American College of Radiology
ACR Appropriateness Criteria®
Stress (Fatigue/Insufficiency) Fracture, Including Sacrum, Excluding Other Vertebrae

Variant 1: **Suspected stress (fatigue) fracture, excluding vertebrae. First imaging study.**

Radiologic Procedure	Rating	Comments	RRL*
X-ray area of interest	9		Varies
MRI area of interest without IV contrast	1		O
MRI area of interest without and with IV contrast	1		O
CT area of interest without IV contrast	1		Varies
CT area of interest with IV contrast	1		Varies
CT area of interest without and with IV contrast	1		Varies
Bone scan whole body with SPECT or SPECT/CT area of interest	1		☢☢☢
US area of interest	1		O
Rating Scale: 1,2,3 Usually not appropriate; 4,5,6 May be appropriate; 7,8,9 Usually appropriate			*Relative Radiation Level

Variant 2: **Suspected stress (fatigue) fracture, hip. Negative radiographs. Next imaging study.**

Radiologic Procedure	Rating	Comments	RRL*
MRI hip without IV contrast	9		O
Bone scan whole body with SPECT or SPECT/CT hip	6	Timing of the study after injury and age of the patient are important considerations.	☢☢☢
X-ray hip repeat in 10-14 days	5	Because of the high risk of complications, it is not advisable to wait 10–14 days in most cases.	☢☢☢
CT hip without IV contrast	5	This procedure may be useful if MRI cannot be performed.	☢☢☢
MRI hip without and with IV contrast	1		O
CT hip with IV contrast	1		☢☢☢
CT hip without and with IV contrast	1		☢☢☢
US hip	1		O
Rating Scale: 1,2,3 Usually not appropriate; 4,5,6 May be appropriate; 7,8,9 Usually appropriate			*Relative Radiation Level

Variant 3: **Suspected stress (fatigue) fracture, excluding hip and vertebrae. Negative radiographs. Next imaging study.**

Radiologic Procedure	Rating	Comments	RRL*
X-ray area of interest repeat in 10-14 days	9		Varies
MRI area of interest without IV contrast	8	This procedure is an equivalent option. It may be used preferentially in high-risk locations.	O
CT area of interest without IV contrast	5	This procedure may offer complementary information to MRI.	Varies
Bone scan whole body with SPECT or SPECT/CT area of interest	5	Timing of the study after injury and age of the patient are important considerations.	☢☢☢
MRI area of interest without and with IV contrast	1		O
CT area of interest with IV contrast	1		Varies
CT area of interest without and with IV contrast	1		Varies
US area of interest	1		O
Rating Scale: **1,2,3 Usually not appropriate; 4,5,6 May be appropriate; 7,8,9 Usually appropriate**			***Relative Radiation Level**

Variant 4: **Suspected stress (fatigue) fracture, excluding vertebrae. Negative radiographs. Immediate "need-to-know" diagnosis. Next imaging study.**

Radiologic Procedure	Rating	Comments	RRL*
MRI area of interest without IV contrast	9		O
CT area of interest without IV contrast	5	This procedure may show complementary information to MRI.	Varies
Bone scan whole body with SPECT or SPECT/CT area of interest	5		☢☢☢
X-ray area of interest	1		Varies
MRI area of interest without and with IV contrast	1		O
CT area of interest with IV contrast	1		Varies
CT area of interest without and with IV contrast	1		Varies
US area of interest	1		O
Rating Scale: **1,2,3 Usually not appropriate; 4,5,6 May be appropriate; 7,8,9 Usually appropriate**			***Relative Radiation Level**

Variant 5: **Confirmed stress (fatigue) fracture, excluding vertebrae. Follow-up imaging study for "return-to-play" evaluation.**

Radiologic Procedure	Rating	Comments	RRL*
MRI area of interest without IV contrast	9		O
DXA total body composition	5	This procedure is not routinely done but may provide complementary information to MRI.	☢
CT area of interest without IV contrast	4	CT will not give prognostic information since stress fracture is already confirmed.	Varies
X-ray area of interest repeat in 10-14 days	3	Repeat x-ray will not give prognostic information since stress fracture is already confirmed.	Varies
MRI area of interest without and with IV contrast	1		O
CT area of interest with IV contrast	1		Varies
CT area of interest without and with IV contrast	1		Varies
Bone scan whole body with SPECT or SPECT/CT area of interest	1	Data are lacking. SPECT may show presence or absence of healing progression.	☢☢☢
US area of interest	1		O
Rating Scale: **1,2,3 Usually not appropriate; 4,5,6 May be appropriate; 7,8,9 Usually appropriate**			***Relative Radiation Level**

Variant 6: **Suspected stress (insufficiency) fracture, pelvis or hip. First imaging study.**

Radiologic Procedure	Rating	Comments	RRL*
X-ray area of interest	9	Pain may be difficult to localize. This procedure is less sensitive than radiographs of extremities.	Varies
MRI area of interest without IV contrast	3		O
MRI area of interest without and with IV contrast	1		O
CT area of interest without IV contrast	1	This procedure is better for pelvis (sacrum) and would also depend on age because of radiation dose.	Varies
CT area of interest with IV contrast	1		Varies
CT area of interest without and with IV contrast	1		Varies
Bone scan whole body with SPECT or SPECT/CT area of interest	1		☢☢☢
US area of interest	1		O
Rating Scale: **1,2,3 Usually not appropriate; 4,5,6 May be appropriate; 7,8,9 Usually appropriate**			***Relative Radiation Level**

Variant 7: **Suspected stress (insufficiency) fracture, pelvis or hip. Negative radiographs. Next imaging study.**

Radiologic Procedure	Rating	Comments	RRL*
MRI area of interest without IV contrast	9		O
CT area of interest without IV contrast	7	This procedure is not as sensitive as MRI but remains a reasonable alternative.	Varies
Bone scan whole body with SPECT or SPECT/CT area of interest	6	This procedure is less specific, but specificity may be age dependent.	☢☢☢
X-ray area of interest repeat in 10-14 days	4		Varies
MRI area of interest without and with IV contrast	1		O
CT area of interest with IV contrast	1		Varies
CT area of interest without and with IV contrast	1		Varies
US area of interest	1		O
Rating Scale: **1,2,3 Usually not appropriate; 4,5,6 May be appropriate; 7,8,9 Usually appropriate**			***Relative Radiation Level**

Variant 8: **Suspected stress (insufficiency) fracture of lower extremity, excluding pelvis and hip. First imaging study.**

Radiologic Procedure	Rating	Comments	RRL*
X-ray lower extremity area of interest (not pelvis or hip)	9		☢
MRI lower extremity area of interest (not pelvis or hip) without IV contrast	1		O
MRI lower extremity area of interest (not pelvis or hip) without and with IV contrast	1		O
CT lower extremity area of interest (not pelvis or hip) without IV contrast	1		Varies
CT lower extremity area of interest (not pelvis or hip) with IV contrast	1		Varies
CT lower extremity area of interest (not pelvis or hip) without and with IV contrast	1		Varies
Bone scan whole body with SPECT or SPECT/CT lower extremity area of interest	1		☢☢☢
US lower extremity area of interest (not pelvis or hip)	1		O
Rating Scale: **1,2,3 Usually not appropriate; 4,5,6 May be appropriate; 7,8,9 Usually appropriate**			***Relative Radiation Level**

Variant 9: **Suspected stress (insufficiency) fracture of lower extremity, excluding pelvis and hip. Negative radiographs. Next imaging study.**

Radiologic Procedure	Rating	Comments	RRL*
MRI lower extremity area of interest (not pelvis or hip) without IV contrast	9		O
X-ray lower extremity area of interest (not pelvis or hip) repeat in 10-14 days	7	This procedure is less sensitive than MRI but is a reasonable alternative.	☢
CT lower extremity area of interest (not pelvis or hip) without IV contrast	5		Varies
Bone scan whole body with SPECT or SPECT/CT lower extremity area of interest	5		☢☢☢
MRI lower extremity area of interest (not pelvis or hip) without and with IV contrast	1		O
CT lower extremity area of interest (not pelvis or hip) with IV contrast	1		Varies
CT lower extremity area of interest (not pelvis or hip) without and with IV contrast	1		Varies
US lower extremity area of interest (not pelvis or hip)	1		O
Rating Scale: **1,2,3 Usually not appropriate; 4,5,6 May be appropriate; 7,8,9 Usually appropriate**			***Relative Radiation Level**

Variant 10: **Follow-up imaging study for characterizing nonspecific focal uptake on Tc-99m MDP bone scintigraphy, suspected to be a stress fracture.**

Radiologic Procedure	Rating	Comments	RRL*
X-ray area of interest	9		Varies
MRI area of interest without IV contrast	8	This procedure is an equivalent, more sensitive option to radiographs.	O
MRI area of interest without and with IV contrast	5	This procedure is useful if there is specific concern for malignancy or soft-tissue mass.	O
CT area of interest without IV contrast	5		Varies
CT area of interest with IV contrast	2	Contrast may be helpful it there is concern for malignancy. This procedure is used only if radiographs are negative and MRI cannot be performed.	Varies
CT area of interest without and with IV contrast	1		Varies
US area of interest	1		O
Rating Scale: **1,2,3 Usually not appropriate; 4,5,6 May be appropriate; 7,8,9 Usually appropriate**			***Relative Radiation Level**

Variant 11: **Suspect stress (fatigue or insufficiency) fracture, pelvis or hip or sacrum. Pregnant patient.**

Radiologic Procedure	Rating	Comments	RRL*
MRI area of interest without IV contrast	9		O
X-ray area of interest	4		Varies
MRI area of interest without and with IV contrast	1		O
CT area of interest without IV contrast	1		Varies
CT area of interest with IV contrast	1		Varies
CT area of interest without and with IV contrast	1		Varies
Bone scan whole body with SPECT or SPECT/CT area of interest	1		☢☢☢
US area of interest	1		O
Rating Scale: 1,2,3 Usually not appropriate; 4,5,6 May be appropriate; 7,8,9 Usually appropriate			***Relative Radiation Level**

Variant 12: **Suspect stress (fatigue or insufficiency) fracture of the long bones. Pregnant patient.**

Radiologic Procedure	Rating	Comments	RRL*
X-ray area of interest	9	This procedure should be the first study.	Varies
MRI area of interest without IV contrast	8	This is a complementary study if initial radiographs are negative.	O
MRI area of interest without and with IV contrast	1		O
CT area of interest without IV contrast	1		Varies
CT area of interest with IV contrast	1		Varies
CT area of interest without and with IV contrast	1		Varies
US area of interest	1	This procedure may have some use but is much less sensitive than MRI.	O
Rating Scale: 1,2,3 Usually not appropriate; 4,5,6 May be appropriate; 7,8,9 Usually appropriate			***Relative Radiation Level**

STRESS (FATIGUE/INSUFFICIENCY) FRACTURE, INCLUDING SACRUM, EXCLUDING OTHER VERTEBRAE

Expert Panel on Musculoskeletal Imaging: Jenny T. Bencardino, MD[1]; Taylor J. Stone, MD[2]; Catherine C. Roberts, MD[3]; Marc Appel, MD[4]; Steven J. Baccei, MD[5]; R. Carter Cassidy, MD[6]; Eric Y. Chang, MD[7]; Michael G. Fox, MD[8]; Bennett S. Greenspan, MD, MS[9]; Soterios Gyftopoulos, MD[10]; Mary G. Hochman, MD[11]; Jon A. Jacobson, MD[12]; Douglas N. Mintz, MD[13]; Gary W. Mlady, MD[14]; Joel S. Newman, MD[15]; Zehava S. Rosenberg, MD[16]; Nehal A. Shah, MD[17]; Kirstin M. Small, MD[18]; Barbara N. Weissman, MD.[19]

Summary of Literature Review

Introduction/Background

Stress fractures occur in 2 varieties: 1) fatigue fractures resulting from repetitive submaximal stress on normal bone, resulting in a region of accelerated bone remodeling [1], and 2) insufficiency fractures due to normal activity on bones that are deficient in microstructure and/or mineralization [2]. At the microscopic level, repetitive overloading leads to increased osteoclastic activity that exceeds the rate of osteoblastic new bone formation. This results in bone weakening and microtrabecular disruption (stress injury) and eventually may lead to a cortical break (stress fracture). Stress fractures are encountered frequently and account for up to 20% of all injuries seen in sports medicine clinics [3]. Stress fractures are particularly common in athletes participating in activities that require running and jumping, as well as in ballet dancers and military recruits [4,5]. On the other hand, we now recognize that certain medical interventions such as radiation therapy and long-term osteoporosis treatment with bisphosphonates predispose patients to stress fractures [6,7].

The use of magnetic resonance imaging (MRI) has greatly improved our ability to diagnose radiographically occult stress fractures. Both fatigue and insufficiency fractures are now being more frequently recognized as a source of pain in patients, and although fatigue and insufficiency fractures can be self-limited and go on to healing with or without diagnosis, there is usually value in making the diagnosis. With continued activity, some stress injuries and incomplete (unicortical) stress fractures will progress to completion and require more invasive treatment or delay in return to activity. Also, the differential diagnosis of fatigue/insufficiency fractures includes entities that would be treated significantly differently than stress fractures (osteoid osteoma or osteomyelitis in the younger patient, metastases in the older patient). The clinical picture is further clouded by the fact that many older patients with insufficiency fractures have histories of previous malignancy.

Overview of Imaging Modalities

Radiography

Radiography is the least expensive and most widely available imaging modality. Radiographs in at least 2 planes should be obtained as the initial imaging study in every patient suspected of having a stress fracture. Early radiographic findings are often nonspecific, for example, subtle periosteal reaction, "gray cortex" sign, or even nonexistent as initial radiographs have reported sensitives of only 15 to 35% [8]. Over time, patients develop more specific radiographic findings, for example, linear sclerosis perpendicular to the trabeculae.

Bone scan

The bone scan was regarded for many years as the gold standard for detecting stress-induced injuries and was valued for its sensitivity. Dobrindt et al [9] reported the sensitivity, specificity, accuracy, positive predictive value, and negative predictive value of bone scintigraphy for detection of stress injuries as 92.9%, 73.8%, 83.3%, 78.0%, and 91.2%, respectively. Planar scintigraphy combined with single-photon emission computed

---

[1]Principal Author and Panel Vice-chair, New York University School of Medicine, New York, New York. [2]Research Author, Charlotte Radiology, Charlotte, North Carolina. [3]Panel Chair, Mayo Clinic, Phoenix, Arizona. [4]James J. Peters VA Medical Center, Bronx, New York, American Academy of Orthopaedic Surgeons. [5]UMass Memorial Medical Center, Worcester, Massachusetts. [6]UK Healthcare Spine and Total Joint Service, Lexington, Kentucky, American Academy of Orthopaedic Surgeons. [7]VA San Diego Healthcare System, San Diego, California. [8]University of Virginia Health System, Charlottesville, Virginia. [9]Medical College of Georgia at Georgia Regents University, Augusta, Georgia. [10]New York University Medical Center, New York, New York. [11]Beth Israel Deaconess Medical Center, Boston, Massachusetts. [12]University of Michigan Medical Center, Ann Arbor, Michigan. [13]Hospital for Special Surgery, New York, New York. [14]University of New Mexico, Albuquerque, New Mexico. [15]New England Baptist Hospital, Boston, Massachusetts. [16]Hospital for Joint Diseases, New York, New York. [17]Brigham & Women's Hospital, Boston, Massachusetts. [18]Brigham & Women's Hospital, Boston, Massachusetts. [19]Specialty Chair, Brigham & Women's Hospital, Boston, Massachusetts.

Reprint requests to: publications@acr.org

tomography (SPECT) is more accurate in diagnosing stress injuries than planar scintigraphy alone [10]. The objection to the studies quoting high accuracy for bone scintigraphy is that in all of them, positive bone scintigraphy is taken as the gold standard for detecting stress fractures and therefore sensitivity is 100%. However, depending on the staging criteria for bone scintigraphy pattern, the abnormalities may in fact be stress reactions rather than actual stress fractures [4,5,7]. Nonetheless, it is clear that bone scintigraphy shows stress fractures days to weeks earlier than radiographs in many instances and differentiates between osseous and soft-tissue injury as well.

Magnetic resonance imaging
MRI is extremely sensitive and demonstrates stress abnormalities as early as bone scintigraphy and with as much sensitivity [11-14]. The recent literature favors MRI as the procedure of choice for making an early diagnosis of both varieties of stress fractures [15-28]. In this regard, MRI outperforms radiography, bone scintigraphy, and computed tomography (CT). Fluid-sensitive sequences are the favored initial sequence for MRI screening [29]. With a small field of view, short tau inversion recovery and/or T1-weighted imaging will usually demonstrate a fracture line surrounded by edema. In the absence of an actual stress fracture, stress reaction or muscle/tendon injuries can be identified using fluid-sensitive sequences. Thus, MRI may be as sensitive as bone scintigraphy but also considerably more specific [19,23]. Intravenous contrast is not needed for diagnosis and has yet to provide any additional information. MRI examination of an osseous stress injury contains prognostic as well as diagnostic information [30,31].

Computed tomography
CT is not typically used as a first- or second-line imaging tool in the workup of stress fractures but may offer an adjunct role when other imaging modalities are equivocal [23], particularly in the pelvis or sacrum. Although superior to radiography, it is less sensitive than nuclear scintigraphy or MRI [19]. The benefit of CT seems to lie in its specificity, ranging from 88% to 98% in a recent meta-analysis looking at diagnostic accuracy of imaging modalities for lower-extremity stress fractures, and thus may confirm a suspected stress fracture based on MRI [32]. However, CT does involve ionizing radiation, so it is typically used only when MRI is equivocal. For the evaluation of stress fractures, intravenous contrast is not helpful as a part of CT examinations.

Ultrasound
There is limited evidence on the utility of ultrasound in diagnosing stress fractures. Ultrasound is a first-line imaging modality in assessing muscles, tendons, joints, and nerves in the extremities [33], so the radiologist should know the typical sonographic appearance of stress fractures. Sonographic findings of stress fractures include subcutaneous edema, periosteal thickening, cortical bone irregularity, local hyperemia [33-35], and periosteal callus. Overall, ultrasound appears to be more sensitive than specific [32], and similar ultrasound findings can be seen in osteomyelitis or neoplasm. Furthermore, ultrasound cannot evaluate the subcortical bone, so trabecular stress fractures may be missed. Although touted as cheap and quick to perform, it is limited as an operator-dependent modality.

Variant 1: Suspected stress (fatigue) fracture, excluding vertebrae. First imaging study.

In the setting of new or repetitive athletic activity, fatigue fractures can develop in patients with normal bone. Furthermore, certain athletic activities often result in specific sites of fatigue fracture, such as olecranon process fractures in javelin throwers and baseball pitchers, proximal femur and tibial stress fractures in runners, and tarsal navicular stress fractures in basketball players [36-38]. Correlation of clinical history, pattern, and site recognition with radiographic findings is usually specific [1,2,4,5,7]. Nevertheless, stress fractures are frequently occult on initial radiographs [1], with conventional radiographs having a sensitivity of 15% to 35% [8]. Early radiographic findings are often nonspecific (subtle periosteal reaction, gray cortex sign) or even nonexistent. Late radiographic findings are often suggestive in appearance and include linear sclerosis (often perpendicular to the major trabecular lines), periosteal reaction, patchy endosteal sclerosis, and soft-tissue swelling. Additionally, radiographs may remain negative depending on the timing of reimaging, the patient’s metabolic bone status, and the type and location of the fracture. Thus, radiographs are specific but significantly insensitive. Despite this limitation, all authorities agree that radiographs should be the initial imaging modality; if the findings are conclusive, no further imaging need be performed.

Variant 2: Suspected stress (fatigue) fracture, hip. Negative radiographs. Next imaging study.

Short-term (10 to 14 days) follow-up radiographs are more sensitive than initial radiographs secondary to overt bone reaction in the location of the stress fracture. Follow-up radiographic sensitivity increases to 30% to 70%

[8]. Detection of osseous change is more limited in areas covered by prominent overlapping soft tissue [17]. If the osseous reaction involves cortical bone, then endosteal/periosteal callus may be visible with or without a fracture line through the cortex. If the trabecular bone is involved, then stress fractures are often more subtle, progressing from patchy areas of increased density into linear areas of sclerosis, oriented perpendicular to the trabeculae.

Although bone scans were regarded as the gold-standard examination for many years, MRI is extremely sensitive and demonstrates stress abnormalities as early as bone scintigraphy and with as much sensitivity [11-14]. The recent literature favors MRI as the procedure of choice for making an early diagnosis of both varieties of stress fractures [15-28]. In this regard, MRI outperforms radiography, bone scintigraphy, and CT. Furthermore, MRI examination of an osseous stress injury contains prognostic as well as diagnostic information [30,31].

CT is not typically used as a first- or second-line imaging tool but may offer an adjunctive role when other imaging modalities are equivocal [23]. Although superior to radiography, it is less sensitive than nuclear scintigraphy and MRI [19].

Stress fractures in the femur most often occur in the femoral neck and represent up to 7% of all stress fractures [39]. Lateral “tension-type” femoral neck stress fractures are inherently unstable and prone to displacement [40] and are high-risk fractures, often necessitating percutaneous screw fixation [41]. Medial “compression-type” femoral neck stress fractures are low risk [40] and can be treated with a non–weight-bearing regimen [42]. Finally, stress fractures of the femoral head are high risk in healthy patients and, if not recognized promptly, have increased rates of delayed union, nonunion, displacement, and avascular necrosis [17]. Given the importance of recognizing these high-risk fractures in the femoral head and neck, MRI is the preferred second-line study after initial negative radiographs to prevent delayed diagnosis.

Variant 3: Suspected stress (fatigue) fracture, excluding hip and vertebrae. Negative radiographs. Next imaging study.

See variant 2. Certain stress fractures are considered high risk based on a tendency for nonunion or delayed union. High-risk stress fractures include the anterior tibial diaphysis, lateral femoral neck and femoral head (see variant 2), patella, medial malleolus, navicular, fifth metatarsal base, proximal second metatarsal, tibial hallux sesamoid, and talus [43].

The second-line test to diagnose a stress fracture should be guided by the location of the patient’s pain and likelihood of high-risk injury. A follow-up radiographic examination has increased sensitivity compared to initial radiographs [8] but is less sensitive than MRI. MRI is extremely sensitive and demonstrates stress abnormalities as early as bone scintigraphy and with as much sensitivity [11-14]. The recent literature favors MRI as the procedure of choice for making an early diagnosis of both varieties of stress fractures [15-28]. MRI is also considerably more specific than bone scintigraphy [19,23]. Stress injuries in athletes that are not identified and managed in a timely fashion can progress to more serious fractures. Preventive strategies, including identifying and modifying risk factors, may help deter progression to frank fractures [31,44,45].

A circumstance that deserves specific attention is the longitudinal stress fracture, particularly in the tibia. Up to 25% may appear normal on radiographs, but CT or MRI findings are characteristic [13,46]. MRI is very sensitive to the bone marrow edema accompanying these longitudinal fractures and may give a misleadingly aggressive appearance [38]. However, axial CT alone can have false negatives because of the constraint of the axial plane (in one study, half of stress fractures were inadequately demonstrated on CT) [47]. Therefore, if CT is used to confirm stress fracture in a long bone, multiplanar reformatting is necessary. Fine detail can be achieved using thinner sections.

Variant 4: Suspected stress (fatigue) fracture, excluding vertebrae. Negative radiographs. Immediate “need-to-know” diagnosis. Next imaging study.

See variant 2. MRI is extremely sensitive and demonstrates stress abnormalities as early as bone scintigraphy and with as much sensitivity [11-14]. The recent literature favors MRI as the procedure of choice for making an early diagnosis of both varieties of stress fractures [15-28]. MRI is also considerably more specific than bone scintigraphy [19,23]. Stress injuries in athletes that are not identified and managed in a timely fashion can progress to more serious fractures. Preventive strategies, including identifying and modifying risk factors, may help deter progression to frank fractures [31,44,45].

Variant 5: Confirmed stress (fatigue) fracture, excluding vertebrae. Follow-up imaging study for "return-to-play" evaluation.

See variants 1 through 3. On initial diagnosis, MRI can be used to predict time to return to play in athletes. Fredericson et al [48] retrospectively correlated return to activity with an MRI grading system based on the pattern of periosteal and marrow edema on T1-weighted and fat-suppressed T2-weighted sequences. Similar findings were confirmed in other studies [49-51], including that the finding of abnormal cortical signal intensity or a fracture line was of prognostic value [51] and that MRI performed better in predicting return to activity than radiographs, bone scintigraphy, or CT [50,52].

A recent prospective study in university athletes found that MRI grading severity, total-body bone mineral density evaluated by dual-energy x-ray absorptiometry (DXA), and location of injury (ie, cortical or trabecular bone) were important variables for predicting time to full return to sport [31]. In this study, periosteal edema as described by Fredericson et al [48] was not associated with return to sport. Using the modified grading scale and a multiple regression model, for every 1-unit increase in MRI grade, the time to full return to sport increased by approximately 48 days [31]. Furthermore, trabecular stress injuries (eg, femur neck and pubic bone) were associated with a longer time to return to sport than cortical bone stress injuries. In addition, decreased bone mineral density leads to increased time to return to sport. Therefore, bone mineral density provides additional diagnostic and prognostic information [31]. The model of MRI grade, trabecular versus cortical bone site, and total-body bone mineral density accounted for 68% of the variation in time to return to sport [31]. Although further studies are needed, optimization of bone mass may reduce risk of sustaining stress injuries or possibly reduce recovery time in athletes with these injuries.

It should be noted that after a diagnosis of stress fracture is made, no additional imaging is typically performed. Patients are typically followed clinically until they are pain free, at which time they can increase activity in a controlled manner [53].

Variant 6: Suspected stress (insufficiency) fracture, pelvis or hip. First imaging study.

See variant 1. Pelvic and hip insufficiency fractures have varied presentations and often insidious onset. Patients frequently present with intractable lower back or pelvic pain, with loss of mobility and independence and symptom exacerbation with weight bearing [54]. Insufficiency fractures occur in patients with abnormal bone, be it from osteoporosis, irradiated bone, or resumption of activity postarthroplasty as typical examples. Insufficiency fractures also occur at fairly predictable sites, including the sacrum, supra-acetabular ilium, superior and inferior pubic rami, and pubic bone. Radiographs should be the initial imaging modality in patients with low back and/or pelvic pain. Anterior-posterior (AP) and lateral lumbar spine and AP pelvis radiographs are usually obtained. Because of overlying bowel gas, fecal material, vascular calcifications, sacral curvature, and/or copious soft tissue, the sensitivity of radiographs is low [55]. Radiographs may be more likely to be negative initially in older or osteoporotic patients with insufficiency fractures, particularly when they occur in the pelvis or sacrum where there is more overlapping soft tissue [17]. However, if the findings are conclusive for insufficiency fracture, no further imaging need be performed.

Variant 7: Suspected stress (insufficiency) fracture, pelvis or hip. Negative radiographs. Next imaging study.

Normal bone scintigraphy generally excludes a diagnosis of stress/fracture, and the patient can return to normal activity. However, there are exceptions. In elderly or osteoporotic patients, abnormalities may not show up on bone scintigraphy for several days postinjury. Patients using corticosteroids may also have less sensitive bone scintigraphy results [1]. The characteristic "Honda" or "H" sign on bone scintigraphy is commonly referred to as diagnostic of sacral insufficiency fracture. A study by Fujii et al [56] confirmed this, finding a positive predictive value of 94% for the Honda sign; however, absence of the sign did not rule out a fracture, as only 63% of patients with sacral insufficiency fractures demonstrated this sign. In fact, there may be an overemphasis on the Honda sign, as many fractures are oriented in the sagittal plane, parallel to the sacroiliac joint. In most cases, bone scintigraphy lacks specificity (with synovitis, arthritis, degenerative joint disease, stress reactions, and tumor appearing similar), and supplemental imaging with MRI or CT may be necessary for conclusive diagnosis or to avoid false positives [1]. Because bone scintigraphy is often nonspecific and time-consuming, and supplemental imaging is frequently required, there is consensus in the literature that cross-sectional imaging should supersede bone scintigraphy as the imaging of choice for suspected insufficiency fracture when the radiograph is negative [17].

It is recommended that cross-sectional imaging for hip fractures also include the sacrum, since stress fractures of the sacrum can be the source of radiated hip/groin pain [15,57,58]. The choice of cross-sectional imaging modality in the evaluation of stress fractures of the sacrum has not always been clear-cut. CT is particularly well-suited for the evaluation of the sacrum and pelvis. If the patient was symptomatic for several weeks before imaging was performed, the CT images may show periosteal reaction, sclerosis, or the fracture lines themselves [18,20,21]. Although the critical time for stress fracture to show up on MRI postinjury has not been established, it seems that the edema pattern would be present within hours [20,25,27,28]. Studies have demonstrated that the MRI pattern can be nonspecific and even confusing when only edema and not the fracture line is shown [1,59]. This problem seems particularly severe in differentiating sacral or pelvic insufficiency fractures from metastases [2,60,61]. These fractures are being recognized with greater frequency as their occurrence has become more widely known [15,60,62,63].

Compounding the problem is the fact that many patients suffering from these insufficiency fractures have a history of previous malignancy, including treatment with radiation (which increases the risk of insufficiency fracture) [64]. Over-reliance on nonspecific low-signal T1 and high-signal T2 MRI patterns can lead to misdiagnosis of stress fractures as more aggressive lesions. The edema associated with stress fractures is typically much more pronounced and linear on T2-weighted sequences than on T1-weighted sequences; in patients with neoplasm, the lesion is typically more obvious on the T1-weighted sequence [65]. The use of in-phase and out-of-phase MRI sequences appears to be more reliable in differentiating benign stress fractures from pathologic fractures [66]. Normal marrow has both fat and water in the same voxel, which results in suppression of signal intensity on opposed-phase images. In a pathologic fracture, a tumor replaces the fat-containing marrow, which should show lack of suppression on the opposed-phase image [66]. However, as described previously, many insufficiency fractures have characteristic locations, for example, the sacrum, supra-acetabular ilium, superior and inferior pubic rami, and pubic bones, and knowledge of the typical locations may add some diagnostic value.

Variant 8: Suspected stress (insufficiency) fracture, lower extremity, excluding pelvis and hip. First imaging study.

See variants 1 and 5. Radiographs of the area of concern should be the initial imaging study. Although not very sensitive, if the findings are conclusive for insufficiency fracture, no further imaging need be performed.

Variant 9: Suspected stress (insufficiency) fracture of lower extremity, excluding pelvis and hip. Negative radiographs. Next imaging study.

See variant 2. Follow-up radiographs, MRI, CT, or bone scintigraphy can be used as subsequent imaging tests, based on the urgency to know the diagnosis and the patient's ability to tolerate the different examinations.

Variant 10: Follow-up imaging study for characterizing nonspecific focal uptake on Tc-99m MDP bone scintigraphy, suspected to be a stress fracture.

Tc-99m-methyl diphosponate (MDP) is a marker of bone perfusion and bone turnover [67]. Relative uptake is dependent on both the perfusion of a region of bone as well as the area of the mineralization front of bone (eg, osteoid). Thus, there will be focal uptake in any location of new bone formation. Although bone scintigraphy is very sensitive for stress reactions and osteoblastic metastases, in most cases it lacks specificity, with synovitis, arthritis, degenerative joint disease, stress reactions, and tumor appearing similar. Supplemental imaging with radiographs, MRI, or CT may be necessary for conclusive diagnosis or to avoid false positives [1]. Furthermore, MRI or CT should be performed without and with contrast when there is suspicion of neoplasm or soft-tissue mass adjacent to the area of abnormal bone [1].

Variant 11: Suspect stress (fatigue/insufficiency) fracture, pelvis or hip or sacrum. Pregnant patient.

Pregnancy-related osteoporosis is rare and its pathogenesis is unclear [60]. Patients are predisposed to develop insufficiency fractures in the spine, pelvis, femoral neck, wrist, or clavicle. Decreased serum calcium levels may occur during pregnancy [20] because of decreased levels of 1,25-dihydroxyvitamin D_3, decreased calcitonin levels, and the effects of cytokines on bone remodeling. Insufficiency fractures of the sacrum secondary to postmenopausal or age-related osteoporosis are frequent and predicted to triple by the year 2030 secondary to raised awareness, advanced radiological methods of diagnosis, and increasing mean age [68]. In contrast, fractures of the sacrum occurring during pregnancy, labor, or immediately postpartum are rare and only a few case reports have been published in the English literature, presenting as insufficiency fractures [69], fatigue fractures [70-74], and those where the authors were not sure if they were dealing with fatigue fractures or insufficiency fractures with underlying osteoporosis [60]. Risk factors for fatigue sacral fractures during pregnancy and the postpartum period likely include vaginal delivery of a high-birth-weight infant, increased lumbar lordosis, excessive weight gain, and rapid vaginal delivery [75].

Imaging findings of pregnancy-related sacral fractures are similar to sacral insufficiency fractures related to involutional osteoporosis, with the exception that patients will be women in the reproductive years and in the last trimester of pregnancy or recently postpartum [57,63]. Radiographs, if obtained, may be normal or demonstrate unilateral or bilateral linear areas of sclerosis. MRI does not use ionizing radiation and has excellent sensitivity, and it should be considered the imaging study of choice for definitive diagnosis. MRI typically demonstrates linear T1 and T2 hypointense signal, representing fracture lines, and T1 hypointense and T2 hyperintense signal in the surrounding bone marrow, representing associated edema. Bone scintigraphy and CT are both associated with radiation exposure to the fetus in a pregnant patient. There is currently insufficient evidence that gadolinium-based contrast agents are without risk to the fetus, so they are recommended in pregnancy only when information cannot be acquired from a noncontrast MRI [76].

For reference, the approximate mean fetal absorbed dose from a pelvis radiograph is 1.1 mGy, from a pelvis CT is 25 mGy, and from bone scintigraphy is 4.6 mGy (early in pregnancy) and 1.8 mGy (at 9 months estimated gestational age) [77]. The specific risk to radiating the fetus appears to be childhood malignancy, with theoretical projections suggesting that for each 10-mGy exposure there is a maximum risk of 1 additional cancer death per 1700 exposures [78]. There are no diagnostic radiographic, CT, or nuclear medicine procedures to be considered a risk factor for genetic damage, malformation, or neurodevelopmental effects based on current knowledge [79].

Furthermore, MRI may also demonstrate other reasons for occult pelvic pain, such as soft-tissue abnormalities or the subchondral hip or supra-acetabular stress fractures described in some osteoporotic patients [63]. The clinical differential diagnosis includes sacroiliitis from inflammatory or infectious causes, osteitis condensans ilii, and lumbosacral degenerative spondylosis [60].

Variant 12: Suspect stress (fatigue or insufficiency) fracture of the long bones. Pregnant patient.

See variant 11. In the case of long bones, the fetus' absorbed dose from radiography and CT will be substantially lower. Women can be reassured that benefit far outweighs the risk with regard to diagnostic imaging, as all radiographs and CT scans not involving the abdomen or pelvis have a predicted fetal absorbed dose of less than 1 mGy [80]. Radiographs should be the initial imaging evaluation because findings may be conclusive, in which case no further imaging should be performed. MRI does not use ionizing radiation and can be used as necessary to make the diagnosis.

Summary of Recommendations

- In the setting of a suspected fatigue fracture, the initial imaging test should be radiography of the area of interest, although it is not a sensitive examination.
- If there is clinical concern for a fatigue fracture of the hip and initial radiographs are negative, MRI without contrast should be performed because of the high risk of complications.
- In the setting of a suspected fatigue fracture in a location other than the hip with initial negative radiographs, either repeat radiographs in 10 to 14 days or MRI without contrast may be appropriate depending on the location of pain and relative risk of complications secondary to stress fractures in that area.
- If there is an immediate need-to-know situation to diagnose a stress fracture in the setting of negative radiographs, for example, professional football player, then MRI without contrast is recommended.
- MRI without contrast and potentially total-body DXA provide prognostic information, which may help initial return-to-play evaluations.
- Although insensitive, radiographs should be the initial imaging study of choice for suspected insufficiency fractures in the pelvis or hip.
- When initial radiographs are negative in the setting of suspected insufficiency fracture of the pelvis or hip, MRI without contrast is recommended, and CT without contrast remains a reasonable, less sensitive alternative.
- Although insensitive, radiographs are the recommended initial imaging procedure for suspected insufficiency fractures in the lower extremities (excluding the pelvis and hip).

- When initial radiographs are negative in the setting of suspected insufficiency fracture of the lower extremities (excluding the pelvis and hip), MRI without contrast is recommended, and repeat radiographs in 10 to 14 days remains a reasonable, less sensitive alternative.
- When there is nonspecific focal uptake on a Tc-99m-MDP bone scan suspected to be a stress fracture, dedicated radiographs are recommended, although MRI without contrast is a more sensitive alternative.
- For a suspected stress (fatigue or insufficiency) fracture in the pelvis of a pregnant patient, MRI without contrast is the initial imaging test of choice.
- When a stress (fatigue or insufficiency) fracture is suspected in the long bones of a pregnant patient, radiographs should be the initial imaging test of choice, with MRI performed as a complementary study if the radiographs are equivocal or negative.

Summary of Evidence

Of the 83 references cited in the *ACR Appropriateness Criteria® Stress (Fatigue/Insufficiency) Fracture, Including Sacrum, Excluding Other Vertebrae* document, all are categorized as diagnostic references, including 4 good-quality studies and 15 quality studies that may have design limitations. There are 64 references that may not be useful as primary evidence.

The 83 references cited in the *ACR Appropriateness Criteria® Stress (Fatigue/Insufficiency) Fracture, Including Sacrum, Excluding Other Vertebrae* document were published from 1986 to 2016.

Although there are references that report on studies with design limitations, 4 good-quality studies provide good evidence.

Safety Considerations in Pregnant Patients

Imaging of the pregnant patient can be challenging, particularly with respect to minimizing radiation exposure and risk. For further information and guidance, see the following ACR documents:

- ACR-SPR Practice Parameter for Imaging Pregnant or Potentially Pregnant Adolescents and Women with Ionizing Radiation [81]
- ACR-ACOG-AIUM-SRU Practice Parameter for the Performance of Obstetrical Ultrasound [82]
- ACR guidance document on MR safe practices: 2013 [83]
- ACR Manual on Contrast Media [76]

Relative Radiation Level Information

Potential adverse health effects associated with radiation exposure are an important factor to consider when selecting the appropriate imaging procedure. Because there is a wide range of radiation exposures associated with different diagnostic procedures, a relative radiation level (RRL) indication has been included for each imaging examination. The RRLs are based on effective dose, which is a radiation dose quantity that is used to estimate population total radiation risk associated with an imaging procedure. Patients in the pediatric age group are at inherently higher risk from exposure, both because of organ sensitivity and longer life expectancy (relevant to the long latency that appears to accompany radiation exposure). For these reasons, the RRL dose estimate ranges for pediatric examinations are lower as compared to those specified for adults (see Table below). Additional information regarding radiation dose assessment for imaging examinations can be found in the ACR Appropriateness Criteria® Radiation Dose Assessment Introduction document.

Relative Radiation Level Designations		
Relative Radiation Level*	**Adult Effective Dose Estimate Range**	**Pediatric Effective Dose Estimate Range**
O	0 mSv	0 mSv
☢	<0.1 mSv	<0.03 mSv
☢☢	0.1-1 mSv	0.03-0.3 mSv
☢☢☢	1-10 mSv	0.3-3 mSv
☢☢☢☢	10-30 mSv	3-10 mSv
☢☢☢☢☢	30-100 mSv	10-30 mSv
*RRL assignments for some of the examinations cannot be made, because the actual patient doses in these procedures vary as a function of a number of factors (eg, region of the body exposed to ionizing radiation, the imaging guidance that is used). The RRLs for these examinations are designated as "Varies".		

Supporting Documents

For additional information on the Appropriateness Criteria methodology and other supporting documents go to www.acr.org/ac.

References

1. Bencardino JT, Kassarjian A, Palmer WE. Magnetic resonance imaging of the hip: sports-related injuries. *Top Magn Reson Imaging.* 2003;14(2):145-160.
2. Li ZC, Dai LY, Jiang LS, Qiu S. Difference in subchondral cancellous bone between postmenopausal women with hip osteoarthritis and osteoporotic fracture: implication for fatigue microdamage, bone microarchitecture, and biomechanical properties. *Arthritis Rheum.* 2012;64(12):3955-3962.
3. Fredericson M, Jennings F, Beaulieu C, Matheson GO. Stress fractures in athletes. *Top Magn Reson Imaging.* 2006;17(5):309-325.
4. McCormick F, Nwachukwu BU, Provencher MT. Stress fractures in runners. *Clin Sports Med.* 2012;31(2):291-306.
5. Williams TR, Puckett ML, Denison G, Shin AY, Gorman JD. Acetabular stress fractures in military endurance athletes and recruits: incidence and MRI and scintigraphic findings. *Skeletal Radiol.* 2002;31(5):277-281.
6. Bernhard A, Milovanovic P, Zimmermann EA, et al. Micro-morphological properties of osteons reveal changes in cortical bone stability during aging, osteoporosis, and bisphosphonate treatment in women. *Osteoporos Int.* 2013;24(10):2671-2680.
7. Tokumaru S, Toita T, Oguchi M, et al. Insufficiency fractures after pelvic radiation therapy for uterine cervical cancer: an analysis of subjects in a prospective multi-institutional trial, and cooperative study of the Japan Radiation Oncology Group (JAROG) and Japanese Radiation Oncology Study Group (JROSG). *Int J Radiat Oncol Biol Phys.* 2012;84(2):e195-200.
8. Lassus J, Tulikoura I, Konttinen YT, Salo J, Santavirta S. Bone stress injuries of the lower extremity: a review. *Acta Orthop Scand.* 2002;73(3):359-368.
9. Dobrindt O, Hoffmeyer B, Ruf J, et al. Blinded-read of bone scintigraphy: the impact on diagnosis and healing time for stress injuries with emphasis on the foot. *Clin Nucl Med.* 2011;36(3):186-191.
10. Bryant LR, Song WS, Banks KP, Bui-Mansfield LT, Bradley YC. Comparison of planar scintigraphy alone and with SPECT for the initial evaluation of femoral neck stress fracture. *AJR Am J Roentgenol.* 2008;191(4):1010-1015.
11. Hatem SF, Recht MP, Profitt B. MRI of Little Leaguer's shoulder. *Skeletal Radiol.* 2006;35(2):103-106.
12. Liong SY, Whitehouse RW. Lower extremity and pelvic stress fractures in athletes. *Br J Radiol.* 2012;85(1016):1148-1156.
13. Oka M, Monu JU. Prevalence and patterns of occult hip fractures and mimics revealed by MRI. *AJR Am J Roentgenol.* 2004;182(2):283-288.
14. Sankey RA, Turner J, Lee J, Healy J, Gibbons CE. The use of MRI to detect occult fractures of the proximal femur: a study of 102 consecutive cases over a ten-year period. *J Bone Joint Surg Br.* 2009;91(8):1064-1068.

15. Ahovuo JA, Kiuru MJ, Visuri T. Fatigue stress fractures of the sacrum: diagnosis with MR imaging. *Eur Radiol.* 2004;14(3):500-505.
16. Anderson MW. Imaging of upper extremity stress fractures in the athlete. *Clin Sports Med.* 2006;25(3):489-504, vii.
17. Berger FH, de Jonge MC, Maas M. Stress fractures in the lower extremity. The importance of increasing awareness amongst radiologists. *Eur J Radiol.* 2007;62(1):16-26.
18. Campbell SE, Fajardo RS. Imaging of stress injuries of the pelvis. *Semin Musculoskelet Radiol.* 2008;12(1):62-71.
19. Gaeta M, Minutoli F, Scribano E, et al. CT and MR imaging findings in athletes with early tibial stress injuries: comparison with bone scintigraphy findings and emphasis on cortical abnormalities. *Radiology.* 2005;235(2):553-561.
20. Kijowski R, Choi J, Mukharjee R, de Smet A. Significance of radiographic abnormalities in patients with tibial stress injuries: correlation with magnetic resonance imaging. *Skeletal Radiol.* 2007;36(7):633-640.
21. Krestan C, Hojreh A. Imaging of insufficiency fractures. *Eur J Radiol.* 2009;71(3):398-405.
22. Lee SH, Baek JR, Han SB, Park SW. Stress fractures of the femoral diaphysis in children: a report of 5 cases and review of literature. *J Pediatr Orthop.* 2005;25(6):734-738.
23. Muthukumar T, Butt SH, Cassar-Pullicino VN. Stress fractures and related disorders in foot and ankle: plain films, scintigraphy, CT, and MR Imaging. *Semin Musculoskelet Radiol.* 2005;9(3):210-226.
24. Nguyen JT, Peterson JS, Biswal S, Beaulieu CF, Fredericson M. Stress-related injuries around the lesser trochanter in long-distance runners. *AJR Am J Roentgenol.* 2008;190(6):1616-1620.
25. Niva MH, Sormaala MJ, Kiuru MJ, Haataja R, Ahovuo JA, Pihlajamaki HK. Bone stress injuries of the ankle and foot: an 86-month magnetic resonance imaging-based study of physically active young adults. *Am J Sports Med.* 2007;35(4):643-649.
26. Sofka CM. Imaging of stress fractures. *Clin Sports Med.* 2006;25(1):53-62, viii.
27. Sormaala MJ, Niva MH, Kiuru MJ, Mattila VM, Pihlajamaki HK. Stress injuries of the calcaneus detected with magnetic resonance imaging in military recruits. *J Bone Joint Surg Am.* 2006;88(10):2237-2242.
28. Sormaala MJ, Niva MH, Kiuru MJ, Mattila VM, Pihlajamaki HK. Bone stress injuries of the talus in military recruits. *Bone.* 2006;39(1):199-204.
29. Nachtrab O, Cassar-Pullicino VN, Lalam R, Tins B, Tyrrell PN, Singh J. Role of MRI in hip fractures, including stress fractures, occult fractures, avulsion fractures. *Eur J Radiol.* 2012;81(12):3813-3823.
30. Fottner A, Baur-Melnyk A, Birkenmaier C, Jansson V, Durr HR. Stress fractures presenting as tumours: a retrospective analysis of 22 cases. *Int Orthop.* 2009;33(2):489-492.
31. Nattiv A, Kennedy G, Barrack MT, et al. Correlation of MRI grading of bone stress injuries with clinical risk factors and return to play: a 5-year prospective study in collegiate track and field athletes. *Am J Sports Med.* 2013;41(8):1930-1941.
32. Wright AA, Hegedus EJ, Lenchik L, Kuhn KJ, Santiago L, Smoliga JM. Diagnostic Accuracy of Various Imaging Modalities for Suspected Lower Extremity Stress Fractures: A Systematic Review With Evidence-Based Recommendations for Clinical Practice. *Am J Sports Med.* 2016;44(1):255-263.
33. Bianchi S, Luong DH. Stress fractures of the ankle malleoli diagnosed by ultrasound: a report of 6 cases. *Skeletal Radiol.* 2014;43(6):813-818.
34. Banal F, Etchepare F, Rouhier B, et al. Ultrasound ability in early diagnosis of stress fracture of metatarsal bone. *Ann Rheum Dis.* 2006;65(7):977-978.
35. Banal F, Gandjbakhch F, Foltz V, et al. Sensitivity and specificity of ultrasonography in early diagnosis of metatarsal bone stress fractures: a pilot study of 37 patients. *J Rheumatol.* 2009;36(8):1715-1719.
36. Gaeta M, Mileto A, Ascenti G, Bernava G, Murabito A, Minutoli F. Bone stress injuries of the leg in athletes. *Radiol Med.* 2013;118(6):1034-1044.
37. Hulkko A, Orava S, Nikula P. Stress fractures of the olecranon in javelin throwers. *Int J Sports Med.* 1986;7(4):210-213.
38. Khan KM, Brukner PD, Kearney C, Fuller PJ, Bradshaw CJ, Kiss ZS. Tarsal navicular stress fracture in athletes. *Sports Med.* 1994;17(1):65-76.
39. Behrens SB, Deren ME, Matson A, Fadale PD, Monchik KO. Stress fractures of the pelvis and legs in athletes: a review. *Sports Health.* 2013;5(2):165-174.
40. Fullerton LR, Jr., Snowdy HA. Femoral neck stress fractures. *Am J Sports Med.* 1988;16(4):365-377.
41. Monteleone GP, Jr. Stress fractures in the athlete. *Orthop Clin North Am.* 1995;26(3):423-432.

42. DeFranco MJ, Recht M, Schils J, Parker RD. Stress fractures of the femur in athletes. *Clin Sports Med.* 2006;25(1):89-103, ix.
43. Boden BP, Osbahr DC. High-risk stress fractures: evaluation and treatment. *J Am Acad Orthop Surg.* 2000;8(6):344-353.
44. Goolsby MA, Barrack MT, Nattiv A. A displaced femoral neck stress fracture in an amenorrheic adolescent female runner. *Sports Health.* 2012;4(4):352-356.
45. Jones BH, Thacker SB, Gilchrist J, Kimsey CD, Jr., Sosin DM. Prevention of lower extremity stress fractures in athletes and soldiers: a systematic review. *Epidemiol Rev.* 2002;24(2):228-247.
46. Craig JG, Widman D, van Holsbeeck M. Longitudinal stress fracture: patterns of edema and the importance of the nutrient foramen. *Skeletal Radiol.* 2003;32(1):22-27.
47. Groves AM, Cheow HK, Balan KK, Housden BA, Bearcroft PW, Dixon AK. 16-Detector multislice CT in the detection of stress fractures: a comparison with skeletal scintigraphy. *Clin Radiol.* 2005;60(10):1100-1105.
48. Fredericson M, Bergman AG, Hoffman KL, Dillingham MS. Tibial stress reaction in runners. Correlation of clinical symptoms and scintigraphy with a new magnetic resonance imaging grading system. *Am J Sports Med.* 1995;23(4):472-481.
49. Arendt E, Agel J, Heikes C, Griffiths H. Stress injuries to bone in college athletes: a retrospective review of experience at a single institution. *Am J Sports Med.* 2003;31(6):959-968.
50. Beck BR, Bergman AG, Miner M, et al. Tibial stress injury: relationship of radiographic, nuclear medicine bone scanning, MR imaging, and CT Severity grades to clinical severity and time to healing. *Radiology.* 2012;263(3):811-818.
51. Yao L, Johnson C, Gentili A, Lee JK, Seeger LL. Stress injuries of bone: analysis of MR imaging staging criteria. *Acad Radiol.* 1998;5(1):34-40.
52. Kijowski R, Choi J, Shinki K, Del Rio AM, De Smet A. Validation of MRI classification system for tibial stress injuries. *AJR Am J Roentgenol.* 2012;198(4):878-884.
53. Matheson GO, Clement DB, McKenzie DC, Taunton JE, Lloyd-Smith DR, MacIntyre JG. Stress fractures in athletes. A study of 320 cases. *Am J Sports Med.* 1987;15(1):46-58.
54. Tsiridis E, Upadhyay N, Giannoudis PV. Sacral insufficiency fractures: current concepts of management. *Osteoporos Int.* 2006;17(12):1716-1725.
55. Shah MK, Stewart GW. Sacral stress fractures: an unusual cause of low back pain in an athlete. *Spine (Phila Pa 1976).* 2002;27(4):E104-108.
56. Fujii M, Abe K, Hayashi K, et al. Honda sign and variants in patients suspected of having a sacral insufficiency fracture. *Clin Nucl Med.* 2005;30(3):165-169.
57. Beltran LS, Bencardino JT. Lower back pain after recently giving birth: postpartum sacral stress fractures. *Skeletal Radiol.* 2011;40(4):461-462, 481-462.
58. Kiuru MJ, Pihlajamaki HK, Ahovuo JA. Fatigue stress injuries of the pelvic bones and proximal femur: evaluation with MR imaging. *Eur Radiol.* 2003;13(3):605-611.
59. Theodorou SJ, Theodorou DJ, Resnick D. Imaging findings in symptomatic patients with femoral diaphyseal stress injuries. *Acta Radiol.* 2006;47(4):377-384.
60. Schmid L, Pfirrmann C, Hess T, Schlumpf U. Bilateral fracture of the sacrum associated with pregnancy: a case report. *Osteoporos Int.* 1999;10(1):91-93.
61. Soubrier M, Dubost JJ, Boisgard S, et al. Insufficiency fracture. A survey of 60 cases and review of the literature. *Joint Bone Spine.* 2003;70(3):209-218.
62. Fayad LM, Kamel IR, Kawamoto S, Bluemke DA, Frassica FJ, Fishman EK. Distinguishing stress fractures from pathologic fractures: a multimodality approach. *Skeletal Radiol.* 2005;34(5):245-259.
63. Steib-Furno S, Luc M, Pham T, et al. Pregnancy-related hip diseases: incidence and diagnoses. *Joint Bone Spine.* 2007;74(4):373-378.
64. Blomlie V, Rofstad EK, Talle K, Sundfor K, Winderen M, Lien HH. Incidence of radiation-induced insufficiency fractures of the female pelvis: evaluation with MR imaging. *AJR Am J Roentgenol.* 1996;167(5):1205-1210.
65. Stacy GS, Dixon LB. Pitfalls in MR image interpretation prompting referrals to an orthopedic oncology clinic. *Radiographics.* 2007;27(3):805-826; discussion 827-808.
66. Erly WK, Oh ES, Outwater EK. The utility of in-phase/opposed-phase imaging in differentiating malignancy from acute benign compression fractures of the spine. *AJNR Am J Neuroradiol.* 2006;27(6):1183-1188.
67. Brenner AI, Koshy J, Morey J, Lin C, DiPoce J. The bone scan. *Semin Nucl Med.* 2012;42(1):11-26.

68. Kannus P, Palvanen M, Niemi S, Parkkari J, Jarvinen M. Epidemiology of osteoporotic pelvic fractures in elderly people in Finland: sharp increase in 1970-1997 and alarming projections for the new millennium. *Osteoporos Int.* 2000;11(5):443-448.
69. Breuil V, Brocq O, Euller-Ziegler L, Grimaud A. Insufficiency fracture of the sacrum revealing a pregnancy associated osteoporosis. First case report. *Ann Rheum Dis.* 1997;56(4):278-279.
70. Karatas M, Basaran C, Ozgul E, Tarhan C, Agildere AM. Postpartum sacral stress fracture: an unusual case of low-back and buttock pain. *Am J Phys Med Rehabil.* 2008;87(5):418-422.
71. Lin JT, Lutz GE. Postpartum sacral fracture presenting as lumbar radiculopathy: a case report. *Arch Phys Med Rehabil.* 2004;85(8):1358-1361.
72. Rousiere M, Kahan A, Job-Deslandre C. Postpartal sacral fracture without osteoporosis. *Joint Bone Spine.* 2001;68(1):71-73.
73. Thein R, Burstein G, Shabshin N. Labor-related sacral stress fracture presenting as lower limb radicular pain. *Orthopedics.* 2009;32(6):447.
74. Thienpont E, Simon JP, Fabry G. Sacral stress fracture during pregnancy--a case report. *Acta Orthop Scand.* 1999;70(5):525-526.
75. Leroux JL, Denat B, Thomas E, Blotman F, Bonnel F. Sacral insufficiency fractures presenting as acute low-back pain. Biomechanical aspects. *Spine (Phila Pa 1976).* 1993;18(16):2502-2506.
76. American College of Radiology. *Manual on Contrast Media*. Available at: http://www.acr.org/Quality-Safety/Resources/Contrast-Manual.
77. ICRP, 2000. Pregnancy and Medical Radiation. ICRP Publication 84. Ann. ICRP 30 (1). Available at: http://www.icrp.org/publication.asp?id=ICRP%20Publication%2084.
78. Winer-Muram HT, Boone JM, Brown HL, Jennings SG, Mabie WC, Lombardo GT. Pulmonary embolism in pregnant patients: fetal radiation dose with helical CT. *Radiology.* 2002;224(2):487-492.
79. Lowe SA. Diagnostic radiography in pregnancy: risks and reality. *Aust N Z J Obstet Gynaecol.* 2004;44(3):191-196.
80. ICRP, 1996. Radiological Protection and Safety in Medicine. ICRP Publication 73. Ann. ICRP 26 (2). Available at: http://www.icrp.org/publication.asp?id=ICRP%20Publication%2073.
81. American College of Radiology. ACR-SPR Practice Parameter for Imaging Pregnant or Potentially Pregnant Adolescents and Women with Ionizing Radiation. Available at: http://www.acr.org/~/media/ACR/Documents/PGTS/guidelines/Pregnant_Patients.pdf.
82. American College of Radiology. ACR-ACOG-AIUM-SRU Practice Paramater for the Performance of Obstetrical Ultrasound. Available at: http://www.acr.org/~/media/ACR/Documents/PGTS/guidelines/US_Obstetrical.pdf.
83. Kanal E, Barkovich AJ, Bell C, et al. ACR guidance document on MR safe practices: 2013. *J Magn Reson Imaging.* 2013;37(3):501-530.