FRACTURE COMPLICATIONS AND THE ROLE OF IMAGING

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INTRODUCTION

When a bone fracture occurs, the primary goal of treatment is to obtain union in anatomic position to facilitate optimal functional outcome and to reduce the risk of complication. Most fractures heal without further problems, however, there are various complications that may occur either at the time of incident trauma, during the healing process or years following fracture union. These complications may be local or systemic. Some of the most common local complications include neurovascular injury, infection and osteoarthrosis. Systemic complications include fat embolism, sepsis and shock, but are beyond the scope of this article. Thus, the purpose of this article is to discuss the potential local complications and the role of imaging in their detection and diagnosis. Knowledge of the various local complications is important to facilitate early diagnosis, timely intervention and prevention of unnecessary morbidity and mortality.

ARTICULAR DISEASE

Intra-articular bodies

Intra-articular fractures may result in fragments being displaced into the joint. In the acute setting, an intra-articular body may prevent adequate reduction of a dislocated joint[1]. In the subacute and chronic setting, fragments may limit range of motion or alter joint biomechanics and thus result in secondary osteoarthrosis. Osteochondral fractures are particularly at high risk for secondary osteoarthrosis, either related to an incongruent joint surface, displacement of a bone fragment or rotation of an articular fragment. Rarely, foreign bodies introduced into the joint during the initial trauma may cause mechanical abnormalities or lead to septic arthritis.

Radiographs are often used to exclude the presence of intra-articular bodies, however computed tomography (CT) or magnetic resonance imaging (MRI) may be useful in complicated or equivocal cases.

Chondrolysis and osteolysis

Post-traumatic loss of articular cartilage is termed chondrolysis. Patients usually present with progressive joint stiffness, pain and loss of motion. Radiographs typically demonstrate concentric loss of joint space, sometimes associated with periarticular osteoporosis. This occurs most commonly in the hip and ankle.

Post traumatic loss of bone is termed osteolysis and may occur following a fracture

or repetitive microtrauma, with most cases beginning about 2 months following an injury. The most common site for post-traumatic osteolysis is the distal end of the clavicle, most often seen in weight lifters. Other sites include the femoral neck, base of the dens and ischial pubic synchondrosis.

Radiographs and CT show osseous resorption and cortical irregularity of the involved bone. Distal clavicle involvement may be associated with small cortical irregularities and even acromioclavicular joint space widening depending on the severity of osteolysis. MRI shows predominant distal clavicle marrow oedema and frequently acromioclavicular joint capsular and pericapsular oedema.

Septic arthritis

Septic arthritis can arise from systemic bacteraemia, direct inoculation following an open fracture, iatrogenic introduction, direct spread from soft tissue infection or osteomyelitis. The most commonly involved organism is *Staphylococcus aureus*.

Early radiographic findings include soft tissue swelling, joint effusion and rarely joint space widening. Periarticular osteoporosis and joint space narrowing may develop at approximately 2 weeks, followed by the development of erosions and rapid joint destruction. Comparison to previous radiographs, including the initial post-injury radiograph, is the key to the identification of subtle abnormalities such as joint space loss or subchondral bone erosion.

Post-traumatic osteoarthrosis

Post-traumatic osteoarthrosis may be related to either abnormal biomechanics, articular surface irregularity or joint malalignment. The initial injury may be an intra-articular fracture, chondral injury, joint dislocation, tendon or ligament injury, infection or osteonecrosis. Prompt recognition of the injury, adequate reduction

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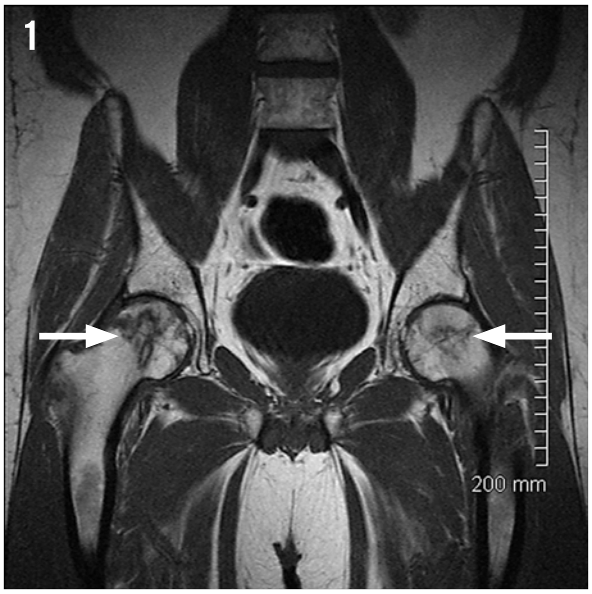

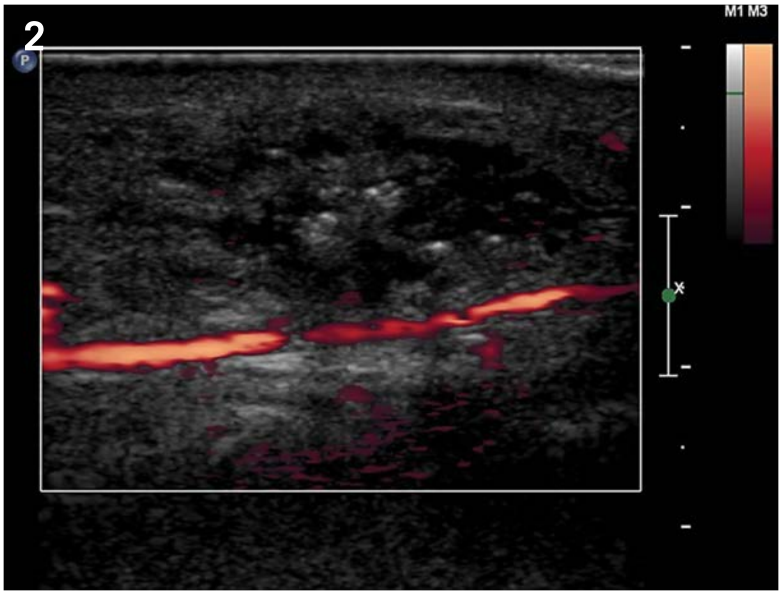

Figure 1: Bilateral hip AVN. T1-weighted MRI image showing serpiginous subchrondral bands of low signal intensity (arrows) in the femoral heads consistent with avascular necrosis.

Figure 2: Wrist abscess. Ultrasound images clearly showing an area of heterogeneous hypoechogenicity with central echogenic foci and increased peripheral flow on Doppler interrogation, consistent with a subcutaneous abscess. The abscess was drained under ultrasound guidance at the bedside.

and immobilisation are all essential in reducing the risk of developing secondary osteoarthrosis.

Radiographic hallmarks of osteoarthrosis include non uniform joint space loss, subchondral cysts, subchondral sclerosis, osteophyte formation and buttressing.

OSTEONECROSIS

Trauma is one of the most common causes of osteonecrosis. When osteonecrosis occurs near the end of a bone it is termed avascular necrosis (AVN), resulting from disruption of arterial blood flow or venous drainage. Anatomic regions with lack of significant collateral circulation are more predisposed to necrosis, with common sites including the femoral head, humeral head, talus, scaphoid, talus and patella[2].

Early recognition of avascular necrosis radiographically, may be difficult, but when diagnosed in a timely fashion, immobilisation of the weight-bearing bones and revascularisation with grafting can be initiated to promote healing. Once articular collapse occurs, treatment is limited to salvage procedures such as arthroplasty or joint fusion.

Initial radiographs are often normal, however early findings may include bone sclerosis, with subsequent progression to subchondral lucency and finally, articular collapse. The characteristic 'crescent sign' in the femoral head is used to describe the subchondral lucency or fracture through the necrotic bone.

MRI can be used to detect AVN prior to articular collapse and offers prognostic value by accurately assessing the size of articular surface involvement. MRI is the most sensitive and specific imaging modality for the evaluation of AVN at the hip, most commonly showing a characteristic 'double line' sign on T2-weighted images.

CT is recommended for assessment of scaphoid AVN. It is not routinely used for evaluation of femoral head or other sites of AVN unless MRI is contraindicated (Figure 1).

INFECTION

Infection is a feared fracture complication, most commonly seen with open and surgically fixated fractures. Infection may not only lead to delayed fracture healing, but increased overall morbidity and mortality. The spectrum of infection includes cellulitis, abscess, myositis, fasciitis, osteomyelitis and septic arthritis. Organisms are introduced either via direct inoculation or haematogenous seeding and will preferentially seed necrotic tissue or foreign bodies, including surgical hardware. Treatment often involves a combination of systemic antibiotics, local debridement, removal of implants, local antibiotic beads and antibiotic imbedded cement spacers.

Soft tissue infection

Risk factors for soft tissue infections include an open wound, retained foreign body and surgical fixation. Soft tissue infection involving the skin and subcutaneous fat is termed 'cellulitis', whereas 'phlegmon' refers to deeper soft tissue infection without liquefaction. An abscess may develop at the site of phlegmon and is characterised by central fluid cavity and peripheral rim of inflammatory tissue. Intramuscular abscess is termed 'pyomyositis'. Infection of the deep fascia may result in necrosis of the tissues and is then termed 'necrotising fasciitis'. The term 'gas gangrene' is reserved for necrotising soft tissue infections caused by Clostridium species, most often resulting from trauma. Severe complications include sepsis, toxic shock and loss of involved limb.

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Radiographs may show focal soft tissue swelling and reticulation of the subcutaneous fat, sometimes with soft tissue gas or the presence of a radiodense foreign body. Linear streaks of gas within the muscle planes indicate myonecrosis. Rarely, a soft tissue abscess may be evident by a discrete air-fluid level[3].

Radiographs, CT, ultrasound and MRI are all used for detection and assessment of soft tissue infection. CT and MRI are used to delineate the extent and topography of the infection, to assess for abnormal enhancement (lack of enhancement in necrotising fasciitis) or to detect the presence of gas. Ultrasound is useful to distinguish between cellulitis, myositis and abscess, in addition to assisting with aspiration and/or drainage (Figure 2).

Osteomyelitis

Osteomyelitis is an infection of the bone and marrow space. Risks or predisposing factors include the extent of soft tissue injury (i.e. open wound), surgical intervention, presence of pathogenic bacteria, vascular stasis and necrotic soft tissue or marrow fat, as well as patients with underlying comorbidities. *Staphylococcus aureus* is causative in up to 70% of cases.

Symptoms may not be clinically apparent for several months and thus the diagnosis often relies on imaging findings. Early radiographic findings include soft tissue swelling, cortical irregularity, lucency, frank osteolysis with destruction and periosteal reaction. Although these findings are somewhat early, radiography remains fairly insensitive. When antibiotic therapy has been initiated, findings may be even further delayed making accurate diagnosis more difficult. Fracture healing also may have overlapping findings, further confounding radiographic findings.

In the transition from the acute to the subacute stage, a focal, well-defined, lytic medullary based lesion called Brodie's abscess may be demonstrated. These tend to be metaphyseal and often develop into more chronic collections over several years.

Chronic osteomyelitis develops in the setting of reduced organism virulence or host immune resistance. The infected bone marrow undergoes slow healing and revascularisation, with persistent regions of necrotic infected bone sometimes occurring, termed a sequestrum. The body attempts to isolate the sequestrum by forming new surrounding bone (involucrum) and the intra-osseous collection may be decompressed through a discontinuity in the cortex, termed cloaca. A sinus tract may also develop decompressing to the soft tissues or skin surface (fistula).

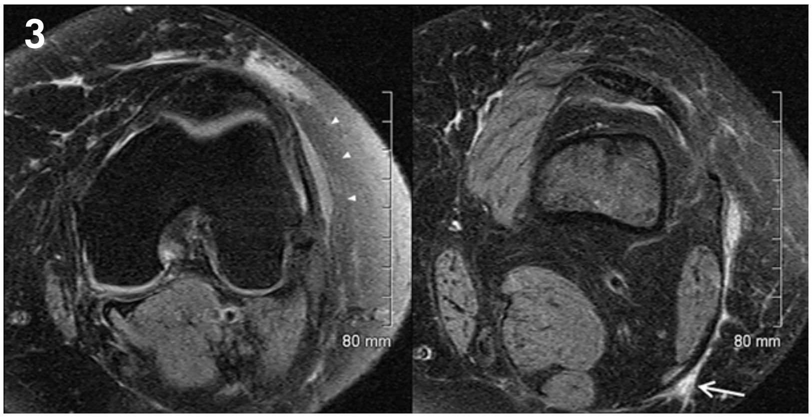
MRI is the recommended study of choice for patients with suspected post traumatic osteomyelitis. Replacement of bright T1 marrow signal is a classic finding for the diagnosis. CT in acute osteomyelitis shows lysis, replacement of marrow fat by soft tissue and periosteal reaction. In chronic osteomyelitis, CT and MRI may show the sequestra, involucrum, cloaca and sinus tract in multiple planes. Nuclear medicine evaluation including Tc-99m bone scan, Indium-111 leukocyte scan, Tc-99m sulphur colloid and Gallium-67 citrate may be useful in the right, uncomplicated, clinical setting.

SOFT TISSUE COMPLICATIONS

Haematomas and de-gloving injuries

Haematomas may be associated with either direct soft tissue injury or bleeding at the fracture site. Pelvic and femoral fractures in particular may lead to significant blood loss with increased risk of systemic shock. Haematomas usually resorb over time, sometimes with residual calcification or heterotopic ossification. Other complications include superimposed infection with abscess formation, acute compartment syndrome or deep venous thrombosis.

Ultrasound can usually identify and characterise haematoma formation, although CT is sometimes beneficial as well. A surrounding capsule may be identified suggesting that healing may occur without



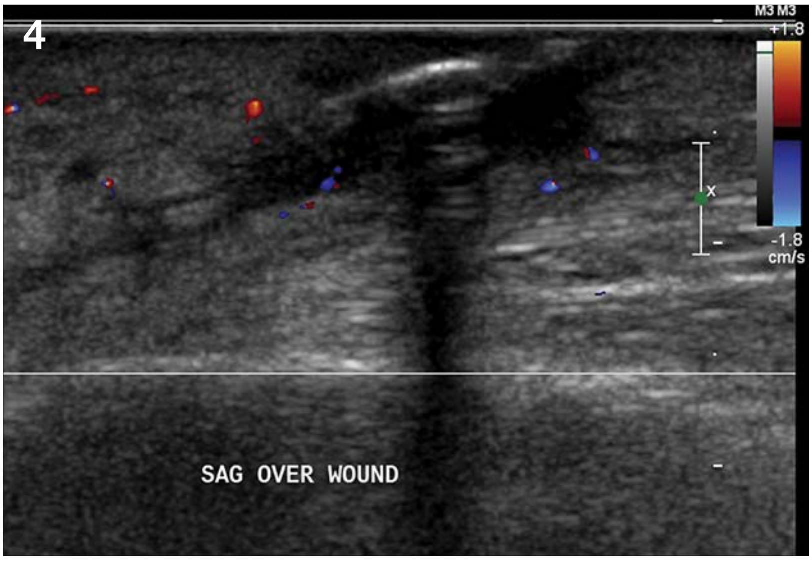


Figure 3: Morel-Lavallée lesion. These axial PD-FS MRI images of the knee demonstrate a small curvilinear fluid collection (arrow heads) within the soft tissues of lateral knee, extending to the skin surface (arrow), consistent with a Morel-Lavallée lesion.

Figure 4: Foreign body. Ultrasound images of the leg post traumatic injury clearly demonstrates shadowing linear echogenic foci within the subcutaneous tissues deep to an open wound consistent with foreign bodies (plastic) which were subsequently debrided.

Figure 5: Myositis ossificans. Coronal PD-FS MRI image of the left thigh demonstrates a heterogeneous high signal mass with extensive soft tissue oedema, which can be easily mistaken for an aggressive sarcoma. Serial X-rays demonstrate progressive peripheral zonal ossification confirming the diagnosis of myositis ossificans.

Figure 6: Posterior tibialis tendon entrapment. CT is helpful in identifying both bony and soft tissue injuries. This CT image of a periprosthetic fracture of the distal tibia demonstrates entrapment of the Posterior tibialis tendon by fracture fragments.

the need for surgery. Fluid-fluid levels are sometimes apparent on CT and MRI[4].

A Morel-Lavallée lesion is a closed degloving injury associated with severe trauma, typically to the pelvis. It is caused by traumatic separation of the deep subcutaneous tissue from the underlying fascia with a resultant haemolymphatic collection[4]. The most common location is the lateral proximal thigh, with additional sites including the distal thigh and knee region. MRI is the modality of choice for assessment, but the collection is also well-demonstrated by ultrasound and CT (Figure 3).

Foreign bodies

Foreign bodies introduced at the time of the initial trauma may serve as an inciting factor for cellulitis, abscess formation, recurrent infection or granulomatous process.

Radiographs are usually positive in the detection of especially radiodense foreign bodies including metal, stone fragments and most glass fragments. Some types of wood, plastic and glass however, may not be visible on radiographs. Ultrasound is a useful tool for the detection of these radiolucent foreign bodies which usually appear echogenic and to mark the site of foreign body prior to surgical removal. CT may, infrequently, be useful in equivocal cases (Figure 4).

Heterotopic ossification

Heterotopic ossification or myositis ossificans (if within muscle), usually occurs following soft tissue injury without a fracture. The degree of bone formation is proportionate to both the extent of manipulation during the attempted closed reduction and the duration of dislocation. Heterotopic ossification may also develop in patients with spinal cord injury or burns, often forming around the pelvis and hips.

Heterotopic ossification should not be mistaken for a tumour or infection. On imaging, the acute stage may show multiple, occasionally rim-enhancing, fluid collections that may ossify. Follow-up radiographs after 4 to 6 weeks are helpful to confirm the diagnosis with progressive zonal ossification from the periphery to the centre. In contrast, osteoid forming neoplasms typically ossify from the centre to the periphery.

CT is helpful to characterise the extent and location of heterotopic ossification, particularly when resection is necessary in patients with limited range of motion. Ultrasound and MRI may present confusing findings in the acute stage, mimicking a collection that may be mistaken for infection or tumour (Figure 5).

Arterial venous injury

Direct arterial injury may occur at the site of fracture or at a dislocated joint when the vessel is tethered proximal and distal to the joint. The spectrum of arterial injury includes transection, dissection, thrombosis, fistula and pseudoaneurysms. Penetrating trauma accounts for the majority of arterial injury in the military population.

The most significant venous injuries occur with pelvic fractures and are associated with significant mortality. Resultant pelvic haematomas are most commonly retroperitoneal and maybe the only clue to subtle organ injury. These can lead to hemodynamic instability and collapse.

CT angiography is now commonly used for vascular injury detection and characterisation in a fast, non-invasive manner. CT angiography can identify the level of vessel occlusion, the relationship to the site of fracture, as well as characterise the extent of the vascular injury. MR angiography may also be used in patients with cervical spine trauma to identify carotid and vertebral artery injury. Ultrasound may be used to identify and characterise arterial lesions, as well as to treat pseudoaneurysms, usually in the setting of subacute trauma.

Nerve injury

Nerve injury may occur acutely via direct piercing or displacement, manipulation at the time of fracture reduction or during surgical intervention. In the subacute setting, nerve injury may be related to overlying cast material or secondary to mass effect from heterotopic ossification.

MRI and ultrasound can demonstrate direct and indirect signs of nerve injury[5]. Direct evidence includes alteration in nerve size, morphology and location. Indirect signs include changes related to muscle denervation (motor nerves) in the acute setting and muscle fatty infiltration in the setting of chronic denervation. CT may help show evidence of nerve injury by assessing the nerve course, loss of fat surrounding the nerve and disproportionate fatty atrophy of muscle.

The most common neurologic sequelae following trauma likely is chronic regional pain syndrome, formally known as reflex sympathetic dystrophy (discussed below).

Tendons and ligaments

A spectrum of tendon injury may occur in the trauma setting including tendinosis, tears, displacement, entrapment by fracture fragments and tendon avulsion. Ligament tears may lead to chronic instability and secondary osteoarthrosis.

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Radiographs may indirectly suggest tendon or ligament injury which may appear as blurring or a contour abnormality of the soft tissue planes. Avulsion fractures or abnormal position of bony structures may serve as clues to underlying tendon pathology, such as seen with a quadriceps tendon tear and high riding patella (patella alta). Radiographs are also helpful in the detection of bony abnormalities such as traction osteophytes, associated with anterior ankle impingement.

Tears, displacement, entrapment and avulsion may be readily identified on CT and MRI. MRI is superior in the assessment of soft tissue and osseous structures that may contribute to patient symptoms, while also providing a window to the detection of alternate or coexistent pathologies such as occult fractures, cartilage damage, intra-articular bodies, osteochondral lesions or ankle instability. Ultrasound is helpful to identify and characterise tendon tears following a soft tissue laceration (Figure 6).

Compartment syndrome

Compartment syndrome is defined clinically as increased pressure in a confined anatomic compartment. The increased pressure from an enlarging space-occupying process such as a haematoma, may lead to compartment syndrome and tissue ischaemia. Muscle tissue can only tolerate 4 to 12 hours of ischaemia prior to necrosis, if not promptly intervened upon. The anterior compartment of the leg is the most commonly affected. Of note, cast material alone is not likely sufficient to cause compartment syndrome.

Aside from the typical clinical information, direct measurement of compartment pressures with needle puncture is used to confirm the diagnosis. On imaging, however, acute compartment syndrome should be suspected with long bone fractures (usually closed fractures), muscle swelling and loss of interfacial fat planes on CT. MRI findings range from muscle signal change to lack of muscle and fascia enhancement. Chronic findings include dystrophic calcification and muscle atrophy. Imaging should not be used to evaluate traumatic compartment syndrome in most cases and is mostly reserved for exercise-induced compartment syndrome only.

HARDWARE AND OTHER COMPLICATIONS

Hardware complications

Orthopaedic hardware complications may occur when subjected to abnormal stress, resulting in elastic deformation or change in the hardware shape. With prompt cessation of the abnormal stressor, hardware shape may return to normal, whereas persistent stress may lead to permanent hardware deformity or fracture.

Hardware components may change position over time, predisposing to secondary complication. For example, pins, screws and nails may back out or protrude into the joint or plates may lift off the cortex, putting adjacent vessels, nerves, joint surfaces or skin at risk for injury. The most common cause for hardware migration is osteoporosis[6].

One of the most common hardware complications is infection, seen more frequently with external fixation. Contributing factors include tissue necrosis around indwelling pins and excessive hardware motion in relation to the adjacent soft tissues or bone. Infection should be suspected on radiographs when the normal sclerotic rim surrounding an external fixation pin is lost and replaced by irregular lucency. The differential diagnosis for infection includes thermal necrosis caused by drill heating during pin insertion, small particle disease and mechanical loosening. Infection should always be suspected in case of hardware loosening.

Radiographs are usually sufficient for hardware surveillance. Progressive periosteal reaction on follow-up studies is highly suggestive of infection, as is increased circumferential lucency around screws.

Re-fracture

A second fracture or re-fracture may occur through already weakened bone. This is more common during the healing process of the original fracture and is quite rare as a late complication. The underlying bone may be weakened by disuse osteoporosis as discussed or by secondary bone defects related to hardware insertion and removal. Usually, there is a history of a second minor trauma. The most common site for re-fracture is in the lower extremity, which is thought to relate to weight-bearing.

Complex regional pain syndrome

Patients with this syndrome present with limb pain accompanied with soft tissue swelling, hyperesthesia, skin atrophy, vasomotor abnormalities, joint stiffness and osteoporosis. Inciting factors may be related to prior trauma, either associated with a fracture, soft tissue injury or nerve injury. Additional causes include prior surgery, myocardial infarction and degenerative changes in the cervical spine.

The pathogenesis is not fully understood, but is likely related to activation of increased sympathetic and parasympathetic activity. The onset of symptoms varies from a week to several months after the trauma. There are three distinct clinical stages of symptoms including inflammatory, dystrophic and atrophic stages.

The radiographic hallmarks of complex regional pain syndrome are periarticular osteoporosis, similar to disuse osteoporosis and soft tissue swelling. MRI may show soft tissue swelling, oedema and even skin thickening, classically without marrow oedema. Nuclear medicine evaluation including triphasic Tc-99m bone scan is also particularly useful for the diagnosis.

KEY POINTS

- Articular complications include intra-articular bodies, chondrolysis, osteolysis, septic arthritis and biomechanical derangement with secondary osteoarthrosis.
- MR is the most accurate modality in the detection of avascular necrosis.
- The spectrum of soft tissue infection includes cellulitis, myositis, abscesses and necrotising fasciitis. Low T1 signal intensity on MRI is classic for osteomyelitis.
- Soft tissue injuries may lead to long-term disability including neuropathy, osteoarthrosis and infection. Ultrasound, CT and MRI have complementary roles.
- Zonal ossification in heterotopic ossification helps distinguish it from soft tissue neoplasm.
- Progressive lucency surrounding orthopaedic hardware requires workup to exclude infection.

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