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Big Foot MRI: A Practical Guide for Radiologists to Soft Tissue Tumors and Tumor-Like Lesions of the Foot

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Introduction

The foot is a relatively rare site of soft tissue neoplasms. About 8% of all benign lesions and 5% of all malignant tumors of the soft tissues occur in this location.[1,2] Including reactive processes, approximately 75% of biopsy proven soft tissue masses of the foot are benign tumors or tumor-like lesions.[3] Soft tissue masses of the foot offer unique diagnostic challenges. The clinical presentation of soft tissue masses of the foot is usually not characteristic, with swelling and pain being the most frequent symptoms.[4] Therefore, malignant tumors are often unsuspected at this site, misdiagnosed clinically, and inappropriately managed, especially if occurring in young individuals with vague or long-standing clinical symptoms.[5]

Conventional radiography has a limited role in the diagnosis of soft tissue masses. Ultrasound imaging can differentiate between cystic and solid masses, and can be used as a guidance for aspiration and biopsy.[6] Magnetic resonance imaging (MRI) is the modality of choice for the evaluation of soft tissue tumors, as a result of its intrinsic high soft-tissue contrast.[7] Computed tomography (CT) is superior relative to MRI in detecting subtle cortical invasion, periosteal and endosteal reaction, and matrix mineralization. Both MRI and CT are useful to evaluate response to chemotherapy and radiation therapy.[8] MRI does not provide a specific histologic diagnosis, in general. Only some of these lesions may have typical imaging features; others are more nonspecific in appearance and require tissue confirmation for diagnosis. However, the imaging features when evaluated together with clinical findings such as age, gender, location, and clinical presentation, may allow the prediction of histology of the lesion.[9]

This article reviews the MRI appearance of the common soft tissue masses in the foot together with their clinical, radiographic, and pathological features, and provides a practical guide for radiologists to formulate a focused differential diagnosis.

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MR Imaging Techniques

The initial MRI should be performed before biopsy, since following a biopsy it is often difficult to distinguish tumor from edema, hemorrhage, and granulation tissue.[3] Our routine MRI protocol for the evaluation of soft masses includes images in 3 planes. Images are obtained using a surface coil and a small field of view, targeted to the area of interest. On occasion, a body coil is required when an entire soft-tissue lesion needs to be included for the detection of multiple skip lesions or for surgical planning. Imaging planes should be optimized to best demonstrate the relationship between the lesion and surrounding anatomic structures.[10] Axial planes are routinely obtained with T1-, and fat-saturated T2-weighted sequences. Coronal or sagittal planes are obtained with fluid-sensitive sequences. A short tau inversion recovery sequence is often obtained in patients with metal hardware. Administration of intravenous (IV) contrast helps to distinguish cystic from solid lesions, and recurrent tumor from postoperative scar. Precontrast and postcontrast images are generally obtained using fat saturated T1-weighted sequences, but T1-weighted sequences without fat saturation can be obtained when it is difficult to achieve homogeneous fat saturation in the foot. Dixon techniques can be used as a means to provide more robust fat saturation.[11] Some supplementary MR imaging sequences such as metal artifact reduction sequences and T2*-weighted gradient echo sequences can also be helpful.[6] The use of diffusion weighted MR images and MR spectroscopy has been described, but these techniques are not yet in common clinical use in the musculoskeletal system.[12]

Cystic Tumor-Like Lesions

Ganglion

Ganglia or ganglion cysts are common soft tissue masses in the foot that result from a myxoid degeneration of connective

 https://doi.org/10.1053/j.ro.2018.09.001
0037-198X/

tissue. After the hand and wrist, the foot is the most common location, mostly seen in the tarsal tunnel, sinus tarsi, and Lisfranc joint.[13,14] Most ganglia in the foot are clinically asymptomatic, but can present with local pain, limited joint mobility, or nerve entrapment due to mass effect.[13] Lesions typically occur in adults, more commonly in women.[6]

A ganglion cyst contains a mucinous fluid, but the wall consists of a discontinuous layer of flattened pseudosynovial cells, surrounded by connective tissue. Communication with the adjacent joint is not always present.[15] Ganglia are lined by a capsule composed of flat spindle cells and contain mucinous fluid.[6]

Ganglia often are diagnosed clinically and never imaged; however, imaging can be helpful to define the cystic nature and exact location of the lesion, and to demonstrate possible communication with a joint or tendon sheath, which is relevant for optimal treatment planning.[15] On MRI, ganglia are well-defined, oval, or lobulated masses with water equivalent signal intensities. (Fig. 1A, B) After contrast administration, they demonstrate a thin, smooth rim of peripheral enhancement (Fig. 1C). They should have no internal enhancement, except for similarly thin, smooth septi.[6] Ganglia with hemorrhage or chronic inflammation demonstrate an uncharacteristic signal intensity, irregular and thickened wall, and inflammatory changes of the surrounding soft tissues.[13] A high T2 curvilinear channel may extend between the ganglion cyst and its site of origin and, when visible, should be reported, to help guide surgical resection.[6]

Synovial Cyst

Synovial cysts are synovial-lined, juxta-articular fluid collections that arise from a joint. There is always communication with the adjacent joint. Usually, associated joint disease is present, like osteoarthrosis, inflammatory, and post-traumatic joint diseases.[16] On MR imaging, they are not distinguishable from ganglion cysts.

Bursitis

Bursae occur in several characteristic locations in the foot. The intermetatarsal bursa is a naturally occurring synovium-lined cavity between the metatarsal heads, located immediately dorsal to the deep transverse metatarsal ligament. Intermetatarsal bursal fluid measuring 3 mm or less in transverse diameter is considered physiologic, and is most commonly seen in the second and third interspace.[17] Because intermetatarsal bursae are synovial-lined spaces, any synovial process, such as inflammatory arthropathy, can produce intermetatarsal bursal distention or inflammation.[18]

MR imaging demonstrates a well-defined fluid collection at a typical location between the metatarsal heads with fluid signal intensity. Subtle peripheral enhancement is seen following IV administration of gadolinium contrast medium.[19]

Adventitious bursae may develop in adulthood at sites where subcutaneous tissue is exposed to high pressure and friction. In the foot, adventitious bursae may develop almost anywhere, usually adjacent to bony prominences.[15] Schweitzer et al found a 70% incidence of adventitial bursitis subjacent to the first metatarsophalangeal joint.[20] MRI demonstrates an ill-defined lesion in the subcutaneous fat with fluid signal intensity, most commonly within the plantar fat pad deep to the first and fifth metatarsal heads, often with intralesional band-like structures with low signal intensity.[21] Inactive bursitis shows little fluid and enhancement interrupting the subcutaneous fat, whereas active inflammation shows greater degrees of fluid and peripheral enhancement.[16]

Solid Tumor-Like Lesions

Morton's Neuroma

Morton's neuroma, or interdigital neuroma, is a non-neoplastic lesion associated with neural degeneration and perineural

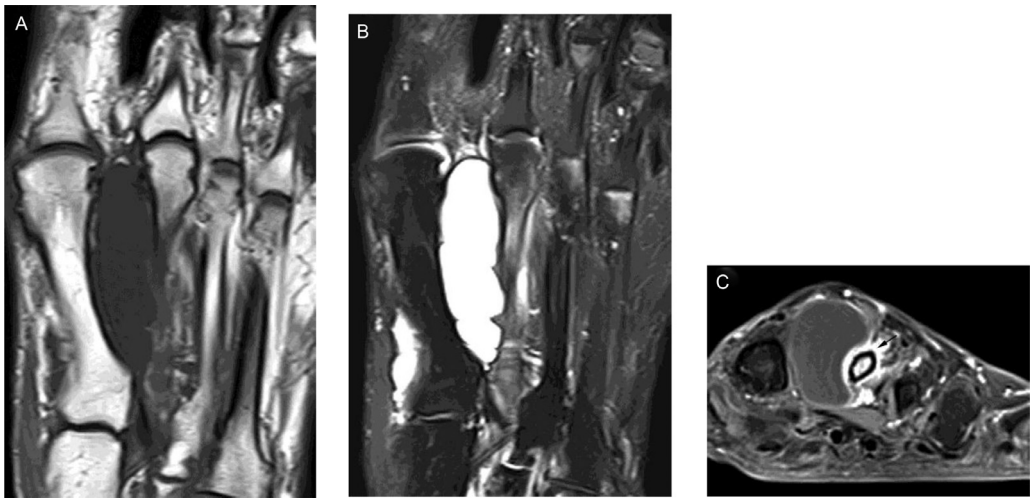

Figure 1 Ganglion cyst. (A) Axial long-axis T1WI demonstrates a well-defined, lobulated mass between the first and second metatarsals. (B) Axial long-axis fat saturated T2WI shows fluid signal. (C) Coronal short-axis fat saturated post-contrast T1WI shows a thin peripheral enhancement. The associated stress fracture in the second metatarsal shows prominent contrast enhancement (black arrow). T1WI, T1-weighted images; T2WI, T2-weighted images.

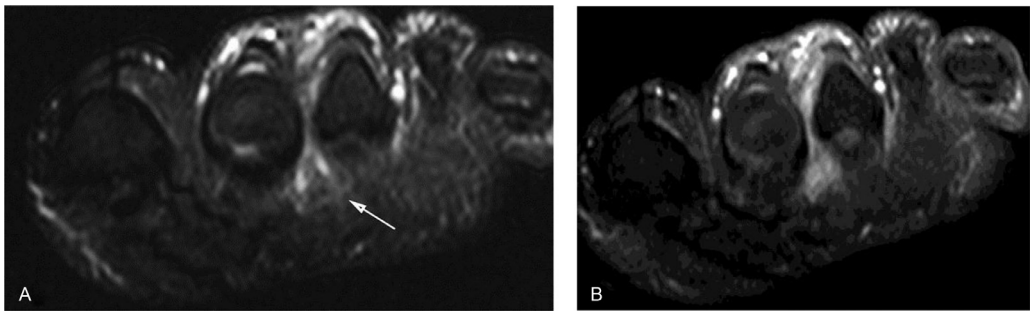

Figure 2 Morton's neuroma. (A) Coronal short-axis fat saturated T2WI shows a hypointense, lobulated, and solid mass between the second and third metatarsal heads (white arrow). (B) Coronal short-axis fat saturated postcontrast T1WI shows diffuse contrast enhancement. T1WI, T1-weighted images; T2WI, T2-weighted images.

fibrosis of a plantar digital nerve most likely due to repetitive compression and irritation of the interdigital nerve.[22,23] It commonly occurs in the second or third intermetatarsal space, and less frequently in the first and fourth, at the level of the metatarsal heads along the plantar aspect of the transverse intermetatarsal ligament.[3,23] It is common in middle-aged women, and is often related to high-heeled or narrow-toed shoes.[22] Lesions with a transverse diameter smaller than 5 mm are often asymptomatic.[17] Clinical symptoms include numbness and intermetatarsalgia radiating into the toes or leg that is exacerbated by standing or walking.[6,24]

Histologically lesions consist of dense fibrosis surrounding the epi- and perineurium associated with degenerative changes of the nerve and inflammation of adjacent soft tissues.[24]

Short axis, coronal MRI typically demonstrates a well-demarcated, dumbbell-shaped mass centered in the intermetatarsal space deep to the transverse metatarsal ligament.[17] The lesions are isointense to muscle on T1-weighted images (T1WI) and hypointense on T2-weighted images (T2WI) due to the presence of fibrous tissue with high collagen content (Fig. 2).[3,17] The enhancement pattern is variable after IV contrast administration, ranging from low to marked enhancement. Intermetatarsal bursal distention may commonly accompany a Morton's neuroma, and coronal T1WI is known to be most accurate in identification of a Morton's neuroma.[22,23]

Rheumatoid Nodule

Rheumatoid nodules are granulomatous lesions that occur in approximately 25% of patients with seropositive rheumatoid arthritis, especially with the more aggressive forms, and are the most common extra-articular manifestation of rheumatoid arthritis.[25] Although these lesions are a common occurrence, only about 1% of all rheumatoid nodules reportedly occur in the feet.[26] It has been reported that the incidence of rheumatoid nodules increases with the use of methotrexate.[27] Rheumatoid nodules also can occur in patients without rheumatoid arthritis, such as systemic lupus erythematosis, ankylosing spondylitis, granuloma annulare, and chronic active hepatitis.[25] They occur in the subcutaneous tissues in areas susceptible to trauma, and in the foot typically at pressure points such as the heel pad and under the metatarsal heads.[15] Rheumatoid nodules usually present clinically as firm, flesh-colored, nontender, and freely movable masses. These lesions can lead to breakdown of the overlying skin resulting in infection, and can erode adjacent bone.[26]

Histologically there is abundant fibrous tissue with areas of fibrinoid necrosis surrounded by palisading fibroblasts and histiocytes with chronic inflammatory infiltration.[4]

The MRI appearance of rheumatoid nodules is nonspecific. They appear most commonly as poorly defined masses within the subcutaneous tissues of the heel pad. They demonstrate isointense signal to muscle on T1WI and heterogeneous signal intensity on T2WI.[15,16] The T2 signal intensity varies based on the lesion's degree of fibrosis (hypointense), central necrosis (hyperintense), and hyperemia (hyperintense).[6] In addition, the T2WI may demonstrate communication between the nodule and the bursal sac of the plantar aponeurosis, and this finding can help in suggesting the correct diagnosis.[27] On contrast-enhanced MRI, rheumatoid nodules display varying patterns of contrast enhancement, ranging from homogeneous enhancement in solid lesions without central necrosis to heterogeneous or faint peripheral enhancement in lesions with central necrosis.[15] (Fig. 3) Correlation with a history of rheumatoid arthritis is important in making the diagnosis.

Synovial Process

Pigmented Villonodular Synovitis and Giant Cell Tumor of the Tendon Sheath

Pigmented villonodular synovitis (PVNS) is a benign proliferative disorder of the synovium that can affect joints, bursae, or tendon sheaths in a localized or diffuse fashion. The common extra-articular manifestations of the disease have traditionally been termed giant cell tumor of the tendon sheath (GCTTS).[24] Both disorders predominate in adult patients, most commonly affecting patients in the third and fourth decades of life.[28] These tumors predominate in women, and there is no association with a history of trauma.[29] Intra-articular PVNS is typically a mono-articular process that can manifest as a single nodule or a diffuse villonodular mass.[28] The ankle represents the third most common site of

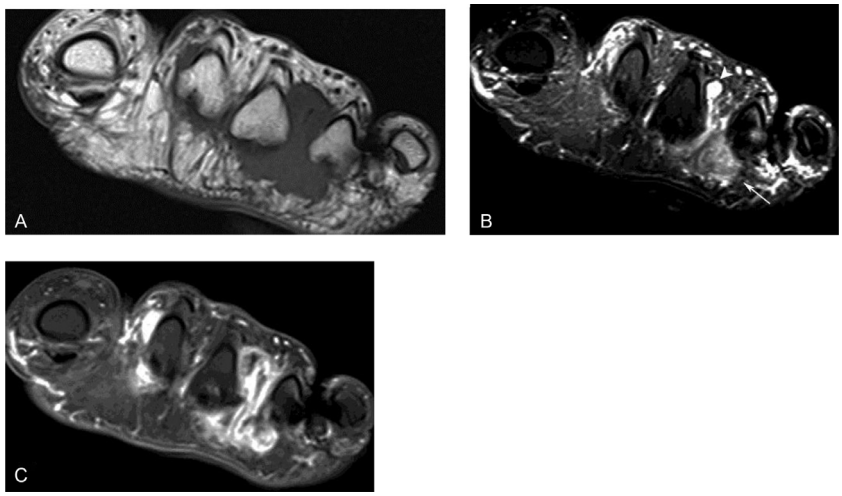

Figure 3 Rheumatoid nodule. (A) Coronal short-axis T1WI shows a lobulated mass between the third and fourth metatarsal heads. The lesion is iso in signal to the muscle. (B) On coronal short-axis fat saturated T2WI, the lesion is hypointense (white arrow). A small amount of fluid is seen in the intermetatarsal bursa (arrowhead). (C) Coronal short-axis fat saturated postcontrast T1WI shows intense heterogeneous enhancement. T1WI, T1-weighted images; T2WI, T2-weighted images.

involvement. Clinical symptoms are usually progressive pain, swelling, and limitation of motion.[28] GCTTS usually manifests as a painless nodular mass. Giant cell tumors are among the most common soft tissue tumors of the foot, showing a predilection for location among the digits.[1,3]

Histologically, GCTTS is a highly vascular mass containing multinucleated giant cells, macrophages, fibroblasts, and xanthoma cells with deposition of hemosiderin which represents the main source of tissue pigmentation.[3] PVNS has the same histologic features as GCTTS, and consists of hyperplastic synovium with hemosiderin and lipid-laden tissue.[4]

On MRI, PVNS demonstrates multiple synovial lesions with low or intermediate signal intensity on T1WI and low signal intensity on T2WI.[4] The hypervascularity and tendency to bleed result in the most characteristic finding of areas of signal void on all sequences due to the paramagnetic effects of intra and extracellular hemosiderin deposits. This is made more apparent on the gradient echo sequences due to characteristic "blooming" (further signal loss) artifact.[30] (Fig. 4) The synovial mass usually shows diffuse but inhomogeneous contrast enhancement.[4] Pressure erosions of bone, invasion of bone via vascular channels, and extracapsular extension are frequent findings in larger lesions.[24] The MRI features of GCTTS and PVNS are similar and reflect their variable composition. Key features of GCTTS are its MRI signal characteristics and its peritendinous location.[30] Calcifications within the lesion are very rare and suggestive of the differential diagnoses of synovial chondromatosis and synovial sarcoma.[3] Its major differential diagnosis is a fibroma of the tendon sheath which shows a similar MR appearance, but fibromas are less common in this location and are not characterized by hemosiderin or by blooming on T2*-weighted gradient echo images.[6]

In PVNS, localized disease is treated with wide surgical excision of the synovium. However, in diffuse disease, it can be difficult to remove all of the affected synovial tissue, and this can contribute to an increased rate of recurrence. Despite surgical intervention, recurrence rates of up to 45% have been reported.[29] In GCTTS, local excision is the treatment, and recurrence rates range from 0% to 30%.[16]

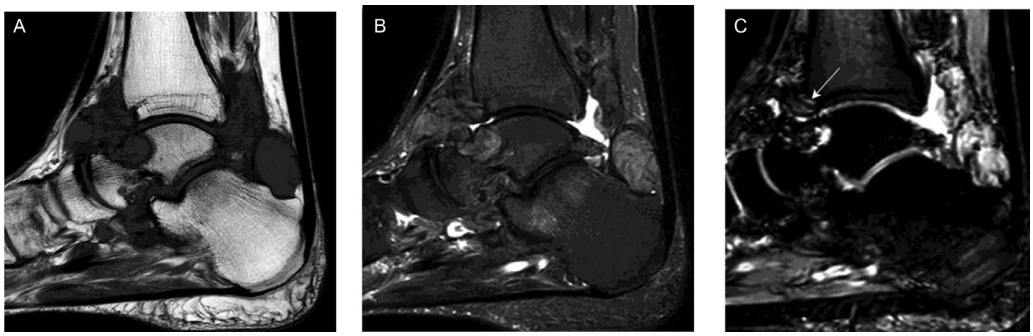

Figure 4 PVNS. (A) Sagittal T1WI shows iso intense lobulated lesions around the ankle and foot eroding tarsal bones. (B) On sagittal fat saturated T2WI, the lesions are hypointense. (C) Sagittal gradient echo image demonstrates "blooming" (white arrow). T1WI, T1-weighted images; T2WI, T2-weighted images.

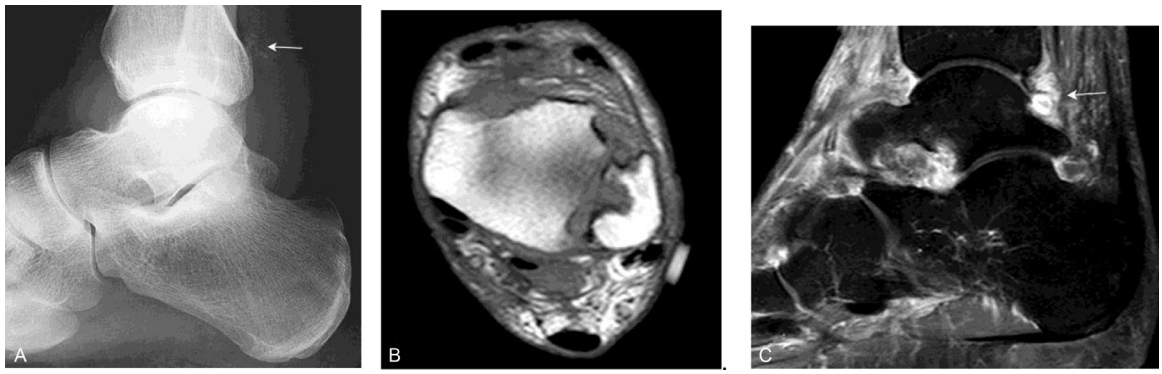

Figure 5 Primary synovial osteochondromatosis. (A) Lateral radiograph of the ankle shows a lobulated mass with calcification (white arrow). (B) Axial T1WI shows intra-articular iso intense lesions with bony erosions. (C) Sagittal postcontrast fat saturated T1WI demonstrates enhancement along the periphery of the lesions (white arrow). T1WI, T1-weighted images.

Primary Synovial Osteochondromatosis

Primary synovial osteochondromatosis is an idiopathic synovial disorder that is characterized by metaplastic cartilaginous proliferation within the synovial membrane of joints, tendon sheaths, or bursae.[31] It is twice as common in men than in women between 20 and 40 years of age.[32] The knee is the most commonly involved joint (more than 50% of cases), while the foot and ankle are uncommonly involved.[1] In the earlier stages, the cartilaginous nodules are largely unmineralized.[30] Calcification or ossification of cartilage nodules can occur as long as vascularization is preserved by contact with the synovial membrane.[32] Long-standing disease is typically complicated by secondary osteoarthritis.[32] Malignant transformation into a secondary synovial chondrosarcoma can occur but is extremely rare.[24] Clinically, patients may present with limitation of motion, mild to moderate pain, and swelling.

Radiographs may be unremarkable or show a synovial-based mass with or without subchondral erosions; calcifications occur in approximately 70%-95% of cases (Fig. 5A).[16] At late stages, secondary osteoarthritis is usually seen.[32] MR imaging can be helpful to diagnose the lesion when there is no mineralization in the lesion, and to evaluate the extent of the lesion. The signal characteristics of the bodies depend on whether or not they are mineralized. Unmineralized bodies closely parallel imaging characteristics of hyaline cartilage, appearing as lobulated intra-articular masses with intermediate signal intensity on T1WI and high signal intensity on T2WI (Fig. 5B).[16] Calcified bodies are usually seen as punctate areas of low signal intensity. Ossified bodies can reveal features of fatty marrow signal surrounded by a hypointense rim of cortical bone. Following IV contrast administration, the hyperplastic synovium demonstrates enhancement at the periphery of the lobules resulting in a "rings and arcs"−like pattern (Fig. 5C).[24]

Gout

Gout is a synovial inflammatory process caused by hyperuricemia. The tophaceous form of gout is a tumor-like process that occurs most commonly as a late manifestation of the disease. Tophi can occur within bone, joints, tendons, and the soft tissues. Periarticular tophi can give rise to characteristic erosions, and the most common site of involvement is the first metatarsophalangeal joint.[33] Gouty tophi develop due to deposition of monosodium urate crystals, which may be accompanied by intercrystalline matrix, and foreign body granulomatous reaction.[6]

Radiographic changes typically develop only after repeated attacks of gout and are seen in approximately 40% of patients.[16] On radiographs, gouty tophi are often slightly more dense than surrounding soft tissues, associated with well-marginated periarticular bony erosions, demarcated by sclerotic rims and overhanging edges. Calcification of the tophus is unusual.[6] On MRI, these tophi are isointense or hypointense to muscle on both T1WI and T2WI with heterogeneous, predominantly peripheral contrast enhancement.[34] (Fig. 6) However, signal intensity on the T2WI may be variable due to additional crystal or calcium deposition.[34] The MRI features of gout are nonspecific, occasionally mimicking a neoplastic or infectious process. Therefore, it is important to review the clinical history, laboratory examination, and radiographic findings.

Benign Tumors

Lipoma

Lipoma is a benign tumor that consists of mature adipocytes, and can occur in a superficial (subcutaneous) or deep location. Rarely, it develops within a tendon sheath or joint. Lipoma is most common between ages 40 and 60 years,[24] and is multiple in approximately 5% of patients.[16] It is the most common mesenchymal soft tissue tumor in adults, with an incidence of up to 2.1 per 100 individuals.[16] Lipoma is uncommon in the foot and ankle, accounting for 4.2% of all benign soft-tissue lesions in this region.[1]

MR imaging is diagnostic, demonstrating the same signal intensity to that of subcutaneous fat on all pulse sequences. Lipomas may have a thin surrounding capsule, and may contain a few thin septations that do not enhance following contrast administration.[35] (Fig. 7) In locations such as the sole

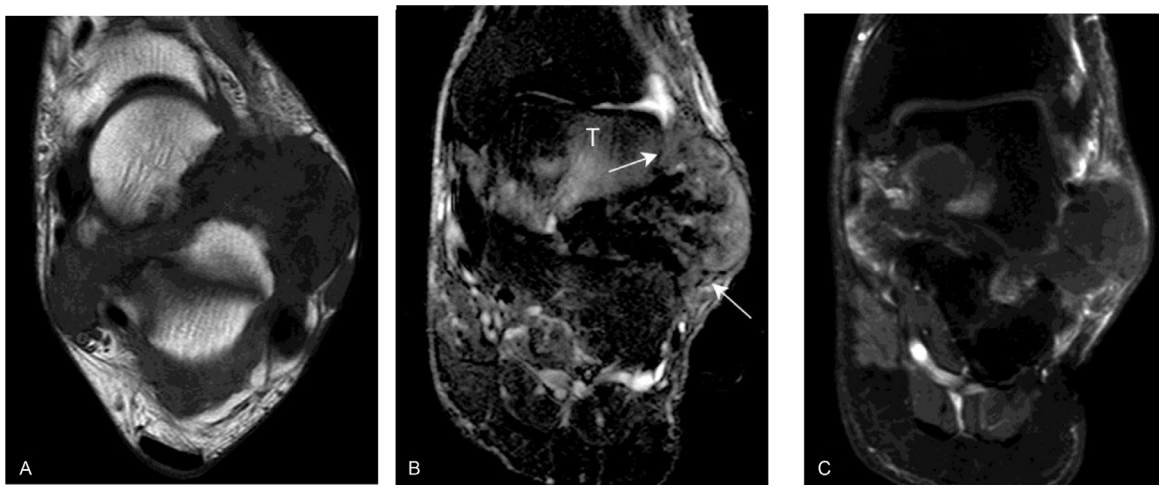

Figure 6 Gout. (A) Axial T1WI shows intra-articular mass involving the sinus tarsi. (B) On coronal short-axis fat saturated T2WI, the lesion is hypointense (white arrows), associated with marrow edema and erosion at the talus (T). (C) Coronal short-axis fat saturated postcontrast T1WI shows peripheral rim enhancement of the intra-articular mass. T1WI, T1-weighted images; T2WI, T2-weighted images.

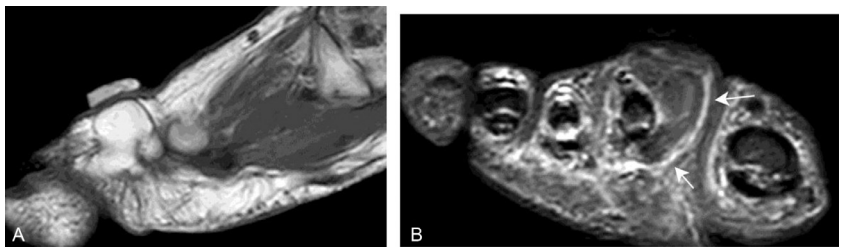

Figure 7 Lipoma. (A) Sagittal T1WI shows a lobulated superficial mass at the dorsum of the second toe which is iso in signal to the subcutaneous fat. (B) On coronal short-axis postcontrast fat saturated T1WI, the mass shows peripheral rim enhancement (white arrows) with iso signal to the subcutaneous fat. T1WI, T1-weighted images.

of the foot, however, heterogeneous signal intensity can be seen due to inflammation, hemorrhage, calcification or ossification, and infarction.[35]

Clear Cell Hidradenoma

Clear cell hidradenoma is a tubular adenomatous tumor of sweat gland origin that typically is located in the superficial and deep dermis and occasionally in the subcutaneous tissue. Synonyms for this tumor include: nodular hidradenoma, solid cystic hidradenoma, eccrine acrospiroma, and eccrine adenoma of clear cell type.[36,37] Clinically, the tumor is often a solitary nodule that can be as large as 2 cm and is usually covered by normal epidermis.[38] It occurs on the trunk in about 52%, 24% are found on the head and neck, and 24% on the extremities.[36] It appears infrequently (3%) on the foot.[39] The tumor may appear pink or brown, with varying sites of translucency or bluish discoloration. There is a low tendency to ulceration (15%), and pain with moderate pressure has been reported.[36] Treatment is surgical excision, with emphasis on the achievement of clear resection margins.[37] Malignant transformation of previously indolent lesions is recognized, requiring extensive surgery to achieve local control.[37]

Characteristic MRI features are most often of a lobulated, multiloculated cystic mass with fluid levels and varying amounts of solid mural nodules. Solid components are often highly vascular with considerable enhancement (Fig. 8).[37,38] Calcifications may be seen in the solid component, and the cystic component may display variable degrees of complexity due to hemorrhage.[37] No associated bony destruction or marrow abnormality is seen.[40]

Hemangioma

Soft tissue hemangiomas are benign vascular lesions that consist of hyperplastic endothelial cells, mast cells, and variable amounts of nonvascular elements including fat, smooth muscle, fibrous tissue, bone, hemosiderin, and thrombus. According to their histologic features, they can be subdivided into capillary, cavernous, venous, and arteriovenous subtypes.[16,24,41] Most intramuscular hemangiomas are of the cavernous subtype.[41] Hemangiomas are common, accounting for 9% of benign lesions in the foot and ankle.[6] Based on their location relative to the deep fascia, soft-tissue hemangiomas of the foot can be superficial (cutaneous or subcutaneous), deep (intramuscular), or a combination of both.[4] They are common in infancy and childhood, but can occur

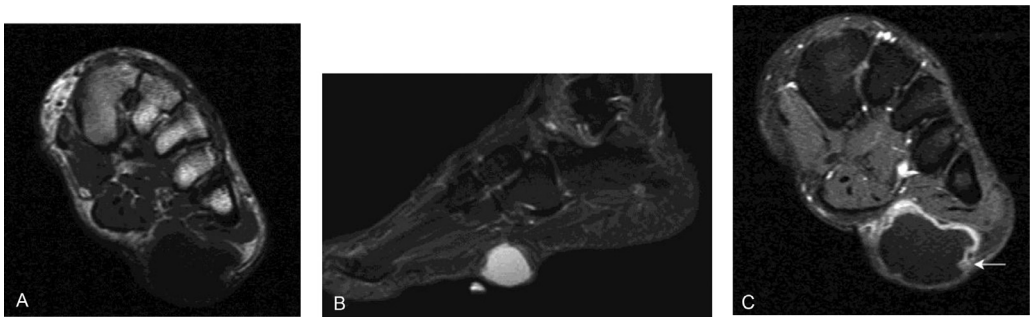

Figure 8 Clear cell hidradenoma. (A) Coronal short-axis T1WI shows a lobulated mass in the plantar aspect of the foot. (B) On sagittal fat saturated T2WI, the mass is hyperintense. (C) Coronal short-axis postcontrast fat saturated T1WI shows thick rim enhancement with nodular portions (white arrow). T1WI, T1-weighted images; T2WI, T2-weighted images.

at any age. The incidence is similar in men and women.[6] Patients may present with blue discoloration on the skin, pain, swelling, or mass that may fluctuate in size, but the majority of hemangiomas of the foot are clinically asymptomatic.[4]

The MR appearance of soft tissue hemangiomas allows a specific diagnosis in most cases.[41,42] The lesions are comprised of multiple lobules or tubules with septations. The masses show irregular margins, and cause little mass effect relative to their size. Hemangiomas typically demonstrate inhomogeneous signal intensity on both T1WI and T2WI because of the admixture of nonvascular tissue components.[24] Fat overgrowth is frequently most prominent at the periphery of the tumor with extension into the septations.[24] The vascular component is characterized by low to intermediate signal intensity on T1WI, very high signal intensity on T2WI, and marked contrast enhancement. The bright signal on T2WI has been attributed to slow blood flow.[3,41,42] Phleboliths are seen in nearly 50% of all cavernous hemangiomas, and they appear as rounded areas of low signal intensity on all pulse sequences (Fig. 9).[1] Intramuscular lesions may be associated with a small amount of surrounding fatty atrophy owing to vascular steal phenomenon. If perilesional hemorrhage has occurred, then low T2 signal hemosiderin may be seen at the periphery of the lesion and can cause blooming on T2*-weighted gradient echo images.[6] Arteriovenous hemangiomas have a typical serpentine appearance of low signal intensity on all pulse sequences caused by rapidly flowing blood in large tortuous vessels.[42]

Angiomyoma

Angiomyoma (vascular leiomyoma, angioleiomyoma) is a rare form of benign tumor of vascular smooth muscle which usually occurs as a solitary subcutaneous lesion. The tumor shows a strong predilection for the lower leg, where the foot and ankle represent the most common locations.[1] Angiomyomas are most common in middle aged women, and they usually present as slowly enlarging small masses that rarely exceed 2 cm.[24] Patients often describe sharp paroxysmal pain precipitated by light touch or changes in temperature.[43] As the tumor is situated in the feet, some patients complain of trouble in fitting on shoes.[44] In contrast to glomus tumors, angiomyomas are almost never encountered in subungual locations.[24] Surgical excision is the treatment of choice.[45] The tumor may become malignant, degenerating into a superficial leiomyosarcoma, but this occurrence is rare.[45]

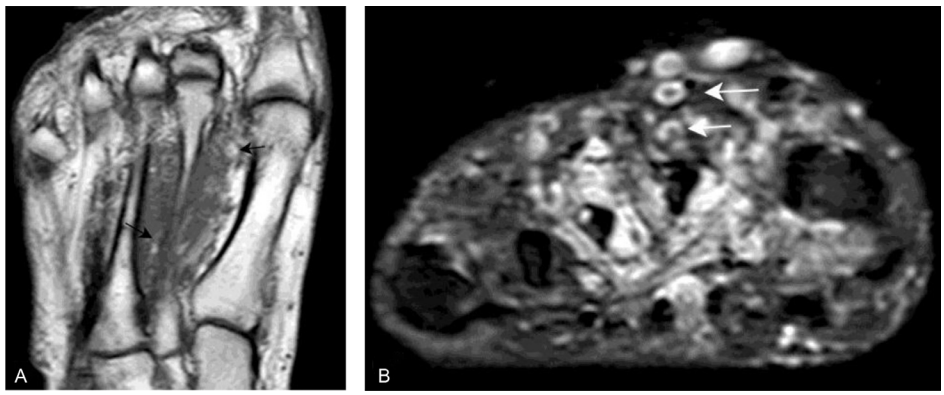

Figure 9 Hemangioma. (A) Axial long-axis T1WI shows an interdigitating mass around the first through third metatarsals with areas of high signal intensity (black arrows). (B) On coronal short-axis fat saturated T2WI, the lesion shows serpinginous high signal intensity. There are dot-like foci of low signal (white arrows) in keeping with phleboliths. T1WI, T1-weighted images; T2WI, T2-weighted images.

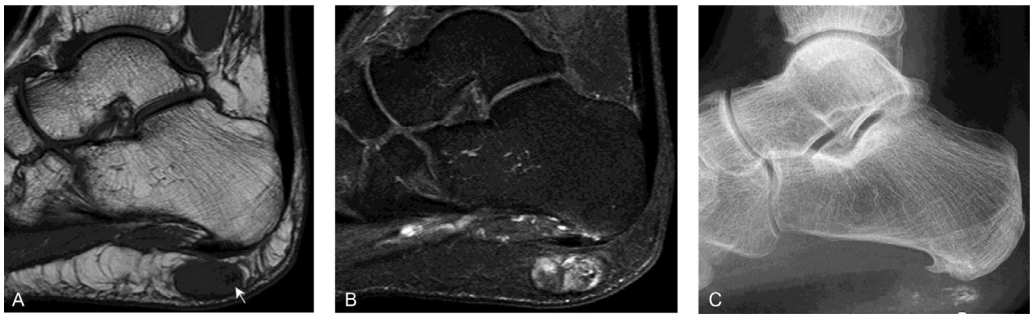

Figure 10 Angiomyoma. (A) Sagittal T1WI shows a small, ovoid, and subcutaneous mass in the heel. It shows iso intense signal to the muscle with hypointense foci that are in keeping with calcifications (white arrow). (B) Sagittal fat saturated postcontrast T1WI shows heterogeneous contrast enhancement. (C) Lateral radiograph of the foot shows calcifications. T1WI, T1-weighted images.

Angiomyomas are histologically classified as solid, cavernous, and venous subtypes, but all subtypes contain benign-appearing smooth muscle cells and vascular channels.[44,46] The lesions can contain areas of myxoid change, hyaline degeneration, fat, and calcification.[24]

On MRI, tumors appear as well defined, round masses mostly bordered by a hypointense lining that corresponds to a fibrous capsule.[24] They are isointense to the muscle on T1WI and inhomogeneous on T2WI.[46] They enhance with contrast (Fig. 10).[43]

Plantar Fibromatosis

Plantar fibromatosis or Ledderhose disease is a form of superficial fibromatosis due to fibrous proliferation that arises from the plantar aponeurosis.[33] Patients present with painless, subcutaneous nodules on the medial, plantar aspect of the foot.[3] It is the most common benign soft-tissue tumor in the foot and ankle, accounting for 15% of lesions in this region.[1,47] Plantar fibromatosis is more common in men and bilateral in 20%-50% of patients.[48] It is related to other superficial fibromatoses; association of plantar fibromatosis with palmar fibromatosis (Dupuytren's contracture) has been reported in up to 65% of cases.

On histology, lesions are nonencapsulated, and characterized by spindle-shaped fibroblasts separated by variable amounts of collagen at early stages. At later stages, the lesions become less cellular and contain increased amounts of dense collagen.[3]

On MRI, plantar fibromatosis is seen as single or multiple nodular masses located in the medial aspect of the plantar aponeurosis with signal intensities equal to or lower than that of the adjacent muscle on T1WI and T2WI.[30,49] Lesions with high cellularity may have a hyperintense signal on T2WI (Fig. 11A).[49] Contrast enhancement is heterogeneous and variable. A characteristic "fascial tail" sign (linear extension of contrast enhancement along the aponeurosis) may be seen (Fig. 11B).[48]

Dermatofibroma

Dermatofibroma, also known as benign fibrous histiocytoma, histiocytoma cutis, nodular subepidermal fibrosis, and fibrous xanthoma, is one of the most common mesenchymal neoplasms of the skin.[50] Less than 1%-2% of all dermatofibromas are found subcutaneously, and pure subcutaneous dermatofibromas have rarely been reported.[51] The lesions may be multiple, and clinically they appear as pigmented papules, a few millimeters to a few centimeters in size.[9]

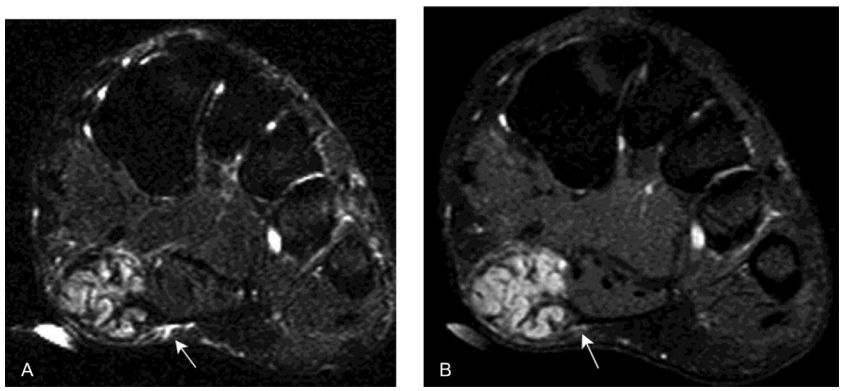

Figure 11 Plantar fibromatosis. (A) Coronal short-axis fat saturated T2WI shows a lobulated mass in the medial aspect of the foot. The mass is relatively high signal to muscle suggesting hypervascularity. (B) Coronal short-axis postcontrast fat saturated T1WI shows homogeneous intense enhancement. The characteristic “fascial tail” sign is seen in both images (white arrows in A and B). T1WI, T1-weighted images; T2WI, T2-weighted images.

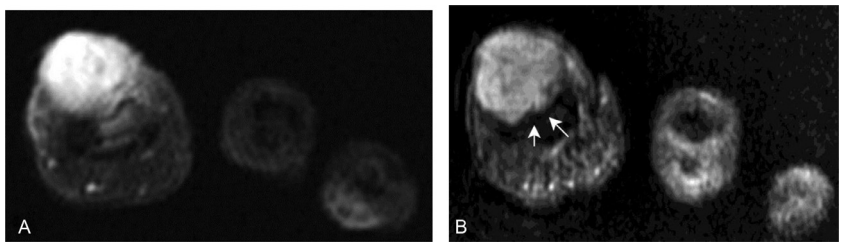

Figure 12 Myxoid dermatofibroma. (A) Coronal short-axis fat saturated T2WI shows a lobulated superficial mass in the dorsum of the first distal phalanx that has high signal intensity. (B) Coronal short-axis postcontrast fat saturated T1WI shows homogeneous contrast enhancement with bony erosion (white arrows). T1WI, T1-weighted images; T2WI, T2-weighted images.

Dermatofibroma is a reactive hyperplastic response of the skin of unknown etiology, which is mostly seen on the extremities of young or middle-aged women.[50] Dermatofibromas are most common on the lower extremities.[50]

On MRI, the lesions tend to be low in signal intensity on both T1WI and T2WI due to a large number of fibroblasts and histiocytes. With gadolinium, variable enhancement is shown, depending on the adjacent inflammatory reaction.[9]

Myxoid dermatofibroma is very rare, characterized by marked stromal mucin deposition, and accounting for only 0.4% of all dermatofibromas.[50] It may be homogeneous or heterogeneous depending on its relative components, with the myxoid component being hypointense on T1WI, and hyperintense on T2WI. It may show homogeneous or heterogeneous contrast enhancement with gadolinium administration (Fig. 12).[52]

Benign Peripheral Nerve Sheath Tumors

Benign peripheral nerve sheath tumors (PNSTs) include schwannoma (neurilemoma) and neurofibroma. They represent approximately 10% of all benign soft-tissue tumors.[53] PNSTs rarely occur in the foot and ankle. Schwannomas and neurofibromas account for 5.4% and 3.9% of all benign soft-tissue masses in this location, respectively.[1] Schwannomas are well-encapsulated tumors that arise from the Schwann cells of the nerve sheath and contain cellular and myxoid elements.[4] Neurofibromas are nonencapsulated, often infiltrative masses. Neurofibromas consist of differentiated Schwann cells with myelinated and unmyelinated axons in an extracellular matrix. In the foot, most neurofibromas occur in the heel and great toe.[6] Schwannomas typically occur along the flexor surface of the extremity.[6] Patients typically present with a painless mass less than 5 cm in size. Neurologic symptoms may present with motor or sensory disturbances, or both.[6]

At MR imaging, PNSTs demonstrate iso signal intensity to the muscle on T1WI and high signal intensity on T2WI in continuity with a peripheral nerve (Fig. 13). They typically show avid enhancement after IV contrast administration.[54] Although it may be difficult to differentiate between schwannoma and neurofibroma at imaging, a PNST that is eccentric to the involved peripheral nerve favors schwannoma. A lobulated contour, hypovascularity, and fusiform shape favor neurofibroma.[33] A “target sign” may be seen on T2WI, with

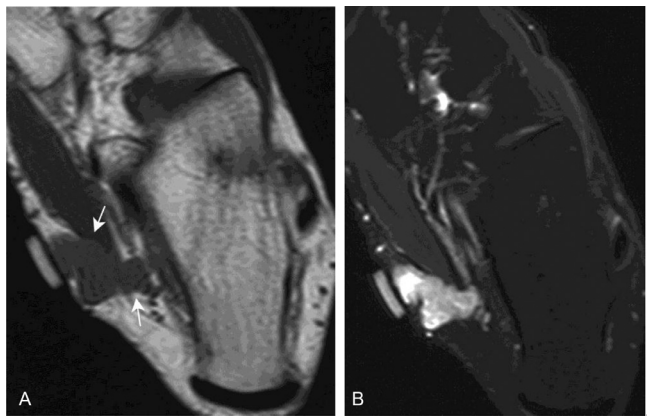

Figure 13 Schwannoma. Axial long-axis T1WI (A), and fat saturated T2WI (B) show a lobulated mass arising from the tarsal tunnel (white arrows in A). The mass has iso signal to the muscle on T1WI, and high signal on T2WI. T1WI, T1-weighted images; T2WI, T2-weighted images.

higher signal peripherally and lower signal centrally, corresponding to myxoid and fibrocollagenous content.[55] A "tail sign" can be seen when the nerve from which the tumor arises becomes thickened immediately adjacent to the tumor.[54] A "split fat sig" may be seen, where normal fat surrounding a peripheral nerve trunk becomes especially apparent on lesions that arise within.[6,33] On imaging, it may be impossible to differentiate benign from malignant PNSTs, although malignant PNSTs are typically larger, have ill-defined margins, and central necrosis and demonstrate rapid growth.[55]

Malignant Tumors

Synovial Sarcoma

Almost 25% of all soft tissue sarcomas occur in the foot and ankle region, and synovial sarcoma is the most common sarcoma in the foot.[3,24] It is a malignant tumor that develops from undifferentiated mesenchymal cells, and it is found slightly more often in males between 15 and 40 years of age.[9] It is unrelated to the synovium and commonly occurs

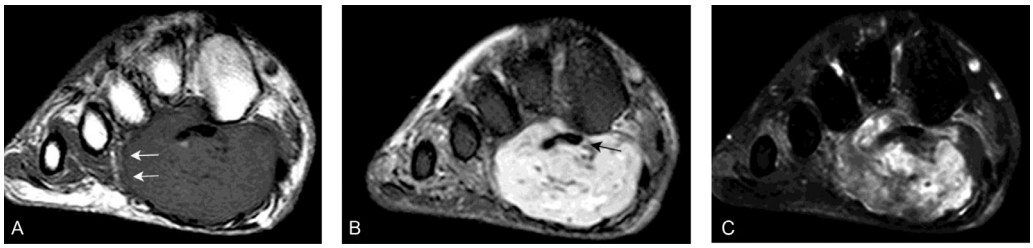

Figure 14 Synovial sarcoma. (A) Coronal short-axis T1WI shows a large lobulated deep-seated mass in the foot. The lesion has slightly ill-defined margins at the lateral aspect (white arrows). (B) Coronal short-axis fat saturated T2WI shows hyperintense signal intensity. There are hypointense foci in keeping with calcifications (black arrow). (C) On coronal short-axis postcontrast fat saturated T1WI, the mass demonstrates heterogenous enhancement. T1WI, T1-weighted images; T2WI, T2-weighted images.

in para-articular locations.[45] Most cases of synovial sarcoma arise in the deep soft tissues around the knee. Lesions in the foot and ankle typically are slowly enlarging masses with variable pain or tenderness. Lesions can invade multiple compartments of the foot and erode into the bones.[16]

Radiographs can show stippled or amorphous calcifications in 20%-30% of the masses.[3,16] On MRI most tumors are commonly found in a juxta-articular location and are often very large.[56] Infiltrative margins, inhomogeneous signal intensity on T1WI and T2WI with solid portions, as well as septated areas of hemorrhage and necrosis represent a typical MR appearance (Fig. 14).[3] T2WI can demonstrate areas that are hyper-, iso-, and hypointense to fat ("triple signal intensity").[16] MR imaging also shows fluid-fluid levels in approximately 10%-25% of cases due to prior hemorrhage.[16] Viable tumor tissue usually demonstrates intense enhancement following contrast administration.[57] Calcifications are often not detectable on MRI.[57] Synovial sarcomas with a diameter of less than 5 cm can show well-defined margins and homogeneous signal on MR images, and thus are frequently misdiagnosed as cysts.[45]

Surgical resection is the treatment of choice. Favorable clinical factors include young age of the patient, tumor size of less than 5 cm, and tumor location in the distal part of the extremity.[45] Approximately half of synovial sarcomas recur and approximately 40% metastasize to the lungs, bones, or regional lymph nodes.[16]

Liposarcoma

Liposarcoma is a malignant neoplasm of soft tissues containing lipobalsts or adipocytes. It is the second most common malignant soft-tissue tumor after malignant fibrous histiocytoma.[9] Clinically, patients usually present with painless masses or the lesions may be discovered incidentally.[58] Its peak incidence is between 50 and 60 years of age. Liposarcomas are most common in the extremities, especially in the thigh, and in the retroperitoneum.[9] Liposarcomas can be divided into 4 groups based on their histologic characteristics: well differentiated, myxoid, round cell, and pleomorphic. The appearance of a liposarcoma on CT and MR depends on its degree of differentiation.[9]

Myxoid liposarcomas are low- to intermediate-grade sarcomas with a higher risk of recurrence and metastatic spread.[59] It is the most common liposarcoma arising in children, adolescents, and young adults.[60] They often contain less than 10% of fat, whereas myxoid tissue with arborizing capillaries is prominent.[59] Necrosis is uncommon, and calcifications are rare. The mass is usually multinodular and well circumscribed. Myxoid liposarcoma most commonly occurs in the extremities, followed by the torso. Myxoid liposarcomas occurring in the foot may appear as a heterogeneous mass with cortical destruction of the adjacent bones and involvement of one of the neurovascular bundles.[60] It comprises up to 35% of all liposarcomas. Most of the tumors occur in the deep soft tissue (deep to the superficial fascia) and present as slowly growing painless lumps.[52]

On MRI, it appears as a well-defined multilobulated mass with imaging characteristics consistent with its varying pathologic profile. Its myxoid component appears T2-hyperintense and T1-hypointense on MRI, and enhances with IV contrast administration (Fig. 15). The fatty component appears T1 hyperintense, and may not always be visible on imaging. There can be a separate nonfatty, nonmyxoid enhancing component that correlates with the round cell high-grade content of the tumor.[52]

Melanoma

Melanoma is the malignant transformation of melanocytes derived from neural crest cells. Primary cutaneous melanoma is the most common malignant tumor of any type in the foot. The term acral lentiginous melanoma is applied to melanoma affecting the hand or foot. Malignant melanoma in the foot has a significantly worse prognosis then melanoma in other body sites.[61] Most patients are young adults, with the most frequent age at presentation being in the 40's. Women are more frequently affected than men, and this cancer presents a particular risk for young women. The most common sites of presentation are the plantar surface and subungual regions, but the tumor may occur anywhere on the foot.[61] Studies have shown that melanoma of the foot tends to present at a more advanced stage and at a greater depth than lesions elsewhere in the body.[62]

On MRI, primary melanoma and nonhemorrhagic melanotic metastasis demonstrate increased signal intensity on T1WI and intermediate to low signal intensity on T2WI, caused by intrinsic paramagnetic effects of their melanin

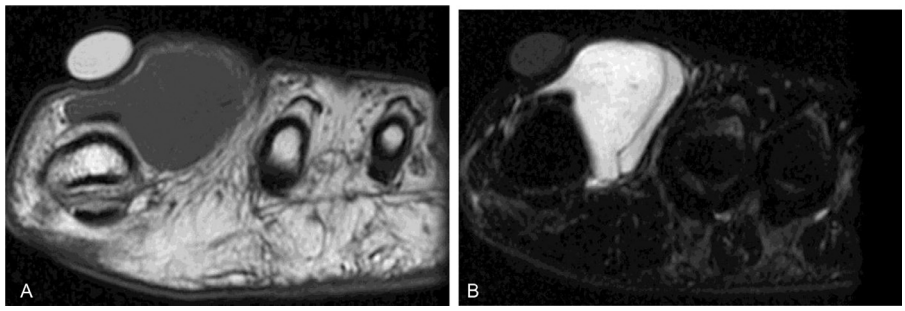

Figure 15 Myxoid liposarcoma. (A) Coronal short-axis T1WI shows a large, well-marginated mass between the first and second proximal phalanx. The mass is iso intense to the muscle without any fatty component. (B) On coronal short-axis STIR image, the mass shows high signal intensity. STIR, short tau inversion recovery; T1WI, T1-weighted images.

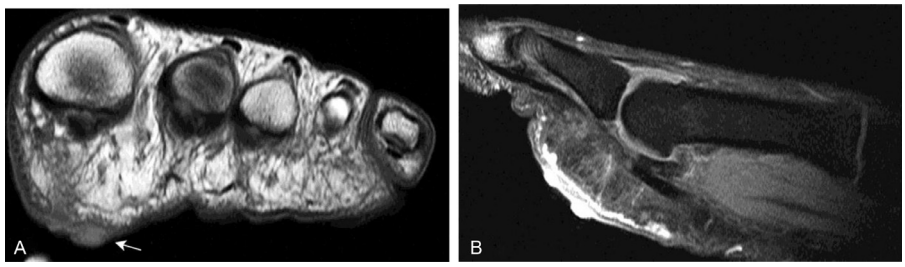

Figure 16 Melanoma. (A) Coronal short-axis T1WI shows nodular superficial masses in the sole of the foot that are slightly hyperintense than the muscle (white arrow). (B) Sagittal postcontrast fat saturated T1WI shows intense contrast enhancement along the skin and the masses. T1WI, T1-weighted images.

content (Fig. 16).[58] However, amelanotic melanoma without hemorrhage may have low signal on T1WI and high signal on T2WI.[9] Melanomas demonstrate solid enhancement after IV contrast administration.

Early detection and complete local excision with wide margins are emphasized. Mohs excision, toe amputation, or ray amputation may be preferential depending on the location and characteristics of the individual lesion.[29]

Clear Cell Sarcoma

Clear cell sarcoma, aka malignant melanoma of the soft parts, is a highly malignant sarcoma of melanocytic differentiation.[3] In contrast to cutaneous melanoma, clear cell sarcoma is a relatively deep-seated lesion.[56] The tumor arises in intimate association with aponeuroses and tendons of the upper and lower extremities, and rarely involves the skin.[56] Clear cell sarcoma usually affects young to middle-aged adults, with more than 90% occurring in the extremities and 40% in the foot and ankle.[2,43] The foot is a common anatomic site, and 25% of tumors in this location involve the heel.[3] Patients present with a small, slowly growing mass, with pain and tenderness in 50% of the cases.[43]

Histologically, clear cell sarcoma consists of compact nests of uniform, round cells separated by a fibrocollagenous stroma.[3]

On MRI, clear cell sarcomas frequently show homogeneous signal intensity and well-defined borders, which may lead to misdiagnosis as a benign lesion. They have low signal intensity on T1WI and high signal intensity on T2WI with strong enhancement after gadolinium application. Almost 50% of the tumors produce melanin, which causes slightly hyperintense signal on T1WI and hypointense signal on T2WI (Fig. 17).[63]

Clear cell sarcoma is treated with surgical resection, but the ultimate prognosis is poor.[64] Local recurrence and metastases are common, and the mortality rate is 37%-59%.[43]

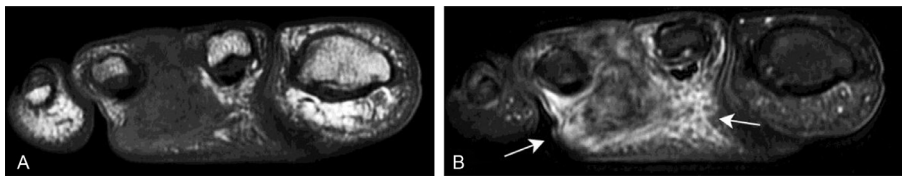

Figure 17 Clear cell sarcoma. (A) Coronal short-axis T1WI shows a large, lobulated, and infiltrative mass in the foot that is slightly hyperintense than the muscle. (B) On coronal short-axis fat saturated T2WI, the mass is hypointense with marked peritumoral edema (white arrows). T1WI, T1-weighted images; T2WI, T2-weighted images.

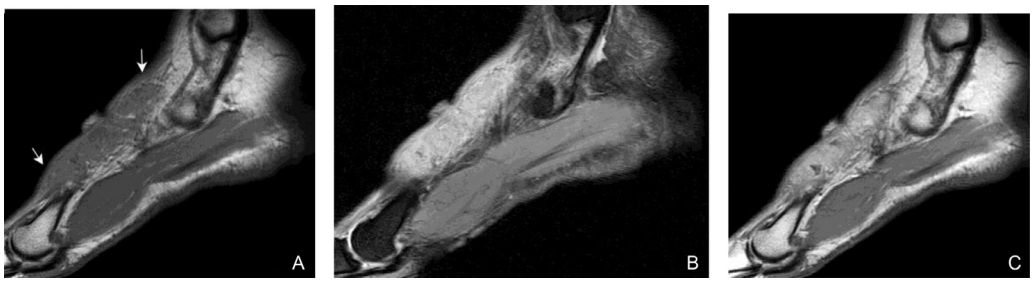

Figure 18 Acral myxoinflammatory fibroblastic sarcoma. (A) Sagittal T1WI shows an infiltrative mass along the dorsum of the foot that is iso intense to the muscle (white arrows). (B) On sagittal fat saturated T2WI, the mass is hyperintense. (C) Sagittal postcontrast T1WI shows diffuse homogeneous enhancement. T1WI, T1-weighted images; T2WI, T2-weighted images.

Acral Myxoinflammatory Fibroblastic Sarcoma

Acral myxoinflammatory fibroblastic sarcoma is a rare, low-grade sarcoma. It can affect all age groups and characteristically involves the extremities.[52] Both men and women are affected equally. The tumor has a prominent inflammatory component, and is associated with synovitis in a significant number of cases.[65] It is located mainly in the subcutaneous layer of the upper extremities in 70% of cases.[59] The diagnosis may be suggested based on the presentation of a painless, slow-growing, non-encapsulated acral lesion with peripheral inflammation. There is usually no calcification in the lesion.[59]

Histologically, it shows four elements on pathologic analysis: proliferative fibroblasts (spindle cells), myxoid matrix, associated inflammatory components, and Reed-Sternberg like atypical giant cells.[52]

On MRI, they may be homogeneous or heterogeneous depending on their relative components, with the predominantly myxoid component being T2 hyperintense and T1 hypointense. They may exhibit homogeneous or heterogeneous contrast enhancement (Fig. 18).[52,59]

Epithelioid Sarcoma

Epithelioid sarcoma is classified within the malignant group of "tumors of uncertain differentiation." [59] It is rare and accounts for 0.6%-1.4% of all soft-tissue sarcomas.[66] Epithelioid sarcoma generally occurs in the distal extremities of adolescents and young adults. The flexor surfaces of the hand and feet are one of the most commonly involved sites.[66] Clinically epithelioid sarcoma may manifest as subcutaneous masses or nonhealing ulcers. Suspicion for epithelioid sarcoma should arise in patients presenting with multiple soft tissue nodules or persistent punched-out ulcers involving the skin and subcutaneous tissues, particularly of the extremities.[45,67] Deep-situated lesions have the potential to spread along or to penetrate through the underlying fascia. Epithelioid sarcoma has the tendency to spread along the neurovascular bundles with potential vascular and lymphatic invasion.[67]

On radiographs, the lesion may be mineralized in approximately 20% of cases.[59] On MRI, the lesion is usually isointense to that of muscle on T1WI and hyperintense on T2WI (Fig. 19). However, signal intensity varies greatly due to hemorrhage, necrosis, or calcifications. Peritumoral edema is commonly seen.[59,67]

Extraskeletal Chondrosarcoma

Chondrosarcoma is a malignant neoplasm characterized by the production of cartilage. There are several types of primary chondrosarcomas: conventional (medullary), clear cell, mesenchymal, and dedifferentiated.[9] Extraskeletal chondrosarcomas are relatively rare neoplasms, and far less common

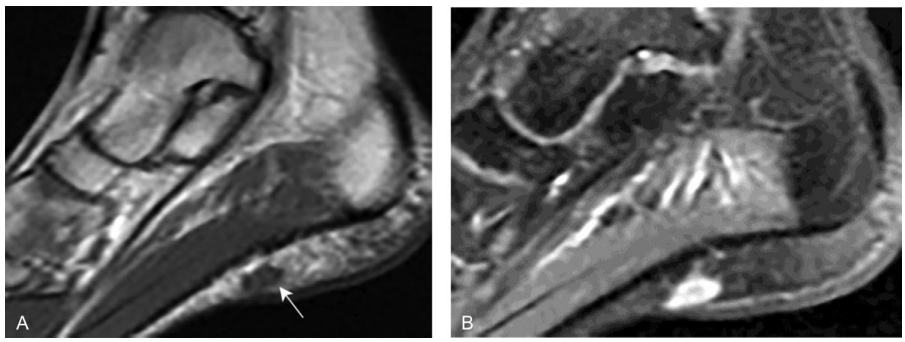

Figure 19 Epithelioid sarcoma. (A) Sagittal T1WI shows a small superficial mass with ill-defined margins (white arrow). (B) Sagittal postcontrast fat saturated T1WI shows intense contrast enhancement of the mass. T1WI, T1-weighted images.

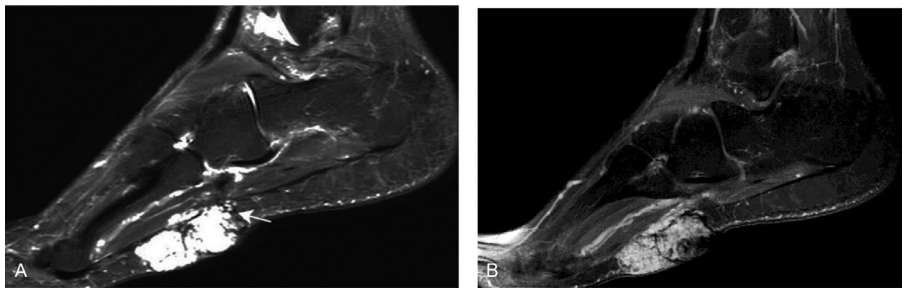

Figure 20 Extraskeletal myxoid chondrosarcoma. (A) Sagittal STIR image shows a multilobulated mass in the plantar aspect of the foot that has homogeneous high signal intensity. The margin has tiny lobules that is typical for chondroid tumors (white arrow). (B) Sagittal postcontrast fat saturated image shows intense heterogeneous enhancement. STIR, short tau inversion recovery.

than their intraosseous counterparts.[68] Extraskeletal chondrosarcomas are subdivided into myxoid, mesenchymal, and the very rare well-differentiated types. These lesions show minimal, if any, cartilage formation except well-differentiated types.[68] The prognosis of extraskeletal chondrosarcoma is generally believed to be more favorable than that of chondrosarcoma of bone, although this is influenced by the histological type.[69]

Extraskeletal myxoid chondrosarcoma is a rare tumor with an indolent course and high propensity for local recurrence and metastasis. This tumor most commonly presents in the proximal extremities of middle-aged males, and is commonly slow growing.[70] Pain or tenderness is seen in approximately one-third of cases.[68]

Histologically, extraskeletal myxoid chondrosarcoma, which resembles myxoid liposarcoma, is characterized by ill-defined nodular masses composed of cords and strands of small acidophilic cells separated by abundant mucoid stroma.[69] It is generally considered to be a low-grade sarcoma, with a 10-year survival rate of 45%. However, local recurrences are common and frequently multiple. Metastases may precede detection of the primary tumor and in general are found in 40%-45% of patients.[68]

On MRI, the tumor is isointense to the muscle on T1WI, although there may be hyperintense components due to the presence of hemorrhage.[52] On T2WI, the tumors are more variable in appearance, but typically hyperintense due to myxoid compoment.[9] The tumors show heterogeneous contrast enhancement and may show areas of necrosis (Fig. 20). Calcification is usually absent or minimal. Vascular or bony involvement may be present.[52]

Practical Guide

Approximately 75% of soft-tissue masses of the foot are benign,[3] and most malignant lesions are primary tumors since metastases to the foot are extremely rare.[56] Even though there is a large overlap between benign and malignant lesions in the foot, MRI characteristics such as signal intensity, lesion location, and involvement of other anatomic structures can be useful for formulating a differential diagnosis when they are evaluated with other clinical findings. On MRI, benign lesions usually demonstrate homogeneous signal intensity, well-defined margins, and no involvement of surrounding anatomic structures. Malignant lesions usually demonstrate heterogeneous signal intensity, poorly defined margins, and involvement of surrounding anatomic structures.[6] Most of the soft tissue masses are isointense to muscle on T1WI and relatively hyperintense on T2WI. Components of the tumor that demonstrate high signal on T1W images include fat, proteinaceous fluid, blood in the methemoglobin phase, and melanin (Table 1). Components of the tumor that demonstrate low signal on T2WI include calcification, fibrous tissue, and hemosiderin (Table 1). IV contrast can help to distinguish cystic from solid lesions (Table 2). Some lesions characteristically arise in association with certain anatomic structures; bursitis (bursae), GCTTS (tendons), PNST

Table 1 Differential Diagnosis Based on Signal Characteristics on MRI

Hyperintense Lesions on T1WI		Hypointense Lesions on T2WI	
Fat	Lipoma/liposarcoma	Calcification	Hemangioma
	Hemangioma		Synovial sarcoma
	Angioleiomyoma		Gout
Melanin	Melanoma	Fibrous tissue	Fibroma
	Clear cell sarcoma		Morton's neuroma
			Desmoplastic fibroma
Methemoglobin	Hematoma	Hemosiderin	GCTS/PVNS
			Hematoma

PVNS, pigmented villonodular synovitis; T1WI, T1-weighted images; T2WI, T2-weighted images.

Table 2 Differential Diagnosis Based on Enhancement Patterns on MRI

Well-Defined Cystic Lesions	Ill-Defined Cystic Lesions	Cyst-Like Solid Lesions
Ganglion / synovial cyst	Abscess	Myxoid dermatofibroma
Epidermal inclusion cyst		Myxoid liposarcoma
Hidradenoma		Chondroma
		Myxoid extraskeletal chondrosarcoma

Table 3 Differential Diagnosis of Superficial Lesions Based on Location

Epidermis	Dermis	Subcutaneous Fat
Superficial PNST	Cutaneous angioleiomyoma	Lipoma/liposarcoma
Melanoma	Epithelioid sarcoma	Angioleiomyoma
	Hidradenoma	Synovial sarcoma
	Dermatofibroma	Acral myxoinflammatory fibroblastic sarcoma

Abbreviation: PNST, Peripheral Nerve Sheath Tumor.

(nerves), plantar fibroma (plantar fascia), and PVNS (joints).[6] Superficial lesions can be differentiated according to their location in one or more skin layers; epidermis, dermis, and subcutis (Table 3).[45]

Conflicts of Interest

The author does not have any disclosure.

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