"Digital" MRI: The Finger and Toes

James P. Earls

INTRODUCTION

Consistent high quality MR imaging of the fingers and toes present a challenge for even the newest of high performance MR technologies. Consistent delineation of fine anatomic detail is accomplished utilizing small fields of view, high performance high field strength MRI systems and dedicated quadrature coils. Referrals from hand surgeons and foot surgeons for MR imaging of the fingers and toes are predicated on excellent depiction of anatomic structures in normal and pathologic states surpassing the image quality demonstrable on early MR units and on current low-field strength MR systems.

TECHNIQUE

It is the opinion of this author, who has experience with both high field and low field MR systems, that higher field strength units have a distinct advantage over lower field strength systems, assuming all other technical factors are equal. In practice, other factors, such as utilization of appropriate surface coils as well as the level of experience and supervision of the radiologist overseeing the study may well offset the intrinsic advantage of high field strength MR systems. The MR imaging protocols presented in this section are applicable only to high field strength MR systems (1.5 Tesla). In general, the presented protocols also require high performance gradient amplifiers and gradient coils that permit the rapid acquisition of images with smaller fields of view and thinner slice thicknesses routinely. This permits the visualization of smaller anatomic structures, which is a requirement for imaging the fingers and toes reliably. An appropriate RF coil is especially critical for consistently good image quality when imaging the fingers and toes.

The author utilizes a dedicated quadrature wrist coil for imaging the fingers and toes. Patient positioning when utilizing this coil is very important. For imaging the fingers, the patient is placed in the ipsilateral decubitus position with pillows placed between the knees to ensure patient comfort. The coil is placed near the isocenter of the bore of the magnet above the patient´s head so that aliasing artifact is not an issue. The ipsilateral fingers are then placed within the coil above the patient´s head. The author´s experience suggests that this position is far more comfortable than the "superman" position. Image quality, in particular, the homogeneity of fat suppression, is also superior when compared to off center field of view imaging done if the fingers are imaged with the arm at the patient´s side. Similarly, patient positioning when imaging the toes is also critical. The patient is placed in a supine position with the knees flexed until the sole of the foot can rest comfortably on the MR table. Pillows are built up behind the knees to support the knees in this position. The toes are then placed within the dedicated quadrature wrist coil which is again positioned near the isocenter of the magnet ensuring good signal-to-noise ratio and homogeneous fat suppression. Pulse sequences are selected from the list included in Table 1 based upon the patient's clinical history and the clinical question that the MR imaging study seeks to answer.

Intravenous gadolinium is generally reserved for the following possible clinical diagnoses: osteomyelitis, septic arthritis, synovitis, tenosynovitis, soft tissue abscess, inflammatory arthritis, non-radiopaque foreign body, osseous neoplasm, soft tissue neoplasm and Morton´s neuroma.

ANATOMY

The thumb MCP joint is a diarthrodial ginglymoid joint. The remaining metacarpophalangeal joints of the fingers are ellipsoid joints. All of the metacarpophalangeal joints are covered by a palmar (volar) plate composed of fibrocartilage, collateral ligaments and deep transverse metacarpal ligaments. The interphalangeal joints are hinge joints with capsules and obliquely oriented collateral ligaments. A volar plate is also present at the level of the interphalangeal joints.

The ulnar collateral ligament (UCL) of the thumb deserves special attention. The UCL originates from the metacarpal head passing obliquely from a proximal-dorsal to distal-palmar direction to insert on the lateral tubercle of the proximal phalanx of the thumb. The UCL is 4-8 mm in width with an average length of 12-14mm. The accessory collateral ligament originates superficially and in a palmar fashion to the UCL proper and blends distally with the palmar plate. The adductor pollicis has three insertions, one of which is confluent with the dorsal expansion hood and is superficial to the UCL. This is referred to as the adductor aponeurosis. This aponeurosis becomes continuous distally with the extensor pollicis longus (EPL) tendon. The complex anatomy of the muscles and tendons about the fingers are readily identifiable on high resolution MR imaging. The flexor tendon apparatus includes the flexor digitorum profundus (FDP) and the flexor digitorum superficialis (FDS). The flexor digitorum profundus inserts at the volar base of the distal phalanx. The flexor digitorum superficialis has a characteristic course, being superficial to the FDP at the level of the MCP joint and the splitting into two leaves, which encircle the FDP and then insert at the sides of the middle phalanx. The fibro-osseous tunnel is a closely applied, semi-rigid tunnel through which the flexor tendons pass. Classically, the fibrous portion of the fibro-osseous tunnel is considered to be composed of (1) five annular pulleys-dense condensations of transversely oriented fibrous bands, (2) three cruciate pulleys and (3) a floor that is the palmar periosteal surface of the phalanges and the joint palmar plates. The most important annular pulleys are the A2 pulley and the A4 pulley. The A2 pulley attaches firmly to the proximal half of the proximal phalanx and is a critical pulley for maintaining maximal finger flexion. The A4 pulley attaches to the middle third of the middle phalanx and is considered a critical pulley for maximal finger flexion.

The extensor mechanism is frequently referred to as the digital extensor hood mechanism. The digital extensor hood includes the extrinsic long digital extensor (extensor digitorum communis) tendon, the extensor hood proper and insertions of the lumbricals, the dorsal and palmar interossei muscles. On the dorsal aspect of the fingers, the extensor digitorum tendons insert into the base of the middle and distal phalanges, forming the extensor expansion. In the index and small fingers they are accompanied by the extensor indices and digiti minimi, respectively.

In addition, there are four lumbrical muscles that arise from the tendon of the flexor digitorum profundus and insert onto the radial aspect of the extensor expansion. The interosseous muscles (three palmar adductors, and four dorsal abductors) arise from the metacarpal bones and insert onto the bases of the proximal phalanges.

Analogous anatomical relationships are present in the toes. The plantar ligament is a dense band crossing each metatarsophalangeal joint and serves as a weight-bearing surface because the ball of the foot supports the metatarsophalangeal

Table 1: Pulse Sequences for MR Imaging of the Finger and Toe

PLANE	WTD	SEQ	TR	TE	ETL	FOV	THCK	MATRIX	NEX
Sag	T1	SE	400	10		10 cm	2.5 mm	192X256	3
Sag	T2	FSE FS	2500	36	8	10 cm	2.5 mm	192x256	4
Ax	T1	SE	480	10		10 cm	3.0 mm	192x256	3
Ax	T2	FSE FS	2500	36	8	10 cm	3.0 mm	192x256	4
Cor	T1	SE	400	10		10 cm	3.0 mm	192x256	3
Cor	T2	FSE FS	2500	36	8	10 cm	2.5 mm	192x256	3
POST GADOLINUM									
Sag	T1	SE-FS	500	14		10 cm	2.5 mm	192x256	2
Ax	T1	SE-FS	420	14		10 cm	3.0 mm	192x256	2
Cor	T1	SE-FS	500	14		10 cm	3.0 mm	192x256	2

joints. The plantar ligaments are interconnected by the deep transverse ligament. The hallux lacks a true plantar ligament, although the inter-connecting ligaments extending between sesamoid bones, first metatarsus and proximal phalanx function as the continuation of the plantar ligament medially. Strong collateral ligaments connect the medial and lateral aspects of the metatarsal bones and the corresponding portion of the phalanges.

The interphalangeal joints of the toes are also supported by collateral ligaments as well as by the tendons of the extensor digitorum longus and brevis, the tendon of the extensor hallucis dorsally and the tendons of flexor digitorum longus and brevis and of the flexor hallucis longus plantarly. Digital fibrous sheaths analogous to those in the fingers begin at the heads of the metatarsal bones in the toes and extend to the bases of the distal phalanges, enclosing the flexor and extensor tendons and the joint capsules.

OSSEOUS PATHOLOGY

One of the most common indications for MR imaging of a digit is the patient clinically diagnosed with cellulitis with or without an associated soft tissue ulcer to evaluate for concomitant osteomyelitis. The negative predictive value of MR imaging in this setting is extremely high with normal marrow signal intensity excluding the diagnosis of osteomyelitis with a high degree of certainty. Enhancing marrow edema with contiguous periosteal edema and enhancing soft tissue edema is strongly suggestive of osteomyelitis involving a digit. Intravenous gadolinium is routinely utilized in this setting. This helps in establishing whether or not there is associated septic synovitis, septic arthritis, septic tenosynovitis or a drainable rim-enhancing soft tissue abscess. Other common clinical presentations that may be associated with osteomyelitis include animal bites involving the digits, puncture wounds, foreign bodies or paronychia.

Radiographically occult osseous trauma including bone contusions, cortical fractures and the spectrum of stress reaction through stress fractures are also well documented with MR imaging. Stress injuries, in particular, are frequently associated with extensive marrow edema and inflammatory-appearing edema in the adjacent soft tissues. Fractures that involve a torsional or compressive mechanism of injury also manifest extensive marrow edema and are readily identifiable on MR imaging. Caution should be exercised regarding the diagnosis of tiny avulsion fractures with MR imaging. These traction or tensile mechanism of injury avulsion fractures may not be associated with significant marrow edema and can be difficult to diagnose with MR imaging as a result. Careful correlation with conventional radiographs is necessary to avoid this pitfall.

Osseous neoplastic disease involving the digits is relatively unusual. Enchondroma is the most common benign bone tumor involving the digits. The cartilage matrix has intermediate signal intensity on T1-weighted and intermediate-weighted images and high signal intensity on T2-weighted images due to the intralesional cartilage. Low signal intensity calcifications and high signal intensity cartilage can give it a so-called strawberry appearance. Other benign bone tumors involving the digits include bone islands, osteoid osteomas and osteochondromas. The most common malignant tumor involving the digits is metastatic disease. Lung carcinoma and breast carcinoma are among the most common primary neoplasms to metastasize to the digits.

Disorders of the hallux sesamoid complex are relatively common and warrant discussion. Numerous painful conditions can affect the first metatarsophalangeal-sesamoid joint complex. The symptoms can either be sudden or insidious in onset and can be either acute or chronic in duration. Conventional radiography remains the initial diagnostic imaging procedure of choice. There is frequently a need to proceed to MR imaging in these cases in order to differentiate soft tissue from osseous pathology. Synovitis, tendinitis and bursitis can be reliably distinguished from bony abnormality such as a sesamoid fracture, osteochondritis of the sesamoid, avascular necrosis and osteomyelitis.

NON-INFECTIOUS INFLAMMATORY ARTHRITIS

There is an emerging role for the diagnosis and surveillance of patients being treated for a variety of inflammatory arthritides utilizing gadolinium-enhanced MR imaging. The greatest experience to date has been in the evaluation of patients with rheumatoid arthritis. It has been well shown that the sensitivity of MR imaging is superior to conventional radiography with respect to detection of bone erosions due to rheumatoid arthritis in the wrist and finger joints. MCP joint bone marrow edema is present in the majority of patients with rheumatoid arthritis at presentation but is seen only occasionally in normal controlled patients. This bone marrow edema occurred rarely in the absence of enhancing synovitis in patients with rheumatoid arthritis suggesting that the bony changes in rheumatoid arthritis are secondary to synovitis. MR imaging with intravenous contrast has also been shown to be reliable for diagnosing synovial inflammation due to rheumatoid arthritis. As a result, it can be extremely useful in diagnosing early rheumatoid arthritis. Sugimoto, et. al. demonstrated a sensitivity and negative predictive value of 100%, specificity of 73%

and accuracy of 89% for MR imaging diagnosis of early rheumatoid arthritis. Contrast-enhanced T1-weighted spin echo imaging, preferably with fat suppression, appears to be the most informative pulse sequence in the literature reviewed to date.

Dactylitis of the toes and fingers in patients with seronegative spondyloarthropathy are also amenable to gadolinium-enhanced MR imaging. It has been well shown that enlargement of the joint capsule, synovitis of the MCP, PIP and DIP joints may not be a required condition of the sausage-shaped appearance of the digit. The dactylitis may be due purely to flexor and/or extensor tenosynovitis. Physical examination is usually a sufficient method for the diagnosis of dactylitis but does not completely characterize the underlying pathology.

In summary, there are a growing number of studies that have demonstrated that contrast-enhanced MR imaging is more sensitive and accurate in assessing soft tissue and osseous involvement in inflammatory arthritis than conventional radiography.

LIGAMENT AND TENDON PATHOLOGY

The gamekeeper´s or skier´s thumb is a very common injury. In fact, this is the most common upper extremity injury in skiing and is second only to medial collateral ligament injuries of the knee among skiing related injuries. The essential lesion in skier´s thumb is an acute rupture of the UCL. Stener recognized that the adductor aponeurosis can also become interposed between the damaged ligament and the attachment site on the proximal phalanx. This is referred to as the Stener lesion. The incidence of the Stener lesion ranges from 14-66% of patient´s with skier´s thumb. Stener noted that this anatomic derangement prevented UCL healing. Non-displaced tears typically heal with immobilization whereas displaced tears required surgery. MR imaging has been shown to be both sensitive and specific in distinguishing displaced versus non-displaced acute, Grade III, unstable UCL lesions of the thumb MCP joint. MR imaging, therefore, is a valuable diagnostic tool for evaluating skier´s thumb and allows physicians to determine more accurately the correct course of treatment. Appropriate diagnostic use of MR imaging should decrease the incidence of unnecessary surgical interventions for patients with non-displaced tears.

The flexor tendon pulley system of the fingers is often ruptured when a flexed finger is forcibly extended. This injury is particularly common in elite rock climbers. In the acute phase soft tissue swelling and pain often make clinical evaluation difficult. The individual flexor tendon pulleys are not consistently visualized on MR imaging, however, rupture of significant components of this pulley system can be inferred by observing bowstringing of the underlying flexor tendons. This finding is augmented when MR imaging is obtained with the finger in flexion. Bowstringing usually indicates disruption of the A2 pulley. These patients are amenable to surgical reconstruction of the disrupted pulley. Bowstringing consists of marked volar displacement of the flexor tendon in the area of the torn annular pulley during forced flexion. A distance between tendon and bone at the area of the ruptured pulley of 3 mm during extension and a distance of 5 mm at flexion is typical of a complete disruption of the annular pulley. MR imaging has been demonstrated to be a valuable technique in diagnosing complete disrupted annular pulleys of the flexor tendons and the fingers.

MR imaging has also been demonstrated to be reliable for evaluating flexor and extensor tendon tears in the digits, both pre- and postoperatively. MR imaging findings in patients with extensor hood injuries include irregularity, poor definition, increased signal intensity and abnormal enhancement by structures within and surrounding the extensor hood in the fingers. MR imaging has been shown to be accurate for determination of the presence and severity of injury to the extensor hood. Accurate assessment of flexor tendon function in a digit with an acute non-penetrating injury is very difficult. MR imaging can negative the need for surgical exploration and the associated morbidity. Drape, et. al. assessed the MRI findings in cases of closed rupture of the flexor digitorum tendons. MR imaging accurately depicted the level of rupture and the gap between the torn tendon ends, which assisted the surgical choice between suture, graft or tendon transfer. In the postoperative setting following flexor tendon repair in the hand, MR imaging can enable distinction among several complications that occur after repair of an injured digital flexor tendon. Matloub, et. al. demonstrated only a 60% accuracy for clinical examination in distinguishing a recurrent tendon rupture from adhesions. MR imaging reliably differentiated tendon rupture from adhesions with a 100% accuracy rate in their series.

Degenerative plantar plate failure is an under-recognized cause of metatarsalgia. MR imaging is a non-invasive technique that can demonstrate plantar plate abnormalities aiding in the clinical evaluation of problematic lesser metatarsalgia. T2-weighted sagittal fast spin echo imaging and post gadolinium T1-weigted spin echo images with fat suppression demonstrate focal hyperintensity in the plantar plate consistent with a rupture of the plate.

The pathologic anatomy of turf toe, a common injury among football and rugby players, is not well documented in the radiology literature. MR imaging findings of classic turf toe include a sprain or tear of the plantar metatarsophalangeal joint capsule. Because the most common mechanism of injury is hyperextension of the MTP joint, shoe wear and the hardness of the artificial playing field are thought to be contributory to the problem. The incidence of this soft tissue injury of the great toe has definitely increased with the advent of artificial turf. There may be associated damage to the articular cartilage of the metatarsal heads or the base of the proximal phalanx. One of the clinical hallmarks of the diagnosis is increasing pain at the MTP joint beginning several hours after the initial injury with ecchymoses, swelling and plantar tenderness beneath the metatarsal head. Conventional radiographs are negative. MR imaging can be helpful in confirming the diagnosis and excluding the possibility of an associated radiographically occult fracture or bone contusion.

SOFT TISSUES

MR imaging is useful in the evaluation of a soft tissue mass involving the fingers or toes providing a specific diagnosis in approximately 40% of cases. The most common mass in the soft tissues of the hand or foot is the ganglion cyst. In many cases, these cysts are incidental findings, underscoring the need to correlate these findings with clinical information before drawing conclusions as to their significance. Two subsets of ganglion cysts are worth mentioning in the digits. The flexor tendon sheath or volar retinacular ganglion is a cyst that arises from the flexor tendon sheath and is most often seen at the base of the finger or along the proximal phalanx. These ganglions are often firm, round and measure up to 1 cm in diameter. They are located close to but separate from the flexor tendons and therefore do not follow the movements of the flexor tendons. A second subset of ganglion cysts is the mucous (mucoid) cyst. They most often appear dorsally at the distal interphalangeal joint but can appear on the palmar side. Not uncommonly, they dissect away from the joint in the subcutaneous tissue and skin. Osteoarthritis is often the underlying etiology. On MR imaging, ganglion cysts appear as very high signal intensity single, multiple or multiloculated fluid collections surrounded by a low signal intensity fibrous

capsule on T2-weighted imaging. Rim enhancement may be identified following intravenous gadolinium administration.

Giant cell tumors of the tendon sheath usually originate from a synovial sheath. These lesions can involve the fingers or the toes. On T1-weighted imaging this soft tissue mass is relatively isointense relative to skeletal muscle while on T2-weighted imaging there may be associated low signal intensity components due to associated hemosiderin. The signal intensity characteristics of this lesion are similar to its pathologic counterpart, pigmented villanodular synovitis. The decreased signal intensity component on both T1 and T2-weighted images is uncommon with other extra-articular soft tissue masses in the digits allowing the diagnosis to be suggested. Treatment consists of surgical excision.

Glomus tumors arise from glomus bodies which are located in great numbers in the digital artery walls. Clinically they are typically painful and sensitive to low temperature. They are usually located either subungually or on the palmar surface of the fingertip. Glomus tumors may be as small as a few millimeters and difficult to palpate. They may be visible clinically as a blue spot. Foucher, et. al. demonstrated a sensitivity of MR imaging for the diagnosis of glomus tumors of 86% in a large series. In most cases, the diagnosis can be made on the basis of clinical findings. MR imaging is most helpful in patients with an atypical presentation, or the postoperative patient where there is concern for recurrence. This lesion is generally treated surgically via a lateral approach with nail complex elevation allowing safe excision of the tumor without nail dystrophy.

Morton neuroma is one of the most common diagnoses to account for pain in the metatarsus. The etiology of Morton neuroma remains controversial. One of the more commonly accepted theories is local entrapment of the digital nerve by the transverse intermetatarsal ligament with subsequent perineural fibrosis. The main complaint clinically is localized pain in the region of the metatarsal head which is aggravated by walking and can be relieved by rest. Palpation of the involved intermetatarsal space causes pain that often radiates to the toes. Recent studies have demonstrated that MR imaging has a high sensitivity (87%) and specificity (100%) for demonstration of Morton neuroma. On MR imaging, the typical Morton neuroma is a relatively well-circumscribed round to ovoid soft tissue mass centered along the plantar aspect of the second or third interspace at the level of the metatarsal heads. This mass demonstrates decreased signal intensity compared to the surrounding subcutaneous fat on both T1 and T2-weighted images and generally enhances following intravenous gadolinium administration. Zanetti, et. al. recently published a study demonstrating the effect of MR imaging findings on diagnostic thinking and therapeutic decisions by orthopedic surgeons when a Morton neuroma is suspected clinically. In their study, the diagnosis of Morton neuroma was withdrawn by the orthopedic surgeon after MR imaging in 28% of feet. In more than one-third of the remaining feet, MR imaging demonstrated a change in the location or number of neuromas. This resulted in a large percentage of changed treatment plans (57%). The authors concluded that MR imaging results have a major effect on diagnostic thinking and therapeutic decision in patients suspected of having Morton neuroma. The effect can be explained by the high diagnostic accuracy of MR imaging which facilitates assessment of the exact location and size of the Morton neuroma. In addition, differential diagnoses such as stress fracture, metatarsophalangeal synovitis and intermetatarsal bursitis can be ruled out.

Localization of radiographically non-opaque foreign bodies in the fingers and toes is notoriously difficult. MRI can be exceptionally useful in planning surgical treatment. Most non-radiopaque foreign bodies contain solid material that can be identified on contrast-enhanced MR imaging with fat suppression and/or gradient recalled echo imaging. Typically they appear as low signal intensity structures that do not correspond to any normal anatomic structure in their location, shape or course. Foreign bodies that have been present for a sufficient period of time will result in an inflammatory reaction in the surrounding soft tissues; i.e. a foreign body granuloma, cellulitis or rim-enhancing abscess. These reactive changes are usually easily identifiable on T2-weighted fat-suppressed images and post gadolinium fat-suppressed images.

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