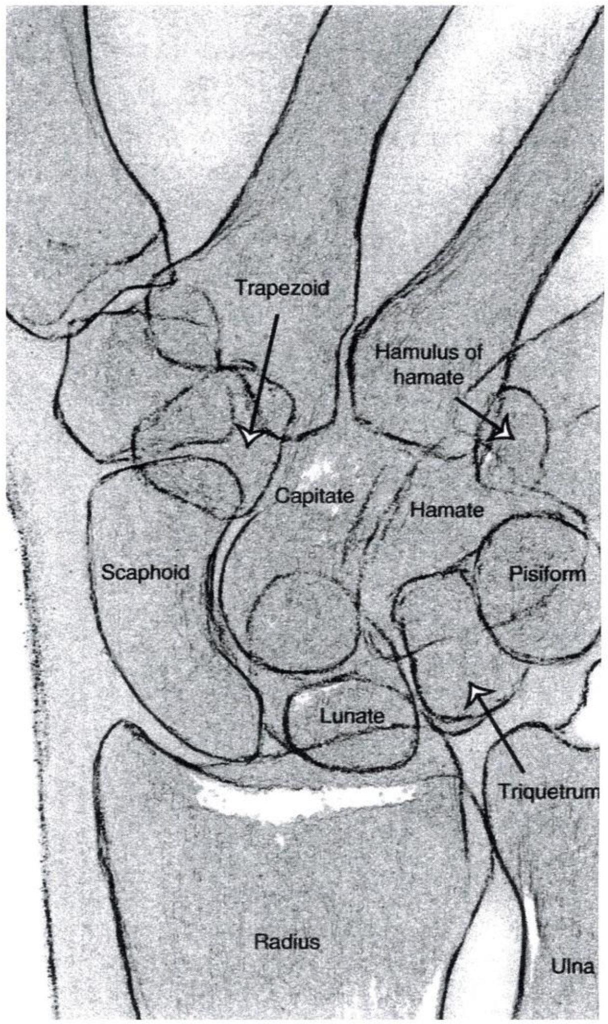


Fig. 3-10. Scaphoid wrist. Delmar's Radiographic Positioning Volume 1, 1E © 1998 Delmar Learning, a part of Cengage Learning, Inc. Reproduced by permission. www.cengage.com/permissions.

For a modified Stecher method, the part is positioned as in the PA axial scaphoid position, except the hand is elevated on a 20 degree angle sponge. The CR is directed perpendicular to the IR and enters at the scaphoid bone. The Stecher method is an alternative to PA axial scaphoid method. To demonstrate fractures of the carpal bones on the ulnar side of the wrist, a PA projection with radial deviation may be obtained. In this examination, the radiographer should gently invert the hand as far as is comfortable for the patient. The lunate, triquetrum, pisiform, and hamate carpal bones are well demonstrated in the radial deviation imaging examination.

When pathology such as median nerve damage is suspected in carpal tunnel syndrome, a tangential inferosuperior (carpal canal or tunnel) projection may be obtained, Figure 3-11. This particular examination also demonstrates fractures of the hamulus process of the hamate, pisiform, and trapezium carpal bones. The patient's assistance in hyperextension of the hand is essential to obtaining a quality image of the carpal canal. The radiographer may want to first demonstrate on his or her own hand and wrist what is expected. The patient should be asked to hyperextend the wrist as far as possible by grasping the fingers with the unaffected hand. Once this is accomplished, the radiographer should gently rotate the entire hand and wrist about 10 degrees internally (toward the radial side). This slight rotation helps to prevent superimposition of the pisiform and hamate.

When a tangential view of the dorsal aspect of the scaphoid, lunate, and triquetrum is needed a tangential projection (carpal bridge) of the wrist may be obtained, Figure 3-12. The patient may be allowed to stand or sit at the end of the examination table and then is asked to lean over and place the dorsal surface of the hand with the palm upward on the IR. The central ray is angled 45 degrees to the long axis of the forearm and should enter at a midpoint on the distal forearm or about one and one half inches proximal to the wrist.

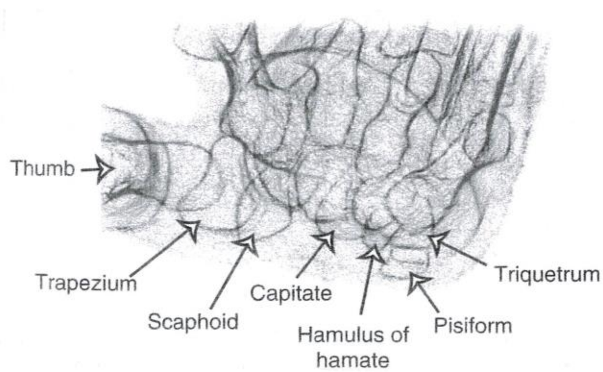


Fig. 3-11. Tangential: Carpal canal. Delmar's Radiographic Positioning Volume 1, 1E © 1998 Delmar Learning, a part of Cengage Learning, Inc. Reproduced by permission. www.cengage.com/permissions.

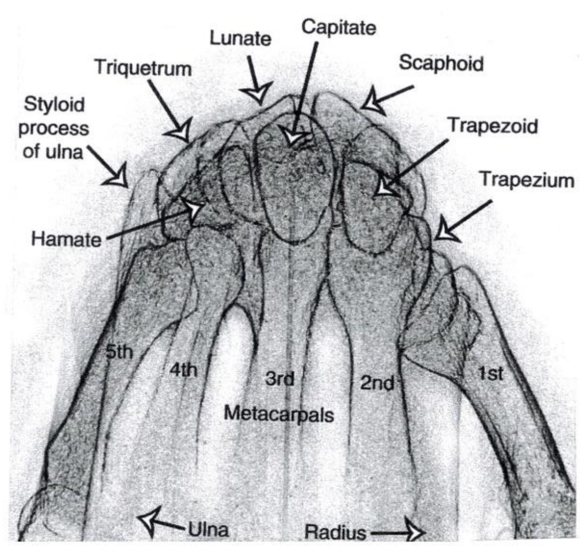


Fig. 3-12. Tangential: carpal bridge. Delmar's Radiographic Positioning Volume 1, 1E © Delmar Learning, a part of Cengage Learning, Inc. Reproduced by permission. www.cengage.com/permissions.

Forearm

The forearm consists of the radius and ulna and is bounded by the wrist and elbow joint. The basic radiography imaging protocol includes an AP and a lateral of the forearm projections, which should include the articulating joints. Additionally the soft tissues including the fat pads and stripes of the wrist and elbow joints should be demonstrated on each image. Radiographers need to position the hand and wrist into a true lateral position, which means that the arm, wrist and hand rest of the medial side of the arm and that the CR is perpendicular to the IR and enters the mid-forearm.

Elbow

The elbow joint, like the wrist joint, is commonly the site of injuries and basic imaging examinations are first conducted prior to performing accessory examinations. The basic imaging protocol for the elbow is AP, oblique with internal and external rotation, and lateral. Special or accessory imaging examinations such as acute flexion or the Jones method, trauma axial laterals, and radial head laterals are all available when specific injuries or fractures are suspected. For imaging examinations of the elbow, the patient should be seated at the end of the radiography table. For the AP projection, the patient should be asked to fully extend the arm and elbow, if possible. The elbow joint should be centered on the IR with the CR directed perpendicular to the IR at the mid elbow joint. If the patient cannot fully extend the arm and elbow, the radiographer is advised to obtain two AP projections, one with the forearm parallel to the IR and one with the humerus parallel to the IR.

For internal and external oblique positions of the elbow, the patient should be asked to fully extend the arm while keeping the shoulder and elbow on the same horizontal level. From this position, the radiographer should make sure that the hand is supinated and should gently rotate the entire arm laterally so that both the distal humerus and anterior surface of the elbow are rotated about 45 degrees. The image should demonstrate the radial head, neck, and tuberosity with superimposition of the ulna.

For the internal rotation, the radiographer should determine that the hand is pronated and should gently rotate the arm until the distal humerus and anterior surface of the elbow are rotated at about 45 degrees. The image should demonstrate the coronoid process of the ulna in profile and the radial head and neck should be superimposed and centered over the proximal ulna.

To produce a true lateromedial projection of the elbow the entire arm, wrist, and hand must rest on the medial surface and be aligned. To rest and align the upper part of the arm, the radiographer can gently move the patient's shoulder downward so that the humerus and forearm are on the same horizontal level.

A special imaging examination referred to, as the Jones method, consists of two AP projections of the elbow in acute flexion, Figure 3-13.

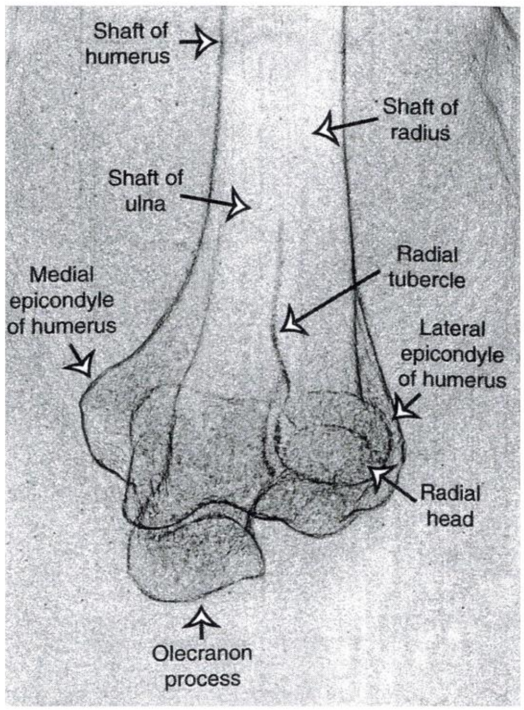


Fig. 3-13. Acute flexion elbow. Delmar's Radiographic Positioning Volume 1, 1E

The first projection of the Jones' method is made with the CR perpendicular to the IR and humerus, at a point midway between the epicondyles. The second projection is made with the CR perpendicular to the forearm. To accomplish the exact CR entrance location, the x-ray tube must be angled until CR reaches the entrance, which is at a point approximately two inches proximal or superior to the olecranon process. A properly executed Jones method will demonstrate the proximal ulna and radius, including an outline of the radial head and neck through the superimposed distal humerus.

The Coyle method is used when the patient cannot fully extend the elbow on the medial or lateral oblique positions, Figures 3-14 and 3-15.

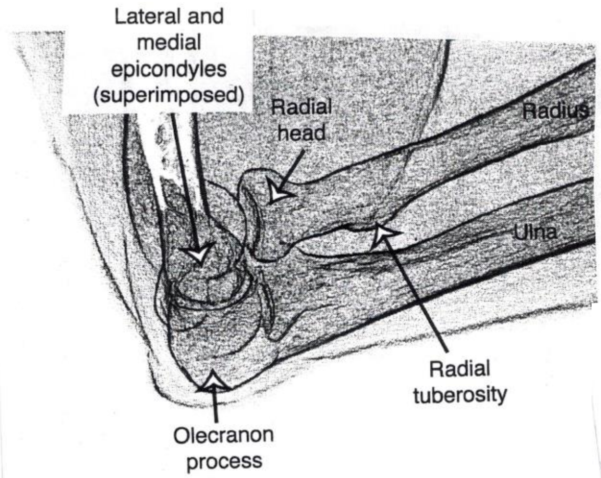


Fig. 3-14. Trauma oblique elbow for the radial head. Delmar's Radiographic Positioning, Vol. E, 1E; 1998 Delmar Learning. Reproduced by permission. www.cengage.com/permissions.

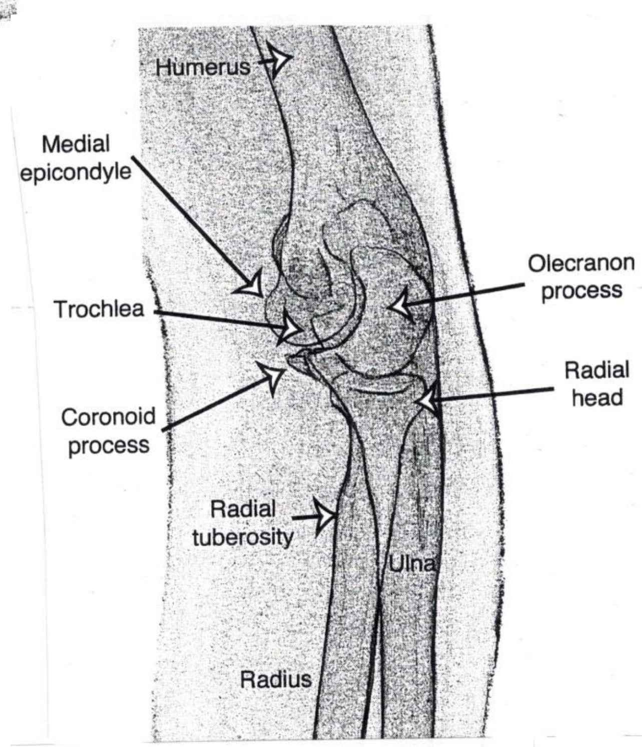


Fig. 3-15. Trauma oblique elbow for the coronoid process. Delmar's Radiographic Positioning, Vol. E, 1E; 1998 Delmar Learning. Reproduced by permission. www.cengage.com/permissions.

There are several approaches that may be used to achieve the Coyle method. These include different combinations of elbow flexion combined with various degrees of CR angulation. For example, to demonstrate the radial head, Bontrager and Lampignano suggest that the patient's hand be placed in a pronated position and the elbow flexed to 90 degrees, if possible. The CR should be directed at a 45 degree angle toward the shoulder.[8] Recommendations to demonstrate the coronoid process include the hand in a pronated position, elbow flexed "only" 80 degrees, and the central ray directed at a 45 degree angle from the shoulder into the mid elbow joint. Radiographers are encouraged to consult radiographic anatomy and positioning references to view the various configurations that may be used to accomplish the Coyle method and an alternative method referred to as radial head laterals.

Humerus & Shoulder Girdle

The basic radiography positioning protocol for the humerus consists of an AP and a rotational lateral and an AP internal and external rotation projection for the shoulder. Radiographers are cautioned to not attempt to rotate or manipulate the arm or shoulder if fracture or dislocation is suspected. Radiographic examinations of the humerus and shoulder may be made with the patient in either the supine or erect position. For the AP projection of the humerus, once the patient's body is in alignment, the radiographer should gently rotate the body toward the affected side, which brings the shoulder and proximal humerus in close contact with the IR. The hand must remain in a supinated position. The CR should be perpendicular to the IR and directed to enter midpoint of the humerus. For the rotational lateral projection of the humerus may be acquired by either a lateromedial or mediolateral rotation of the arm. As with the AP projection, the radiographer should gently rotate the body toward the affected side in order to bring the humerus and shoulder in contact with the IR. Patients who arrive holding their arm or in cases where trauma is suspected, the arm should not be manipulated and radiographers are advised to take requested radiography examinations "as is". In such cases, adequate images of the humerus may be obtained by taking a trauma horizontal beam lateral or a transthoracic lateral projection, Figure 3-16.

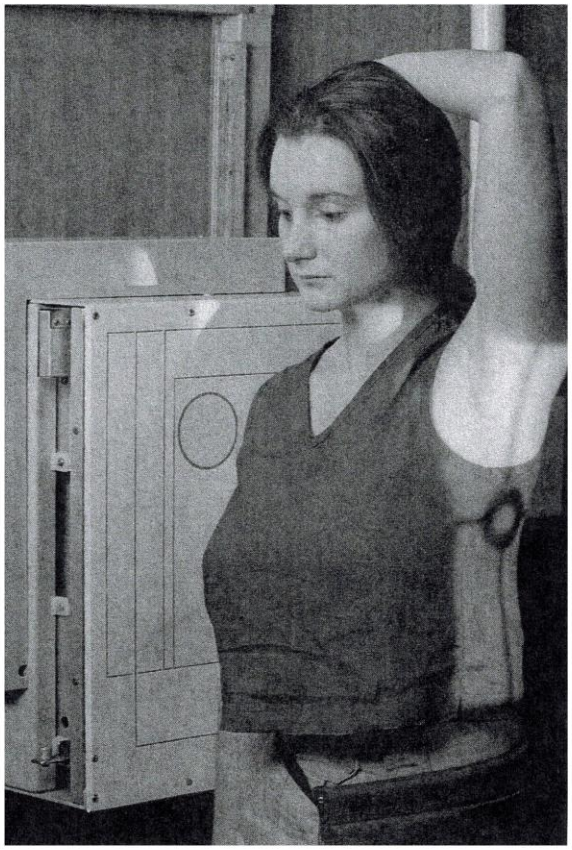


Fig. 3-16. Trauma lateral humerus. Delmar's Radiographic Positioning Volume 1, 1E © 1998 Delmar Learning, a part of Cengage Learning, Inc. Reproduced by permission. www.cengage.com/permissions.

Generally, the trauma horizontal beam projection produces a lateral image that demonstrates the humerus from the mid to the distal portion, including the elbow joint. The transthoracic lateral projection demonstrates the entire humerus and glenohumeral joint. Because the anatomy must be demonstrated through the thorax, motion from respiration is a concern; so, the preferred breathing method is for the radiographer to ask the patient to breathe gentle short, shallow breaths (i.e., shallow breathing method), Figure 3-17.

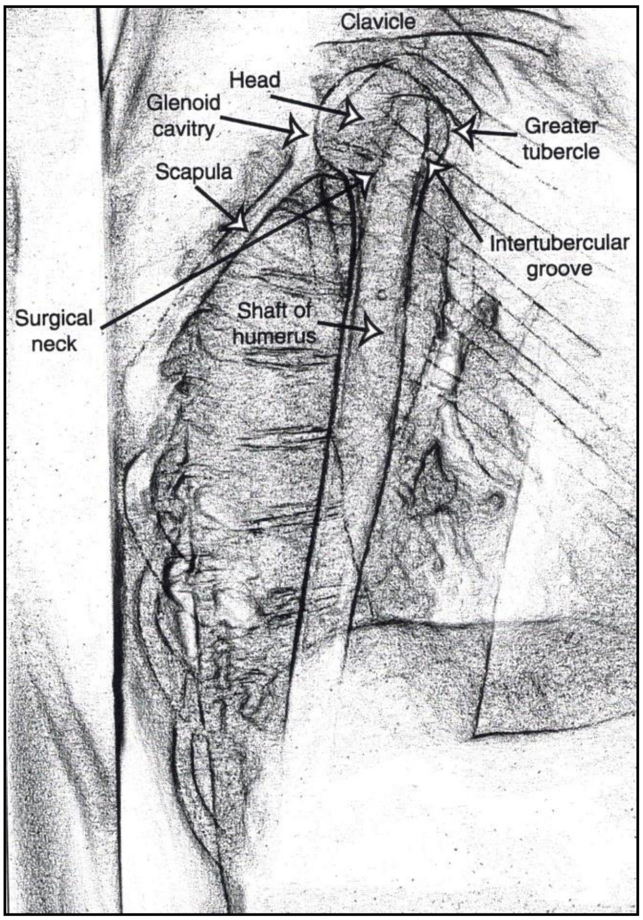


Fig. 3-17. Trauma lateral humerus for coronoid process. Delmar's Radiographic Positioning Volume 1, 1998 Delmar Learning, a part of Cengage Learning, Inc. Reproduced by permission. www.cengage.com/permissions.

The radiography imaging protocol for the shoulder on patients who are classified as being "nontrauma" is internal and external rotation and the examination may be performed with the patient erect or supine. Once the patient is in position, the radiographer should gently abduct the extended arm and then internally rotate the arm for the first projection and then for the second projection, the arm should be gently externally rotated. The CR for both projections should be directed perpendicular to the IR and should enter one inch inferior to the coracoid process. The patient should be instructed to suspend respiration during the exposure.

An inferosuperior axial projection, the “Lawrence method,” may be used to demonstrate a lateral view of the proximal humerus in relationship to the scapulohumeral cavity. This projection is also useful for demonstrating a Hill-Sachs defect, an anterior dislocation of the humeral head resulting in a compression fracture of the articular surface of the humeral head. This is a “nontruma” type position requiring that a sponge support be placed under the affected shoulder raising it about two inches from the tabletop. The affected arm is abducted about 90 degrees from the body and the CR should be directed 25 to 30 degrees to enter at a point horizontally to the axilla and humeral head. If the patient cannot abduct the arm fully, the x-ray tube angle should be decreased to 15 to 20 degrees. The patient should be instructed to suspend respiration.

There are several additional special projections of the shoulder that may be acquired to demonstrate specific anatomy. These include the Hobbs modification (superoinferior PA transaxillary projection) to demonstrate the proximal humerus in relationship to the glenohumeral articulation and the Clements modification (inferosuperior axial projection) to demonstrate the proximal humerus in relationship to the scaphulohumeral cavity. Both the Hobbs and Clements modification projections require manipulation of the arm and shoulder joint and should not be attempted when a fracture or dislocation is suspected. The Grashey method is used when the desired outcome is to visualize the glenoid cavity without superimposition of the humeral head. Generally, for the Grashey examination, the patient is in an erect AP position with the entire body rotated 35 to 45 degrees toward the affected side. The patient’s entire body should be aligned and the projection is referred to as a posterior oblique position with an AP projection. The patient’s affected arm should be slightly abducted so that the arm is in a neutral rotated position. The CR is directed perpendicular to the IR and enters the scaphulohumeral joint. The patient

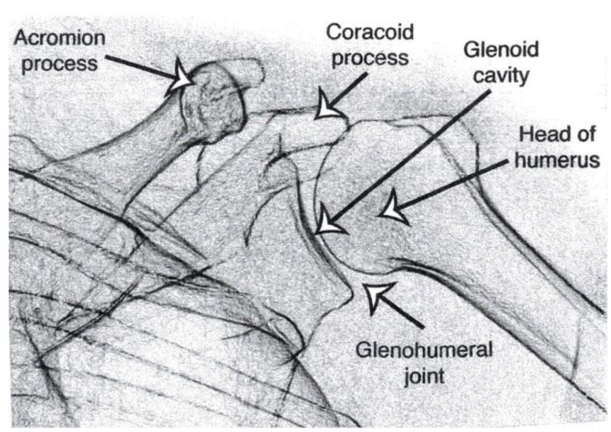


Fig. 3-18. Shoulder, glenoid cavity. Delmar's Radiographic Positioning Volume 1, 1E © 1998 Delmar Learning, a part of Cengage Learning, Inc. Reproduced by permission. www.cengage.com/permissions.

should be asked to suspend respiration
during the exposure, Figure 3-18.

A transthoracic lateral projection of the shoulder may be obtained when fracture or dislocation of the shoulder is suspected. Although a transthoracic lateral projection may be obtained in the supine position, the erect position may be easier for the patient to assume. Because a transthoracic projection of either the humerus or shoulder is obtained by imaging the part through the thorax, there is always a concern about superimposition of the ribs and lung structures. To aid in obscuring this anatomic superimposition, the radiographer can request that the patient breathe short, shallow breaths and to "not move, but remain still" during the exposure. For patients who cannot adequately drop the injured shoulder and elevate the uninjured shoulder high enough to avoid superimposition, the radiographer may angle the x-ray tube 10 to 15 degrees cephalad to achieve the desired effect.

Scapula

The scapula forms the posterior portion of the shoulder girdle and is a flat triangular bone with three borders, three angles, and two surfaces that pose certain positioning challenges to the radiographer. Generally for patients presenting with shoulder trauma or pain, the basic imaging protocol of an AP with neutral rotation and a transthoracic lateral are obtained prior to acquiring additional special projections of the scapula region, Figure 3-19.

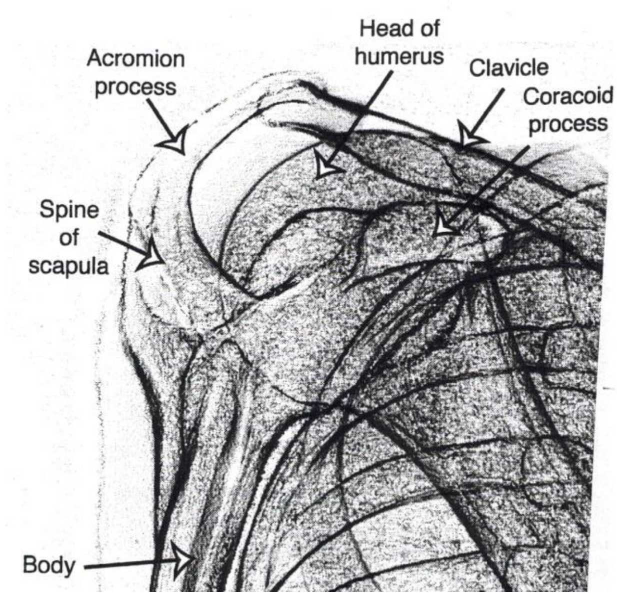


Fig. 3-19. Lateral scapula. Delmar's Radiographic Positioning Volume 1, 1E; © 1998 Delmar Learning, a part of Cengage Learning, Inc. Reproduced by permission. www.cengage.com/permissions.

The scapular Y lateral projection with the patient in an anterior oblique position is obtained to demonstrate a true lateral view of the scapula, proximal humerus, scapulohumeral joint, and the coracoid process.

The erect position is usually more comfortable for the patient and often easier for the radiographer to manage. The patient faces the IR and the radiographer arranges the entire body into an anterior oblique position. The affected side will be closest to the IR with the unaffected side of the body rotated away from the IR at a 45 to 60 degree oblique position. Each patient will present with a unique body habitus so the radiographer must palpate the scapular borders to determine the exact degree of rotation necessary to move the scapula into a true lateral position. The scapulohumeral joint should be centered to the IR and the CR should be directed perpendicular to the IR and should enter the scapulohumeral joint at a point about two or two and one half inches below the top of the shoulder. The patient should be instructed to suspend respiration during the exposure. The ideal result will be an image that demonstrates the thin body of the scapula with superimposition.

There are numerous special or additional projections that may be used to demonstrate specific anatomic areas of the humeral head, glenoid cavity, and the scapula. These are generally associated with suspected trauma and require various x-ray tube angulations to visualize specific anatomic details. Radiographers are advised to consult available radiographic positioning references to gain competency in the many available special or additional projections for the shoulder and humerus.

Clavicle & Acromioclavicular Joints

The basic radiography positioning protocol for the clavicle is AP and AP axial. The basic positions may be obtained with the patient in either an erect or supine position. The patient should be arranged so as to center the clavicle to the IR. The radiographer should ask the patient to place their arms at the sides, chin raised, and looking straight ahead. The posterior side of the shoulder should be in contact with the IR to avoid image magnification. For the AP projection the CR should be directed perpendicular to the midclavicle.

The AP axial projection of the clavicle requires that the CR be directed 15 to 30 degrees cephalad with the patient in the same alignment as for the AP projection. The patient should be asked to suspend respiration during the exposure. A properly executed AP axial projection should demonstrate most of the clavicle above the scapula and ribs; whereas in the AP with no x-ray tube angulation, the entire clavicle, including both acromioclavicular and sternoclavicular joints will be demonstrated.

The radiography imaging protocol for the acromioclavicular joints (AC) includes bilateral AP projections with weights and without weights, Figure 3-20.

If injury to the shoulder is suspected, the radiographer may obtain an AP projection of the AC joints first as a scout image. After review of the image, if no injury is evident, the examination with weights may be performed. To obtain bilateral AC joints two 8 x 10 inch (18 x 24 cm) cassettes arranged in a crosswise position are used for the examination.

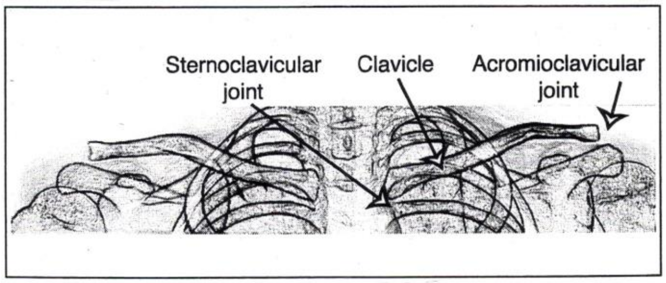


Fig. 3-20. AP acromioclavicular joints. Delmar's Radiographic Positioning Volume 1, 1E; © 1998 Delmar Learning, a part of Cengage Learning, Inc. Reproduced by permission. www.cengage.com/permissions.

The radiographer should fully acquaint the patient with the requirements of the examination and the importance of "not moving" during the exposure. Once the patient's body is aligned with the posterior shoulders against the cassette or IR, the first examination without weights is obtained. For the second examination equal weights are used. Prior to handing the weights to the patient, the radiographer should confirm that the patient's entire body is in alignment. The CR for both projections is centered perpendicular to the IR and should enter at a midpoint between the AC joints. The patient should be asked to suspend respiration during the exposure.

Toes & Foot

The basic radiography imaging protocol of the toes (digits one through five) includes an AP and AP oblique projection and lateral position (mediolateral projection). Whether to include all of the toes and distal metatarsals or to only include the specific digit being examined on the image is a matter of individual facility protocol and radiographers are advised to follow the established routine. Depending on the established routine, the radiographer may either acquire all three projections on one IR that is 8 x 10 inches (19 x 24 cm) or use two IRs for all of the projections. If using one IR for all 3 projections, precise collimation and the use of lead masking will generally be necessary. For the AP projection, a 15 degree wedge is used under the foot to attain parallel part to film alignment. In cases where a wedge is not available, as an alternative, the radiographer may angle the x-ray tube so that the CR is directed 10 to 15 degrees toward the calcaneus. The CR should enter the metatarsal phalangeal (MTP) joint of the toe being examined. For the oblique AP projection, the radiographer should gently rotate the patient's leg and foot 30 to 45 degrees medially for the first, second, and third digits and laterally for the fourth and fifth digits. If available, a 45 degree support sponge will provide stability for the foot in this position and aid in reducing movement during the exposure. For both the AP and AP oblique projections, the digit being examined should be seen on the image with superimposition of other digits.

A lateral projection of the toes is often strategically difficult to obtain due individual patient limitations, Figure 3-21.

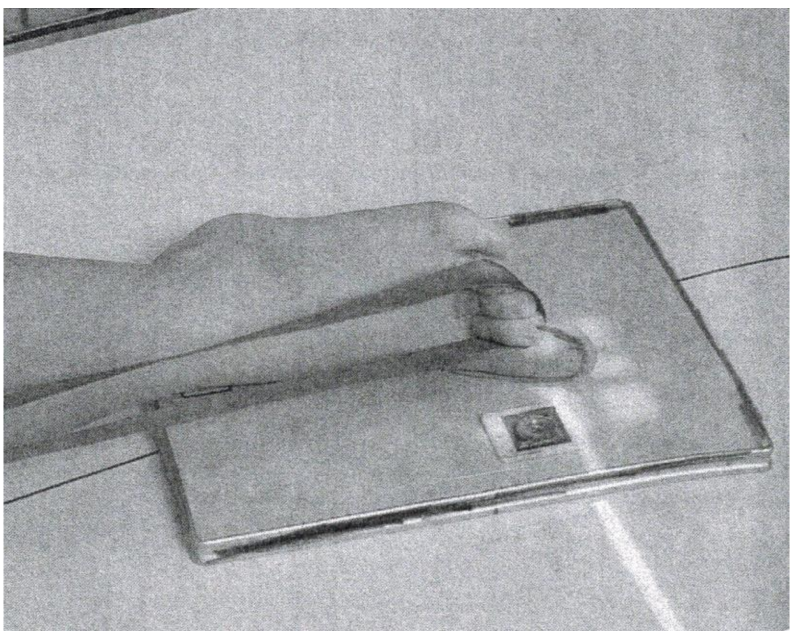


Fig. 3-21. Lateral great toe. Delmar's Radiographic Positioning Volume 1, 1E, © 1998 Delmar Learning, a part of Cengage Learning, Inc. Reproduced by permission. www.cengage.com/permissions.

The digit being examined will dictate whether a mediolateral or a lateromedial projection is attempted. A lateromedial lateral projection should be obtained if the site of injury is the first, second, and third digits and a mediolateral lateral projection are used for imaging the fourth and fifth digits. The radiographer will need to advise the patient on how to restrain the toes that overlap the affected digit. Tape, gauze, or a toe depressor may be used as restraining tools. Once the restraining tool is in place, the radiographer should work quickly to obtain to finish the examination because the position may be awkward or uncomfortable for the patient to maintain.

In certain cases, the radiographer may be requested to demonstrate the sesamoid bones at the first metatarsal phalangeal (MTP) joint. A tangential projection may be acquired with the patient in the prone position or as an alternative the patient may assume a supine position, Figure 3-22.

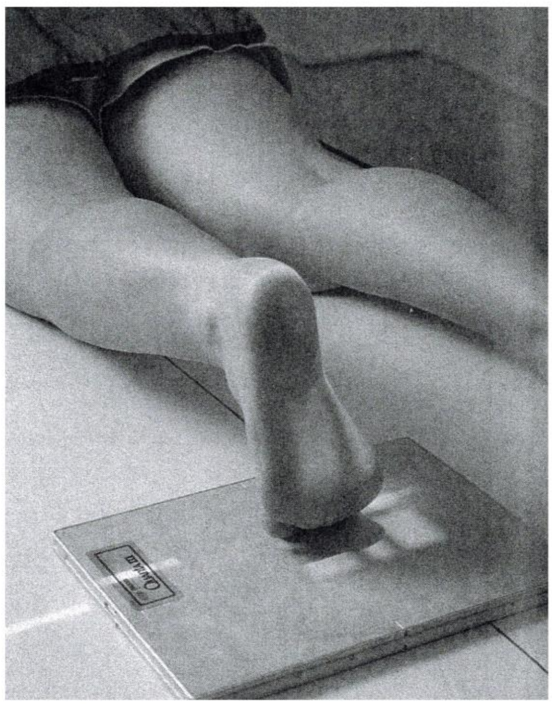


Fig. 3-22. Tangential sesamoids. Delmar's Radiographic Positioning Volume 1, 1E © 1998 Delmar Learning, a part of Cengage Learning, Inc. Reproduced by permission. www.cengage.com/permissions.

In the prone position, the radiographer should gently assist the patient to dorsiflex the foot until the plantar surface of the foot forms a 15 to a 20 degree angle from the vertical surface. The CR should be directed perpendicular to the IR and should enter the posterior aspect of the first MTP joint. With the patient in the final position with no rotation of the foot, the radiographer should work quickly to make the exposure. The objective of the tangential projection of the toes is to demonstrate the sesamoids in profile and free of superimposition.

The basic radiography imaging protocol of the foot includes AP (dorsoplantar projection), oblique (medial rotation), and a lateral. The AP projection of the foot requires that the x-ray tube be angled 10 degrees posteriorly so that the CR enters at the base of the third metatarsal. An ideal AP foot image will include the entire foot including all phalanges and metatarsals and the navicular, cuneiforms, and cuboids, Figure 3-23.

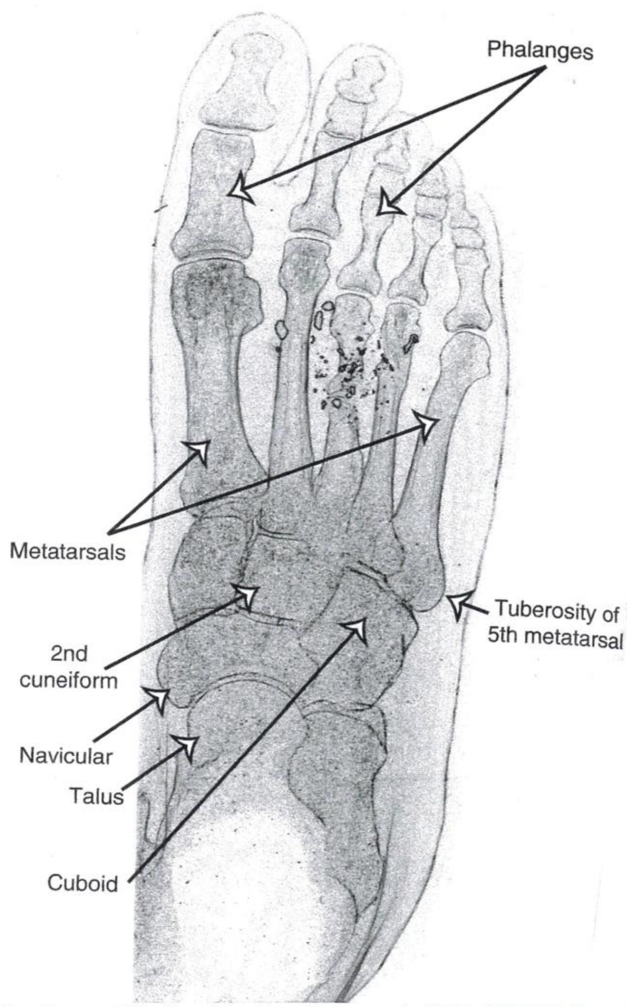


Fig. 3-23. AP foot. Delmar's Radiographic Positioning Volume 1, 1E © 1998 Delmar Learning, a part of Cengage Learning, Inc. Reproduced by permission. www.cengage.com/permissions.

For the AP oblique projection, the radiographer should gently rotate the patient's foot medially about 30 to 40 degrees. The CR should be directed perpendicular to the IR and should enter at the base of the third metatarsal. In addition to the entire foot, the posterior calcaneus and talus are demonstrated on the AP oblique projection of the foot.

Radiographers are advised to follow their facility protocol on the degree of obliquity of the foot for this projection since this may differ from what has been recommended in this course. The difference between 30 degrees obliquity and 40 to 45 degrees is that the greater degree of obliquity provides the best visualization of the tarsals and proximal metatarsals free of superimposition for a foot with an average transverse arch, Figure 3-24.

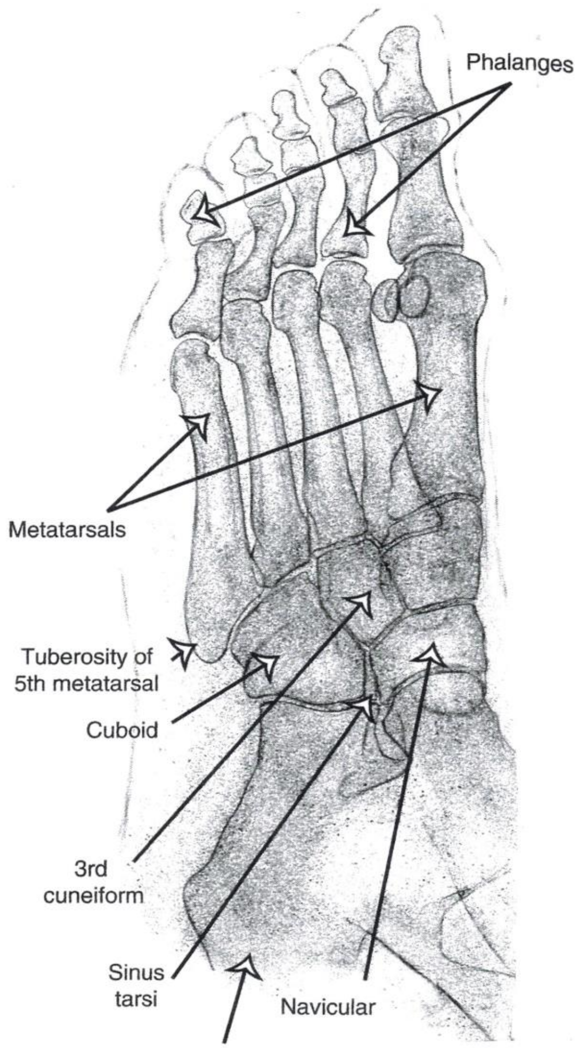


Fig. 3-24. Oblique foot. Delmar's Radiographic Positioning Volume 1, 1E © Delmar Learning, a part of Cengage Learning, Inc. Reproduced by permission. www.cengage.com/permissions.

For the lateral projection of the foot, the patient should be assisted onto the radiographic table and should roll onto the affected side with the knee flexed about 45 degrees. The lateral side of the affected foot should be positioned on the IR and the uninjured limb should be behind the body for support. The radiographer will need to adjust the patient until a true lateral position of the foot is achieved. The CR should be directed perpendicular to the IR and enter the medial cuneiform (i.e., at about the base of the third metatarsal). The projection demonstrates the entire foot and should be free of superimposition.

Because the calcaneus is not demonstrated in either the AP or AP oblique projections of the foot, special or accessory images may be requested. The plantodorsal (axial) projection and a lateral with the calcaneus centered to the IR are ideal examinations to provide detail of the entire calcaneus, Figure 3-25.

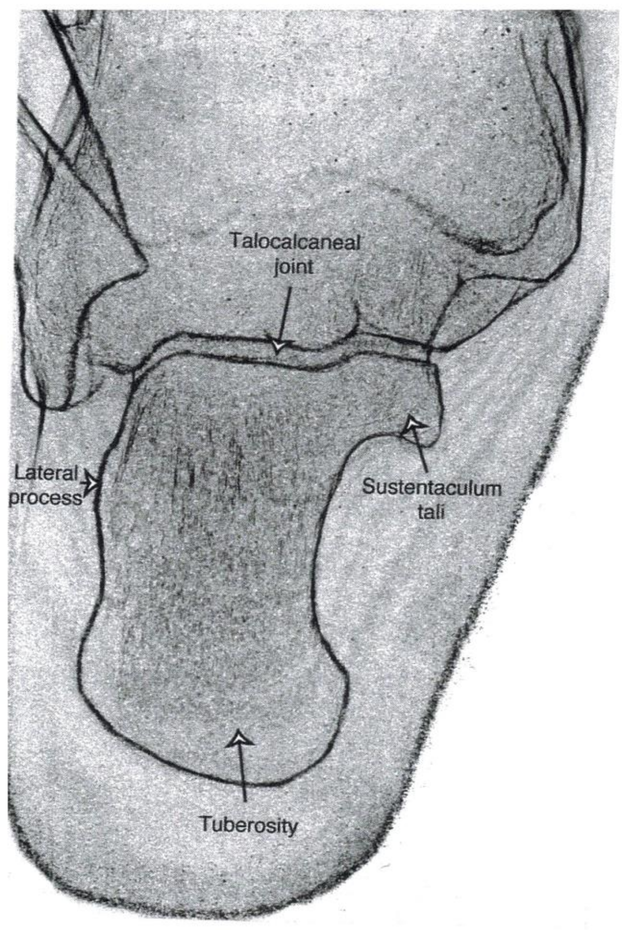


Fig. 3-25. Axial calcaneus. Delmar's Radiographic Positioning Volume 1, 1E © 1998 Delmar Learning, a part of Cengage Learning, Inc. Reproduced by permission. www.cengage.com/permissions.

The patient may be assisted onto the radiographic table and may either assume a supine or seated position with the affected leg extended, Figure 3-26.

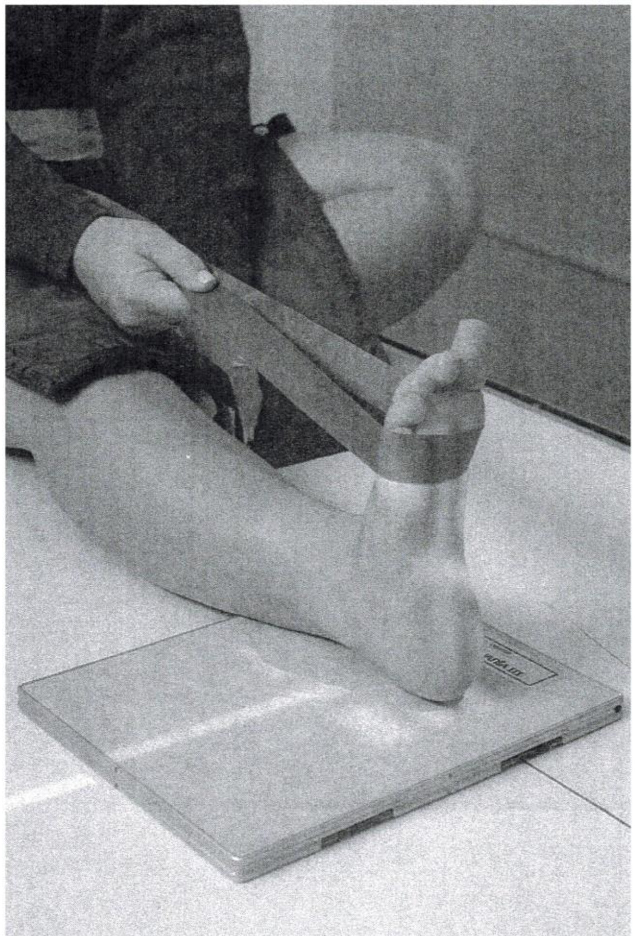


Fig. 3-26. Axial calcaneus. Delmar's Radiographic Positioning Volume 1, 1E © 1998 Delmar Learning, a part of Cengage Learning, Inc. Reproduced by permission. <u>www.cengage.com/permissions.</u>

After the calcaneus is centered to the IR, the radiographer should gently wrap a gauze or tape loop around the upper part of the foot and ask the patient to pull gently when instructed. The x-ray tube should be angled about 40 degrees cephalad; the CR should enter at the base of the third metatarsal and exit just distal to the lateral malleolus.

Weight-bearing radiographs of the foot, ankle, knee, and hip are often requested to demonstrate various conditions. Weight-bearing radiographs of the foot consist of an AP and lateral with the exception that the patient is erect (i.e., weight-bearing). Actual part positioning to acquire weight-bearing radiography images is similar to the positioning just described for the basic radiography imaging protocol.

Ankle & Leg

The basic radiography imaging protocol for the ankle is an AP, mortise, oblique (medial rotation), and a lateral. For all of the basic images, the patient's entire leg and ankle should be aligned without rotation; the foot should remain in a natural dorsiflexed position, with the ankle joint centered to the IR. Upon first observing the ankle positioned for an AP oblique and AP mortise projection they seem very similar in alignment and medial rotation, Figures 3-27 and 3-28.

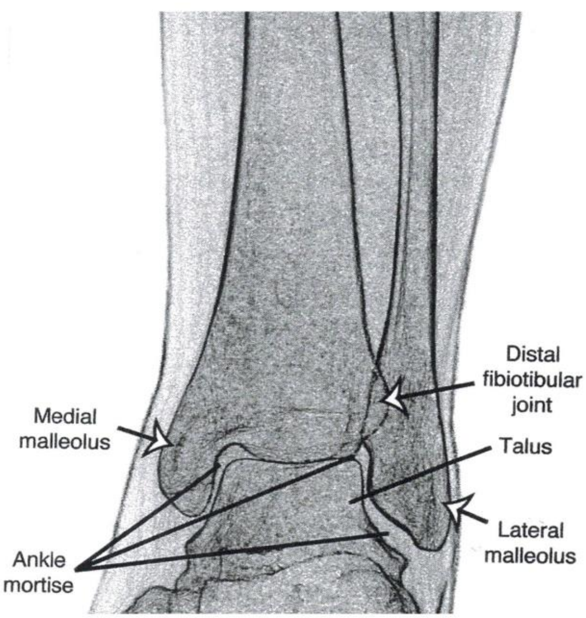


Fig. 3-27. AP mortise. Delmar's Radiographic Positioning Volume 1, 1E © 1998 Delmar Learning, a part of Cengage Learning, Inc. Reproduced by permission. www.cengage.com/permissions.

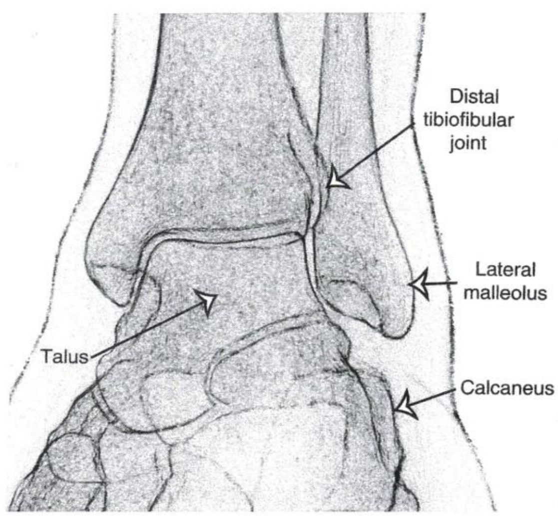


Fig. 3-28. Oblique ankle. Delmar's Radiographic Positioning Volume 1, 1E © 1998 Delmar Learning, a part of Cengage Learning, Inc. Reproduced by permission. www.cengage.com/permissions.

A major difference is that the AP mortise projection requires that the entire leg and foot be rotated internally about 15 to 20 degrees until the intermalleolar line is parallel to the IR whereas for the AP oblique projection, the entire leg and foot is internally rotated 45 degrees.

The 45 degree rotation allows for an image which demonstrates the distal tibiofibular joint open with minimal overlap of surrounding structures. For the lateral ankle projection, the patient is assisted into a recumbent position with the affected ankle resting on the external or lateral surface and placed in the center of the IR. The CR is directed perpendicular to the IR and enters the medial malleolus.

Pathology of the ankle associated with joint separation due to ligament tear or rupture may be demonstrated by special or accessory examinations. These include AP stress projections or inversion and eversion. Such special "stress" projections require that a physician or qualified professional hold the patient's foot and ankle, in the inversion and eversion position, during the exposure, Figures 3-29 and 3-30.

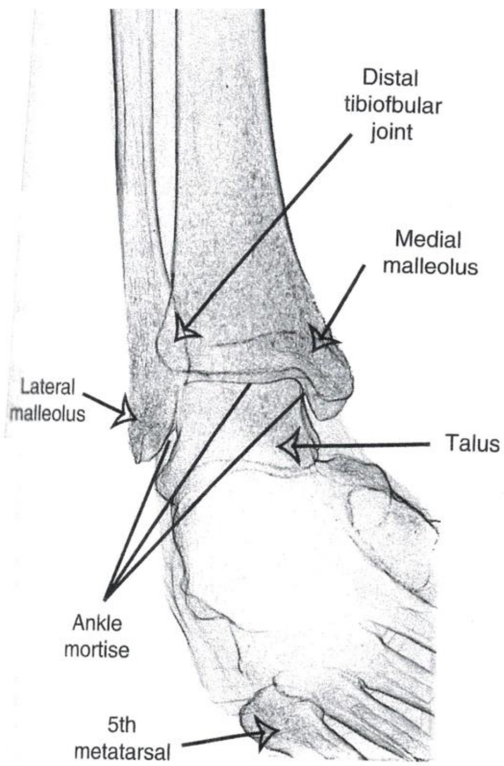


Fig. 3-29. AP ankle with inversion stress. Delmar's Radiographic Positioning Volume 1, 1E © 1998 Delmar Learning, a part of Cengage Learning, Inc. Reproduced by permission. www.cengage.com/permissions.

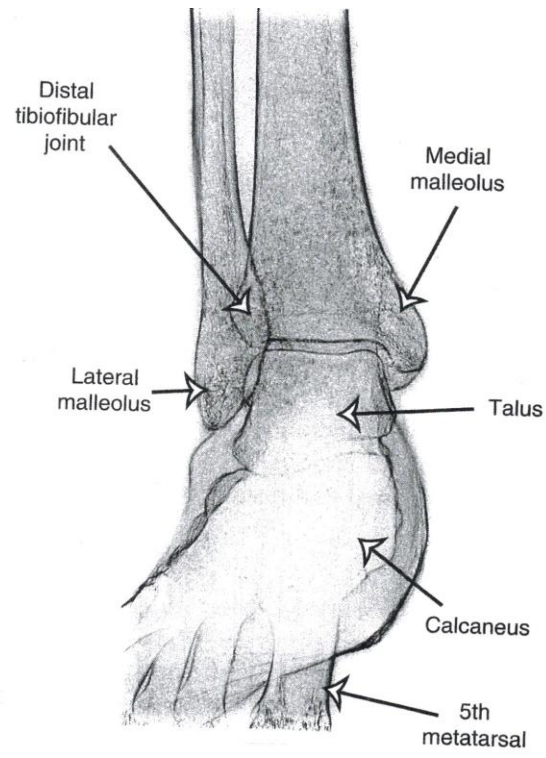


Fig. 3-30. AP ankle with eversion stress. Delmar's Radiographic Positioning Volume 1, 1E © 1998 Delmar Learning, a part of Cengage Learning, Inc. Reproduced by permission. www.cengage.com/permissions.

The radiography imaging protocol for the leg includes an AP and a lateral. The leg is situated between two joints, the knee and the ankle, and for the initial images it is important to demonstrate both joints as to not exclude any fracture or injury. The entire limb should be aligned in a true AP and the leg extended with the foot dorsiflexed to allow visualization of the ankle joint. For both the AP and lateral projection, the CR should be directed perpendicular to the IR and enter midpoint of the leg.

For the lateral projection, the patient should be assisted into a lateral recumbent position with the leg resting on the lateral or external surface and the knee flexed so as to attain a true lateral position. The entire tibia, fibula, and the ankle and knee joints should be visible on properly acquired images of the leg.

Knee & Femur

The basic radiography imaging protocol for the knee includes an AP, oblique (medial and lateral), and a lateral. The radiographer should assist the patient to assume a supine position on the radiography table. Every effort should be made to assure that there is no rotation of the pelvis and to align and center the leg and knee to the midline of the table (i.e., for bucky exposures), or to the IR. The radiographer should gently rotate the leg internally three to five degrees to achieve a true AP image of the knee. The CR should be directed to the articular facets (tibial plateau) which are dictated by the patient's body habitus. For example, the following are basic guidelines for proper direction of the central ray for the AP projection of the knee.

- For a patient with thin thighs and buttocks, the CR should be angled three to five degrees caudad;
- For a patient with average thighs and buttocks, a zero degree angle should be used; and,
- For a patient with thick thighs and buttocks, the CR should be angled three to five degrees cephalad.

For the AP oblique projection in both the medial (internal) and lateral (external) rotation, the radiographer should assist the patient to partially rotate away from the side of interest. The entire leg and knee should be aligned and should be internally rotated 45 degrees. Immobilization aids should be used when necessary to allow the patient to maintain the proper position. For the lateral or externally rotated AP oblique projection, the same maneuver is used, except that the leg is externally rotated 45 degrees. The

CR for both AP oblique projections should be directed to a point located midpoint of the knee at a level one half inch distal to the apex of the patella.

A lateral image of the knee joint may be acquired using a horizontal beam projection or with the patient in a lateral recumbent position for those unable to sufficiently flex the knee. If a horizontal beam method is used, the radiographer must place a sponge support under the knee to elevate the part so that all of the area will be included on the image. If a lateral recumbent method is used, the radiographer should assist the patient into the correct position and gently flex the knee 20 to 30 degrees. In this method, the x-ray tube may be angled five to seven degrees cephalad to achieve a true lateral image with superimposition of the distal borders of the condyles.

The anatomy that should be demonstrated on the basic radiography images of the knee include the distal femur and the proximal tibia and fibula. The lateral condyles of the femur and tibia and the knee joint spaces should be visualized on the AP oblique projections. The lateral and mediolateral, projection of the knee demonstrates the distal femur, proximal tibia and fibula, and patella in profile.

Special or accessory radiography examinations of the knee include bi-lateral AP weight-bearing, PA axial (i.e., Tunnel view), and tangential (i.e., axial or sunrise/skyline) projections. The bi-lateral AP weight-bearing examination requires that the projection be taken with the patient erect and standing, Figure 3-31.

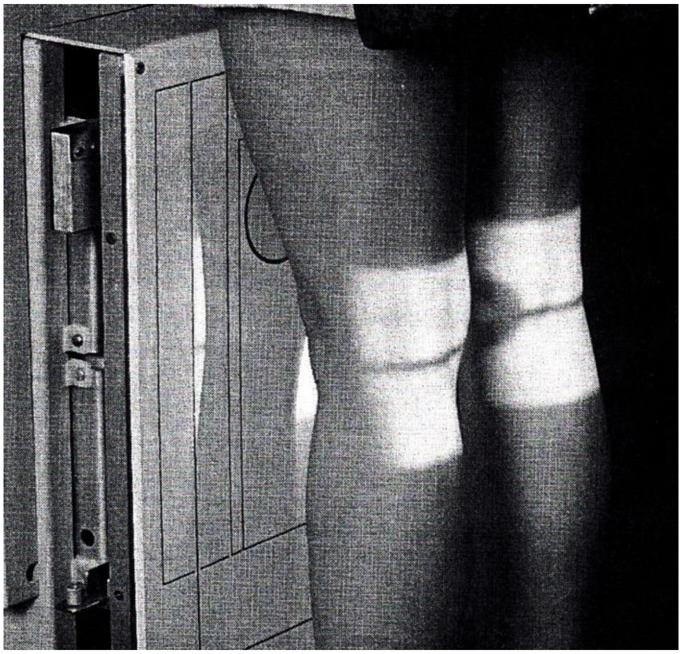


Fig. 3-31. PA weight-bearing knee (extended). Delmar's Radiographic Positioning Volume 1, 1E; 1998 Delmar Learning, a part of Cengage Learning, Inc. Reproduced by permission. www.cengage.com/permissions.

The radiographer is advised to use the CR placement and angulation previously mentioned in the basic AP projection of the knee.

The purpose of the PA axial projection, also referred to as the Tunnel view, is used to demonstrate the intercondylar fossa, articular facets, and knee joint space. The tangential, also referred to as the sunrise or skyline projection, is used to demonstrate the intercondylar sulcus and patella of each distal femur, Figures 3-32 and 3-33.

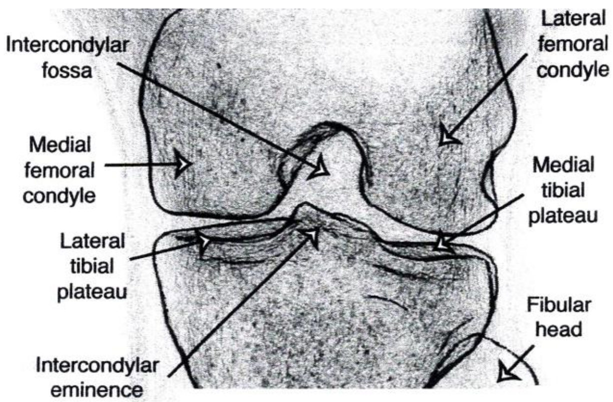


Fig. 3-32. Intercondylar fossa (Camp-Coventry). Delmar's Radiographic Positioning Volume 1, 1E © 1998 Delmar Learning, a part of Cengage Learning, Inc. Reproduced by permission. www.cengage.com/permissions.

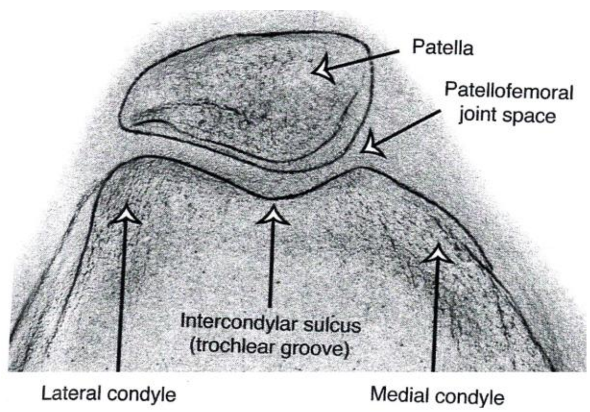


Fig. 3-33. Tangential patella (Settegast). Delmar's Radiographic Positioning Volume 1, 1E © 1998 Delmar Learning, a part of Cengage Learning, Inc. Reproduced by permission. www.cengage.com/permissions.

Depending on the patient's particular circumstances (i.e., evident trauma, body habitus, and physical condition) there are several positioning variations that may be used to attain an image of the intercondylar fossa and the intercondylar sulcus. Radiographers are advised to consult current radiographic anatomy and positioning textbooks in order to become acquainted with the possible variations of each of these examinations since the patient's condition will dictate which may be used.

The basic radiography imaging protocol for the femur includes the AP and the lateral (either mediolateral or lateromedial) projection. Both basic images demonstrate mid and distal femur and are used when trauma is not suspected. Each imaging facility has a particular radiography imaging protocol for the femur, hip, and pelvis whenever trauma is suspected and radiographers are advised to adhere to their imaging protocols. As with all positioning of the lower limb, the radiographer should assure that once the patient is in a supine position that the entire limb is aligned with no evidence of rotation. Immobilization sponge blocks should be used whenever necessary to assist the patient in maintaining the position without discomfort or movement.

Hips

The basic nontrauma radiography imaging protocol for an individual with a single affected hip is unilateral AP and AP "frog-leg" projections. An AP bilateral projection that includes both hips may be requested in special circumstances. For either AP bilateral hips or AP unilateral individual hip projection, the radiographer should assist the patient to assume a supine position and ensure that the patient's entire body is aligned without evidence of rotation. For the AP projection, the radiographer should separate the patient's legs and feet then internally rotate the long axes of the feet and lower limbs 15 to 20 degrees, Figure 3-34.

The radiographer should use immobilization aids, such as sandbags, placed against the patient's feet to assist the patient in maintaining the proper position without movement. For the AP bilateral projection of the hips, the CR is directed perpendicular to the IR and should enter midway between the level of the anterior superior iliac spines (ASIS) and the symphysis pubis. For the AP unilateral projection of an individual affected hip, the CR should be directed perpendicular to the IR and should enter one to two inches distal to the midfemoral neck. Radiographers should be aware if there is an orthopedic appliance present in the hip; and, if present, the entire appliance should be included within the image boundaries.

Once the AP projection has been acquired, the radiographer should assist the patient to assume a "frog-leg" position. For the bilateral "frog-leg" position, the radiographer will ask the patient to flex the knees approximately 90 degrees and then to abduct both femora 40 to 45 degrees from the vertical surface, Figure 3-35.

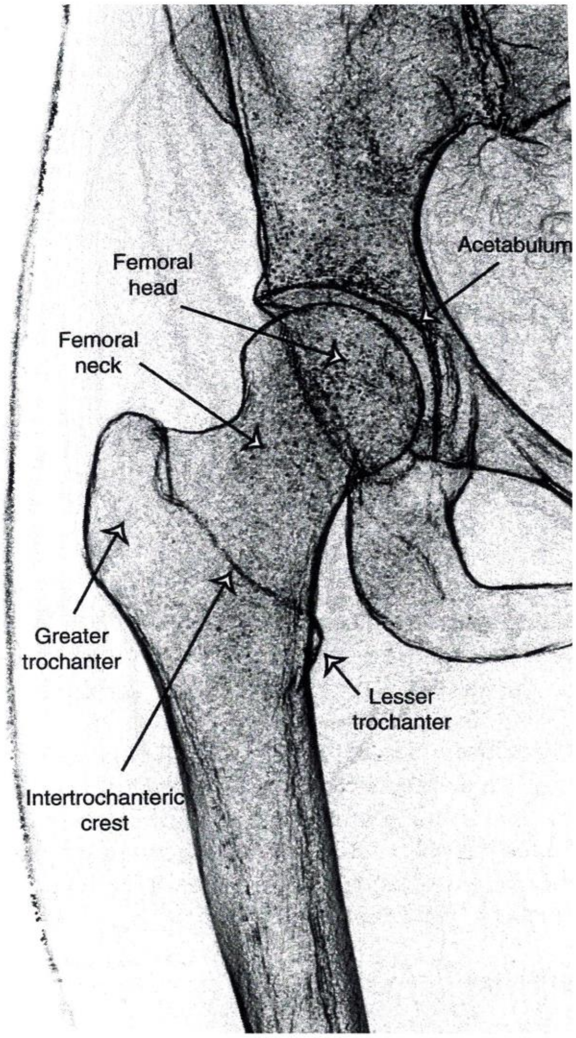


Fig. 3-34. AP hip. Delmar's Radiographic Positioning Volume 1, 1E © 1998 Delmar Learning, a part of Cengage Learning, Inc. Reproduced by permission. www.cengage.com/permissions.

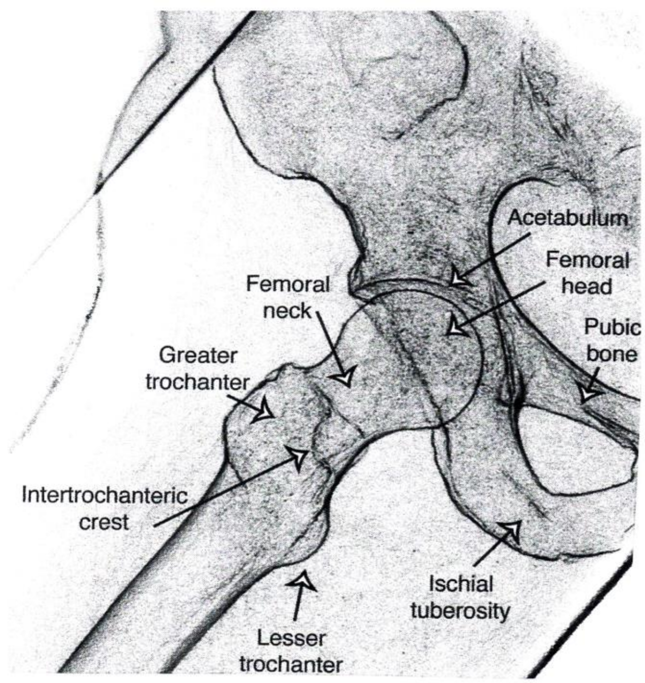


Fig. 3-35. Lateral hip. Delmar's Radiographic Positioning Volume 1, 1E © 1998 Delmar Learning, a part of Cengage Learning, Inc. Reproduced by permission. www.cengage.com/permissions.

The radiographer should check to determine that both femora are abducted to the same degree and that there is no rotation of the pelvis. The CR is directed perpendicular to the IR and should enter a point three inches below the level of the ASIS. For the unilateral "frog-leg" projection, the same procedure just described is used, except that the affected hip is centered and the CR is directed to the midfemoral neck. For radiography imaging examinations of the hip(s), the radiographer should ask the patient to suspend respiration during the exposure. The AP unilateral projection of the hip demonstrates the proximal one-thirds of the femur along with the acetabulum and adjacent parts of the pubis, ischium, and ilium. The "frog-leg" image provides a lateral view of the acetabulum and femoral head and neck, trochanteric area, and proximal one-third of the femur. There are several alternative methods to acquire substitute images of the hips when trauma to the area is suspected. Radiographers are advised to consult radiographic anatomy and positioning textbooks to become familiar with these alternative methods. Radiographers should be knowledgeable about the trauma radiography imaging guidelines and protocols recommended by their individual medical facility.

Bedside Mobile Radiography

Patients confined to nursing homes, assisted living facilities and even their own homes often require radiography; however, they cannot be transported to a hospital or radiology clinic. Mobile radiography equipment that is transported via a van to the patient is the solution to such dilemmas. Bedside radiography typically refers to radiography performed while the patient is in a bed confined to a hospital room, intensive or cardiac-care unit. During war and conflict, mobile radiography has served the imaging needs of wounded soldiers. During World War I, the Picker Corporation introduced the first mobile radiography unit for use on the battlefield. Mobile units can be either light duty or full power institutional models. While advancements in mobile radiography equipment have improved during the last 20 years, bedside radiographic images are often compromised by factors such as the patient's condition and ability to cooperate during the procedure. Mobile radiography is also used in emergency care and disaster sites, and in other unusual environments.

In a medical facility, the radiographer should first check with the patient's attending nurse before entering the patient's room. Also, the radiographer should first enter the patient's room without the portable x-ray unit. After confirming the status of the patient, the radiographer should complete all routine tasks before attempting to move or position the patient. Patients in critical care units may be able to assume an erect position for only a short period of time because of instability of their blood pressure. Cassettes should be covered with a plastic isolation bag to limit transferring disease causing organisms and to avoid placing the cold surface against the patient's back.

The clinical and environmental challenges that confront radiographers in mobile radiography require creative adaptation to routine positioning and selection of technical exposure factors. Because these challenges are unique to mobile radiography, the radiographer must be ever mindful to use all of the recommended radiation protection measures. Also, as a result of the need for unique adaptations in positioning and technical factors, additional projections and retakes are common problems in mobile radiography. Additional projections and retakes result in increased radiation dose to both the patient and the operator. Radiographers should observe all radiation protection measures during mobile radiography, including the use of protective apparel. A protective apron should be assigned to each mobile unit. The radiographer should apply principles of the inverse square law, and stand as far from the patient as possible during the exposure. Most mobile radiography units are equipped with an exposure cord that is six feet long which allows the operator to gain maximum distance. Also, the radiographer should attempt to stand at a right angle (90 degrees) to the x-ray beam scattering object (the patient). This location and direction receives the least amount of scatter radiation during mobile radiography procedures. The following are standard radiation protection guidelines that should be observed during mobile radiography. The radiographer should:

- Recognize that mobile radiography is performed in surroundings that do not have structurally designed radiation barriers;
- Not allow others to remain in the room or nearby area during the exposure;
- Verbally announce, in a loud voice, that the exposure is about to be made;
- Wear a protective apron and have an extra protective apron available for the patient;
- Provide gonadal protection for the patient; and,
- Maintain maximum distance from the patient during the exposure.

Surgical Radiography

Surgical intervention is often required in the treatment of various diseases and orthopedic conditions affecting musculoskeletal structures. When radiography examinations are required during surgery, the radiographer must adhere to and apply the principles supporting the sterile environment of the surgery suite. Most modern surgery units have designated mobile radiography equipment that is maintained in the sterile environment. Specialized orthopedic surgery suites may have fixed radiography equipment designed with a C-arm x-ray tube. Fluoroscopy equipment is also used during surgical procedures and this may be highly specialized for cardiovascular and orthopedic interventional and diagnostic imaging examinations. Both radiography and fluoroscopy equipment is available as mobile C-arm units. The C-arm merely describes the basic design of the unit which forms a large C shape, with the x-ray tube located at one end of the C-arm and the image capture system at the other end. Radiation protection measures are of special concern during radiography examinations in the surgical suite and additional information will be provided later in the *Radiation Protection* chapter.

Technical Overview

Conventional radiography of musculoskeletal structures has demonstrated value in the diagnosis and treatment of disease conditions and consequences of trauma. As cited previously, the ACR Appropriateness Criteria® lists many indications for radiography of the extremities. The ultimate goal of any imaging examination is to provide diagnostic quality radiography for prompt and accurate interpretation. The following provides a review of the factors related to optimum image quality that must be considered when evaluating radiography images of the extremities.

Evaluation of Conventional Radiography Images

The physician is responsible for requesting conventional radiography examinations that are deemed necessary to obtain a diagnosis. For each individual patient, the physician must weigh the benefits versus risks of the each diagnostic procedure ordered and must convey this information to the patient. A qualified physician will interpret the radiography studies and document the findings. The radiographer is responsible for proper care of the patient before, during, and after the radiography study.

Prior to beginning any procedure, the radiographer should carefully review the radiographic request and the reason for the examination. If at any time during this preliminary review the radiographer is uncertain about the radiographic request, he or she should not proceed until clarification can be obtained. Also in reviewing the radiographic request the radiographer may be aware of alternate projections or positions that may better demonstrate the particular pathology. In such cases and whenever questions about the request should arise, the radiographer should consult with the supervisor. After the radiography examination, the radiographer's final duty is to evaluate the images for diagnostic quality. To view the images, the radiographer follows standard protocols for the proper display on a cathode ray monitor (CRT) or on a viewbox. Global guidelines for displaying images on a CRT monitor or for hanging hard copy radiographs on a viewbox include:

- Shoulder and hip images should be displayed as if the patient were standing in an upright position;
- Finger, wrist, and forearm images should be displayed as if the patient were hanging from their fingertips;
- Elbow and humerus images should be displayed as if they were hanging from the patient's shoulder;
- Toes and AP and oblique foot images should be displayed as if the patient were hanging from their toes; and,
- Lateral foot and ankle, lower leg, knee and femur images should be displayed as if these were hanging from the patient's hip.[8-10]

The characteristics of a high quality radiograph include adequate density, good contrast, clear detail and sharpness with no distortion of size and shape. The radiographer evaluates images based upon the photographic and geometric properties of the image as well as standard requirements such as the complete inclusion of the requested anatomic structures. Each radiography examination has certain image evaluation guidelines. The following are suggested image evaluation questions that should be answered during review of radiography images of bones, joints, and soft tissue structures.

One of the first things the radiographer should review is the proper identification of the image. The patient identification marker should be clear and legible; and a properly placed R or L marker should be visible without superimposing the requested anatomy. The imaging facility's identification should be visible. The correct examination time and date should be visible on the image. Additional questions to ask regarding image identification include such things as:

- Is the image identification maker visualized within the collimated field and not obscuring anatomic areas of interest?
- Is the image identification maker located in the best possible place for the projection and position presented?; and,
- Does the R or L marker correspond to the correct side of the patient?

The radiographer may use the following additional questions in determining the quality of an image.

- Are the anatomic areas requested demonstrated on this image?
- Are the anatomic areas accurately displayed on this image?
- Are the anatomic areas requested visible on the image with adequate penetration?
- Does the image demonstrate unwanted shape distortion in the form of magnification, elongation, foreshortening?
- On images of the long bones, have both articulating joints been included on the image? If not, why not?
- Is there evidence of a collimation on the image?
- Are artifacts evident on the image? If so, is a retake examination required?
- If a retake examination is required, what positioning and technical exposure adjustments must be made?

The radiographer should use the following additional information when viewing and evaluating musculoskeletal structures prior to forwarding them for interpretation.

The bony trabecular patterns and cortical outlines should be evident on images of bones and joints. Loss of definition may be the result of some pathological process but may also be caused by voluntary and involuntary motion. The radiographer may reduce patient motion by providing immobilization devices and by the use of positioning supports such as sponge blocks, wedges, etc. Loss of definition may also occur if the anatomic area being examined is not placed in close contact with the cassette or IR. Individuals with certain types of extremity trauma may be reluctant or unable to place the injured part flat against the cassette or IR. When this occurs, the radiographer must make adjustments (i.e., generally to the SID), to prevent loss of recorded detail on the image.

The radiographer is responsible for ensuring that the entire limb is in proper alignment. Rotation of the anatomic part results in distortion and loss of image quality.

An optimal kVp must be used in imaging examinations of the bones and joints. The proper amount of kVp will provide sufficient penetration of the bone and soft tissue structures so as to demonstrate the bony details.

Image Evaluation-Upper Extremity

The following discussion focuses on evaluation of the bones and joints of the extremities, starting with images of the fingers and the thumb. When evaluating radiography images of the fingers (digits two through five) and the thumb, the radiographer should look at the following related to the digit or digits being examined.

- The digit should not be rotated;
- The distal, middle, and proximal phalanges should be visible; and
- The distal end of the metacarpal should be included in the image.

For images of the thumb, the radiographer should determine if the distal and proximal phalanges and the distal end of the first metacarpal have been included. Radiography images of the hand should demonstrate all the phalanges, metacarpals, and carpals with the thumb seen in an oblique position. Approximately one-half to one inch of the distal radius and ulna should also be visible and there should be no evidence of motion on the image. One of the most common problems associated with the PA hand position is that after final positioning the patient often lets the hand relax. If the hand relaxes, it may naturally assume an external oblique position. Improper hand positioning may be identified on the image by looking for superimposition of the third through the fifth metacarpal heads and an unequal amount of soft-tissue thickness on the sides of the phalanges.

Additionally, when viewing a PA projection image of the hand, the fingers should appear spread slightly with no rotation of soft tissue overlapping. The radiographer can quickly determine if a 45 degree rotation was used on an oblique position of the hand by determining the amount of metacarpal midshaft and metacarpal head superimposition. If an insufficient amount of rotation was used, the anatomic relationship of the hand structures will appear similar to that of a PA projection of the hand. Likewise, if the hand is rotated more than the required 45 degrees, the joint spaces are obscured and the fourth and fifth metacarpals demonstrate superimposition.

A proper image of the hand in the “fan” lateral position (lateromedial projection) should demonstrate that the second through the fifth metacarpal midshafts are superimposed. Often, this is not the image acquired and the usual correction that the radiographer should take is to internally rotate or pronate the patient's hand until the metacarpals are superimposed.

Radiography of the wrist joint seems like a simple examination; however, any incorrect rotation of the hand, elbow, and humerus can affect image quality. The scaphoid fat stripe is one of the soft-tissue structures that must be visible on all wrist images and incorrect alignment can cause these important tissues to be obscured. All eight carpal bones and about one to two inches of the metacarpals should be demonstrated on wrist images. The distal radius and ulna should also be visualized on wrist images. If a retake wrist image is required, the radiographer should ensure that the patient's hand is internally rotated until the wrist is in a true PA projection and the proximal forearm is flat on the cassette or IR. Occasionally on wrist images the scaphoid will appear foreshortened and have a signet ring configuration. To correct this, the radiographer will need to ask the patient to curl the fingers, flexing the hand until the second through fifth metacarpals are angled at approximately 10 to 15 degrees with the cassette or IR. Occasionally when viewing lateral wrist images the radiographer may notice that certain carpal bones are either more anterior or posterior than they should normally appear. This is a sign of rotation and the correction is to reposition the wrist into a true lateral position.

Special accessory images of the wrist are taken to demonstrate specific anatomical details. For example the Stecher method (i.e., scaphoid position) is obtained to provide an elongated view of the scaphoid, free from superimposition. Although unintentional elongation is considered undesirable, it is the objective in the Stecher method. In the carpal canal and the carpal bridge methods, the objective is to intentionally demonstrate specific anatomy free of superimposition. In both of these methods, although the objective is increased visualization of specific anatomic areas, because of either hyperextension of the wrist or the increased x-ray tube angulation, the anatomy will appear somewhat distorted.

Forearm images include an AP projection and a lateral position (lateromedial projection). In each of these basic images, both the wrist and elbow joints should be included and the radius and ulna should exhibit only slight superimposition at both the proximal and distal ends. The radiographer should inspect the forearm images to detect rotation from improper positioning of the hand and wrist. When the hand and wrist are not properly positioned, the radial styloid will not appear in profile and the distal radius, ulna and the metacarpal bases will be superimposed. Improper positioning of the proximal forearm will also result in rotation and is demonstrated when the humeral epicondyles are poorly positioned.

The anterior and posterior fat pads and the supinator fat stripe at the elbow and the pronator fat stripe at the wrist are important soft tissue structures that should be seen in the lateral forearm image. A change in the shape or placement of these soft tissue structures usually indicates joint effusion and elbow injury. When an effusion is present in the elbow joint, the fluid pushes the posterior fat pad out of the fossa, allowing the olecranon fossa to be visualized proximal and posterior to the fossa, which is not normally seen in this location. Any degree of rotation of the structures may portray shape displacement and may falsely indicate pathology. The radiographer can verify correct positioning of a lateral forearm by determining the relationship of the pisiform and distal scaphoid. If a true lateral was obtained, the pisiform and distal scaphoid will appear visible anterior to the capitate and lunate with their anterior aspects aligned and the distal scaphoid seen distal to the pisiform.

The basic radiography protocol for the elbow is an AP projection, lateral position (lateromedial projection), and anterior oblique projections (i.e., internal and external rotation). The AP projection should clearly demonstrate the joint space open and it should be centered to the cassette or IR. The radius and ulna should appear slightly superimposed near the radial tuberosity and the epicondyles should not be rotated.   The lateral position should demonstrate that the humerus and radius/ulna form a 90 degree angle with the epicondyles superimposed.

Detecting rotation of the AP projection of the elbow may be identified on the image by whether the epicondyles are visualized in profile and whether the coronoid process is seen in profile. To correct any degree of rotation of the elbow for an AP projection, the radiographer should evaluate the degree of radial head superimposition of the ulna. The degree of flexion of the elbow joint must also be considered when evaluating images of the elbow joint. The way that the flexed elbow is positioned on the IR determines which elbow structures appear distorted on the image, and the distortion increases with increased elbow flexion. When positioning the AP projection of the elbow, a simple positioning mistake can occur if the hand and wrist are not supinated into an AP projection. If the hand and wrist are positioned PA rather than AP, on the image, the radius will appear crossed over the ulna, and the radial tuberosity will not be demonstrated in profile. The simple correction is for the radiographer to ensure that the patient's hand and wrist are placed into a true AP projection.

For evaluation of the anterior oblique projections (i.e., internal and external rotation), the radiographer should keep in mind the following information. For the internal rotation the radius and ulna should be substantially superimposed with the coronoid process visualized in profile. For the external rotation the radius and ulna should be free from superimposition of each other with the radial tuberosity, head, and neck clearly visualized.

The basic radiography protocol for the humerus includes an AP projection and a lateral position. Both the elbow and shoulder joints should be included on the AP and lateral images. In the AP projection, the greater tubercle should be demonstrated in profile on the lateral aspect of the humerus. In the lateral position the epicondyles should be superimposed and the lesser tubercle demonstrated in profile on the medial aspect of the humerus. A transthoracic lateral position is usually requested in cases of trauma to the upper arm or shoulder. Because this position is considered an adaptation to accommodate for trauma, only the proximal two-thirds of the humerus and the relationship of the humeral head to the glenohumeral joint will be demonstrated through the thorax. This position provides an image of the upper arm; however, definition of fine anatomic details is usually compromised.

The basic radiography protocol of the shoulder is an AP projection with internal rotation and an AP projection with external rotation. The internal and external rotation views should demonstrate the proximal humerus and at least the distal two-thirds of the clavicle, and most of the scapula. In the internal rotation view, the lesser tubercle should be demonstrated in profile on the medial aspect of the humerus. In the external rotation view the greater tubercle should be demonstrated in profile on the lateral aspect of the humerus.

The scapular Y position is an alternate view of the shoulder that may be used to demonstrate possible dislocation of the humeral head. A scapular Y image should demonstrate the scapula in a true lateral position that is free of superimposition. The shaft of the humerus should be seen superimposed on the body of the scapula.

In the AP projection of the scapula, the image will demonstrate the entire scapula superimposed over the lung and the ribs. If the patient was positioned properly, the radiographer should be able to visualize the lateral border of the scapula mostly free from superimposition of the ribs and lung.

The basic radiography protocol for the clavicle is a PA projection and an AP axial projection. On both images, both acromioclavicular and sternoclavicular joints should be demonstrated. Generally both the right and left acromioclavicular joint is visualized on the AP projection. When viewing the AP projection image, the acromioclavicular joint space should be well demonstrated with no rotation as observed by the symmetry of the sternoclavicular joints.

Image Evaluation-Lower Extremity

When evaluating radiography images of the toe(s) the radiographer should determine if the image meets the following basic requirements.

- The distal, middle, and proximal phalanges should be visible.
- The distal end of the metacarpal should be included in the image.
- The anatomic part should not be rotated and there should not be evidence of motion.

The basic radiography protocol for the toe(s) and the feet includes the following projections: AP, oblique (medial or lateral for the toe(s) and medial rotation for the foot), and a lateral (mediolateral or lateromedial). When evaluating images of the toe(s), the radiographer should see no rotation of the phalanges and should see the digit(s) of interest included on the image. When the AP projection of the toe(s) and foot has been properly positioned and the x-ray tube correctly angled, the radiographer should be able to observe that the joint spaces are open. When the proper degree of obliquity of the toes has been attained, the radiographic image should show the second through the fifth interphalangeal and metatarsophalangeal joint spaces open. Generally, the first metatarsophalangeal joint space will not appear open. For both the lateral toe(s) and foot, the area of interest should be seen in profile without rotation. An accessory view of the foot is the tangential position used to demonstrate the sesamoid bones. In this method the patient must assume a position that may be uncomfortable and difficult to maintain, so the radiographer must work quickly to acquire a quality image that is free of motion and distortion.

The radiography imaging protocol of the ankle joint includes the following projections; AP, AP mortise, AP oblique (medial) and lateral (mediolateral or lateromedial). When viewing the AP projection of the ankle, the radiographer should be able to see both the lateral and medial malleoli with moderate overlapping at the distal tibiofibular articulation. In this projection, the tibiotalar joint space should be visualized with the medial tibiotalar articulation free of overlap. Correct patient positioning for the AP oblique projection requires that the radiographer internally rotate the patient's leg and foot 45 degrees. When proper positioning is used, the radiographer should see that the distal one-third of the lower leg, the malleoli, the talus, and the proximal half of the metatarsals are visible on the image. A major visual difference between the AP and the AP oblique projection of the ankle is that the joint should appear open and free of superimposition on the AP oblique image. The lateral projection of the ankle should demonstrate the distal one-third of the tibia, and fibula with the distal fibula superimposed by the distal tibia. In this projection, the talus and the calcaneus will appear in a lateral profile. Accessory positions and projections are used to demonstrate specific anatomical details, as is the case in the AP mortise projection of the ankle. When evaluating this projection, the radiographer should see the mortise joint free of superimposition from both the tibia and fibula.

The leg is a long bone with two joints the ankle and the knee. The radiography imaging protocol is an AP and a lateral projection of the leg. When evaluating leg images, the radiographer should be able to see both the ankle and knee joints. In certain cases, if both joint are not visible, the radiographer should determine if additional images may be required. For both the AP and lateral projections, the entire limb should be aligned with no evidence of rotation or motion on the image. The knee usually requires several projections to include AP, obliques (internal and external rotation) and a lateral.

Evaluation of the AP knee projection should start with determining if the knee is centered to the cassette or IR and shows evidence of rotation or motion on the image. The femorotibial joint space should be open with the head of the fibula slightly overlapping the proximal tibia. The patella should be completely superimposed over the femur. When the entire leg is internally rotated 45 degrees for an AP oblique projection, the image should provide an adequate view of the lateral condyles of the femur and the medial and lateral knee joint spaces in unequal portions. When the entire leg is externally rotated 45 degrees for an AP oblique projection, the image should provide an adequate view of the medial condyles of the femur and tibia demonstrated in profile. For a lateral projection of the knee joint, the radiographer should see the distal femur, proximal tibia, fibula and patella in profile with no rotation.

The radiography imaging protocols (nontrauma) for the femur and hip joint is an AP and a lateral projection. If an orthopedic appliance or device is present within the femur or hip, the entire device must be visible on the image. The following are general guidelines for including a joint(s) on the femur images.

- The same joint that is included on the AP projection should also be included on the lateral projection (i.e., a separate image of one of the joints may be indicated).
- Any orthopedic appliance should be visualized in its entirety on the image.
- If the knee is the joint selected to be included on the femur images, the same criteria used for evaluating a lateral knee image should be used.
- If the hip is the joint selected to be included on the femur images, the thigh of the unaffected leg should not overlap the area of clinical interest.

Standardized Image Evaluation

Many imaging facilities provide a standardized form for radiographers to follow when evaluating radiographic images for diagnostic quality. An example of a standardized image evaluation form is provided in Figure 3-36. This example provides a suggested starting point for standardizing the manner in which radiographers evaluate radiographic images; however, is not considered all-inclusive.

Radiographic Image Evaluation Form	**Yes**	**No**
Facility identification visible on the image?		
Patient identification visible on the image?		
Right or left identification marker visible on the image?		
Evidence of radiation protection (i.e., collimation, gonadal shields, etc.)?		
Are artifacts visible on the image? If so, are they internal or external?		
Is all of the required anatomy for the particular imaging request visible?		
Is the anatomic part properly centered on the film?		
Is the anatomic part sufficiently penetrated?		
Is the overall image density and contrast sufficient for diagnostic interpretation?		
Is there evidence of distortion and/or magnification of the anatomic image?		
Is there evidence of motion in the image?		
Does the examination require a retake?		
If a retake is required what are the suggested changes that need to be made?		

Fig. 3-36. Sample radiographic image evaluation form.

Retaking Radiographs

When a radiograph is retaken the radiation dose received by the patient increases. The ultimate goal of all imaging procedures is the production of high quality images. A retake may be required whenever the image quality fails to provide adequate diagnostic information. The reasons for retakes range from simple radiographer forgetfulness to complex technical errors. The most common causes of retakes include improper positioning of the part or patient, inaccurate selection of the technical factors (over or under exposure of the image), patient motion (voluntary and involuntary), and improper film processing techniques. The observant radiographer can correct many of these errors beforehand thus minimizing the number of retakes and reducing the patient radiation dose.

If in doubt about the need for a retake, the radiographer should consult with a supervisor to determine whether the image provides sufficient diagnostic information. Since retakes result in increased radiation dose to the patient, each image should be thoroughly evaluated for diagnostic integrity prior to the decision to perform a retake. Factors such as whether the patient's condition, technical factors, etc. can be improved upon during the retake examination must also be considered prior to actually taking the retake. In many cases, these factors cannot be easily changed, and the outcome of the retake may not yield any improvement in image quality, so a retake should not be attempted. Sometimes, it helps to have a starting point before attempting a retake examination. The following suggestions provide just that.

- **If the overall image appears over-or-underexposed, the factors to be considered include:**

-Check the amount of mAs used with the original examination
-Check the exact measurement of the part to evaluate kVp used with the original examination
-Check processing factors to determine if chemical contamination may have contributed to increased density due to chemical fog and also check processor temperature and time settings.

- **If the overall image appears flat and gray or if the anatomy is improperly penetrated, the factors to be considered include:**

-Check the kVp used and the exact measurement of the part. A flat gray or fogged coloration is usually a sign of scatter radiation due to excessive kVp.
-Check the amount of mAs used. A gray coloration may result from using more mAs than required.

- **If the image appears blurred (lacks sharpness), the factors to be considered include:**

  -Is there evidence of motion (voluntary and involuntary) in the image? If so, use of a faster exposure time may be required as well as application of any and all immobilization devices.

- **If the anatomy appears distorted in size or shape, the factors to be considered include:**

  -Check the source to image distance and the object film distance to determine if each of these were correct during the examination. Such errors are generally caused by incorrect alignment of either the x-ray tube or the part being examined.

- **If the anatomy appears to be incorrectly positioned, the factors to be considered include:**

  -Check the relationship of the anatomy to the image receptor plane as well as the relationship of the CR to the anatomy. Improper patient/part positioning is a common error and can usually be easily corrected.

Retake Analysis

A retake analysis program can easily be incorporated into the overall quality control program. Whether performed by a staff radiographer or a quality control radiographer, analysis of the number and causes of retake examinations can result in heightened awareness of areas needing correction. Such information can be used to design staff in-service training and customized continuing education. Further, information about an individual radiographer can be used during personnel evaluations as a way to begin a self-improvement plan, or at worst to begin the documentation for punitive action and eventual termination of employment.

To begin a retake analysis program, the discarded radiographs need to be separated into categories. The list below should be considered a starting point, and should be adapted to the needs of the particular department or clinical situation. The following is a short list of some of the most common reasons for retake radiographs, and may used for sorting retakes. Categories of retake radiography images include:

- Radiographs too dark or too light because of improper selection of technical exposure factors
- Incorrect patient positioning.
- Incorrect centering of the x-ray beam to the part or the film holder/image receptor (IR).
- Motion and/or artifacts on the image.
- Improper collimation or use of accessory devices.

Conclusion

Conventional non-contrast radiography examinations of musculoskeletal structures are among the most common imaging procedures requested. The radiographer is responsible for producing quality diagnostic radiography images, providing quality care, and serving as a customer service representative of the imaging facility. This chapter has provided a review of the fundamental information that supports all of the radiographer’s daily responsibilities and duties.

Chapter 4 Imaging Modalities

"Everyone has his day and some last longer than others."
Winston Churchill

Introduction

Today, the availability of various imaging modalities provides excellent assistance in the identification of abnormalities and disease processes affecting the musculoskeletal structures. Often several imaging modalities are used on the same patient during the assessment to detect fractures and to depict skeletal pathology, bone loss, and disease. These modalities include conventional radiography, computed tomography (CT), magnetic resonance imaging (MRI), bone scintigraphy, interventional and diagnostic procedures, and dual energy x-ray absorptiometry (DXA). Imaging assessment of the musculoskeletal system is important to the prompt and accurate diagnosis of diseases and traumatic injuries. Often, the clinician selects a particular imaging modality based on the suspected disease process or injuries. Radiography without contrast provides noninvasive imaging examinations of the bones and joints and is usually the first choice in initial examinations for non-trauma cases. CT has become the "gold standard" for imaging bony detail, either before or after initial radiography has established the need for further investigation. MRI has the capacity to demonstrate injuries involving soft tissue, muscles, ligaments, tendons and joints better than any other imaging modality. Fluoroscopy is used to guide both diagnostic and interventional procedures and nuclear medicine examinations provide information about a wide range of conditions. Radiation therapy is used as primary, adjunct, and palliative treatment for malignant musculoskeletal diseases.

Dual-energy x-ray absorptiometry (DXA) is considered the "gold standard" for bone mineral density (BMD) measurements. Bone densitometry includes the following modalities:

- Radiographic absorptiometry (RA);
- Single-energy photon absorptiometry (SPA);
- Dual-energy photon absorptiometry (DPA);
- Single-energy x-ray absorptiometry (SXA);
- Dual-energy x-ray absorptiometry (DXA);
- Quantitative computed tomography (QCT); and,
- Quantitative ultrasound (QUS).

Currently DXA, QCT, and QUS are the more commonly used imaging modalities. The SPA and DPA imaging modalities, which use radioactive sources instead of a x-ray tube, are no longer in clinical use.

Decisions regarding the appropriate selection of imaging modalities for trauma patients with possible musculoskeletal injuries are quite controversial. Currently, the debate centers on the question of whether CT should be an integral part of the initial imaging examination of trauma victims. CT has been cited as having a greater ability to demonstrate skeletal fractures as compared with conventional radiography. Decisions regarding the choice of which imaging modality to use in general skeletal assessment and trauma care are often dictated by institutional polices and often restricted by availability of various equipment and the patient status, etc. In any case, imaging examinations of the upper or lower extremity should demonstrate the portion(s) of the extremity or the area of clinical interest requested and should be repeated if the image quality is insufficient. Any prior imaging examinations including radiography, CT, MRI, and nuclear medicine should be obtained, if possible, to provide additional correlation information for the radiologist. The American College of Radiology (ACR) along with a panel of experts has published recommendations regarding appropriateness of imaging examinations of extremities based on several specific chief complaints. Detailed information concerning the ACR's Appropriateness Criteria is provided in Chapter 3 *Conventional Radiography and Positioning Protocols.*

Computed Tomography

The use of CT in the detection of bone fractures has been well documented and is considered the "gold standard" of imaging modalities when multi-trauma victims must be evaluated in life-threatening situations.[1,2] For the initial evaluation of certain bone disorders, depending on the nature of the disorder, CT may be the primary modality used or it may complement other modalities such as conventional radiography, MRI, or nuclear medicine.[1,2] Computed tomography of the foot and ankle is useful for the evaluation of complex fractures and tarsal coalition. CT scanning provides exacting bone detail and may be performed with a sequential single-slice technique or with single or multidetector helical protocol.[1,2] For CT of bone, contiguous or overlapping axial slices with an optimal slice thickness, depending on the anatomic segment of interest, are preferred.[3] CT examinations of bone may include a series of multi-planar reformations; such as sagittal and coronal reformations, which are extremely helpful in assessment. [3]

History of CT

Computed tomography, originally known as computed axial tomography, employs tomography and digital geometry processing to generate three-dimensional images of the internals of an object. The final images are created from a large series of images produced by a single axis of rotation. The discovery of CT is considered to be the greatest innovation in the field of radiology since the discovery of x-rays.

CT provides ultimate clinical information in the detection and differentiation of disease.[1-3] In the examination a volume of data is produced, which can be manipulated, through a process known as windowing, in order to demonstrate various structures based on their ability to attenuate x-rays**.**

In 1979, Godfrey Newbold Hounsfield and Allan McLeod Cormack were awarded the Nobel Prize in medicine for the invention of CT. Hounsfield conceived the first commercially viable CT scanner in Hayes, England (1967) at Thorn EMI Central Research Laboratories while Cormack was also independently working on the concept at Tufts University. The first scanner was installed at the Mayo Clinic in the U.S.

CT provides excellent visualization of anatomic details even in the most obese patients. CT has limitations, including increased noise due to inadequate beam penetration, limited field of view, which can result in beam-hardening artifacts in areas where the patient’s body exceeds the size of the field of view; and image quality limitations because of image cropping.[1] After a CT study is acquired, radiographers may crop the images to focus on internal organ structures at the expense of subcutaneous tissues.[1] Cropping subcutaneous fat can result in the loss of valuable information, especially in patients undergoing evaluation for malignancies or nonspecific abdominal pain for which the abnormality may be within the subcutaneous tissues.[1] Patients who have predominantly intraperitoneal or retroperitoneal fat have improved visualization of internal organ structures compared with patients with less intraperitoneal fat due to increased delineation of internal organ structures by the fat.[1] Abdominal and pelvis CT is a sensitive imaging modality for diagnosis of abdominal and spinal diseases and pathology due to intentional and unintentional injury and trauma. CT imaging is also being increasingly used in the guidance of surgical and radiation therapy treatment procedures.

Increased noise is a result of inadequate beam penetration. Solutions to decrease noise involve increasing kVp to 140 and increasing the effective mAs.[1] Two ways to accomplished this include decreasing the CT gantry rotation speed or using automated tube current modulation, which will allow the scanner to determine the amount of mAs to deliver per body section.[2] Although both of these solutions improve the image quality, they increase the radiation dose to the patient.[1] Due to the availability of CT scanners from different manufacturers, as well as the rapid evolution of the technology, the ACR recommends that radiographers use the manufacturer's recommendations with respect to image acquisition in order to optimize spatial and contrast resolution.

The ACR is more definitive regarding CT equipment specifications and the minimum requirements necessary for patient monitoring during the procedures.[4] The ACR states that patient monitoring equipment and facilities for cardiopulmonary resuscitation including vital sign monitoring, support equipment, and an emergency crash cart should be immediately available.[4] Radiologists, technologists, and staff members should be able to assist with procedures, patient monitoring, and patient support. Appropriate emergency equipment and medications must be immediately available to treat adverse reactions associated with administered medication.[4] The equipment, medications, and other emergency support must also be appropriate for the range of ages and/or sizes in the patient population. A written policy should be in place for dealing with emergency situations such as cardiopulmonary arrest.[4]

Despite all the advantages of CT, the benefits of using CT imaging must be carefully weighed against the risks. The amount of radiation dose from clinical imaging exams experienced by the U.S. public may have increased more than 600% in the last two decades, most of it due to CT. Additional information concerning radiation protection is provided later in this course.

Magnetic Resonance Imaging

Felix Bloch of Stanford University and Edward Purcell of Harvard University conducted the first successful nuclear magnetic resonance experiment to study chemical compounds in 1956. Dr. Bloch and Dr. Purcell were awarded the Nobel Prize for Physics in 1946. In the early 1980s, the first "human" magnetic resonance imaging scanners became available, producing images of the inside of the body. Current MRI scanners produce highly detailed two dimensional and three dimensional images of the human anatomy.

Magnetic resonance imaging (MRI) is primarily used in medical imaging to visualize the structure and function of the body.[2] It provides detailed images of the body in any plane and has much greater soft tissue contrast than CT making it especially useful in neurological, musculoskeletal, cardiovascular, and oncological imaging.[2] MR imaging is useful in the evaluation of osteochondral defects, osteonecrosis, neoplasm, and other soft tissue pathologies. MRI is the modality of choice in differentiating common causes of heel pain such as, but not limited to, plantar fasciitis, fracture syndrome, bursal abnormalities, or tendon rupture.[3] Heel pain is a common complaint and many times can be managed conservatively. However, in cases where etiology is questionable and management is unsuccessful, MR imaging is useful in determining not only the diagnosis, but also the extent and severity of diagnosis.[3] Additionally, information gleaned from MRI can provide preoperative information for the surgeon. One such example occurs when the radiologist can alert the surgeon to a labral shoulder tear that is displaced and communicates whether it's a surgical lesion or a nondisplaced tear that may not require surgery.[5] A retrospective study confirmed that MRI has a high degree of accuracy in regard to depicting labral tears. In one study of 100 consecutive patients who had shoulder labral tears the MRI results were positively correlated with surgical reports.[5] The most obvious advantage to the positive correlation is to reinforce treatment decisions, which in the case of labral tears, could include no surgical intervention or surgery.[5]

MR images provide high contrast soft-tissue and the multiplanar capabilities are superior to images acquired with CT examinations.[2] MRI is particularly well suited to differentiate the precise anatomic location of diseases within musculoskeletal structures.[2] Overall, MRI appears to be more sensitive than single photon emission computed tomography (SPECT) bone scintigraphy for the detection of metastatic disease but may not be as sensitive for detecting small metastases in the bone.[2]

MR imaging has standard protocols regarding pulse sequence parameters and imaging options based on the specific anatomic regions and suspected abnormalities. Like other imaging procedures, MRI requires more than one set of images to provide necessary diagnostic information. MR images may be acquired in the sagittal, axial, coronal, or oblique planes. The basic types of pulse sequences are: proton (spin) density, T1 relaxation time, and T2 relaxation time.[2] Each type of pulse sequence demonstrates the anatomy differently and helps differentiate between normal and abnormal structures. For a complete diagnostic evaluation, a combination of these pulse sequences is usually required.[2] A proton-density-weighted image uses long repetition time (TR) and shorter echo time (TE) values to produce images based on the concentration of hydrogen protons in the tissue.[2] The brighter the area on the image, the greater the concentration of hydrogen protons. The darker the area on the image, the fewer the number of hydrogen protons. A T1-weighted pulse sequence uses short TR and short TE values to produce a high or bright signal in substances such as fat, acute hemorrhage, and slow-flowing blood.[2] A T2-weighted pulse sequence uses long TR and long TE values to obtain a high signal in substances such as cerebrospinal fluid, simple cysts, edema, and tumors.[2]

MR image quality is least affected by obesity although increased body habitus introduces noise and the large field of view needed decreases the in-plane resolution of the images. The main limitations of MRI are the size of the bore and the table weight limits, which prevent imaging of large individuals. To compound problems associated with MRI bore size and table weight restrictions for overweight and obese patients, there is always the concern about claustrophobia. Due to the construction of closed MRI scanners, they are potentially unpleasant for someone who cannot bear the feeling of being closed within a structure. Those who are claustrophobic may require high doses of weight-based sedative medications, which may put certain individuals at risk for respiratory depression.

Traditionally, open-bore MRI magnets use lower field strengths, often 0.2 Tesla (T) to 0.5T, but newer models have increased the open-bore capability to handle 1.0T and 1.5T field strength, making it possible to obtain better-quality images as well as perform newer applications. To image the extremely obese patient a high field strength magnet is needed. Strengths of 0.2 to 0.5T do not provide adequate signal to noise and sometimes render it impossible to perform the examination even with a longer acquisition time. The 1.5T magnet is a new standard and may prove helpful in imaging overweight and obese patients. Higher strength magnets and improved software techniques, such as fat saturation, may improve the MRI procedures used in imaging obese patients. MRI has the following advantages:

- Acquires patient information without the use of ionizing radiation;
- Produces excellent soft tissue contrast;

- Can acquire images in the transverse (axial), sagittal, coronal, and oblique planes; and,
- The quality of the image is not affected by bone.[1,2]

MRI has the following disadvantages:

- Any contraindication that would present a detrimental effect to the patient or health care personnel;
- Long scan time compared to CT; and,
- Cost.[1,2]

Additionally, before entering a high magnetic field, individuals should be screened for contraindications including biomedical devices/implants or a device that is electronically, magnetically, or mechanically activated such as pacemakers, cochlear implant, certain intracranial aneurysm clips, and orbital metallic foreign bodies. These devices may move or undergo a torque effect in the magnetic field, overheat, produce an artifact on the image, or become damaged or functionally altered. Most MRI magnets are superconductive and the magnetic field is always on. Any ferromagnetic material, oxygen tank, wheelchair, scissors, etc., may become a projectile object.

Fast spin-echo short inversion time inversion-recovery (STIR) whole-body MR imaging is an evolving technique that allows imaging of the entire body in a reasonable time.[1] Its wide availability and lack of radiation exposure makes this method appealing for the evaluation of children. The STIR technique is highly sensitive for detection of pathologic lesions, but it is not specific for malignancy; thus the method cannot be used to differentiate benign conditions from malignant neoplastic lesions.[1] The STIR methods allows whole-body evaluation of the entire skeleton; however, more experience and data are needed to determine its efficacy for staging neoplasms and assessing other multifocal disease in children. Fast STIR whole-body MR imaging is a sensitive radiation-free technique for screening the entire body in a reasonable time and is easily applicable for assessing skeletal, marrow, and soft-tissue disease in children.

Nuclear Medicine Imaging

In 1896, Henri Becquerel was investigating phosphorescence in uranium salts when he discovered a new phenomenon, which came to be called radiosensitivity. He along with Marie and Pierre Curie began investigating the new discovery, which today plays a significant role in nuclear medicine imaging.

Nuclear medicine imaging procedures use pharmaceuticals that have been labeled with radionuclides. In diagnosis, radioactive substances are administered to patients and the radiation emitted is detected by using a gamma camera or positron emission tomography. Nuclear medicine differs from most other imaging modalities in that the tests primarily show the physiological function of the system being investigated as opposed to traditional anatomical imaging such as CT or MRI. The physiologically mapped image allows skeletal changes to be detected earlier than demonstrated by conventional radiography. Abnormal images illustrate “hot spots” produced by an increase in uptake of the radionuclide that is directly proportional to the emission of gamma radiation or “cold spots” reflecting a decrease in uptake of the radionuclide.

Bone scintigraphy uses a form of technetium 99-m injected intravenously. Tc-99-m is absorbed by bone and provides a survey study of the skeletal system for evaluation of abnormal musculoskeletal conditions such as stress fracture, injuries, and metastases. Skeletal scintigraphy has a resolution of about 5-mm in the best conditions.[7] In a normal skeletal scintigram, the radioactive tracer uptake is fairly uniform and symmetric. Uptake is greater in the axial skeleton (pelvis and spine) than in the appendicular skeleton (skull and extremities). The ability of a scintigram to demonstrate trauma precedes conventional radiography detection of fracture healing by approximately 10 days.[7] Bone dysplasia often shows an increase in uptake on the scanned images. Paget’s disease of bone, fibrous dysplasia, and many other benign and malignant bone conditions are detected by bone scintigraphy.

Two of the many indications for bone scintigraphy are to detect bone lesions and impacts of metabolic diseases on the skeleton. On bone scintigraphy images, osteomalacia is usually demonstrated as a random distribution of intense activity with looser zones and pseudofractures.[7] Looser zones also called looser lines are areas of insufficiency fracture with incomplete healing due to mineral deficiency in the bone. The pathology of looser zones relates to areas of poorly mineralized woven bone occurring at sites of mechanical stress. Looser zones are frequently associated with osteomalacia, Paget disease, osteogenesis imperfecta tarda, fibrous dysplasia, renal disease, congenital hypophasphatasia, vitamin D malabsorption, and neurofibromatosis. Common locations of looser zones are the scapula, medial femoral neck, femoral shaft, pubic and ischial rami, ribs, lesser trochanter and the proximal one third of the ulna, and the distal one third of the radius. Looser zones are generally visualized as a two to three millimeter wide stripe of lucency at a right angle to the cortex of the bone.[7]

Positron emission tomography (PET) is a nuclear medicine imaging technique, which produces a three dimensional image of functional processes in the body. The PET system detects pairs of gamma rays emitted indirectly by positron-emitting radionuclide (tracer), which is introduced into the body on a biologically active molecule. Images of tracer concentration in three dimensional or four dimensional space with the body are then reconstructed by computer analysis.

Single photon emission computed tomography (SPECT) is a nuclear medicine tomographic imaging technique using gamma rays. It is very similar to conventional nuclear medicine planar imaging using a gamma camera. Also, three dimensional information may be provided as cross-sectional slices through the part and can be freely reformatted or manipulated as required. SPECT can be used to complement other imaging studies and is usually used to image tumors, infection, and thyroid or bone visualization.

Ultrasonography (US)

Ultrasonography (US) is an imaging technique used to visualize muscles and internal organs, their size, structures and possible pathologies or lesions.[8] In the late 1940s, Dr. George Ludwig at the Naval Medical Research Institute in Bethesda, Maryland was the first to apply US energy to the human body for medical purposes.[8] According to a recent article published in AuntMinnie.com, musculoskeletal ultrasound usage nearly quadrupled between 2000 and 2008.[9] The increase is partially attributed to utilization by nonradiologists and may be driven by "self-referral". Data collected by the U.S. Centers for Medicare and Medicaid Services (CMS) indicates that podiatrists and privately owned medical facilities were among those contributing to the increased utilization.[9] CMS data can also track the geographic distribution of US utilization and this indicates that nearly all CMS regions experienced significant increases in nonradiologist use of ultrasound.[9] Some of the strengths of US are:

- It images muscle and soft tissue very well and is particularly useful for delineating the interfaces between solid and fluid-filled spaces;
- It renders "live" images, where the operator can dynamically select the most useful section for diagnosing and documenting changes, often enabling rapid diagnoses;
- It shows the structure of organs;

- It has no known long-term side effects and rarely causes any discomfort to the patient;
- The equipment is widely available and comparatively flexible;
- Small, easily carried scanners are available and examinations can be performed at the bedside; and,
- The procedure is relatively inexpensive compared to other modes of investigation (e.g., CT, x-ray tomography, and MRI).

Some of the weaknesses of US imaging are:

- US devices have trouble penetrating bone;
- US performs very poorly when there is a gap between the transducer and the organ of interest, due to the extreme differences in acoustic impedance;
- Even in the absence of bone or air, the depth penetration of US is limited, making it difficult to image structures deep in the body, especially in overweight and obese patients;
- The method is operator-dependent. A high level of skill and experience is needed to acquire diagnostic quality images; and,
- There are no scout images so once an image has been acquired there is no exact way to tell which part of the body was imaged.

Arthrography

Arthrography is imaging the joint space and its surrounding structures. Conventional radiography is the most common imaging modality used in arthrography; however, magnetic resonance imaging, computed tomography, and ultrasonography may also be used. The joint space and its surrounding structures can be the site of many different types of pathologies and arthrography may be helpful in the diagnosis, treatment, and monitoring of the condition.

Prior to initiating any imaging examination, radiographers review the patient's current clinical history and findings and assist with procedures to verify that the patient has been informed of the risks and benefits of imaging examinations. The patient's history should be reviewed as well as specific questions about relevant medications, prior seizures, prior allergic reactions, and clotting ability should be reviewed. Patients who are taking the drug Plavix (clopidogrel) should be advised to discontinue the drug for at least five days prior to certain invasive diagnostic and interventional imaging examinations.

Arthrography may be performed with a negative or a positive contrast agent, or both.[10] Pneumoarthrography examinations use air or other easily absorbed gases as the contrast agent. A disadvantage to this method is that the use of negative contrast agents such as air, requires injection of a sufficiently large quantity, which produces distention of the area and results in patient discomfort.[10]

Positive contrast arthrography uses nonionic, water-soluble contrast agents because they are readily absorbed, generally well tolerated by the patient and are easily excreted by the body. Positive contrast arthrography has increased diagnostic accuracy compared to pneumoarthrography. A double-contrast arthrogram examination combines the use of smaller quantities of both a negative and a positive contrast agent. If arthrography is performed with MR imaging, gadolinium is used as the contrast agent.

Fluoroscopy is used throughout the procedure to localize the landmarks in the joint space and to obtain spot film images that provide documentation of areas of pathology. Scout film images of the area to be examined are taken and viewed by the imaging team. The various positions and projections used during arthrography are dictated by the anatomic area under investigation, imaging modality used, individual patient conditions, and the imaging center's standard protocol.

There has been recent concern about the radiation exposure received by patients and staff when fluoroscopy is used in diagnostic and interventional imaging procedures. Additional information is provided in the Chapter 7 titled *Radiation Protection*.

Bone Mass Measurement Technologies

In this section the term operator is used when referring to the person who operates bone densitometry equipment.

Bone loss diseases drain the skeleton of essential minerals that comprise the bony matrix, thus leaving a porous, weakened skeletal framework. Many of the consequences of bone loss diseases can be diminished or halted if therapeutic interventions are initiated in the early stages. Bone mass measurement technologies along with advanced laboratory tests have helped to recognize these diseases. The introduction of new technologies to measure bone mass was critical since ordinary x-ray techniques cannot detect less than 30% loss in bone mass. Using bone mass measurement technologies, as little as 1% change in bone mass is detectable.[11]

The first documented use of bone densitometry was in the field of dentistry. Over 100 years ago, dentists used crude instruments to measure the density of the mandible. According to early bone densitometry pioneers, medical care providers were not interested in bone density technology until pharmacology agents became available to treat osteoporosis.

In the late 1980s, dual energy x-ray absorptiometry (DEXA) technology (now, simply referred to as DXA), was introduced and was applied to the measurement of bone mass. Tests for bone mass density are classified as either central or peripheral tests. A central test is used to quantify BMD in the spine and proximal femur. A peripheral test is used to quantify BMD in the heel, radius, and ulna. Bone densitometry has four major applications in clinical practice: quantification of bone mass or density, assessment of fracture risk, skeletal morphology, and body-composition analysis.

Current bone measurement devices do not actually measure BMD rather information is provided about bone mineral content (BMC) and the length or area of bone. The BMD score provides information that is useful when related to a comparative score. The method used to develop the reference data for which the score is compared has a great impact on the estimation of peak bone mass of young normal women and on the estimation of population standard deviations.

When bone densitometry is used to quantify the BMD for the purpose of diagnosing osteopenia and osteoporosis or predicting fracture risk, it is critical that the measurement be accurate. The purpose of bone densitometry is to follow changes in bone density over time, precision is a critical factor since any change between measurements is a key factor in monitoring progression of the disease and responsiveness to treatment. Precision of BMD studies is dependent on the technical skill and competency level of the person performing the examination. Although equipment manufacturers provide precision values expressed as a percent coefficient of variation (%CV), each facility must establish its own %CV value.

Operators of BMD testing equipment and physicians involved in BMD testing must be familiar with testing objectives, diagnosis and treatment protocols. Operators must also be proficient in machine operation and calibration. Generally, when a facility purchases a BMD machine, the manufacturer provides initial hands-on staff training in the application and use of the BMD equipment.

Patient Preparation, History and Positioning

No special preparations are required prior to a bone density examination other than refraining from taking calcium and vitamin supplements the day of the examination. Some special considerations include:

- If there is any possibility of pregnancy, the bone density study should not be done until the pregnancy is ruled out;
- Patients who have had diagnostic testing that included contrast material or radioisotopes (nuclear medicine testing) must wait at least seven days before undergoing a bone density study; and,
- There may be weight restrictions on table equipment; for example, certain tables may have a maximum weight limitation.

Patients may wear their street clothes during the bone density procedure. Metal objects such as zippers, belt buckles, and snaps should be removed from the area being scanned. The technologist should evaluate each patient to determine if they require assistance in sitting or lying down and especially in regaining equilibrium after the examination.

Questionnaires are useful in gathering relevant patient information that may assist in bone density measurement. Most importantly, patient history questionnaires provide consistency so that every patient is asked the same questions. The operator should review all available patient records and the physician request to confirm the anatomic site to be scanned. In the case of ongoing BMD measurements, the patient's medical record should also be reviewed to confirm positioning and exact placement of the region of interest (ROI) prior to the scan.

Bone density measurements may be made in the vertebral spine, proximal femur, forearm, metacarpals, phalanges, and calcaneus. A physician is responsible for issuing the request for a BMD examination. The operator is responsible for ensuring that the measurement is made of the region requested and that patient positioning is correct. When serial BMD examinations are conducted to monitor therapy, evaluate bone loss, and to follow patients at risk for bone disease, consistent positioning in subsequent examinations is critical. A notation should be included in the patient's chart regarding exact positioning, unique patient considerations, and the presence of artifacts that may have been noted. The operator's competency skill level and knowledge of the procedural applications is important because accuracy and precision in BMD measurements determines ongoing patient monitoring and treatment. Additional skeletal sites for BMD measurements include the metacarpals, phalanges, and calcaneus. These sites are commonly used today with the use of computerized radiographic absorptiometry, computerized radiogrammetry, and ultrasound equipment. A BMD study of the calcaneus and the phalanges, are useful sites in the prediction of future fracture risk.

Interpretation of BMD Results

It is important for the person performing BMD scans and the interpreting physician to establish routine procedural and interpretation protocols. The physician bears the ultimate responsibility for interpretation of BMD measurement results. The equipment operator; however, must have an understanding of how the BMD values are interpreted and what the scores imply. Additionally, because of the time spent with the patient during the BMD examination, the operator should be able to respond to questions and concerns that the patient might express. The operator should be able to determine which of these to answer and which the physician must address.

The operator may be directed by the interpreting physician to provide information about the BMD results and what they represent to the referring physician. Also, the operator may be asked to provide community education about osteopenia, osteoporosis, and related topics related about bone health; such as, nutrition, exercise, and fall prevention, drug therapies, and healthy lifestyle choices.

Most x-ray densitometry machines provide a paper copy image of the ROI being studied. Although these images are not approved by the Food and Drug Administration (FDA) for making a structural diagnosis, the operator should review the image to determine if artifacts are present. If artifacts are present in the ROI, the operator should refer to the supervising physician in selecting an alternate site. The operator should note on the paper copy the presence of any structural artifacts or abnormalities and this information should also be provided to the interpreting physician. The operator performing the BMD scan is responsible for establishing a copy of the scan for the patient's permanent record.[8] Information provided by the BMD scan is part of the patient's medical record, a legal document, and as such is subject to the provisions of the Patient Privacy Act.

Physicians use BMD values to predict the patient's likelihood of future fracture risk. Predictions of fracture risk are either global or site-specific fracture risk predictions. A doubling of fracture risk for each standard deviation (SD) decline in bone density is used for global fracture predictions. For site-specific fracture predictions, the predicative value depends on the anatomic site where the measurement is obtained. The standardized BMD information is reported in milligrams/square centimeter and is not used for diagnosis, fracture risk assessment, or serial monitoring. Typically, after a bone densitometry test, a person will receive one of four diagnoses: normal, osteopenia, osteoporosis, or established osteoporosis with fragility fracture. These include:

- Normal (the skeletal system is as strong as that of a young, normal person);
- Osteopenia (the skeletal bone density is 10% to 25% below peak mass, and the person is at risk for osteoporosis);
- Osteoporosis (the skeletal bone density is 25% or more below peak mass); or,
- Established osteoporosis with fragility fracture. In this case, skeletal bone density is 25% or more below peak bone mass and the person has had a fracture, typically in the spine, hip, or forearm.[8]

Introduction to FRAX®

FRAX® was developed by the World Health Organization (WHO) as a tool to evaluate fracture risk of individual people. It is based on individual patient models that integrate the risks associated with clinical risk factors as well as bone mineral density at the femoral neck.[12] Recently, presented results of a study evaluating the external validity of FRAX® using data from the Women's Health Initiative were disappointing.

> *"While studies differ, they do suggest that risk factors for fracture differ between women of different ethnicities, and between men and women. These differences add complexity to the assessment of fracture risk."*[13]

Many of the issues concerning FRAX® application in clinical practice were discussed at the 2010 International Society for Clinical Densitometry (ISCD) Position Development Conference and an official ISCD position statement has been released (April 2011). Some of the highlights from the 2010 ISCD Official Positions on FRAX® are included at the end of this section; however, complete information may be found at http://www.iscd.org.

The FRAX® models have been developed from studying population-based cohorts from Europe, North America, Asia, and Australia. FRAX® is a computer-driven tool and is available at http://www.shef.ac.uk/FRAX/.[12] Simplified paper versions based on several risk factors are also available and can be downloaded for clinical use.

How the FRAX® Model Works

FRAX® algorithms give the 10-year probability of hip fracture and the 10-year probability of a major osteoporotic fracture (clinical spine, hip or shoulder fracture). This information is very valuable in making clinical treatment decisions that relate to fracture risk assessment, fracture risk reporting, intervention thresholds, treatment decisions, and follow-up. By including information provided by FRAX®, clinicians have yet another tool to use when talking with individual patients about their personal risk of fracture within the next 10-year period.[12] The WHO and other national and international groups have validated risk factors for the prediction of future fractures. These factors are considered within the FRAX® assessment and include:

- Femoral neck BMD;
- Demographic information such as age, sex, height, weight, ethnicity (i.e., for the United States only to include Caucasian, African-American, Hispanic, and Asian); and,
- Seven clinical risk factors:
  -Previous low trauma fracture;
  -Current cigarette smoking;
  -Rheumatoid arthritis;
  -Secondary osteoporosis;
  -High alcohol intake (three or more units/day);
  -Parental history of hip fracture; and,
  -Systemic glucocorticoid use.[12]

The FRAX® assessment report provides a 10-year probability of osteoporotic fracture.[12] The following example using two people with a hip T-score of –2.5 illustrates differences based on just one demographic variant (i.e., age).[12] All other factors being the same, a person 80 years old will have a 19.4% 10-year relative risk of fracture compared to a person 50 years old with a 1.9% 10-year relative risk of fracture using the FRAX® assessment tool. The FRAX® model accepts ages between 40 and 90 years. Clinicians are advised to use clinical judgment to interpret the risk when using the model for patients under age 40. If, when entering the age data, the age is below 40 or above

90, the program will compute probabilities at 40 and 90 years of age, respectively. Age is just one of the variant factors within the FRAX® assessment model.

For assessments within the United States, the FRAX® questionnaire gives four ethnicity options and also allows customization for specific machines.[12] The individual's weight in kilograms and height in centimeters are entered into the questionnaire. The model uses these factors to calculate the body mass index and fracture prediction. Low body mass index is a risk factor for hip fracture but obesity is not protective against hip fracture.[12]

A very important factor used in predicting future fracture risk is prior history of fracture.[12] A question in the model asks about previous fractures in adult life occurring spontaneously, or a fracture arising from trauma which, in a healthy individual, would not have resulted in a fracture. Also the model asks about parental hip fracture since a family history of fragility fracture is a significant risk factor that is largely independent of BMD. A family history of hip fracture is a stronger risk factor than any other bone fractures.

A patient who has a confirmed diagnosis of rheumatoid arthritis is at increased risk of fracture. Rheumatoid arthritis increases fracture risk independently of BMD and the use of glucocorticoids. The model does not account for dose effect due to severity or duration of the disease.[13] The benefits of using the FRAX® assessment includes:

- Quantitative assessment of fracture risk rather than qualitative;
- Fracture probability that provides greater clinical utility than relative risk;
- Application beyond postmenopausal Caucasian women; and,
- It can be used with cost-utility analysis to determine cost-effective intervention thresholds.

The National Osteoporosis Foundation (NOF) has issued intervention thresholds, which are based on fracture probability where treatment is considered cost-effective. The following NOF treatment guidelines are based on postmenopausal women and men age 50 and older:

<u>Osteopenia</u>

T-score between –1.0 and –2.5 at the femoral neck or lumbar spine; and,

FRAX 10-year probability of hip fracture ≥3% or major osteoporotic fracture ≥20%.[12-15]

Osteoporosis

T-score –2.5 or less at the femoral neck or lumbar spine after evaluation for secondary causes; or,

Hip or vertebral (clinical or morphometric) fracture.[14]

The NOF intervention thresholds are calibrated to United States data on fracture incidence, morbidity, and mortality.[14] The thresholds are case-based assumptions of a 35% fracture risk reduction with treatment costing $600 a year for five years.[14] Also, they are based on societal willingness to pay up to $60,000 per quality of life gained and serves only as a guideline for making clinical decisions and is not a mandate to treat or not to treat.[14] A few of the benefits of the NOF guidelines include improved selection of patients most likely to benefit from therapy, better use of limited healthcare resources, and application beyond postmenopausal Caucasian women. A few of the risks associated with the new NOF guidelines are that the cost-effectiveness may be used to determine pharmacy benefits and that the cost-effectiveness may be irrelevant if the drug cost is extremely small. Additional risks include possible limitations of treatment options, treatment recommendations that may be conflicting if the FRAX® model is used inappropriately, and physicians may have less control of clinical decisions.[14]

The 2010 ISCD Official Positions on FRAX® include statements that help to clarify clinical application of the results obtained from the FRAX® model.[15] A few of the highlights are:

- FRAX® may underestimate fracture probability in patients with rheumatoid arthritis;
- There is no consistent evidence that non-glucocorticoid medications for rheumatoid arthritis alter fracture risk;
- It is not possible to quantify the impact of tobacco smoking on fracture risk;
- Fracture probability may be underestimated in individuals with a history of frequent falls, but quantification of the risk is not currently possible;
- FRAX® underestimates fracture probability in persons with a history of multiple fractures;
- FRAX® may underestimate fracture probability in individuals with prevalent severe vertebral fractures;

- It is not possible to quantify the incremental risk associated with prior hip, vertebral, and humeral fractures;
- FRAX® may underestimate fracture probability in individuals with a parental history of non-hip fragility fracture.

The ISCD 2010 Official Positions on FRAX® include four statements regarding the relationship between glucocorticoid use and fracture risk. These statements address under and over-estimates of fracture risk based on a dose relationship and also address inhaled glucocorticoids as well as gluocorticoid replacement in individuals with adrenal insufficiency. Further, the newly released ISCD Official Positions include information about FRAX® and BMD measurements. It is clear that ongoing use of the FRAX® by clinicians will bring refinements in its use in the identification of patients at high risk for fractures.

Conclusion

Conventional radiography as well as other imaging modalities such as CT, MRI, scintigraphy, and ultrasonography may be used to accurately diagnose conditions and trauma of the musculoskeletal system. Radiographers have an important role in the delivery of diagnostic quality images and providing patient care during imaging examination. This chapter has provided a brief introduction to adjunct imaging modalities. Radiographers should consult additional references and resources when further technical information is needed about a specific imaging modality or imaging examination.

Chapter 5 General Pathology

"Wrinkles should merely indicate where smiles have been."
Mark Twain

Pathology is defined as the branch of medicine concerned with the study of the nature of disease and its causes, processes, development and consequences. The term pathology originates from the Greek term pathos meaning suffering. Pathology can be considered to be any abnormal disturbance of the structure or function of the human body as a result of injury. This is sometimes referred to as a disease or a disease process. Pathogenesis refers to the origin and development of a disease.

A symptom is any perceptible change in the body or its functions that indicates disease or phases of disease. Symptoms may be classified as objective or subjective. Clinicians will consider the following when evaluating presenting symptoms; onset, date, manner, whether gradual or sudden, and causative factors. The characteristics of the presenting symptoms are also important clues to a diagnosis and include the nature, location, severity, timing, and aggravating or relieving factors associated with the presenting symptom(s).

A sign is any objective evidence or manifestation of an illness or dysfunction of a body system. Signs are more or less definitive. Objective signs are those that can be seen, heard, measured, or felt by the clinician. Findings of such sign(s) can confirm or deny the clinician's impressions of the disease suspected.

Etiology is the study of the origin of a disease. A number of agents such as viruses, and bacteria cause diseases. If no known cause exists for a disease it is called an idiopathic disease. The number of deaths resulting from a confirmed disease is referred to as the mortality rate. National, state, and regional groups, such as the U.S. Public Health Service and the U.S. Department of Health and Human Services monitors and reports mortality rates in an attempt to spot trends that have impacts for public health and safety. If trends are spotted, intervention and or prevention steps can be taken to reduce mortality rates.

One way to discuss pathology affecting the musculoskeletal system is to group diseases into several broad categories, to include:

- Skeletal Dysplasias
- Inflammatory Conditions and Infections of Bone
- Metabolic Diseases
- Trauma and Injury

- Bone Tumors

The following provides a brief overview of the most common diseases and conditions within each of the broad categories listed above. Information concerning the category of trauma and injury to the musculoskeletal system is covered in a separate chapter.

Skeletal Dysplasias

The word "congenital" originates from a Latin word meaning born together or present at birth. A hereditary disease is defined as having genetic characteristic from parent to offspring whereas heredofamilial disease refers to any disease that occurs in families due to an inherited defect or process. The overall incidence of skeletal dysplasias is approximately 1 case per 4000-5000 births. The true incidence may be twice as high because many skeletal dysplasias do not manifest until complications arise during childhood, such as short stature and joint symptoms.

Information provided in the following italicized paragraphs is attributed to adaptations of content from the cited source listed as citation 1. Chen H. Skeletal dysplasia. September 14, 2009. Retrieved from http://www.emedicine.medscape.com on January 14, 2011.

Among infants with skeletal dysplasias detected at birth, approximately 13% are stillborn, and 44% die during the perinatal period. The overall frequency of skeletal dysplasias in infants who die perinatally is 9.1 per 1000 with no racial predilections are described. Males are primarily affected in X-linked recessive disorders. X-linked dominant disorders may be lethal in males. Otherwise, males and females are usually equally affected by skeletal dysplasias. Skeletal dysplasias are usually detected in the newborn period or during infancy.

Skeletal dysplasia is a heterogeneous group of disorders characterized by abnormalities of cartilage and bone growth. Their modes of inheritance are heterogeneous (i.e., autosomal recessive, autosomal dominant, X-linked recessive, or X-linked dominant). Lethal skeletal dysplasias are estimated to occur in 0.95 per 10,000 deliveries. The 4 most common skeletal dysplasias are thanatophoric dysplasia, achondroplasia, osteogenesis imperfecta, and achondrogenesis. Thanatophoric dysplasia and achondrogenesis account for 62% of all lethal skeletal dysplasias. Achondroplasia is the most common nonlethal skeletal dysplasia.

Radiographers are likely to encounter any of the skeletal dysplasias in the course of their work; however, there are three that are more common. These are osteogenesis imperfecta, which has several sub-types, achondroplasia, and osteopetrosis. Osteogenesis is the formation and development of bone in place of connective tissue or in cartilage. Osteogenesis imperfecta is an inherited disorder of connective tissue characterized by defective bone matrix with calcification occurring on the matrix. Clinical findings are multiple fractures with minimal trauma, blue sclera, early deafness, opalescent teeth, tendency to capillary bleeding, translucent skin, and joint instability. There is no known cure for osteogenesis imperfecta; therefore, treatment is still supportive and palliative. Osteogenesis is often referred to as brittle bone disease.

Achondroplasia is a defect in the formation of cartilage at the epiphyses of long bones, which results in a form of dwarfism sometimes seen in rickets. Persons with achondroplasia will have a normal trunk size (thorax, abdomen, and pelvic cavity) but abnormally shortened extremities. Osteopetrosis is a hereditary condition characterized by excessive calcification of bones resulting in spontaneous fractures and a marble like appearance. A synonym for osteopetrosis is marble bones. An osteosclerotic form of osteopetrosis is called Albers-Schonberg disease.

Imaging Studies

Conventional radiographic examination remains the most useful means of studying the dysplastic skeleton. The skeletal survey should probably include the skull (anteroposterior [AP], lateral, and Towne views), chest (AP), spine (AP and lateral), pelvis (AP), tubular bones (AP), and/or hands and feet (AP).

Inflammatory Conditions & Infections of Bone

Inflammatory conditions and infections can either directly or indirectly impact the integrity of the bony skeleton. Inflammation is a process in which the white blood cells release chemicals to protect the body from foreign substances such as bacteria and viruses. In some diseases, the body's immune system inappropriately triggers an inflammatory response when there are no foreign substances to actually fight off. In a broad sense, these diseases are classified as autoimmune diseases, which cause the body's normal protective immune system to damage its own tissues. When inflammation occurs, chemicals from the white blood cells are released into the blood or affected tissue in an attempt to rid the body of the foreign substance. This chemical release increases blood flow to the area causing redness and warmth. Some chemicals cause leakage of fluid into the tissues, resulting in swelling, which can stimulate nerves, and ultimately causes pain.

Many inflammatory conditions affect women and minorities disproportionately, both in increased numbers and increased disease severity. For example, female systemic lupus erythematosus (SLE) patients outnumber males nine to one.[2] African American women are three times as likely to get SLE as Caucasian women, and the disease is also more common in Hispanic, Asian, and American Indian women.[2] Rheumatoid arthritis, osteoporosis, and osteoarthritis (in patients over 45 years of age) are also more prevalent among women, whereas certain forms of ankylosing spondylitis occur more frequently in men.[2] SLE risk genes have been identified on the X chromosome, which provides potential evidence for the gender bias in this autoimmune disease.[2]

Rheumatologists have long recognized the incidence of many rheumatic diseases within families and certain ethnic populations, pointing to some role of genetic risk.[2] The perseverance of scientists in gathering biospecimens and clinical histories from patients and their relatives, along with the explosion of knowledge and techniques in genetics, have opened new avenues of research.[2] Genome-wide association studies have transformed the discovery of gene regions, or loci, related to disease risk, through unbiased analyses of patients with a disease compared to controls without it.[2] Association linkage studies have yielded important insights into complex rheumatic disorders, such as lupus, rheumatoid arthritis, and ankylosing spondylitis.[2] Current research also has revealed common genetic factors contributing to other autoimmune diseases as well as co-morbidities.[2]

Inflammatory arthritides

Inflammatory arthritides are diseases of the synovium and lead to erosive changes of the adjacent bones. Examples of inflammatory arthritis include rheumatoid arthritis (RA) and psoriatic arthritis. Degenerative arthritis/osteoarthritis is secondary to articular cartilage damage from repetitive microtrauma that occurs throughout life. Other factors in degenerative arthritis include heredity, nutrition, metabolic factors, preexisting articular disease, and body habitus. Osteoarthritis most often affects the proximal and distal interphalangeal joints of the hands and the major weight-bearing joints, the hips and the knees, Figure 5-1.

The carpal joints at the base of the thumb and the first metatarsophalangeal joint of the foot are commonly affected by degenerative arthritis. Any joint damaged by trauma that results in an irregular articular surface can become prematurely arthritic and produce nodes.

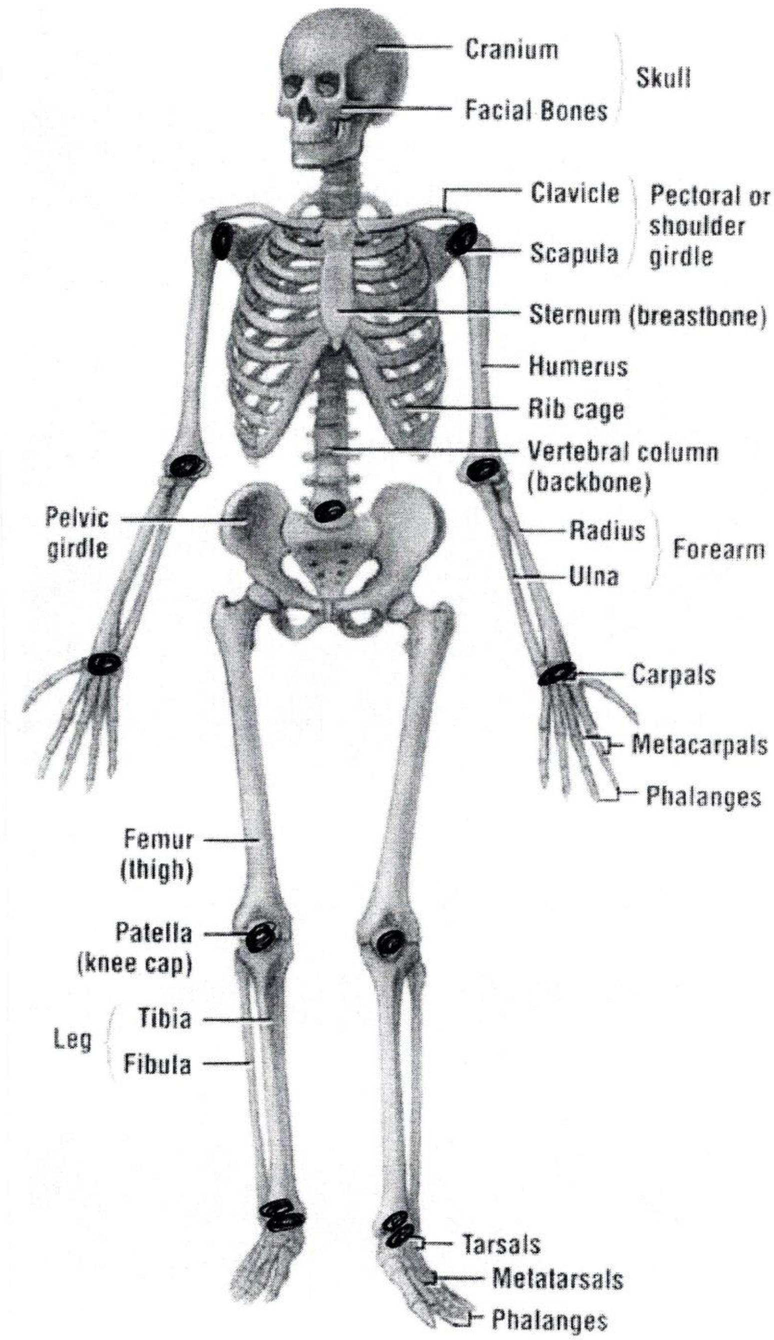


Fig. 5-1. The joints most commonly affected by osteoarthritis. Retrieved from http://neotral.com on December 31, 2010.

Heberden nodes are osseous outcroppings involving the distal interphalangeal joints. Bouchard nodes involve the proximal interphalangeal joints, Figure 5-2.

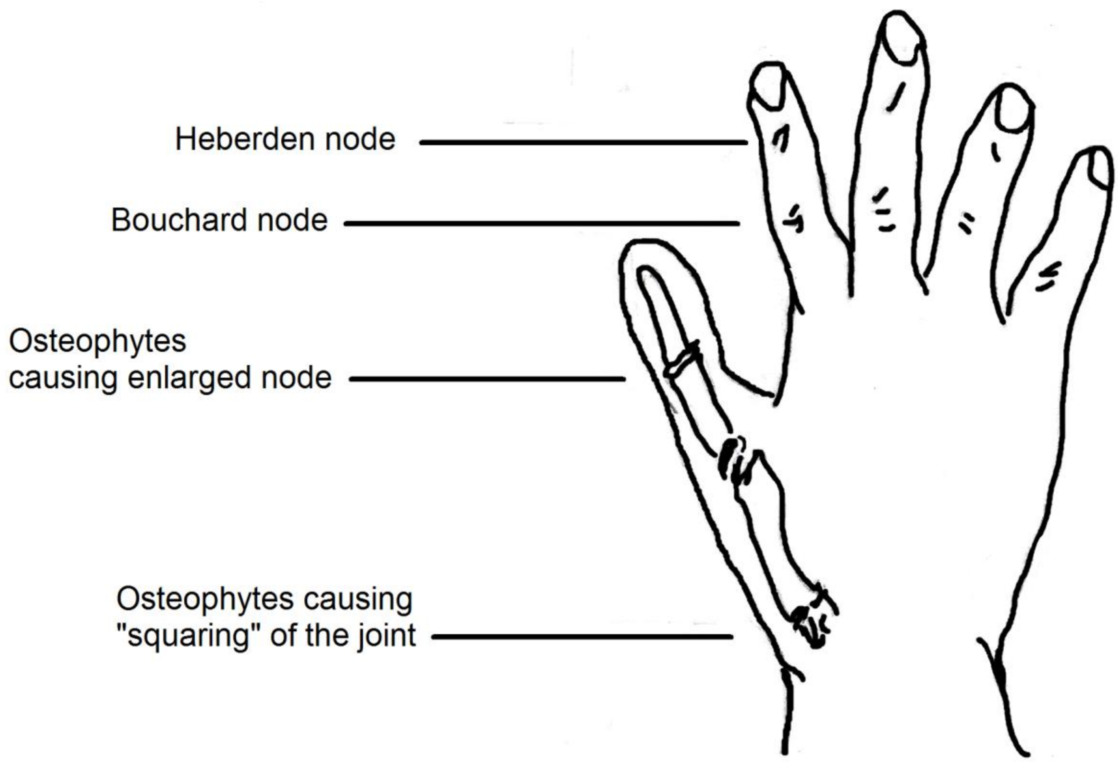


Fig. 5-2. Nodes and osteophytes of the hand. Drawing courtesy of DGM Consulting.

Arthroses may be classified into 4 basic groups based on their common characteristics.

- Noninflammatory arthritides includes osteoarthritis, neuropathic arthropathy, acute rheumatic fever, and a variety of other entities (osteonecrosis, osteochondritis dissecans, and osteochondromatosis). The knee is the most common joint affected by osteoarthritis.
- Inflammatory arthritides include many rheumatologic disorders such as rheumatoid arthritis (RA), systemic lupus erythematosus, the spondyloarthropathies, and crystalline arthropathies. These disorders may be associated with a human leukocyte antigen (HLA) complex region. Rheumatoid arthritis is common in the carpal and tarsal bones and their associated joints. Joint involvement tends to be bilateral, but not always symmetric. Usually the metacarpophalangeal and the metatarsophalangeal joints are affected first. Psoriatic arthritis tends to involve the terminal interphalangeal joints of both hands; whereas RA commonly involves more proximal joints in the hands and wrists.

- Infectious arthritides include pyogenic arthritis, tuberculous arthritis, fungal arthritis, and Lyme disease. Septic arthritis is the infection of a joint and is demonstrated on radiography images by a widening of the joint space secondary to joint effusion.
- Hemorrhagic arthritides include hemophilic arthropathy, sickle cell joint destruction, and pigmented villonodular synovitis.

Advancements in musculoskeletal imaging allow clinicians to accurately monitor arthritic disease conditions and to determine the effectiveness of drug therapies. An imaging examination offers the clinician insight to make the initial clinical diagnosis. Imaging examinations also help detect complications in the earliest stages and thus improve the patient's prognosis. Conventional non-contrast radiography has traditionally been useful in identifying structural damage.

Radiography provides the clinician with information about the possible causes of joint pain and swelling, such as that associated with trauma, skeletal abnormalities, infection and tumors. Radiographs deemed necessary following the initial diagnosis, when a patient's symptoms worsen, or to assess the effectiveness of drug therapies.[4] One of the major disadvantages of radiography is that it cannot demonstrate synovial hyperplasia in a joint; thus is limited on the information that can be gleaned about the amount of inflammatory change occurring in the joints. The sensitivity of radiography to detect early changes of rheumatoid arthritis (RA) is limited but MR imaging has been shown to be sensitive to early changes, such as marrow edema, erosions, and synovial inflammation. MR imaging has significantly improved the clinician's ability to evaluate joint complaints and to identify pathology of the muscles, tendons, ligaments, bones, and soft tissue at an early stage of progression.[4] MR imaging demonstrates soft tissue and the integrity of cartilage and provides insights into articular destruction in the early stages of disease. Various MR imaging sequences are used to evaluate the synovium, cartilage. and bone marrow. For the clinician's evaluation, the most important aspect is to be able to visualize the inflamed synovium. MR may also has proven its ability to demonstrate erosive joint changes, bone marrow edema, and soft tissue swelling.[4] On MR images, inflamed synovium appears as thickened and uneven irregular outlines. After the administration of gadolinium contrast, rapid enhancement of inflamed synovium is seen on MR images.[4]

Ultrasonography (US) has a unique advantage over both MR imaging and radiography in the evaluation of the joints of children because the imaging examination can be conducted without ionizing radiation. US is more sensitive than any other diagnostic imaging modality in detecting joint effusions, cortical erosion, synovial thickening, and cysts in the synovium.[4] US cannot identify erosions and cartilage thinning in patients with long standing arthritis; however, computed tomography excels in demonstrating skeletal changes.[4]

Osteoarthritis

Osteoarthritis is the most common type of arthritis and the percentage of people affected increases with age. As the U.S. population ages, the number of people with the condition will only grow. By 2030, 20% of Americans, or about 72 million people, will have passed their 65th birthday and will be at risk for the disease.[5] An estimated 12.1% of the U.S. population (nearly 12 million Americans) age 25 and older have osteoarthritis.[5] Although osteoarthritis is more common in older people, younger people can develop it; usually as a result of a joint injury, joint malformation, or genetic defect in the joint cartilage. Both men and women have the disease but before age 45, more men than women have osteoarthritis. After age 45, it is more common in women.[6] It is also more likely to occur in people who are overweight and in those whose jobs or leisure activities puts stress on particular joints. Osteoarthritis most often occurs in the hands (at the ends of the fingers and thumb), spine (neck and lower back), knees, and hips.[6]

Osteoarthritis, also known as degenerative arthritis and degenerative joint disease, is a condition in which low-grade inflammation results in pain in the joints. It is associated with abnormal wearing of the cartilage that covers the joints.[6] The condition destroys or decreases the synovial fluid that lubricates the joints and as the bone surfaces become less well protected by cartilage, the individual experiences pain upon weight bearing, including walking and standing. Healthy cartilage allows bones to glide over one another and it also absorbs energy from the shock of physical movement. In osteoarthritis, the surface layer of cartilage breaks down and wears away.

> ***Cartilage*** *is a hard but slippery coating on the ends of bones. Cartilage is a type of connective tissue composed of cells called condrocytes that are embedded in a matrix strengthened with fibers of collagen. Cartilage supports body tissues and provides a cushion type effect for the joint spaces.*

Once the surface layer of the cartilage is reduced, the bones under the cartilage rub together, causing pain, swelling, and loss of joint motion. Over time, the joint may lose its normal shape and small deposits of bone called osteophytes or bone spurs may grow on the edges of the joint. Bits of bone or cartilage can break off and float inside the joint space causing pain and damage.

*A **joint capsule** is a tough membrane sac that encloses the articulating ends of bones.*

***Synovium** is a thin membrane inside the joint capsule that secretes synovial fluid.*

***Synovial fluid** is a fluid that lubricates the joint and keeps the cartilage smooth and healthy.*

***Collagen** is a family of fibrous proteins, which are the building blocks of skin, tendon, bone, and other connective tissues.*

***Proteoglycans** are made up of proteins and sugars that interweave with collagen and form a mesh-like tissue. This allows cartilage to flex and absorb physical shock.*

***Chondrocytes** are found throughout the cartilage and are cells that produce cartilage and help it stay healthy as it grows.*

Ligaments, tendons, and muscles are tissues that surround the bones and joints and allow the joints to bend and move. Ligaments are tough, cord-like tissues that connect one bone to another. Tendons are tough, fibrous cords that connect muscles to bones. Muscles are bundles of specialized cells that, when stimulated by nerves, either relaxes or contracts to produce movement.

Those affected with osteoarthritis may have muscular atrophy due to decreased movement because of pain, regional muscle atrophy, and lax ligaments. Age is positively correlated with osteoarthritis; however, this does not account for the condition in younger people.[5] There is usually an underlying cause of osteoarthritis, for example, a previous injury or cumulative trauma, in which case it is described as secondary osteoarthritis.[6] If no underlying cause can be identified it is described as primary osteoarthritis. The warning signs of the condition consist of stiffness in a joint, swelling of one or more joints, and a crunching feeling or sound of bone rubbing on bone.

Radiography examinations are usually the first imaging procedures requested when osteoarthritis is suspected. MRI is used to visualize joint tissue such as ligaments and muscles. CT may also be used when MRI is contraindicated or when bony structures require additional investigation. Also, many of the changes due to osteoarthritis are initially subtle and are best detected by MR imaging examinations.

Osteoarthritis accounts for 25% of visits to primary care physicians, and half of all non-steroidal anti-inflammatory drug (NSAID) prescriptions.[6] It is estimated that 80% of the population will have radiographic evidence of osteoarthritis by age 65, although only 60% will be symptomatic.[6] Individuals who are overweight or obese increase their risk for the development of osteoarthritis.[7] The association between increased weight and the risk for development of knee osteoarthritis is stronger in women than in men.[7] In a study of twin middle-aged women, it was estimated that for every kilogram increase of weight, the risk of developing osteoarthritis increases by 8 to 14%.[7] An increase in weight is significantly associated with increased pain in weight-bearing joints. There is no evidence that the development of osteoarthritis leads to the subsequent onset of obesity.[7] A decrease in body mass index (BMI) of two units or more during a 10 year period decreases the odds for developing knee osteoarthritis by more than 50%; weight gain was associated with a slight increased risk.[7]

Rheumatoid Arthritis

Rheumatoid arthritis is an inflammatory disease that causes pain, swelling, stiffness, and loss of function in the joints. It has several special features that distinguish it from other kinds of arthritis.[8] For example, rheumatoid arthritis generally occurs in a symmetrical pattern, meaning that if one knee or hand is involved, the other one is also involved.[8] The disease often affects the wrist joints and the proximal finger joints. In addition, those with rheumatoid arthritis may have fatigue, occasional fevers, and a general malaise. Rheumatoid arthritis affects people differently; for example, in some people it may last only a few months or a year and disappears without causing any noticeable damage. While some people may have mild or moderate forms of the disease others may experience periods of worsening symptoms, called flares, and periods of remission. The following are common features of rheumatoid arthritis:

- Tender, warm, swollen joints;
- Symmetrical pattern of affected joints;
- Joint inflammations that can affect the neck, shoulders, elbows, hips, knees, ankles, and feet;
- Fatigue, occasional fevers, and general malaise;
- Pain and stiffness lasting for more than 30 minutes in the morning or after a long rest;
- Symptoms that last for many years; and,
- Variability of symptoms among people with the disease.

Like other rheumatic diseases, rheumatoid arthritis is an autoimmune disease (i.e., one in which the immune system attacks joint tissues, for unknown reason). White blood cells travel to the synovium and cause inflammation (synovitis), characterized by warmth, redness, swelling, and pain. During the inflammation process, the normally thin synovium becomes thick and makes the joint swollen and puffy to the touch. As rheumatoid arthritis progresses, the inflamed synovium invades and destroys the cartilage and bone within the joint. The surrounding muscles, ligaments, and tendons that support and stabilize the joint become weak and unable to function normally. This can lead to the pain and joint damage often seen in rheumatoid arthritis. Researchers studying rheumatoid arthritis now believe that the process begins to damage bones during the first two years that a person has the disease, one reason why early diagnosis and treatment are so important.

> ***Enthesitis*** *refers to inflammation of the location where a bone has an insertion to a tendon or a ligament.*

Scientists estimate that about 2.1 million people, or between 0.5% and 1% of the U.S. adult population, have rheumatoid arthritis.[8] The disease occurs in all races and ethnic groups. Although the disease often begins in middle age and occurs with increased frequency in older people, children and young adults also develop it. Rheumatoid arthritis occurs much more frequently in women than in men.[8] Scientists still do not know exactly what causes the immune system to turn against itself in rheumatoid arthritis but several factors have been implicated. These include genetic (inherited) factors, environmental factors such as a viral or bacterial infection, and an interaction of many factors.

To arrive at a diagnosis of rheumatoid arthritis, laboratory and imaging examinations are performed. One common laboratory examination is a test for rheumatoid factor, an antibody that is present eventually in the blood of most people with rheumatoid arthritis. Other common laboratory tests include a white blood cell count, a blood test for anemia, and a test of the erythrocyte sedimentation rate, which measures inflammation in the body. C-reactive protein is another common test that measures disease activity resulting from inflammatory processes.

Radiography of the area under investigation is usually among the first imaging examinations requested when rheumatoid arthritis is suspected. MR imaging is used to visualize joint tissue such as ligaments and muscles. CT may also be used when MRI is contraindicated or when certain bony structures require additional investigation. Current treatment approaches include lifestyle/health behavior changes, medications, surgery, and routine monitoring and ongoing care.

Seronegative spondylosteoarthritis

Seronegative spondylosteoarthritis is a general term for a group of joint conditions that are not associated with rheumatoid factors or rheumatic nodules. Five subgroups of spondylosteoarthritis are distinguished: ankylosing spondylitis, reactive arthritis (e.g., Reiter syndrome), psoriatic arthritis, arthritis associated with inflammatory bowel disease (e.g., Crohn's disease or ulcerative colitis), and undifferentiated spondylosteoarthritis.[98] The subtypes are generally distinguished on the basis of the patient's history and clinical findings. Imaging does not play a major role in differentiating between the subtypes of spondylosteoarthritis because their imaging features are comparable, especially in early disease. Exceptions to this include undifferentiated spondylosteoarthritis and psoriatic arthritis, which is known to produce syndesmophytes.

> *A **syndesmophyte** is a bony growth inside a ligament, similar to osteophytes, appearing in the intervertebral joints of the spine.*

All forms of spondylosteoarthritis may ultimately develop into ankylosing spondylitis in those with long-standing disease.[9] Radiography images of the areas affected will demonstrate fine, confluent syndesmophytes. The condition affects men 3 to 10 times more often than women, with the age of onset between 15 and 35 years.[9]

As with other rheumatic conditions, early diagnosis and treatment are essential for avoiding structural damage and functional impairment. In many cases, rheumatologists referring patients for radiography evaluation request detailed images that demonstrate the inflammatory changes in specific area of the skeleton.

Ankylosing spondylitis

Ankylosing spondylitis is a progressive form of arthritis due to chronic inflammation of the joints, generally occurring in the spine. Ankylosing spondylitis belongs to a group of disorders called seronegative spondyloarthropathies. When a seronegative test result is confirmed it means that an individual has tested negative for a rheumatoid factor autoantibody. The hallmark of ankylosing spondylitis is "sacroiliitis", or inflammation of the sacroiliac (SI) joints.[10]

In some people, ankylosing spondylitis affects joints such as the shoulders, ribs, hips, knees, and feet can also be affected. Ankylosing spondylitis may also affect organs, such as the eyes, bowel, and more rarely, the heart and lungs. The presenting symptoms include pain and loss of flexibility in the affected area. Ankylosing spondylitis typically begins in adolescents and young adults, but has lifelong impacts. Approximately, 80% of people who have the disorder develop symptoms before age 30.[10] Only 5% of those affected develop symptoms after age 45. Some experts contend that the condition affects twice as many men as women.[10]

The cause of ankylosing spondylitis is unknown, but it is likely that both genetic and environmental factors play a role. The main gene associated with susceptibility to ankylosing spondylitis is called HLA-B27, but having the gene is not always a positive indication of disease onset. Scientists have discovered two additional genes, ERAP1 and IL23R, that, along with HLAB27, may represent a large portion of the genetic risk for ankylosing spondylitis. Factors such as infections or normal bacteria that live in the intestines may trigger the disease in people who are genetically susceptible.

Long-term inflammation leads to calcification that causes two or more bones, especially in the spine, to fuse and may be demonstrated by radiography examinations of the affected structures. Conventional, non-contrast radiography may be able to demonstrate changes in the spine and sacroiliac joints that indicate ankylosing spondylitis; however, it may take years of inflammation to cause damage that is visible on the images. MRI may allow for earlier diagnosis, because it can illustrate damage to soft tissues and bone before these changes are demonstrable on radiography images. A blood test for ankylosing spondylitis is available to check for the HLA-B27 gene, which is present in more than 95% of Caucasians with ankylosing spondylitis.

Systemic Lupus Erythematosus

Systemic lupus erythematosus (SLE) is a chronic autoimmune disorder. SLE may affect the skin, joints, kidneys, and other organs. The underlying cause of the disease is not fully known. Nine times as many women are affected with SLE than men.[11] African Americans and Asians are affected more often than people from other races.[11] Symptoms vary from person to person, and may come and go. Also the condition may affect one organ or body system first and others may become involved later.[11] Almost all people with SLE have joint pain and swelling and some develop arthritis. The most frequently affected joints are in the fingers, hands, wrists, and knees.[11] Other common symptoms include:

- Chest pain when taking a deep breath;
- Fatigue;
- Fever with no other cause;
- Hair loss;
- Mouth sores;
- Sensitivity to sunlight; and,
- A “butterfly” rash over the cheeks and the bridge of the nose. The rash may worsen in sunlight and the rash may be widespread.[11]

As SLE progresses the body’s ability to recognize and maintain normal tissue function is compromised, leading to chronic inflammation, tissue damage, and organ failure.[12] Those with SLE are prone to infections, body-wide arthritis, spontaneous tendon rupture, joint deformities, and soft tissue calcification.[12]

Bone infection and fracture are common in those affected with SLE. Radiography indications of infection include cartilage loss, joint effusion, and progressive bone loss. Bone scintigraphy may be requested to illustrate the extent of bone infections. MR imaging assists in the visualization of micro fractures and marrow edema.[12]

Bone Infections

Osteomyelitis is an infection of bone and bone marrow that may be caused by direct inoculation of an open traumatic wound or by blood-borne organisms. Bone and bone marrow infection caused by blood-borne organisms is common in children and occurs more frequently in boys than girls. In children, the infection is most common in the metaphysis or epiphysis of the long bones and more common in the lower extremity than the upper extremity. The most common organisms include *Staphylococcus aureus,* gram-negative bacilli, and group B *streptococcus*.[13] The four main routes through which osteomyelitis may be acquired include hematogenous spread of infection from the bloodstream, spread of infection from adjacent soft tissues, direct inoculation through penetrating trauma, and postoperative infection.[13]

Radiographic changes of acute osteomyelitis include soft tissue swelling, bone demineralization (10-14 days), and sequestra and involucrum later.[13] Pain, loss of function of the involved extremity, and a soft tissue abscess may be present. MRI images shows changes in bone and bone marrow before plain radiographs. Radiography evidence of osteomyelitic bone changes often take 7 to 14 days to develop.[13] Skeletal lesions appear as enlarging ill-defined radiolucent areas in the infected bone. Magnetic resonance imaging and 3-phase bone scan may be used to diagnose acute osteomyelitis.[13] In the inflammation process fluid (i.e., edema) replaces marrowfat, osteomyelitis shows low to intermediate signal intensity on T1-weighted MR images and high signal intensity on fat-saturated T2-weighted and short-tau inversion recovery (STIR) images.[13]

Injection of gadolinium contrast is useful in differentiating an abscess from bone marrow edema in the marrow space or in differentiating a soft tissue abscess from surrounding cellulitis.[13] An abscess exhibits as a thick, enhancing wall without central enhancement. Image detection of sinus tracts and sequestra is also improved after gadolinium administration.

A ***sequestrum*** *is a fragment of necrotic bone that is separate from the living parent bone. A sequestrum may be absorbed, be discharged through a sinus tract, or persist as a focus of infection.*

*An **involucrum** is a layer of healthy bone that has formed around the dead bone. It may merge with the parent bone or become perforated with tracts through which pus can escape.*

*A **choaca** is an opening in the involucrum through which granulation tissue and the sequestra may be discharged.*

*A **sinus tract** is a channel extending from the bone to the skin surface that is lined with granulation tissue.*

A Brodie abscess is a bone abscess found characteristically in subacute pyogenic osteomyelitis, but which also may be identified in chronic osteomyelitis. A Brodie abscess typically occurs near the ends of tubular bones and may present as single or multiple lesions, and is especially common in children. On radiography images, a Brodie abscess appears as a well-defined circular or elliptic radiolucency with adjacent sclerosis.[13]

Treatment of osteomyelitis includes antibiotic therapy and surgery in some cases. The type of surgery depends on which bone is infected and may include drainage of the infected area, removal of diseased bone and tissue, or bone and tissue grafting.

Tuberculosis

Tuberculosis is an infectious disease caused by the tubercle bacillus. Mycobacterium tuberculosis is pathologically characterized by inflammatory infiltration, formation of tubercles, necrosis, abscesses, fibrosis, and calcification. It most commonly affects the respiratory system but other parts of the body such as bones, joints, nervous system, lymph nodes, and skin may be affected. Tuberculosis of the bone generally affects the hip, knee, and spine.

Potts' disease is the term given for tuberculosis of the spine and was first discovered in Egyptian mummies dating to 3000 BC. Potts' disease, also known as tuberculous spondylitis, is one of the oldest demonstrated diseases of humankind. The disease is named after Percivall Pott (1779) who presented the first classic description of spinal tuberculosis.[14] Today morbidity and mortality has decreased due to antituberculous drugs and improved preventative health measures, but the disease is still a significant cause of death in developing countries.[14]

Bone and soft-tissue tuberculosis accounts for approximately 10% of extrapulmonary tuberculosis cases and between 1% and 2% of total cases.[15] Tuberculous spondylitis is the most common manifestation of musculoskeletal tuberculosis, accounting for approximately 40%-50% of cases.[15] Approximately 1-2% of the total cases of tuberculosis are attributable to Potts' disease.[14,15] Spinal tuberculosis can result in serious health impairment ranging from permanent neurologic deficits and severe deformities to death. Potts' disease is the most dangerous form of musculoskeletal tuberculosis because if untreated or ineffectively treated it can lead to bone destruction, deformity, and paraplegia. Potts' disease most commonly involves the thoracic and lumbosacral spine with 10% of cases involving the cervical spine.[14] Abscesses in the lumbar region may descend down the sheath to the femoral trigone region and eventually erode into the skin. The presentation of Pott's disease depends on the stage of the disease, affected site, and presence of complications such as neurologic deficits, abscesses, or sinus tracts. Tuberculosis involves 3-5% of those who test HIV-negative and as much as 60% in those who test HIV positive.[14]

Radiography changes associated with Pott's disease present relatively late in the course of the disease. When radiography changes become evident they include lytic destruction of bone and reactive sclerosis. CT imaging provides better bony detail of the irregular lytic lesions, sclerosis, and disruption of bone circumference.
MR imaging is useful for differentiating tuberculous spondylitis from pyogenic spondylitis.[16,17] Contrast-enhanced MR imaging is an important tool in the differentiation of the two types of spondylitis. Radionuclide scanning is not indicated for diagnosis of Potts' disease. Percutaneous CT-guided needle biopsy may be used to obtain tissue samples of bone lesions.

Human Immunodeficiency Virus

Patients with human immunodeficiency virus (HIV) infection and acquired immunodeficiency syndrome (AIDS) are susceptible to a variety of complications that can affect the musculoskeletal system. Radiology plays an important role in early diagnosis and treatment planning in this affected population. In 2004, it was projected that 45 million people will become infected between 2002 and 2010.[19] Beyond 2010, the number of infected individuals continues to grow. MR imaging allows evaluation of the central nervous system and best demonstrates pulmonary and abdominal complications of the disease.

Osteomyelitis is a common cause of musculoskeletal complications in AIDS patients.[19] The most frequently involved bones are the tibia, wrist bones, femoral heads, ribs, and thoracolumbar spine.[19] Tuberculosis and bacillary angiomatosis are two specific forms of osteomyelitis that have been observed with increasing frequency in HIV-positive and AIDS patients. Bone scintigraphy is the most sensitive imaging method for detection of early osteomyelitis.[18]

HIV-positive and AIDS patients are susceptible to a variety of neoplasms of the musculoskeletal system. Non-Hodgkin's lymphoma and Kaposi sarcoma are the two most common neoplasms observed in those who are HIV-positive and have AIDS. The presence of primary bone tumor in the absence of extraskeletal disease has been reported and usually affects the lower extremities, spine, pelvis, and skull. Radiography, CT, and MRI are used in the diagnosis and staging of these neoplasms.[16,17]

Metabolic Diseases

Metabolic bone disease is an umbrella term referring to abnormalities of bones caused by a broad spectrum of disorders.[20] Most commonly these disorders are caused by abnormalities of minerals such as calcium, phosphorus, magnesium, or vitamin D leading to dramatic clinical disorders that are commonly reversible once the underlying defect has been treated.[20] These disorders are to be differentiated from a larger group of genetic bone disorders where there is a defect in a specific signaling system or cell type that causes the bone disorder.[20] There may be overlap of such conditions. For example, genetic or hereditary hypophosphatemia may cause the metabolic bone disorder osteomalacia.[20] Although there is currently no treatment for the genetic condition, replacement of phosphate often corrects or improves the metabolic bone disorder.[20]

Gout

Gout and osteoporosis are examples of metabolic diseases that have a serious impact on skeletal structures. Gout, a metabolic hereditary disease, is a form of acute arthritis and is marked by inflammation of the joints. Gout is also known as podagra when it involves the metatarsalphalangeal joint at the base of the big toe. The etiology of gout is excessive uric acid in the blood which deposits urates of sodium in and around the joints. Several different metabolic abnormalities may cause hyperuricemia (i.e., abnormal amounts of uric acid in the urine).

Presenting symptoms include a sudden onset of pain and intense signs of inflammation. Affected joints may be at any location, but usually begins in the knee or foot. Those affected with gout are asymptomatic; however, when an acute attack does develop, it usually begins at night with moderate pain that increases in intensity. Gout may be diagnosed and treated without further investigations. In a person with hyperuricemia and the classic podagra, testing of synovial fluid can be helpful in arriving at a clinical diagnosis. Radiography, while useful for identifying chronic gout, has very little utility in acute attacks. Treatment of acute gout is usually colchicine. Long term therapy of gout is directed at preventing hyperuricemia. Patients with gout have a tendency to form uric acid kidney stones. To prevent stone formation, patients with gout should be given forced fluids at the rate of three liters each day. Salicylates interact and interfere with the uricosuric action of probenecid and allopurinol and should not be prescribed. Likewise, a person with gouty arthritis should maintain a diet low in purine. Foods that are known to be high in purine are anchovies and sardines. Foods having moderate levels of purine include asparagus, cauliflower, lima beans, lobster, and salmon.

Osteoporosis

Osteoporosis is considered a major health problem in the U.S. Osteoporosis is called a silent disease since its presence may not be evident until a bone fracture occurs. The National Osteoporosis Foundation (NOF) estimates that approximately 10 million Americans have osteoporosis, 44 million are at risk of developing osteoporosis, and more than 1.5 million fractures are attributed to osteoporosis each year.[21] Typically those with osteoporosis have no pain or indication of the disease process until they break a hip, wrist, or sustain spinal fracture(s) that may leave a dowager's hump or reduce their height by a few inches. A broken hip or crushed vertebrae may begin an initial downward spiral of lost mobility and illness, culminating in death. Approximately 15% of white females will break a hip, and the injury will prove fatal in 10% to 20% of those cases.[21] Among people who live to be 90, approximately 32% of women and 17% of men will suffer a hip fracture, most due to osteoporosis.[21] Medical costs in the U.S. related to osteoporosis have been estimated at $3.8 billion dollars annually.[21]

Osteoporosis is a disease that causes bones to become more porous, gradually making them weaker and more brittle. The word osteoporosis literally means porous bones. Normal bone is dense and strong but bone with osteoporosis is thin and porous, making it more likely to break. Many assume that the adult skeleton is an inert framework, a sort of stone like foundation for the living flesh of our bodies. However, this assumption is false since bone is living tissue, and from birth to death, is in a constant state of flux. After menopause, many women experience bone loss that can eventually lead to osteoporosis. About one in three women over the age of 50 have osteoporosis, and many more are at risk for developing the disease.[21] Only a small number of women with osteoporosis have been diagnosed or treated. Although osteoporosis is linked to a decline in estrogen in women, about 20% of its victims are men.[21] Women are considered to be at twice the risk of developing osteoporosis as men. Idiopathic juvenile osteoporosis is a rare, self-limiting disorder that appears between the ages of 8 and 14. The disorder results in osteopenia, growth arrest, and bone and joint pain. Idiopathic juvenile osteoporosis must be differentiated from other causes of osteopenia (e.g., osteogenesis imperfecta, malignancy, and Cushing's disease).

Osteomalacia, Paget's Disease, and Acromegaly

Osteomalacia and Paget's disease are also metabolic disorders that should be mentioned. Osteomalacia is defined as a softening of the bones. It is a disease marked by increasing bone softness and eventually the bone becomes more flexible and brittle, thus causing deformities. If osteomalacia occurs before the growth plate is closed, it is known as rickets. The clinical presenting symptoms of osteomalacia include rheumatic pain in the limbs, spine, thorax, and especially the pelvis with accompanying anemia.

Paget's disease, named after British surgeon Sir James Paget (1814-1899), is a skeletal disease of the elderly. This disease causes chronic inflammation of bones, resulting in thickening and softening of bones and bowing of long bones. A synonym for Paget's disease is ostetitis deformans. For asymptomatic cases, treatment is not recommended. No specific curative therapy exists; however, administration of vitamin D three times a week and anabolic hormones reduces the resulting osteoporosis. Calcitonin, etidronate disodium, and mithramycin have been used to control resorption of bone, which assists in alleviating bone pain.

Acromegaly is a chronic disease generally seen in middle-aged individuals. Characteristic features of acromegaly are elongation and enlargement of the extremities, frontal bone, and mandible. Facial deformities are also evident in acromegaly and include enlargement of the nose and lips with thickening of the facial soft tissue. Persons with acromegaly present with a prominent forehead and jaw, widened teeth, and abnormally large, spadelike fingers.

Conditions of the Foot and Ankle

The feet bear the weight of the entire body and are subject to a variety of conditions that may result in chronic foot pain. The ACR address several of the more common conditions affecting the feet and provides suggestions for imaging them.[22] The conditions are discussed in detail in the document titled *ACR Appropriateness Criteria for Chronic Foot Pain* and includes tarsal coalition, reflex sympathetic dystrophy, avascular necrosis of the metatarsal head, painful accessory bones, arthritis, plantar fasciitis, tarsal tunnel syndrome, interdigital (Morton's) neuroma, tendon pathologies, hallux valgus, neoplasm, stress fracture, and osteomyelitis.[22] A few of the more common of these will be covered in the following discussion.

Hallux valgus (i.e., bunion) is a lateral deviation of the great toe. The etiology of the condition is thought to be multifactorial including genetics and inappropriately sized shoes. Hallux varus is a medial deviation of the great toe and is considered to be an inherent deformity secondary to overcorrecting of hallux valgus.

The three most common lesser-toe deformities are hammer toe, claw-toe, and mallet-toe. Sesamoid disorders can include acute injury (fracture, dislocation, sprain), sesamoiditis, stress fracture, arthrosis and avascular necrosis.

Interdigital neuritis also called Morton neuroma is a compressive neuropathy of the interdigital nerve, usually between the third and fourth metatarsals and affects females more than males. The presenting symptoms include a burning pain and paresthesia in the affected toes. Conventional radiography examinations are often requested to rule out bony masses or deformity; however, MR imaging has been used to diagnose the condition.

Plantar fasciitis is a painful heel condition that can affect both sedentary and active individuals and is most often seen in the adult population. The typical presentation includes intense pain and tenderness over the plantar medial tuberosity of the calcaneus at the proximal insertion of the plantar fascia. The origin of the condition is thought to involve microtears at the origin of the plantar fascia, which initiates inflammation and an injury-repair process that leads to a traction osteophyte. The condition can present as a bilateral condition.

Calcaneal and metatarsal fractures are the most frequent sites of stress fractures in the foot. Calcaneal stress fractures can be a cause of heel pain, especially in active individuals. MR imaging is the most sensitive and specific test for determining if a calcaneal stress fracture is present. Periostitis, often referred to as “stone bruise,” results in pain and tenderness in the central portion of the heel pad and can represent traumatic peristeal or bursal inflammation.

The Achilles tendon is the most commonly injured tendon of the ankle and usually tears three to five centimeters (cm) superior to its calcaneal insertion, where the blood supply of the tendon is poorest. The anterior talofibular, calcaneofibular, and posterior talofibular ligaments form the lateral collateral ligament. The anterior talofibular ligament is the most commonly injured.

Freiberg’s disease presents as pain in the forefoot usually localized to the head of the second metatarsal and occasionally the fourth metatarsal. Clinical presenting symptoms include localized swelling and limitation of motion in the MP joint. It often occurs during the growth spurt at puberty and is more common in females. It originates from avascular necrosis of the metatarsal head and from repetitive stress with microfractures at the junction of the metaphysis and the growth plate. These fractures thus deprive the epiphysis of adequate circulation.

Radiography findings of Freiberg’s disease illustrate increased density of the metatarsal head, flattening, collapse, and cystic changes and widening of the MTP joint. Initially treatment is conservative including immobilization of the foot; however surgical intervention may be required if the condition does not resolve.

Accessory bones in the foot may be a source of pain. For example, pain associated with an accessory navicular bone has been attributed to traumatic or degenerative changes at the synchondrosis and soft-tissue inflammation. Radionuclide bone scans and MR imaging has been used to investigate conditions caused by accessory bones. Lesions related to accessory bones usually demonstrate an increased radiotracer uptake or marrow edema across the synchondrosis.

All forms of arthritis, including rheumatoid and seronegative arthritis, affect the feet and can cause chronic foot pain. Conventional radiography is usually the first examination ordered when any of the arthritides are considered in the diagnosis.

Radiography is also the imaging modality of choice for detecting and monitoring changes in Charcot disease. Research studies now support the use of gadolinium-enhanced MRI in the early detection of rheumatoid and seronegative arthritis.

Reflex Sympathetic Dystrophy

Reflex sympathetic dystrophy (RSD) is also referred to as complex regional pain syndrome (CRPS). The symptoms of RSD include pain, tenderness, swelling, and diminished mobility and vasomotor instability. Fractures, trauma, central nervous system and spinal disorders, and peripheral nerve injury have been associated with RDS. According to the Reflex Sympathetic Dystrophy Syndrome Association anyone can get RSD, but studies show that it is more common in people between the ages of 25 and 55, and is more frequently seen in women than in men. Clinicians should consider RSD for people who present with moderate-to-severe pain that is disproportionate to any event such as a sprain, fracture, surgery, etc. and has some of the following characteristics:

- Pain, which is described as deep, aching, cold, burning, and/or increased skin sensitivity;
- The presence of an initiating noxious event (sprain, fracture, etc);
- Continuing pain (moderate to severe) associated with allodynia, such as the touch of clothing or water from a shower, or hyperalgesia;
- Abnormal swelling in the affected part;
- Abnormal hair or nail growth;
- Abnormal skin temperature;
- Abnormal sweating; and,
- Limited range of movement and muscular weakness.

Approximately 69% of those with RSD often experience diffuse osteopenia of the involved part. A three phase radionuclide scan has been used to diagnose RSD of the foot. Currently there are no specific RDS findings on MR imaging.

Charcot-Marie-Tooth disease

Charcot-Marie-Tooth disease (CMT) is best described as a compartment syndrome of the foot that may lead to development of lesser toe deformity. It is often associated with neurologic dysfunction and causes weakness or loss of the intrinsic muscles of the foot. The dysfunction may be secondary to central nervous system disorders (i.e., stroke or traumatic head injury), peripheral nerve injuries, or peripheral neuropathy). The disease is named for the three physicians who first identified it in 1886—Jean-Martin Charcot, Pierre Marie, and Howard Henry Tooth.[23] CMT is also known as hereditary motor and sensory neuropath (HMSN) or peroneal muscular atrophy and comprises a group of disorders that affect peripheral nerves. The peripheral nerves lie outside the brain and spinal cord and supply the muscles and sensory organs in the limbs. Disorders that affect the peripheral nerves are called peripheral neuropathies.

The neuropathy of CMT affects both motor and sensory nerves. Typical features include weakness of the foot and lower leg muscles, which may result in foot drop, and a high-stepped gait with frequent tripping or falls. Foot deformities, such as high arches and hammertoes (a condition in which the middle joint of a toe bends upwards), are also characteristic due to weakness of the small muscles of the feet. In addition, the lower legs may take on an "inverted champagne bottle" appearance due to the loss of muscle mass. As the disease progresses, persons affected experience weakness and muscle atrophy may occur in the hands, resulting in difficulty with fine motor skills.

The onset of symptoms commonly occurs in adolescence or early adulthood, but the presentation may be delayed until mid-adulthood. The severity of symptoms is variable in different patients and even among family members with the disease. Progression of symptoms is gradual with pain ranging from mild to severe. Some patients may need to rely on foot or leg braces or other orthopedic devices to maintain mobility. CMT is not considered a fatal disease and people with most forms of CMT have a normal life expectancy.

There are many forms of CMT disease, including CMT1, CMT2, CMT3, CMT4, and CMTX. CMT is caused by mutations in genes that produce proteins involved in the structure and function of either the peripheral nerve axon or the myelin sheath. The degeneration of motor nerves results in muscle weakness and atrophy in the extremities (arms, legs, hands, or feet) and in some cases the degeneration of sensory nerve results in a reduced ability to feel heat, cold, and pain. Diagnosis of CMT begins with a standard patient history, family history, and neurological examination.

Tarsal Tunnel Syndrome.

Tarsal coalition is a congenital condition. It is an abnormal bridging across two or more tarsal bones and is bilateral in about 50% of those affected. Tarsal coalition is a well-recognized cause of foot pain and causes restricted mobility in adolescents and young adults. The calcaneonavicular and middle-facet talocalcaneal coalitions are the most commonly affected structures of the foot. The cause of a coalition is uncertain but some speculate that a lack of differentiation and segmentation of embryonic mesenchyme cause it. In the general population, coalition occurs at a frequently of less than 1%.

The calcaneonavicular coalition is usually detected on radiography images (i.e., especially oblique positions) of the foot and may be confirmed by CT. The talocalcaneal coalition is frequently "overlooked" on conventional radiography due to overlapping of other anatomic structures. It has been suggested that secondary signs on the lateral view of the foot could be suggestive of a subtalar coalition and include talar beaking, flattening and broadening of the lateral talar process, positive C-sign, and narrowing of the posterior talocalcaneal joint. Both CT and MR imaging have been demonstrated to be effective in visualizing all types of coalition.

*The **C Sign** is a continuous C-shaped line that extends from the talus to the sustentaculum tali and can be seen on lateral radiographs of the ankle. The anatomic-pathologic basis for a talocalcaneal C-Sign is the bony ridge that extends from the talar dome to the sustentaculum tali in combination with a prominent inferior outline of the sustentaculum tali. Images of the C-sign may be viewed at http://radiology.rsna.org/content/223/3/756.full.*

Conventional radiography is usually the initial imaging study requested, with additional projections such as a well-penetrated Harris-Beath view (axial view), followed by CT and MRI images of the foot.

The tarsal tunnel is located on the medial side of the ankle. It begins superiorly at the medial malleolus and extends inferiorly to the navicular bone. The lateral side of the tunnel is formed by the calcaneus, including the sustentaculum, tali, and the talus. The tunnel is covered with a thick ligament that protects and maintains the structures contained within the tunnel (i.e., arteries, veins, tendons, and nerves). One of these structures is the posterior tibial nerve, which is the focus of tarsal tunnel syndrome.

Tarsal tunnel syndrome presents as a compressive neuropathy of the posterior tibial nerve. Presenting symptoms include a burning sensation on the plantar surface of the foot and occasional sharp pains or paresthesias.

Tarsal tunnel syndrome is similar to carpal tunnel syndrome, which occurs in the wrist. Both disorders arise from compression of a nerve in a confined space. A few of the common causes include injury, systemic disease (i.e., arthritis), and any abnormal structure that occupies space within the tunnel such as a ganglion cyst, swollen tendon, etc. Diagnosis of tarsal tunnel syndrome begins with the initial examination. The clinician will position the foot and tap on the nerve to see if the symptoms can be reproduced. Advanced imaging studies may be used if a lesion is suspected.

Knee Pathology

The knee joint is the largest joint in the body, consisting of four bones and an extensive network of ligaments and muscles. The knee and its surrounding structures are subject to a variety of conditions and disorders.

A Baker or popliteal cyst is a bursa that extends from the knee joint posteriorly between the tendons of the semimembranosus and medial head of the gastrocnemius. The presence of a Baker cyst suggests a chronic or recurrent knee joint effusion. MR imaging is used to evaluate the knee for a torn meniscus. The medial and lateral menisci are crescent-shaped structures that lie at the medial and lateral aspects of the superior articular surface of the tibia. On sagittal images, the menisci appear as bow tie-shaped structures.

The anterior cruciate ligament (ACL) arises on the medial surface of the lateral femoral condyle at the intercondylar notch and attaches on the anterior portion of the intercondylar eminence of the tibia. The posterior cruciate ligament (PCL) arises from the lateral surface of the medial femoral condyle within the intercondylar notch and attaches at the posterior surface of the intercondylar eminence. The ACL is more commonly injured than the PCL. The direct appearance of a torn ACL on MR imaging include:

- Visible disruption of the ligament;
- Irregular or wavy contour;
- Focal signal abnormality within the ligamentous substance;
- “Empty notch” sign on coronal images; and,
- Anterior tibial spine avulsion.[17,18]

MR imaging has an approximate sensitivity of 94% and a specificity of 94% for complete ACL tears and a sensitivity of 91% and a specificity of 99% for complete PCL tears.[17,18]

O'Donoghue's "unhappy triad" is a common football and skiing injury that occurs as a result of valgus stress and twisting motion during weight bearing. Classically, in the "unhappy triad" a medial collateral ligament injury, ACL tear, and medial meniscal tear occurs.

Jumper's knee, also known as patellar tendinitis, is an overuse syndrome that classically occurs in young athletes who kick, jump, and run. Such actions place stress on the patellofemoral joint with intrasubstance degeneration and partial tearing of the tendon.

Hip Pathology

Pain is a frequent reason given for conventional radiography evaluation of the hip. For evaluation of hip pain, conventional radiography is often the first imaging modality employed. Those with degenerative arthritis of the hip describe pain anterior to the hip or along the greater trochanteric region.[25] In any case, if conventional radiography examinations fail to reveal sufficient information about the source of the pain, MR imaging is used for continuous ongoing evaluation.

Avascular necrosis of the hip is a pathological process where subchondral bone becomes necrotic. The most common cause of avascular necrosis is disruption of the blood supply to the femoral head from a displaced femoral neck fracture.[25] Compromised blood supply leads to infarct of the subchondral bone beneath the articular surface of the femoral head and bilateral osteonecrosis. A few of the most common nontraumatic causes of avascular necrosis are excessive alcohol use and systemic steroid use.[25] Nontraumatic causes include sickle cell diseases, post-irradiation, chemotherapy, arterial disease, smoking, and kidney and liver disease.[25] Early in the course of the disease, the patient may be asymptomatic but as the disease progresses, the patient may complain of pain in the groin area.[25] In the late stages of the disease, the patient may have severe pain, limp, and loss of hip motion.[25] Other areas of the skeleton that can become affected by avascular necrosis are the humeral head and the distal femur, especially the medial femoral condyle.[25]

Legg-Calve-Perthes (LCP) disease is a temporary interruption of the blood supply to the bony nucleus of the proximal femoral epiphysis with impairment of the epiphyseal growth and subsequent remodeling of revascularized, regenerated bone in the pediatric patient. LCP disease generally occurs between the ages of 3 and 12 years, most commonly in children between five and seven years of age. The disorder may be bilateral in up to 20% of patients; boys are affected three to five times more often than girls. Those affected usually present with a limp accompanied by pain in the hip or referred to the thigh or knee often following traumatic injury. The etiology of the avascular changes in the femoral head of children with LCP disease remains unclear.

In the early stages of LCP disease, standard radiography images may remain normal. Technetium bone scans often provide evidence of the disease in the early stages. MR imaging facilitates the early diagnosis and quantification of osteonecrosis and provides a clear image of the articular disease. Those affected may recover without residual problems if the signs and symptoms of the disease develop before the age of five years. However, patients older than nine years at presentation almost universally have a poor prognosis.

Bone Tumors

Many skeletal disorders result from either a benign or malignant bone tumor. Tumors can originate in the bone (primary tumors) or arise from metastases from tumors originating elsewhere in the body. Primary bone tumors can be either benign or malignant. The effect that the lesion has on bone is an indicator of the type of tumor. For example high-grade malignant tumors generally spread rapidly through the medullary cavity. Low-grade malignant lesions tend to spread slowly, but they can also destroy the cortical bone and produce a soft tissue mass. Benign bone tumors are more common than malignant ones. Both malignant and benign bone tumors may grow and compress healthy bone tissue, Benign tumors however do not spread, do not destroy bone tissue, and rarely a threat to life.

Osteochondroma is the most common benign bone tumor. Osteosarcoma and Ewing’s sarcoma are the most common malignant bone tumors. The most common types of primary bone cancer include osteosarcoma, chondrosarcoma and the Ewing sarcoma family of tumors (ESFTs). Osteosarcoma arises from osteoid tissue in bone and occurs most often in the knee and upper arm. Chondrosarcoma begins in cartilaginous tissue and primarily occurs in the pelvis, upper leg, and shoulder. The Ewing sarcoma family of tumors (ESFTs) occurs in bone but may also arise in soft tissue such as muscle, fat, fibrous tissue, blood vessels, or other supporting tissue. ESFTs occur most commonly along the backbone and pelvis and in the legs and arms.

Metastatic bone tumors are frequently the result of breast or prostate cancer that has spread to bone.[26] Metastatic lesions from breast cancer are usually osteolytic, while most prostate cancer metastases are osteoblastic.[26] Metastases are the most common malignant skeletal tumors. A few primary tumors account for most metastatic bone lesions; however, cancers that are most likely to metastasize to bone include prostate, breast, kidney, thyroid, and lung.

The anatomic location of a lesion within bone is also a key to its identification. For example adamantinoma, a malignant tumor, usually occurs in the tibia in young patients.[26,27] Chondroblastoma most often occurs within the epiphysis in long bones. A giant cell tumor typically begins in the metaphysis and extends through the epiphysis to lie just below the cartilage. A Ewing tumor frequently involves the diaphysis. Osteogenic sarcoma usually occurs in the metaphysis of the distal femur and proximal tibia but occurs within the diaphysis in about 7% of patients with long-bone tumors.[26,27]

The axial skeleton often is the site of increased metastases because of the presence of red bone marrow. It is rare to have bone metastases below the elbow or knee. Radiography images often demonstrate lytic bone metastases but at least 30% to 50% of the bone must be destroyed before it is evident.[26] Bone metastases from renal cell carcinoma and thyroid cancer can show a lytic, expansile, “blown-out” appearance of bone.

Formulation of the differential diagnosis is based on several clinical and radiographic parameters. The age of the patient helps to investigate for diseases in defined age groups. Certain diseases are uncommon in particular age groups. For example, in the middle and older age group of patients (ages 40-80 years), the most likely diagnosis is metastatic bone disease, multiple myeloma, or lymphoma. In young patients (ages 15 to 40 years), multiple lytic and oval lesions are most likely a vascular tumor.[26,27] In children below age five, multiple destructive lesions may represent metastatic disease such as neuroblastoma or Wilm’s tumor.[26,27] Figure 5-3 illustrates the usual age distribution of various bone lesions.

Although bone cancer does have a clearly defined cause, researchers have identified several factors that increase the likelihood of developing these tumors. Osteosarcoma occurs more frequently in people who have had high-dose external radiation therapy or treatment with certain anticancer drugs; children seem to be particularly susceptible. A small number of bone cancers are due to heredity. For example, children who have had hereditary retinoblastoma are at higher risk of developing osteosarcoma, particularly if they have been treated with radiation. Additionally, people who have hereditary bone defects and people with metal appliances like those used in fracture repair are more likely to develop osteosarcoma. Ewing's sarcoma is not strongly associated with any heredity cancer syndromes, congenital childhood diseases, or previous radiation exposure.[27]

	Malignant	***Benign***
Birth to 5 years		
	Leukemia	Osteomyelitis
	Metastatic neuroblastoma	Osteofibrous dysplasia
	Metastatic rhabdomyosarcoma	
10 to 25 Years		
	Osteosarcoma	Eosinophilic granuloma
	Ewing tumor	Osteomyelitis
	Leukemia	Enchondroma
		Fibrous dysplasia
40 to 80 years		
	Metastatic bone disease	Hyperparathyroidism
	Myeloma	Paget disease
	Lymphoma	Mastocytosis
	Chondrosarcoma	Enchondroma
	Paget sarcoma	Bone infarct
	Malignant fibrous histiocytoma	
	Postradiation sarcoma	

Fig. 5-3. Age distribution of various bone lesions.[26]

Imaging plays an important role in the evaluation of bone tumors. The radiologist, together with a multi-disciplinary team including the orthopedic surgeon and oncologist work closely to evaluate patients with bone tumors.[27] Conventional, non-contrast radiography examinations are usually the first images obtained. Further evaluation often follows using other imaging modalities such as CT, MRI, and radionuclide bone scans.

Radiography assists in the evaluation of suspected bone tumors by allowing visualization of morphology features, periosteal reaction, location in the bone, and distribution within the skeleton. Morphology features of a lesion refer to the pattern of bone destruction and the size, shape, margins, and zone of transition of the lesion. For example, a lesion with a sharp border suggests a nonaggressive or benign lesion. When poorly defined bone margins are seen on images, it is associated with cortical destruction and is suggestive of malignancy. Periosteal reaction reflects the rate of growth of the underlying lesion. Slow-growing lesions may produce a laminated periosteal reaction with uniform wavy layers. Malignant lesions that grow in spurts can produce an "onion-skin" pattern, and aggressive lesions having a rapid growth pattern associated with a "starburst" or "hair-on-end" periosteal reaction. A Codman triangle occurs when uplifting of the periosteum occurs in a triangular configuration and may be suggestive of both benign and malignant lesions. There are key features that may be used to help distinguish bone tumors and these include:

- Morphologic features and pattern of bone destruction resulting in a zone of transition;
- Periosteal reaction;
- Location in the bone and distribution in the skeleton;
- Presence of tumor matrix; and,
- Presence of soft tissue mass.[26,27]

MR imaging is the most important diagnostic test for local staging and preoperative planning of primary bone and soft tissue tumors. MR imaging is also useful for monitoring the response to chemotherapy or radiation therapy and for detecting postoperative tumor recurrence. On MR imaging, most bone tumors have a similar appearance, being T1 hypointense and T2 hyperintense.[17,18] If present, hemorrhage, necrosis, and calcification/ossification may give the lesion a heterogeneous appearance. The main purpose of MR imaging in the evaluation of a primary malignant bone tumor is to assess the extent of tumor spread.[17,18] MR imaging is able to detect tumor involvement of the adjacent muscle compartments, neurovascular structures, and joints.[17,18]

CT may be helpful in the detection of tumor matrix and the location of the nidus in suspected osteoid osteoma. CT is also used for percutaneous image-guided biopsy of bone tumors. MR imaging is helpful in detecting tumor location, extent, and relationship to the neurovascular bundle.[17,18] CT is used to evaluate the degree of cortical involvement and breakthrough of the tumor and to detect the presence of calcifications within the tumor. CT is particularly useful in providing information about tumors located in complex-shaped bones such as the spine and pelvis, which are not easily evaluated on radiography images.

Image-guided biopsy of primary bone tumors is an alternative to open biopsies and has the advantages of being less expensive and less invasive, with lower complication rates than with open biopsy.[26] Utilization of advanced imaging modalities such as CT and MR imaging helps with the direct site of needle biopsy by identification of high-yielding solid tumor tissue and low yielding necrotic or hemorrhagic areas.

Primary bone tumors may metastasize to bones and nuclear imaging studies are helpful in mapping this spread. Technetium (Tc)-99m-labeled diphosphonate scintigraphy is used in the pre-operative staging of bone tumors to evaluate for metastases and lesions that may not have been apparent on other imaging studies.[26] When an area of increased tracer uptake is noted on the bone scintiscans, radiography examinations of that region may be performed to further evaluate metastases.[26]

Types of Bone Tumors

Osteochondroma is a cartilage-covered bony protuberance arising from a bone surface. These lesions are usually discovered during childhood and adolescence but up to 20% are discovered after the age of 20 years.[26,27] Osteochondromas occur in any bones that arise from enchondral ossification and usually present as non-tender slow growing lesions. Radiography images of osteochondroma illustrate a bony protuberance(s) arising from the external surface of a long tubular bone, commonly occurring in the metaphyseal regions.

Enchondromas are benign cartilage-forming tumors that arise within the medullary cavity of bone. The lesions generally do not cause any symptoms. Radiography images of enchondroma show medullary lesions with geographic margins, endosteal scalloping, and calcifications. Multiple enchondromas may be part of a syndrome and are predisposed to sarcomatous transformation.

Osteoblastoma is a rare bone-producing tumor that has the potential to become a large growth, which is not self-limiting. Telangiectatic osteosarcoma accounts for 5% of all osteosarcomas.[26,27] Telangiectatic osteosarcomas are more aggressive than conventional osteosarcomas. These lesions tend to occur within the metaphysis and diaphysis. These lesions contain large cystic cavities filled with fresh and clotted blood, which distinguishes them from conventional osteosarcomas. Radiography images of telangiectatic osteosarcomas may demonstrate predominantly osteolytic lesions. MR imaging shows characteristic fluid levels due to layering of different blood products.

Hematopoietic tumors include lymphoma and myeloma and are the two malignant hematopoietic tumors that may involve bone. Lymphoma of bone is uncommon; multiple myeloma occurs in people between the ages of 50 and 80.[26,27]

Additional diagnostic tools used to determine the origin of bone lesions are laboratory studies and biopsy.

Chondroblastoma and giant cell tumors tend to involve the epiphysis. Osteosarcoma is the second most common primary bone tumor after multiple myeloma. About 75% of osteosarcoma lesions occur around the knee and typically arise in the metaphyseal region of long bones.[26,27] The peak incidence is in the second and third decades of life, and there is a smaller second peak in people older than 50 years.[26,27] Radiography images of osteosarcoma lesions demonstrate an ill-defined, sclerotic, lytic pattern. Periosteal reaction appearing as a “sunburst” reaction or Codman’s triangle may also be evident.[26,27] On MR imaging, the osteosarcoma lesion is typically low in signal intensity on T1-weighted spin-echo sequences and high in signal intensity on T2-weighted spin-echo sequences.[16,17] Tumor extension into the surrounding soft tissue is a common occurrence.

Giant cell tumor is a locally aggressive tumor that is composed of connective tissue, stromal cells, and giant cells. Pain and swelling are the most common presenting complaints. Radiography images demonstrate tumor involvement of the metaphysis and epiphyses that extends to the subarticular border. A giant cell tumor usually has geographic margins and is eccentrically situated with bony expansion, cortical thinning, and erosion.

Parosteal osteosarcomas usually occur in the second to fifth decades of life.[26,27] The paraosteal osteosarcoma is the most common type of surface osteosarcoma and accounts for up to 5% of all types of osteosarcomas.[26,27] The most common site is in the metaphysis of long bones, with the femur being the most frequent site. Patients usually present with mild pain or limited range of motion due to interference with a joint. Radiography images of a parosteal osteosarcoma demonstrate a large, dense, ovoid or rounded mass. In the initial stages, the lesion is connected to the cortex of the underlying bone by a narrow stalk. The tumor may occasionally extend into the underlying medullary cavity. A thin radiolucent line separating the tumor from the underlying bone is a classical radiography finding.

Adamantinoma is a rare, low-grade locally aggressive malignant tumor of epithelial origin. It typically occurs in the diaphysis of the tibia arising from cortex of the anterior mid-shaft. The tumor usually affects males in the fourth to fifth decades of life and females in the second to third decades of life.[26,27] On radiography images, an adamantinoma tumor appears with mixed sclerotic and lytic areas, usually eccentrically situated within the affected bone. Radiography images of an adamantinoma lesion usually demonstrate a well-defined lesion whose margins are intact. The lesion may have a "soap-bubble" appearance. The radiography images may illustrate cortical thinning without periosteal reaction. The lesion may be seen to extend through the cortex of the bone and into the surrounding soft tissue.

Ewing sarcoma is a malignant round cell tumor with an attraction for the long bones and pelvis. Plain radiography may show a permeative or moth-eaten pattern of bone destruction with an onion-skin type of periosteal reaction and an associated soft tissue mass.

An enchondroma is the most common benign bone tumor of the hand. On radiography images they appear as well-defined lytic lesions that are usually benign. Bone hemangiomas are frequently found in the vertebrae and skull and are the most common primary benign tumors of bone. These are most often found in the thoracic and lumbar spine, typically involving the vertebral body, and are usually asymptomatic. Bone hemangiomas have a corduroy appearance on radiography images and a polka dot appearance on CT.[60,61]

Fibrosarcoma most commonly occurs in the metaphysis or meta-diaphysis of long bones, especially around the knee. The tumor most commonly presents in the fourth to sixth decades of life with no sexual predominance.[26,27] Fibrosarcoma can arise as primary lesions or in areas of bone already affected by Paget's disease, fibrous dysplasia, bone infarct, or chronic osteomyelitis. Presenting complaints include pain, swelling, and limitation of motion and pathologic features. Radiography images illustrating fibrosarcomas usually show non-specific and usually as moth-eaten osteolytic lesions with ill-defined margins.

Malignant fibrous histiocytoma is a lesion that usually occurs in the metaphyseal or diaphyseal regions of long bones. The lesion occurs most commonly during the fifth to seventh decades of life.[26,27] Malignant fibrous histiocytoma may occur in bones with prior insult such as radiation, surgery, fracture, avascular necrosis, Paget's disease or fibrous dysplasia. Individuals affected with Paget's disease report acute or chronic pain, tenderness, and swelling over the lesion. Radiography images illustrate malignant fibrous histiocytoma as an aggressive permeative lesion associated with a soft tissue mass and with little periosteal reaction. Calcifications may be seen in the periphery of the mass.

Aneurysmal bone cysts are expansile lesions with a blood filled cystic area. There is a female predominance with over 80% detected by age 20.[26,27] They may result from trauma or coexist with other bone lesions, both benign and malignant. Aneurysmal bone cysts are one of several hypervascular lesions that may cross disc spaces to involve adjacent vertebral levels, others being chordoma and giant cell tumor.

Osteoid osteoma and osteoblastoma usually occur in males in the second decade of life.[26,27] Those affected present with the classic clinical history of night pain, which is relieved by salicylates. Osteoid osteomas are benign and account for 12% of all bone lesions.[26,27] Such lesions have an osteoblastic central area of vascular osteoid tissue and a peripheral zone of sclerotic bone. Classically, a clinical history of pain, worse at night and relieved by aspirin is reported. Radiography images usually demonstrate a radiolucent cortical-based nidus measuring less than two centimeters in size with marked surrounding sclerosis.[26,27] CT can demonstrate these features, including the calcification seen within the nidus, better than other modalities. On MR imaging, the surrounding bone marrow reaction can obscure the nidus and suggest a more aggressive process.[16,17]

Multiple Myeloma

Myeloma means, literally, a “tumor composed of cells normally found in bone marrow.” Multiple myeloma is the most common primary malignancy of bone with an incidence of 3 per 100,000 in the U.S.[26,27] Multiple myeloma generally affects people over 50 years of age with the most common age group being between 60 and 65 years of age.[26,27] Men are affected twice as often as women. Pain, especially of the lower back, is the most common presenting symptom, but symptoms of anemia may also be present due to marrow failure.

There are four radiographic patterns of multiple myeloma. Radiography images may appear normal, or demonstrate diffuse demineralization, a single osteolytic lesion, or widespread lytic lesions. Approximately 75% of patients with multiple myeloma have positive radiography findings with “punched-out” osteolytic lesions that have discrete margins and uniform size.[26,27] MR imaging is very sensitive for detecting the presence of marrow lesions and may help in detecting tumor spread. A majority of those with myeloma develop destructive bone lesions also known as osteolytic bone lesions.[15,16] These lesions or nests of myeloma cells accumulate primarily in the red bone marrow of the vertebrae, ribs, pelvis, and skull.[26,27] Myeloma cells do not have a direct effect on the skeleton; rather, they cause bone destruction by producing signals that signal normal osteoclasts to reabsorb bone.

Approximately 70% of myeloma patients experience pain of varying intensity, often in the lower back.[26,27] Sudden severe pain can be a sign of fracture or collapse of a vertebra. Occasionally nerve compression syndrome results when the lesions occur in the vertebrae.[26,27] Patients also have general malaise and vague complaints because hypercalcemia, present in 30% of patients, can cause fatigue, thirst, and nausea, and usually occurs when a patient has impaired kidney function.[26,27]

Myeloma is more common in African-Americans than Caucasians, and the male to female ratio is 3:2.[26,27] The incidence varies from country to country, with a higher incidence found in most Western industrialized countries. Over the past 30 years there has been a 400% increase in the incidence of the disease.[26,27] The apparent increase is probably due to better diagnostic techniques and the higher average age of the general population. However, over the past three decades, myeloma has become more frequent in those under age 55 and this may indicate environmental causative factors.[26,27]

It is not yet possible to cure myeloma, although it is possible to improve clinical status and survival through the use of chemotherapy, alpha interferon, and possibly, bone marrow transplantation. For myeloma patients with hypercalcemia, the goal is to treat the hypercalcemia and its potentially dangerous complications. In these patients, hypercalcemia is always associated with increased bone resorption and frequently with impaired kidney function. The best approach is to treat the myeloma itself and to treat the hypercalcemia with drugs that inhibit bone resorption, such as bisphosphonates, and the careful use of intravenous fluids.[26,27] Bisphosphonates have been very effective in the treatment of hypercalcemia related to myeloma.

The more common situation is the patient with myeloma bone disease who does not have hypercalcemia. Until recently, these patients have been treated for the bone disease with symptomatic therapy, namely; analgesics for pain, orthopedic treatment for fractures, or local radiation therapy for localized bone pain.

Recent studies have indicated that potent bisphosphonate drugs may have beneficial effects in the treatment of myeloma. This treatment may reduce pain and lessen the need for analgesic. Also treatment with bisphosphonates have been effective in reducing episodes of fracture, hypercalcemia, and the need for palliative radiation therapy.[26,27] As a consequence, pamidronate has received FDA approval in the U.S. for treatment not only of hypercalcemia in myeloma, but also myeloma bone disease in the absence of hypercalcemia.[26,27] Further studies are ongoing to determine the effects of bisphosphonates on survival of patients, the ideal dose and duration, and whether other new and more potent bisphosphonates have similar beneficial effects. One important and unanswered question is whether bisphosphonates should be used when no symptoms or evidence of myeloma bone disease is evident.

Conclusion

The vast array of imaging modalities available today gives clinicians more selections in their pursuit of a diagnosis and treatment of musculoskeletal pathologies. Imaging examinations provide the clinician with insight into the initial clinical diagnosis and allow for the detection of complications in the earliest stages of disease and thus improve the patient's prognosis. Radiographers play an important role in the timely acquisition of quality images when musculoskeletal pathology is suspected.

Chapter 6 Trauma & Injury to the Extremities

"If you have ever driven over a pothole in the street, then you know what osteoarthritis feels like." Finley

Introduction

Regardless of age, gender, race, or economic status, injuries remain a leading cause of death in America.[1] Death is only a part of the outcome from accidents. Millions of Americans are injured each year and survive, suffering pain and inconvenience, but for some the injury leads to disability, chronic pain, and lifestyle change.[1] The financial and economic impact of injuries in the U.S. is a serious matter and involves families, communities, as well as the workforce and utilization of healthcare.[2]

Musculoskeletal injuries include both acute and chronic injury to the muscles, tendons, ligaments, peripheral nerves, joint structures, bones, and the associated vascular system. These injuries may be reported as sprains, strains, inflammations, irritations, and dislocations. In medical literature, this broad classification of physical symptoms and complaints are referred to as wear-and-tear disorders, overuse or overexertion injuries, osteoarthritis, degenerative joint diseases, chronic microtraumas, repetitive strain injuries, and cumulative trauma disorders.[3] Musculoskeletal injuries are a leading cause of disability during a person's working years.[3] Musculoskeletal injuries are ranked high among health problems affecting the quality of life and the cost of such injuries account for one-third of annual worker's compensation claims.[3]

Acute musculoskeletal injury most often develops from specific mechanical stressors that traumatize certain musculoskeletal tissues and results in the sudden onset of pain and possible movement limitation. An example would be when a person slips and falls while walking. The injurious mechanical stress could be of an internal type, when the neuromuscular system quickly contract muscles to stop the impending fall as the foot slips. This unexpected muscle contraction may tear muscles and tendons in the legs, back, and arms and may even dislocate joints. In other cases, the mechanical stress could be external in nature, resulting from the impact of the person with an object or the floor during the fall. In this case the impact stress may rupture muscles and ligaments or even fracture bones.

In contrast, the specific site of anatomical damage in most chronic musculoskeletal injuries or disorders is less clear. Chronic work or sports related injuries or disorders of the upper extremity have been given a number of names including cumulative trauma disorders, repetitive trauma disorders, repetitive strain injuries, overuse syndromes, and regional musculoskeletal disorders. Acute and chronic work and sports related musculoskeletal disorders present a spectrum ranging from conditions such as a prolapsed lumbar disc or carpal tunnel syndrome, where the cause of the pain or loss of function is clear, to conditions where the specific diagnosis is less evident. These conditions are also quite variable in terms of severity and level of impairment.

In the last decade considerable improvements have been made toward the management of trauma. Trauma is the most common cause of death for persons under the age of 34.[4] Each year two million people are hospitalized following traumatic events.[4] People experiencing minor traumatic injuries may first seek medical attention from their primary caregiver, immediate care or ambulatory care center, or other outpatient medical service center, only to be later referred to a hospital trauma setting.

Radiographers are employed in a variety of medical settings from industrial plants, rural and urban ambulatory care clinics, physician's offices, worker's compensation clinics, and hospitals, and will encounter all forms of trauma and injury to the musculoskeletal structures. This chapter provides a basic review of trauma care and the role of imaging examinations. Included is an introduction to the evolution of trauma care.

History of Trauma Care

The historical evolution of trauma care in the U.S. has been greatly influenced by major military events, government, and motor vehicle accident (MVA) deaths and injuries. The Hill Burton Act was passed in 1946 and its intent was to develop a framework which could be used to determine the number of hospitals that were actually needed for emergency care. In those early years there was no indication that hospitals needed special facilities to attend to trauma victims. Also, there was no national trauma system such as the emergency medical services that exist today.[4]

From the 1940s to the 1960s, the incidence of injuries and fatalities from MVAs increased, as more Americans were able drive vehicles. During that time period, there was no standardized approach to "field response" to these accidents and the mortality rate was high. In 1960, John F. Kennedy announced that car crashes were a national problem, which brought public attention to the extent of the problem. During the 1960s the Division of Emergency Health Services, National Academy of Sciences, and National

Research Council began to review the level and quality of “first response” care that was available to the American public.[4]

In 1965 a report titled “Health, Medical Care and Transportation of the Injured” was published by the Commission on Highway Safety.[4] The report suggested that to improve the level of “first response” to trauma victims, officers and firefighters would need medical training. The report also suggested that a national certification process be established to standardized competency and that both ground ambulances and aircraft be included in the overall plan to improve “first response”. Prior to the passage of the Emergency Medical Services Systems Act in 1973, mortuary personnel operated most ambulance services, with minimal training in first aid.

In 1966, the National Academy of Sciences and the National Research Council released a paper that recommended criteria for the implementation and development of the Emergency Medical Service (EMS) system. Also in 1966, Congress passed the Highway Safety Act (HSA), which suggested that all states include EMS in their highway safety program and that funding be provided to upgrade care received prior to reaching the hospital. The HSA also indicated that highway safety standards should be developed, and that funding for the purchase of rescue vehicles and equipment be made available to EMS systems. Further, the act required that each state develop a highway safety program in accordance with the standards suggested by the Secretary of Transportation.

The federal government continued to be involved throughout the 1970s with improvements to EMS programs. The Emergency Medical Services Systems Act of 1973 was modified in 1976 and again in 1979, and the amendments mandated that emergency care, supported by federal funds, utilize a 15 component system in providing “first response” care.[4] Also included were seven illnesses and injuries that were to be the basis for the development of the EMS. The conditions included trauma, burns, spinal cord injuries, poisonings, cardiac conditions, psychiatric emergencies, and high-risk infants and mothers.[4]

Lessons learned about the delivery of medical care “in-the field” and on the “front-lines” from World War I, World War II, Korea, Vietnam, and most recently Iraq have been absorbed by EMS and those delivering emergency medical care. According to most accounts, in each military conflict since World War I there has been a decline in mortality because the same concepts that the military used to reduce mortality have been successfully adapted and applied to civilian trauma care. Concepts such as field triage, patient packaging, transport, and radio communications have all been applied to reducing mortality in civilian populations.

Pre-hospital trauma care has also been greatly influenced by the military. Two areas that have been significantly influenced are basic trauma life support and triage. Triage of patients helps to identify what level of care a patient will require in a certain timeframe, thus influencing transport destination decisions with the goal of improved patient outcomes. Most EMS units have pre-hospital trauma protocols that ensure patients are delivered to the most appropriate hospital for care. Within a trauma system there may be several trauma centers with various levels of expertise. The American College of Emergency Physicians and the American College of Surgeon's Committee on Trauma have published guidelines for various levels of trauma care. These range from a level I trauma center to a level V.[5] A level I trauma center offers the entire spectrum of care, from prevention to rehabilitation. Level I trauma centers are often found in university settings, with emphasis on research, education, and system planning. A level II trauma center is capable of managing most trauma cases and may offer prevention programs.[5] A level III trauma center is often located in community-based hospitals.[5] A level III center offers initial resuscitation and stabilization after which the patient is transferred to a level I or to a level II trauma center, if necessary.[5] A level IV trauma center is a remote or rural clinic that offers advanced life support after which the patient is transferred to a suitable level trauma center.[5] A level V trauma center is one that is usually located in desolate areas of the country with the objective of initial resuscitation and transfer of the patient to a suitable level trauma center.[5] The main goal of the trauma care system is that all citizens have access to initial emergency care with transport arrangements to a regional or specialty trauma center. It is important for trauma victims to receive definitive early care in order to reduce their morbidity and mortality. The "golden hour," proposed by R. Adams Cowley, is accepted as the national standard in trauma care. The "golden hour" concept states that the patient has 60 minutes from initial injury to a trauma center to achieve optimal outcomes.[4] For a trauma victim to benefit from the "golden hour" several factors have to be met. The incident must be reported quickly and the EMS dispatched. The patient must be extricated and immobilized within the "platinum ten" minutes. During transport, resuscitation must occur. The "golden hour" is difficult to attain in a rural or desolate geographical area.[6] Although trauma related mortality rates nationwide have declined, the mortality rate is higher in rural areas. Several factors are at play, including delays in

EMS notification and in locating the incident or the victims, the severity of the patients' condition, and the lack of advanced life support and skilled emergency responders.[6]

Assessment of Trauma

The term trauma refers to a wound, especially one produced by sudden physical injury. Major trauma refers to a severe or critical injury. The patient's presenting chief complaint and mechanism of injury are often sufficient information to allow the physician to predict most extremity injuries. Imaging examinations combined with a complete medical history and physical examination, including degree of pain and neurovascular changes, allows for the prediction of orthopedic injuries with a high degree of accuracy. Specific facts should include information about the patient's position upon arrival, details about the mechanism of injury (such as the amount and speed of force applied and the mechanism of forces involved), weight, and distance if applicable. Other patient information that should be obtained includes the age of the patient, history of current symptoms and preexisting medical conditions.

Mechanisms of Injury

The origin of injury from various forms of trauma is related to the release of physical energy into human tissue. Human tissue has a characteristic known as "human tolerance", and injuries occur when the forces of energy exceed that tolerance limit.

Unexpected traumatic injuries are a significant cause of morbidity and mortality. Treatment begins at the location of the trauma with the physical assessment. During the initial assessment, emergency medical personnel use their knowledge of the biomechanics of trauma to further evaluate potential consequences of the injuries. A major challenge to emergency responders is to determine if occult (i.e., usually internal) injuries have been sustained.

Injury is the result of tissue stress beyond its tolerance limits. Blunt trauma is a non-penetrating injury that occurs as a result of forces being applied to the body. The most common causes of blunt trauma are motor vehicle accidents (MVAs), pedestrian-automobile collisions, motorcycle collisions, falls, and assaults. In blunt trauma there are four primary injury mechanisms; tensile strain, sheer strain, torsion, and compression.

Tensile strain occurs when the length dimension of the anatomic structure is changed. When human tissue, such as muscles, arteries, and organs, is stretched beyond their tensile strength along their longitudinal axes they stretch beyond limits and may break or rupture. Tensile strain injuries include fracture, laceration, avulsion, and rupture of vasculature.

Specific examples of tensile strain injuries include the following:

- Mid-shaft femur fracture in MVAs due to force of the collision following along the long axis of the femur and increasing curvature until fracture occurs; and,
- Rib fractures and aorta injuries (i.e., tear, aneurysm and rupture), when tensile strain causes compression of the chest wall.

Shear strain occurs when energy is applied to tissues from opposing directions and human tolerance is exceeded. Shear strain injuries occur during blunt trauma when there are impacts against the thorax but internal structures such as the aorta, liver, brain, etc., continues a forward movement, resulting in tears and transections.

Torsion occurs when one end of the tissue is twisted while the other end or part remains stable or is twisted in the opposite direction. An example of torsion trauma occurs when someone is forcibly struck on one side of their face or head.[3] The energy from the impact moves to the upper vertebral spine and causes the person's head to pivot in the opposite direction. It is estimated that approximately 40 to 50% of all torsion injuries involving the head cause injuries to the first and second cervical vertebrae and are often fatal.

Compression forces during blunt trauma cause either an increase in tissue density or a decrease in its volume. Human tolerance of the chest to blunt frontal impact is 20%, meaning that the thorax can only withstand being compressed by 20% from its original diameter without injury. As the thorax is compressed the internal organs are squeezed between the chest wall and the spinal column. Compression injuries to the chest cause pneumothorax, myocardial contusion, pericardial tamponade, and various vascular injuries. In the extremities, compression forces can cause crush injuries and in the spine can cause compression fractures. Finally, the energy of the collision applies forces capable of shear decompression, torsion, and tensile strain to the internal organs. In the thorax the lungs, heart, and great vessels are particularly susceptible to extensive damage.

> ***Crush injury*** *typically refers to trauma of the chest, abdomen, and pelvis. In these locations, the term crush is most frequently used to describe a mechanism of injury involving a specific type of blunt-force trauma.*

Crush syndrome *refers to the multiple systemic complications of soft tissue injury and the disruption of muscle integrity following a crush injury. These complications include rhabdomyolysis, electrolyte disturbances, hypovolemia, renal failure, acidosis, and disseminated intravascular coagulation.*

Rhabdomyolysis *is the destruction of skeletal muscle cell membranes with a release of myoglobin into the blood serum. The toxic effects of myoglobin result in intravascular hypovolemia and decreased renal function.*

Change of speed injury occurs when there is a difference in speed between a vehicle and its occupants. When a frontal motor vehicle collision is occurring, the vehicle begins to slow and energy is released as the front of the vehicle begins to deform. The passenger compartment begins to decelerate but the occupant continues at his or her initial velocity and may strike portions of the vehicle's interior, beginning with the feet impacting the floor and the knees impacting the dashboard or the back of the front seat. The force of the impact may result in fractures to the ankles, legs, femurs, and pelvic girdle. A classic triad of the knee-femur-hip injury is often associated with frontal MVA impacts.

Although the use of automobile restraints is highly regarded in saving lives during MVAs, they may be implicated in certain types of injuries, especially if not worn properly. There has been an increase in serious injuries to the lower extremities associated with air bag deployment. It is thought that air bags may not be responsible for an increase in extremity trauma; rather, in the past MVA victims without air bag protection may have died of head and chest injuries and the extremity injuries were inconsequential. Shoulder harness restraints in conjunction with air bags provide the best possible protection during MVAs.

It is estimated that motorcycle collisions result in 20 times more fatalities than MVAs. In a collision, the cyclist is usually ejected off of the motorcycle and may hit objects before eventually making contact with the ground. During these impacts, the cyclist's internal organs strike the walls of the cavity in which they reside. Motorcycle collisions can result in a multitude of injuries to the rider. During front motorcycle impacts the riders' torso continues forward, up and over the handlebars and potential injuries to the groin and pelvis and femur fractures are likely. With angular motorcycle accidents the rider tends to remain on the bike longer and during impact the rider's legs may be crushed between the bike and the object, causing fractures and crush injuries. Motorcycle sliding injuries usually result in severe abrasions and fractures and with total ejection from the motorcycle serious injuries may result.

When a pedestrian has an impact with a motor vehicle, various traumas may result and the nature of the injury is dependent upon the person's height. Because height is often associated with age, injury patterns can be grouped directly to the height of the pedestrian. The mortality is high in the toddler height group because the initial blow is usually to the head and chest. In children, because of growth rate variability, their injury patterns vary between those of toddlers and adults. Children typically receive initial contact with the femur or pelvis. Adult pedestrian MVA injuries are more predictable than for those of children. In adults, lower extremity injuries are common; however, head injury is responsible for the majority of fatalities in this population group.

Victims of falls experience the same type of blunt trauma, as do victims of MVAs. Those who fall from a distance greater than twice the height of the victim are likely to result in life threatening injuries. The extent of a fall victim's injury not only relates to the height from which they fall but also the initial point of contact on impact. For example, if the fall victims' impact is over a large body surface, the energy from the fall usually tends to disperse the forces of impact. The most devastating consequences of a fall occurs when the victim's point of contact is the head.[3] When a fall victim lands on their feet, the force of impact is initially transferred to the feet and ankles and typically results in bilateral calcaneus fractures. If the victim falls into their outstretched arms, they are likely to suffer posterior shoulder dislocations as well as a Colle's fracture.

Penetrating Trauma

Penetrating trauma results when sharp objects such as knives, glass, etc. enter the body causing tissue laceration along their trajectory. Penetrating trauma causes bleeding or infarction from vascular injury. Blunt trauma is the leading mechanism of injury in the U.S.; however, penetrating trauma resulting in acts of violence (i.e., gunshot wounds), is rapidly becoming as prevalent as blunt trauma. Intentional penetrating injuries in the U.S. are generally related to gunshot wounds and knife wounds. The mechanism of damage from gunshots is compression and strain as the bullet impacts the tissue. The magnitude of injury from gunshots is dependent upon the energy, size, and profile of the bullet and the path of the bullet through the body. As the bullet passes through the body, tissue is stretched by the shock wave of the traversing bullet. The first wave of injury occurs as the bullet passes through, damaging blood vessels, nerves, organs, and bones.[3] In the wake of the passage of the bullet, the temporary cavity collapses leaving a smaller permanent cavity. Since the bullet penetrated the skin, it also pulls skin surface contaminates along its tract, a common entry of pathogenic microorganisms. Knife wounds, like gunshot wounds, cut into the skin and tissue causing hemorrhage and damage to tissue, muscles, nerves, organs and also provide a portal of entry for pathogenic microorganisms.

CT demonstrates hemorrhage and laceration along the bullet track. Once the hemorrhage clears usually a pneumotocele formation may be visible, often accompanied by hemothorax and pneumothorax. Also on CT the bullet path can often be recognized as a linear strip caused by hemorrhage. Conventional radiography can be useful in confirming the presence and location of radiopaque bullet fragments.

In a peer reviewed article appearing in the *Radiologic Technology* Journal (January/February 2007) of the American Society of Radiologic Technologists, radiographers are provided with an important concept to aid effective communication among trauma team members who care for patients with multiple ballistic injuries.[7] The authors call the guide the “even-number” guide to imaging ballistic injuries.[7] “The guide calls for counting the entrance and exit wounds and bullets found on clinical examination and images. Ideally, the total should be an even number.”[7] If there is any deviation from the even-number guide, the trauma team will need to acquire additional images in order to locate the missing bullet or bullets.[7] The article further discusses imaging injuries from improvised explosive devices (IEDs) and blast injuries, such as those experienced in the war in Iraq. Radiographers employed in facilities that are equipped to manage such injuries will benefit from reading the entire article.

Assessment of Trauma

Most trauma victims present with a singular system injury that does not systemically compromise the individual. However, for those presenting with multi-system, multi-organ injuries, death from their injuries can be described as trimodal:

- Within seconds to minutes;
- Within minutes to hours (golden hour); and
- Within several days or weeks after the initial injury.[5]

The golden hour refers to the care given to multi-system trauma victims immediately after the event. Approximately 85% of those who are received into surgery within an hour of their trauma survive.[4] The initial assessment of life-threatening conditions includes:

- A-Airway management and cervical spine control;
- B-Breathing (ventilation);
- C-Circulation and control of hemorrhage;
- D-Disability assessment;, and,
- E-Expose, examine, and evaluate.[4]

The purpose of triage of trauma victims is identifying those with the potential for life-threatening injuries. Figure 6-1 lists important signs of cardiovascular and thoracic trauma.

Finding	Suggested Problem
Pale skin color, conjunctiva, palms, and oral mucosa	Indicative of blood loss
Decreased blood pressure in the left arm	Traumatic rupture of the aortic isthmus, pseudo-coarctation, or traumatic thrombosis of the left subclavian artery
Decreased blood pressure in the right arm	Possible innominate artery avulsion
Subcutaneous emphysema and tracheal deviation	Possible pneumothorax
Elevated jugular venous pulse with inspiratory raise (i.e., Kussmaul's sign)	Possible cardiac tamponade or tension pneumothorax
Prominent systolic V wave in the venous pulse examination	Suggestive of tricuspid insufficiency as a result of tricuspid valve tear
Pulsus paradoxus	Possible cardiac tamponade with massive pulmonary embolism or tension pneumothorax

Fig. 6-1. Important signs of cardiovascular and thoracic trauma.[4]

Assessment of the extremities of a victim of a MVA or fall is important to evaluate for injury. During the initial assessment signs such as limb shortening, swelling, ecchymosis, tenderness, grating, crepitus, and exposed bone ends may indicate life threatening extremity trauma. Dislocations are common in MVAs, especially when the knees hit the dashboard. This possibly disrupts the blood supply to the femoral head. Initial basic assessment includes looking for hip flexion, adduction, internal rotation and shortening of the leg. A noticeable prominence in the inguinal area is a positive sign of an anterior hip location. If the patient is positioned with the leg and foot rotated laterally, the head of their femur has a posterior dislocation and is considered an orthopedic emergency because the blood supply to the femur may be obstructed. Femur fractures are also considered to be life threatening and are always examined during the initial triage assessment. The knee is also evaluated for dislocation or fracture because an orthopedic emergency can exist, especially if the popliteal artery or peroneal nerve is damaged.

Impacts to the lower leg may also produce fractures. A direct blow to the lower leg is likely to result in open fractures requiring hemorrhage control. Closed fractures can develop into compartment syndrome and should be evaluated for the “5 Ps” of ischemia: pain, pallor, paresthesia, paresis, and puffiness.

> *A **compartment syndrome** occurs when the injured tissue is confined within a fixed compartment with minimal capacity to expand and an increase in pressure exists within the compartment.*

Complications of Trauma

Shock is defined as a condition resulting from serious injury in which insufficient amounts of oxygen are carried to tissues. A weak rapid pulse, pale cool skin and overall listlessness characterize shock. There are four primary causes of shock (respiratory, perfusate, vascular, and cardiac), each resulting from a failure of one component necessary for oxygen delivery to the tissues. Respiratory failure occurs when the lungs and muscles involved in respiration are unable to provide efficient gas exchange to ventilate and oxygenate the tissues.[3] Many chest injuries may be responsible but respiratory failure is an expected and anticipated event in victims of traumatic chest injury. Tension pneumothorax is a common complication of blunt thoracic trauma and penetrating injury.

The second type of shock is perfusate failure, which is due to a loss of blood or plasma. Trauma victims may have internal or external hemorrhage as a result of their injuries. Significant hemorrhage can occur in the interstitial spaces surrounding fractures. Various references suggest that each long-bone fracture can result in as much as 500 milliliter (mL) of hemorrhage. Previously mentioned a femur fracture may be life threatening because such a fracture may be associated with 1 liter or more of blood loss.

The third type of shock is vascular failure with resultant vasodilatation or vascular permeability and finally cardiac failure leading to reduced heart function. Vascular failure may occur due to injury to the central nervous system, sepsis, and anaphylaxis causing disruption in the normal functioning of blood vessels. Sepsis is the body's response to bacteremia. Septic shock is a leading cause of death after trauma, having a 50% mortality rate.[4] Blunt traumatic injuries, especially soft tissue injuries, produce ischemia, which is conducive to the growth of bacteria. Stab wounds and gunshot wounds allow bacteria from the skin to easily enter via the puncture and cause infection. The highest mortality from sepsis is related to abdominal injury involving the colon. If the colon integrity is compromised and leaks fecal bacteria into the area, the probability of septic infection is 2-12%.[4] Multiple organ failure is a complication of multiple system trauma that often necessitates surgery and extended immobilization and recovery time.

Cardiac failure is the fourth type of shock and may be caused by intrinsic or extrinsic factors. Intrinsic causes of cardiac failure include valvular disruption, myocardial infarction, and dysrhythmias. Extrinsic causes of cardiac failure include pericardial tamponade and tension pneumothorax.

Thromboembolism affecting the lungs is called pulmonary emboli. Blood clots that form in the venous system (i.e., usually, in the lower extremities) travel and lodge in the lungs. There are many risk factors but in trauma patients thromboembolism is often associated with immobilization. Symptoms include tachypnea, chest pain, hypoxemia, tachycardia, and pulmonary infiltrates on conventional chest radiographs, although chest radiography examinations are often normal in appearance. Ventilation and perfusion scanning, pulmonary arteriography, and Doppler ultrasonography studies may also be performed to obtain a diagnosis of thromboembolism.

Fat embolism is the most common form of embolism causing vascular occlusion following trauma. Fat embolism typically results from fracture of the long bones and pelvis, causing pulmonary effects of hypoxia and pulmonary hypertension. Air embolism occurs when an open vein is at or below atmospheric pressure and the air is sucked into the vessel and travels through the circulation.

Physical Examination

An attending physician will conduct an examination on individuals presenting with extremity injury and will use the basic physical examination elements of visual inspection, palpation, and auscultation to assess the extent of the injuries. The objectives of the visual inspection are to detect deformities, angulations, swelling, edema, and discoloration. The physician will use palpation skills to determine if defects, deformities, tightness, crepitus, and points of tenderness are present. During the palpation evaluation, the physician will also check the usual pulses, capillary refill, and skin temperature.

Penetrating or blunt trauma and fractures can cause injury to the major blood vessels supplying the limbs. Such injuries can be direct laceration or stretching, which causes the vessel lining (intima) to sag. Vascular injuries have been associated with minor blunt upper extremity trauma and may easily be missed or neglected leading to long-term adverse outcomes.[8] In both the upper and lower extremity nail color and warmth of the skin is usually assessed by comparison to the uninjured extremity. The brachial, radial, and ulnar pulses are evaluated when the upper extremities are involved. The femoral, popliteal, posterior tibial, and doralis pulse sites are evaluated when the lower extremities are involved.

The physician will also perform a neuromuscular examination prior to any manipulation or intervention of extremity injuries. For upper and lower extremity injury, all sensory and motor components will be evaluated. Sensory function is tested by light touch and two point discrimination, which is performed by placing a sharp instrument against the skin approximately one centimeter (cm) apart. The physician will move sharp instruments closer together until reaching a distance at which the patient can no longer distinguish between points one and two. The physician will also evaluate muscle function by observing active movement and evaluating muscle strength against resistance. Upper extremity motor and sensory components include:

Deltoid muscle-------------------Axillary nerve
Shoulder external rotation-------Suprascapular nerve
Biceps---------------------------Musculocutaneous nerve
Thumb interphalangeal extensor---Radial nerve
Index finger flexor--------------Median nerve
Interossel----------------------Ulnar nerve

For the lower extremity, nerve testing should include the femoral nerve, sciatic nerve and its major branches (peroneal, saphenous, and tibial nerves).

The patient is also evaluated for compartment syndrome, which occurs when tissue edema compromises local circulation and neuromuscular function. Compartment syndromes most frequently occur in association with crush injuries, fractures, burns, snake bites, tight casts, and a hematoma within a compartment. Compartment syndrome can also occur when a trauma victim has been lying for some time across a limb with the body weight occluding arterial blood supply. The lower leg and forearm are the most common sites for a compartment syndrome because tight fascia encases the muscle compartments in these regions. The patient with compartment syndrome often complains of severe limb pain that seems out of proportion to the injury.

Crush injuries occur when a heavy object entraps a limb for several hours. Two things occur from crush injury; local effects and generalized systemic effects. Local crush injury occurs when weight is allowed to push on tissue for hours, crushing the musculoskeletal structure. As the muscle tissue disintegrates and myoglobin, potassium, and phosphorus leak into the circulation, a systemic crush syndrome results. Crush syndrome causes hypovolemic shock, hyperkalemia, and eventual renal failure.

Strains and Sprains

The musculoskeletal system provides four basic functions: 1) support of vital organs against gravity, 2) protection against external mechanical stressors (i.e., impact forces), 3) mobility to move about and reach objects within the physical environment, and 4) control of the manual forces necessary to alter performance and the environment. These four functions are made possible by the unique structure and physiological performance capability of the human musculoskeletal system.

The components of the system are arranged such that relatively small movements of muscles allow the extremities to demonstrate large motions. This is accomplished by rotating bones about several joints in a coordinated fashion. Unfortunately, the same structural form that provides this mobility also produces very large muscle, tendon, ligament and joint internal forces when reacting to the weight of the body and any other external forces acting on the body.

When the internal forces become very large, as they do during manual tasks, sports, and accidents, a person’s precise control of several different muscles is necessary. Otherwise a single muscle, tendon or ligament becomes over-stressed, and acute injury results. Further, even at levels of exertion that is well below the short-term mechanical capacity of individual tissues, injuries can occur. This is because these tissues cannot tolerate sustained or highly repeated stresses. In fact, skeletal muscles lose their capacity to contract and precisely shorten when statically contracted for several hours at only 5% of their short-term strength.[3] This muscle fatigue results in acute pain and diminished coordination. Repeated episodes of muscle fatigue may result in chronic changes in either the structure or metabolism of muscle fibers. The precise mechanisms of these hypothesized changes have not been clearly delineated, but may be associated with chronic pain.

Likewise, with tendons that are repeatedly stressed during low force, tendon fiber tears and inflammation can occur. If a tendon that is subjected to such repeated stresses also passes around or through other supporting tissues at a joint (i.e., synovium or bursa), then these may also become irritated and inflamed (i.e., tendinitis, synovitis and bursitis), all of which can produce chronic limitations for the individual. Typically, the pain and motion limitation is progressive with each episode when associated with bouts of repetitive or strenuous exertions. The course and severity of these tendon-related disorders is “cumulative trauma disorders” based on the scientific belief that these disorders are due to repeated stresses on the tendons not the result of a single stress.[3] The level of force and repetition that causes the chronic inflammation may not be hazardous if adequate periods of rest or recovery from mild symptoms are used.

If inflammation involves those tendons that pass through the palmar side of the hand (i.e., the finger flexor tendons) the resulting swelling in this region can entrap the median nerve in the wrist. Such entrapment produces chronic pain in the hand with loss of sensation and coordination (i.e., carpal tunnel syndrome develops).

Most people suffering from both acute and chronic musculoskeletal injuries will recover from their symptoms within two weeks following the cessation of the offending stresses.[3] For some, particularly if significant structural damage or neural trauma has occurred, the symptoms will persist, possibly for the rest of their lives.

Ligaments and muscles are frequently injured. When tears occur in ligaments, it is referred to as a sprain. A tear in a muscle or tendon is a strain. Sprains commonly involve the acromioclavicular joint(s), proximal interphalangeal joint(s) knee, or ankle joint.

A sprain may be categorized into one of three grades. A first degree sprain involves partial disruption of some of the ligament fibers with mild interior hemorrhage, but the joint remains stable and range of motion is normal. A second degree sprain involves complete disruption of some portion of the ligament fibers with moderate hemorrhage, but the joint remains stable. A third degree sprain consists of complete disruption of the ligament fibers, marked disability, and usually an unstable joint.

Joint Dislocation

Each joint has a certain degree of stability and normal range of motion and when these are exceeded a dislocation can occur. A joint dislocation results when a bone is out of its joint and not in contact with its normal articulation. Common sites for dislocations are the shoulder, hip, and acromioclavicular joint, Figure 6-2, provides additional information about other sites that joint dislocation occurs.

Acromioclavicular joint dislocations usually result from a fall on an outstretched arm and represent about 10% of all dislocations involving the shoulder girdle.[9] The glenohumeral joint allows a wide range of motion and is the most frequently dislocated major joint, accounting for 40% of all dislocations.[9] Glenohumeral dislocations are classified as anterior, posterior and rarely inferior or superior.[9] Anterior dislocations which are commonly associated with a posterolateral humeral compression fracture are also called a Hill-Sachs deformity.[9] Although radiography examinations are usually the first imaging examination, MR imaging may be necessary to demonstrate cartilage and ligament damage.

Fractures

The term fracture refers to a break involving bone or cartilage and may be broadly classified as either a closed or open wound. An open fracture is one that has a break in the skin that communicates with the fracture site. When a closed fracture occurs, the skin overlying the fracture remains intact and is often referred to as a simple fracture.

Body Area & Mechanism of Injury	Clinical Findings
Anterior shoulder Fall on an outstretched arm or direct impact on the shoulder	The arm will be abducted and the patient cannot bring the elbow down to the chest or touch the opposite ear with their hand
Posterior shoulder This dislocation is rare and occurs from a strong blow in front of the shoulder	The arm will be at the patient's side and they will be unable to externally rotate the arm
Elbow (radius and ulna) Fall on an outstretched hand when the elbow is extended	The arm will have loss of length and motion will be painful and swelling will be present
Radius head (children) Results from a sudden pull, jerk or lift on the child's wrist or hand.	The child presents with pain and refusal to use the arm. There is limited supination.
Hip (usually posterior) Results from a blow to the knee while the hip is flexed and adducted. This is a common injury seen in passengers seated in the front seat	The hip will be flexed, adducted, internally rotated and shortened. This may occur with fracture of the femur
Patella This dislocation may occur spontaneous or associated with other trauma	The knee will be flexed and the patella can be palpated lateral to the femoral condyle. If associated with other trauma, there will be excessive swelling, tenderness and a palpable soft tissue defect
Knee Knee dislocation is rare and occurs when direct severe blow is sustained to the upper leg or there is forced hyperextension of the knee	Results in ligament instability
Ankle Dislocation is usually associated with other injury such as fracture and soft tissue trauma	Ankle dislocation will result in swelling, tenderness and loss of alignment and function

Fig. 6-2. Adapted from Emergency Nurses Association (ENA). Emergency Nursing Core Curriculum. 4th ed. ENA: 1994.[10]

There is an entire vocabulary of terms used to describe and classify bone fracture. For example, a fracture may be described as being either an open or closed wound. A break may completely transverse the bone, (i.e., a complete fracture) or may only involve one cortex. A fracture that results from repeated, low-intensity trauma, such as marching, is called a "stress" fracture. A fracture may be described as angulated or displaced, meaning that the fracture has disrupted the normal alignment along the long axis of a bone. An avulsion fracture occurs when a fragment of the bone has pulled away from the shaft. An avulsion type fracture usually occurs around a joint due to tearing that accompanies a sprain or dislocation. The term "greenstick fracture" refers to an incomplete fracture resulting from bending force on the bone. Further descriptive terms such as spiral, transverse, and oblique are used to explain bone fracture. The term “torus” is used to describe a fracture that compresses the bone without cortical disruption. A torus fracture often occurs in the forearms of children.

The term “pathological” fracture may be used when discussing a bone break due to an underlying disease mechanism such as osteoporosis. Pathologic fracture occurs through areas of weakened bone from tumor, infection, or metabolic bone disease. The factors most predictive of the risk of pathologic fracture are pain, anatomic location, and the pattern of bony destruction. The anatomic site with the highest risk of pathologic fracture is the subtrochanteric femur. Recently, it was discovered that long-term use of androgen deprivation therapy to treat prostate cancer might increase older patient’s risk of fractures.[11] Data from a National Institutes of Health (NIH) study of more than 46,500 men aged 66 and older found that men treated with androgen deprivation therapy had a 20% increased risk of a first fracture and a 57% increased risk of a second fracture after two years of treatment.[11] The NIH study cautions that physicians should consider a patient’s risk of fracture while initiating treatment because a fracture incidence has a strong impact on quality of life and mortality.[11]

Rare femur fractures have also been linked to the use of bisphosphonates. A 27-person international task force convened by the American Society of Bone and Mineral Research to study the link between bisphosphonates and atypical femur fractures stated that “…The panel members believe there is a relationship between the bisphosphonate class of drugs and the atypical femur fracture.”[12] The panel further concluded that the relationship is stronger in people who have taken bisphosphonate drugs for a longer time.[12] It is believed that although this relationship has been acknowledged that femur fractures are unusual and uncommon when they are viewed in the context of more common osteoporosis fractures, such as rib, spine, and arm fractures. Unusual femur fractures actually comprise less than 1% of all hip and thigh fractures and less than 1/10th of 1% of patients on bisphosphonate drugs have sustained a femur fracture.[12] However, 94% of people who sustained an atypical femur fracture had taken bisphosphonates for more than five years.[12] Many of the reports of femur fractures have come from women who have been very physically active, so low impact exercise might be the most prudent kind, if they are taking bisphosphonates.

Exactly how bisphosphonate drugs may increase the risk of atypical femur fractures while decreasing the risk of fractures at other sites is not fully understood. Individuals now taking bisphosphonate drugs should be educated as to symptoms of fracture, such as pain in the thigh or groin. Physicians are urged to see their patients on these drugs at least once a year, and to ask specifically if they are having thigh pain.

Based on the new evidence, the research panel has requested that the label for bisphosphonates (i.e., Aclasta, Actonel, Aredia, Bondronat, Boniva, Didronel, Fosamax, Fosavance, Reclast, Skelid, and Zometa) now state that there is a risk for developing atypical femur fractures.[12] Fracture healing begins with a hematoma that bridges the one end, progresses to an inflammatory phase, and ends with remodeling. The rate of healing is affected by the type of bone (cancellous heals faster than cortical), degree of fracture, and systemic states such as hyperthyroidism and hypoxia. Nerve injuries are also a frequent complication of fractures.

Bone Repair

Bone fractures may cause significant hemorrhage, especially in the femur and the pelvis. In addition to blood loss and nerve damage, other complications associated with bone fracture include compartment syndrome, Volkmann's ischemic contracture, avascular necrosis, reflex dystrophy, and fat embolism.

Immobility is problem that accompanies the healing process of skeletal fractures. Some of the more common complications associated with immobility include pneumonia, deep venous thrombophlebitis, pulmonary embolism, urinary tract infection, wound infection, decubitus ulcers, muscle atrophy, stress ulcers, gastrointestinal bleeding, and psychiatric disorders.

Bone fracture repair represents a continuum of healing proceeding from inflammation through repair and ending in remodeling. Fracture healing is influenced by a variety of biologic and mechanical factors. The most important factor in fracture healing is blood supply. Nicotine from smoking increases the time to fracture healing, increases the risk of nonunion (particularly in the tibia), and decreases the strength fracture callus. Smoking also increases the risk of pseudoarthrosis after lumbar fusion by up to 500%.[13] Nonsteroidal anti-inflammatory drugs (NSAIDs) have an adverse effect on fracture healing. The stages of fracture repair include inflammation, repair, and remodeling.

Inflammation occurs when bleeding from the fracture site and surrounding soft tissue creates a hematoma. The hematoma provides a source of hematopoietic cells, which secrete growth factors. Fibroblasts, mesenchymal cells, and osteoprogenitor cells are present at the fracture site and granulation tissue forms around the fracture ends.

Repair begins with the primary callus response usually occurring within two weeks. If the bone ends are not in continuity, a bridging (soft) callus occurs. The process of enchondral ossification later replaces a soft callus by woven bone (hard callus). Another type of callus, medullary callus, supplements the bridging callus, although it forms more slowly and occurs later.

The remodeling process begins during the middle of the repair phase and continues long after the fracture has clinically healed (up to seven years). Remodeling allows the bone to assume its normal configuration and shape based on the stress to which it is exposed. Throughout the remodeling process, woven bone formed during this phase is replaced with lamellar bone. Fracture healing is complete when there is repopulation of the marrow space.

Impediments to the bone healing process include lifestyle habits such as smoking and drinking alcohol, use of certain medications, and underlying medical conditions or comorbidities. Literature abounds with the negative effects of tobacco on a person's health status. Specifically, the compounds present in tobacco, including nicotine have been implicated in suppressing normal bone healing.[14] Excessive alcohol has clearly been linked to a compromise in bone health and increased risk of osteoporosis and is considered an impediment to normal bone healing after fracture.[11] Medications such as steroids and nonsteriodal anti-inflammatory drugs (NSAIDs) have been implicated in inhibiting normal bone healing after fracture.[16] Data from a study conducted by the National Arthritis Foundation found that the early inflammatory phase of bone healing may be critical to successful fracture healing.[16] However, the use of NSAIDs for the first couple of weeks following fracture has been shown to delay fracture healing.[16]

Common Fractures by Anatomic Location

Upper Extremity Fractures

Fractures of the phalanges can occur as a result of crush injury to the tip of the finger. These injuries frequently occur when a finger or fingers are caught in equipment or other devices (i.e., a car door). Small avulsion fractures may accompany this type of injury when the digit is hyperextended.

A fracture at the base or shaft of one or more metacarpals occurs with crush type injuries or when the hand makes a direct blow to an immovable object. A boxer's fracture is one that occurs at the distal neck of the fifth metacarpal. The injury was given its name because it generally results from the hand punching an object with a closed fist. The wrist joint is made up of the two forearm bones and the many carpal bones in the base of the hand. The normal wrist anatomy consists of eight carpal bones, which intricately articulate to form the carpus. Fractures of the forearm bones are the most common wrist fractures in all age groups. These fractures generally occur during a fall on an outstretched hand. Children with these fractures may have only a small amount of swelling and deformity. In adults, particularly the elderly, fractures near the wrist can cause a large amount of swelling and deformity. Wrist fractures are common among individuals with osteoporosis and are a future indicator of possible hip and vertebral fractures as the disease progresses.

Fractures of the carpal bones are common with an annual incidence of 159 per 100,000 in the U.S.[16] Because of the complexity of the carpal anatomy and the limitations of conventional radiography, many carpal fractures are not detected on initial interpretation.[14,17] If a fracture is overlooked, often treatment is delayed, and this can lead to dysfunction in the mobility of the wrist. CT imaging is often used to find carpal fractures that are occult on radiography images.[14,17]

Carpal bone fractures occur because of significant rotational force or with falls onto the hand. The patient's chief complaint is usually pain followed by swelling of the wrist with limited mobility. A combination radial/ulnar fracture may also produce a fractured wrist with the classic silver fork deformity (Colle's fracture). Wrist fractures may also be associated with wrist dislocation.

Specific Carpal Bone Fractures

In the proximal carpal row the scaphoid bone is the most commonly fractured and is most frequently initially overlooked on conventional radiography.[17] Scaphoid fractures account for 50% to 80% of all carpal bone fractures and are more common in young men.[14,17] The scaphoid is the largest bone of the proximal carpal row resembling the shape of a boat (the term scaphion is Greek for boat). The scaphoid bone is a critical link between the proximal and distal carpal rows and acts as an intercalated segment between the lunate proximally and the trapezium and trapezoid distally. About 80% of the scaphoid surfaces are articular facets covered in articular cartilage.[17] Because the surfaces of the scaphoid are covered in articular cartilage there is an increased risk of delayed union and nonunion of fractures. Avascular necrosis occurs in 13% to 50% of scaphoid fractures.[17]

The scaphoid is typically injured due to hyperextension which may result in complications such as progressive fragment displacement, avascular necrosis, malunion, delayed union, and nonunion.[17] When fractures of the scaphoid bone are misdiagnosed, chronic wrist pain, loss of full mobility and early degenerative changes may occur. CT has an increasing role in the evaluation of suspected scaphoid fractures when conventional radiographs are negative. The sensitivity and specificity of CT for detecting scaphoid fractures have been reported at 89%-97% and 85%-100%, respectively.[17] A high negative predictive value of CT (96.8%-99%) makes it very useful for excluding a fracture.[17]

The lunate carpal bone is moon-shaped when viewed on a lateral radiographic image. It serves as the foundation of the proximal carpal row, sitting in the central position of the carpus. Fractures of the lunate bone usually occur from direct axial compression from the head of the capitate driven into the lunate. Such fractures may result in carpal instability, nonunion, and avascular necrosis if not promptly recognized and treated. Radiography images of the wrist illustrate an isolated lunate fracture that is often obscured because of the overlapping of other carpal bones on lateral radiography images. CT has proven useful in illustrating lunate fractures and its associated injuries. Kienböck disease can occur when a lunate fracture fails to unite. Kienböck disease is an avascular necrosis of the lunate bone, occurring primarily in young adults. The precise etiology of Kienböck disease is unknown, but it has been linked to a traumatic event.

Triquetral fractures are the second most common carpal bone fractured with a prevalence of 18.4%.[17] A triquetral fracture usually results from impingement of the ulnar styloid process against the dorsal surface of the triquetrum during wrist hyperextension and ulnar deviation.

Fractures of the pisiform are uncommon, accounting for 1.3% of all carpal fractures.[17] The pisiform is a sesamoid bone enclosed within the flexor carpi ulnaris tendon and articulates with the triquetrum dorsally. Most pisiform fractures result from a fall on an outstretched hand, causing a direct blow to the pisiform. Fractures of the pisiform may be linear, comminuted, or chip-type with or without associated pisiform dislocation.[17] Due to its close proximity to the ulnar nerve, fractures of the pisiform may cause ulnar nerve injury.

In the distal carpal row, trapezium fractures account for 3%-5% of all carpal fractures.[17] The trapezium is the most mobile bone of the distal carpal row. Fractures of the trapezoidal ridge may result from a direct blow to the volar surface of the trapezium or an avulsion injury. Conventional radiography carpal tunnel views may be helpful in detecting a trapezium fracture. CT may also be useful in identifying a fracture of the trapezium.

The trapezoid is the least commonly fractured carpal bone.[17] A trapezoid fracture is usually caused by a high-energy axial blow to the second metacarpal bone. Trapezoid fractures are most commonly associated with other carpal bone fractures. Conventional radiography of the wrist may demonstrate trapezoid fractures however CT may illustrate the degree of displacement and fractures of adjacent bones.

The capitate is the largest of the carpal bones in the distal carpal row. The capitate bone has a rounded head that articulates with the scaphoid and lunate bone and partially articulates with the hamate. Because the capitate head is covered almost completely with articular cartilage and has a limited vascular blood supply it is at increased risk of prolonged healing and avascular necrosis. Palmar ligaments support it and injuries to the capitate are usually due to a high-energy hyperextension blow.

In the distal carpal row, fractures of the hamate bone account for 1.7% of all carpal bone fractures[17] The hamate bone has a hook that is a prominent rounded projection at the palmar nonarticular surface. The hamate hook is generally a frequent site of fractures and most occurs in athletes participating in racket type sports. Hamate hook fractures generally result from direct compression of the handle of the racket against the protruding hook. The tip of the hamate hook serves as an attachment site for several flexor tendons, muscles, and ligaments and displacement of these due to trauma may result in delayed healing or nonhealing. Radiography image signs of a hamate hook fracture include absence of the hook in an acute displaced fracture or sclerosis in the area near the hook.

Carpal Tunnel Syndrome

The carpal tunnel contains the median nerve and tendons of the flexor digitorum superficialis and produndus and the tendon of the flexor pollicis longus. Classic signs and symptoms of carpal tunnel syndrome include parenthesia in the median nerve sensory distribution (the first three digits and the radial aspect of the fourth digit) that may be worse at night.[17]

Forearm and Elbow Joint

The forearm consists of two bones, the radius and ulna, and two articulations, the wrist and elbow joint. Fracture of the radius is most commonly associated with direct blows received in motor vehicle accidents (MVAs) and falls.[17] Radius fractures are often associated with workplace injuries involving twisting motions. Fractures of the radius and ulna tend to occur to the shaft at the junction of the middle and distal thirds.[17] Fracture of the proximal two-thirds of the radius is uncommon because the ulna and surrounding musculature provides some protection. Fracture of the distal third of the radius is usually the result of a fall on an outstretched hand or a direct blow and is frequently associated with a radioulnar joint dislocation (i.e., a Galeazzi fracture), which requires surgical open reduction and fixation.

A Monteggia fracture occurs in the proximal third of the ulna with anterior dislocation of the radial head. This fracture is accompanied by pain and swelling around the elbow; pain is increased when the patient attempts to rotate his or her arm. Radial dislocation may be missed if the elbow is not included in the radiograph. Nightstick fracture is an isolated fracture of the midshaft of the ulna and results from a sharp blow to the limb. If the presenting injury to the ulna is an angulated fracture, injury to the radius should also be suspected. Fractures of the proximal ulna (olecranon) occur as a result of a fall onto the posterior elbow. Individuals with such injuries will present with pain, edema, and ecchymosis. The olecranon may have a palpable gap and an open fracture may be present.

Some fractures occur in specific regions of an anatomic structure. Two such fractures are a Colle's fracture and a Smith's fracture. A Colle's fracture is the most common fracture of the wrist and produces a break through the distal part of the radius. The fragment is usually angled backward on the shaft, with impaction along the dorsal aspect. An avulsion fracture of the ulnar styloid process occurs in more than half of all Colle's fractures.[17] A Colle's fracture results from a falling on an outstretched hand. A Smith's fracture, also referred to as a reverse Colle's fracture results in a volar angulated fracture of the distal radius. Like the Colle's fracture it results from falling but the blow is received to the dorsum surface of the hand.[17]

Dislocations of the elbow occur from a fall on an outstretched hand with the arm abducted or extended. About 40% of elbow dislocations are associated with fractures of adjacent bony structures.[17] The patient with an elbow dislocation will present with an elbow locked in moderate flexion (45 degrees) with foreshortening of the forearm and marked prominence of the olecranon.

Humerus

The structural components of the glenohumeral joint allow a wide range of motion and stability and are subject to dislocation. The glenohumeral joint is the most frequently dislocated major joint, accounting for 40% of all dislocations.[9] A low energy fracture of the proximal humerus may indicate an underlying pathological process, such as osteoporosis. It has been suggested that bone density measurements taken at the hip or lumbar spine may misrepresent the bone strength in the upper limb.

Proximal humeral fractures occur as a direct force against the upper arm or when axial loads transmit through the elbow. Fractures of the humerus also occur when the patient experiences a high-velocity fall onto an outstretched and abducted arm. These fractures account for 4% to 5% of all fractures and are often difficult to distinguish from a shoulder dislocation.[17]

Midshaft humeral fractures most often result from direct trauma such as from falls and MVAs.[17] The location of a midshaft humeral fracture will dictate the degree of deformity of the limb. Patients may present with very specific symptoms including pain, limited range of motion, and shortening or rotation of the arm.

When a person falls on an outstretched hand or sustains a direct blow to the elbow, the trauma is usually responsible for a distal humeral fracture. The location of the fracture dictates the clinical presentation, which may include pain, localized tenderness, swelling, distortion of the normal olecranon prominence, abnormal positioning of the elbow, crepitus, and limited range of motion.

Clavicle and Scapula

The clavicle is the most frequently fractured bone, accounting for 5% of all fractures.[17] Approximately 80% of fractures to the clavicle occur in the middle third of the bone.[17] The patients presenting signs and symptoms include pain over the fracture site. A clear indication of fracture and dislocation is when the patient presents by holding the affected extremity close to their body.

Fractures of the scapula are rare, accounting for less than 1% of all fractures.[17] The scapula is well protected by muscle and soft tissue and a great force to the area is required for a fracture to occur. Scapula fractures occur in young men more frequently than young women.[17] The usual mechanism of injury includes falls, MVAs, or crush injuries and although fractures of the scapula are rare, when they do occur they are associated with a 4% to 10% mortality rate because of the location of the scapula to the chest wall, vertebrae, and shoulder girdle.[17]

Sternoclavicular and Acromioclavicular Joints

The sternoclavicular joint is one of the least frequently injured joints in the body, accounting for only 1% of all dislocations.[17] The usual mechanism of injury is MVAs or sports injuries involving significant force directly to the joint area. Patients may present with the injured extremity supported tightly against their body and complaining of pain with movement or palpation of the joint. Sternoclavicular dislocations, when present, are frequently associated with life-threatening chest injuries.[17]

Acromioclavicular joint injuries or separations are the result of contact sports such as football and wrestling, but may also result from MVAs and falls.[17] Patients with an acromioclavicular joint injury may present with mild tenderness and swelling, full range of motion and no deformity of the area.

Glenohumeral Joint

The glenohumeral joint is the most frequently dislocated major joint in the body, accounting for over 50% of major joint dislocations.[17] With anterior dislocations, the patient presents with severe pain and with the arm abducted and externally rotated.[17] On physical examination of the patient, it will generally be noted that there is an absence of normal shoulder contour and an inability to move the shoulder joint.

Posterior glenohumeral dislocations usually result when the patient falls onto an outstretched arm held in flexion, adduction, and internal rotation.[17] The patient presents with severe pain, adduction, and internal rotation of the affected limb, prominent acromion and coracoid processes, and an abnormal shoulder contour.

Inferior glenohumeral dislocations are rare. They result from an indirect force that thrusts the humeral head below the inferior rim of the glenoid fossa.[17] The patient generally presents with the affected arm locked overhead, typically with elbow flexed and the hand either on or behind their head. Neurovascular and soft tissue damage often accompany inferior glenohumeral dislocations.

Shoulder Pathology

Impingement syndrome is a condition caused by entrapment of the supraspinatus tendon, biceps tendon, and subacromial-subdeltoid bursa between the humeral head and coracoacromial arch. It is thought that 95% of rotator cuff tears are related to chronic impingement.[17] The supraspinatus is the most common tendon affected in rotator cuff tears.

The Hill-Sach's lesion is an impaction fracture of the posterolateral aspect of the humeral head. A Hill-Sach's lesion is best demonstrated by axial images above the coracoid process. The Bankart lesion is defined as an injury to the anterior-inferior glenoid and can be an osseous or nonosseous abnormality.

Lower Extremity

The lower limb is comprised of the foot, leg, femur, and bones of the hip. The femur is the longest and strongest bone in the entire body. The entire weight of the body is transferred through this bone and the associated joints at each end. These joints are a frequent source of pathology when trauma occurs and are also commonly affected by bone loss diseases.

Fracture of long bones generally occurs due to substantial trauma, and males are more frequently affected than females.[17] In these cases, it is the magnitude of trauma rather than deficiency of bone strength. In the elderly, low bone mass is the critical factor, with most fractures occurring with minimal force.

Phalangeal and Metatarsal

Toe Injury usually occurs when objects being dropped on the unprotected foot strike the phalanges or when the toes are stubbed against a hard object. Most great toe fractures are minimally displaced. Generally, a single digit is involved in the injury but frequently the injury causes displacement, angulation, or rotation from normal position. Foreign objects lodged in the foot or toes are a common source of injury particularly in people who do not wear shoes.

Fractures that occur at the bases of the metatarsals often occur in combination with midfoot dislocation. This type injury occurs when the foot is subjected to axial loading while it is positioned in maximum plantar flexion. Metatarsal shaft fractures occur with crush injuries and when the person falls or jumps from moderate heights. Midshaft metatarsal fractures are often classified as stress fractures due to the repetitive nature of the cause of the injury.

Tarsal Fracture

The most commonly fractured tarsal bones are the calcaneus and talus. Tarsal fracture often occurs when a person jumps or as a result of a fall with the victim landing on their feet. The main presenting symptoms of patients with calcaneal fracture are heel pain, tenderness, and swelling distal to the malleoli. An injury to the distal tibia, medial malleolus, distal fibula, or any combination of these may be involved in an ankle fracture. When a fall or jump results in axial loading, the distal tibia is likely to sustain a fracture. The patient’s chief presenting symptoms are significant pain and swelling.

Tibia and Fibula Fracture

The most frequent site of injury to the tibia is the tibial plateau, the broad surface of the proximal tibia that articulates with the distal femur. Tibial plateau injuries are usually associated with soft tissue injuries; these injuries present with the patient in pain and swelling and deformity of the area. Motor vehicle accidents (MVAs) are the usual mechanism for injury to the tibia and fibula. Tibial shaft fractures are often accompanied by fibular shaft fractures and frequently are the result of direct trauma to the shaft portion of the bone. Fractures of the tibial shaft are associated with fractures in the rest of the body (ipsilateral extremity or elsewhere). Tibial shaft fractures are more prone to complications and these include increased incidence of compartment syndrome and arterial injuries.

A proximal fibula fracture usually results from a direct blow to the side of the leg. Such injuries are often responsible for concomitant peroneal nerve injury. A fibula shaft fracture is considered a minor injury, but is often associated with ankle injuries.

Femur and Patella Fracture

Fractures of the proximal femur tend to occur in children due to falls from a great height, high-speed MVAs, and gunshot wounds. Older individuals tend to experience fractures in the neck of the femur with less traumatic impact due to changes in bone density. The patient’s presenting signs and symptoms include swelling or deformity, pain with movement of the leg, and often a noticeable shortening and external rotation of the extremity. Fractures of the femoral shaft have the same mechanisms of injury, as do the proximal fractures and the patient's presenting signs include crepitus and deformity at the midthigh.

A mid-shaft fracture of the femur is associated with high force, such as may be experienced in a MVA. Several powerful muscle groups surround the femur; when mid-shaft fractures occur, contraction of these muscles causes angulation and an overriding to produce deformity. The patient's presenting signs are severe pain and blood loss into the tissue.

Hip Fracture

Although fractures of the upper arm, pelvis, and some other sites are more common in the elderly, the fractures most closely associated with bone disease are those of the hip (proximal femur), spine (vertebrae), and wrist (distal forearm).[18] The annual incidence of hip fractures increases dramatically with age, from just 2 fractures per 100,000 among Caucasian women under age 35 to over 3,000 fractures per 100,000 among Caucasian women age 85 and older.[18]

A non-vertebral fracture is also a major risk factor for vertebral and new nonvertebral fracture. Measurements that have been shown to enhance the predictive value over and above BMD are age, family history of fracture, markers of bone resorption, hip geometry, fall risks, quantitative ultrasonography findings, self-reported poor health, and poor mobility.

There are also age-related increases in fractures of other bones, such as the humerus, pelvis, and ribs. The majority of deaths after hip fracture are due to pre-existing comorbidity, such as ischemic heart disease, with the majority a direct result of complications or management of the fracture itself.[18]

There is an exponential increase in hip fracture with aging due to and age-related increase in the risk of falling and reduction in bone strength.[18] The majority of hip fractures occur after a fall from standing height or lower. Hip fractures are more frequent among Caucasians than among non-Caucasians and is explained by the higher bone mass observed in African Americans compared to Caucasians.[18] Hip fractures are seasonal, occurring more frequently in both sexes during the winter in temperate countries. Falls occurring indoors are the major cause of hip fractures. The age-adjusted male to female incidence ratio for hip fracture is about 1:2.[18] Women have an expected longer lifetime longevity and approximately 80% of hip fractures occur in women.[18] Men; however, especially older men are subject to hip fracture. Approximately 20% of the total health care costs of osteoporosis can be attributed to fracture in men.[18]

Chronic Hip Pain & Insufficiency

Adult chronic hip pain may elude clinicians both clinically and radiographically.[19] Subtle radiographic signs have been documented that indicate traumatic, infectious, arthritic, neoplastic, congenital, or other causes. For example, stress fractures appear as a lucent line surrounded by sclerosis or as subtle lucency.[19] Subtle femoral neck angulation, trabecular angulation, or a subcapital impaction line indicates an insufficiency fracture.[19] Apophyseal avulsion fractures appear as a subtle, disk-shaped opacity. Effusion, cartilage loss, and cortical bone destruction are diagnostic of a septic hip.[19] Transient osteoporosis manifests as osteoporosis and effusion.[19] Subtle osteophytes or erosive change is indicative of arthropathy. Rheumatoid arthritis may manifest as classic osteopenia, uniform cartilage loss, and erosive change. Osteoarthritis may result in cyst formation, small osteophytes or buttressing of the femoral neck.

Magnetic resonance imaging has been used to evaluate a variety of hip disorders, particularly the evaluation of avascular necrosis.[20] Glucocorticoid therapy can cause aseptic (avacsular) necrosis, most commonly in the femoral neck, distal femur, and proximal humerus and is dose dependent. It also has an effect on muscle tissue.

MR imaging is valuable in the evaluation of hip disorders because it provides assessment of articular structures, extra-articular soft tissues, and osseous structures that can be affected by hip disease.[20] Individual patient clinical findings help determine the examination protocol. Some of the issues determining MR imaging protocol include:

- Distribution of disease (unilateral or bilateral);
- Location of the disease (intra-or extra-articular); and,
- Type of disorder suspected (i.e., infection, neoplastic).[20]

Occupational and Sports Related Risk Factors

Sports injuries are a frequent reason for radiography examinations of the lower extremity. Radiographers should be familiar with some of the more common sport injuries to the lower leg in order to produce the highest quality images possible. Often patients who havea sports related injury to the lower extremity might not seek medical attention immediately. Some of the warning signs that a sports injury may require immediate medical intervention includes when the victim:

- Has severe pain in the front of the leg that does not disappear when the sport or exercise stops;
- Hears a pop just above the heel and is unable to rise onto the toes; and,
- Has pain, swelling, and redness in the upper calf.

Several risk factors that have been linked to the incidence of musculoskeletal injuries include repetitive exertions, forceful exertions, and awkward postures. Repetitive exertions have been identified as one of the leading risk factors for upper extremity cumulative trauma disorders. The repetitiveness of a task or operation can be described in several ways including: 1) the number of cycles per hour, 2) the number of lifts per hour, 3) the number of steps (exertions) included in each work *cycle,* or 4) the total number of exertions per hour. Forceful exertions performed by the upper extremities in a hand-intensive task or by the whole body are associated with the development of musculoskeletal injuries. The force requirements of an activity are related to the weight of the object lifted or carried, the slipperiness of objects being gripped, and other manual reaction forces such as torque. The pace of the activity, the use of gloves, and hand posture has been shown to increase the force requirements to perform an activity. Awkward postures of the upper extremities and torso have also been identified by researchers and linked to the incidence of musculoskeletal disorders. Standing erect with the arms hanging at the side is considered to be a non-stressful posture.

The knee is a hinge joint with a range of motion of 0 degrees in full extension to 130 degrees of full flexion.[17] Dislocation of the knee is considered an emergency due to the high rate of associated vascular and nerve damage. Patellar dislocations are more common in females than males because of the increased femorotibial angle in females.[17]

Medial collateral ligament (MCL) injuries are often caused by a direct blow such as those sustained in contact sports. In MCL injuries the patient may present with medial knee pain and joint instability. Lateral collateral ligament (LCL) is rarely injured but when it does result from stress the patient presents with tenderness over the head of the fibula with lateral instability. The posterior cruciate ligament (PCL) is frequently injured as a result of contact sports or MVAs and is accompanied by injury to other ligaments of the knee. The patient presents with posterior knee pain and may walk with the knee flexed slightly. Swelling and ecchymosis may be present in the posterior popliteal space.

The anterior cruciate ligament (ACL) is the most commonly injured ligament of the knee and most frequently occurs in non-contact type sports where the person is running, firmly plants the foot, and then cuts in the opposite direction. This also occurs when a snow ski binding fails to release during a fall. The patient may report hearing a “pop” at the time of the injury followed by severe instability of the joint. The patient may also present with varying degrees of pain and report immediate swelling.

The menisci are two areas of semilunar cartilage in the capsule of the knee joint. Their purpose is to act as shock absorbers, lubricate the joint, and they serve to evenly distribute weight to the femoral condyles and the tibial plateau. The medial meniscus is more frequently injured than the lateral meniscus. The usual cause of menisci injury is a twisting motion. The patient presents with tenderness of the medial or lateral joint line with delayed swelling.

Ankle dislocations are almost always accompanied by fractures of both the medial and lateral malleoli. Ankle dislocations often result from falls on uneven surfaces or twisting motions. There are four classifications of ankle dislocations; posterior, anterior, upward, and lateral. Ankle sprain is one of the most common musculoskeletal injuries.

Contusions often result from a direct blow to the lower extremity during a sport. In the case of a contusion caused by a direct kick, if the kick occurs directly over a bone, the bone usually will not fracture but causes bleeding under the bone. Swelling lifts nerve endings away from the bone, thus extreme tenderness and pain. Pain, swelling, and discoloration are the results of contusions. Compression on the area, elevation of the limb, and application of ice are often recommended to reduce swelling.

Tennis leg typically occurs in those who play tennis, however, this injury may occur in hikers and in team sports such as baseball, football, basketball, soccer, racquetball, handball, and participants in any running sports that demand quick thrusts and sudden changes of direction. All of these sport activities may result in tennis leg, especially in people between the ages of 30 and 45 years of age. Tennis leg rarely is evident in children or people past middle age. Tennis leg can also be called calf strain. It is actually the ripping away of the part of the calf muscle from the Achilles tendon. The patient may describe tennis leg as “being hit with a ball”. A hiker may say that it felt like their leg was hit with a rock. Generally, the patient with tennis leg will recall their symptoms as sudden pain and maybe a popping sound. They may explain that they were able to continue doing what they had been doing for a while, because about 75% of the calf muscle are still attached to the Achilles tendon. Eventually, the muscles go into a spasm, contracting violently, and the foot begins to point downward. The tender area in the calf region marks the point where the muscle fibers flow into tendon fibers. It is at that point that the tennis leg rupture occurs. Doctors advise patients with tennis leg to stretch right away to help bring the foot back to neutral. The motion stretches out the gastrocnemius muscle and provides internal compression for the injured part, slowing the blood rush to the area, thus reducing swelling. Additional treatment measures include the application of ice and compression. Following this treatment, the patient must slowly re-stretch the muscles. Eventually the muscle reattaches to the tendon, not in the same attachment position and usually a little shorter than it was originally.

Patellar tendinitis or jumper's knee is a common sports injury to high jumpers, basketball and volleyball players, dancers, runners, and anyone who runs and jumps in their sport. This inflammation of the patella may be minor or can be acute. In acute patellar tendinitis, the bottom of the kneecap swells and there is difficulty in moving the patella. In this case, the tendon actually tears away from the kneecap.

Osgood-Schlatter disease is not really a disease but rather a form of tendinitis at the lower end of the patellar tendon where it goes into the shinbone. This is a common condition in adolescents because when their bone grows it doesn't stretch like elastic; rather it expands at certain spots near the upper and lower ends of bone at the growth centers. It is at this growth center where new bone is made, pushing out to lengthen and thicken the existing bone. The patellar tendon is connected at the shin to a growth center. When a tendon strains against a bone's growth center, it can pull away pieces of soft, forming bone, as in Osgood-Schlatter disease. The result is a lumpy knee, pain, and tenderness. Because the patellar tendon is so near the skin, it may get red, swollen, and very tender. The usual treatment is medication to reduce the inflammation and application of ice.

The bursas are envelopes of paper-thin, slippery tissue that reduce friction and act as the body's slipping and sliding mechanism. Bursitis is the inflammation of any of the bursas. Inflammatory changes may result from a direct blow or other trauma or pathology within the anatomic area.

Golfer's elbow and tennis elbow are lay terms for medial and lateral epicondylitis. These conditions represent injuries of the tendons and muscles. On plain radiographs elevation of the anterior fat pad has been referred to as the "anterior sail" sign. Visualization of either a posterior fat pad sign or an anterior sail sign may indicate the presence of a joint effusion or hemarthrosis. If the presenting complaint is elbow trauma, these signs are highly suggestive for the presence of a fracture, whether or not a fracture is visualized.

Conclusion

Musculoskeletal trauma and injury is a very real fact of life that almost every American will face at some time during their lifetime. Emergency medical service personnel as well as staff in trauma centers and emergency departments are highly trained to respond to victims of trauma and injury. Radiographers have a very important role in delivering imaging services to victims of trauma and injury because quality images allow for a prompt and accurate diagnosis so treatment can begin. Radiographers who are actively employed in such situations are encouraged to continue to develop skills and proficiencies that will allow them to "be all they can be" in responding to victims of musculoskeletal trauma and injury.

Chapter 7 Radiation Protection

"At my age, the radiation will probably do me good."
Norman Wisdom

Obligations to Protect

The radiographer has moral, ethical, and legal obligations to protect the public, patients, co-workers, staff, and self from harm while in the service of providing imaging services. "From harm" is an all-encompassing concept that sometimes may seem overwhelming to the individual radiographer; however, when put into perspective, one realizes that he/she is part of a healthcare team, where each member shares a portion of the burden of safety. The American Registry of Radiologic Technologists (ARRT), American College of Radiology (ACR), and the Mammography Quality Standards Act (MQSA) provide guidelines for radiographers about safe practices, professional behavior, and the scope of imaging practice.

ARRT's Standards of Ethics is a professional document that provides registered technologists (i.e., radiographers), registered radiologist's assistants, and candidates with guidelines for acceptable ethical conduct in ensuring protection, safety, and comfort while providing imaging services.[1] Specifically, item 7 of the ARRT Code of Ethics states that a "radiologic technologist uses equipment and accessories, employs techniques and procedures, performs services in accordance with an accepted standard of practice, and demonstrates expertise in minimizing radiation exposure to the patient, self, and other members of the healthcare team."[1]

ASRT, the premier organization for imaging professionals, provides further guidance to radiographers in the form of practice standards. For example, Standard 4 of the ASRT *Radiography Clinical Performance Standards* section states that quality patient services are provided through the safe and accurate performance of a deliberate plan of action.[2] Specific criteria associated with this standard further emphasize that radiographers use radiation shielding devices and set "…technical factors according to equipment specifications to minimize radiation exposure to the patient."[2] Additionally, ASRT Standard 8 is based on the specific criteria that radiographers document radiation exposure parameters.[2]

The *Radiography Quality Performance Standards* component of the ASRT *Practice Standards* further states that the radiographer must:

Maintain controlled access to restricted areas during radiation exposures;

Follow federal and state guidelines to minimize radiation exposure levels;

Maintain and perform quality control on radiation safety equipment such as aprons, thyroid shields, etc.;

Develop and maintain a technique chart for all equipment; and,

Participate in radiation protection, patient safety, risk management, and quality management activities.[2]

Additional information about the ASRT *Practice Standards for Medical Imaging and Radiation Therapy* is available on the ASRT website (www.asrt.org).[2]

For all diagnostic imaging procedures there are universal practices that must be followed by all personnel.[4-5] The ACR has issued detailed universal practice guidelines that support personnel actions during imaging procedures. The ultimate goal of the practice guidelines is to minimize radiation exposure to patients, staff, and the public while delivering high-quality diagnostic images.

Radiographer Non-Compliance

The philosophical concepts of radiation safety and ALARA become real when, in everyday practice, technologists implement universal practice standards. Although ALARA universal practice standards are easy to perform, there exists widespread concern that radiological personnel are not performing them on a consistent basis. Variations have been found to range from strict adherence to shielding and collimation to no compliance.[4] Several studies (i.e., Tilson and Lemley) and national reports (i.e., *The Challenges and Potential for Assuring Quality Health Care for the 21st Century)* have provided information about the reasons for lack of ALARA compliance.[4] Data from a study conducted in 2003 (i.e., Slechta and Reagan) of the factors related to radiation protection practices indicate that there is poor compliance with radiation safety practices, especially safety practices designed to reduce unnecessary exposure to personnel.[4] Slechta and Reagan based their research on variable factors such as the type of initial professional education, work site type, and years of employment.[4] The results showed that the type of initial professional education was not significantly related to compliance with ALARA practices, although it had a small, significant association with knowledge of safety practices.[4] The type of work site and years of employment in medical imaging were found to be the more important variable factors in determining compliance with ALARA practices. Specifically, a higher rate of ALARA compliance was found to exist in large hospitals than in any other type of work site.[4] Reagan and Slechta conducted a recent survey with 2 primary objectives:

- To ascertain whether key findings of the 2003 national study of radiologic technologists' radiation safety practices would be replicated with a revised instrument and with the California-based population of ARRT radiologic registrants; and,
- To determine whether there was a significant difference between compliance with personnel safety practices and compliance with patient safety practices.[5]

The findings from the recent study support the findings of the 2003 national study and support predictions that compliance would be higher for patient safety practices than for personnel safety practices, and that years in practice and type of work site would be related to safety compliance.[5] The major findings from the national and the current study are as follows for those surveyed:

- Participation in continuing education (CE) was high, yet compliance with safety practices was low;
- Knowledge of safety practices was higher than compliance with safety practices.[5]

After analyzing the research data, Reagan and Slechta conclude that additional research is needed to address certain questions.[5] For example, continuing education (CE) is required for radiographer compliance with certain state statutes and ARRT registration and yet there is low compliance with safety practices. Also, the researchers question why compliance with safety practices is greater for patients than for personnel.

Appropriateness of Imaging Examinations

The current literature focuses on potentially medically-unnecessary imaging examinations as the cause of the rapidly rising costs of healthcare in the U.S. and the ever increasing radiation exposure to Americans.[6-7] There are several moves to curb both the cost and the additional radiation exposure. Because sophisticated medical imaging examinations now account for 60% of radiology costs and 80% of cost increases, third party payers are tightening the requirements for pre-authorization of the examinations.[6-7] One of the challenges has been the lack of a commercially available, research-driven guide for physicians on how to judge the appropriateness of imaging examinations for patients. The ACR has published appropriateness criteria, which serves as foundation guidelines based on the patient's condition or disease. The ACR appropriateness criteria ranks imaging examinations from 1 to 9 based on the condition.

Recently researchers at Massachusetts General Hospital in Boston found that an electronic system when used consistently prevents nurses or office assistants from ordering low-yield CT, nuclear medicine, or MR imaging scans. Use of the decision support software allowed for a drastic reduction in the rate of such examinations and markedly increased the percentage of test personally ordered by physicians. The Web-based software advantage includes offering the physician suggestions for a better examination in the event of a low score or inappropriate examination.[6-7] With the continued improvement in such decision making tools, it is anticipated that physician ordering of unnecessary and/or inappropriate medical imaging examinations and an overall reduction in exposure to ionizing radiation will decrease.

Factors Impacting ALARA

Recognized ALARA practices consist of simple yet effective measures that can be applied in all imaging procedures. These include those items directly related to the imaging procedure, such as patient communication, examination preparation, motion control, and reduction in repeat examinations. Other items that contribute to the overall goal of ALARA include the design of the x-ray room, structural protective shielding, protective barrier requirements, and equipment design.

Retake Exposures

When an image must be retaken the radiation dose received by the patient increases. The ultimate goal of all imaging procedures is the production of high quality images. A retake of an image may be required whenever the image quality fails to provide adequate diagnostic information. The reasons for retake examinations range from simple radiographer forgetfulness to complex technical errors. The most common causes of retakes include improper positioning of the part or patient, inaccurate selection of the technical factors (over or underexposure of the image), patient motion (voluntary and involuntary), and improper film processing techniques. The observant radiographer can correct many of these errors beforehand, thus minimizing the number of x-ray exposures and reducing the patient radiation dose.

If in doubt about the need to retake a particular image, the radiographer should consult with a supervisor to determine whether the image provides sufficient diagnostic information. Since additional exposures result in increased radiation dose to the patient, each image should be thoroughly evaluated for diagnostic integrity prior to the decision of retaking an examination. Factors such as whether either the patient's condition or the technical factors can be improved upon during the retake examination must also be considered prior to actually subjecting the patient to additional radiation exposure. In many cases, these factors cannot be easily changed, and the outcome of the retake examination may not yield any improvement in image quality, so should not be attempted.

A retake analysis program can easily be incorporated into the overall quality control program. Whether performed by an individual or the supervisor, analysis of the number and causes of retake examinations can result in heightened awareness of areas needing correction. Such information can be used to design staff in-service training and customized continuing education. Further, information about an individual radiographer can be used during personnel evaluations as a way to begin a self-improvement plan, or at worst, to begin the documentation for punitive action and eventual termination of employment.

ALARA in Action

The concept of ALARA is best explained as actions the radiographer performs in every imaging examination to provide maximum radiation protection to the patient, public, and self. Some of the simplest ALARA actions performed by the radiographer can be the most effective. Examples of these include when the radiographer:

- Uses the lowest exposure factors that will produce a high-quality diagnostic image;
- Performs the procedure correctly the first time to avoid retake examinations;
- Properly shields the patient with gonadal shields; and,
- Limits the primary radiation beam to the area of clinical interest.

There are many factors contributing to the overall goal of ALARA. Each of the following will be briefly reviewed: cardinal principles, structural design, protective apparel, primary beam limitation, filtration, selection of technical exposure factors, film-screen combinations, grids, and equipment design.

The cardinal principles of radiation protection are time, distance, and shielding (TDS). If used together, these principles can effectively minimize radiation exposure. The cardinal principles were first introduced for nuclear-energy employees who had the potential to be exposed to high levels of radiation in the workplace. Individuals employed in medical imaging are not expected to receive such high levels of radiation; however, the cardinal principles have practical application to everyday medical imaging and special procedures.

The T in TDS refers to the fact that radiation exposure is proportional to the length of time exposed to radiation. A five minute radiation exposure would result in a radiation dose five times as great as a one minute radiation exposure. This has several implications that can be related to minimizing radiation exposure. The radiographer has a responsibility to:

- Reduce the amount of time exposed to radiation. The radiographer should stand behind the protective barrier during the exposure, and should not allow visitors in the room during the exposure.
- Make the x-ray exposure only when the imaging room doors are closed. This practice provides a substantial degree of protection for patients and staff who may be walking past the imaging room.
- Reduce the amount of time that the patient is exposed to radiation. The radiographer should reduce retake examinations, which subsequently reduces the total quantity of radiation dose received.
- Use a fast exposure-time whenever possible. A fast exposure time helps minimize patient motion. Motion results in image blurring, which reduces image quality and increases the need for retake examinations.

Exposure Control

There are many factors that influence the amount of radiation that the patient receives. Of these, there are only a few within the radiographer's control. The correct selection of exposure factors is under the direct control of the radiographer, and if performed consistently can reduce radiation exposure to patients and staff. There are various systems available for the selection of technical exposure factors; these include both manual and automatic variables on computed and direct digital equipment.

Automatic exposure control (AEC) systems limit the length of the exposure and thereby have some impact on overall radiation dose. AEC devices, also referred to as phototimers, are programmed to terminate the radiographic exposure time at a predetermined value. Radiographers are advised to continually review current technical and positioning references in regard to proper selection of AEC chamber(s), and correct positioning when using them.

The D in TDS is for the distance between the patient, radiographer, and the radiation source. One of the most effective methods that radiographers can use is to put as much distance between themselves and the radiation source as possible. The inverse square law applies to point sources of radiation, and can be used to demonstrate the effect of distance on radiation intensity. The distance principle as applied to patient protection refers to the fact that every imaging procedure should be performed with the x-ray tube or source positioned at the proper distance from the patient or part being examined.

The S in TDS is for shielding. The quantity and energy of the x-ray decreases when x-ray travels through living tissue as a result of attenuation. The degree to which the quantity and energy of the x-ray beam is decreased depends upon the following 3 factors:

- Original quantity and energy of the x-ray;
- Type of absorber material, or atomic number of the tissue; and,
- Thickness of the absorber material in centimeters or inches, and consideration of any existing pathology.

Structural Design for Radiation Protection

An imaging room must be designed to ensure proper placement of the equipment and that the structural protective shielding meets recommended protective guidelines. A qualified medical physicist must survey the prospective room design and determine the exact requirements for structural shielding. Whether the prospective imaging room is already in existence or is part of a new construction, appropriate thickness of lead structural shielding must be installed according to the physicist’s specifications, which are usually mandated by state and/or federal laws. The physicist provides recommendations for both primary and secondary protective barriers.

Primary structural protective shielding provides protection from the primary x-ray beam. Primary radiation emerges directly from the x-ray tube window and moves without deflection toward a wall, door, etc. A wall in the path of the primary radiation requires the most protective shielding. For x-ray equipment capable of operating up to 150 kVp, the protective primary structural shielding should contain $1/16^{th}$ inch of lead and extend as high as seven feet from the imaging room floor.[8] Primary structural protective shielding is installed perpendicular to the primary x-ray beam.

Secondary radiation occurs when the primary x-ray beam is deflected or re-directed by the object being irradiated. Radiation leakage around the x-ray tube and scatter radiation generated by the patient and other objects receiving radiation comprise secondary radiation. Secondary protective structural shielding should consist of $1/32^{nd}$ inch of lead, extend to the ceiling, and be located parallel to the primary beam.[8] Secondary protective shielding is also installed in the control console shield and structural barrier window through which the radiographer can observe the patient. The window is required to contain 1.5 mm of lead equivalent.[8]

Protective apparel for Radiation Protection

Protective apparel is used for the patient and radiographer whenever additional protection is desired or necessary. Protective apparel consists of lead-impregnated vinyl gloves and aprons. If the x-ray tube operating capacity is in the 100-kVp range, the lead gloves and aprons should contain at least 0.25 mm of lead equivalent; however, a lead apron is typically lined with 0.5 mm of lead or its equivalent.[8]

Gonadal shielding protects the patient's gonads from direct exposure to the primary radiation beam. Gonadal shields should be used in addition to collimation. Gonadal shielding should be provided for all persons having reproductive potential, including adults of reproductive age and children. The anatomic location of the testes in the male generally allows for adequate shielding while not obscuring important anatomic structures; however, the ovaries are located near the vertebral spine, ureters, and the small and large intestines, and pose a shielding challenge. Gonadal shields should meet the following specifications based on the kilo-voltage range of the radiography equipment being used:

0.25 mm of lead equivalent for 100 kVp or less;

0.5 mm of lead equivalent for 100 to 150 kVp; and,

1.0 mm of lead equivalent for 150 kVp and above.[8]

Protective gloves, aprons, and gonad shields impregnated with lead should be handled and stored with care. Protective apparel should not be folded during storage since cracks may result from bending. If cracks occur, radiation may leak through and diminish the protective characteristic. Protective apparel should be checked at least every three months for cracks.[8]

Primary beam limitation

Primary beam limitation is one of the most effective methods that can be employed to reduce unnecessary radiation exposure to the patient. Limitation of the primary x-ray beam has a twofold benefit: it reduces the amount of radiation dose to the patient by reducing the amount of scatter radiation while also producing a high quality image. As the amount of primary radiation is reduced, the quantity of secondary scattered radiation is also reduced.

Filtration

Filtration of the primary radiation beam is another method that contributes to the overall goal of ALARA. A filter removes low-energy, long-wavelength photons from the primary radiation beam. The two major functions of a radiographic filter are (1) protecting the patient's skin and superficial tissue, and (2) improving the radiation beam quality.[8] The filter removes the longer wavelengths, or the lower energy photons, from the primary radiation beam, resulting in a primary radiation beam that is more homogeneous in nature.

Quality assurance and quality control are very important aspects of an active ALARA-based radiation safety program. Quality assurance consists of all the activities that support the delivery of high-quality imaging and patient care. Quality assurance is the broad umbrella of evaluation and monitoring which encompasses all the systems that affect the delivery of imaging services and patient care. This includes patient information data systems, personnel policies and procedures, and overall operating procedures (clerical, technical, support, administrative, etc).

All imaging systems and accessory equipment, such as cassettes, viewboxes, and darkroom environmental features, are subject to regular required inspection, maintenance, and testing protocols that must be performed to assure the integrity of the system. Radiographers are encouraged to continue to expand their knowledge and understanding of quality assurance and quality control by consulting specific references on these subjects.

Radiation Detection and Monitoring

Radiation detection and monitoring are important to the overall radiation protection program in any facility. Monitoring of personnel provides important information regarding the amount of radiation exposure received. Information gathered from personnel monitoring is generally reviewed by the radiation safety officer (RSO) to determine if it is within the acceptable exposure guidelines. After review, corrective actions may be required to reduce or eliminate the radiation exposure. It should be noted that monitoring is not considered a protective method; rather, the data gathered from monitoring provides information about the wearer's personal radiation safety habits and the imaging environment.

Radiation monitoring is recommended for those who are exposed occupationally on a regular basis to ionizing radiation, and who are at risk of receiving 10% or more of the annual occupational effective dose limit of five rems in any single year.[8]

Regardless of the company supplying personnel radiation monitors and reporting, there is a certain amount of information that is commonly contained in a report. This information is listed as follows:

Personnel identification, usually by a number (name, birthdate, and sex);

Type of dosimeter;

Radiation quality (e.g. X-rays, beta particle, neutron, combined radiation exposure);

Equivalent dose data for the entire reporting period; and,

Notation of the starting date that the monitoring company began keeping records for the individual.[10]

Radiographers should maintain a copy of their accumulated permanent equivalent dose record. This information can then be conveyed from employer to employer throughout the person's work life.

The optically-stimulated luminescence (OSL) dosimeter combines the best features of the traditional film badge monitor and thermoluminescent dosimeter, while eliminating some of their disadvantages. The OSL dosimeter can be worn for up to one year, but in actual practice is usually only worn for a two month period.[10] A disadvantage of the OSL dosimeter is that it must be shipped to the radiation monitoring company for reading, so determination of exposure is delayed.[8] The OSL dosimeter has a sensitivity reading as low as one rem for x-ray and gamma ray photons, and is considered the monitor of choice for monitoring personnel.[10]

The Safety Manual from the Office of Safety and Environmental Health at Johns Hopkins offers the following additional tips regarding personnel radiation monitoring:

-Individuals who may receive an occupational radiation dose in excess of 10% of the allowed limits shall be required to use a personnel monitor.

The monitor is a measure of the individual's personal exposure.

It should not be given to other people to wear.

Once a month, the films within the monitor must be changed.

Failure to change the film at the proper time negates the monitor's usefulness.

Monitors should not be put in radiation sources for experimental purposes. The personnel radiation monitor is issued to document exposure to the head and trunk of the body. The monitor should be worn at the waist or chest level, never at the extremities. When wearing a protective apron, the personnel radiation monitor should be worn outside the apron at the collar level.

If a monitor is lost or damaged, a new monitor must be obtained before continuance of activities involving possible radiation exposure. There is a charge for exchange of damaged holders.

Technologists should take care of the personnel radiation monitor as it is also sensitive to heat, moisture and pressure.

Appropriate precautions should be observed.

A personnel radiation monitor should never be worn when receiving radiation exposure as a patient.

An annual record of radiation exposure should be provided to the technologist at his/her request.[10]

Radiation protection procedures for patients, staff, and the general public require that radiography personnel be knowledgeable about the nature of ionizing radiation, and constantly attentive to all safety measures. Radiography personnel are challenged to apply a variety of methods, techniques, skills, and knowledge in an effort to practice ALARA in every imaging procedure.

Conclusion

Radiographers are important members of the imaging team and should expect that the demand for their services will increase in the coming decade. It is also expected that as the U.S. population ages, that the demands on all imaging professionals will increase. Not only will the population of patients be older but also in many instances they may be more gravely ill and have need specialized services. Radiographers have always accepted the challenges of providing high quality images despite less than ideal circumstances. It is expected that they will continue to do so and that providing services to the aging population will be no different than the challenges that have come before.

References Chapter 1 The Appendicular Skeleton: A Review

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