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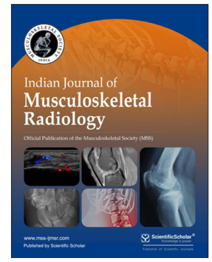

Pictorial Review

Magnetic resonance imaging in stress fractures: Making a correct diagnosis

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ABSTRACT

Stress fractures are fractures that occur due to a mismatch between bone strength and long-term mechanical stress. It is common to see magnetic resonance imaging (MRI) being used as first line of investigation for patients with bone pain. Lack of understanding of imaging appearances of a stress fracture can result in misinterpretation of bone marrow edema on MRI. We aim to stimulate readers' thinking by illustrating MRI findings, in stress fractures and their possible differentials at various sites, with a view to reduce misinterpretation of MR scans and facilitate patient management.

Keywords: Stress fracture, Infection, Malignancy, Magnetic resonance imaging

INTRODUCTION

Stress fractures are fractures that occur due to a mismatch between bone strength and long-term mechanical stress. These are divided into two types: Insufficiency and fatigue fractures. Insufficiency fractures result due to normal stress on abnormal bone in patients with osteoporosis, osteomalacia, Paget's disease, fibrous dysplasia, osteogenesis imperfecta, radiation, hyperparathyroidism, anorexia, etc.[1] Fatigue fractures occur due to the reaction of normal bone to abnormal repetitive stress. These are commonly encountered either in unconditioned individuals who abruptly engage in a strenuous sports activity or in trained conditioned athletes who had acutely intensified the training regimen.[2]

Due to technological advancement, it is common to see magnetic resonance imaging (MRI) being used as first line of investigation for patients with bone pain. Lack of imaging standards and poor scan quality can result in misinterpretation of marrow edema on MRI, in the absence of corresponding plain radiograph or computed tomography (CT) scan, as early tumor or osteomyelitis. Furthermore, insufficient and inappropriate clinical history prevents reaching a correct diagnosis and delays appropriate management. We aim to stimulate readers' thinking by illustrating MR findings, in stress fractures and their possible differentials at various sites, to reduce misinterpretation of MR scans and facilitate patient management.

BONE STRUCTURE AND PATHOPHYSIOLOGY OF STRESS FRACTURES

Basic knowledge of the physiology, architecture, and metabolism of bone is essential to understand the pathophysiology of stress fractures. Bone is constantly metabolizing, maintaining a balance between osteoclastogenesis and osteoblastogenesis. Bone comprises woven and lamellar bone, at the microscopic level. Woven bone is immature, identified by randomly orientated matrix of collagen. Contrarily, lamellar bone is maturely characterized by stress-oriented organized collagen. A discord between tissue tolerance and an externally applied load results from an imbalance in the interaction between bone remodeling and notable risk factors.[3]

ROLE OF IMAGING

The role of imaging in the diagnosis of stress fractures is indispensable. It is essential to detect and treat fatigue and insufficiency fractures at the earliest, to prevent morbidity and hindrance in normal physical activity which may result due to delay in diagnosis.[4]

Radiographs should always be the first line of investigations in patients with bone pain. Although, the occult stress fractures may not be identified on the initial radiograph due to low sensitivity,it is crucial to rule out other diseases, such as infections, or tumors.[5] A negative radiograph warrants a follow-up radiograph after about a week or should initiate further imaging.

Bone scan has extremely high sensitivity but with a very low specificity in detecting stress fractures. Increased uptake is also seen in tumors, infection, inflammation, or trauma.[6]

CT may not be the initial investigation of choice for diagnostic evaluation of stress fractures, however, it is useful as supplementary imaging in ruling out false positives and making the final diagnosis.[5-7] It helps identifyperiosteal reaction, sclerosis, and intracortical changes.[1]

MRI plays a crucial role in the diagnosis due to its ability to visualize early subtle edema, weeks before the appearance of the fracture line. MRI has an added advantage over CT in detecting soft-tissue abnormalities like localized edema, which can be helpful in localizing the site of subtle fracture.[8] Standard musculoskeletal imaging protocol includes T1-weighted and STIR coronal images, axial and sagittal T2- and proton density-weighted sequences with and without fat saturation. In non-specific MR findings, before visualization of a fracture line, there may be suspicion of neoplasm or infection. Similarly, pathological fracture in an underlying bone lesion should be carefully interpreted, keeping in mind the history and imaging features typical of a stress fracture.

SITES

There are various sites of stress fractures [Table 1] depending on the kind of exercise or physical activity and awareness about the injury mechanism is valuable in localizing the fracture site.[8] Overall, stress fractures of the lower extremity are much more common, especially in sports activities such as running and jumping. Upper limb fractures may be seen in activities such as rowing, baseball, tennis, or billiard players. Femoral neck, proximal tibia, distal fibula, tarsals, and metatarsals are the most common sites of stress fractures.

Correct diagnosis with appropriate patient management and estimation of the time required to full recovery isis the main objectives in the treatment of patients with stress injuries.

A variety of classification systems has been described for stress injuries which are clinically relevant and help in predicting the prognosis. Some are general classification systems used for any bone, and others are specific to a particular bone. Among all such classification systems, maximum attention has been given to those describing femoral neck injuries [Table 2].[2]

Femur

Stress fractures in the femur can occur anywhere along the entire bone that includes neck, trochanter, intertrochanteric region, shaft, and condyles; however, these are the most common in the shaft. Female athletes are more prone to fractures than their male counterparts.[9] Femoral neck stress fractures have been classified

Table 1: Sites of stress fractures.

Lower limb
Femur (neck, head)
Tibia (anterior cortex)
Fibula (distal shaft)
Patella
Medial and lateral malleoli
Tarsals (talus, navicular, calcaneus)
Metatarsals (base of 5th metatarsal, neck of 2nd to 4th metatarsals)
Sesamoids
Upper limb
Proximal humerus
Axial skeleton
Ribs
Pubic rami
Sacrum

Pars interarticularis lumbar spine

Table 2: MRI classification system for FNSIs.

FNSI grade	MRI findings
Low grade	
1	Endosteal marrow edema ≤ 6 mm
2	Endosteal marrow edema > 6 mm and no macroscopic fracture
High grade	
3	Periosteal edema and bone marrow edema visible only on T2-weighted images
4	Periosteal edema and bone marrow edema visible on both T1-weighted and T2-weighted images

FNSI: Femoral neck stress injuries

into superolateral or inferomedial fractures, representing the tension side and compression side, respectively.[10]

Normal appearing plain radiographs can lead to delay in identifying femoral stress fractures [Figure 1a], which may be associated with but needs to be differentiated from transient osteoporosis. Any case with gradual onset deep thigh or hip pain should be evaluated for the possibility of stress fracture and prevent its evolvement into a displaced fracture or cortical collapse. CT scan can detect the majority of occult fractures, but one should not completely exclude the diagnosis based on a negative CT scan in a patient with persistent, localized hip pain. MRI should be performed since bone marrow edema can be easily and accurately identified at an early stage [Figure 1b]. To ensure appropriate treatment, the entire pelvis and both proximal femurs should be studied simultaneously on MRI.[11]

All patients with isolated edema in the femoral neck without a fracture line on the initial MRI generally improve without the need for surgical intervention.[12] Follow-up interval imaging and absence of any associated soft-tissue component or osteolysis help to differentiate early stress-related edema from an infective or neoplastic lesion. For patients with a femoral neck stress injury with evident fracture line [Figure 2], the presence of hip effusion on the initial MRI screening is an independent risk factor for progression of fracture and needs early prophylactic surgical intervention.[13]

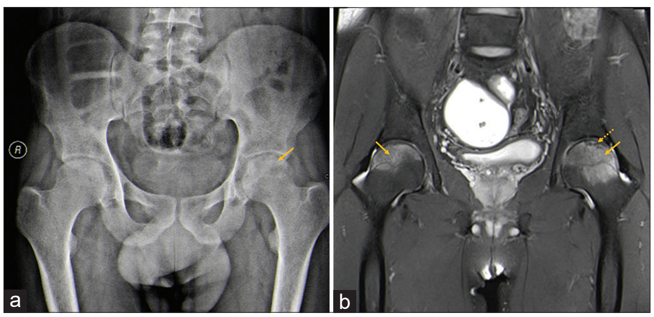

Figure 1: A 47-year-old male with a history of acute pain in the left hip. (a) Radiograph shows articular surface irregularity with thin subcortical sclerotic line (arrow) in the left femoral head. The right femoral head appears normal. (b) Coronal STIR images show hyperintense signal in bilateral femoral heads (arrows), suggesting transient osteoporosis with associated subcortical insufficiency fracture (dashed arrow) in the left femoral head.

Subchondral insufficiency fracture (SIF) of the femoral condyles occurs below the cartilage and is more commonly seen in the medial compartment [Figure 3] than the lateral compartment. It is a poorly understood condition, which has been related to various causative factors that include a local or systemic decrease in bone density,[14] transient osteoporosis, osteoarthritic changes, and even secondary to meniscal injury.[15] SIF is considered to be the preceding event for spontaneous osteonecrosis of the knee, and these terms are at times used interchangeably.

Atypical femoral fractures are seen in patients undergoing long-term therapy with bisphosphonate medications. In 2013, the American Society for Bone and Mineral Research released revised guidelines defining an atypical femoral fracture.[7] To meet the criteria, the fracture is to be located within the femoral diaphysis (distal to the lesser trochanter and proximal to the supracondylar flare) and has to be atraumatic or associated with minimal trauma. Fractures at other sites are more likely to be associated with trauma or osteoporosis. The integral morphologic diagnostic feature is the substantially transverse orientation of the non-comminuted fracture at the origin in the lateral cortex which may also be associated with characteristic spiking of the medial cortex.

When an atypical femoral fracture injury is recognized, screening of the contralateral hip and entire femur is suggested with AP and lateral radiograph.

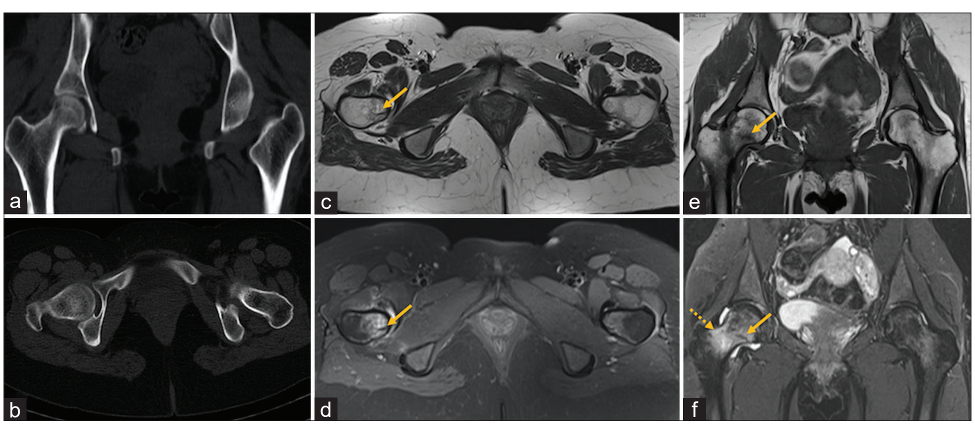

Figure 2: A 24-year-old doctor presented with the right hip pain. (a and b) No fracture seen on CT. (c and e) Axial and coronal T1W MRI images show focal linear hypointense line in the right femoral neck (arrow) representing fracture line. (d and f) Corresponding axial and coronal STIR images show corresponding hypointense fracture line (arrow) with surrounding hyperintense edema (dashed arrow). The patient was found to have elevated PTH, low calcium, and Vitamin D, leading to secondary hyperparathyroidism and resulting stress fracture.

Tibia

The most commonly involved site is the tibia,[16,17] typically in runners in distal two-thirds of the posteromedial aspect. The commonly associated signs in medial tibial stress syndrome (MTSS) and stress fractures[18] are pain, localized tenderness, and soft-tissue edema. MTSS represents the earlier changes in the spectrum of tibial stress injuries, seen over the medial tibia. The range is 13.6–20% in runners and can be up to 35% in military recruits.[19] Tibial stress injuries depict a continuous spectrum of changes occurring in reaction to excessive repetitive stress and may present with fractures or stress edema at other sites [Figure 4].

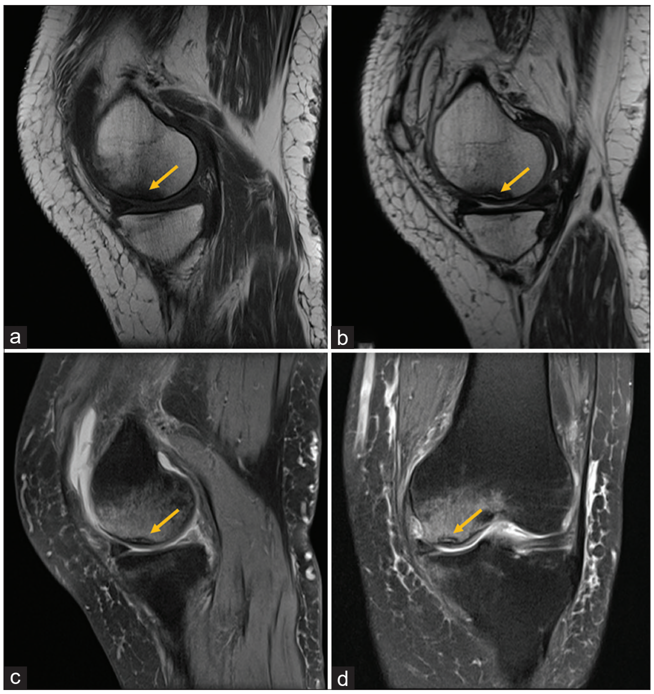

Figure 3: A 44-year-old female with knee pain. (a and b) Sagittal T1- and T2-weighted images show subchondral fracture (arrows) parallel to the cortex involving the medial femoral condyle. (c and d) Corresponding sagittal and coronal STIR images show subchondral fracture (arrows) with surrounding hyperintense edema.

MRI examination identifies the bone marrow edema at the earliest, even before the appearance of fracture line [Figure 5 and 6]. The morphology of bone marrow edema/STIR hyperintensity and T1 hypointensity as well as identifying cortical break without extraosseous soft-tissue component is useful in cases with overlapping imaging features to rule out the possibility of malignancy or osteomyelitis [Figure 7]. In patients with atypical MR features, a follow-up or bone biopsy is required [Figure 8].

In cases where contrast has been given, enhancement of both bone marrow and periosteal edema may be seen, making it difficult to distinguish from neoplastic changes. Any evidence of soft-tissue mass and pathological destruction of the bone should always be looked for.[1] CT may help to identify cortical changes, if any, and help to distinguish an intracortical osteoid osteoma from a stress fracture. A partially healed stress fracture can be confused as an intracortical osteoid osteoma [Figure 9] and thin 1 mm high-resolution images are facilitative.

Fredericson *et al*.[20] had described the imaging findings on MRI [Table 3], beginning with periosteal edema, advancing to marrow edema, and ultimately intracortical signal change representing frank cortical fracture.

Time to healing is positively related to the severity score on MRI, whereas all other modalities including radiographs, bone scan, and CT are found to be unrelated.[21] In a study by Nattiv *et al*.,[22] MRI grading severity along with other factors (including bone marrow density and location of bone injury) aswas found to be independently associated with recovery of bone stress injuries in athletes and their full return to activity.

Fibula

Stress fractures of fibula were first described in military trainees in the beginning of the 20th century. Devas and

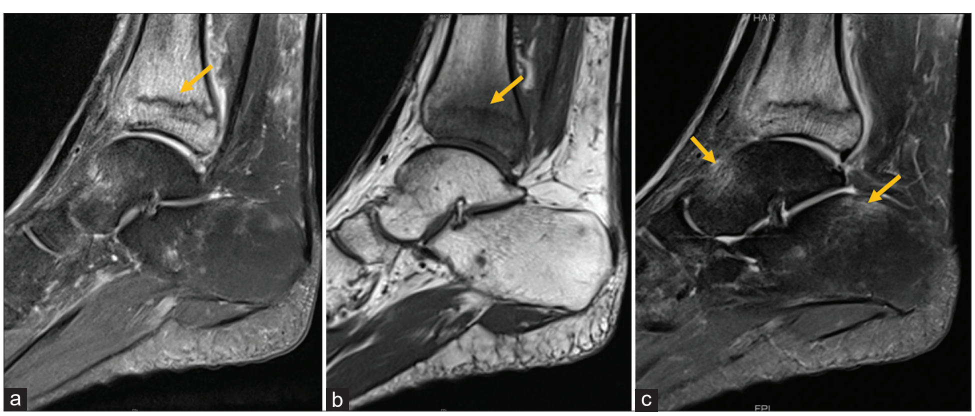

Figure 4: Distal tibial fracture. (a) Sagittal STIR image shows hypointense fracture line in the distal tibia (arrow) with surrounding hyperintense edema. (b) Corresponding T1W image again shows hypointense fracture line (arrow) with surrounding hypointense edema. (c) Sagittal STIR image reveals hyperintense marrow edema involving the talus and calcaneum as well, though without any definite fracture line.

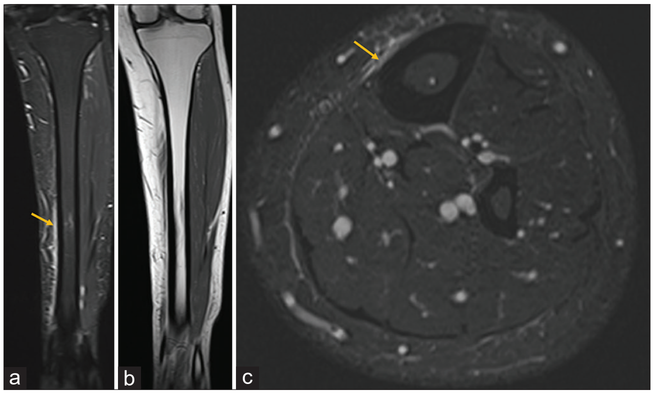

Figure 5: A 31-year-old with shin pain with Grade 1 MTSS. (a and c) Coronal and axial STIR images show hyperintense periosteal edema along the medial side of tibia. (b) Corresponding coronal T1-weighted image shows no significant abnormality.

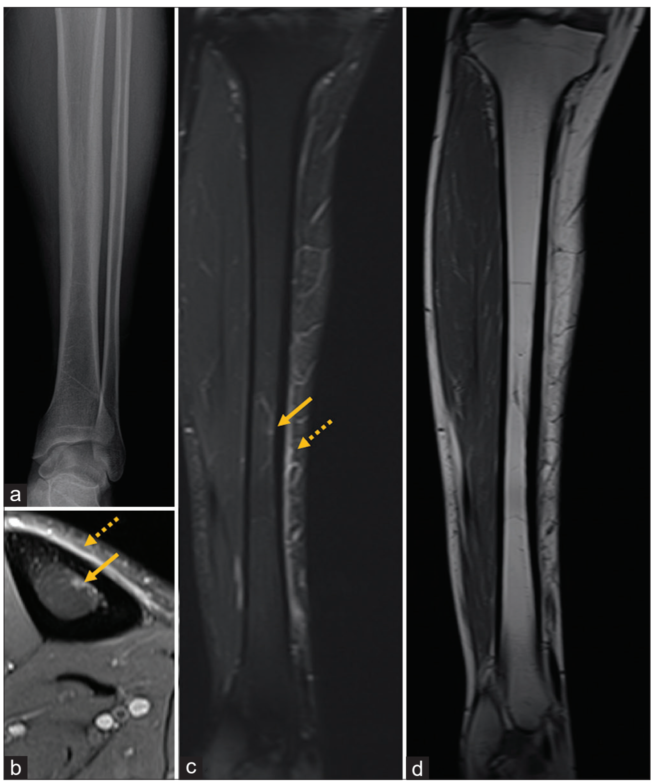

Figure 6: A 26-year-old with shin pain showing Grade 2 MTSS. (a) Radiograph was normal. (b and c) Axial and coronal STIR images show hyperintense periostitis (dashed arrow) with subtle marrow edema (arrow) in mid-tibial shaft (separate from the nutrient artery). (d) Coronal T1W image does not show any significant marrow edema or fracture line.

Sweetnam[23] reported a group of 50 athletes with fibular fractures. Fibular stress fractures account for 1.3–12.1% of stress fractures in athletes.[16,24]

Distal end of the bone is the most common site,[23,25] though proximal shaft fractures have also been seen.[9]

Table 3: Fredericson MRI classification system for tibial stress injuries.

Grade of stress injury	MRI findings
0	No abnormality
1	Periosteal edema with no associated bone marrow signal abnormalities
2	Periosteal edema and bone marrow edema visible only on T2-weighted images
3	Periosteal edema and bone marrow edema visible on both T1-weighted and T2-weighted images
4a	Multiple focal areas of intracortical signal abnormality and bone marrow edema visible on both T1-weighted and T2-weighted images
4b	Linear areas of intracortical signal abnormality and bone marrow edema visible on both T1-weighted and T2-weighted images

Tenderness to palpation is a useful sign that helps to make a diagnosis of fibular fracture. Plain radiograph may be helpful in some cases; however, the fracture line or even periosteal reaction [Figure 10] is usually seen weeks after the symptoms.[10] These fractures overall have good prognosis with adequate rest if diagnosed early.[10,26]

Sacrum

Pelvic fractures are more commonly insufficiency rather than fatigue fractures and are of growing concern in the elderly, due to osteoporosis.[27] These are challenging to diagnose radiographically due to obscuration by fecal loaded bowel loops.[28]

MRI or CT scan must be advised in suspicious cases, with negative initial radiographs. MRI is of paramount importance and helps by depicting bone marrow edema and fracture line [Figure 11].[29] Pelvic fractures are vertical and horizontal types, horizontal fracture usually occurring secondary to vertical fractures.[30] STIR coronal images are mandatory in sacral fractures, especially in identification of the horizontal component.

Bone marrow edema identified on MRI is not specific to only stress fracture.

Bony metastasis in carcinoma breast and prostate will also show edema and FDG uptake, however, there will be no fracture line which helps differentiating it from insufficiency fracture [Figure 12].

Pars interarticularis (PI) fracture

Stress fractures of the spine may involve the vertebral body, PI, and the pedicle.[31] PI serves as a junction between the pedicle and the articular processes. Spondylolysis is defined as a bone defect of the posterior element of the vertebra amongst which PI is the most commonly affected.[32] The fifth lumbar vertebra [Figure 13] is affected in 95% of cases.

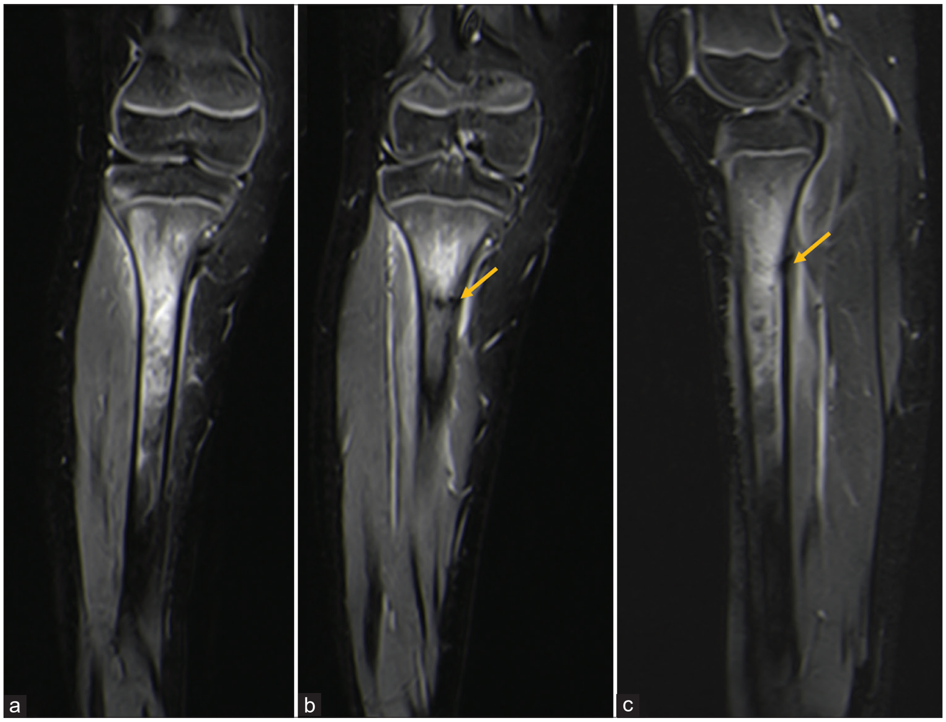

Figure 7: A 7-year-old female with proximal tibial fracture. Bone marrow edema (a and c) in proximal tibial meta-diaphysis, initially interpreted to be secondary to infection or malignancy. However, careful review revealed a transversely oriented intracortical hypointense line (b and c) suggestive of stress fracture.

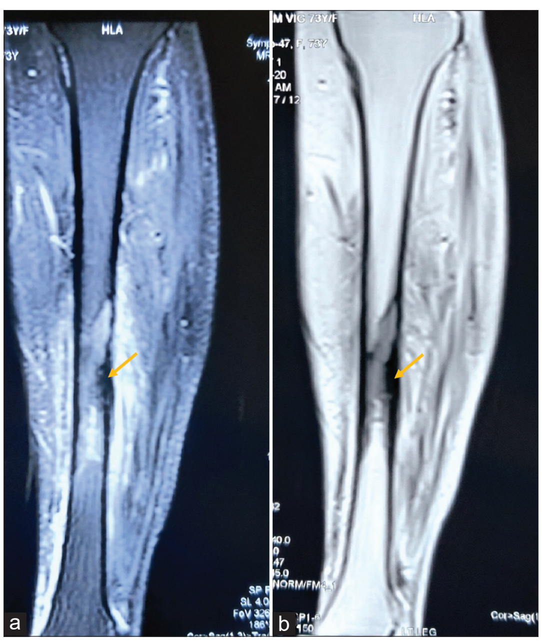

Figure 8: A 73-year-old female with a history of carcinoma breast, experiencing pain in the left leg since 1 year. (a an b) Coronal STIR and T1-weighted MR imaging performed in a different hospital shows focal intracortical area of low signal with adjacent intramedullary bone marrow edema in mid-tibial shaft and surrounding soft-tissue edema. MRI report suggested the possibility of osteomyelitis or stress fracture. Bone biopsy was performed in our hospital and report came as metastasis from carcinoma of breast.

Hollenberg *et al*.[33] classified the injury to PI into five grades based on MRI investigation [Table 4] and the hypothesis that spondylolysis develops in stages due to repetitive trauma. However, the role of these findings in the management of young athletic patients with low back pain is yet unsure. In another classification by Sundell *et al*.[34] which is a modified version of Hollenberg classification, CT investigation was added for better evaluation.

Metatarsals and calcaneum

Metatarsal stress fracture also known as march fracture, first recognized as an entity in 1855 by Breithaupt[35] is an overuse injury seen in the basketball players and in the military personnel.[36]

Calcaneus [Figure 14] and metatarsal stress fractures have been reported to be the most commonly injured bones in the new military trainees.[18] The metatarsal injury results due to an increase in vertical load distributed over the proximal third of metatarsals. MRI [Figure 15] can identify stress changes in the form of bone marrow edema, allowing early treatment and prevent the development of stress fractures.[37] The classical location and characteristic imaging findings should help to avoid confusion with an infective or neoplastic lesion.

Sesamoid fractures

Sesamoids are osseous structures enclosed in a tendon, their function being protecting the tendon from friction.

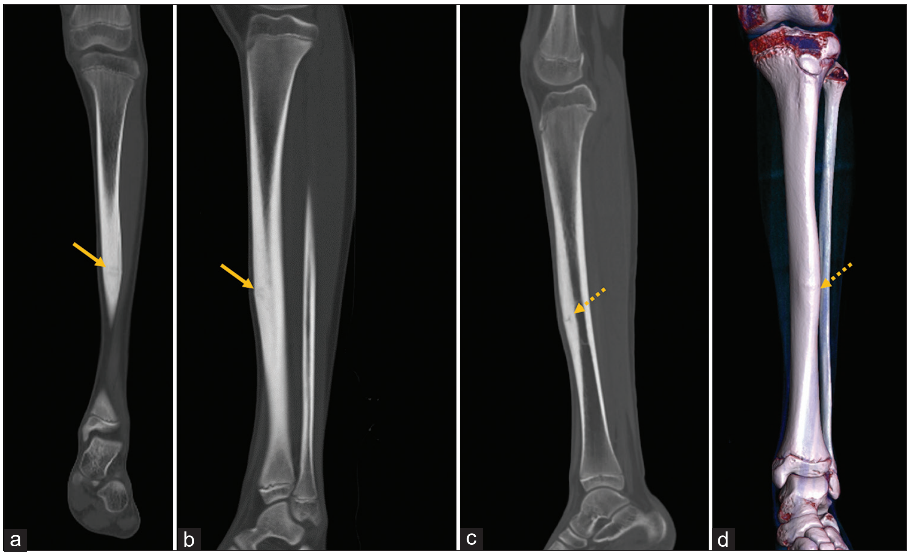

Figure 9: A 15-year-old male with the left leg pain. (a and b) Coronal and sagittal oblique images of CT scan performed in a different hospital, reported as intracortical osteoid osteoma (yellow arrow). (c and d) Sagittal and volume rendered CT images of a repeat scan performed at our hospital, however, showed a horizontal partially healed linear fracture line (dashed arrow).

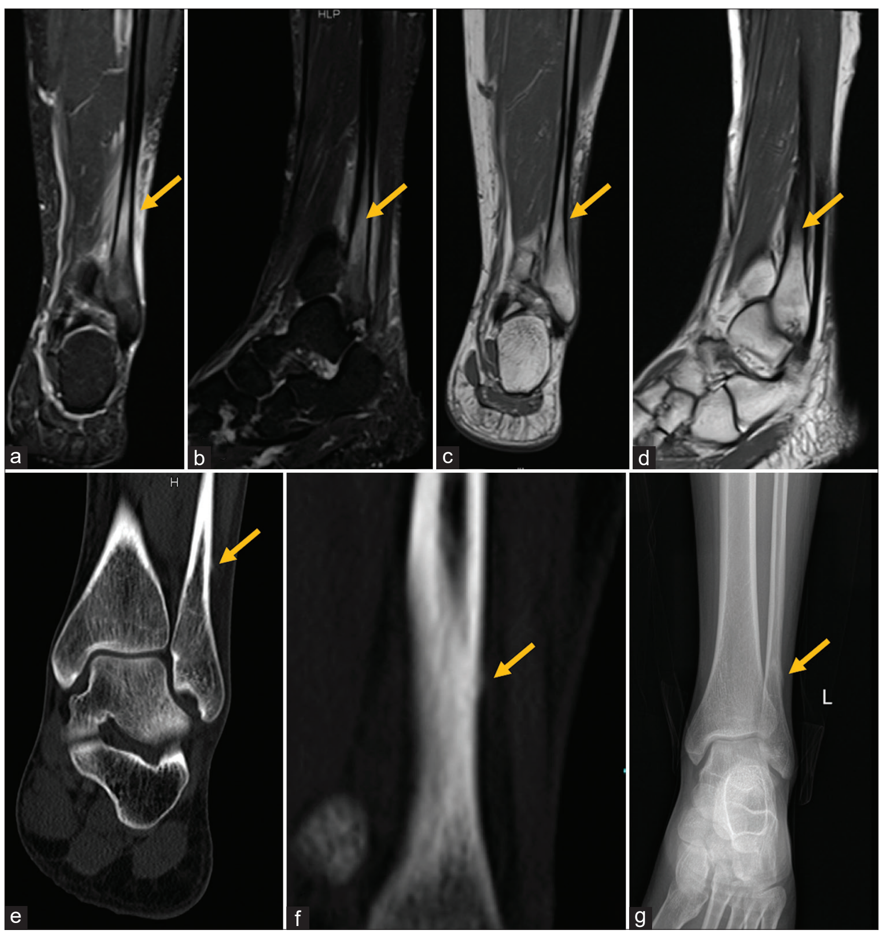

Figure 10: A 33-year-old radiologist with recent history of starting to jog. (a and b) Coronal and sagittal STIR images show hyperintense edema (arrows) in the distal fibula and surrounding soft tissues. (c and d) Corresponding coronal and sagittal T1W images show hypointensity (arrows) at the same location. (e and f) Coronal reformatted CT image and zoomed-in image show periosteal reaction. (g) Follow-up anteroposterior radiograph after 5 weeks shows periosteal reaction.

Table 4: Modified Hollenberg classification (CG Sundell).

Modified Hollenberg classification							
	Grade 0	**Grade 1**	**Grade 2**	**Grade 3**	**Grade 4**	**Grade 5**	**Grade 6**
	No edema in PI on MRI, normal CT	Edema in PI on MRI, no sign of fracture on CT	Edema in PI on MRI, incomplete fracture in PI on CT	Edema in MRI, complete fracture in PI on CT	Edema in PI on MRI, signs of healing in PI on CT (periosteal callus, sclerosis, reduced extent or gap of fracture)	No edema in PI on MRI, healed fracture in PI on CT	No edema in PI on MRI, pseudoarthrosis in PI on CT
CT	No sign	No sign		Sign	Sign	Sign	Sign
MRI	No sign	Edema		Edema	Edema	No sign	No sign

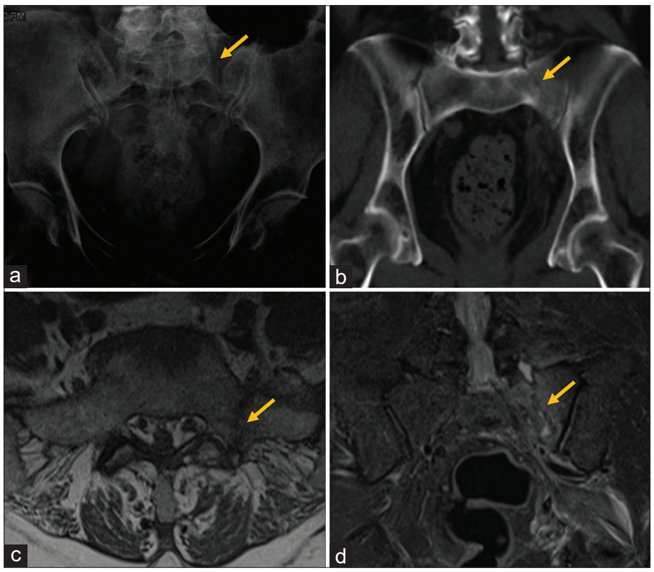

Figure 11: A 75-year-old female presented with back ache. (a) Initial anteroposterior radiograph of the pelvis shows fracture line (arrow) through the left sacral ala. (b) Coronal reformatted CT image of the pelvis also demonstrates fracture line (arrow). (c) Axial T1W image shows an irregular hypointense fracture line (arrow). (d) Coronal STIR image demonstrates a hypointense fracture line with surrounding hyperintensity (arrow) in the left sacral ala.

Accessory ossicles, on the contrary, are supernumerary bones derived from unfused primary or secondary ossification centers. Both are small, ovoid and well-corticated bony structures, bipartite or multipartite, and are seen near a bone or joint. Both can be associated with pathological conditions that include trauma, inflammation, infection, osteoarthritis, and pain syndromes.

Sesamoids commonly found in the foot are paired medial and lateral hallucal sesamoids, interphalangeal joint sesamoid of the great toe, and lesser metatarsal sesamoids. The commonly reported accessory ossicles include os trigonum, os peroneum, and accessory navicular.

Sesamoid fractures [Figure 16] can be seen in ballet dancing or in other activities such as sprinting and running. These fractures are seen to occur more commonly with barefoot activities. It results in painful sesamoid which warrants early consideration of MRI to identify the cause of pain accurately and quickly.[38] A more gradual onset and a lesser uptake on the bone scintigram can be helpful in distinguishing stress fractures from acute fractures.[39] Bipartite medial or lateral sesamoid bone shows corticated edges, smooth rounded margins with no increased uptake on bone scan, differentiating it from fracture.

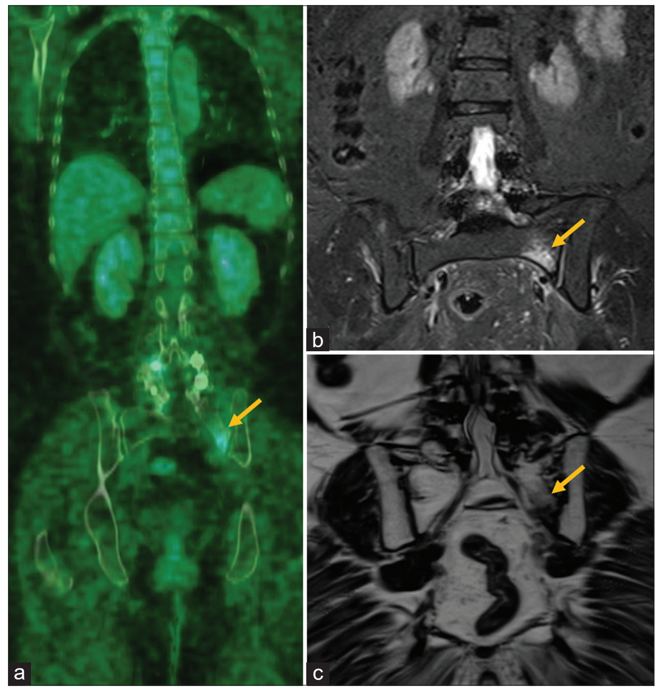

Figure 12: A 65-year-old female with carcinoma breast and bony metastasis in the left sacral ala. (a) Whole-body PET-CT image demonstrates focal uptake in the left sacral ala. (b) Coronal STIR image shows focal hyperintensity (arrow) without any hypointense fracture line. (c) Corresponding coronal T1-weighted image shows ill-defined hypointense signal without any definite fracture line.

Humerus

Stress fractures of humerus are reported in overhead athletes, baseball, tennis, and golf players.[40] The proximal humerus is affected more frequently than the distal shaft

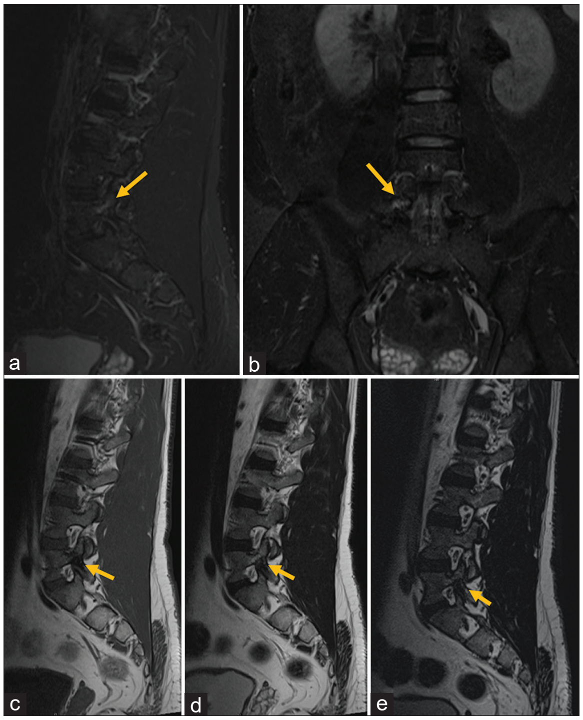

Figure 13: A 32-year-old male presented with back ache. (a and b) Sagittal and corresponding coronal fat-suppressed T2-weighted images of lumber spine show edema (arrow) in the right pars interarticularis at L5-S1 level suggesting stress edema. (c-e) Sagittal T1W, T2W, and SPC sequences acquired after 2 weeks show thin hypointense fracture line (arrow) at the same location.

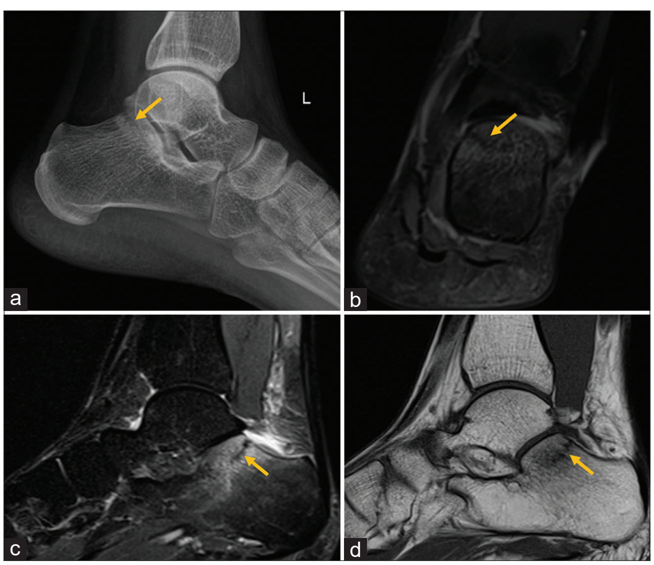

Figure 14: A 27-year-old aerobic instructor with heel pain. (a) Lateral radiograph of the ankle shows a thin lucent line (arrow) in the superior aspect of calcaneum. (b and c) Coronal and sagittal STIR images show hypointense fracture line (arrows) with surrounding hyperintensity. (d) Corresponding sagittal T1 image shows hypointense fracture line (arrow) with surrounding edema.

Figure 15: March fracture. (a and b) Coronal T2W and STIR images show hyperintense periosteal edema (arrows) involving the midshaft of the second metatarsal without any fracture line (arrow). (c and d) Corresponding axial and sagittal STIR images also show hyperintense periosteal edema (arrows). (e) Follow-up radiograph after 2 weeks reveals periosteal reaction (arrow).

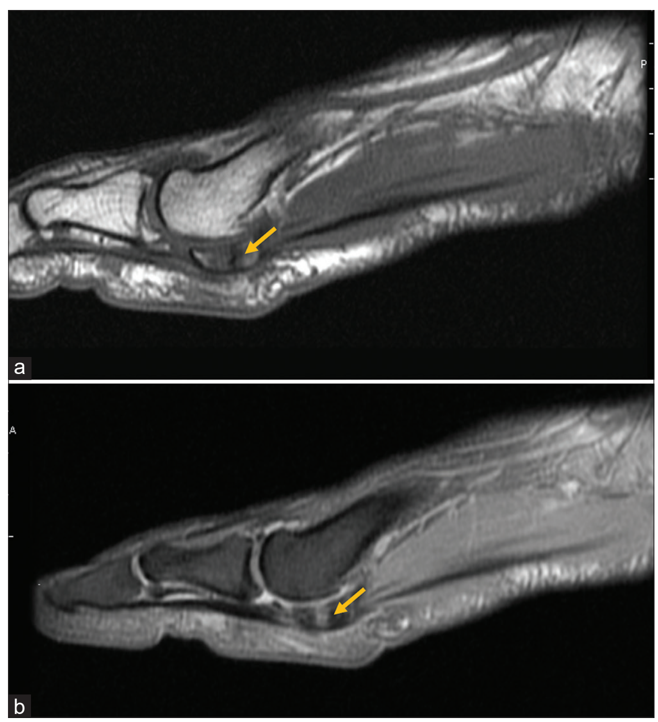

Figure 16: Sesamoid fracture. (a) Sagittal T1 image shows hypointense fracture line (arrow) involving the sesamoid bone. (b) Sagittal STIR image shows corresponding hyperintense edema (arrow).

[Figure 17]. Due to the low sensitivity of radiographs in stress fractures as in other bones, MRI helps in identifying early marrow changes.[41] Classical location and presence of a T1 hypointense linear fracture line with surrounding bone marrow edema with a corroborative history helps in clinching the diagnosis.

Anderson fractures (AS)

AS is a seronegative spondyloarthropathy, particularly affecting and resulting in fusion of the spine and sacroiliac joints, though other large and small joint involvement can also be seen. The localized involvement of intervertebral discs and adjoining vertebrae is a recognized complication, described by Anderson in 1937.[42]

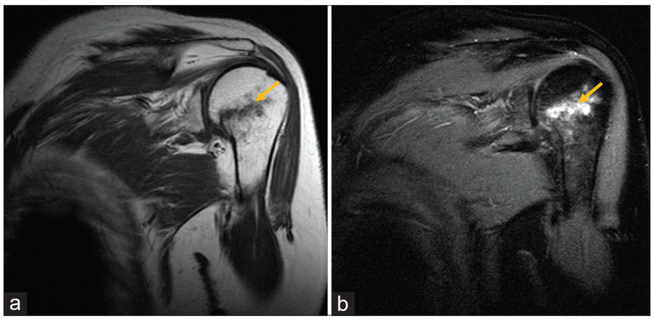

Figure 17: Humeral neck stress fracture in a golfer. (a) Coronal T1 image shows hypointense fracture line (arrow). (b) Coronal STIR image shows corresponding hyperintensity (arrow) representing surrounding edema.

Debate about its etiology exists with one of the hypotheses suggesting stress fracture of the ankylosed spine being the cause of Anderson lesion (AL). The fracture involves the anterior and posterior part of the vertebral column and may pass through the vertebrae or more commonly through the calcified disc region. Movement at the fracture site hinders with fracture healing and union and can result in pseudoarthrosis.

MRI is very sensitive and identifies the early edematous changes not visualized on plain radiographs.

AL is seen as abnormal signal intensity in the discovertebral unit which includes the disc and one or both vertebral halves, appearing hypointense on T1-weighted images and bright on T2W [Figure 18] and STIR images. Careful evaluation of the rest of the spine to look for syndesmophytes and sacroiliac joints for inflammatory arthropathy changes should be done to avoid confusing these findings for osteomyelitis and infective spondylodiscitis.

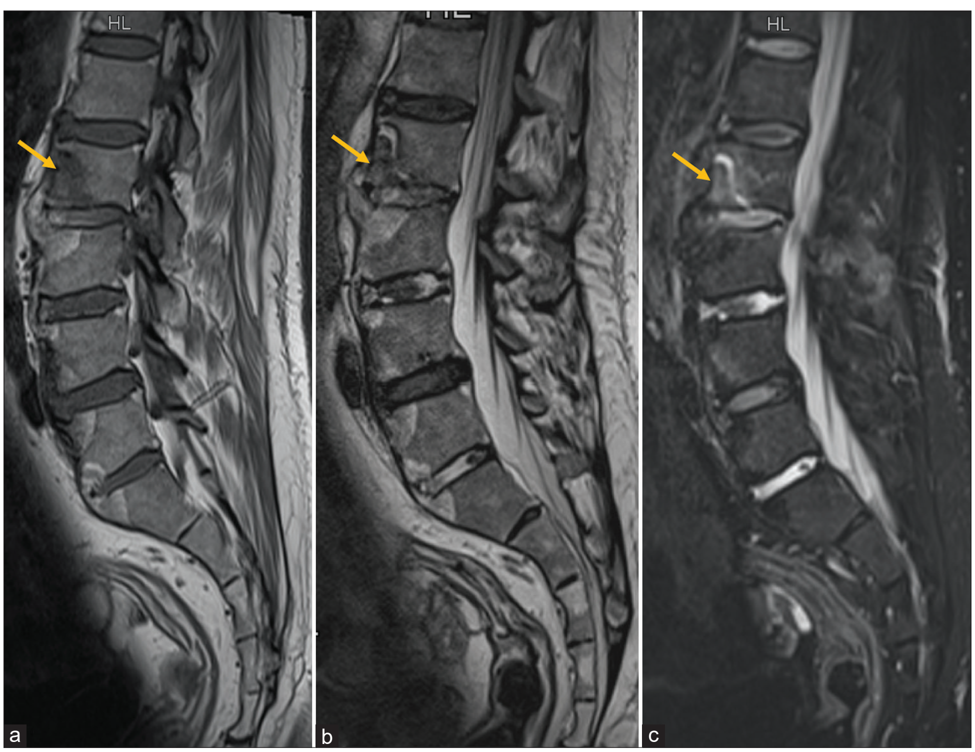

Figure 18: Anderson fracture. (a) Sagittal T1W image shows characteristically reduced signal intensity (arrow). (b) Sagittal T2W space image shows central destructive zone (dashed arrow) surrounded by an area with reduced signal intensity (arrows). (c) Sagittal STIR image shows central destructive zone (dashed arrow) surrounded by an area of increased signal intensity (arrows) representing edema.

CONCLUSION

We have illustrated MRI findings, in stress fractures and their possible differentials at various sites, discussed about MR grading and role of early identification of stress fractures to reduce morbidity and quick return to activity. It is important to think the possibility of a stress fracture, particularly while reporting MR cases with non-specific marrow edema, and be aware that insufficiency related or early overuse related stress injury can be a possible differential, keeping in mind the other close differentials such as infection, neoplasm, or transient osteoporosis.

Declaration of patient consent

The authors certify that they have obtained all appropriate patient consent.

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Conflicts of interest

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