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MUSCULOSKELETAL MRI PART I: THE ANKLE, FOOT, WRIST AND HAND

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OVERVIEW OF MUSCULOSKELETAL IMAGING

Imaging of the bones, joints, muscles, and cartilage represents the radiologic subspecialty of musculoskeletal imaging. Although imaging can be performed using a number of modalities, magnetic resonance imaging (MRI) is now the preferred modality for most types of musculoskeletal abnormalities. The strength of MRI in imaging physiologic processes is due to its combined strengths of high detail, multiplanar imaging capability, lack of ionizing radiation, and sensitivity to physiologic changes. MRI also excels in the ability to distinguish various types of tissues on the basis of water and fat content. Because MRI provides a wide range of choices for imaging in the form of various pulse sequences and options, it allows for a very comprehensive evaluation of an injury in a fairly short period of time.

JOINT AND EXTREMITY MRI

From an imaging perspective, musculoskeletal MRI can be subdivided into joint survey studies and examinations of the extremities. The former—and more common of the two—can be performed on almost any articulation in the body. Proper joint MRI will evaluate all the structures of the articulation, including the articulating bones and surrounding cartilaginous, synovial, ligamentous, tendinous, and muscular structures. Careful attention is paid to appropriate anatomic coverage, plane angulation, technical parameter selection, and patient positioning, because errors in any of these areas can adversely affect the sensitivity or specificity of the examination. A complete medical history is a key component in providing a high-quality examination. This information will assist the radiologist who is interpreting the study as well as guide the technologist in making decisions regarding specific imaging parameters. The second category of musculoskeletal MRI, that of the extremities, encompasses a wider variety of abnormalities. These processes may include muscle injuries, soft-tissue tumors, cellulitis, and osteomyelitis. Because the anatomic structure of the extremities allow these processes to spread along numerous pathways, before the examination the abnormality must be thoroughly evaluated relative to both its extent and involvement with surrounding structures such as muscles, blood vessels, nerves, and bony structures. In some situations, it may also be necessary to scan the entire length of the extremity in question. Gadolinium intravenous contrast injection should also be considered for many extremity MRI examinations because it can be of great value in differentiating inflammatory processes from malignant ones and helping to determine tissue viability.

In this article, we'll discuss the joints of the foot, ankle, wrist and hand, as well as techniques for imaging these joints from an MRI perspective. Also, some detail on anatomy, pathology, and imaging protocols will be included. Due to the complexity of the structures included in this article, it is not possible to be fully comprehensive, so a general overview—with attention to the most common points—will be provided. After finishing this article, the reader should have a general understanding of the anatomy of the joints and supporting structures, their most common pathologies, and a general understanding of the most efficacious methods of imaging them with MRI. The protocols included within this article reflect the specific preferences of a small number of fellowship-trained musculoskeletal imaging specialists, not the entirety of the musculoskeletal imaging community. These protocols are provided for the purpose of reference and should in no way be construed as the only means of evaluating the joints and structures discussed herein. Within our practice, musculoskeletal imaging is performed at field strengths ranging from 0.7 Tesla (T) to 1.5 T.

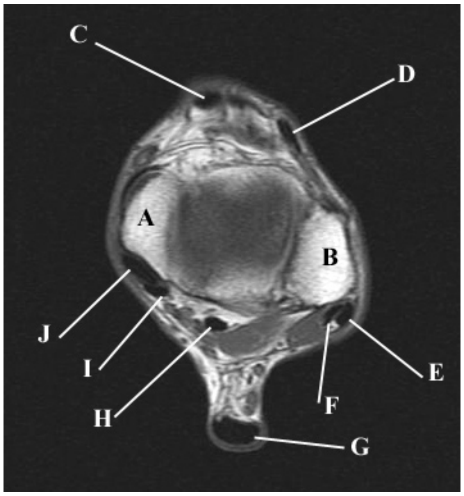

FIGURE 1. T1–weighted axial through ankle at the level of the mortise. A–medial malleolus of tibia, B–lateral malleolus of fibula, C–tibialis anterior tendon, D–extensor igitorum longus tendon, E–peroneus longus tendon, F–peroneus brevis tendon, G–Achilles tendon, H–flexor hallucis longus tendon, I–flexor digitorum longus tendon, J–tibialis posterior tendon

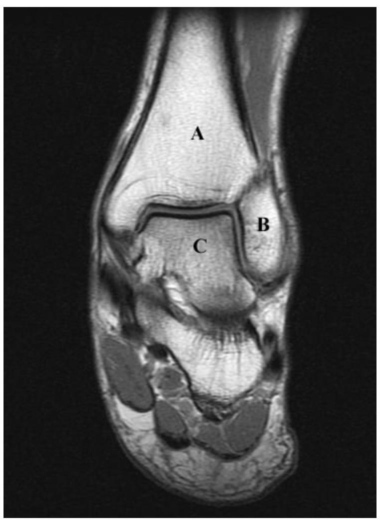

FIGURE 2. PD–weighted coronal ankle. A–tibia, B–fibula, C–talus

FIGURE 3. T1–weighted sagittal ankle. A–tibia, B–talus, C–calcaneus, D–navicular, E–Achilles tendon, F–plantar fascia

JOINTS

ANKLE (FIGURES 1-3)

The ankle joint is formed by the articulation of the dome or trochlea of the talus and the tibial and fibular articular surfaces. Together, they form a *hinge-type* joint. There are three sets of tendons associated with the ankle joint. The *posterior tendons*, consisting of the posterior tibialis, flexor digitorum longus, and flexor hallucis longus; the *anterior tendons*, consisting of the anterior tibialis, extensor hallucis longus, and extensor digitorum longus; and the *lateral tendons*, consisting of the peroneus longus and peroneus brevis.

Three ligaments provide support to the lateral side of the ankle joint. It is fairly simple to determine the bones they support by their names. The *anterior talofibular ligament* (ATFL) runs from the anterior fibular malleolus to the anterolateral talus. The *posterior talofibular ligament* (PTFL) is transversely oriented and runs from the posterior fibular malleolus to the posterior talar tubercle. The third ligament is the *calcaneofibular ligament* (CFL), which has a vertical course, runs from the inferior fibular malleolus to the lateral calcaneus.

The *deltoid ligament* provides support to the medial aspect of the ankle and has both superficial and deep components. It attaches proximally to the tip of the medial malleolus and fans out distally into four parts that attach to three of the tarsals—the calcaneus, navicular, and talus. The individual ligaments are called the anterior and posterior tibiotalar, tibionavicular, and tibiocalcaneal ligaments. The *Achilles tendon* is the thickest tendinous structure in the ankle. It represents the distal portion of the *triceps surae tendon*. The triceps surae muscle is composed of the lateral and medial heads of the gastrocnemius and soleus muscles, all in the posterior compartment of the calf. The tibia is one of the strongest long bones in the body. It is responsible for carrying the majority of the weight of the body during ambulation and can be subjected to significant stresses during axial load impacts. The fibula itself is not a weight-bearing bone, but rather acts as a brace for the tibia and an attachment point for muscles and ligaments. The inferior articular surface of the tibia is often referred to as the *tibial plafond*, which forms the roof of the ankle joint. The medial malleolar process of the tibia forms the medial portion of the ankle joint, and the lateral malleolar process of the fibula forms the lateral portion of the ankle joint. The dome of the talus forms the inferior portion of the joint; due to its shape, this dome allows for flexion and extension, inversion and eversion of the foot occurs at the level of the subtalar joint. The talus articulates inferiorly with the calcaneus and navicular bones. The calcaneus does not truly form a part of the bony articulation of the ankle, but does serve as an attachment point for ligaments of the ankle joint.

Ankle abnormalities. Because the ankle bears the majority of the body's weight when standing, walking, and running, a variety of traumatic pathologies, variants, and congenital abnormalities are seen.

The *os trigonum* is an accessory bone present in less than 15% of people who have normal feet. It is located immediately posterior to the talus adjacent to the lateral tubercle and is the product of a secondary ossification center. This bone is occasionally viewed as a portion of the lateral tubercle that fails to fuse. *Os trigonum syndrome* involves impingement of this process between the tibia and calcaneus on plantar flexion and can result in pain, restriction of plantar flexion, and tendinopathy of the flexor hallucis longus tendon. This is also called posterior impingement.

Achilles tendon injuries are commonly seen as a result of ankle trauma. During jumping and landing, as occurs when playing volleyball and basketball, the Achilles tendon can be placed under tremendous stress, which can result in a variety of tendinopathies ranging from partial fiber tears and longitudinal cleavage to complete transverse ruptures with retraction of the torn proximal portion. MRI is of substantial utility in imaging Achilles tendon injuries. As a result of the collagenous composition of the tendon, a normal tendon will have low signal on all MRI sequences. Injuries such as strain, tear, and rupture are easily visualized using MRI. Due to the longitudinal course of the tendon, it is best seen on axial and sagittal scans.

Although the majority of ankle sprains are inversion injuries, eversion sprains are also seen and can result in tears of any of the components of the deltoid ligament. Either type of sprain can be accompanied by plantar or dorsiflexion, which can complicate the injury further. Inversion under extreme force—as occurs with a sprain—can result in strains, tears or ruptures of any or all f the lateral collateral ligaments (ie, the ATFL, CFL, and the PTFL). When evaluating MR images for lateral collateral ligament damage from an inversion injury, the first ligament to tear will be the ATFL; therefore, this ligament must be evaluated first. Lateral ligament tears typically occur in sequence, beginning with the ATFL, followed by the CFL, and then the PTFL. Isolated ruptures of the CFL and PTFL in the absence of a concomitant rupture of the ATFL are very rare. Therefore, it is generally a safe assumption that if the ATFL is intact, the CFL and PTFL will be as well. If the patient's pain does not involve joint instability and is more inferolateral, a tear, rupture, or avulsion of the *peroneus brevis* should be suspected. The peroneus brevis tendon, which attaches to the base of the fifth metatarsal, can be strained or avulsed from its insertion, resulting in a common injury known as a *Jones fracture.* Although bony avulsions can be visualized on plain x-ray, MRI can image the ligamentous and tendinous injuries as well; if a tear or rupture is present, MRI can help define the extent of the tear and the position and condition of the avulsed portions and bony fragments.

Classic ankle sprains are among the most common injuries to the ankle. They are usually the result of sudden inversion under force. Sports such as skiing and skating can produce a variety of plantar and dorsiflexion injuries, although by far the most common mechanism of injury to the ankle is the simple fall or twist followed by a fall. These inversion and twisting mechanisms put the majority of strain on the lateral ligaments and tendons. Injuries with plantar flexion also place the anterior tendons at risk for strain. Sharp dorsiflexion under force can result in tears or rupture of the Achilles tendon.

Scan techniques for the ankle. We encourage the axial series to be acquired first to facilitate proper angulation of the sagittal and coronal series. Axial scans are aligned perpendicular to the long axis of the tibia, and coverage is from the proximal Achilles tendon and extends distally to below the calcaneus. On occasion, specific evaluation of the peroneus longus and brevis, posterior tibialis, or flexor hallucis longus tendons is requested. In this setting, we angle the proton density (PD) axial series 45 degrees such that the slice plane runs perpendicular to the course of these tendons at the level of the talus. Sagittal scans are planned using a slice that shows the ankle mortise; these scans are angled perpendicular to a line intersecting the medial and lateral malleoli. Coverage begins several millimeters medial to the medial malleolus and extends laterally to include the base of the fifth metatarsal. Coronal scans are also planned from an axial slice through the mortise and are angled parallel to a line intersecting the medial and lateral malleoli. Coverage begins several millimeters posterior to the tibia and continues anteriorly through the entire talus.

ROUTINE ANKLE SCAN TECHNIQUES

* *3-plane localizer*
- Gradient echo: Scan time < 60 sec
- 5–7 slices per plane
- 260 mm Field of View (FOV)
- 8.0-mm skip 2.0 mm
- Matrix 256 F x 128 P

* *PD-weighted FSE (TE = 20)*
- Axial plane unless angling for tendons
- 140 mm FOV
- 4-mm skip 1 mm
- Matrix 256F x 192P with 512 interpolation
- RBw 20-25 kHz
- Spatial presaturation bands inferior and superior to the imaging volume
- Phase axis R-L

* *T2-weighted FSE (TE = 70) with spectral fat suppression*

- Axial plane matched to PD series, unless PD series is angled for tendons
- 140 mm FOV
- 4-mm skip 1 mm
- Matrix 256F x 192P
- RBw 20-25 kHz
- Spatial presaturation bands inferior and superior to the slice group
- Phase axis R-L

* *T1-weighted spin echo (SE) (TE = minimum to 17ms)*

- Oblique sagittal plane as described above
- 4-mm thickness with 1-mm gap
- 160 mm FOV
- Matrix 256F x 192P with 512 interpolation
- RBw 16kHz
- 100% phase oversampling
- Phase axis A-P

* *Fast STIR (FSE-IR) (TE = 50/TI=125 for 1.5T) or T2-weighted fast spin echo (FSE) (TE = 70) with spectral fat suppression*

- Oblique sagittal matched to T1 series
- 4-mm thickness with 1-mm gap
- 160 mm FOV
- Matrix 256F x 192P
- Receiver bandwidth (RBw) 20-25kHz
- Spatial presaturation band superior to the slice group
- 100% phase oversampling
- Phase axis A-P

* *PD-weighted FSE (TE = 26)*

- Oblique coronal plane as described above
- 4-mm thickness with 1-mm gap
- 140 mm FOV
- Matrix 384F x 224P with 512 interpolation
- RBw 25-32 kHz
- Spatial presaturation band superior to the slice group
- Phase axis R-L

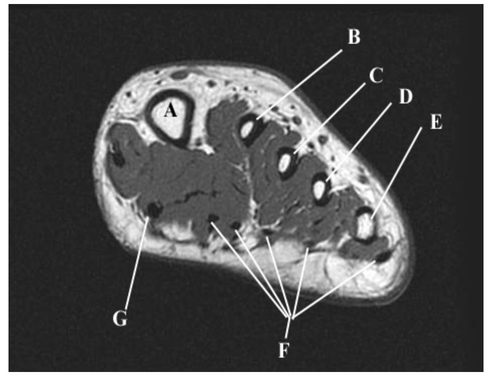

FIGURE 4. T1–weighted short axis of foot through metatarsals. A–1st metatarsal, B–2nd metatarsal, C–3rd metatarsal, D–4th metatarsal, E– 5th metatarsal,F– flexor digitorum tendons,G– flexor hallucis longus tendon

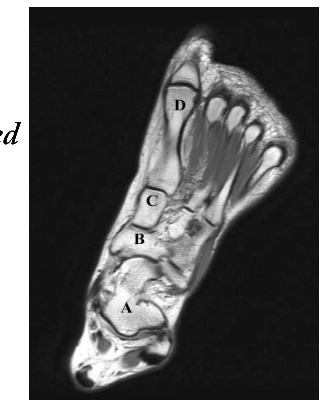

FIGURE 5. PD–weighted long axis foot. A–talus, B–navicular, C–1st cuneiform, D–head of 1st metatarsal

FIGURE 6. T1–weighted sagittal foot. A–tibia, B–talus, C–calcaneus, D–Achilles tendon

FOOT (FIGURES 4-6)

The foot is a highly complex unit because it not only is composed of 26 bones, 33 individual joints, approximately 20 muscles, and more than 100 ligaments, but also because it bears all the body weight during standing and ambulation. The plantar surface of the foot in most people is arched—hence the term “arch” of the foot. Technically, there are in fact three distinct arches that support the foot. The *transverse arch* bears most of the weight of the foot and runs in a medial to lateral orientation. It is centered in the midfoot. The l*ongitudinal arch* actually consists of a medial and lateral arch. The *medial longitudinal arch* spans the instep of the foot and is the most noticeable. Most people usually recognize this arch as the "arch" of the foot. The *lateral longitudinal arch* is flatter and runs the length of the lateral foot. Both longitudinal arches are integral in providing balance and absorbing shock forces.

For the purposes of imaging with MRI, it is helpful to subdivide the foot into functional geographic units. The *hindfoot* is generally accepted as the "heel" of the foot. This segment is composed of the talus, calcaneus, and in some cases the navicular and cuboid bones. The *midfoot* is generally considered to be comprised of the tarsals, including the cuboid and navicular, and also the proximal to mid-metatarsals and tarsometatarsal joints (ie, *Lisfranc joint complex*—to be discussed later). Therefore, the forefoot consists of the mid- to distal metatarsals, metatarsophalangeal (MTP) joints, and the phalanges. It is also worthwhile to note that there are two sesamoid bones on the plantar aspect of the head of the first metatarsal. These sesamoids are located within the tendons of the flexor hallucis brevis muscle.

Because the muscles of the foot are numerous, an endeavor to thoroughly explain each one in great detail would exceed the scope of this work. In general terms, however, the muscles responsible for foot movement can be divided into *functional groups* and *geographic groups*. The functional groups are the flexor muscles, extensor muscles, and muscles of inversion and eversion; there are also muscles that abduct and adduct the great toe. Some muscles are involved in multiple motions and therefore fall into more than one group. The geographic divisions are the extrinsic and intrinsic muscles. Extrinsic muscles are located proximal to the ankle joint and act at the ankle as well as the foot. Intrinsic muscles are located distal to the ankle joint and act at the midfoot and forefoot only.

Flexor muscles serve to flex the ankle and dorsiflex the foot. The principal muscle of dorsiflexion is the tibialis anterior. The peroneus (fibularis) tertius, extensor hallucis longus, and extensor digitorum longus are also involved in dorsiflexion of the foot, although that is not their principal action. The lumbricals and interossei are small intrinsic muscles in the foot that both provide minor flexor movements to the mid- and forefoot. Muscles involved in flexion of the forefoot and toes include the flexor digitorum longus and brevis, flexor hallucis longus and brevis, flexor digiti minimi brevis, and quadratus plantae.

Extensor muscles serve to extend the ankle and plantarflex the foot. Muscles of the extensor group include the gastrocnemius, soleus, plantaris, tibialis posterior, and peroneus (fibularis) longus and brevis. The flexor hallucis longus and flexor digitorum longus muscles are also involved with plantar-flexion of the foot/extension of the ankle; however, as previously mentioned, with their extensor counterparts, the principal action of these muscles is at the toes. Muscles involved in extension of the forefoot and toes include the extensor hallucis longus and brevis and extensor digitorum longus and brevis. Muscles of the lateral leg—the peroneus longus and brevis—serve to evert the foot. The muscles of the medial leg—the tibialis anterior and posterior—are invertors of the foot. Intrinsic muscles include the aforementioned lumbricals and interossei as well as the flexor and extensor digitorum brevis, flexor and extensor hallucis brevis, and flexor digiti minimi brevis, which act to flex or extend the toes. Other intrinsic muscles of the foot are the quadratus plantae, an accessory flexor of the toes; the abductor and adductor hallucis, which act to abduct and adduct the great toe, respectively; and the abductor digiti minimi, which acts to abduct the fifth toe.

The bones that compose the foot are the tarsals, metatarsals, and phalanges. There are seven tarsals: the calcaneus; talus; navicular; cuboid; and the first, second, and third *cuneiforms*. There are five metatarsals numbered 1 through 5. The phalanges number 14. The great toe or *hallux* has two phalanges, a proximal and distal. Toes 2 through 5 each have 3 phalanges—a proximal, middle, and distal phalanx. As mentioned previously, there are two sesamoids associated with the head of the first metatarsal.

Foot abnormalities. The two most common categories of abnormalities seen in the foot are traumatic and degenerative. Because the foot carries the body's weight much of the time, it's not surprising that after decades of use, degeneration of the cartilage and articular surfaces will develop. Likewise, traumatic injuries are common—especially in people who engage in sports that involve significant running and jumping.

Tarsal tunnel syndrome is a term used to describe a variety of conditions that result in the compression and neuropathy of the tibial nerve. Like the well-known *carpal tunnel syndrome* of the wrist, tarsal tunnel syndrome occurs in an area where tendons, ligaments, and vessels share a tight space with the nerve. Enlargement of any of these structures as well as bony overgrowth or the development of ganglion cysts can result in compression of the tibial nerve. This results in paresthesias on the plantar surface of the foot. The diagnosis of tarsal tunnel syndrome is most often made clinically; however, the underlying cause may be more elusive due to the number of potential structures involved. MRI can be helpful in assessing the contents of the tarsal tunnel.

The *sinus tarsi* (or *tarsal canal*) is an approximately conical structure—larger laterally, whose contents include a number of ligaments that support the talus and calcaneus and serve to moderate inversion of the foot. *Sinus tarsi syndrome* is the term applied to the symptoms associated with injuries to the ligaments within the tarsal canal. This is most often a result of inversion injury. Due to this mechanism of injury, associated tears of the peroneus brevis and peroneus longus and lateral ligaments are also seen with some frequency. MRI can be very useful in imaging the contents of the tarsal canal and evaluating the nature of the injury and ligaments involved.

A condition known as *tarsal coalition* can occur when two adjacent bony surfaces are fused. This fusion can be fibrous or cartilaginous, and therefore somewhat flexible, or bony and rigid. This condition occurs in the foot most commonly at the middle subtalar talocalcaneal joint and the calcaneonavicular joint. The diagnosis of coalition may be made using conventional x-ray or computed tomography (CT); however, the characterization of the coalition can be further refined using MRI.

Lisfranc is a term occasionally applied to the *tarsometatarsal* (TMT) *articulations* (ie, Lisfranc joint complex); but more specifically, the term *Lisfranc joint* is used to describe the articulation between the first and second cuneiforms and the first and second metatarsals. The joint takes its name from one of Napoleon's field surgeons who performed an amputation through this joint level. Lisfranc joint injuries can result from a direct crush trauma to the dorsum of the midfoot, a sharp axial impact with loads transmitted directly to the TMT joints, or more complex twisting injuries of the foot. Lisfranc joint injuries can occur as isolated injuries or may be accompanied by fracture. These injuries are often misdiagnosed, and MRI can play a role in confirming or excluding this type of injury. MRI for Lisfranc injuries should include the area of the tarsals of the midfoot through the midshaft of the metatarsals. Images should be acquired in three planes and with slices thin enough and resolution fine enough to be able to demonstrate the ligaments of the TMT joints.

Morton's neuroma is a reactive perineural fibrosis involving the interdigital nerve that occurs most commonly at the second or third interspace between the metatarsal heads. This neuropathy is caused most frequently by shoes with a toebox that is too snug or shoes with high heels. Over time, the nerve is traumatized, resulting in a chronically painful condition that can be easily diagnosed using MRI. Coronal (horizontal long axis) and axial (short axis) images along with a sagittal series for angulation of the axials is necessary. The use of contrast is key in this setting in order to demonstrate nerve inflammation.

The heel of the foot bears a significant portion of the body's weight and is subject to an enormous amount of stress forces during the course of walking, running, and jumping. Inflammation of the fascia between the calcaneus and fat pad of the heel can result in a painful condition referred to as *plantar fasciitis*. This term is used in a broad sense and can include abnormalities ranging from simple inflammation to thickening to frank disruption of the fascia. MRI can very elegantly demonstrate this abnormality, although ultrasonography and 3-phase radionuclide bone scans have also demonstrated a capability to diagnose plantar fasciitis.

Hallux valgus deformity is a common degenerative deformity involving the great toe (hallux) and the first metatarsophalangeal joint. The abnormality usually begins as a result of deviation of the great toe laterally or in a valgus deviation. As this abnormality progresses, the medial aspect of the first metatarsophalangeal joint protrudes, causing a deformity referred to as a *bunion*. This deformity is most commonly a result of the shape and fit of shoes. It is interesting to note that hallux valgus deformity is rare in people who do not wear shoes.

Each toe is controlled by no less than six sets of muscles. The tendons of the extensor digitorum longus and brevis join on the dorsal surface of the toes and insert at the middle and distal phalanges, respectively. The flexor digitorum longus remains separate from the flexor digitorum brevis. The flexor digitorum longus inserts at the distal phalanx, and the flexor digitorum brevis inserts at the middle phalanx. Smaller muscles called lumbricals and interossei attach at the proximal phalanx. *Claw toe* and *hammer toe* abnormalities occur when the flexor and extensor muscles exert excessive control over the smaller muscles in the case of chronic pronation or fallen arch. Claw toe occurs when the flexor digitorum brevis muscle contracts first and the other muscles do not exert enough counterforce to overcome it. This results in the middle phalanx being pulled down, which causes the proximal interphalangeal joint to arch upward. Hammer toe is caused when the flexor digitorum longus is the first to contract, causing the proximal phalanx to be pulled, which results in the proximal and distal interphalangeal joints being pulled toward the plantar surface of the foot. Early symptoms of claw toe and hammer toe can often be treated with *orthotics*. As the deformity becomes more chronic, rigidity can result as adhesions form; surgical intervention is then generally required. The diagnosis of claw toe or hammer toe is generally made clinically; imaging is rarely required unless specific confirmation of involvement of the joint capsule itself is necessary.

Scan techniques for the foot. Scanning the foot using MRI can be a challenge for the technologist in many respects. The complexity of the anatomy contributes to this challenge as well as the fact that the familiar imaging planes take on confusing new meanings with respect to the axes of the foot. An axial scan of the ankle if continued distally yields images that would be considered coronal to the foot. For this reason, we have adopted terms that avoid the confusing ambiguity of conventional coronal and axial planes. When we desire scans that are axial to the metatarsals (which most scanners interpret as coronal), we call them *short axis scans*. Scans oriented along the long axis of the metatarsals can either be in the sagittal or global coronal plane. The sagittal plane is usually not a source of confusion, so we refer to it as simply *sagittal*. However, the angulation of this plane does vary, depending on the region of the foot under examination. For the hindfoot, the sagittal plane is aligned with the anteroposterior long axis of the calcaneus. For the mid-and forefoot, the sagittal plane is aligned along the long axis of the metatarsals. For the coronal orientation, we have chosen the term *horizontal long axis*, which is often shortened to *long axis*.

The specific angulation of the short and long axis planes are another source of contention. Our routine has been to align these axes differently, depending on what region of the foot is being examined—hindfoot, midfoot, or forefoot. For the purpose of evaluating the hindfoot and tarsals, a short axis scan is aligned perpendicular to the plantar surface of the heel of the foot. In examinations wherein the midfoot or forefoot is the primary area of interest, the short axis plane is aligned perpendicular to the long axis of the metatarsals. Similarly, the horizontal long axis scans of the mid- and forefoot are aligned parallel to the long axis of the metatarsals. Additionally, a secondary angle is employed so that the plane is also aligned along the plane that intersects the second through fifth metatarsals as viewed on a short axis image. This multi-angle oblique alignment necessitates that two separate images are used for setting up this scan; in this respect, we have found the three-plane localizer scans to be very helpful in this respect. Long axis plane angulation for the hindfoot is typically parallel to the plantar surface of the heel of the foot. The actual position of the foot at the time of scanning is often dependent on the type of coil used. In our practice, it is routine to use a knee/foot coil that is a cylindrical volume coil with an area on the top surface of the coil designed to accommodate the foot in a neutral to semi-dorsiflexed position with the toes pointing upward. In some instances, patients with particularly large feet may be too large for this coil to effectively image the distal phalanges. In this case and when the toes themselves are the area of interest, we place the foot plantar-flexed with the toes inserted into the coil's imaging volume. If very fine detail of the toe anatomy is required (interphalangeal joint ligaments), a surface coil may be used with the understanding that the area imaged will be limited to usually no more than 120 mm[2].

ROUTINE FOOT SCAN TECHNIQUES

* *3-plane localizer*

- Gradient echo: Scan time < 60 sec
- 5–7 slices per plane
- 260 mm FOV
- 8.0-mm skip 2.0 mm
- Matrix 256 F x 128 P
- Sagittal T1-weighted SE
- Angled appropriately to the portion of the foot under examination
- 160 mm FOV
- 4-mm skip 1 mm
- Matrix 256F x 192P with 512 interpolation
- RBw 16-20 kHz
- Phase axis AP
- 100% phase oversampling

* *Long Axis FSE STIR (TE50/TI 125 for 1.5T, TI 90 for 0.7T)*

- Angled appropriately to the portion of the foot under examination
- 160 mm FOV
- 4-mm skip 1 mm
- Matrix 256F x 192P with 512 interpolation
- RBw 20-32 kHz
- Phase axis RL
- Partial phase FOV may be used if anatomy is adequately accommodated
- Spatial presaturation bands superior to the slice volume are recommended

* *Axial (Short Axis) FSE STIR (TE50/TI 125 for 1.5T, TI 90 for 0.7T)*

- Angled appropriately to the portion of the foot under examination
- 120-140 mm FOV
- 5-mm skip 1 mm
- Matrix 256F x 192P with 512 interpolation
- RBw 20-32 kHz
- Phase axis SI
- Partial phase FOV may be used if anatomy is adequately accommodated
- For the hindfoot, 100% phase oversampling is recommended

* *Axial (Short Axis) SE T1*

- Angled appropriately to the portion of the foot under examination
- 120-140 mm FOV
- 5-mm skip 1 mm
- Matrix 256F x 192P with 512 interpolation
- RBw 16-20 kHz
- Phase axis SI

- Partial phase FOV may be used if anatomy is adequately accommodated
- For the hindfoot, 100% phase oversampling is recommended

* *Axial (Short Axis) FSE T2*

- Angled appropriately to the portion of the foot under examination
- 120-140 mm FOV
- 5-mm skip 1 mm
- Matrix 256F x 192P with 512 interpolation
- RBw 20-32 kHz
- Phase axis SI
- Partial phase FOV may be used if anatomy is adequately accommodated
- For the hindfoot, 100% phase oversampling is recommended

Morton's neuroma

3 plane localizer
Gradient echo: Scan time < 60 sec
5–7 slices per plane
260 mm FOV
6.0 mm skip 1.0 mm
Matrix 256F x 128P

* *Axial (Short Axis) SE T1*

- Angled appropriately to the portion of the foot under examination
- 120 mm FOV
- 3-mm skip 0 mm
- Matrix 256F x 192P with 512 interpolation
- RBw 16-20 kHz
- Phase axis SI
- Partial phase FOV may be used if anatomy is adequately accommodated

* *Axial (Short Axis) FSE T2*

- Angled appropriately to the portion of the foot under examination
- 120 mm FOV
- 3-mm skip 0 mm
- Matrix 256F x 192P
- RBw 20-32 kHz
- Phase axis SI
- Partial phase FOV may be used if anatomy is adequately accommodated

* *Axial (Short Axis) FSE STIR (TE50/TI 125 for 1.5T, TI 90 for 0.7T)*

- Angled appropriately to the portion of the foot under examination
- 120 mm FOV
- 3-mm skip 0 mm
- Matrix 256F x 192P
- RBw 20-32 kHz
- Phase axis SI
- Partial phase FOV may be used if anatomy is adequately accommodated

* *Axial (Short Axis) SE or FSE T1 with spectral fat suppression PRE GAD*

- Angled appropriately to the portion of the foot under examination
- 120 mm FOV
- 3-mm skip 0 mm
- Matrix 256F x 192P
- RBw 16-20 kHz
- Phase axis SI
- Partial phase FOV may be used if anatomy is adequately accommodated

* *Axial (Short Axis) SE or FSE T1 with spectral fat suppression POST GAD*

- Angled appropriately to the portion of the foot under examination
- 120 mm FOV
- 3-mm skip 0 mm
- Matrix 256F x 192P
- RBw 16-20 kHz
- Phase axis SI
- Partial phase FOV may be used if anatomy is adequately accommodated

* *Coronal (Long Axis) SE or FSE T1 with spectral fat suppression POST GAD*

- Angled appropriately to the portion of the foot under examination
- 120mm FOV
- 3-mm skip 0 mm
- Matrix 256F x 192P
- RBw 16-20 kHz

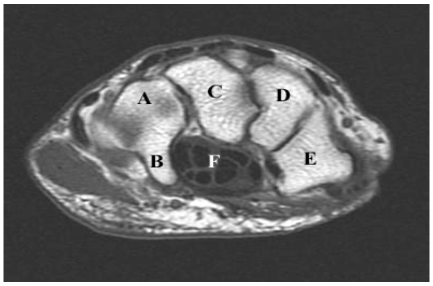

FIGURE 7. T1–weighted axial of wrist through distal carpals. A–hamate, B–hook of hamate, C–capitate, D–trapezoid, E–trapezium, F–flexor tendons in carpal tunnel

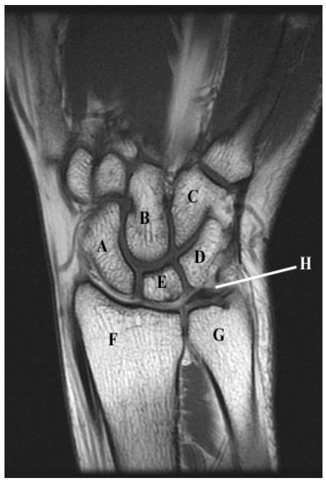

FIGURE 8. T1–weighted coronal wrist. A–scaphoid, B–capitate, C–hamate, D–triquetrum, E–lunate, F–radius, G–ulna, H–triangular fibrocartilage (TFC)

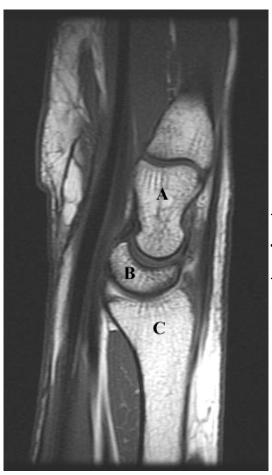

FIGURE 9. T1–weighted sagittal wrist. A–capitate, B–lunate, C–radius

- Phase axis RL
- Partial phase FOV may be used if anatomy is adequately accommodated

Osteomyelitis
3-plane localizer
Gradient echo: Scan time < 60 sec
5–7 slices per plane
260 mm FOV
6.0-mm skip 1.0 mm
Matrix 256F x 128P

* *Coronal (Long Axis) FSE STIR (TE50/TI 125 for 1.5T, TI 90 for 0.7T)*
- Angled appropriately to the portion of the foot under examination
- 160 mm FOV
- 4 mm skip 1 mm
- Matrix 256F x 192P
- RBw 20-32 kHz
- Phase axis RL
- Partial phase FOV may be used if anatomy is adequately accommodated
- Spatial presaturation band superior to the slice volume is recommended.

* *Coronal (Long Axis) SE or FSE T1*
- Angled appropriately to the portion of the foot under examination
- 160 mm FOV
- 4 mm skip 1 mm
- Matrix 256F x 192P
- RBw 16-20 kHz
- Phase axis RL
- Partial phase FOV may be used if anatomy is adequately accommodated

* *Sagittal FSE STIR (TE50/TI 125 for 1.5T, TI 90 for 0.7T)*
- Angled appropriately to the portion of the foot under examination
- 160 mm FOV
- 4-5 mm skip 1 mm
- Matrix 256F x 192P with 512 interpolation
- RBw 20-32 kHz
- Phase axis AP
- 100% phase oversampling

* *Axial (Short Axis) FSE STIR (TE50/TI 125 for 1.5T, TI 90 for 0.7T)*
- Angled appropriately to the portion of the foot under examination
- 140-160 mm FOV
- 3-mm skip 0 mm
- Matrix 256F x 192P

- RBw 20-32 kHz
- Phase axis SI
- Partial phase FOV may be used if anatomy is adequately accommodated

* *Axial (Short Axis) SE or FSE T1 with spectral fat suppression PRE GAD*

- Angled appropriately to the portion of the foot under examination
- 140-160 mm FOV
- 4-5 mm skip 1 mm
- Matrix 256F x 192P
- RBw 16-20 kHz
- Phase axis SI
- Partial phase FOV may be used if anatomy is adequately accommodated

* *Axial (Short Axis) SE or FSE T1 with spectral fat suppression POST GAD*

- Angled appropriately to the portion of the foot under examination
- 140-160 mm FOV
- 4-5 mm skip 1 mm
- Matrix 256F x 192P
- RBw 16-20 kHz
- Phase axis SI
- Partial phase FOV may be used if anatomy is adequately accommodated

* *Coronal (Long Axis) SE or FSE T1 with spectral fat suppression POST GAD*

- Angled appropriately to the portion of the foot under examination
- 140-160 mm FOV
- 4-mm skip 1 mm
- Matrix 256F x 192P
- RBw 16-20 kHz
- Phase axis RL
- Partial phase FOV may be used if anatomy is adequately accommodated

* *Optional sagittal T1 (SE or FSE) T1 with spectral fat suppression POST GAD*

- Angled appropriately to the portion of the foot under examination

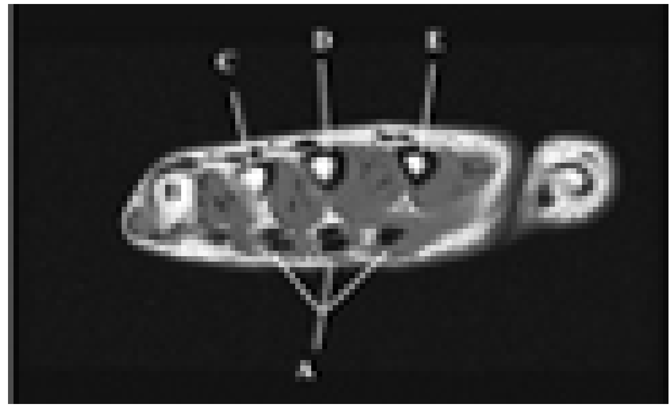

FIGURE 10. T1–weighted axial through hand at mid metacarpals. A–flexor digitorum tendons, B–head of 5th metacarpal, C–4th metacarpal, D–3rd metacarpal, E–2nd metacarpal

FIGURE 11. T1–weighted coronal of hand. A–muscles of thenar compartment, B–muscles of hypothenar compartment

FIGURE 12. T1– weighted sagittal hand through index finger. A–flexor digitorum indicis tendon, B–distal phalanx, C–middle phalanx, D–proximal phalanx, E–2nd metacarpal

- 140-160 mm FOV
- 5-mm skip 1 mm
- Matrix 256F x 192P
- RBw 16-20 kHz
- Phase axis AP
- 100% phase oversampling

WRIST (FIGURES 7-9)

To say that the wrist is a complex structure is indeed an understatement. There are eight carpal bones that compose the wrist: the proximal row being (medial to lateral) the *pisiform*, the *triquetrum* , the *lunate*, and the *scaphoid* (or navicular); the distal row being the *trapezium* (or greater multangular), the *trapezoid* (or lesser multangular), the *capitate*, and the *hamate*. There are two primary sets of ligaments: the *extrinsic ligaments*, which connect the radius and ulna to the carpals, and the *intrinsic ligaments,* which form intercarpal connections.

As its name suggests, the triangular fibrocartilage complex (TFC or TFCC) is a fibrous cartilaginous structure roughly triangular in shape that functions to provide support to the distal radioulnar joint. TFC tears are common injuries to the wrist and are frequently the result of a "fall on outstretched hand". The *scapholunate ligament* (SLL) and *lunotriquetral ligament* (LTL) are two other significant cartilaginous structures within the wrist. The SLL and LTL are part of the group of ligaments that maintain the intercarpal joints referred to as intrinsic ligaments. Tears of the SLL and/or LTL can result in a condition termed *carpal instability.* SLL tears are more common and have a more significant associated morbidity. The role of MRI in imaging the wrist is integral. A high-resolution MRI examination of the wrist can allow a thorough evaluation of the carpal bones, intrinsic and extrinsic ligaments, and cartilaginous structures.

Wrist abnormalities. As previously mentioned, the bones of the wrist consist of the eight carpal bones. But the wrist joint itself is a complex series of articulations that includes the intercarpal articulations, the radio- and ulnocarpal articulations, and the carpometacarpal articulations. Wrist injuries are frequent, because the hand is used almost constantly and the wide variety of normal and abnormal movements the hand and wrist are subjected to can result in numerous types of traumatic and chronic or repetitive motion injuries. *Carpal tunnel syndrome* is a common type of traumatic syndrome that can be the result of overuse or repetitive motion injury (RMI) often due to the use of computer keyboards and mouse devices. As with tarsal tunnel syndrome, carpal tunnel syndrome is caused by compression of a nerve—in this case, the median nerve as it passes through the carpal tunnel. Symptoms include dull pain and tingling within the fingers in the distribution of the median nerve. In addition to the more well-known carpal tunnel syndrome, compression of the ulnar nerve is also common. The ulnar nerve passes through Guyon's canal, medial to the carpal tunnel proper. This compression manifests as paresthesias in the distribution of the ulnar nerve, which is anatomically distinct from that of the median nerve. Whereas RMI is most commonly implicated as the cause of carpal tunnel syndrome, the most frequent etiology of ulnar nerve compression is ganglion cysts.

The most common mechanisms of injury to the wrist are a result of hyperflexion, hyperextension, impact, or deviation (abnormal abduction/adduction) under force. Twisting or torquing injuries can also occur as a result of using certain types of equipment or tools such as power drills and nut drivers. Most soft-tissue injuries of the wrist are a result of abnormal motion or movement in excess of the normal range of motion under force. Fractures of the carpal bones are fairly common as well—particularly in osteopenic or osteoporotic patients—and are most commonly the result of a fall and impact injury.

ROUTINE WRIST SCAN TECHNIQUES

* *3 plane localizer*
  - Gradient echo: Scan time < 60 sec
  - 5–7 slices per plane
  - 220 mm FOV
  - 6.0-mm skip 2.0 mm
  - Matrix 256 F x 128P
* *Axial FSE T2 (TE = 70) with spectral fat suppression*
  - 110 mm FOV
  - 4-mm skip 0.4 mm
  - Matrix 256F x 224P with 512 interpolation
  - RBw 20-32 kHz
  - Phase axis SI
  - Spatial presaturation bands superior and inferior to the slice volume are recommended
* *Axial FSE PD (TE = 26)*
  - 110 mm FOV
  - 4-mm skip 0.4 mm
  - Matrix 256F x 224P with 512 interpolation
  - RBw 20-32 kHz
  - Phase axis SI
* *Coronal SE T1 (TE = 17)*
  - 120 mm FOV

- 3-mm skip 0 mm
- Matrix 384F x 256P with 512 interpolation
- RBw 16-20 kHz
- Phase axis RL

* *Coronal FSE T2 (TE = 70) with spectral fat suppression*

- 120 mm FOV
- 3-mm skip 0 mm
- Matrix 256 x F256P with 512 interpolation
- RBw 20-32 kHz
- Phase axis RL

* *Sagittal SE T1 (TE = 17)*

- 120 mm FOV
- 3.5-mm skip 0.4 mm
- Matrix 384F x 256P with 512 interpolation
- RBw 16-20 kHz
- Phase axis AP

* *Coronal 2-D Conventional Gradient Echo (Grass or FISP) (TE = 20)*

- Flip Angle = 15 degrees
- 120 mm FOV
- 2-mm skip 0 mm
- Matrix 256F x 224P with 512 interpolation
- RBw 10.4 kHz

HAND (FIGURES 10-12)

The complexity of the hand is similar to that of the foot. Because humans are bipedal, the hand no longer has to bear body weight under normal circumstances and thus has evolved to be an extremely versatile and dexterous appendage. The hand as a whole is often considered to include the carpal bones, but for the purpose of this article we will discuss the hand as including only the metacarpals and phalanges. There are 5 metacarpals and 14 phalanges; the thumb is the only digit to have just two phalanges. Unlike the hallux (or great toe) of the foot, the thumb differs because its range of motion allows it to be opposed against the other digits of the hand—hence the term *opposable digit*. This opposability allows for significant precision in movement and is responsible for the motion of gripping.

The movement of the hand is controlled by two sets of muscles: *extrinsic* and *intrinsic*. Extrinsic muscles are located proximal to the wrist and control general movements such as flexion and extension of the wrist/hand unit and individual digits as well as some abduction movement. Extrinsic muscles fall into the category of *flexors*, *extensors*, and *abductors*. Some muscles are involved in several movements and therefore fall into multiple categories. The flexor muscles include the palmaris longus, flexor carpi radialis, flexor carpi ulnaris, flexor digitorum profundus and superficialis, and flexor pollicis longus. The extensor group is comprised of the extensor carpi radialis brevis and longus, extensor carpi ulnaris, extensor digitorum, extensor digiti minimi, extensor indicis, and extensor pollicis brevis and longus. Abduction of the thumb is accomplished by the abductor pollicis longus, whereas abduction of the hand is the action of the flexor carpi radialis and extensor carpi radialis brevis and longus.

The intrinsic muscles of the hand are located distal to the wrist and are responsible for finer movements of the fingers. The *opponens pollicis* and *opponens digiti minimi* act on the thumb and fifth digit, respectively, and are responsible for the movements that allow the opposition of the thumb against the fifth digit. The abductor pollicis brevis and abductor digiti minimi also act on the thumb and fifth digit, respectively, for abduction. The abductor pollicis brevis also assists in opposing the thumb. The flexor pollicis brevis acts to flex the thumb, and the flexor digiti minimi brevis acts to flex the proximal phalanx of the fifth digit. Other intrinsic muscles include the lumbricals and interossei muscles of the hand. The geography of the palmar surface hand is also referred to in terms of compartments. The *thenar* compartment contains the flexor pollicis brevis, opponens pollicis, and abductor pollicis brevis muscles. The *hypothenar* compartment contains the opponens digiti minimi flexor digiti minimi, and abductor digiti minimi muscles.

Hand abnormalities. Injuries to the hand and digits are very common and can have a variety of presentations and causes. Fractures of the metacarpals and phalanges are frequently seen as a result of impact or crush injuries. A *boxer's fracture* is a fracture of the distal metacarpal with palmar deviation of the fracture fragment. This aptly named injury is often the result of striking an unyielding object or surface with a closed fist. Injuries to the ligaments and tendons of the hand and fingers can result from hyperextension or hyperflexion of the digits and can be accompanied by *cortical avulsion fractures*. Abduction of the thumb under force can result in a disruption of the *ulnar collateral ligament* on the medial side of the thumb at the metacarpophalangeal joint. This type of injury is often referred to as a *gamekeeper's thumb*. Tendon and ligament tears in the hand and fingers also occur. It is worthwhile to note that a *hyperextension injury* can result in a strain or disruption of the flexor tendons, whereas conversely, a *hyperflexion injury*, although less likely to occur, can result in a strain or tear of the extensor tendons. Ligaments can also be injured by forced deviation of the digits as well as distraction such as pulling on the fingers to crack the knuckles.

Scan techniques for the hand. In our practice, MRI of the hand is not a routine examination; therefore when this study is requested, it is done in consultation with the musculoskeletal radiologist who in turn decides on the imaging protocol based on the specific reasons for the examination. These reasons can include—but are not limited to—occult fracture, ligamentous or myotendinous injury, soft-tissue mass, or cellulitis. Soft-tissue masses and cellulitis or osteomyelitis are imaged well with the use of gadolinium contrast agents that aid in differentiating neovascularity from normal vessels and inflammation from edema.

SUMMARY

Although musculoskeletal imaging can be accomplished with a number of different modalities, it is unequivocally one of the core competencies of MRI. This is due to the flexibility of imaging planes and sequences as well as the high spatial detail possible. MRI excels at depicting any processes—whether traumatic, neoplastic, or metabolic—that affect the bones or soft tissues of the body. In addition to the role MRI plays in imaging the joints, it is also highly sensitive to injuries and processes involving the bones and muscles of the extremities themselves. This sensitivity can be further enhanced with the use of gadolinium contrast agents.

MUSCULOSKELETAL MRI PART I: THE ANKLE, FOOT, WRIST AND HAND POST TEST

Expires: May 15, 2013 Approved for 1 ARRT Category A Credit.

1. **What type of joint is the ankle?**
   a. Ball and socket
   b. Gliding
   c. Hinge
   d. Polyaxial
2. **The deltoid ligament provides support to the**
   a. medial aspect of the ankle.
   b. lateral aspect of the ankle.
   c. posterior aspect of the ankle.
   d. anterior aspect of the ankle.
3. **The distal portion of the triceps surae tendon is commonly known as the**
   a. tendon of Zinn.
   b. tendon of Lockwood.
   c. palmaris tendon.
   d. Achilles tendon.
4. **The os trigonum is a (an)**
   a. tendon in the foot.
   b. accessory bone present in less than 15% of people who have normal feet.
   c. type of fracture of the calcaneus.
   d. benign tumor of the foot.
5. **The majority of ankle sprains are due to**
   a. blunt trauma.
   b. underlying bone abnormalities.
   c. eversion injuries.
   d. inversion injuries.
6. **Lateral ligament tears of the ankle most often occur in what sequence?**
   a. ATFL, CFL, PTFL
   b. CFL, PTFL (with the ATFL seldom affected)
   c. PTFL, CFL, ATFL
   d. Achilles, deltoid, peroneus brevis
7. **Why is it recommended that when scanning the ankle, axial images be done first?**
   a. In most cases, axial images are all that is required when scanning the ankle.
   b. This measure allows for proper angulation of the sagittal and coronal images.
   c. This measure makes best use of the intravenous contrast agent.
   d. This measure speeds the scanning process.
8. **How many bones make up the foot?**
   a. 15
   b. 22
   c. 26
   d. 29

9. **Where are the two sesamoid bones of the foot located?**
   a. The plantar aspect of the head of the first metatarsal
   b. The dorsal aspect of the head of the third metatarsal
   c. The dorsal aspect of the fourth phalange
   d. Within the joint space of the tarsal and metatarsal bones
10. **The flexor muscles, extensor muscles, and muscles of inversion and eversion of the foot are considered to be**
    a. geographic groups of muscles.
    b. functional groups of muscles.
    c. intrinsic muscles.
    d. extrinsic muscles.
11. **Which of the following muscles extend the ankle and plantarflex the foot?**
    a. Tibialis anterior, peroneus tertius
    b. Popliteus, biceps, semimembranosus
    c. Pyriformis, gemellus superior, gemellus inferior, obturator internus
    d. Gastrocnemius, soleus, plantaris, tibialis posterior, peroneus longus
12. **Which of the following is correct concerning the number of bones in the foot?**
    a. 5 tarsals, 7 metatarsals, 12 phalanges
    b. 7 tarsals, 5 metatarsals, 14 phalanges
    c. 6 tarsals, 5 metatarsals, 10 phalanges
    d. 8 tarsals, 10 metatarsals, 15 phalanges
13. **Sinus tarsi is another name for**
    a. tarsal tunnel syndrome.
    b. the distal aspect of the tibial nerve.
    c. the tarsal canal.
    d. a condition wherein two adjacent bony surfaces of the foot are fused.
14. **The term Lisfranc joint is used to describe the**
    a. fusion of the talocalcaneal and calcaneonavicular joints.
    b. structures that lie within the tarsal tunnel.
    c. articulation between the first and second cuneiforms and the first and the second metatarsals.
    d. relationship between the tendons, ligaments, and vessels of the foot.
15. **Inflammation of the fascia between the calcaneus and the fat pad of the heel is known as**
    a. catarrhal inflammation.
    b. interstitial inflammation.
    c. planta pedis.
    d. plantar fasciitis.
16. **Which of the following is a common degeneritive deformity involving the great toe and the first metatarsophalangeal joint?**
    a. Morton's neuroma
    b. Hallux valgus
    c. Tarsal coalition
    d. Plantar fasciitis
17. **Carpal instability can result from**
    a. tears of the SLL and/or the LTL.
    b. TFC tears.
    c. benign tumors.
    d. osteoporosis.
18. **Carpal tunnel syndrome is caused by compression of the**
    a. ulnar nerve.
    b. SLL.
    c. median nerve.
    d. LTL.
19. **The extrinsic muscles of the hand**
    a. are located distal to the wrist.
    b. are located proximal to the wrist.
    c. are responsible for finer movement of the fingers.
    d. include the opponens pollicis and the opponens digiti minimi.
20. **A fracture of the distal metacarpal with palmar deviation of the fracture fragment is known as a**
    a. greenstick fracture.
    b. gamekeeper's thumb.
    c. punch fracture.
    d. boxer's fracture.

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