Stress Fractures: Radiological Findings

Poster No.: P-0101
Congress: ESSR 2013
Type: Scientific Exhibit
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Keywords: Trauma, Osteoporosis, Athletic injuries, Education, Conventional radiography, MR, CT, Musculoskeletal bone, Extremities
DOI: 10.1594/essr2013/P-0101
Purpose

To describe the radiological findings in stress fractures.
Methods and Materials

We briefly explain the definitions, biomechanics, and typical clinical signs of stress fractures.

We describe and illustrate findings on plain-film X-rays, CT, bone scan, and MRI to enable the correct diagnosis of stress fractures.

We describe lesions common in different anatomical locations.
Results

Stress fractures are a common cause of pain and morbidity in our environment due to the increase in the elderly population and increasing physical activity. The can be difficult because the clinical presentation is nonspecific and may initially suggest tendon or muscle injuries. Stress fractures have no gender predilection and occur in people of all ages. They can occur bilaterally, can involve multiple bones, and can be recurrent; approximately 60% of individuals with a stress fracture have a history of a previous stress fracture.

From an etiologic standpoint, there are two general types of stress fractures: insufficiency fractures and fatigue fracture. Insufficiency fractures occur when normal or physiologic muscular activity stresses a bone that is deficient in mineral or elastic resistance. Fatigue fractures are caused by the prolonged cyclical application of abnormal mechanical stress to a bone that has normal elastic resistance.

The term pathologic fracture should be restricted to situations in which a neoplasm or infection has weakened the bone.

**Insufficiency fractures:**
These usually occur in the context of conditions in which the mineral content or the elasticity of bone is abnormal. Although insufficiency fractures are more common in elderly women who have postmenopausal osteoporosis, they also occur in patients with osteoporosis of any cause, including corticosteroid use, rheumatoid arthritis, and diabetes mellitus. Other causes include Paget's disease, osteomalacia, hyperparathyroidism, renal osteodystrophy, osteogenesis imperfecta, rickets, osteopetrosis, fibrous dysplasia, and irradiation. In addition, some drugs, including methotrexate and etidronate have been associated with the development of stress fractures.

The most common sites of fractures in patients with osteoporosis are the sacrum, pubic rami, and lower limbs Fig. 1 on page 10 Fig. 2 on page 10

**Fatigue fractures:**
These usually occur in young adults, particularly in athletes, but they also can occur in the elderly and children. The location of the fracture is related to physical activity.

**Biomechanics:**
Unlike an acute fracture, which usually occurs from a single supraphysiologic stress, a stress fracture is a result of a dynamic process over time.
Stress fractures occur when there is an increased rate of bone remodeling in response to repetitive submaximal stress. Initially, bone remodeling manifests as osteoclastic activity and resorption of lamellar bone. This is replaced by denser, stronger osteonal bone. In repetitive stress overload, however, the accelerated remodeling results in an imbalance between bone resorption and bone replacement, leading to bone weakening. Continued stress results in further imbalance, leading to bone fatigue and fracture.

Clinical evaluation:
Symptoms are often insidious in onset and nonspecific; pain with activity is the most common. Most fatigue fractures are related to activity that involves the following three factors: it was new or different for the individual, it was exhausting, and it was repetitive.

Clinical signs of stress fracture are also nonspecific, including tenderness and swelling.

It is important to recognize stress fractures so that the patient can be advised to refrain from the injury-producing activity. Continued activity when a bone has been compromised may result in a complete or catastrophic fracture, in distraction of the bone fragments from that bone, in a fracture of another bone in the same limb, or in a fracture of the same bone in the opposite limb as the person shifts his or her body weight to the opposite side.

RADIOLOGICAL FINDINGS:

Radiography:
Plain-film X-rays play an important role in the work-up of a suspected stress fracture and should be the first imaging study obtained. They can be used to confirm the diagnosis at a relatively low cost. Unfortunately, initial radiographs are often normal.

Radiographic findings are usually seen after 2 to 8 weeks of symptoms. In the early stages of these injuries, the sensitivity of radiography may be as low as 10%; at follow-up, sensitivity increases to 30% to 70%.

When visible, an early stress fracture in the shaft of a long bone typically appears as a lucency through the cortex without any periosteal reaction or callus Fig. 3 on page 11. As the bone heals, a solid or thick lamellar periosteal reaction occurs. Often, this occurs on the endosteal surface as well as on the periosteal surface.

In stress injuries in cancellous bone, such as the calcaneus or femoral neck, plain films initially demonstrate subtle blurring of trabecular margins and focal faint sclerosis perpendicular to the trabeculae, representing the fracture and peritrabecular callus.

Ultimately, the area of periosteal reaction thickens, and the fracture line, if actually seen previously, disappears.
Bone scintigraphy:

Bone scintigraphy scanning is more sensitive but less specific for imaging bony stress fractures and can provide the diagnosis as early as 2 to 8 days after the onset of symptoms.

Before the advent of MRI, bone scintigraphy was the gold standard for evaluating stress fractures.

In the early stages of osseous stress injury, bone scintigraphy will show ill-defined areas of slightly increased uptake of radionuclide. As the injury becomes more severe, radionuclide uptake becomes more intense and focal Fig. 4 on page 12.

Computed tomography:

The typical appearance of a stress fracture on CT is that of focal callus formation and endosteal thickening around a fracture site Fig. 5 on page 13. However, CT has only a limited role in stress fracture detection, because it is less sensitive than bone scintigraphy and MRI. Therefore, the use of CT should be reserved for specific indications such as more advanced injuries and injuries in specific anatomic locations where the role of radiography is limited, such as in the tarsal navicular, or sacrum, or in longitudinal fractures of the tibia.

CT is also useful in differentiating conditions that mimic stress fractures on bone scan, such as osteoid osteoma or pathologic fractures.

Magnetic Resonance Imaging:

MRI is an effective diagnostic technique for the evaluation of patients in whom there is clinical suspicion for stress fracture and radiographs are negative.

MRI can depict abnormalities weeks before they can be seen on plain-film X-rays. MRI's sensitivity is similar to that of bone scintigraphy and its specificity is higher.

Resorption and replacement of bone are early changes in stress injuries to bone, manifesting as local hyperemia and edema. MRI's high sensitivity for the detection of edema, make it an excellent modality for detecting early osseous stress injury.

MRI should include both a T1-weighted sequence and fluid-sensitive T2-weighted sequence with fat suppression or short tau inversion recovery (STIR) sequence. Fat-suppressed T2-weighted or STIR images are important for detecting edema of the periosteum, muscle, or bone marrow. These findings are the earliest changes in stress reaction. As the injury becomes more severe, findings include marrow edema on both T1- and T2-weighted MR images and signal abnormalities in the cortical bone. The
most common pattern of a fatigue-type fracture is a low signal intensity line on all pulse sequences, surrounded by a larger, ill-defined zone of edema Fig. 6 on page 18. The fracture line is continuous with the cortex and extends into the intramedullary space oriented perpendicular to the cortex and the major weight-bearing trabeculae.

Despite resolution of symptoms, marrow edema may persist on MRI for many months. In most cases, asymptomatic athletes are allowed to return to play. However, the decision to resume activity should be made on an individual basis depending on the athlete and, the sport.

SITE-SPECIFIC STRESS FRACTURES IN ATHLETES:

The anatomic sites of involvement can often be predicted by analysis of the specific sporting activity that has led to the fatigue fractures. We describe some lesions common in different anatomical locations.

**Pelvis:**

Stress fractures occurring at the pubic rami have been reported in runners and in players of Australian football. These fractures usually occur on the inferior rami, adjacent to the symphysis pubis. Pubic rami fractures may manifest as undisplaced fracture lines on X-rays, but MRI usually reveals marrow edema before these signs appear on X-rays Fig. 7 on page 17. Most stress fractures of the pubic rami heal after 6 to 10 weeks' rest. There is a small risk of non-union or refracture in patients who do not rest long enough.

Sacral fatigue fractures in younger patients are unusual but can result from serious athletic training like long distance running, or from an acute event like childbirth.

**Femur:**

Stress fractures of the femur are more common in female athletes, especially runners, and can occur at the femoral neck or shaft. Femoral neck stress fractures are often classified as tension side (superolateral) or compression side (inferolateral), with the contention that tension side fractures are associated with poorer prognosis and are potentially unstable. The femoral shaft is particularly susceptible to repetitive stresses on the medial compression side of the femur at the junction of the proximal and middle thirds.

Plain-film X-rays are usually normal, contributing to the delay in diagnosis. Athletes presenting with insidious-onset exertional groin or thigh pain should raise high suspicion, because early diagnosis and management can prevent progression to a displaced fracture. In this context, MRI should be done to check for signs of stress fracture like marrow edema on the compression or tension sides of the femur or a hypointense fracture line Fig. 8 on page 16.
Tibia:

The most common site of stress fractures in the lower limb is the tibia. Many athletes, particularly runners, commonly experience pain along the medial border of the tibia.

Early MRI shows periosteal edema; as the injury progresses, MRI shows marrow involvement and ultimately frank cortical stress fracture. Terms like shin splints, soleus syndrome, medial tibial stress syndrome, and tibial stress fractures have been used to describe this continuum of stress-related injuries, with the first three terms usually being used for stress injuries in which no fracture line is evident. Typically, the distal two-thirds of the posteromedial tibia is affected Fig. 9 on page 14.

Two types of tibial stress fractures have been described: transverse and longitudinal.

Fibula:

The most common site is the lower fibula, just proximal to the tibiotalar syndesmosis, but fractures of the proximal fibula have also been reported.

Tarsal:

The calcaneus is the most common tarsal bone affected by stress fracture. The injury manifests as heel pain aggravated by running and jumping, and physical examination reveals posteroinferior calcaneal tenderness. First described in military recruits, these fractures have been reported in athletes participating in running, walking, and aerobics.

Plain-film X-rays often show a sclerotic line at the posteroinferior aspect of the calcaneus running parallel to the posterior cortex and perpendicular to the trabecular bone. MRI can differentiate stress fractures from other conditions that cause pain in the same region, like Achilles tendinosis, Haglund's syndrome, bursitis, or plantar fasciitis Fig. 10 on page 15.

Navicular stress fractures are relatively rare; they are difficult to diagnose both clinically and radiographically, so athletes presenting with mid-foot or arch pain should raise suspicion. Plain-film X-rays often fail to depict the fracture, probably because most cases involve partial fractures in the sagittal plane.

Stress fractures of the talus are rare, but stress fractures of the talar neck, body, and lateral process have been reported in long-distance runners and female gymnasts.

Metatarsals:
The metatarsals are frequent sites of stress fracture, which may be caused by marching, ballet dancing, prolonged standing, foot deformities, or surgical resection of adjacent metatarsals. The most common sites are the middle and distal portions of the shafts of the second and third metatarsals, but any metatarsal bone may be involved, including the first.

Initial plain-film X-rays may appear normal; two to three weeks after the injury, a periosteal bone reaction may be visible. MRI has high sensitivity in the diagnosis of these fractures, depicting edema of the bone marrow and periosteum as well as of the surrounding soft tissues. A hypointense fracture line may also be visible on MRI Fig. 11 on page 19.

Stress fractures of the fifth metatarsal base occurring in the region of Jones's fracture or slightly more distal deserve special mention, because high-performance athletes with this injury may benefit from early intramedullary screw fixation. These high-risk fractures are prone to delayed union or non-union as well as to refracture.
Fig. 1: (A),(B) CT scan of the pelvis in a 86-year-old woman shows vertically oriented fracture in R and L sacral ala, and horizontal fracture in S2. (C) CT 3D reconstruction in the same patient (D) Bone scintigraphy shows the characteristic "H" or "Honda" sign.
**Fig. 2:** T1-weighted and short tau inversion recovery [STIR] coronal, and sagittal MRI of the left ankle in a 65-year-old woman show horizontal stress fracture in the left distal tibia.

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Fig. 3: 45-year-old woman with left groin pain after intense exercise (aerobics). (A) AP radiograph of the left proximal femur shows subtle linear lucency at the superior and lateral aspect of the femoral neck. The patient resumed physical activity and (B) shows a complete fracture of the femoral neck and its treatment on (C).

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**Fig. 4:** 45-year-old woman with left groin pain after intense exercise (aerobics). Bone scintigraphy shows increased focal radiotracer uptakes in left femoral neck.

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Fig. 5: CT scan of the right ankle in a 43-year-old woman with ankle pain after intense exercise. (A) Transverse CT section shows cortical thickening with periosteal and endosteal callus in the distal fibula. (B) CT image in the coronal plane demonstrates a horizontal linear sclerotic band indicating a distal fibular stress fracture.

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Fig. 9: (A) Axial short tau inversion recovery [STIR] MRI of the right lower leg in a 34-year-old female runner with right shin pain demonstrates subtle periosteal edema (large arrows) and endosteal edema (small arrows). (B) Coronal plane shows extent of marrow edema (arrows).

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Fig. 10: (A) Calcaneus stress fracture in a 40-year-old male cross-country runner. (A) Initial plain radiograph shows normal findings. (B) Sagittal short tau inversion recovery [STIR] and (C) T1-weighted MRI show marrow edema and partial fracture parallel to the posterior border of the right calcaneus.

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**Fig. 8:** 32-year-old male distance runner with groin pain. (A) AP radiograph obtained 10 days before MR does not show fracture. (B) Coronal short tau inversion recovery [STIR] image shows marrow edema, partial fracture and periosteal edema of the right femoral neck.
Fig. 7: (A) AP radiograph, (B) coronal short tau inversion recovery [STIR], (C) axial gradient-echo, and (D) coronal T1-weighted MRI in a 34-year-old female distance runner with groin pain show a stress fracture and bone marrow edema in the left superior and inferior pubic ramus. Some reactive edema in the adductor muscles to the left is also present.

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**Fig. 6:** Stress reaction at the level of the left lesser trochanter in a 33-year-old male triathlete. Coronal T1-weighted and short tau inversion recovery [STIR] images show marrow edema along the endosteal surface of the left inferomedial femoral neck.

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Fig. 11: AP and oblique radiograph of the left foot obtained from a 29-year-old female runner with foot pain show no obvious abnormality. T1-weighted and short tau inversion recovery [STIR] MR (B) sagittal and (C) coronal images taken 2 weeks later show bone marrow edema, hypointense periosteal thickening and marked surrounding soft tissue edema of the left second metatarsal shaft.

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Conclusion

Although stress fractures are not infrequent, the diagnosis is often delayed. Patients with fatigue fractures present with vague symptoms that may initially suggest tendon or muscle injuries. Early recognition with pertinent imaging studies is important to prevent progression of the injury and to facilitate the return to normal function and activity.
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