

Nomenclature for Musculoskeletal Infection on MRI

Erin Alaia, MD (1)
Avneesh Chhabra, MD (2)
Claus Simpfendorfer, MD (3)
Micah Cohen, MD (4)
Doug Mintz, MD (5)
Josephina Vossen, MD, PhD (6)
Adam Zoga, MD, MBA (7)
Jan Fritz, MD (8)
Charles Spritzer, MD (9)
David Armstrong, PhD, DPM (10)
William B. Morrison, MD (11)

- (1) NYU (Erin.Fitzgerald@nyumc.org)
- (2) U T Dallas (avneesh.chhabra@utsouthwestern.edu)
- (3) Cleveland Clinic (simpfec2@ccf.org)
- (4) Albert Einstein (cohenmic@einstein.edu)
- (5) HSS (mintzd@hss.edu)
- (6) VCU (josephina.vossen@vcuhealth.org)
- (7) Thomas Jefferson University Hospital (adam.zoga@jefferson.edu)
- (8) NYU (janfritz777@gmail.com)
- (9) Duke (chuck.spritzer@duke.edu)
- (10) Keck Hospital of USC (dgarmstr@usc.edu)
- (11) Thomas Jefferson University Hospital (william.morrison@jefferson.edu)

Introduction

Terms describing musculoskeletal infection on imaging exams have been circulated in the literature since ‘plain film’ days. These terms have been adapted to magnetic resonance imaging in chapters and scientific articles, often without evidence or consensus. As a result, a problem has emerged that is not unique in medicine and radiology: poorly defined and variably applied terms are used to describe infection that can confuse referring physicians. Terms such as “osteitis” are nebulous; they are applied heterogeneously and lack the scientific weight to guide medical and surgical decisions. An article by Duryea et al [1] found that MRI reports of patients with infection had little influence on clinical management.

This issue is magnified by the problems associated with aspiration and biopsy for definitive diagnosis of bone infection. Hirschfeld et al[2] and Hoang et al [3] have demonstrated that culture yield is as low as 21-28% for diagnosis of infection. Meanwhile, many radiologists are justifiably reticent to biopsy a suspected bone infection for fear of a self-fulfilling prophesy – if the bone is not infected, breaching the cortex in an area of soft tissue infection could actually result in an iatrogenic bone infection; so certainty and clarity on MRI is paramount.

Our goal is to use a panel of Musculoskeletal Radiologists to search the MRI literature for terms relevant to description of infection and clearly define these terms using evidence-based analysis and expert consensus. Recommendations of the panel will form a base for future research as well as clinical work, facilitating effective medical and surgical management decisions.

Methods:

The Practice Guidelines and Technical Standards Committee of the SSR identified musculoskeletal infection as a topic for study and selected SSR members to compose an ad hoc White Paper Committee; twelve musculoskeletal radiologists and one internationally recognized expert surgeon were tasked with developing a consensus on nomenclature for musculoskeletal infection. We limited our study to MR imaging (where the need for standardization is greatest), and limited scope to infection outside of the spine. A literature search and conference call determined the range of terms used; the committee was divided into six subgroups.

Subgroups and assigned terms were as follows: 1) Soft tissue 1—Cellulitis, Soft tissue edema vs ‘bland’ edema, Ulcer, Cloaca, and Sinus tract; 2) Soft tissue 2—Abscess, Phlegmon, Devitalized tissue, and Necrotizing fasciitis; 3) Joints/sheaths—Septic arthritis, Synovitis, Septic tenosynovitis and Erosion; 4) Bone surface—Periostitis, Periosteal reaction, Cortical breakthrough, and subperiosteal abscess; 5) Medullary space—Osteitis, Reactive marrow edema, Osteomyelitis, Intra-osseous abscess, and Brodie’s abscess; 6) Necrosis—Sequestrum and involucrum.

Each subgroup performed a literature review using the following inclusion criteria: original scientific papers pertaining to the terms assigned; preference for manuscripts with a study population of more than 10 patients; and English language articles. The subgroups identified controversies and formulated recommendations (**Table 1**). For each term and clinicopathologic entity, a precise definition was proposed; debate followed, and the committee reached consensus. The work was presented to the membership of the Society of Skeletal Radiology at the annual

meeting for additional recommendations. After modification and Society consensus, the final manuscript was submitted for publication.

Soft Tissue

Edema and Cellulitis

Definition and Diagnosis

Edema is defined as enlargement of tissues in any organ system secondary to entrapped fluid. Soft tissue edema refers to non-encapsulated fluid accumulated in the integumentary system. The term soft tissue edema does not, alone, indicate infection. Non-inflammatory causes of soft-tissue edema include congestive heart failure, diabetic vascular insufficiency, lymphatic obstruction, and acute and subacute venous thrombosis. Inflammatory causes of soft tissue edema include trauma, hypersensitivity response, and infection. Lymphedema is increased fluid in both the integumentary and deep tissues on the extremities related to obstruction of elements of the lymphatic system. Pedal edema indicates a diffuse build-up of fluid, particularly in the subcutaneous and perivascular soft tissues, of the lower legs and feet, and is associated with pregnancy, immobility and obesity.

Cellulitis is an infection of the skin or underlying tissues. Cellulitis is a non-necrotizing superficial bacterial infection involving the dermis and hypodermis (subcutaneous fat and the superficial fascia) without extension to the deep fasciae[4]. Cellulitis is most often caused by β -hemolytic streptococci (groups A, B, C, G, and F), followed by methicillin-sensitive *Staphylococcus aureus* or methicillin-resistant *S aureus*, particularly in high-risk populations[5]. Clinically, cellulitis presents with local erythema, warmth, swelling and tenderness, with

systemic signs of fever and leukocytosis. Bacteria can be introduced through an area of open skin, such as an abrasion or an insect bite, but in some cases, there is no obvious entry site. Once bacteria are in the skin, they cause redness and swelling that can spread rapidly. Cellulitis can happen almost anywhere on the body but the most common place it occurs is the lower legs[6]. Physical signs of cellulitis include progressive erythema, warmth under the skin, and fever. The affected area is often painful, but there can also be regional anesthesia. Many different bacteria can cause cellulitis, but the most common are streptococci (especially beta-hemolytic streptococci) and *Staphylococcus aureus*. Risk factors for cellulitis include chronic swelling (lymphedema), obesity, diabetes and trauma. Other predisposing factors include venous stasis, poor general health, skin laceration or ulceration, venipuncture, eczema, and immunosuppression.

Ultrasound can be a useful first-line investigation. Ultrasound findings may vary according to the site and severity of infection. Ultrasound appearance ranges from diffuse swelling and increased echogenicity of the skin and subcutaneous tissues, to a variable cobblestone appearance depending on the amount of perifascial fluid, the degree of subcutaneous edema, and the orientation of the interlobular fat septa [7]. Color or power Doppler imaging showing hyperemia within the subcutaneous tissues is helpful in establishing an inflammatory element[8].

CT can be useful for evaluation of presence of soft tissue gas, and for the extent of the lesion [9].

MRI is considered the most accurate and specific imaging modality for confirmation of cellulitis, and delineation of the soft-tissue infection extent [10-12]. MRI is more sensitive in the early stages of cellulitis, showing signal changes indicating early inflammation in the subcutaneous

tissues [13]. On MRI, edema and cellulitis can be seen as a reticulated pattern of signal abnormalities within the superficial fascia, seen as hypointense signal on T1 weighted images and hyperintense signal on T2 weighted images[14, 15], with post-contrast images showing an ill-defined area of diffuse enhancement (**Figure 1**) [16-19]. The extent of enhancement depends to some degree on the delay in image acquisition. Diffusion weighted imaging (DWI) can help in identifying abscess formation [20], and can be helpful in diagnosing cellulitis, which will demonstrate some restriction (ADC 1.2–2.0), while simple subcutaneous edema will show lack of restricted diffusion (ADC 2.0–3.0)[21].

Controversy

Bland edema is occasionally difficult to differentiate from cellulitis in the absence of contrast enhanced images (**Figure 2**). Cases of deep cellulitis may be differentiated from necrotizing fasciitis by the absence of involvement of the deep intermuscular fascia[14, 15].

Recommendations

- The term skin and soft-tissue infection (SSTI) should be used over cellulitis until the infection is proven to be confined to the superficial soft tissue [22, 23].
- Intravenous gadolinium enhancement should be used to differentiate abscess from focal cellulitis and other noninfectious causes of subcutaneous edema.

Ulcer

Definition and Diagnosis

Ulcer is the breach of the continuity of skin, epithelium or mucous membrane, that can extend to the epidermis, further to the dermis, or into the deep soft tissue compartments. The lifetime risk for development of foot ulcers among diabetic patients is approximately 34%[24]. Foot ulcers generally result from cumulative mechanical trauma, and their distribution varies according to the patient's gait, type of footwear, and level of activity. Insensate patients with diabetic neuropathy are particularly susceptible to the evolution of foot ulcers, and immobile patients are prone to development of pressure ulcers about the pelvis, heels, and other high risk areas. Skin ulcers compromise the natural defense of the integumentary system and lead to local eschar and scar formation as well as poor perfusion, creating an ideal substrate for bacterial reproduction and invasion. Mild ulcers are often difficult to heal, and severe cases may lead to amputations or systematic infection. Skin ulcers are frequently complicated by bacterial infection, with Gram positive bacteria being the most common pathogen using standard microbiological techniques in most Western nations. More severe wounds have a greater chance of being infected with Gram negative and anaerobic infection [25-27].

MRI allows for preoperative mapping of the extent of the ulcer and the infection and thus can optimize surgical technique and minimize the area of resection [28, 29]. The MR imaging examination should be tailored to the patient and the specific clinical concern. A marker should be placed over shallow ulcers that may not be visible at imaging, and care should be taken to prescribe an imaging field of view such that the entirety of the ulcer and infection are imaged.

MRI imaging manifestations include focal skin disruption with elevated margins, with an associated soft-tissue defect, demonstrating hyperintense signal on T2-weighted images, with marked peripheral enhancement, a finding indicative of granulation tissue at the base of the ulcer **(Figure 3)**.

Controversy

Care must be taken with granulated ulcers that do not have visible soft-tissue defects because the likelihood of a deep infection is similar to that with an open ulcer. Both sterile granulation tissue and soft tissue infection show hyperintense signal on T2-weighted imaging and enhance with intravenous contrast. In this setting, relative indicators of infection include direct continuity of the tissue with a skin ulcer, soft tissue gas and contained fluid collections.

Recommendations

- The presence of ulcer can be an important secondary signs of osteomyelitis and improve diagnostic confidence [16, 30].
- Two clinical findings have been found to have predictive value for osteomyelitis: the size and depth of the ulcer [31] and a positive probe-to-bone test result (i.e., the bone can be probed at the base of the ulcer with a steel probe) [32].
- Markers should be placed over shallow ulcers that may not be visible at imaging. The field of view includes the area of concern and should be tailored to the anatomy.

Cloaca

Definition and Diagnosis

The term cloaca has been used in different contexts. The non-medical definition refers to the structure through which the waste material of cities is discarded. In zoology it refers to the common cavity, located at the end of the digestive tract, for the release of both excretory and genital products in birds, reptiles, amphibians, and most fishes. In medicine and particularly in embryology, at one point in the development of the human embryo, there is a cloaca, located at the far end of the hindgut [33]. As for infection, the term cloaca is used to indicate an opening or rupture of bony cortex overlying an area of osteomyelitis that allows granulation tissue and/or intramedullary pus to be discharged out of the bone [34]. Inherently, the term implies either active or chronic infection of bone, and a cloaca is often continuous with an intraosseous abscess (Brodie's abscess).

On MRI, cloaca demonstrates hypointense signal on T1 weighted images and hyperintense signal on T2 weighted images through the most superficial osseous cortex that can extend only intracortical or can extend to the medullary cavity (**Figure 4**). CT can demonstrate focal thickening of the cortex with a lucent tract extending from the soft tissues into the bone.

Controversy

After an osseous infection is cleared, the remnants of a cloaca often remain at the cortex of the bone. This is essentially reparative callus, but there can be a relative lucency at the site of the previous opening. Thus, it can be difficult to determine when a cloaca is closed on imaging.

Recommendations

- Consider MRI to identify intraosseous fluid collections (abscess) deep to the cloaca as in indicator of persistent infection.
- In the musculoskeletal system, the term cloaca is most appropriate when extension into osseous structures is present.

Sinus tract

Definition and Diagnosis

A sinus tract is an abnormal channel that originates or ends in one opening. A soft tissue ulcer can show a sinus tract leading to a deeper soft tissue collection or abscess. An extra-articular soft tissue process can follow a sinus tract into a joint. Chronic osteomyelitis can be associated with a sinus tract, draining granulation tissue and/or pus from the bone to the skin.

MRI findings of sinus tract include linear fluid-filled structure extending from bone to the skin surface with hypointense signal on T1 weighted images and hyperintense signal on T2 weighted images. On contrast-enhanced images, in the setting of infection, sinus tracts display a “tram-track” pattern of peripheral enhancement (**Figure 3**) [30, 35].

Controversy

The term sinus tract is not specific to infection, but in the setting of soft tissue or osseous infection, an identified sinus tract generally maps the extent of the infection.

Recommendations

- Sinus tracts should be evaluated in all imaging planes. A meandering sinus tract may appear round if viewed in cross section and may be mistaken for an abscess [36].
- While sinus tract is not specific for infection, it is an appropriate term for processes isolated to soft tissues.
- Longstanding sinus tracts from chronic osteomyelitis may lead to malignant transformation, with squamous cell carcinoma being the most frequent malignancy developing from the epithelial lining of the tract [37, 38]

Abscess

Definition and diagnosis

A soft tissue abscess is defined as a well-circumscribed collection with a capsular or fibrous rim in the vicinity of a soft tissue infection, for which common organisms include: staphylococcus aureus, streptococcus, serratia marcescens, and pseudomonas aeruginosa. MR imaging is the preferred modality of choice for evaluating abscess formation[39, 40].

The excellent soft tissue contrast and spatial resolution of MR imaging allows detection and localization of the abscesses, with a reported sensitivity of 97%, and specificity of 77% [39]. On MRI imaging, an abscess is demonstrated as a well-circumscribed area of isointense or hypointense signal alteration on T1W images, fluid signal intensity on T2W images, and with rim enhancement on post contrast T1W images (**Figure 5**), with good to substantial inter-observer performance for detection ($k=0.71$, 95% CI 0.50-0.93) [41]. A surrounding fibrous capsule is seen as a high signal intensity rim on T1W images, and a low signal intensity rim on T2W images [40]. The hyperintense rim on T1W images is referred to as the ‘penumbra sign’. In

isolation, its sensitivity and specificity has been reported as 54% and 98%, respectively for differentiation of soft tissue infection from neoplasm [42].

Abscesses are much more conspicuous on post contrast imaging, with increased reader confidence shown in both diagnosis or exclusion of the lesion in about 46-50% cases [17, 41, 43]. Presence of intravenous contrast helps delineate the necrotic non-enhancing contents within the abscess, which can be masked in the mound of hyperintense edema on the fluid-sensitive sequences [18, 19, 44]. The majority of abscesses occur near a skin ulcer, or at the sites of osteomyelitis [45], and may be present in subcutaneous, fascial or intramuscular tissue planes. False diagnoses can occur due to low conspicuity of an enhancing wall, and tissue necrosis without organized wall or abscess formation.

The addition of diffusion weighted MR imaging (DWI) to conventional MR imaging enhances the detection of soft tissue abscess (**Figure 6**) [46]. Unal et al. had reported sensitivity and specificity of DWI for detecting soft tissue abscesses at 92% and 80%, respectively [47]. Chun et al. recently reported comparable diagnostic performance of MR imaging evaluations with the addition of DWI or post-contrast imaging for finding soft tissue abscess (AUC 0.94, 0.94 for reader 1 and 0.88, 0.87 for reader 2). The apparent diffusion coefficient (ADC) values were also different for abscess (697-1170 mm²/s) versus edema (2842-3259 mm²/s) (p<0.01). False diagnoses were however reported due to phlegmon, devitalized tissue, susceptibility artifacts and partial volume imaging [48].

Abscess more commonly forms in the setting of immunocompromised status, underlying osteomyelitis or diabetes mellitus (DM) [45]. Older patients or those with DM have been shown to encompass larger abscesses [49]. MR imaging appearances in DM or otherwise show similar appearances. On serology, patients with abscesses demonstrate significantly higher erythrocyte sedimentation rates (ESR) and C-reactive protein (CRP) values on admission than those without such complication (ESR= 74 ± 19 vs 56 ± 24 mm/h; $p < 0.05$) [50, 51]. ESR cutoff value of 55 mm/h shows AUC of 0.72 and likelihood ratio test = 12.49; $p < 0.01$ for presence of an abscess. Patients with abscesses show positive blood cultures in 48% patients [51] and require longer hospital stays and more surgical interventions. Bierry et al. had also reported that resolution of abscess is a useful indicator for successful therapy [52].

Controversy

Diagnostic difficulty on the MR imaging diagnosis of abscess arises when there is no intravenous contrast imaging, no rim enhancement is seen on contrast imaging, or DWI imaging has not been performed. Institutions across USA have been slow to adopt DWI in the setting of infections and some do not perform contrast imaging due to the concerns, such as limited diagnostic yield in osteomyelitis detection [17, 41], nephrogenic systemic fibrosis in renal insufficiency patients, and gadolinium-based contrast agent accumulation in the brain [53, 54]. On contrast imaging, both thick and thin rim enhancement could be seen, and it may not be possible to distinguish sterile from actively infected abscess [44, 49]. Although air can be seen more commonly in pyogenic abscess, most abscesses appear similar. Diabetic versus non-diabetic abscesses, as well as tubercular and fungal abscesses show similar appearances and underlying clinical picture is paramount to arrive at such diagnoses [55, 56]. Other terms used in this domain include tissue

necrosis or pyomyositis [57, 58]. Pyomyositis is a primary infection of the muscle but can also occur from a contiguous infection from the skin ulcer or sinus tract (**Figure 1**). It can present as an enlarging soft tissue mass. The abscess characteristics on MR imaging are similar to what has been described above, with presence of focal hyperintense areas on fluid sensitive images showing rim enhancement and diffusion restriction, with underlying muscle changes of inflammation and edema. Patients with such suppurative complications also require longer hospital stays, more surgical interventions and longer duration of antimicrobial and parenteral therapies [57]. In addition, pathologic fractures are common in such patients. Belthur et al. reported that an intramuscular abscess was present in 11/16 patients in the fracture group compared with 8/49 in the non-fracture group ($p < 0.001$)[59].

Recommendations

In the setting of musculoskeletal infection, presence of focal fluid collection, penumbra sign, well-circumscribed borders, rim enhancement on contrast MR imaging and diffusion restriction are adequate for the diagnosis of soft tissue abscess. Due to the clinical, management and prognostic importance of the abscess, these lesions should be actively sought after in the imaging field of view, especially near the site of ulcer/sinus tract and adjacent to the osteomyelitis. Effective communication of presence of drainable abscess is paramount. Contrast administration or DWI are essential for finding otherwise inconspicuous abscesses [17, 43, 48]. Intramuscular abscess is a preferred term to report than pyomyositis, especially if there is a clear drainable abscess. Histopathology terms, such as tissue necrosis, liquefied necrosis or tissue infarction are discouraged. Unless clinical setting dictates, it may not be prudent to render specific microbiology diagnosis, such as tubercular or fungal abscesses.

Phlegmon

Definition and diagnosis

A phlegmon (also referred to as a pre-abscess or immature abscess) is an ill-defined inflammatory mass-like lesion reflecting the acute or infiltrative phase of infected soft tissue, before liquefaction and formation of a pseudocapsule. This is characterized on MRI as an ill-defined area of low T1 and intermediate to high T2 signal, less bright than water signal on fluid sensitive images, and without a circumscribed rim. Following intravenous contrast, there is variable enhancement without a discrete capsule or rim enhancement, which clinically implies that there is no drainable fluid collection (**Figure 1**)[48, 60].

Controversy

The term phlegmon gained acceptance in the setting of retroperitoneal inflammation in the setting of pancreatitis, mediastinal, and head and neck infections, however this term is discouraged in those locations as well [61], since it does not specify the presence of infection or necrosis. Diffusion weighted imaging may show abscess with restriction on ADC map in the region of phlegmonous change.

Recommendations

The use of term phlegmon is discouraged as it would not lead to meaningful clinical action or impact. Focal or diffuse cellulitis are the preferred terms.

Devitalized Tissue

Definition and diagnosis

Devitalized tissue denotes necrotic tissue and occurs almost exclusively in the diabetic foot, or in the setting of peripheral vascular disease. It can be reliably identified on contrast enhanced MR imaging as areas of non-enhancing tissue without rim enhancement [62]. The non-enhancing areas show homogeneously low signal after contrast, often with an abrupt cutoff of enhancement at the demarcating the border (**Figure 7**). This can be seen in up to one fourth of diabetic foot infections [45]. This is clinically important, since complete removal of necrotic tissue is an important component to promote successful wound healing [63, 64].

Controversy

The term devitalized tissue has not gained much popularity in the literature as compared to cutaneous ulcers. The reason might be that ulcer is clinically visible, while devitalized tissue is only visible after contrast administration, which may or may not be administered as part of the protocol, depending on the institution. In addition, it is not clear whether the non-enhancing component truly reflects necrosis, or simply ischemia due to arterial disease or venolymphatic congestion. More studies with pathologic correlation are needed to determine the accuracy of prospective imaging in determining devitalized tissue short of histologic sampling.

Recommendations

For complete reporting, the readers should look for non-enhancing areas, especially underneath and beyond the ulcer margins and can suggest the findings as devitalized or ischemic tissue.

Necrotizing Fasciitis

Definition and diagnosis

Necrotizing infectious fasciitis (NIF) is characterized by rapidly spreading progressive necrosis of the subcutaneous fat and fascia. As opposed to uncomplicated infectious cellulitis or fasciitis, NIF can be rapidly fatal if not promptly diagnosed or treated with surgical debridement [65]. The diagnosis is based on clinical and/or supportive MR imaging findings. Clinical presentation can be very similar to non-necrotizing fasciitis, cellulitis or myositis. The definite diagnostic criterion is surgical exploration depicting necrotic fat with brownish color and lack of resistance to manual debridement along the deep fascial plane. LRINEC (laboratory risk indicator for necrotizing fasciitis) score is used clinically, and patients with a score of >6 should be carefully evaluated for the presence of necrotizing fasciitis [66].

On MR imaging, presence of deep fascial thickening, fascial fluid pockets, heterogeneous fascial enhancement, fascial air pockets, and peripheral band-like limited muscle edema and/or enhancement in a swollen extremity or trunk are suggestive signs of NIF in the setting of increased serology markers of CRP, ESR and white cell count (**Figure 8**) [14, 15, 67, 68]. In a small series, Kim et al. reported significantly greater frequency of findings, such as thickened (more than or equal to 3mm) deep fascia, low signal intensity of the deep fascia on fat suppressed T2W imaging with gas pockets, heterogeneous enhancement of the deep fascia and involvement of three or more compartments in one extremity in NIF as compared to non-necrotizing fasciitis [69]. CT has the advantage over MR imaging in NIF related to its speed, availability and ability to reliably identify even small amounts of soft tissue gas. CT findings include fascial thickening, fat infiltration, focal fluid collections and soft tissue gas, although gas

is seen in less than 50% of cases [69, 70]. On the contrary, in the absence of deep fascial abnormality, MR imaging excludes NIF with excellent negative predictive value [15]. Yoon et al. recently published their work by integrating MR imaging findings with LRINEC score for differentiating NIF from non-necrotizing fasciitis in a case-control study. The AUC was 0.814 (95% CI, 0.727–0.900; $p < 0.001$) for the LRINEC score alone, and 0.862 (95% CI, 0.787–0.938; $p < 0.001$) for the integrated model using two important MR imaging features- thickening of the deep fascia ≥ 3 mm and multi-compartmental involvement[71].

Controversy

Diagnostic dilemma arises as many clinically related and unrelated conditions, such as non-necrotizing fasciitis, pyomyositis, cellulitis with vascular thrombosis, recent radiation treatment, ruptured popliteal cyst, etc. present similarly and on MR imaging, and deep fascial thickening, fluid pockets, and enhancement may be observed in all such conditions, limiting the imaging evaluation [15, 72]. The LRINEC score in isolation exhibits moderate accuracy. Although an integrated predictive model appears to be the most accurate [71], no single criteria serves as a deal breaker or a definitive tool, as identification of necrosis in the mound of inflammation and edema might be beyond the resolution of current imaging [67]. The disease process is also named differently depending upon the anatomic site resulting in confusion in terminology and clinical diagnosis, e.g. Fournier gangrene at the perineum, Ludwig angina at the submandibular region, and gas forming myonecrosis, etc. [73].

Recommendations

Necrotizing soft tissue infection has been previously proposed to encompass all soft tissue infections deep to the dermis [73]. The authors also recommend this term in the impression and the reader can describe the extent of findings in the findings section of the report.

Joints/Sheaths

Septic arthritis

Definition and Diagnosis

The term *septic arthritis* (Origin: Latin *septicus*, from Greek *sēptikos*, from *sēpein* to putrefy) is widely used and part of standard nomenclature. On MR imaging septic arthritis is characterized by joint effusion (often complex, depending on chronicity) although this finding is obviously nonspecific. Following contrast administration, due to synovial inflammation, the capsule and synovium shows thick enhancement. Typically, there is pericapsular edema and enhancement, which helps distinguish infective etiology from chronic inflammatory arthropathies like rheumatoid arthritis. A thin rim of subchondral edema may be observed representing hyperemia (**Figure 9**). In later stages erosions may occur at the margins of the joint, followed by frank bone destruction and osteomyelitis. Generally when septic arthritis is associated with bone marrow edema extending into the medullary space, osteomyelitis should be suggested (**Figure 10**)[52, 74-80].

Controversy

The MR imaging appearance of septic arthritis mimics that of other inflammatory arthropathies, including rheumatoid arthritis, gout, psoriatic arthritis, reactive arthritis, among others. In

addition, the source of the infection can be difficult or impossible to determine by imaging alone. Therefore, history and laboratory correlation are paramount.

Recommendations

We recommend use of the term *septic arthritis* when MR imaging findings fit the criteria above; the terms *infectious arthritis* and *pyogenic arthritis* are rarely used. However, considering overlap of the appearance with other inflammatory conditions, clinical correlation is advised. A monoarticular arthropathy in the appropriate clinical setting should raise the concern for septic arthritis.

In the case of the sacroiliac joint it is acceptable to combine the root term for infection with the joint name: the term *septic sacroiliitis* is part of common usage (use of *infectious sacroiliitis* is less common) [76, 79, 81]. Other specific terms for a particular infection of a particular joint, especially with reference to Mycobacterial infections, have mostly become obsolete: these include *caries sicca* (tuberculous infection of the shoulder) and *spina ventosa* (tuberculous infection of the digit); although *tuberculous dactylitis* is in common use. Similarly, there are many clinical terms used to describe various atypical infections. To avoid confusion, we recommend that standard nomenclature for infection outlined in this article be applied uniformly when reporting MR imaging findings, with a differential regarding the infecting organism, if relevant.

Synovitis

Definition and Diagnosis

Synovitis (the word *synovium* was coined by Paracelsus from Ancient Greek *σύν* (*sún*, “with”) + Latin *ovum* (“egg”), as synovial fluid resembles the consistency and appearance of raw egg

whites) is a nonspecific term commonly used to describe a variety of inflammatory and noninflammatory conditions involving the inner lining of joints. The synovium normally exists as a thin membrane of vascular tissue lining the inner margin of the joint capsule that helps create and maintain the joint fluid through an active process of transudation. Imperceptibly thin, it is barely visible on standard MR imaging exams. If the synovium becomes inflamed it thickens and forms fronds that extend into the joint fluid. Synovitis arising from inflammatory conditions is highly vascular, easily seen on MR imaging as a thick, irregular tissue at the inner margin of the capsule, with thick enhancement on post-contrast images. In later stages, synovial fronds and synecchia extend into the joint fluid (**Figures 9-11**) [52, 77, 78, 80, 82].

Controversy

Synovitis is a nonspecific term that applies to infectious and noninfectious conditions. Care must be taken to communicate any concern for infection when applying the term in this context.

Recommendations

Synovitis is in common usage for a variety of conditions; it is not specific for infection. Therefore, when it is used in an imaging report it must be accompanied by a differential diagnosis including an estimation of risk of infection based on available information.

Septic tenosynovitis / Infectious tenosynovitis

Definition and Diagnosis

The term *tenosynovitis* refers nonspecifically to an abnormal amount of fluid within a tendon sheath. On MRI septic tenosynovitis often demonstrates complex fluid signal with septations or

synechiae (**Figure 11**). On contrast-enhanced sequences there is thick enhancement of the synovial membranes and septations. Often there is ill-defined soft tissue edema around the sheath reflecting hyperemia or capsular rupture and soft tissue spread. Abscesses or sinus tracts may be seen arising from the sheath. Septic tenosynovitis may be primary but more commonly arises from overlying ulceration or underlying septic arthritis [82-85].

A similar definition can be applied to other synovial based tissue such as bursae. *Septic bursitis* or *infectious bursitis* has been described with complex fluid signal in a distended bursa and thick rim enhancement following contrast administration [84, 86].

Controversy

Similar to septic arthritis, without history or laboratory findings the imaging appearance of septic tenosynovitis and septic bursitis overlaps the appearance of other non-infectious inflammatory conditions including rheumatoid arthritis, gout and psoriatic arthritis.

Recommendations

The terms *septic tenosynovitis* and *infectious tenosynovitis* can be used interchangeably when MR imaging findings meet criteria in the setting of infection. For tendons with a paratenon instead of a tendon sheath (such as the Achilles tendon), there is no equivalent term in common usage. In these cases, use of the term *septic tenosynovitis* is inappropriate; descriptive terms including infection of the involved tendon are recommended (i.e., *infection of the Achilles tendon*).

The term *tenovaginitis* has been previously used as a synonym for tenosynovitis (*vagina* is Latin for sheath). However, given its overlapping associations we do not recommend that this term be used in any context.

Erosion

Definition and Diagnosis

The term *erosion* (from Latin *erodere* ‘to wear or gnaw away’) is used in numerous contexts to describe loss of cortical integrity; for example, joint erosions in inflammatory arthropathies can be marginal, periarticular or central depending on the etiology. *Erosion* implies a more active or rapid loss of cortex as opposed to the term *scalloping* which connotes slow remodeling of the bone resulting from juxtacortical mass effect, as can be seen with tenosynovial giant cell tumor.

Erosion is also seen in the context of septic arthritis, initially at the bare areas at the joint margins, later progressing to more generalized articular surface destruction if left untreated. In prior work, erosions related to infection have been described as T2 marrow hyperintensity at the joint margins with variable T1 signal and loss of the black cortical signal on all sequences (Figures 9-11) [52, 80-82].

Controversy

As with *osteitis*, MR imaging findings described for *erosion* may actually represent the early stages of medullary involvement and osteomyelitis. Also, erosions are not specific for infection so without history or lab findings a differential diagnosis of other inflammatory arthropathies would be considered.

Recommendations

The term *erosion* in the context of septic arthritis can be used with the above findings, but with a caveat that the finding could represent early osteomyelitis, especially if the T2 finding extends beyond the immediate subcortical bone.

Bone Surface

Periosteal reaction, Periostitis, Periosteal new bone formation

Definition and Diagnosis

Involvement of the outer layer of the cortex, the periosteum, is a classically described secondary sign of osteomyelitis[87-91]. While the terms periosteal reaction, periostitis, and periosteal new bone formation are used interchangeably in the literature, its presence can be seen in the setting of multiple underlying pathologic conditions, including both septic and sterile etiologies.

The periosteum histologically comprises two layers; an inner cambium layer which is adherent to the bone surface via loosely arranged collagen bundles, spindle shaped connective tissue cells, and elastic fibers, and an outer fibrous layer which is adherent to the adjacent soft tissue via dense connective tissue with interposed blood vessels [92]. The vascular supply of the periosteum in tubular bones is comprised of a plexus of arteries which are supplied by adjacent muscle and soft tissue arteries, and which anastomose with cortical capillaries, believed to supply the outer third of the cortex in adults. In flat bones, periosteal arteries also anastomose with nutrient vessels which act as the predominant blood supply to the cortical and trabecular bone. The periosteum is much more vascular in younger patients which is believed to at least partially account for differences in degree of periosteal reaction

in patients of different ages [87, 89, 90].

The term periosteal reaction describes both processes extending in a centripetal fashion, such as direct spread of soft tissue infection; as well as those extending in a centrifugal fashion, including acute hematogenous osteomyelitis and bone tumors, the latter of which may only result in a lifting of the periosteum from the underlying cortex.

Periosteal reaction can be subdivided into aggressive and nonaggressive forms. Common descriptors of nonaggressive types of periosteal reaction include non-interrupted, smooth, thick or thin, and undulating. Common descriptors of aggressive types of periosteal reaction include interrupted, lamellated/onion skinning, sunburst, Codman triangle, and spiculated[87, 88]. While several authors contend that specific appearances of the types of periosteal reaction can narrow the differential diagnosis of the underlying disease process [87, 88], other studies have shown a lack of specificity, including one attempt to use secondary radiographic and MRI signs to differentiate between Ewing's sarcoma and osteomyelitis [93].

Periosteal reaction may be focal or multifocal. Focal forms include those related to infection, trauma, stress, and neoplasm. Multifocal involvement can be seen with multiple areas of one disease (such as chronic multifocal osteomyelitis) or, especially when diffuse, heralds a systemic process such as hypertrophic osteoarthropathy, which may be primary (pachydermoperiostitis) or secondary (such as from underlying pulmonary pathology in the setting of hypertrophic pulmonary osteoarthropathy, or HPOA), chronic venous stasis/insufficiency, thyroid acropachy, hypervitaminosis A, fluorosis (such as with voriconazole therapy or aerosol fluorocarbon sniffing), and infantile cortical hyperostosis

(Caffey disease) [87, 88].

In the setting of infection, periosteal reaction has been described as a common finding in both the acute and chronic setting and from both hematogenous and contiguous spread. It tends to me a more pronounced finding in osteomyelitis of childhood, in particular in the acute hematogenous form of the infancy period, due differences in local vascularity and degree of adherence to the underlying cortex over time[87, 88]. Various sources have described that the radiographic appearance of periosteal reaction may take anywhere between one to six weeks to develop [87, 88]. Histologically, periosteal reaction in the setting of infection, trauma, stress, and neoplasm reflects an inflammatory response to an injury of the underlying cortex, with reparative granulation tissue and new bone/callus formation as a result of a cytokine mediated response activating osteoclasts and osteoblasts [92].

Controversy

Primarily described as a radiographic and CT finding, periosteal reaction has rarely been described in the MRI literature. One such description is that of a low signal line separated from the underlying cortex by high signal fluid or pus (**Figure 12**) [91]. Perhaps this relative paucity of inclusion in the MRI literature reflects the subtler appearance on MR imaging in addition to the lack of a truly standardized definition of the finding on this lower resolution modality. Also, periosteal reaction becomes a more important finding on radiography and CT which have decreased sensitivity for the more specific bone marrow signal alterations which are easily identified on MRI, often obviating the need for description and detection of periosteal reaction on MRI.

Recommendations

As mentioned previously, the terms periosteal reaction, periostitis, and periosteal new bone formation have previously all been used interchangeably, and are all accurate descriptors of the underlying histopathologic process. However, for the purpose of standardization and in order to create a less nebulous lexicon, it is recommended that the term periosteal reaction be used, as this is the term more ubiquitously found.

Subperiosteal Abscess

Definition and Diagnosis

Subperiosteal abscess is most commonly found in pediatric forms of osteomyelitis, as these patients are known to have looser adherence of the periosteum to the underlying cortex[88]. The development of a subperiosteal abscess, not to be confused with a Brodie's abscess, which occurs in the medullary space typically in the metaphysis in the setting of subacute to chronic osteomyelitis, is a significant prognostic finding often resulting in escalation to surgical management [59, 94-96]. Subperiosteal abscess has been shown to have a higher association with pathologic fracture and higher morbidity, with postulation that the accumulation of pressurized septic material in the subperiosteal and medullary spaces results in compression of the periosteal and endosteal vascular supply and necrosis[59]. In addition to MRI (**Figure 13**), ultrasound has also been found to be a useful modality to establish the diagnosis and to follow patients with known subperiosteal abscess, with the benefits of decreased exam time and precluding the need for sedation or anesthesia[95].

Controversy and recommendations

It is sometimes difficult to assess by imaging alone whether T2 hyperintense material in the subperiosteal space represents a true organized collection/abscess, or a more primitive form of less

defined infection (phlegmon). This distinction does not appear to be clinically significant, as any form of spread of infectious material into the subperiosteal space creates increased pressure and increased risk of necrosis and fracture, and both would intuitively be indications for surgical management. As such, the term subperiosteal spread of infection is the proposed, more inclusive and accurate, descriptor.

The classically held theory of the sequence of infectious seeding in acute hematogenous osteomyelitis stems from the work of Trueta [90, 94], in which the author describes an inward-out propagation of infection, with initial deposition of infectious material in the medullary space of the metaphysis via the nutrient vessels, with subsequent centrifugal extension across the cortex and into the subperiosteal space. More recently, this notion has come into question with the observation that many pediatric patients demonstrate subperiosteal abscess prior to metaphyseal medullary imaging signs of infection[95]. Based on these findings, newer theories are suggesting that infection first spreads to the subperiosteal region, raising the question of the need for more appropriate terminology such as acute infectious “osteoperiostitis” in the setting of findings of subperiosteal involvement without medullary involvement in the course of the evolution of acute hematogenous osteomyelitis[95]. While these newer theories may be true, it is felt that the general term “subperiosteal spread of infection”, as discussed previously, is the preferred term in this specific situation until any future work shows a clinical benefit to making further distinction.

Cortical breakthrough

Definition and Diagnosis

Cortical breakthrough is a descriptive term that also has no specific research around it. Bone destruction

with extension of the disease process through the bony cortex can occur in both neoplastic and non-neoplastic conditions and is distinct from fracture. Intraosseous abscesses can decompress through defects that the infection creates in the cortex (**Figure 4**).

Controversy and Recommendation

It is unclear if there needs to be a distinction between the semantics of cortical breakthrough, cortical destruction and pathologic fracture, given the ultimate common denominator of requiring surgical stabilization. Surely there is overlap in each of these situations and common to each, there is a violation of the cortex due to an underlying infectious or neoplastic process. While cortical breakthrough always results in soft tissue extension of the underlying process, the same is not always true of pathologic fracture. As such, the term cortical breakthrough should be reserved for instances when there is demonstration of direct excavation of the underlying pathologic process through the cortex into the adjacent soft tissue. Certain neoplastic processes are known to have a propensity for this type of spread without overt fracture or cortical destruction, including osseous lymphoma and Ewing's sarcoma. Pathologic fracture should be used in instances where there is a delineated fracture cleft as a result of weakened bone undergoing normal or minimal stresses. When there is poor delineation of the preexisting bone with many small fragments, cortical destruction is the better descriptor. Often times, these processes coexist in the same region of pathology.

Medullary space

Osteomyelitis

Definition and diagnosis

Osteomyelitis is defined as infection of bone which involves the medullary canal. MRI is the preferred diagnostic imaging modality, with prior meta-analysis demonstrating pooled sensitivity of 90%, and specificity ranging from 79-82.5%[97, 98]. In the foot, osteomyelitis almost always occurs from contiguous spread of soft tissue infection—either from a skin ulceration (in the setting of diabetes) or from a post-operative soft tissue defect[99].

On MRI, osteomyelitis can be diagnosed prospectively in cases of clinically suspected infection when marrow demonstrates low signal on T1 weighted images, high signal on T2 fat-suppressed images[100], and enhances after intravenous contrast administration (**Figure 14**) [101]. The appearance of T1 marrow replacement (low T1 signal) is crucial for high specificity for the diagnosis of osteomyelitis. Collins et al found pedal T1 marrow replacement in a *confluent* pattern (contiguous and complete replacement of marrow signal) and a *medullary* distribution (low signal involving a geographic portion of the medullary canal), with concordant matching high T2 signal in 100% of surgically proven cases of pedal osteomyelitis[102]. Conversely, in the same study, osteomyelitis was not observed in any patient with T1 marrow signal abnormality which was either subcortical in location (linear T1 marrow signal abnormality subjacent to the cortex, less than 3mm thick) or in a hazy or reticular pattern (scattered foci of incomplete T1 marrow replacement)[102]. Johnson et al similarly evaluated pedal T1 marrow signal patterns in cases of confirmed osteomyelitis (either by histopathologic sample or secondary clinical endpoint), finding a medullary distribution in 95%, and a confluent pattern of T1 marrow replacement in 100% of cases[103]. Howe et al found similar findings of T1 marrow replacement in non-pedal osteomyelitis[104].

Osteomyelitis is considered acute when symptoms are present for less than two weeks, and chronic when symptoms are present for greater than four weeks[100], with some studies

describing an additional subacute phase, with 1-3 months of symptoms[105, 106]. Aside from clinical history, MRI features are useful in predicting disease duration. Chronic osteomyelitis demonstrates inhomogeneous marrow signal, with areas of active disease demonstrating high T2, low T1 signal, interposed with areas of fibrosis which will demonstrate low signal on both T1 and T2 weighted images[106]. Brodie's abscess is a feature specific for subacute or chronic osteomyelitis[107], while features of chronic osteomyelitis include cortical remodeling, sinus tracts, and sequestra[100, 106].

Controversy

Diagnostic difficulty in the MRI diagnosis of osteomyelitis largely arises when marrow signal is discordant—when marrow is high in signal on T2 weighted images without a matching confluent, medullary pattern of marrow replacement on T1 weighted images. Marrow signal may also be potentially contributed or caused by concomitant trauma, neoplasia, osteonecrosis, arthropathies (including septic arthritis) or may be persistently abnormal after healing[100]. Erdmann et al found marrow signal changes misinterpreted as osteomyelitis in 60% of uncomplicated septic joint infections[100]. Neuropathic osteoarthropathy frequently demonstrates marrow abnormality in the absence of infection and is another commonly encountered diagnostic dilemma[108]. Also, neuropathic osteoarthropathy and infection often coexist.

Vascular insufficiency and tissue necrosis pose additional difficulty in the diabetic population commonly referred for MRI. Vascularity is needed for fat metabolism required to produce confluent, medullary T1 marrow replacement, as well as measurable contrast enhancement. In a cohort of patients with non-enhancing (necrotic) tissue, Ledermann et al found lack of T1

marrow replacement and marrow enhancement to be a source of false negative imaging[45].

Morrison et al also noted lack of vascular enhancement to be a source of false negative imaging in patients with chronic osteomyelitis[101].

In the frequently encountered pediatric population with sickle cell disease,

T1 marrow signal has not been shown to be a reliable diagnostic indicator in differentiating between bone infarct and osteomyelitis ^[109]. Early osteomyelitis may also demonstrate normal T1 signal; fat metabolism and its disappearance in infection occurs more slowly than hyperemia, bone marrow edema and cellular infiltration that results in T2 hyperintensity and enhancement. Therefore, in the case of a discordant marrow pattern on MRI (T1 normal, T2 bright) early onset of osteomyelitis may be proposed.

Recommendations

T1 weighted images should be carefully scrutinized, as an accurate MRI diagnosis of osteomyelitis relies heavily on presence of confluent marrow signal abnormality in a medullary distribution. When T1 marrow signal is discordant (high T2 signal, normal T1 signal), is subcortical in location, or has a hazy, reticular pattern, secondary features should be actively sought after in order to determine and effectively communicate the likelihood of osteomyelitis to the referring clinician. Specifically, cutaneous ulcer and/or sinus tract adjacent to a marrow abnormality has a high positive predictive value for osteomyelitis[110]. Therefore, if a discordant marrow finding is adjacent to an ulcer or sinus tract (or if there are other soft tissue features suggesting infection such as cellulitis or abscess), based on available evidence it should

be communicated to the clinical service that the finding could represent early osteomyelitis; aggressive medical management including wound care and antibiotics (and revascularization as needed) is recommended, with MR imaging follow-up to assure resolution. A diagnosis of chronic osteomyelitis can be made if the marrow cavity demonstrates patchy areas of active disease and fibrosis, especially when coupled with features such as cortical remodeling, Brodie's abscess, sequestrum, or sinus tract.

With regard to neuropathic arthropathy, presence of sinus tract, replacement of subcutaneous fat (indicating cellulitis), and joint erosion are secondary features associated with osteomyelitis, while thin rim enhancement of soft tissue fluid collections, presence of periarticular subchondral cysts, and intraarticular bodies support isolated neuropathic arthropathy without superimposed osteomyelitis[108]. Again, if there is adjacent soft tissue infection and questionable marrow findings, it should be communicated to the clinical team that osteomyelitis is possible. On the other hand, in a diabetic patient with neuropathic disease lack of adjacent soft tissue infection makes osteomyelitis unlikely.

Osteitis

Definition and diagnosis

Osteitis is a nonspecific term for cortical inflammation. Osteitis been previously applied to entities such as osteitis pubis[111], SAPHO (synovitis, acne, pustulosis, hyperostosis, osteitis) syndrome[112], CRMO (chronic recurrent multifocal osteomyelitis)[113, 114], osteitis condensans ilii[115], condensing osteitis of the clavicle, alveolar osteitis, radiation osteitis[116], osteitis fibrosa cystica, osteitis deformans, and with reference to inflammatory or crystal

arthropathies, including rheumatoid arthritis[117] and gout[118] .On MRI, infectious osteitis demonstrates blurring or destruction of the low signal intensity cortex on all pulse sequences, with high T2 signal, and variable signal on T1 weighted images (**Figure 15**).

Controversy

Regarding osteomyelitis, usage of the term osteitis or reactive marrow edema, particularly when there are other imaging features with high positive predictive value for osteomyelitis (adjacent ulceration) is potentially misleading and may result in incorrect management.

MRI imaging manifestations of osteomyelitis are dependent on both the imaging timepoint and vascular integrity of the regional soft tissues. The overwhelming majority of pedal infections result from contiguous spread from an ulceration, involving first the subjacent soft tissues, the cortex, and finally the medullary canal. Subjects imaged prior to metabolization of fat within the medullary canal, either because of early onset of infection or because of insufficient or nonexistent tissue vascularity may fail to demonstrate the expected confluent, medullary T1 marrow replacement[45].

Conversely, T2 marrow signal changes subjacent to an ulceration will appear earlier in the infection. The pattern and distribution of T2 discordant marrow signal in this population has been only sparsely explored. In patients with discordant marrow signal, Sax et al found a marrow/joint fluid ROI ratio of >53% to be the strongest risk factor for developing osteomyelitis[119]. Collins et al also found the intensity of T2 signal relative to joint fluid to have predictive value, demonstrating marrow T2 signal approaching that of joint fluid to have an

80% positive predictive value, relative to 38% positive predictive value for T2 signal abnormality measuring less than joint fluid[102].

Recommendations

We recommend avoiding usage of the term osteitis in patients referred for MRI evaluation of osteomyelitis. Instead, categorization of “high likelihood of osteomyelitis” or “low likelihood of osteomyelitis” or “suspicion for early osteomyelitis” should be used in the report impression to more effectively communicate to the referring clinician. In cases with equivocal marrow findings choice between these terms is primarily based upon other information (soft tissue findings, laboratory findings, clinical course).

Any T2 hyperintense marrow signal abnormality (regardless of T1 signal) in close proximity to a soft tissue ulceration, sinus tract or abscess should be reported a “high likelihood of osteomyelitis”. This is supported by the findings of Duryea et al, who reported 61% of patients with discordant T2 hyperintense signal either had an initial histologic diagnosis of osteomyelitis, or ultimately progressed to osteomyelitis[1].

Clinical parameters should be reviewed to determine post-MRI likelihood of osteomyelitis.

Markanday previously proposed a scoring system to determine likelihood of osteomyelitis, with the accumulation of four points indicative of high probability. Clinical parameters in this scoring system included positive probe to bone test or visible cortical bone in ulcer (1 point), visible cancellous bone in ulcer (2 points), ESR >70 (1 point), cortical destruction on radiographs (1 point), ulcer size greater than 2 cm² (1 point), clinical gestalt (1 point), positive MRI (2 points),

negative MRI (-2 points)[120]. Despite the high sensitivity, specificity, and positive predictive value of MRI for osteomyelitis, scoring systems such as these reinforce that MRI is just a component of the overall clinical diagnosis and management of osteomyelitis.

In difficult or uncertain cases, it is reasonable to recommend interval follow-up MRI. In patients with soft tissue infection we do not recommend percutaneous biopsy, which may potentially seed the uninfected bone and cause iatrogenic osteomyelitis.

Intraosseous Abscess

Definition and diagnosis

An intraosseous abscess is an intraosseous cavity filled with pus, with a rim of granulation tissue. First described by Brodie, intraosseous abscesses occur most often in children, have a predilection for the metaphysis of long bones, and are observed in the subacute or chronic stage of osteomyelitis, when the organism has reduced virulence[87]. On MRI, intraosseous abscesses demonstrate high T2 and low to intermediate T1 weighted signal, rim enhancement after contrast administration, and occasionally have a rim of medullary sclerosis or associated periosteal new bone formation (**Figure 16**) [105]. In pediatric patients, occasionally the abscess will traverse the physis and extend into the epiphysis, although with effective antibiotic treatment, growth disturbance is rare (**Figure 17**) [121].

Controversy

In patients referred with clinical suspicion of osteomyelitis, the diagnosis of intraosseous abscess may be relatively straightforward. Difficulty arises, however, if there is any dilemma in differentiating between abscess and neoplasia, for example Ewing's sarcoma or other marrow

replacing process. A cortically based abscess with perilesional sclerosis and periosteal new bone formation may mimic an osteoid osteoma.

Recommendations

All cases should be scrutinized for presence of the penumbra sign, a discrete peripheral rim of mildly hyperintense signal about the low signal central abscess cavity on T1 weighted images, seen in 75% of intraosseous abscesses in a series by Grey et al, and histologically representing a rim of hypervascular granulation tissue [105]. Another series by McGuinness et al found the penumbra sign to have an average specificity of 96%, and a sensitivity of 27% for the identification of bone or soft tissue abscess[42]. The rim sign has also been described as a useful indicator of intraosseous abscess on MRI, appearing as well defined T1 and T2/STIR hypointense rim about the periphery of the abscess cavity, and found in 93% of a series by Erdman et al[100].

Diffusion weighted imaging has been previously described as an adjunct diagnostic tool for the diagnosis of soft tissue abscesses, and may have a role, particularly in patients unable to receive intravenous contrast, although further studies are needed to determine utility for intraosseous abscesses[48].

Necrosis

Sequestrum

Definition and Diagnosis

While somewhat arbitrary in terms of time course, the presence of dead bone usually with fistulous tracts secondary to infection confirms the presence of chronic osteomyelitis [122].

Mechanistically, increased osseous pressure leads to vascular compromise and ultimately bone death. In addition, the host's inflammatory response including cytokines and leucocytes increase osteoblastic activity and lead to bone loss[123]. This devitalized bone becomes distinct from or "sequestered" from the adjacent more viable bone. Such nonviable, necrotic, and distinct bone contains bacteria which are protected from circulating antibiotics and is called a *sequestrum* [122, 124, 125]. Sequestra may be surrounded by granulation tissue [126]. More simplistically, a "bony sequestrum is defined as a piece of devitalized bone that has become separated from the surrounding bone during the process of necrosis"[127, 128].

While often adequately depicted with radiographs, sequestra are best identified with CT. On CT a sequestrum will appear as a focal area of mineralization surrounded by relative lucency [125]. The addition of Spect CT and Pet CT will show a relative area of absent tracer accumulation corresponding to the sequestrum surrounded by increased tracer accumulation corresponding to the more viable infected tissue [129, 130]. The appearance of sequestra on MRI are not well described, but are likely going to be poorly visualized as areas of decreased signal given the mineralized bony constituent (**Figure 18**). Importantly, the sequestrum, if identified as such, often in conjunction with CT imaging, should not enhance appearing similar to an abscess, especially if cortically based. However, peripheral enhancement due to granulation tissue surrounding the sequestrum may be possible [127].

Controversy

In a chronically infected patient, the presence of a sequestrum is definitive for chronic osteomyelitis. However, a sequestrum per se on an imaging study is not definitive of infection.

Sequestrum have been reported in primary lymphoma of bone, Langerhans Cell Histiocytosis, malignant fibrous histiocytoma, and occasionally metastatic disease. In addition, an osteoid osteoma or osteoblastoma may be confused for a sequestrum. Rarer lesions which have sequestra reported include chondroma and osseous lipomatous tumors[125, 127].

Recommendations

A clinical history of chronic infection is paramount to arriving to the diagnosis of bony sequestrum. If the diagnosis is unclear on MRI, CT should be recommended for further characterization.

Involucrum

Definition and Diagnosis

The term *involucrum* evolved from the Latin words *involvere* and *involucre*, which mean *roll in* or *envelope*[131]. In the context of *osteomyelitis*, an *involucrum* describes the formation of a spherical capsule of viable, new bone around an area of sequestered, necrotic bone. The involucrum can be viewed as a response to wall-off the necrotic, infected *sequestrum*. Depending on the location of the sequestrum, the involucrum may involve cancellous or cortical bone but often involves periosteal new bone formation.

The involucrum consists of different layers. The inner lining of the involucrum faces the sequestrum and consists of granulation tissue, which is often covered by a biofilm that protects bacteria from phagocytosis and humoral immunity[132]. The outer layer of the *involucrum*

consists of expansile, coarse, woven bone, which is typically sclerotic in the mature stage. Eventually, the outer margin of the *involucrum* merges with the parental bone (**Figure 19**).

A *cloaca* refers to a focal perforation of the *involucrum* new bone formation. In former times, the term *cloaca* described sewer systems and likely evolved from the Latin word *cluere*, which means to cleanse. The *cloaca* permits drainage of the sequestrum contents via a *sinus tract*. Eventually, sinus tracts perforate through the skin surface and decompress debris, bacteria, and pus. The size of an *involucrum* can increase substantially with persistent chronically active osteomyelitis.

In hematogenous osteomyelitis, the formation of an *involucrum* is more common in metaphyseal infections of infants and children, and less common in epiphyseal infections in adults.

The typical radiographic appearance of an *involucrum* is sclerotic, expansile bone that wraps around a sequestrum. The outer surface near periosteum may be coarse and irregular. The thickness varies depending on the length of time of the chronically active osteomyelitis, whereas increasing thickness over time suggests active infection[133]. A *cloaca* presents as focal partial-thickness defect (incomplete) or full-thickness perforation within the *involucrum* of varying sizes. On radiographs, the visibility of a *cloaca* depends on the location relative to the direction of the x-ray beam[134], whereas even small and incomplete *cloaca* are well visible on high-resolution CT images [135]. MRI can demonstrate and characterize a *cloaca* to better advantage, although the mineralized contents are less well visualized than on CT image. On MR images, the inner granulation tissue lining of the *involucrum* may demonstrate signal hyperintensity on T1-

weighted MR images, like the penumbra sign described in subacute chronic osteomyelitis[136]. The signal intensities of the osseous component of the *involucrum* vary and include edema pattern on STIR and T2-weighted images, and hypo- or hyperintensity on T1-weighted MR images depending on the amounts of marrow fat contents and sclerotic bone [137].

Curative surgical intervention is usually referred to as *debridement*, which refers to the removal of infected and necrotic bone and tissues. During surgery, *sequestrectomy* and the complete opening of the *cloaca* are essential to incite healing. In contrast, resection of the *involucrum* is not required but can be performed to correct deformities and to avoid the formation of a new sequestrum within the remaining *involucrum*. Local treatment of the resulting bone cavity includes antibiotic beads and cancellous bone grafts.

Controversy

Differential diagnostic consideration of an involucrum consist of cortical thickening secondary to an osseous stress reaction, benign bone lesions (osteoid osteoma , osteoblastoma, fibrous dysplasia), malignant bone lesions (osteosarcoma, Ewing sarcoma, lymphoma, and chondrosarcoma), Paget's disease, avascular necrosis, and healing or healed trauma.

Recommendations

A diagnosis of chronic infection is important in establishing the diagnosis of involucrum. Cases with potential involucrum should be carefully inspected for the presence of sequestrum and cloaca, which should be communicated to the ordering team, with CT and MRI playing potential complementary roles in optimizing diagnostic accuracy.

Conclusion

This consensus statement summarizes current understanding of the pathophysiologic characteristics and MR imaging findings of musculoskeletal infection outside of the spine and proposes nomenclature to improve effective communication across clinical specialties in order to help avoid diagnostic errors that could affect patient care.

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Table 1. Summary of terms, controversy, and recommendations for Musculoskeletal Infection on MRI

Current Term	Definition	Controversy/Difficulty	Recommendations	Recommended Terms
Soft tissue				
Edema	Tissue enlargement secondary to entrapped fluid	Differentiation of bland edema from cellulitis	Intravenous gadolinium enhancement differentiates focal cellulitis from bland edema	Edema
Cellulitis	Non-necrotizing superficial bacterial infection	Differentiated from necrotizing fasciitis by absence of involvement of deep intermuscular fascia	“Skin and Soft Tissue Infection” recommended until infection proven to be limited to superficial soft tissue	Skin and soft tissue infection: Extent of soft tissue infection unknown Cellulitis: Soft tissue infection without deep fascial extension
Ulcer	Breach of the continuity of skin, epithelium, or mucous membrane	Granulated ulcers may not have an identifiable skin breach, but carry a similar risk of deep infection.	Tailor field of view to region of concern, and place markers over shallow ulcers	Ulcer
Cloaca	Cortical disruption overlying an area of osteomyelitis that allows granulation tissue and/or intramedullary pus to be discharged from bone	Remnant of reparative callus may persist within the cortex after the infection has cleared.	<ul style="list-style-type: none"> • Consider repeat MRI to identify intraosseous fluid collections deep to the cloaca as an indicator of persistent infection. • Term most appropriate when intraosseous extension is present. 	Cloaca
Sinus Tract	Abnormal channel with single opening	<ul style="list-style-type: none"> • Meandering sinus tract may be mistaken for abscess if viewed in cross section • May undergo malignant transformation to squamous cell carcinoma 	Should be evaluated in all imaging planes	Sinus Tract

Abscess	Circumscribed collection with capsular or fibrous rim in the vicinity of a soft tissue infection	Difficult to discern without intravenous contrast or diffusion weighted imaging (DWI)	<ul style="list-style-type: none"> • Intravenous contrast or DWI • Intramuscular abscess is preferred over pyomyositis 	Abscess
Phlegmon	Acute or infiltrative phase ill-defined inflammatory mass-like lesion, prior to liquefaction and pseudocapsule formation	<ul style="list-style-type: none"> • Does not specify the presence of infection • DWI may show abscess in a region of phlegmonous change 	The term phlegmon should be avoided.	Focal or Diffuse Cellulitis
Devitalized Tissue	Necrotic soft tissue	<ul style="list-style-type: none"> • Only visible after contrast administration • Unclear whether tissue is truly necrotic or ischemic 	<ul style="list-style-type: none"> • Recommend contrast administration • Careful scrutiny of soft tissues underneath or beyond ulcer margin 	Devitalized Tissue
Necrotizing Fasciitis	Rapidly spreading progressive necrosis of the subcutaneous fat and fascia.	Clinical and imaging findings overlap with non-necrotizing fasciitis, pyomyositis, cellulitis with vascular thrombosis, prior radiation treatment, ruptured popliteal cyst	The term Necrotizing soft tissue infection is proposed to encompass all soft tissue infections deep to the dermis.	Necrotizing soft tissue infection
Joints/Sheaths				
Septic arthritis	Intrarticular infection	Imaging appearance indistinguishable from inflammatory or crystal arthropathies	<ul style="list-style-type: none"> • Clinical correlation paramount • Monoarticular arthropathy should raise suspicion • Specific terms for type of infection of specific joint should be avoided • Acceptable to use term septic sacroiliitis 	Septic arthritis Septic sacroiliitis
Synovitis	Inflammatory and non-inflammatory conditions involving the inner lining of joints.	Nonspecific term applying to infectious and non-infectious conditions	When reported, must be accompanied by a differential diagnosis including an estimation of risk	Synovitis
Septic or infectious tenosynovitis	Infection of tendon sheath	Imaging overlap with tenosynovitis due to inflammatory or crystal arthropathies	<ul style="list-style-type: none"> • Septic or infectious tenosynovitis may be used when imaging findings match clinical picture • Term should be avoided in tendons without sheath (i.e. Achilles) • Tenovaginitis should be avoided 	Septic or infectious tenosynovitis

Erosion	Loss of cortical integrity	<ul style="list-style-type: none"> • May represent early stage of medullary involvement and osteomyelitis • Also seen in inflammatory or crystal arthropathies 	May be used in the context of septic arthritis, with caveat of possible early osteomyelitis, particularly with extension beyond the immediate subcortical bone	Erosion
Bone Surface				
Periosteal reaction, periostitis, periosteal new bone formation	Infection involving the outer layer of the cortex	Paucity of MRI literature on term due to lower MR spatial resolution, marrow signal changes specific for osteomyelitis		Periosteal reaction
Subperiosteal abscess	Encapsulated fluid collection confined to the subperiosteal space	May be difficult to differentiate subperiosteal abscess from phlegmon	Subperiosteal location and not differentiation between abscess and phlegmon is clinically important	Subperiosteal spread of infection
Cortical breakthrough	Neoplastic or non-neoplastic bone destruction, with extension of disease through cortex, distinct from fracture	Difficult to differentiate cortical breakthrough from pathologic fracture	Term should be limited to demonstration of direct excavation of pathologic process through cortex into adjacent soft tissue.	Cortical breakthrough
Medullary Space				
Osteomyelitis	Infection of bone which involves the medullary canal	<ul style="list-style-type: none"> • Discordant marrow signal • Concomitant trauma, neoplasia, arthropathies, or osteonecrosis • Vascular insufficiency may fail to produce T1 marrow replacement, enhancement 	<ul style="list-style-type: none"> • Discordant marrow signal adjacent to ulcer or sinus tract should be communicated as possible early osteomyelitis • Secondary features (adjacent soft tissue infection) should be sought out in cases of complicated osteomyelitis 	Osteomyelitis
Osteitis	Nonspecific cortical inflammation	Early osteomyelitis may fail to demonstrate confluent T1 marrow replacement	<ul style="list-style-type: none"> • Avoid terms osteitis and reactive marrow edema • In selected cases, follow-up MRI reasonable 	<ul style="list-style-type: none"> • High likelihood of osteomyelitis • Low likelihood of osteomyelitis
Intraosseous Abscess	Intraosseous cavity filled with pus, with rim of granulation tissue	May be difficult to differentiate between intraosseous abscess and neoplasia	<ul style="list-style-type: none"> • “Penumbra sign”, “rim sign” serve as useful indicators of intraosseous abscess • DWI helpful 	Intraosseous abscess

Necrosis				
Sequestrum	Devitalized bone sequestered from viable bone in chronic osteomyelitis	Not definitive for infection, and have been reported in lymphoma, Langerhan's Cell Histiocytosis, malignant fibrous histiocytoma, metastatic disease	<ul style="list-style-type: none"> • Clinical correlation paramount • CT most useful diagnostic modality 	Sequestrum
Involucrum	Formation of a spherical capsule of viable, new bone around an area of sequestered, necrotic bone	Potential mimics include osseous stress reaction, benign bone lesions (osteoid osteoma, osteoblastoma, fibrous dysplasia), malignant bone lesions (osteosarcoma, Ewing sarcoma, lymphoma, and chondrosarcoma), Paget's disease, avascular necrosis, and healing or healed trauma.	<ul style="list-style-type: none"> • Clinical correlation imperative • Cloaca and sequestrum should be actively sought out in any case of potential involucrum 	Involucrum

Figures



Fig. 1- Focal cellulitis of the hand in a 54-year-old male. Coronal T2 fat-suppressed (A) and coronal T1 fat-suppressed post-contrast (B) images demonstrate focal, somewhat mass-like edema and enhancement of the subcutaneous tissues (white arrowheads) and the regional musculature (black arrowheads) along the radial aspect of the second metacarpophalangeal joint, compatible with focal cellulitis, and pyomyositis, respectively, without discrete rim enhancement to indicate abscess formation. Also noted is osteomyelitis of the second metacarpal head and proximal phalanx base (arrows, A, B).

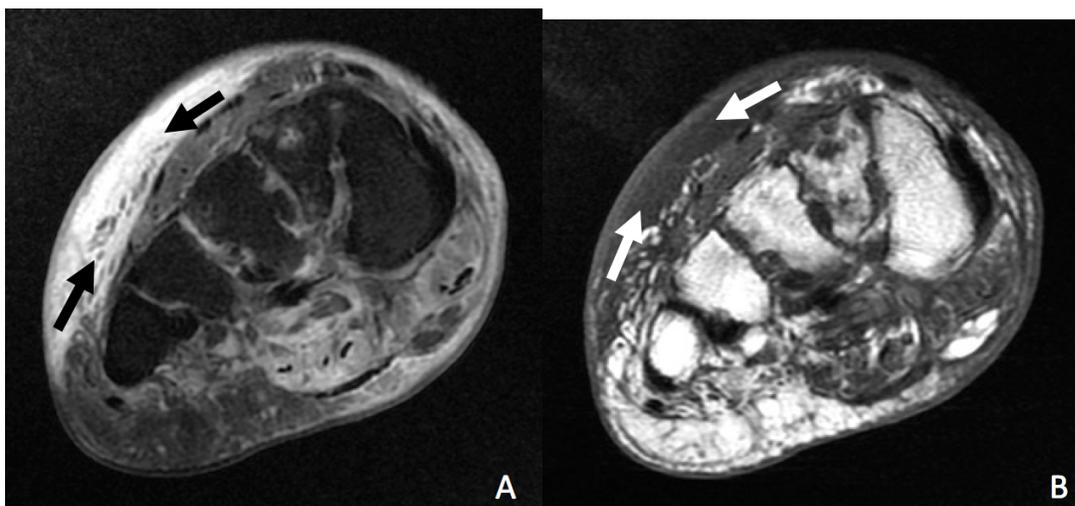


Fig. 2-Bland edema in a 72-year-old male. Short axis T2 weighted fat suppressed (A) and T1 weighted (B) images show confluent subcutaneous edema at the dorsum of the foot (arrows),

with thickening of the dermis but no visible skin defect or organized fluid collection. This is a diagnostic conundrum, as conventional MR sequences cannot reliably differentiate cellulitis from bland edema in this scenario.

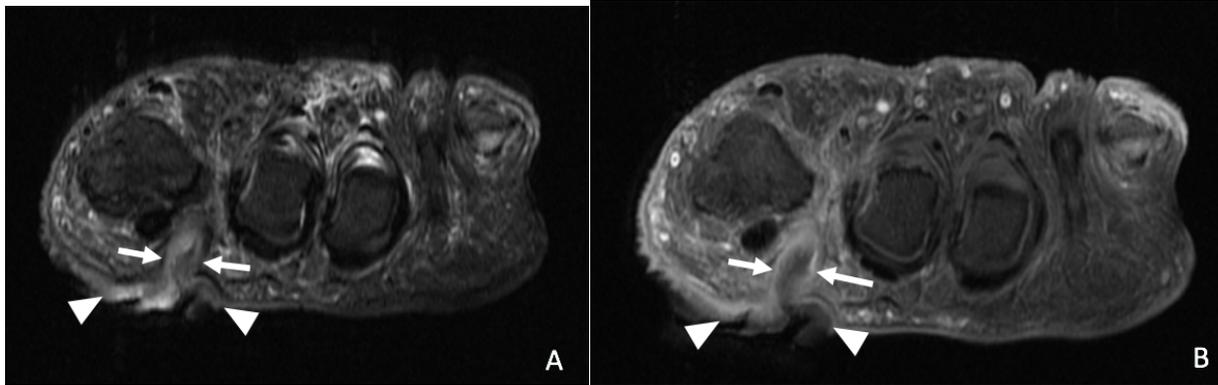


Fig. 3 –Plantar ulcer and sinus tract in a 55-year-old male. Short axis T2 fat-suppressed (A) and T1 fat-suppressed post-contrast images (B) demonstrate ulceration of the plantar soft tissues underlying the first webspace (arrowheads), with contiguous sinus tract (arrows) outlined by thin enhancing granulation tissue.

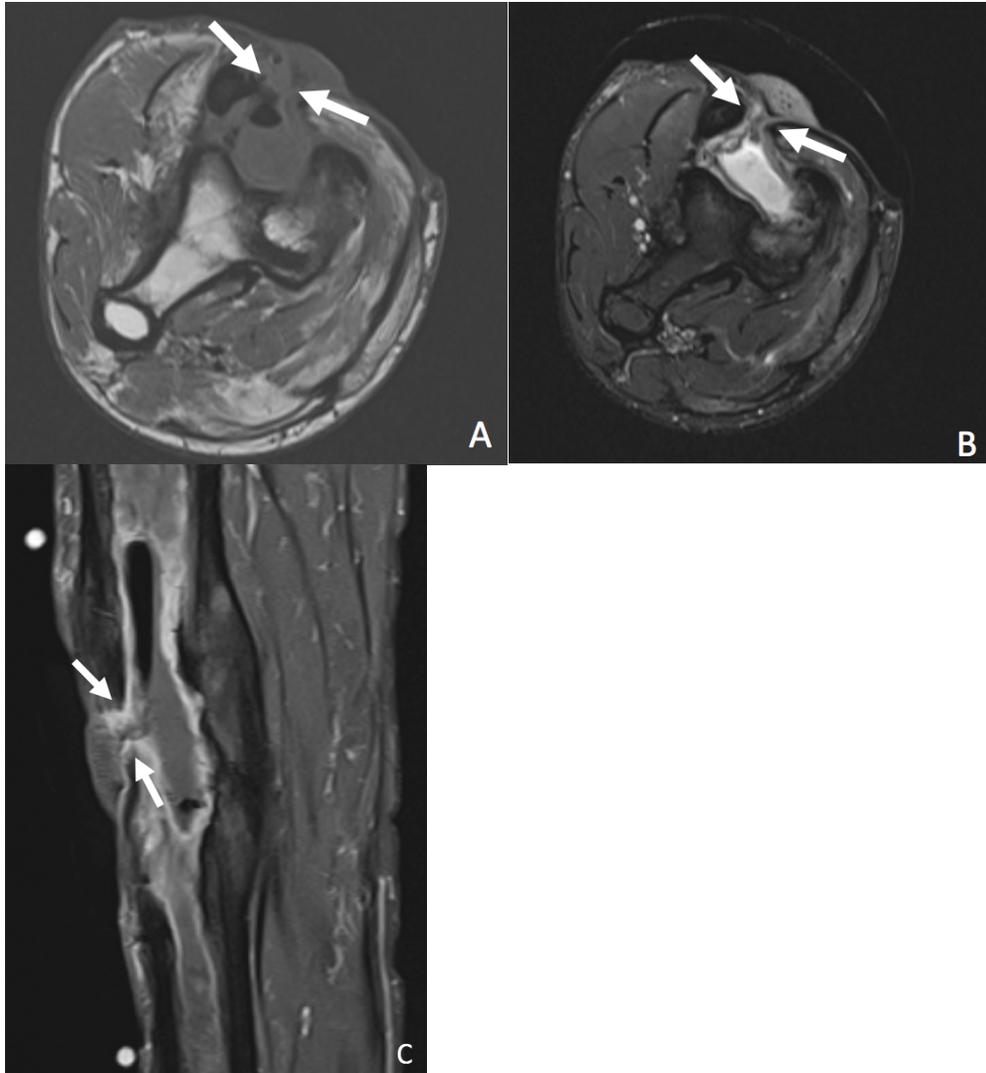


Fig. 4- Cloaca and sinus tract in a 55-year-old male with chronic osteomyelitis. Axial 1(A), axial T2 fat-suppressed, and sagittal (C) T1 fat-suppressed post-contrast images of the lower leg demonstrate chronic tibial osteomyelitis, with intramedullary fluid collection demonstrating cortical breakthrough, and decompressing to the skin surface via a cloaca and a contiguous sinus tract (arrows).

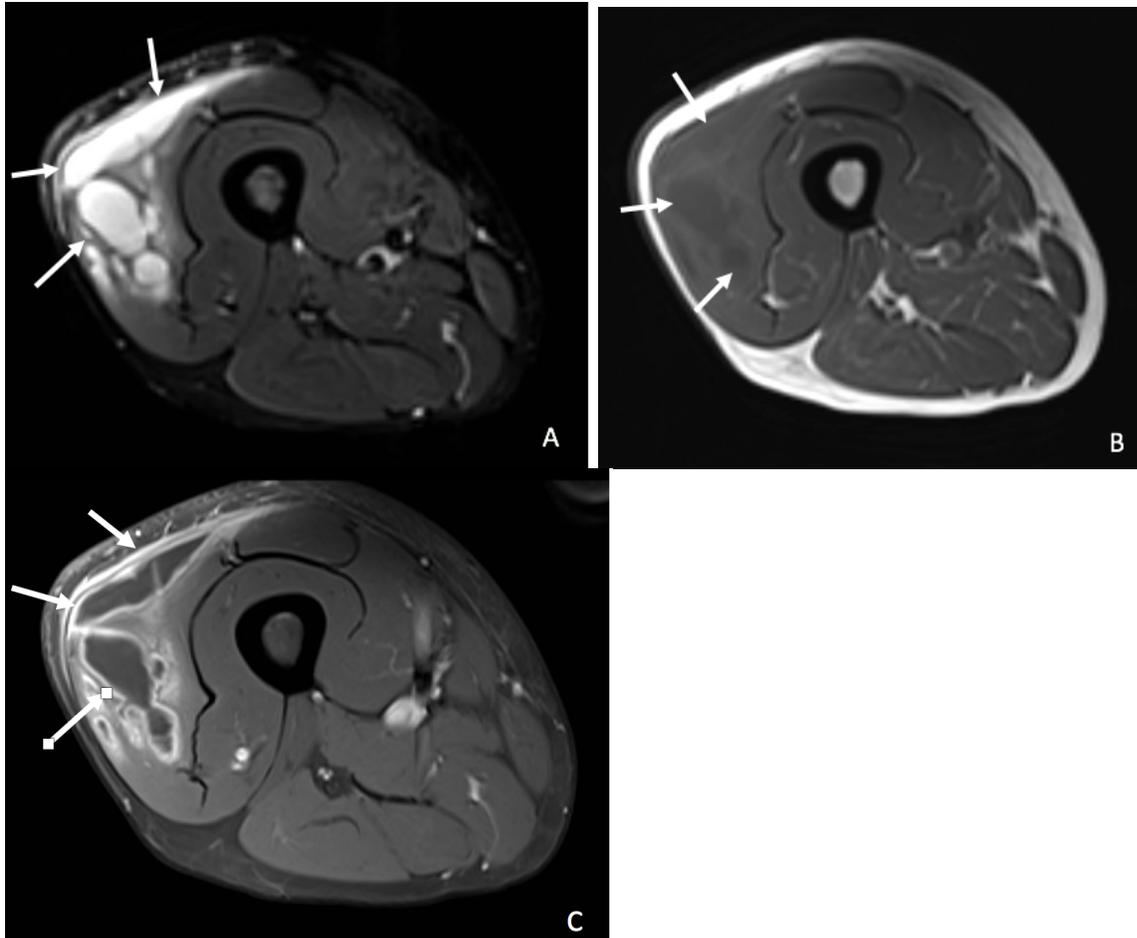


Fig. 5- Thigh abscess in a 33-year-old male. Axial STIR (A), axial T1 (B), and axial T1 fat suppressed post-contrast (C) images demonstrate an intramuscular multiloculated fluid collection within the lateral thigh (arrows), involving the vastus lateralis and rectus femoris muscles, demonstrating avid peripheral rim enhancement (arrows, C).

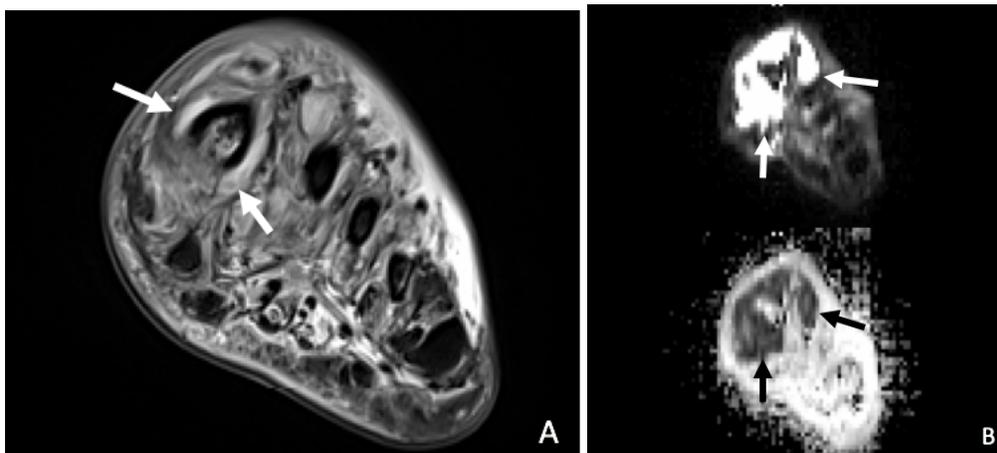


Fig. 6- Utility of diffusion weighted imaging for abscess detection in a 47-year-old female. Short axis T2 Dixon water map image of the foot demonstrates a fluid collection encircling the

first metatarsal (arrows), demonstrating high signal on diffusion weighted images (arrows B, image above, b=800), and low signal on the ADC map (arrows B, image below), features compatible with abscess (ADC= 0.5-0.6).

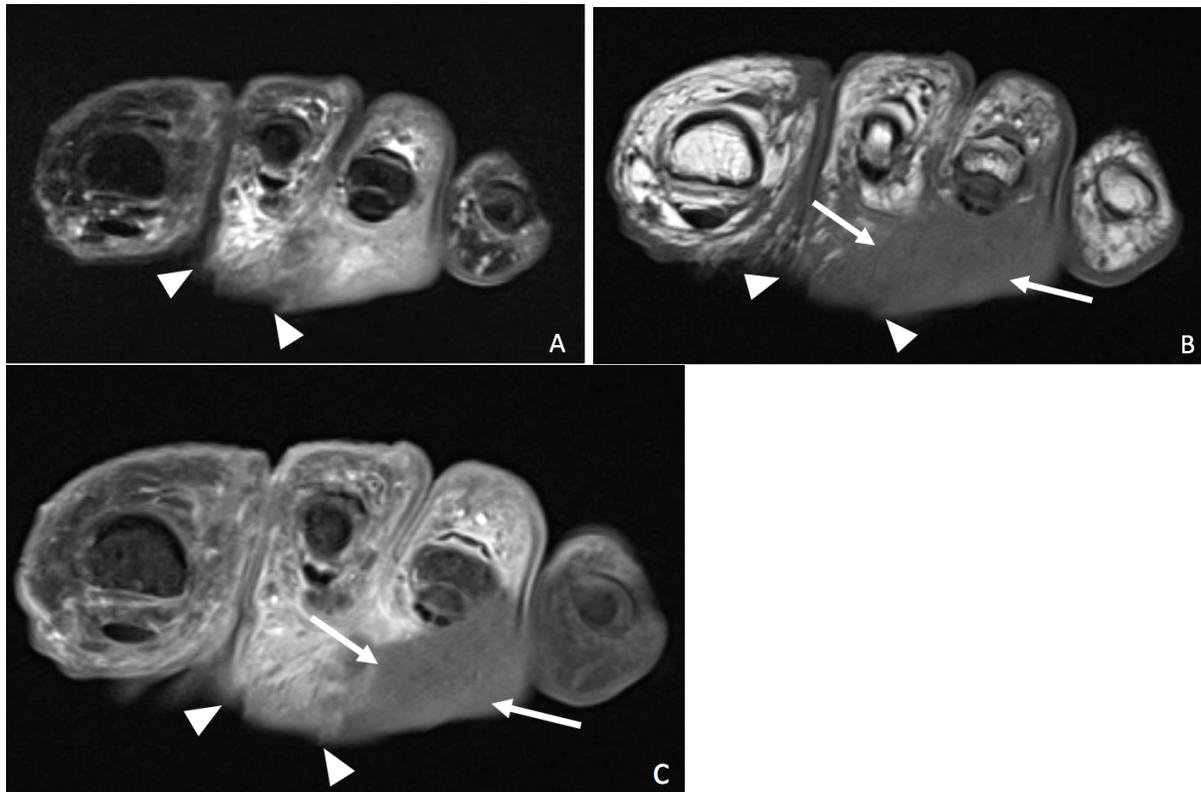


Fig. 7- Devitalized tissue in an 83-year-old diabetic female. Short axis STIR (A), T1 (B), and T1 fat-suppressed post-contrast (C) images of the foot demonstrating shallow ulceration of the plantar soft tissues (arrowheads), with surrounding cellulitis, and a geographic area of non-enhancement (arrows), compatible with devitalized tissue.

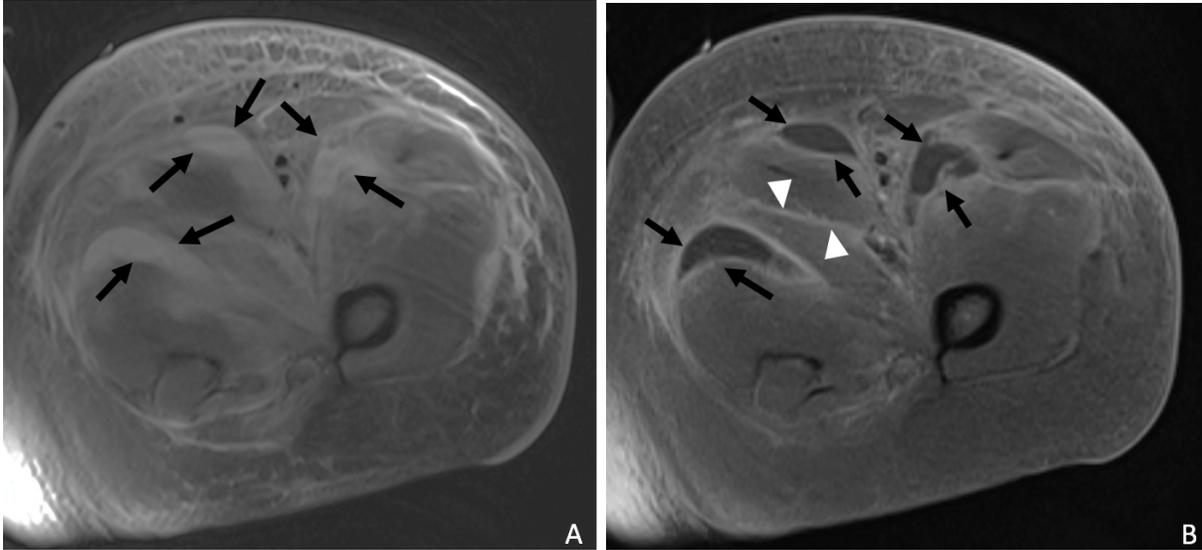


Fig. 8- 39-year-old female with necrotizing soft tissue infection of the thigh. Axial T2 fat-suppressed (A) and T1 fat-suppressed post-contrast (B) images of the thigh demonstrate evidence of a necrotizing soft tissue infection, with rim-enhancing abscesses extending along deep fascial planes (arrows), with thick enhancement of the deep fascia (arrowheads).



Fig. 9- Septic arthritis in a 35-year-old male.

A) Sagittal T1-weighted MR image of the ankle shows erosion (arrow) at the anterior joint margin with loss of black cortical signal.

B) Sagittal STIR MR image demonstrates a joint effusion (arrows) with complex signal representing synovitis (black arrowhead). Thin, subcortical bone marrow edema (white arrowheads) at the bare area of the joint is related to erosion.

C) Sagittal T1-weighted fat suppressed post-contrast MR image shows thick synovial enhancement (arrows) consistent with synovitis. Note subchondral enhancement (arrowheads) in areas of erosion.



Fig. 10- Septic arthritis with osteomyelitis in a 67-year-old male.

A) Coronal T1-weighted MR image of the hip shows erosion at the lateral femoral neck and superomedial acetabulum with loss of cortical signal (arrowheads). Confluent replacement of normal fat signal in the medullary space of the adjacent acetabulum (arrow) is consistent with progression to osteomyelitis.

B) Coronal T1-weighted fat suppressed post-contrast MR image reveals synovitis with enhancement of the joint fluid and capsule (arrowheads). Medullary enhancement in the acetabulum (arrow) represents osteomyelitis.

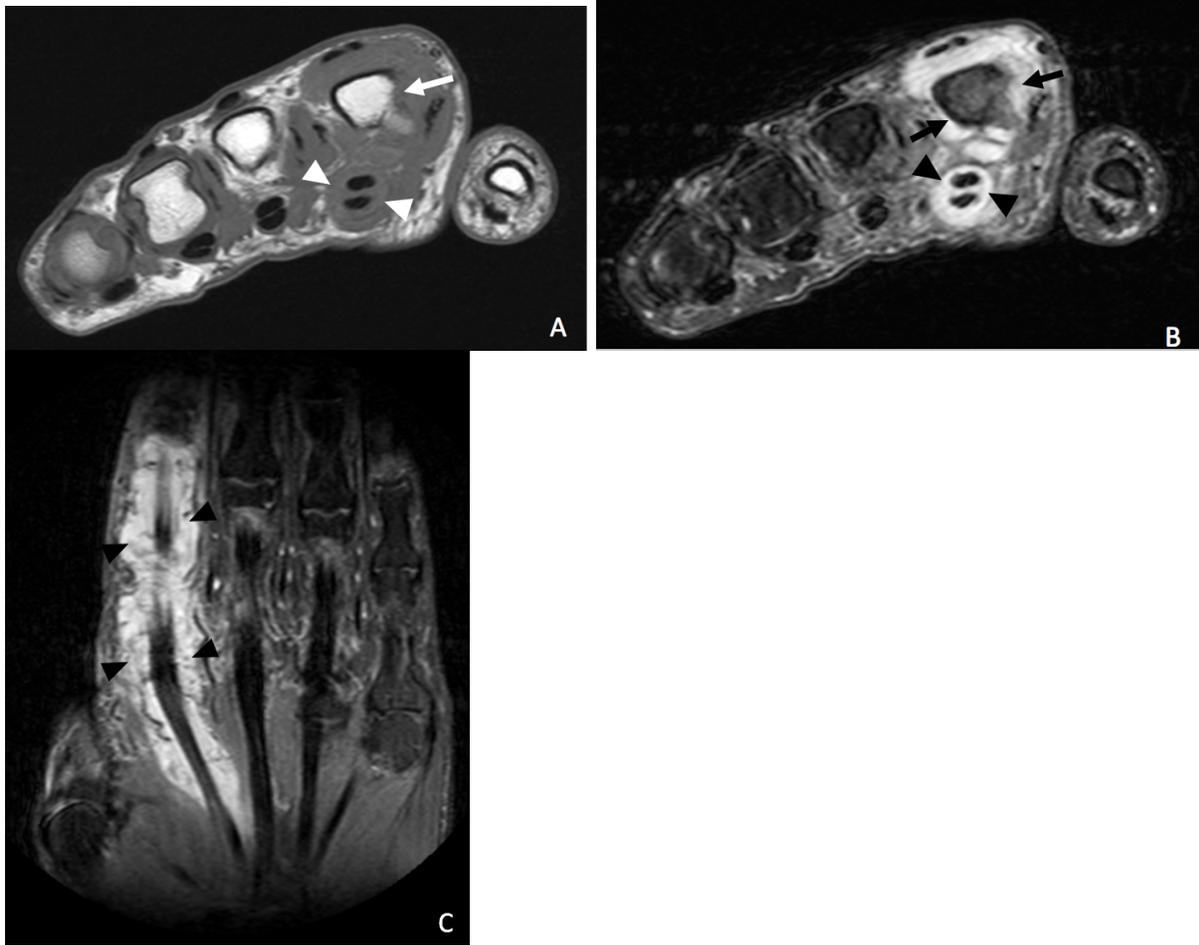


Fig. 11- Septic tenosynovitis in a 48-year-old male.

A) Axial T1-weighted MR image of the hand shows soft tissue around the second flexor tendon sheath (arrowheads) and erosion at the metacarpal head (arrow).

B) Axial T2-weighted fat suppressed MR image shows complex fluid signal within the second flexor tendon sheath (arrowheads) and adjacent second metacarpophalangeal joint (arrows) representing septic arthritis with secondary septic tenosynovitis.

C) Coronal STIR MR image reveals extensive complex fluid signal within the second flexor tendon sheath (arrowheads) consistent with septic tenosynovitis.



Fig. 12-Humeral osteomyelitis, with periostitis in a 16-year-old male. Axial T1 (A) images demonstrate confluent T1 marrow replacement of the humeral medullary canal (asterisk, A), compatible with osteomyelitis, with thick periosteal new bone formation (arrowheads). Axial T2 fat-suppressed (B), and axial (C) and coronal (D) T1 fat-suppressed post-contrast images demonstrate a thick rim of periosteal edema and enhancement, compatible with periostitis.

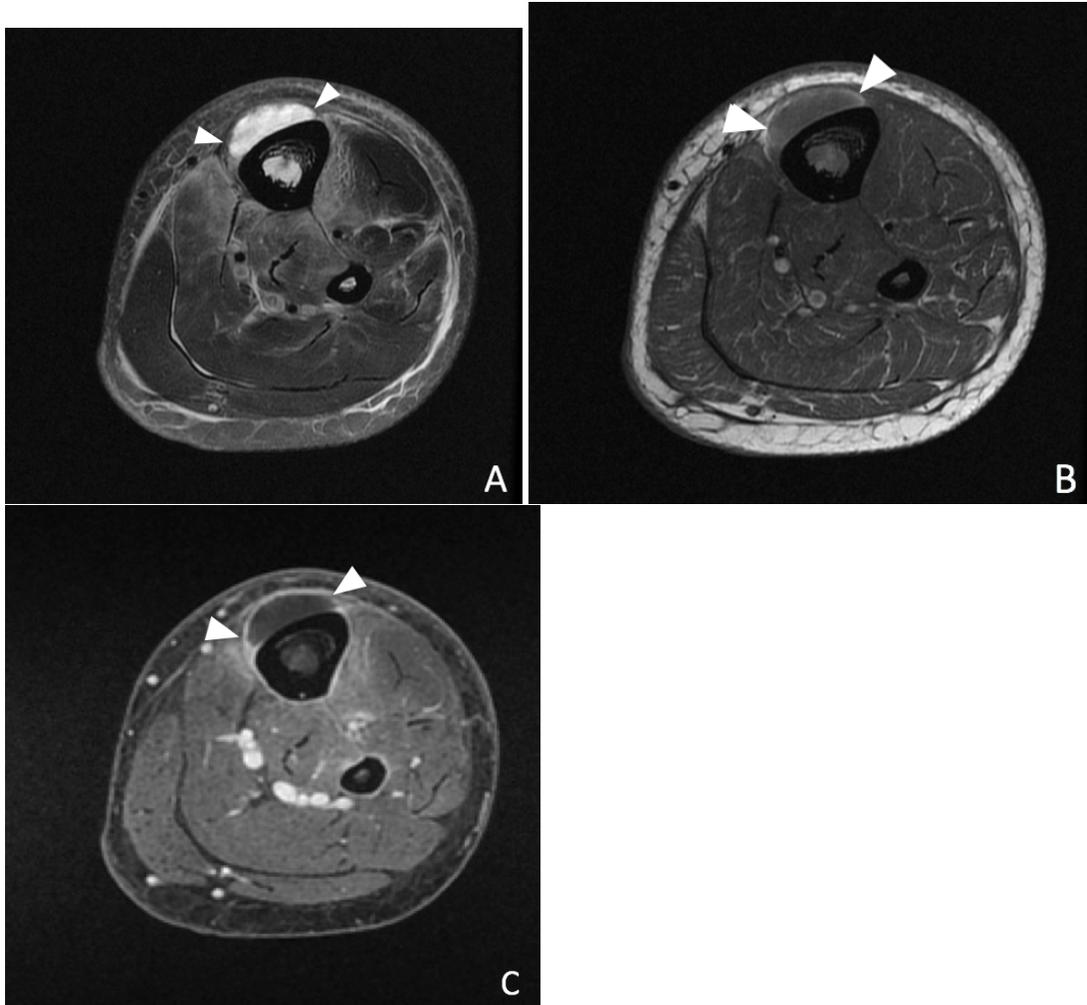


Fig. 13- Subperiosteal abscess in a 21-year-old female with sickle cell disease and bone infarcts. Axial T2 fat-suppressed Dixon image with water amplification (A), axial T1 (B), and axial T1 fat-saturated post-contrast images of the lower leg demonstrating a subperiosteal fluid collection (arrowheads, A) which demonstrates a thin T1 hyperintense rim (arrowheads, B) which enhances after contrast administration (arrowheads, C), confirming subperiosteal abscess.

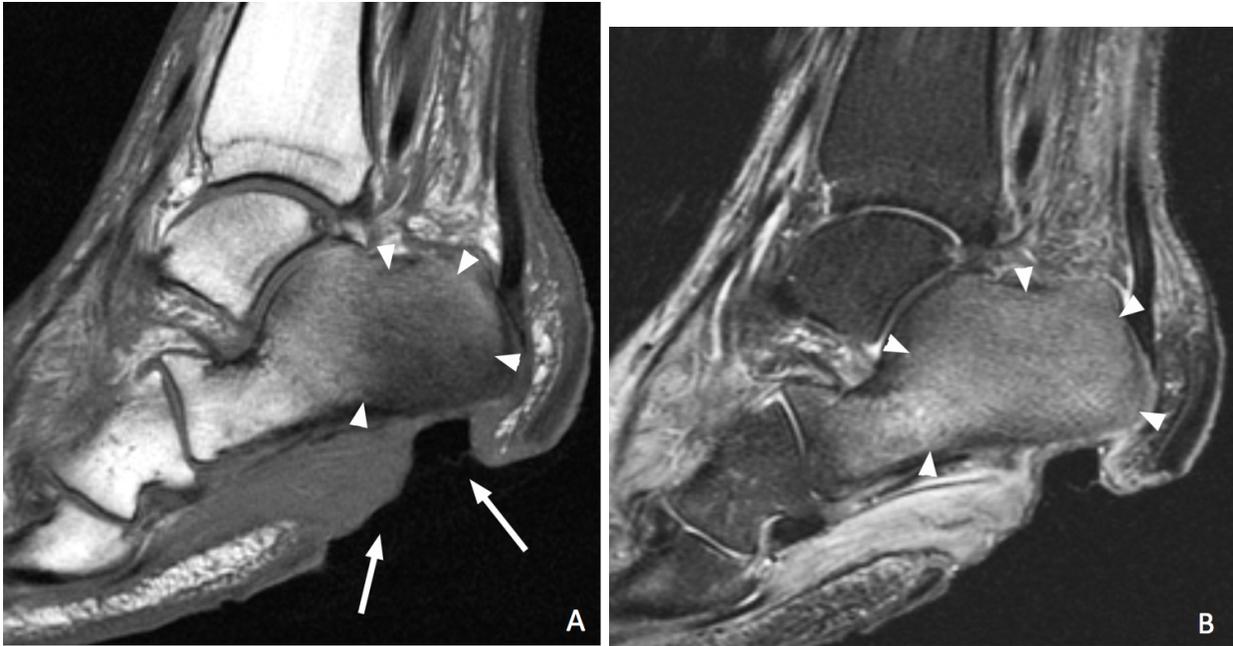


Fig. 14- Osteomyelitis of the calcaneus in a 48-year-old diabetic female.

A) Sagittal T1-weighted MR image of the ankle shows a large ulcer at the plantar aspect (arrows) communicating with the inferior calcaneus. Replacement of the normal fatty marrow (arrowheads) within the medullary space represents osteomyelitis.
 B) Sagittal STIR MR image shows diffuse corresponding bone marrow edema in the calcaneus (arrowheads).

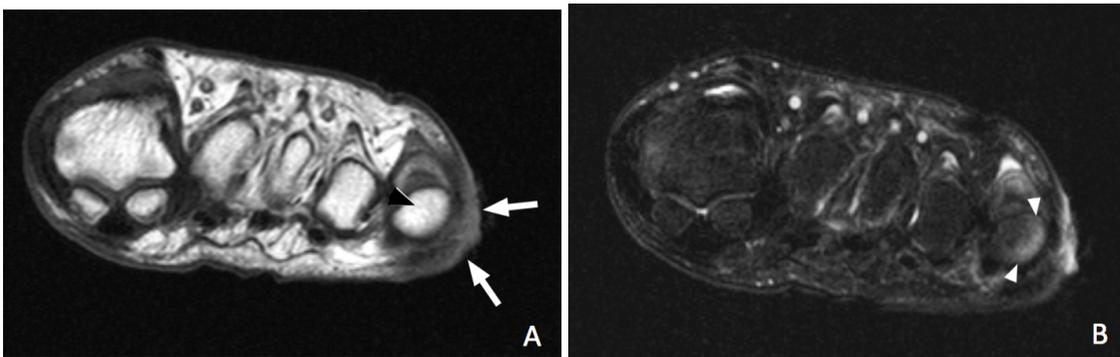


Fig. 15- Marrow signal changes with high likelihood for osteomyelitis of the fifth metatarsal head in a 54-year-old diabetic female.

A) Short-axis T1-weighted MR image of the forefoot shows ulceration at the lateral aspect (arrows). Signal in the adjacent fifth metatarsal head (arrowhead) is normal.
 B) Short-axis T2-weighted fat-suppressed MR image demonstrates subcortical bone marrow edema (arrowheads), which in the presence of an adjacent soft tissue infection should be considered to represent a high likelihood for early osteomyelitis.

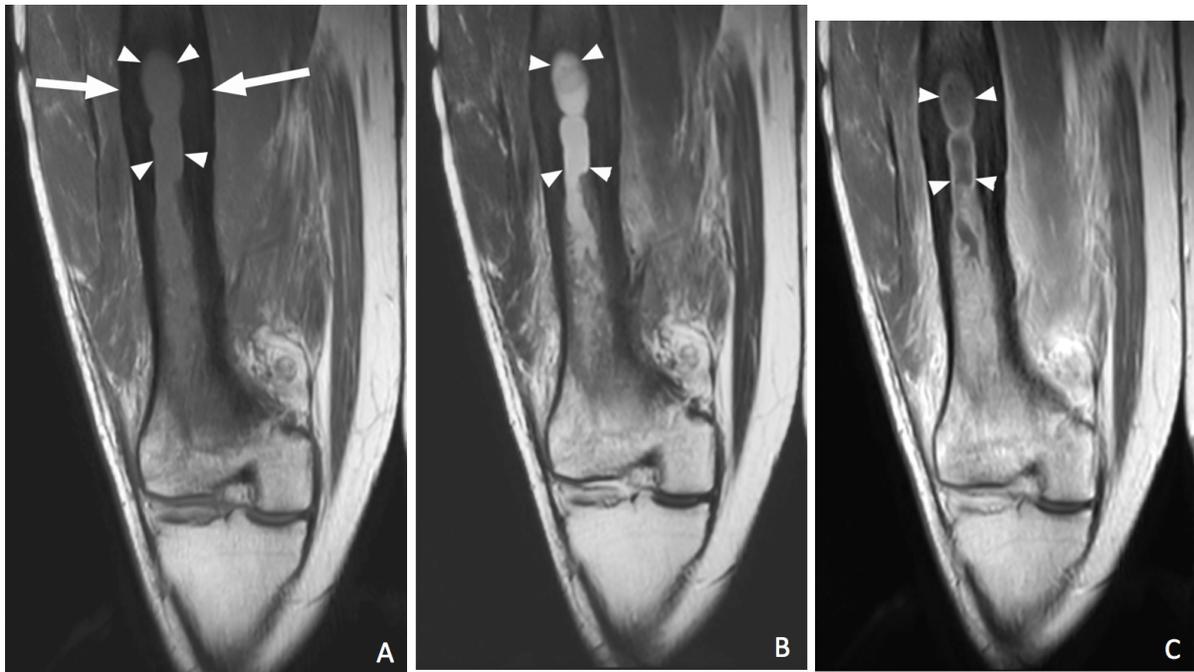


Fig. 16- Intra-osseous abscess in a 35-year-old male with chronic osteomyelitis.

A) Coronal T1-weighted MR image of the distal femur shows cortical thickening (arrows) related to chronic osteomyelitis. A rounded region of low signal (arrowheads) in the central medullary canal is present.

B) Coronal T2-weighted MR image demonstrates fluid signal within the medullary space (arrowheads) consistent with an intra-osseous abscess.

C) Coronal T1-weighted post-contrast MR image reveals rim-enhancement of the intramedullary fluid collection (arrowheads); in the setting of infection this meets criteria for intra-osseous abscess.



Fig. 17- Brodie abscess in a 14-year-old male with chronic ankle pain and swelling.

A) Sagittal T1-weighted MR image of the ankle shows a focus of low signal (arrow) in the metaphysis abutting the open physal plate (arrowheads).

B) Sagittal STIR MR image shows fluid signal in the lesion (arrow) with surrounding periosteal reaction (arrowheads) consistent with a Brodie abscess.

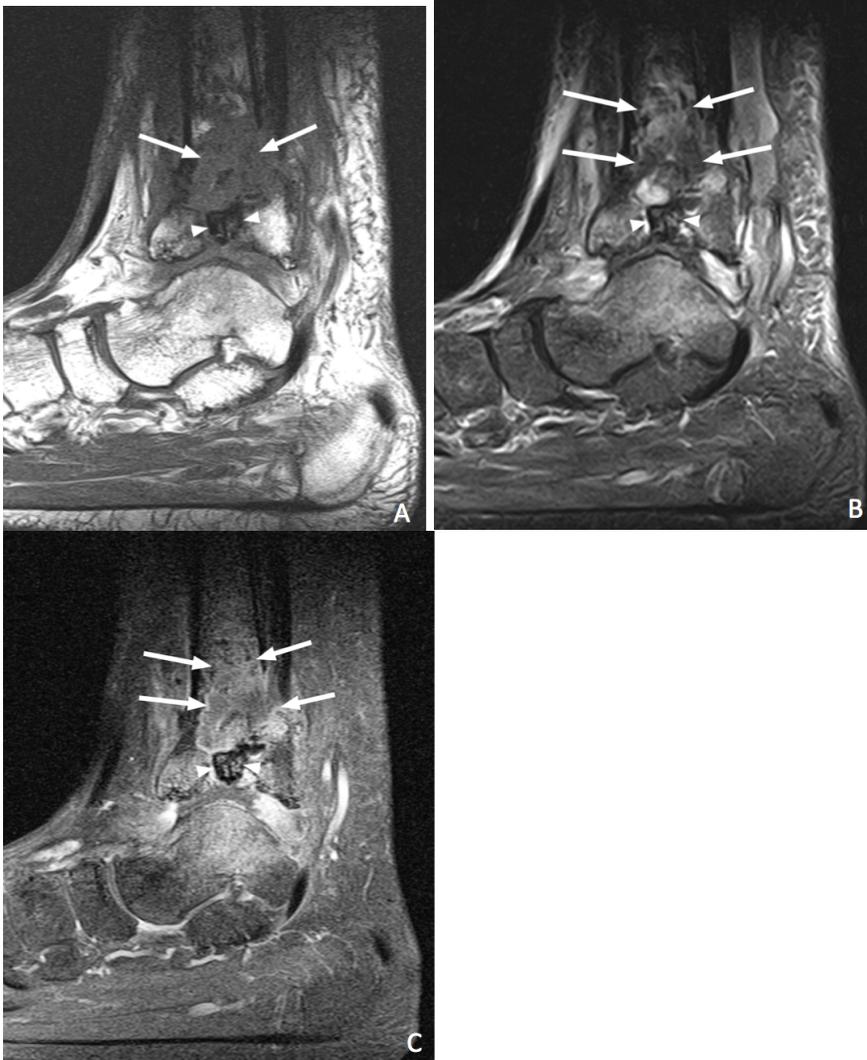


Fig. 18- Sequestrum in a 40 year-old male with chronic osteomyelitis of the distal tibia following an open fracture.

A) Sagittal T1-weighted MR image of the ankle shows disruption of the distal tibia with low signal in the distal tibial medullary space (arrows) representing chronic osteomyelitis. A focus of black signal (arrowheads) at the articular surface represents a sequestrum.

B) Sagittal STIR MR image shows heterogeneous intermediate-to-high signal in the medullary space (arrows) representing chronic osteomyelitis. The sequestrum (arrowheads) demonstrates black signal representing necrosis.

C) Sagittal T1-weighted fat suppressed post-contrast MR image shows heterogeneous enhancement of the medullary space (arrows). The low signal sequestrum (arrowheads) shows no/minimal enhancement representing devitalization.

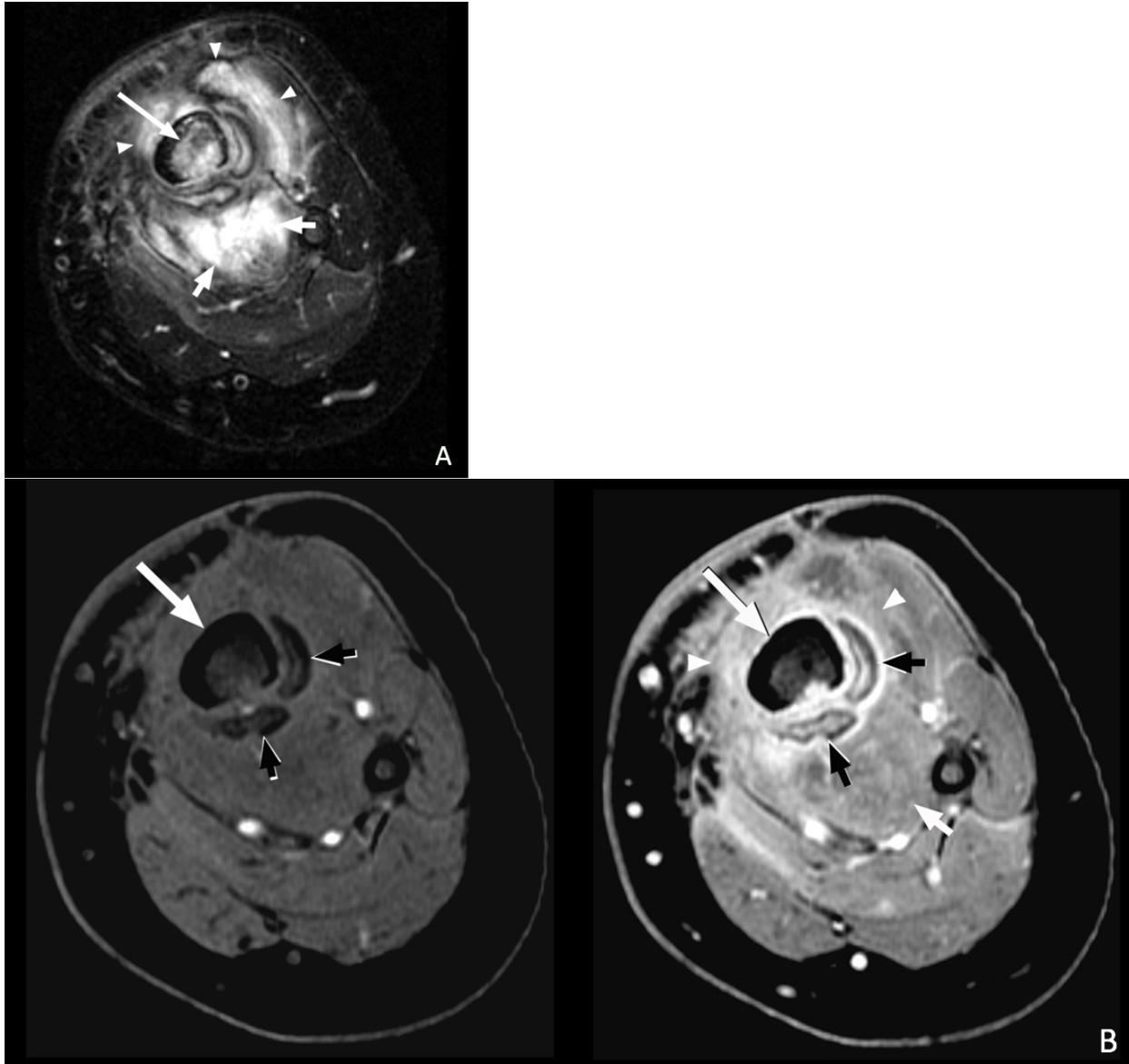


Fig. 19- Involucrum and sequestrum in the lower leg of a 4-year-old male with chronic osteomyelitis.

Axial T2-weighted fat-suppressed MR image (A) and corresponding axial pre and post-contrast T1-weighted fat suppressed MR images (B) of the lower leg show diffuse edema within the tibia (long arrow) with lack of enhancement, consistent with sequestrum formation. Surrounding soft tissue edema and enhancement (arrowheads) represents cellulitis. A heterogeneous region of fluid-like signal without central enhancement (short white arrow) is compatible with phlegmon formation. The shell of enhancing bone (short black arrows) represents the new bone formation (involucrum).

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