[Imaging]

Orthopaedic Magnetic Resonance Imaging Challenge

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CHALLENGE

Two patients are presented with differing histories, but one diagnosis.

Patient 1

A 61-year-old man presents with tibial pain and an abnormal bone scan suspicious for a possible mass. An axial fat-suppressed proton-density image through the mid-lower left leg and a coronal fat-suppressed T2-weighted image along the posterior tibial cortex are provided (Figure 1).

Patient 2

A 52-year-old man presents with tibial pain after golfing. An axial fat-suppressed proton-density image obtained at the level of the distal tibial shaft and a sagittal fat-suppressed T2-weighted image of the lower half of the tibia are provided (Figure 2).

The findings are marked with arrows. What is your diagnosis? See Figures 1 and 2.

DIAGNOSIS

Longitudinal stress fracture of the tibia.

DISCUSSION

Marrow edema visible on magnetic resonance imaging (MRI) can have multiple causes and may raise concerns of malignancy or osteomyelitis, particularly when a periosteal reaction is present. Other causes of marrow edema include stress reaction, trauma, or secondary changes from adjacent inflammatory arthritis or tenosynovitis. In young patients, red marrow may mimic or mask marrow edema. The finding of marrow edema should prompt a search for a more specific underlying abnormality. A longitudinal stress fracture of the tibia is a challenging but recognizable diagnosis on MRI and is much more common than previously reported. Patients with longitudinal stress fractures may present with an atypical clinical history; thus, recognition of the characteristic MRI appearance of these lesions is critical in making the correct diagnosis.

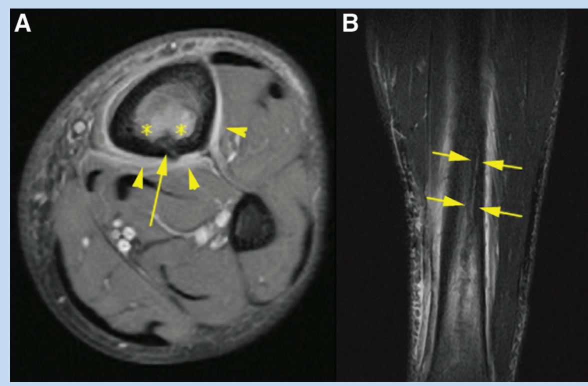

Figure 1. The axial fat-suppressed proton density–weighted image (A) shows marrow edema (*) and periosteal edema (arrowheads) involving the midtibia, most prominent posteriorly. The posterior tibial cortex is discretely disrupted as a linear cleft with adjacent elevated cortical ridges (arrow). The coronal fat-suppressed T2-weighted image (B) demonstrates a vertically oriented high signal line, bordered by dark sclerotic lines (arrows). Additional images (not shown) confirmed that this corresponded in position to the abnormality found on the axial image and not a nutrient vessel. There is no osseous or soft tissue mass.

The tibia is the most common location for the development of stress fractures. Tibial stress fractures are most often found in distance runners, in whom normal bone is subjected to repetitive microtrauma such that the rate of osteoclastic resorption exceeds the rate of repair. Stress fractures of the tibia have been most frequently reported in transverse orientation, with a longitudinal orientation in a small minority.[1,6,7]

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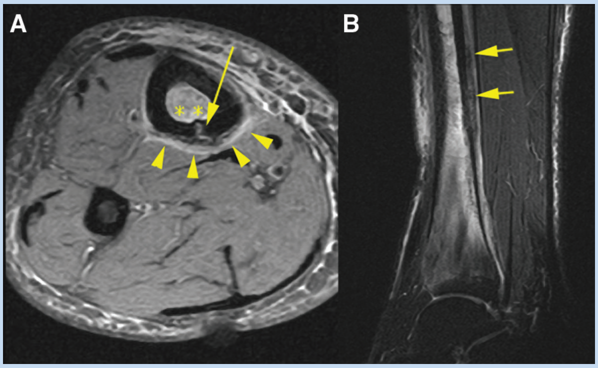

Figure 2. The axial fat-suppressed proton density–weighted image (A) reveals marrow edema (*) and periosteal edema (arrowheads) involving the midtibia, most prominent along the posterior tibial cortex. The posterior tibial cortex is discretely disrupted in a linear configuration (arrow), with elevated cortical ridges along the disruption line. The sagittal fat-suppressed T2-weighted image (B) demonstrates a vertically elongated area of linear cortical abnormality (arrows) spanning several centimeters in length. Edema is seen in a large portion of the tibial marrow but is most prominent adjacent to the posterior cortical abnormality.

Radiographs have a low sensitivity for detection of stress fractures; therefore, relative-incidence determinations of fracture orientation based on radiographs are limited in accuracy. Owing to its increased sensitivity, bone scan was for some time the favored method for diagnosing early stress injuries. However, the technique has low specificity,[7] leaving diagnostic uncertainty, particularly in patients who do not have the typical history of distance running. MRI has subsequently become the gold standard for diagnosis of tibial stress fractures and their earlier precursors of stress reaction and periosteal reaction (medial tibial stress syndrome).

The examples given in the challenge cases show perhaps the most common appearance for a longitudinal fracture of the tibial shaft. The fracture involves a single cortex and is oriented in a plane radial to the center of the bone and perpendicular to the cortex (Figure 3).

Several additional examples are presented to demonstrate some of the variations of fracture position, orientation, and clinical history (Figures 4–8).

Previous estimates of transverse versus longitudinal stress fracture orientations in the tibial shaft likely underestimated numbers of the latter. In a sample of MRI cases performed at our affiliated centers, this proportion appears reversed. As based on this gold standard diagnostic technique, longitudinal fractures of the tibial shaft likely occur more commonly than previously thought and are in fact more common than transversely oriented fractures.

Longitudinal fractures have been underappreciated because transverse fractures are more visible on radiographs. If an X-ray beam encounters a radial longitudinal fracture line at any angle other than perfect en face alignment, it may be obscured by the adjacent sclerotic borders and at best interpreted as periosteal reaction. Even if the fracture is seen, it may be mistaken for a normal nutrient foramen. Oblique coronal fractures may be even less visible. Meanwhile, a transverse fracture is more likely to extend into the portion of the cortex that is tangent to the beam, allowing it to be distinctly visible. The lower radiographic sensitivity to longitudinally oriented fractures in particular may be the underlying reason for underestimates of their prevalence. Additional support for this hypothesis is that the typical appearance of a positive bone scan is that of increased uptake over a several-centimeter vertical segment.

Figure 3. Typical appearance of longitudinal fracture. The fracture is several centimeters long and involves a single cortex. Elevated cortical margins are seen from endosteal and periosteal callus formation and indicate a subacute to chronic fracture age.

CLINICAL CONSIDERATIONS AND UNDERLYING BIOMECHANICS

In a running athlete with lower leg pain, the primary differential diagnostic considerations include muscle and tendon injuries, chronic compartment syndrome, shin

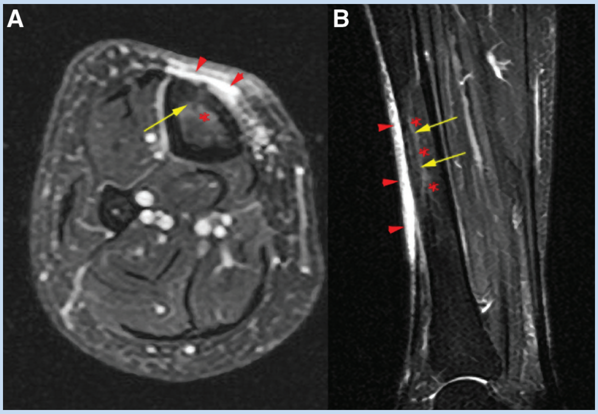

Figure 4. Sixty-eight-year-old with history of persistent tibial pain since "bumping the leg" 2 months earlier. Axial (A) and sagittal (B) fat-suppressed T2-weighted images demonstrate a longitudinal fracture (arrows) of the anteromedial cortex of the tibial shaft. The typical feature of elevated ridges along the fracture line projecting outward from the bone and inward toward the marrow space is seen, associated with periosteal (arrowheads) and endosteal (*) edema. The history in this case also suggests that these fracture types may in some cases not be stress related or perhaps that gradual bone fatigue may not be recognized. The relatively minor trauma may have been causative, or it may not have been but merely the only injury that the patient can recall as a possible explanation for the pain.

splints, and stress fracture. Additional differential diagnostic considerations, especially in patients who are not distance runners, include intermittent claudication, osteomyelitis, and neoplasm.

Medial tibial stress syndrome, also known as *shin splints*, is an early stage in the continuum that culminates in a stress fracture. The pain is typically that of posteromedial soreness, and the diagnosis is usually made clinically without the need for further imaging assessment. On a microscopic level, repetitive stress leads to osteoclastic resorption exceeding osteoblastic bone regeneration. The associated edema along the periosteum and endosteum of the bone is visible on MRI. Periostitis may be directly caused by traction at muscle or fascial attachments, or it may be a response to developing changes in the underlying bone. The relative roles of compressive versus torsional forces in the development of medial tibial stress syndrome and, ultimately, stress fractures have been debated. Recent work appears to favor the latter.[3,5] Compressive forces account for the transverse, often subchondral, stress fractures in the proximal tibia. Torsional forces may be of greater significance in the tibial shaft and may account for the higher number of longitudinal fractures.

Clinical histories in patients with stress fractures may be atypical. An example is a case presented by a perplexed infectious disease specialist: A patient with a remote history of a gunshot wound and a gradual onset of lower leg pain had been referred to him after results of a bone scan and MRI were interpreted as being positive for osteomyelitis. However, the white blood cell count and erythrocyte sedimentation rate were normal. On further review of the MRI, a longitudinal stress fracture of the tibial shaft was identified. To remove any lingering doubt, the finding was confirmed by subsequent computed tomography (CT). The MRI also showed an unusual pattern of muscle atrophy, evidently from the gunshot injury. Chronic muscle imbalance from muscle injury was likely the underlying cause of the stress fracture that developed years after the initial trauma.

MRI EVALUATION

Clues to the MRI diagnosis of longitudinal fracture of the tibial shaft include edema distribution along the endosteum and periosteum of one cortex, most often posteriorly or anteromedially. The axial images are frequently diagnostic, demonstrating a linear cortical defect on multiple sequential images and, often, endosteal and periosteal callus formation.[9] The sagittal or coronal sequences are helpful in demonstrating the length of involvement and the site of greatest edema, which indicates the most likely fracture site. A fracture line is occasionally visible on the coronal or sagittal sequences, depending on fortuitous positioning of the image slice relative to the effected cortex.

An imaging pitfall in the diagnosis of stress fractures is that of a normal nutrient foramen (Figure 9). Nutrient foramina course obliquely through the tibial cortex and exhibit a round shape on axial images, progressing from the inner to the outer cortical surfaces. An associated vessel can typically be seen extending beyond the foramen, within the marrow space as well as external to the bone.

MRI is well suited for distinguishing stress and pathologic fractures. Well-demarcated T1 signal abnormality, endosteal scalloping, and an adjacent soft tissue mass are each indicators of neoplasm rather than stress fracture.[4]

When a distinct fracture is not seen and a typical history is not present, the diagnosis may not be definitive. Additional correlation with clinical history is often necessary. Laboratory analysis assists in excluding the possibility of osteomyelitis. Although CT will not detect the edema and periosteal reaction visible on MRI in early stages of medial tibial stress syndrome, imaging with thin-section CT may allow more detailed osseous assessment and clearer depiction of a fracture line.[5] Another alternative, if confirmation is needed, is a follow-up MRI study following a period of limited weightbearing or cessation of the inciting activity.

TREATMENT

Once the diagnosis of tibial stress injury is established by clinical or imaging assessment, a treatment plan can be determined on the basis of injury severity. Symptomatic

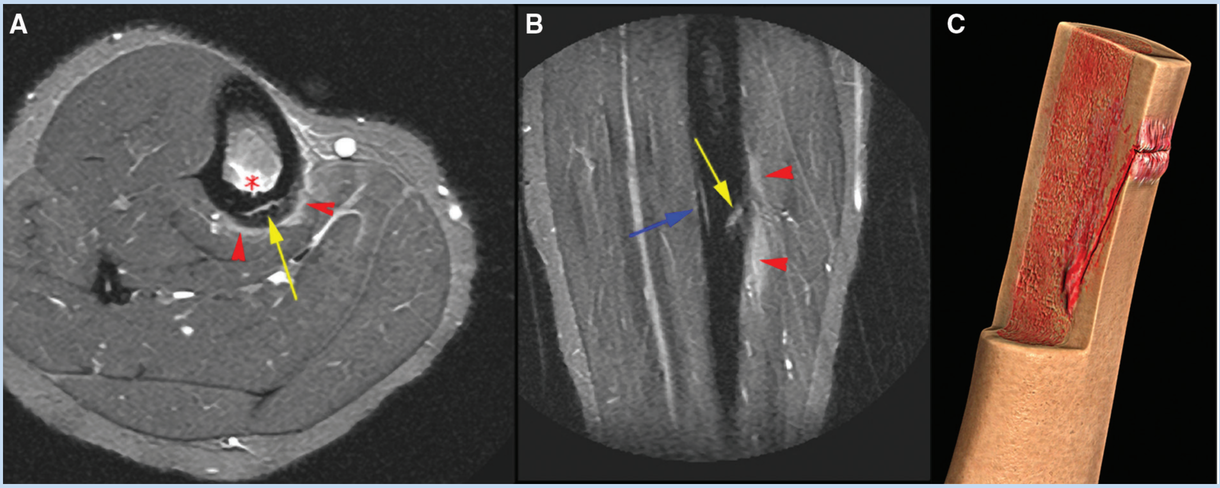

Figure 5. Twenty-one-year-old runner with midtibial pain for 2 months despite cessation of running for the past month. Axial (A) and coronal (B) fat-suppressed T2-weighted images and a corresponding illustration (C) demonstrate an oblique coronal fracture of posterior cortex of the tibia (yellow arrows) with endosteal edema (*) and periosteal edema (arrowheads). This is a common longitudinal fracture orientation, although more difficult to recognize than the radially oriented version. On sequential axial images (not shown), the line can be seen to course from the outer to the inner cortical surfaces over a length of several centimeters. A normal nutrient foramen is seen on the coronal image (blue arrow) without adjacent edema.

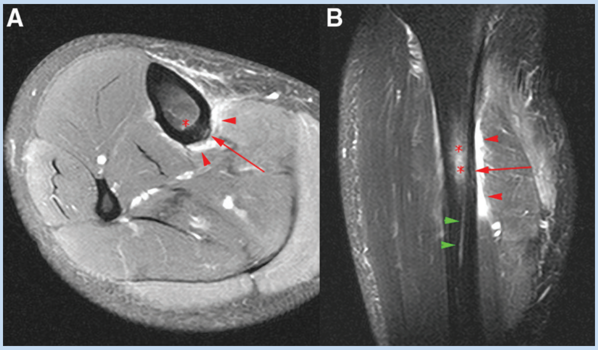

Figure 6. Forty-seven-year-old runner with shin pain. Axial fat-suppressed proton-density (A) and coronal fat-suppressed T2-weighted (B) images demonstrate a small oblique coronal fracture of posterior cortex of the right tibia (arrows). This is similar to the prior case, although the fracture is smaller and more subtle. The associated endosteal edema (*) and periosteal edema (arrowheads) help to localize the fracture site, although the fracture itself cannot be clearly discerned on the coronal image. Note the normal nutrient foramen (green arrowheads) without surrounding edema.

patients with stress reaction and no fracture can be treated with nonimpact training, whereas a fracture may require casting for 6 weeks. Low grades of tibial stress injury (ie, periosteal and marrow edema) can be seen in nearly half of asymptomatic collegiate distance runners and are not predictive of future stress fracture.[2] This emphasizes the importance of correlating the MRI findings with the clinical findings before making therapeutic decisions.

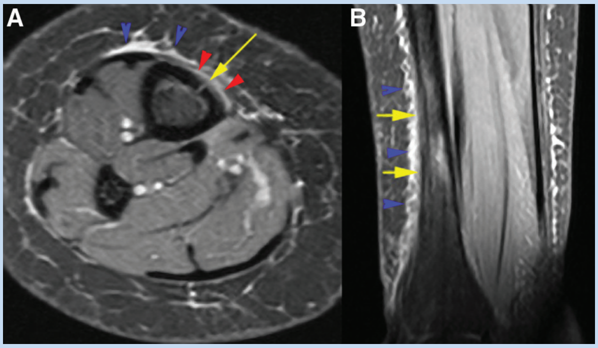

Figure 7. Forty-nine-year-old woman with persisting tibial pain 3.5 months after a bicycle accident. Axial (A) and sagittal (B) fat-suppressed proton density–weighted images demonstrate a longitudinal fracture of the anteromedial cortex of the tibia (arrows). Periosteal edema is seen on the axial image (red arrowheads) but is difficult to distinguish from adjacent deep subcutaneous edema (blue arrowheads) on the sagittal image. This is not a stress fracture but illustrates the similarity in appearance. Longitudinal fractures at this site are prone to delayed union, presumably because of torsional stresses that normally occur at this location. The fatigue strength of compact bone subjected to torsional stress is significantly lower than that in bone subjected to compression stress.[8]

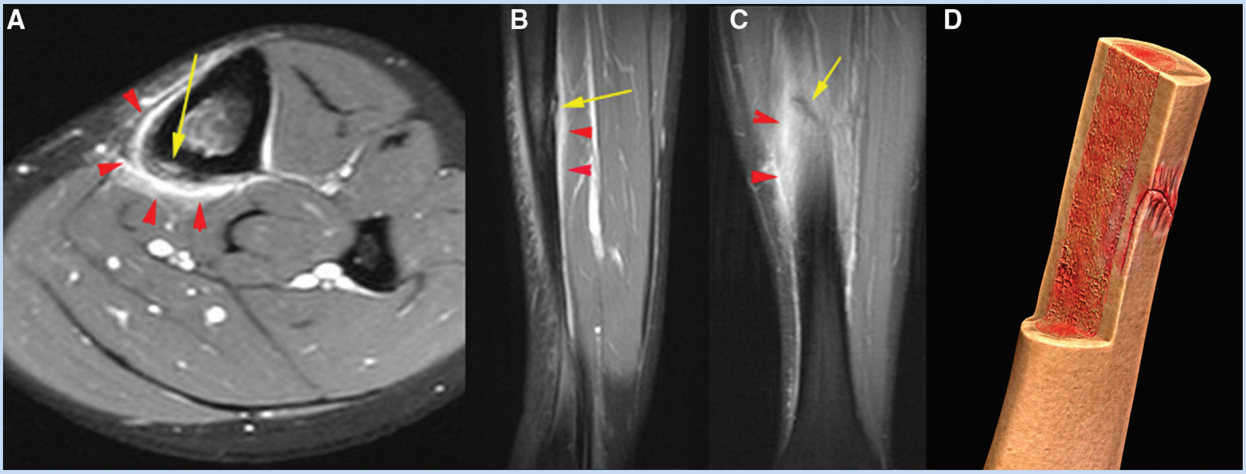

Figure 8. Sixteen-year-old with tibial pain for 5 weeks, which developed while running. Axial (A), sagittal (B), and coronal (C) images and corresponding illustration (D) demonstrate an oblique fracture of the posterior cortex of the left tibia (arrows) with prominent periosteal edema (arrowheads). This fracture orientation has an oblique orientation along the cortical surface and courses almost coronally within the cortex. This may be viewed as a variant between the other 2 types shown.

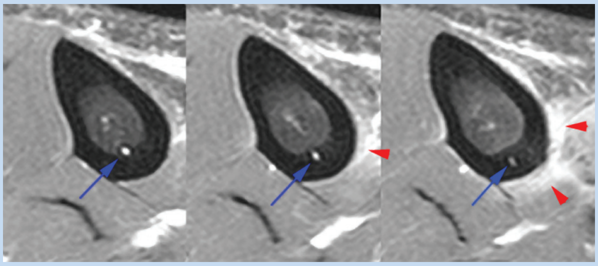

Figure 9. Axial fat-suppressed proton-density images in sequence from inferior to superior, showing a normal nutrient foramen (arrows), with a characteristic round shape, progressing from the marrow space through the posterior tibial cortex. This patient also had a stress fracture (visible in Figure 6) just superior to the third image in this series. The associated periosteal edema (arrowheads) increases in degree as it approaches the fracture site; it is not associated with the normal nutrient foramen.

CONCLUSION

Longitudinal fractures of the tibial shaft are most often caused by repetitive torsional loading in distance runners as the endpoint of a continuum of medial stress injury, although patients may present with an atypical clinical history. Longitudinal tibial shaft fractures are more common than previously reported, likely because of the low sensitivity of radiographs for this fracture orientation. An astute MRI reader can often make a definitive diagnosis of a longitudinal fracture upon finding a linear cleft on sequential axial images, bordered by a longitudinal rim of endosteal and periosteal callus and accompanied by endosteal and periosteal edema. Less typical fracture orientations and earlier stages of stress reaction can also be confidently diagnosed by MRI, although correlation with clinical labs, additional imaging with CT, or follow-up MRI after a period of rest may be useful when findings are atypical.

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