Imaging of Insufficiency Fractures

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ABSTRACT

This review article focuses on occurrence, imaging, and differential diagnosis of insufficiency fractures. Prevalence and the most common sites of insufficiency fractures and their clinical implications are discussed. Insufficiency fractures are due to normal stress exerted on weakened bone. Most commonly postmenopausal osteoporosis is the cause for insufficiency fractures. Additional conditions affecting bone turnover include osteomalacia, chronic renal failure, and high-dose corticosteroid therapy. It is a challenge for the radiologist to detect and diagnose insufficiency fractures as well as to differentiate them from malignant fractures. Radiographs are the basic modality used for screening of insufficiency fractures, yet depending on the location of the fractures, sensitivity is limited. Magnetic resonance imaging is a very sensitive tool to visualize bone marrow abnormalities associated with insufficiency fractures and allows differentiation of benign versus malignant fractures. Thin section multidetector computed tomography (CT) depicts subtle fracture lines allowing direct visualization of cortical and trabecular bone. Dedicated Mikro-CTs (Xtreme-CT) can detect subtle fractures reaching an in-plane resolution of 80 μm. Bone scintigraphy still plays a role in detecting fractures, with good sensitivity but unsatisfactory specificity. Positron emission tomography-CT with hybrid-scanners has been the upcoming modality for the differentiation of benign from malignant fractures. Bone densitometry and clinical fracture history may determine the future risk of possible insufficiency fractures.

KEYWORDS: Insufficiency fractures, osteoporosis, osteomalacia, chronic renal failure, bone densitometry, magnetic resonance imaging

BACKGROUND

Insufficiency fractures are stress fractures that occur when stress is applied to abnormal weakened bone with less than the normal elastic resistance. The most prevalent disease leading to insufficiency fractures is postmenopausal osteoporosis, followed by osteomalacia. Unlike the other subtype of stress fractures, fatigue fractures are due to normal or physiological stress on weakened bone. They result from the application of abnormal stress or torque on a bone with normal elastic resistance and strength. Loss of bone trabeculae decreases the bone’s elastic resistance. Awareness is increasing concerning the occurrence of these fractures among older persons. The prevalence of both osteoporosis and osteomalacia increases with age, and in subjects >90 years of age, osteoporosis is found in 71% of patients and osteomalacia in 29%. Insufficiency fractures occur most commonly at the pelvic girdle including the sacrum, followed by the proximal femur and the vertebral bodies in particular at the lumbar spine and the lower thoracic spine. Other sites frequently affected by insufficiency fractures are the tibia, fibula, and calcaneus.

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and metatarsal bones. Insufficiency fractures of the femoral diaphyses are rare. Most frequently insufficiency fractures are due to undiagnosed or untreated osteoporosis.

**PATHOPHYSIOLOGY**
A fracture represents the end result of the spectrum of a bone’s response to an increasing level of stress. According to Wolff’s law, stress that occurs beyond the bone’s elastic range causes persistent plastic deformity as a result of microfractures. In this situation, osteoclastic resorption exceeds osteoblastic activity. A strong association exists between fractures of the sacrum and those of the pubic bone. They can often be found in a symmetrical fashion and are often due to osteomalacia. Pubic fractures may develop as a result of increased anterior arch strain secondary to initial failure of the posterior arch (sacrum). The many causes of insufficiency fractures include postmenopausal osteoporosis, rheumatoid arthritis, Paget’s disease, osteomalacia, hyperparathyroidism, renal osteodystrophy, osteogenesis imperfecta, osteoporosis, and fibrous dysplasia. Other important causes are senile osteoporosis or pelvic irradiation and corticosteroid therapy leading to secondary osteoporosis. Also reported are total hip replacement, scurvy, osteopetrosis, primary biliary cirrhosis, organ transplants, tabes dorsalis, and high-dose fluoride therapy.

**FREQUENCY**
Most patients with insufficiency fractures are >60 years of age. The mean age ranges from 62 to 74 years. Women predominantly are affected especially in the postmenopausal state. On the average, insufficiency fractures are estimated to occur in 1 to 5% of the population, depending on the referral population. In most patients, insufficiency fractures resolve or improve significantly with conservative management.

**CLINICAL PRESENTATION**
Patients typically present with acute pain in the groin, back, or buttock, foot, or around the knee, depending on the site of the fracture. Twenty-five percent of patients have multiple sites of pain. In many patients, pain is severe enough to render the patient nonambulatory. Patients usually present with either no history of trauma or a history of low-impact trauma. On physical examination usually signs of insufficiency fracture are non-specific or nonexistent. Neurological deficits are rarely found. Typically, discordance exists between the severe symptoms and the mild or absent physical signs. Management is conservative and consists initially of bed rest, reduced weightbearing, and simple analgesics for pain relief. In severe cases, a more aggressive approach can be performed. Imaging-guided sacroplasty for treatment of sacral insufficiency fractures has been described. Vertebroplasty or kyphoplasty to treat vertebral insufficiency fractures is a common procedure in radiology or orthopaedic departments.

**LOCATIONS**

**Pelvis**
Insufficiency fractures of the pelvis are being increasingly recognized as a major cause of low back pain in elderly women with osteoporosis (Fig. 1). Fractures in the sacrum are difficult to diagnose because plain radiographic findings are sometimes unhelpful or misleading. Bone scintigraphy is very sensitive for the detection of fractures in the sacrum, with demonstration of the H-shaped (or butterfly) sacral pattern or the combination of concomitant sacral and parasymphseal uptake considered a typical finding of insufficiency fractures. Magnetic resonance imaging (MRI) is a very sensitive method for detecting insufficiency fractures by visualizing the bone marrow edema pattern and occasionally the fracture lines. It can be helpful in distinguishing insufficiency from pathological fractures due to tumor infiltration. Most patients respond well to periods of enforced bed rest and administration of analgesics. Recognition of the spectrum of imaging findings for this entity should lead to its correct identification and the institution of appropriate treatment. Insufficiency fractures following total hip arthroplasty frequently occur in the superior and inferior pubic ramus, the puboischiol rami, or the ischium around the obturator foramen; they rarely occur in the medial wall of the acetabulum (Fig. 4). Computed tomography (CT) is helpful for confirming the presence of fractures in cases with atypical scintigraphic patterns, particularly in those with a
known primary malignant neoplasm. CT is especially useful in further evaluation of parasymphyseal and pubic rami lesions (Figs. 5, 6). Radiotherapy is a well-known risk factor for pelvic insufficiency fractures in postmenopausal women. Recognition of insufficiency fractures helps to avoid the pitfalls of misdiagnosing tumor recurrence or bony metastases\(^\text{12}\) (Fig. 7).

It should also be noted that multiple pelvic insufficiency fractures are frequently found, particularly in the presence of pubic or acetabular fractures, and careful search for concomitant fractures is warranted. In a previous study, in 70.3% of cases with pelvic insufficiency fractures, multiple fracture sites were present. In the case of pubic fractures concomitant fractures were present in 90%. Also, 76% of acetabular fractures had concomitant fractures present.\(^\text{13}\)

**Lower Extremity**

Insufficiency fractures of the fibula are typically found in patients with underlying rheumatic diseases, mainly rheumatoid arthritis\(^\text{14,15}\) (Figs. 8, 9). Insufficiency fractures are also frequently found at the metatarsal bones, in particular in the setting of inflammatory arthropathies (Fig. 10). Also these may be diagnosed in patients with severe osteoporosis and patients on high-dose corticosteroids or methotrexate therapy. Patients with marked

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**Figure 2** Axial magnetic resonance image (short tau inversion recovery sequence) of the pelvis demonstrating bone marrow edema (arrows) in the sacrum, compatible with bilateral insufficiency fractures.

**Figure 3** Axial T1-weighted magnetic resonance image, demonstrating signal loss in both sacral ala compatible with bilateral insufficiency fractures (arrows) in a 55-year-old woman after radiotherapy of the pelvis for cervical carcinoma.

**Figure 4** Anteroposterior radiograph of both hip joints shows insufficiency fractures (arrows) in the left parasymphyseal region and the left periacetabular region. Total hip replacement is an additional predisposing causative factor.

**Figure 5** Coronal computed tomography reformation of the sacrum demonstrates insufficiency fractures at S1 with fracture lines and sclerosis. Posterior spinal fusion Th12-S1 with loosening of T12 pedicle screws.
joint deformity are also at high risk for developing insufficiency fractures. Less frequently, in up to 25%, insufficiency fractures at the femoral shaft can occur, predominantly in elderly patients with osteoporosis\(^1\). Insufficiency fractures at the tibia (Fig. 12) may be found as an early manifestation of bone failure in patients after renal transplant as reported by a previous study.\(^2\) The main causes are preexisting renal osteodystrophy, glucocorticoid therapy, and hyperparathyroidism, whether residual or secondary to imperfect graft function.\(^3\) Longitudinal stress fractures of the tibia can also occur in patients with healed chronic osteomyelitis.\(^4\) Even postpartum osteoporosis was found to be a cause of insufficiency fractures around the knee.\(^5\)
One of the important differential diagnoses of subchondral insufficiency fractures of the femoral head may include osteonecrosis. Typical MR imaging findings in insufficiency fractures include a pattern of bone marrow edema with a low-signal-intensity fracture line on the T1-weighted images parallel to the subchondral bone. In general, the circumscribed lesions on MR imaging, which are commonly observed in osteonecrosis, are not found. Histopathologically, fracture callus, reactive cartilage, and granulation tissue are seen without any evidence of antecedent osteonecrosis. The subchondral insufficiency fracture of the femoral head is a recently recognized cause of acute onset arthritis mostly in elderly women, which previously had been commonly considered either as osteonecrosis or osteoarthritis.

**Spine**

Insufficiency fractures at the spine are a leading cause for acute low back pain without an acute traumatic event. Usually a concave or wedge-shaped deformity of the affected vertebra is found, and a wide range of the vertebral height ratios and fracture distribution were reported. Once an initial vertebral fracture is sustained, the risk of subsequent vertebral fracture increases significantly. However this effect cannot be explained by low bone mass alone, suggesting that factors independent of this parameter contribute to this occurrence. The assessment of vertebral fractures using a semiquantitative approach has been described, grading osteoporotic fractures into type 1 (20 to 25% deformity), type 2 (25 to 40%), and type 3 (>40%). Accurate radiographic diagnosis of osteoporotic vertebral fractures is important. Several studies indicated a false-negative rate of up to 34% in reports of lateral radiographs of the thoracolumbar spine. Radiologists should be aware of the importance of vertebral fracture diagnosis in assessing future osteoporotic fracture risk. Vertebral fractures incidental to radiologic examinations done for other reasons should be identified and reported; in particular, vertebral fractures should be assessed in lateral chest radiographs. Proper training of radiologists is necessary to improve detection of vertebral fractures. In oncology patients, differentiation form benign and malignant vertebral fractures is important and can be achieved by MRI or positron emission tomography (PET)-CT (Figs. 13, 14).

**Upper Extremity**

A common site of fragility fractures is the distal forearm. In addition, fractures involving the wrist are known to be strongly associated with osteoporosis. It is well known that patients with distal radius fracture who are otherwise healthy have a preferential bone loss at the distal forearm. Distal radius fractures are also associated with generally low bone mass and elevated fracture risk at...
other skeletal sites. In these subjects pharmacotherapy for osteoporosis is warranted.27 Interestingly, in osteoporosis the proximal humerus may also be a fracture site at risk.28

DIFFERENTIAL DIAGNOSIS

An important differential diagnosis of a stress/insufficiency fracture is a fracture due to malignant disease. MR imaging features of a malignant fracture are a diffusely or focally abnormal bone marrow signal that may be either well defined or ill defined and does not follow fracture lines. In addition, abnormal intracortical, periosteal, or muscle signal intensity are found as well as endosteal scalloping and soft tissue masses. The features seen on CT are bone marrow abnormality that may be well defined, ill defined, permeative, or moth eaten, endosteal scalloping, periosteal reaction, and a soft tissue mass. Accuracy for differentiating malignant fractures from stress fractures was reported to be highest with MRI (93 to 98%) followed by CT (82 to 88%) and radiographs (88 to 94%).29

Figure 12 Patient with history of tumor endoprosthesis at the proximal femur and insufficiency fracture at the proximal tibia. (A) Lateral radiograph of the distal femur and knee shows severe osteopenia but no fracture. (B) The coronal short tau inversion recovery magnetic resonance image shows significant bone marrow edema pattern and subtle fracture line at the lateral tibia (arrow). (C) The sagittal proton-density-weighted image better demonstrates the fracture line in the same patient (arrow).
**IMAGING METHODS AND LIMITATIONS**

Radiographs are the initial imaging test in patients with pain localized to the skeleton. If the radiographs are inconclusive and pain persists, either MRI or CT should be performed. Multidetector CT (MDCT) is currently the gold standard and allows multiplanar reconstruction, three-dimensional reconstructions of anatomical structures, reduction of artifacts as well as thin-section high-resolution imaging that is also beneficial in visualizing subtle fracture lines. MR imaging is more sensitive and the modality of choice if the history suggests malignant disease and thus metastasis might be responsible for fracture. Although MR imaging is very sensitive for the detection of fractures, bone marrow changes, and related soft tissue edema, in the absence of fractures lines or a typical history it may also be misleading and suggest other bone marrow pathology such as malignant infiltration. Although MR imaging is the most sensitive technique in the visualization of insufficiency fractures, CT sometimes tends to depict the extent and stability of these fractures better. Bone scintigraphy is highly sensitive but not specific. Atypical uptake patterns may be difficult to interpret, and abnormal uptake may persist for several months.

**Radiographs**

Radiographic findings depend on the site of the fracture. Parasymphyseal and pubic ramus fractures may have an aggressive appearance that depends on the stage of fracture maturity. Findings include sclerosis, lytic fracture line, bone expansion, exuberant callus, and osteolysis. The most common finding is a sclerotic band or line. A lytic fracture line or cortical break is rarely observed. The degree of confidence is low in sacral fractures because of osteoporosis, overlying bowel gas, and calcified vessels. Confidence in diagnosis is increasing in long bones and the metatarsals. Parasymphyseal and pubic ramus fractures often are misinterpreted as malignant lesions. Sacral, iliac, and supra-acetabular fractures often are difficult to detect.

**Multidetector Computed Tomography**

On CT images a linear fracture line with surrounding sclerosis may be observed, but depending on its age, sometimes only sclerosis may be demonstrated. Public fractures may be seen as a lytic fracture line often surrounded by callus. Typically, a soft tissue mass is absent, bone destruction is lacking, and adjacent fascial planes are preserved. MDCT also is useful for detecting large bony sacral defects such as Tarlov cysts and for the diagnosis of coexisting malignant lesions. MDCT is very specific for the definitive diagnosis of an insufficiency fracture of the pelvis but may have limitations with sensitivity. MDCT is useful as an alternative to bone...
scintigraphy when radiographs are inconclusive and MR imaging is not available. MDCT reformats are essential for the diagnosis of insufficiency fractures of the long bones and pelvic girdle. Dedicated MDCT protocols using thin-section multiplanar reformatations with adequate overlap and reconstruction kernels are essential for detecting even subtle fractures.

In the diagnosis and staging of osteoporosis, the three-dimensional bone structure is an important predictor of bone strength in addition to bone mass or the mineral content of the bone. Micro-CT scanning has shown promising results in the differentiation of osteoporotic and nonosteoporotic individuals with respect to histomorphometry and quality of trabecular fractures.

MR imaging shows decreased signal on T1-weighted images and increased signal on T2-weighted images. In the sacrum, signal changes are seen as linear bands within the sacral ala and body and are parallel to the sacroiliac joints. On T2-weighted images, the fracture line may be seen if it is surrounded by an adjacent marrow edema pattern. MR imaging is highly sensitive and specific, but it cannot be used in patients with pacemakers, a significant limitation in the elderly population. Iliac and sacral bones are frequently involved in patients with osteomalacia. MR imaging can determine the clinical activity and can monitor the response to the treatment of insufficiency fractures. Diffusion-weighted MR imaging may be capable of differentiating malignant from benign lesions.

NUCLEAR MEDICINE
In nuclear studies, the typical H-shaped or butterfly pattern of uptake in the sacrum is diagnostic of insufficiency fracture. The vertical limbs of the H lie within the sacral ala, parallel to the sacroiliac joints; the transverse limb of the H extends across the sacral body. Other sacral variant uptake patterns occur frequently and include the unilateral ala, incomplete H, and horizontal linear dot patterns. Iliac fractures are seen as linear areas of uptake. PET-CT using 18F-fluorodeoxyglucose combined with MDCT gives metabolic and morphological information at the same time, allowing the differentiation of pathological fractures and insufficiency fractures (Figs. 15, 16). Pubic and supra-acetabular fractures produce areas of linear or focal uptake. Concomitant findings of two or more areas of uptake in the sacrum and at another pelvic site are considered diagnostic of insufficiency fractures of the pelvis. Nuclear studies are highly sensitive and highly specific when a typical pattern of sacral uptake or concomitant sacral and pubic uptake is observed. If a typical pattern of abnormality is not present, the bone scan is much less specific. If abnormal or incomplete patterns of uptake are observed, findings may be mistaken for malignancy and other diseases. CT or MR imaging is useful in these cases.

INTERVENTIONAL RADIOLOGY
Sacroploasty is a variation of the vertebroplasty technique for treatment of a sacral insufficiency fracture. Sacroplasty is a procedure in which polymethyl acrylate, a quick-setting bone cement, is injected into the fractured bone. This technique appears to be useful in providing symptomatic relief to affected patients. Other authors proposed a novel technique in which guidance with CT fluoroscopy allows placement of a transiliosacral bar in conjunction with sacroplasty combining the use of metallic hardware and bone cement for stabilization. There are numerous publications about the treatment of vertebral fractures with vertebroplasty. Percutaneous vertebroplasty is a safe and effective treatment for relieving pain in patients complaining of severe back pain induced by osteoporotic compression fractures.
The success rate exceeds 90%, and the complication rate is <1%.40 A substantial number of patients with osteoporosis develop new fractures after undergoing percutaneous vertebroplasty; two thirds of these new fractures occur in vertebrae adjacent to those previously treated.41

SUMMARY AND CONCLUSION

Due to the increase of the average age of the population, the number of insufficiency fractures is steadily increasing. Most insufficiency fractures are due to weakened bone by osteoporosis. Usually the patients experience acute onset of pain after a minor trauma. Insufficiency fractures can initially be missed on standard radiographs due to subtle findings. It is important to know the most commonly affected sites and the appearance with different radiologic modalities. MDCT is superior to radiographs in the diagnosis of insufficiency fractures and should be used, in the case of negative radiographs, yet with high clinical suspicion of an insufficiency fracture. As insufficiency fractures usually occur in elderly patients; radiation dose is not a major concern. MR imaging should be used as a problem solver to distinguish between pathological fractures and insufficiency or stress fractures and to monitor the bone marrow edema pattern. Radiographs can also be used for the follow-up of insufficiency fractures and the monitoring of callus formation and bone healing. Nuclear medicine studies have gained a significant role in the diagnostic workup, due to the introduction of PET-CT with hybrid scanners in clinical routine. The radiologist’s role nowadays also includes treatment of fractures, with an increasing number of vertebroplasties performed each year. Other sites, such as the sacrum, have also been treated, and the results seem promising.

REFERENCES


Figure 17 Lateral radiograph of the lumbar spine demonstrating wedge fracture of L2 vertebral body. Bone cement is injected during vertebroplasty into the vertebral body by CT-guided intervention.

(Fig. 17). The success rate exceeds 90%, and the complication rate is <1%.40 A substantial number of patients with osteoporosis develop new fractures after undergoing percutaneous vertebroplasty; two thirds of these new fractures occur in vertebrae adjacent to those previously treated.41