Longitudinal stress fracture: patterns of edema and the importance of the nutrient foramen in MRI evaluation.

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Aims and objectives

Longitudinal stress fractures are uncommon fractures that are thought to be related to rotational stress. While they most commonly occur in the tibia, cases have also been reported in the femur and fibula. The fracture was first described by Divas in 1960. The fracture may be of the fatigue or insufficiency type.

A longitudinal stress fracture is a challenging but recognizable diagnosis on MR and the findings may be misinterpreted as other pathology, particularly tumor or infection.

Patients with longitudinal stress fractures may present with an atypical clinical history, and thus recognition of the characteristic MR appearance of these lesions is critical in making the correct diagnosis.

In this paper, we reviewed patients with longitudinal stress fracture of the lower extremity and emphasized the secondary findings that may assist in diagnosis, position of the fracture relative to the nutrient foramen of the long bone and the patterns of edema. Finally give the discriminative signs allowing differentiation of this condition from other tumoral or inflammatory conditions.
Methods and materials

We reviewed our MR data based on identified eight patients with longitudinal stress fracture of the lower extremity.

The MR examinations were performed on 1.5 Tesla Signa scanners (GE Medical Systems). The MR parameters and sequences varied between patients. In all cases, the limb was imaged using a torso coil. Imaging sequences included coronal, sagittal and axial T1-weighted, coronal, sagittal and axial fat-saturated T2-weighted sequences and a coronal fast STIR sequence. Pre and post gadolinium axial and coronal fat-saturated T1-weighted sequences were obtained in 3 patients.

The field of view varied between 16 and 48 cm, the slice thickness varied between 3 and 5 mm with a 1 mm interspace, and the number of excitations varied from two to three.
Results

Results:

All patients had longitudinal stress fractures diagnosed by finding a cleft on several or multiple axial images(Figure, 1).

Of the seven tibial fractures, 5 showed a typical pattern of edema starting at the level of the entrance of the nutrient vessel into the medullary cavity with a vertical fracture identified below this on the antero-medial cortex of the tibia (Figure, 2, 3, 4). One case demonstrated tibial fracture starting at the level of the nutrient foramen and runs back into the proximal tibia (Figure, 5, 6, 7, 8). Only one patient presented a tibial longitudinal fracture located at the postero lateral tibial cortex starting at the level of medullary entrance of nutrient vessel (Figure, 9).

Endosteal and periosteal edema are noted in all cases and extend away from the fracture site (Figure 10).

Three of these fractures had central marrow edema and eccentric soft tissue edema and periosteal reaction (Figure 3, 6, 7, 10). In the other cases, the medullary edema was minimal with eccentric soft tissue edema (Figure 1).

The femur fracture showed eccentric periosteal reaction, soft tissue and marrow edema (Figure, 11). The edema started just below the level of the nutrient foramen but no communication of the nutrient foramen with the fracture could be defined.

After IV contrast injection all three cases demonstrated enhacement at the site of cortical cleft and only one showed eccentric bone marrow contrast uptake near the site of fracture (Figure, 7. 11).

Discussion

Longitudinal stress fracture is an unusual fracture of the lower limb, first described by Divas in 1960 (1). tibia is the most common location for the development of stress fractures (1, 2). 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. Patients who developed this fracture may give a history of no increased physical activity nor of trauma. In these cases, the fracture may be of the insufficiency type (3). Careful review of our patients' histories showed that the fractures are likely fatigue in nature. In one case, which was obese and sedentary, it was difficult to determine definitively the nature of the stress fracture, but it is likely it was an insufficiency type longitudinal stress fracture.
Stress fractures of the tibia have been reported to be most frequently transverse in orientation, with a longitudinal orientation in a small minority (1,2,3). It has also been noted that radiographs have a low sensitivity for detection of stress fractures, and therefore relative incidence determinations of fracture orientation based on radiographs are limited in accuracy. Due to its increased sensitivity, bone scan was for some time the favored method for diagnosing early stress injuries. However, the technique has low specificity (3), leaving diagnostic uncertainty particularly in patients that do not have the typical history of distance running.

The fracture involves a single cortex, and is oriented in a plane radial to the center of the bone, perpendicular to the cortex. The key to the diagnosis is to define a cleft on one or several images. The axial plane is the ideal plane for imaging on both CT and MRI, and the diagnosis can confidently be made by finding a cleft in the cortex on several or multiple axial slices.

MRI has subsequently become the gold standard for diagnosis of tibial stress fractures and their earlier precursors of stress reaction and periosteal reaction(6, 7, 8). 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 anteromedially or posterolaterally and rarely laterally. In our series the edema distribution and the fracture sites were predominantly anteromedial in the 5 tibial fractures and were posterolateral or lateral in 2 cases. The axial images are frequently diagnostic, demonstrating a linear lucency on multiple sequential images, and often endosteal and periosteal callus formation (7, 8).

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 affected cortex.

An imaging pitfall in the diagnosis of stress fractures is that of a normal nutrient foramen. 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 (8). The round shape of the foramen and the absence of an endosteal and periosteal edema along the nutrient vessel course can rule out a stress fracture. The foramen may be a potential area of weakness in some patients. This was noted in two of the seven tibial fractures of our series which started at the nutrient foramen. When under stress because of increased physical activity or decreased quality of the bone, the foramen may allow development of a vertical fracture.

Safiuldin and colleagues noted that both the longitudinal stress fracture described were located superomedial to the nutrient foramen of the tibia (7, 8). Three of our eight patients showed eccentric edema within the marrow on T1-weighted, T2-weighted and STIR sequences secondary to fractures.
MRI is well suited for distinguishing between stress fractures 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.7

When a distinct fracture is not seen and a typical history is not present, the diagnosis may not be definitive. Additional correlation with further 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 (8). Another alternative, if confirmation is needed, is a follow-up MRI study following a period of limited weight-bearing or cessation of the inciting activity. This should show improvement or resolution of abnormalities.
Fig. 1: Axial fat-suppressed proton density-weighted images demonstrate a longitudinal fracture of the anteromedial cortex of the tibia (yellow long arrow). Periosteal edema is seen (red arrowheads) but is difficult to distinguish from adjacent deep subcutaneous edema (blue arrowheads).

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**Fig. 2:** Axial fat suppressed T2 weighted image shows the entrance of the nutrient vessel in the medullary cavity (straight arrow), of the mid tibia and the start of marrow edema (curved filled arrow). Note there is thickening of posteromedial tibial cortex (curved open arrow).

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Fig. 3: Axial fat suppressed T2 weighted image below fig 2, shows thickening of the postero medial cortex (long arrow), medullary edema (curved arrow) and eccentric soft tissue edema (short arrows).

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Fig. 4: Axial fat suppressed weighted image, below fig 3, shows diffuse marrow edema, eccentric antero medial soft tissue edema (curved arrows) and the longitudinal fracture ( black straight arrows) . Note the thickening of the antero medial cortex at the site of fracture.

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Fig. 5: Axial fat supressed T2 weighted image shows the nutrient vessel (long straight arrow) with adjacent eccentric edema within the bone marrow and posterior to the tibia (curved arrow). Note the minimal periosteal reaction secondary to the start of the fracture (short straight arrow).

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Fig. 6: Axial fat supressed T2 weighted image shows the fracture (long straight arrow) eccentric bone marrow edema (curved filled arrow) and soft tissue edema (curved open arrows). Eccentric periosteal reaction (short straight arrow)

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Fig. 7: Same patient as fig 5 and 6, Axial fat suppressed T1 weighted image with contrast injection, shows the enhancing nutrient artery (long arrow) with marrow and soft tissue edema. Note also the minimal periosteal reaction secondary to the start of the fracture. (short straight arrow)

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**Fig. 8:** Axial fat suppressed weighted image above fig 6 and 7, shows the fracture (straight long arrows) with the nutrient vessel on the outer aspect of the foramen (curved arrow). Note the periosteal reaction and new bone formation posteriorly (short straight arrow). The fracture runs up into the proximal tibia.

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Fig. 9: Axial fat suppressed T2 weighted image, shows cortical cleft at the postero lateral aspect of tibial cortex (straight thin arrows) at the outer part of the nutrient vessel (curved arrow) associated with eccentric soft tissue edema at the lateral aspect of tibia (open straight arrow).

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**Fig. 10:** Coronal proto density fat suppressed image, shows eccentric bone marrow and periosteal edema in the tibial shaft. Note the longitudinal fracture in lateral tibial cortex with cortical thickening and periosteal reaction.

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Fig. 11: Axial post gadolinium T1 weighted image through the shaft of the femur shows enhancement of the eccentric marrow edema (long straight arrow). The cleft of the fracture (short straight arrows), eccentric periosteal reaction (curved filled arrows) and new bone formation (curved open arrow)

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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. 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. 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.


