American College of Radiology
ACR Appropriateness Criteria®

Stress (Fatigue/Insufficiency) Fracture, Including Sacrum, Excluding Other Vertebrae

Variant: 1 Adult. Suspect stress fracture, excluding vertebrae. Initial imaging.

Procedure	Appropriateness Category	Relative Radiation Level
Radiography area of interest	Usually Appropriate	Varies
Bone scan whole body with SPECT or SPECT/CT area of interest	May Be Appropriate (Disagreement)	☢☢☢
US area of interest	Usually Not Appropriate	O
MRI area of interest without and with IV contrast	Usually Not Appropriate	O
MRI area of interest without IV contrast	Usually Not Appropriate	O
CT area of interest with IV contrast	Usually Not Appropriate	Varies
CT area of interest without and with IV contrast	Usually Not Appropriate	Varies
CT area of interest without IV contrast	Usually Not Appropriate	Varies

Variant: 2 Adult. Suspect stress fracture, excluding vertebrae. Radiographs negative or indeterminate. Next imaging study.

Procedure	Appropriateness Category	Relative Radiation Level
MRI area of interest without IV contrast	Usually Appropriate	O
Radiography area of interest repeat in 10-14 days	May Be Appropriate	Varies
Bone scan whole body with SPECT or SPECT/CT area of interest	May Be Appropriate	☢☢☢
CT area of interest without IV contrast	May Be Appropriate	Varies
US area of interest	Usually Not Appropriate	O
MRI area of interest without and with IV contrast	Usually Not Appropriate	O
CT area of interest with IV contrast	Usually Not Appropriate	Varies
CT area of interest without and with IV contrast	Usually Not Appropriate	Varies

Variant: 3 Adult. Suspect pelvis or hip or sacrum stress fracture. Pregnant patient. Radiographs negative or indeterminate. Next imaging study.

Procedure	Appropriateness Category	Relative Radiation Level
MRI area of interest without IV contrast	Usually Appropriate	O
US area of interest	Usually Not Appropriate	O
Radiography area of interest repeat in 10-14 days	Usually Not Appropriate	Varies
MRI area of interest without and with IV contrast	Usually Not Appropriate	O
Bone scan whole body with SPECT or SPECT/CT area of interest	Usually Not Appropriate	☢☢☢
CT area of interest with IV contrast	Usually Not Appropriate	Varies
CT area of interest without and with IV contrast	Usually Not Appropriate	Varies
CT area of interest without IV contrast	Usually Not Appropriate	Varies

Variant: 4 Adult. Suspect stress fracture, excluding vertebrae. High risk for fracture completion (ie, a patient with osteoporosis on bisphosphonate therapy) or immediate "need-to-know." Radiographs negative or indeterminate. Next imaging study.

Procedure	Appropriateness Category	Relative Radiation Level
MRI area of interest without IV contrast	Usually Appropriate	O

Bone scan whole body with SPECT or SPECT/CT area of interest	May Be Appropriate (Disagreement)	☢☢☢
CT area of interest without IV contrast	May Be Appropriate	Varies
US area of interest	Usually Not Appropriate	O
Radiography area of interest repeat in 10-14 days	Usually Not Appropriate	Varies
MRI area of interest without and with IV contrast	Usually Not Appropriate	O
CT area of interest with IV contrast	Usually Not Appropriate	Varies
CT area of interest without and with IV contrast	Usually Not Appropriate	Varies

Variant: 5 Adult. Suspect subchondral stress fracture at an extremity joint. Radiographs negative or indeterminate. Next imaging study.

Procedure	Appropriateness Category	Relative Radiation Level
MRI area of interest without IV contrast	Usually Appropriate	O
Bone scan whole body with SPECT or SPECT/CT area of interest	May Be Appropriate	☢☢☢
CT area of interest without IV contrast	May Be Appropriate	Varies
US area of interest	Usually Not Appropriate	O
Radiography area of interest repeat in 10-14 days	Usually Not Appropriate	Varies
MRI area of interest without and with IV contrast	Usually Not Appropriate	O
CT area of interest with IV contrast	Usually Not Appropriate	Varies
CT area of interest without and with IV contrast	Usually Not Appropriate	Varies

Variant: 6 Adult. Positive stress fracture on radiographs, excluding vertebrae. Need for determining extent (ie, for surgical planning, return to activity) or associated complication (ie, osteonecrosis or delayed healing). Next imaging study.

Procedure	Appropriateness Category	Relative Radiation Level
MRI area of interest without IV contrast	Usually Appropriate	O
CT area of interest without IV contrast	Usually Appropriate	Varies
Radiography area of interest repeat in 10-14 days	May Be Appropriate	Varies
US area of interest	Usually Not Appropriate	O
MRI area of interest without and with IV contrast	Usually Not Appropriate	O
CT area of interest with IV contrast	Usually Not Appropriate	Varies
CT area of interest without and with IV contrast	Usually Not Appropriate	Varies

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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 [1,3-6]. The fatigue variation of stress fractures are particularly common in athletes participating in activities that require running and jumping, as well as in ballet dancers and military recruits [7-9]. Certain medical interventions such as radiation therapy and long-term osteoporosis treatment with bisphosphonates predispose patients to the insufficiency variation of stress fractures [10-12].

Initial Imaging Definition

Initial imaging is defined as imaging at the beginning of the care episode for the medical condition defined by the variant. More than one procedure can be considered usually appropriate in the initial imaging evaluation when:

- There are procedures that are equivalent alternatives (ie, only one procedure will be ordered to provide the clinical information to effectively manage the patient's care)

OR

- There are complementary procedures (ie, more than one procedure is ordered as a set or simultaneously wherein each procedure provides unique clinical information to effectively manage the patient's care).

Discussion of Procedures by Variant

Variant 1: Adult. Suspect stress fracture, excluding vertebrae. Initial imaging.

Area of Interest: pelvis, ankle, elbow, femur, foot, forearm, hand, hip, humerus, knee, leg tib/fib, ribs, sacrum, shoulder, or wrist.

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 [13-15]. Insufficiency fractures occur in patients with abnormal bone, be it from osteoporosis or irradiated bone, 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. These patients often present with intractable low back and/or pelvic pain [16].

Variant 1: Adult. Suspect stress fracture, excluding vertebrae. Initial imaging.
A. Bone scan whole body with SPECT or SPECT/CT area of interest

The bone scan was regarded for many years as the reference standard for detecting stress-induced injuries and was valued for its sensitivity. Dobrindt et al [17] 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 CT (SPECT) is more accurate in diagnosing stress injuries

than planar scintigraphy alone [18]. The objection to the studies quoting high accuracy for bone scintigraphy is that, in all of them, positive bone scintigraphy is taken as the reference 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 [19-21]. Nonetheless, bone scintigraphy shows stress fractures days to weeks earlier than radiographs in many instances and differentiates between osseous and soft tissue injury as well.

Variant 1: Adult. Suspect stress fracture, excluding vertebrae. Initial imaging.
B. CT area of interest with IV contrast

There is no relevant literature to support the use of CT area of interest with intravenous (IV) contrast because it does not provide added information over noncontrast imaging with regard to stress injury.

Variant 1: Adult. Suspect stress fracture, excluding vertebrae. Initial imaging.
C. CT area of interest without and with IV contrast

There is no relevant literature to support the use of CT area of interest without and with IV contrast because it does not provide added information over noncontrast imaging with regard to stress injury.

Variant 1: Adult. Suspect stress fracture, excluding vertebrae. Initial imaging.
D. CT area of interest without IV contrast

CT is not supported for the initial imaging of suspected stress fractures but may offer an adjunct role when other imaging modalities are equivocal [22], particularly in the pelvis or sacrum. Although superior to radiography, it is less sensitive than nuclear scintigraphy or MRI [23]. The benefit of CT seems to lie in its specificity, ranging from 88% to 98% in a recent meta-analysis regarding accuracy of imaging modalities for lower extremity stress fractures, and thus may confirm a finding suspected to represent stress fracture on MRI [24]. CT may also be useful in cases where MRI results are equivocal.

Variant 1: Adult. Suspect stress fracture, excluding vertebrae. Initial imaging.
E. MRI area of interest without and with IV contrast

There is no relevant literature to support the use of MRI area of interest without and with IV contrast because it does not provide added information over noncontrast imaging with regard to stress injury.

Variant 1: Adult. Suspect stress fracture, excluding vertebrae. Initial imaging.
F. MRI area of interest without IV contrast

MRI demonstrates stress abnormalities as early as bone scintigraphy and with as much sensitivity [25-28]. 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 considerably more specific than scintigraphy [22,23]. The recent literature supports MRI as the procedure of choice for early diagnosis of both fatigue and insufficiency types of stress fractures, outperforming all other modalities [15,22,23,29-39]. Fluid-sensitive sequences are the favored initial sequence for MRI screening [40]. Short tau inversion recovery (STIR) and T1-weighted images demonstrate a fracture line surrounded by edema. MRI of an osseous stress injury contains prognostic as well as diagnostic information [41,42].

Variant 1: Adult. Suspect stress fracture, excluding vertebrae. Initial imaging.
G. Radiography area of interest

Radiographs are insensitive for stress fracture in the early stages of injury and in elderly patients with underlying osteoporosis. However, if symptoms have been present for at least 10 to 14 days, radiographs can achieve sensitivity of 30% to 70%, making them an effective screening tool [43]. If the findings on radiographs are conclusive for stress fracture, often no further imaging needs to be performed. Detection of osseous change is limited in areas covered by prominent overlapping soft tissue or bowel gas [31]. 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.

Variant 1: Adult. Suspect stress fracture, excluding vertebrae. Initial imaging.
H. US area of interest

There is increasing evidence of the usefulness of ultrasound (US) in the early diagnosis of stress fractures of the extremities [44,45]. Although later US findings of stress fractures, including subcutaneous edema, periosteal thickening, cortical bone irregularity, local hyperemia [44-46], and periosteal callus are often nonspecific, these findings provide useful information in the setting of suspected stress fracture. Because US cannot evaluate the subcortical bone, trabecular stress fractures may be missed.

Variant 2: Adult. Suspect stress fracture, excluding vertebrae. Radiographs negative or indeterminate. Next imaging study.

Area of Interest: pelvis, ankle, elbow, femur, foot, forearm, hand, hip, humerus, knee, leg tib/fib, ribs, sacrum, shoulder, or wrist.

Variant 2: Adult. Suspect stress fracture, excluding vertebrae. Radiographs negative or indeterminate. Next imaging study.
A. Bone scan whole body with SPECT or SPECT/CT area of interest

Bone scintigraphy shows stress fractures days to weeks earlier than radiographs in many instances and differentiates between osseous and soft tissue injury as well. Although bone scan was regarded as the reference standard examination for many years, MRI demonstrates stress abnormalities as early as bone scintigraphy and with as much sensitivity [25-28]. Because standard planar whole body bone scintigraphy is often nonspecific and supplemental imaging is frequently required, there is consensus in the literature that MRI should supersede bone scintigraphy as the imaging examination of choice for suspected stress fracture when radiographs are negative [31].

Variant 2: Adult. Suspect stress fracture, excluding vertebrae. Radiographs negative or indeterminate. Next imaging study.
B. CT area of interest with IV contrast

There is no relevant literature to support the use of CT area of interest with IV contrast because it does not provide added information over noncontrast imaging with regard to stress injury.

Variant 2: Adult. Suspect stress fracture, excluding vertebrae. Radiographs negative or indeterminate. Next imaging study.
C. CT area of interest without and with IV contrast

There is no relevant literature to support the use of CT area of interest without and with IV contrast because it does not provide added information over noncontrast imaging with regard to stress injury.

Variant 2: Adult. Suspect stress fracture, excluding vertebrae. Radiographs negative or indeterminate. Next imaging study.

D. CT area of interest without IV contrast

CT is not supported as the next imaging study for suspected stress fractures following radiographs but may offer an adjunctive role when other imaging modalities are equivocal [22]. Although superior to radiography, it is less sensitive than nuclear scintigraphy and MRI [23]. CT is useful in cases where MRI results are equivocal.

Variant 2: Adult. Suspect stress fracture, excluding vertebrae. Radiographs negative or indeterminate. Next imaging study.
E. MRI area of interest without and with IV contrast

There is no relevant literature to support the use of MRI area of interest without and with IV contrast because it does not provide added information over noncontrast imaging with regard to stress injury.

Variant 2: Adult. Suspect stress fracture, excluding vertebrae. Radiographs negative or indeterminate. Next imaging study.
F. MRI area of interest without IV contrast

MRI outperforms radiography, bone scintigraphy, and CT with recent literature supporting MRI as the procedure of choice for making an early diagnosis of both fatigue and insufficiency fractures [15,22,23,29-39]. MRI of an osseous stress injury contains prognostic as well as diagnostic information [41,42].

Variant 2: Adult. Suspect stress fracture, excluding vertebrae. Radiographs negative or indeterminate. Next imaging study.
G. Radiography area of interest repeat in 10-14 days

Short-term (10-14 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 is reported to be 30% to 70% [43]. Detection of osseous change is more limited in areas covered by prominent overlapping soft tissue [31]. 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.

Variant 2: Adult. Suspect stress fracture, excluding vertebrae. Radiographs negative or indeterminate. Next imaging study.
H. US area of interest

There is increasing evidence of the usefulness of US in the early diagnosis of stress fractures of the extremities [44,45]. Although later US findings of stress fractures, including subcutaneous edema, periosteal thickening, cortical bone irregularity, local hyperemia [44-46], and periosteal callus are often nonspecific, these findings provide useful information in the setting of suspected stress fracture. Because US cannot evaluate the subcortical bone, trabecular stress fractures may be missed.

Variant 3: Adult. Suspect pelvis or hip or sacrum stress fracture. Pregnant patient. Radiographs negative or indeterminate. Next imaging study.

Area of Interest: pelvis, hip, or sacrum.

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, independence,

and symptom exacerbation with weight bearing [47]. Insufficiency fractures occur in patients with abnormal bone, be it from osteoporosis, irradiated bone, or resumption of activity.

Pregnancy-related osteoporosis is rare, and its pathogenesis is unclear [48]. Patients are predisposed to develop insufficiency fractures in the spine, pelvis, femoral neck, and sacrum. Decreased serum calcium levels may occur during pregnancy [33] because of decreased levels of 1,25-dihydroxyvitamin D3, 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. 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 [49], stress fractures [50-54], and those in which the authors were not sure if they were dealing with stress fractures or insufficiency fractures with underlying osteoporosis [48]. Risk factors for stress 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 [55].

Imaging findings of pregnancy-related sacral fractures are similar to sacral insufficiency fractures related to involutional osteoporosis, with the exception that patients will be in their reproductive years and in the last trimester of pregnancy or recently postpartum [56,57].

Stress fractures in the femur most often occur in the femoral neck and represent up to 7% of all stress fractures [58]. Lateral tension-type femoral neck stress fractures are inherently unstable and prone to displacement [59] and are high-risk fractures, often necessitating percutaneous screw fixation [60]. Medial compression-type femoral neck stress fractures are low risk [59] and can be treated with a non–weight-bearing regimen [61]. 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 [31]. The clinical differential diagnosis includes sacroiliitis from inflammatory or infectious causes, osteitis condensans ilii, and lumbosacral degenerative spondylosis [48].

Variant 3: Adult. Suspect pelvis or hip or sacrum stress fracture. Pregnant patient. Radiographs negative or indeterminate. Next imaging study.
A. Bone scan whole body with SPECT or SPECT/CT area of interest

Bone scintigraphy and CT are both associated with radiation exposure to the fetus in a pregnant patient. 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 a bone scintigraphy is 4.6 mGy (early in pregnancy) and 1.8 mGy (at 9 months estimated gestational age) [62]. Because bone scintigraphy is often nonspecific 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, regardless of the risks of radiation exposure [31].

Variant 3: Adult. Suspect pelvis or hip or sacrum stress fracture. Pregnant patient. Radiographs negative or indeterminate. Next imaging study.
B. CT area of interest with IV contrast

There is no relevant literature to support the use of CT area of interest with IV contrast because it does not provide added information over noncontrast imaging with regard to stress injury.

Variant 3: Adult. Suspect pelvis or hip or sacrum stress fracture. Pregnant patient.

Radiographs negative or indeterminate. Next imaging study.
C. CT area of interest without and with IV contrast

There is no relevant literature to support the use of CT area of interest without and with IV contrast because it does not provide added information over noncontrast imaging with regard to stress injury.

Variant 3: Adult. Suspect pelvis or hip or sacrum stress fracture. Pregnant patient. Radiographs negative or indeterminate. Next imaging study.
D. CT area of interest without IV contrast

CT and bone scintigraphy are both associated with radiation exposure to the fetus in a pregnant patient [62]. Therefore, MRI is preferred.

Variant 3: Adult. Suspect pelvis or hip or sacrum stress fracture. Pregnant patient. Radiographs negative or indeterminate. Next imaging study.
E. MRI area of interest without and with IV contrast

There is no relevant literature to support the use of MRI area of interest without and with IV contrast because it does not provide added information over noncontrast imaging with regard to stress injury.

Variant 3: Adult. Suspect pelvis or hip or sacrum stress fracture. Pregnant patient. Radiographs negative or indeterminate. Next imaging study.
F. MRI area of interest without IV contrast

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. MRI does not use ionizing radiation, has excellent sensitivity, and allows 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. MRI demonstrates stress abnormalities as early as bone scintigraphy and with as much sensitivity [25-28].

In addition to confirming a suspected stress fracture, 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 patients with osteoporosis [57].

Variant 3: Adult. Suspect pelvis or hip or sacrum stress fracture. Pregnant patient. Radiographs negative or indeterminate. Next imaging study.
G. Radiography area of interest repeat in 10-14 days

A follow-up radiographic examination has increased sensitivity compared to initial radiographs [43] but is less sensitive than MRI.

Variant 3: Adult. Suspect pelvis or hip or sacrum stress fracture. Pregnant patient. Radiographs negative or indeterminate. Next imaging study.
H. US area of interest

There is increasing evidence of the usefulness of US in the early diagnosis of stress fractures of the distal extremities [44,45] and may allow visualization of posterior sacral fractures without the risk of ionizing radiation. However, definitive diagnosis of suspected hip or pelvic fractures should not be delayed by choosing US as the second-line study following negative or indeterminate radiographs, considering that additional imaging may be required following a negative or US indeterminate examination.

Variant 4: Adult. Suspect stress fracture, excluding vertebrae. High risk for fracture completion (ie, a patient with osteoporosis on bisphosphonate therapy) or immediate "need-to-know." Radiographs negative or indeterminate. Next imaging study.

Area of Interest: pelvis, ankle, elbow, femur, foot, forearm, hand, hip, humerus, knee, leg tib/fib, ribs, sacrum, shoulder, or wrist.

Patients at high-risk for fracture completion include patients with osteoporosis, those on bisphosphonate therapy, and athletes. Stress fractures in this population that are not identified and managed in a timely fashion can progress to more serious fractures and complications (eg, risk of fatty emboli in completed femoral shaft fractures). Preventive strategies, including identifying and modifying risk factors, may help deter progression to complete fracture [42,63,64].

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, patella, medial malleolus, navicular, fifth metatarsal base, proximal second metatarsal, tibial hallux sesamoid, and talus [65].

Stress fractures in the femur most often occur in the femoral neck and represent up to 7% of all stress fractures [58]. Lateral tension-type femoral neck stress fractures are inherently unstable and prone to displacement [59] and are high-risk fractures, often necessitating percutaneous screw fixation [60]. Medial compression-type femoral neck stress fractures are low risk [59] and can be treated with a non–weight-bearing regimen [61]. 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 [31].

Variant 4: Adult. Suspect stress fracture, excluding vertebrae. High risk for fracture completion (ie, a patient with osteoporosis on bisphosphonate therapy) or immediate "need-to-know." Radiographs negative or indeterminate. Next imaging study.
A. Bone scan whole body with SPECT or SPECT/CT area of interest

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 patients with osteoporosis, abnormalities may not show up on bone scintigraphy for several days after the injury. Patients using corticosteroids may also have less sensitive bone scintigraphy results [66]. 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 [67] confirmed this finding with a positive predictive value of 94% for the Honda sign; however, absence of the sign did not rule out a fracture because only 63% of patients with sacral insufficiency fractures demonstrated this sign. In fact, there may be an overemphasis on the Honda sign, because many fractures are oriented in the sagittal plane, parallel to the sacroiliac joint. In most cases, bone scintigraphy (even with SPECT) 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 [66]. Because bone scintigraphy is often nonspecific, 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 [31].

Variant 4: Adult. Suspect stress fracture, excluding vertebrae. High risk for fracture completion (ie, a patient with osteoporosis on bisphosphonate therapy) or immediate

"need-to-know." Radiographs negative or indeterminate. Next imaging study.
B. CT area of interest with IV contrast

There is no relevant literature to support the use of CT area of interest with IV contrast because it does not provide added information over noncontrast imaging with regard to stress injury.

Variant 4: Adult. Suspect stress fracture, excluding vertebrae. High risk for fracture completion (ie, a patient with osteoporosis on bisphosphonate therapy) or immediate "need-to-know." Radiographs negative or indeterminate. Next imaging study.
C. CT area of interest without and with IV contrast

There is no relevant literature to support the use of CT area of interest without and with IV contrast because it does not provide added information over noncontrast imaging with regard to stress injury.

Variant 4: Adult. Suspect stress fracture, excluding vertebrae. High risk for fracture completion (ie, a patient with osteoporosis on bisphosphonate therapy) or immediate "need-to-know." Radiographs negative or indeterminate. Next imaging study.
D. CT area of interest without IV contrast

CT is not supported as the next imaging study for suspected stress fractures following radiographs but may offer an adjunctive role when other imaging modalities are equivocal [22]. Although superior to radiography, it is less sensitive than nuclear scintigraphy or MRI [23]. The benefit of CT seems to lie in its specificity, ranging from 88% to 98% in a recent meta-analysis regarding accuracy of imaging modalities for lower extremity stress fractures and thus may confirm a finding suspected to represent stress fracture on MRI [24].

Variant 4: Adult. Suspect stress fracture, excluding vertebrae. High risk for fracture completion (ie, a patient with osteoporosis on bisphosphonate therapy) or immediate "need-to-know." Radiographs negative or indeterminate. Next imaging study.
E. MRI area of interest without and with IV contrast

There is no relevant literature to support the use of MRI area of interest without and with IV contrast because it does not provide added information over noncontrast imaging with regard to stress injury.

Variant 4: Adult. Suspect stress fracture, excluding vertebrae. High risk for fracture completion (ie, a patient with osteoporosis on bisphosphonate therapy) or immediate "need-to-know." Radiographs negative or indeterminate. Next imaging study.
F. MRI area of interest without IV contrast

MRI is beneficial after initial negative radiographs to prevent delayed diagnosis. MRI has excellent sensitivity, and it allows 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. MRI demonstrates stress abnormalities as early as bone scintigraphy but with more specificity [25-28].

Variant 4: Adult. Suspect stress fracture, excluding vertebrae. High risk for fracture completion (ie, a patient with osteoporosis on bisphosphonate therapy) or immediate "need-to-know." Radiographs negative or indeterminate. Next imaging study.
G. Radiography area of interest repeat in 10-14 days

A follow-up radiographic examination has increased sensitivity compared to initial radiographs [43] but is less sensitive than MRI. Radiographs are typically not useful for assessing a patient's "return to play." In patients with high risk for fractures or in the need-to-know setting, imaging should not

be delayed.

Variant 4: Adult. Suspect stress fracture, excluding vertebrae. High risk for fracture completion (ie, a patient with osteoporosis on bisphosphonate therapy) or immediate "need-to-know." Radiographs negative or indeterminate. Next imaging study.
H. US area of interest

There is increasing evidence of the usefulness of US in the early diagnosis of stress fractures of the distal extremities [44,45] and may allow for visualization of posterior sacral fractures. However, definitive diagnosis of suspected hip or pelvic fractures should not be delayed by choosing US as the second-line study following negative or indeterminate radiographs, considering that additional imaging may be required following a negative or US indeterminate examination.

Variant 5: Adult. Suspect subchondral stress fracture at an extremity joint. Radiographs negative or indeterminate. Next imaging study.

Area of Interest: pelvis, ankle, elbow, femur, foot, forearm, hand, hip, humerus, knee, leg tib/fib, shoulder, or wrist.

Variant 5: Adult. Suspect subchondral stress fracture at an extremity joint. Radiographs negative or indeterminate. Next imaging study.
A. Bone scan whole body with SPECT or SPECT/CT area of interest

Normal bone scintigraphy generally excludes a diagnosis of stress fracture, and the patient can return to normal activity. Tc-99m-methyl diphosphonate is a marker of bone perfusion and bone turnover [68]. 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, including subchondral stress fractures, in most cases it lacks specificity, with synovitis, arthritis, degenerative joint disease, stress reactions, and tumor appearing similar. Supplemental imaging with MRI may be necessary for conclusive diagnosis or to avoid false positives [66]. Because planar bone scintigraphy is often nonspecific and supplemental imaging is frequently required, there is consensus in the literature that cross-sectional imaging should supersede planar bone scintigraphy as the imaging of choice for suspected stress fractures when the radiograph is negative [31].

Variant 5: Adult. Suspect subchondral stress fracture at an extremity joint. Radiographs negative or indeterminate. Next imaging study.
B. CT area of interest with IV contrast

There is no relevant literature to support the use of CT area of interest with IV contrast because it does not provide added information over noncontrast imaging with regard to stress injury.

Variant 5: Adult. Suspect subchondral stress fracture at an extremity joint. Radiographs negative or indeterminate. Next imaging study.
C. CT area of interest without and with IV contrast

There is no relevant literature to support the use of CT area of interest without and with IV contrast because it does not provide added information over noncontrast imaging with regard to stress injury.

Variant 5: Adult. Suspect subchondral stress fracture at an extremity joint. Radiographs negative or indeterminate. Next imaging study.
D. CT area of interest without IV contrast

CT is not supported as the next imaging study for suspected subchondral stress fractures following

radiographs but may offer an adjunctive role when other imaging modalities are equivocal [22]. Although superior to radiography, it is less sensitive than nuclear scintigraphy or MRI [23]. The value of CT in the setting of suspected subchondral stress fracture primarily lies in detection of articular surface collapse and sclerosis that could indicate secondary necrosis. CT is useful in cases in which MRI results are equivocal.

Variant 5: Adult. Suspect subchondral stress fracture at an extremity joint. Radiographs negative or indeterminate. Next imaging study.
E. MRI area of interest without and with IV contrast

There is no relevant literature to support the use of MRI area of interest without and with IV contrast because it does not provide added information over noncontrast imaging with regard to stress injury.

Variant 5: Adult. Suspect subchondral stress fracture at an extremity joint. Radiographs negative or indeterminate. Next imaging study.
F. MRI area of interest without IV contrast

MRI is beneficial after initial negative radiographs to prevent delayed diagnosis. MRI has excellent sensitivity and allows for definitive diagnosis.

Variant 5: Adult. Suspect subchondral stress fracture at an extremity joint. Radiographs negative or indeterminate. Next imaging study.
G. Radiography area of interest repeat in 10-14 days

In general, follow-up radiographic examination has increased sensitivity compared to initial radiographs [43]. However, subchondral insufficiency fractures are typically radiographically occult until collapse or flattening of the articular surface occurs, at which point morbidity is significantly increased. Therefore, MRI without IV contrast should be considered as the next imaging study after initial negative radiographs to prevent delay in diagnosis and preventative treatment.

Variant 5: Adult. Suspect subchondral stress fracture at an extremity joint. Radiographs negative or indeterminate. Next imaging study.
H. US area of interest

US does not allow evaluation of subchondral bone and so provides no benefit in this scenario.

Variant 6: Adult. Positive stress fracture on radiographs, excluding vertebrae. Need for determining extent (ie, for surgical planning, return to activity) or associated complication (ie, osteonecrosis or delayed healing). Next imaging study.

Area of Interest: pelvis, ankle, elbow, femur, foot, forearm, hand, hip, humerus, knee, leg tib/fib, ribs, sacrum, shoulder, or wrist.

After a diagnosis of stress fracture is made, additional imaging is typically not needed. Most patients are followed clinically until they are pain free, at which time they can increase activity in a controlled manner [14]. Fractures in the long bones may be followed up by radiography, CT, MRI, or a combination thereof as needed to determine full extent of involvement. Occasionally, once activity/weightbearing is increased, an unexpected incomplete response to conservative therapy becomes evident with the return of pretreatment symptoms. In this situation, it is recommended that follow-up imaging be performed as well as re-evaluation of the original imaging studies to determine whether the true etiology of pain was obscured or simply misdiagnosed.

Other scenarios include progression to osteonecrosis, especially in the case of femoral subchondral

or neck stress fractures, for which MRI should be considered as the next line of imaging. For further reading on this condition, please see the ACR Appropriateness Criteria® topic on Osteonecrosis [69]. Patients with osteoporosis or those on bisphosphonate therapy are especially prone to progression of incomplete stress fractures to completion. More information is available in the ACR Appropriateness Criteria® topic on Osteoporosis and Bone Mineral Density [70].

Variant 6: Adult. Positive stress fracture on radiographs, excluding vertebrae. Need for determining extent (ie, for surgical planning, return to activity) or associated complication (ie, osteonecrosis or delayed healing). Next imaging study.
A. CT area of interest with IV contrast

There is no relevant literature to support the use of CT area of interest with IV contrast because it does not provide added information over noncontrast imaging with regard to stress injury.

Variant 6: Adult. Positive stress fracture on radiographs, excluding vertebrae. Need for determining extent (ie, for surgical planning, return to activity) or associated complication (ie, osteonecrosis or delayed healing). Next imaging study.
B. CT area of interest without and with IV contrast

There is no relevant literature to support the use of CT area of interest without and with IV contrast because it does not provide added information over noncontrast imaging with regard to stress injury.

Variant 6: Adult. Positive stress fracture on radiographs, excluding vertebrae. Need for determining extent (ie, for surgical planning, return to activity) or associated complication (ie, osteonecrosis or delayed healing). Next imaging study.
C. CT area of interest without IV contrast

CT is useful in identifying possible etiologies in delayed healing after conservative therapy for suspected stress fracture, such as osteoid osteoma or suspected completion of fracture.

Variant 6: Adult. Positive stress fracture on radiographs, excluding vertebrae. Need for determining extent (ie, for surgical planning, return to activity) or associated complication (ie, osteonecrosis or delayed healing). Next imaging study.
D. MRI area of interest without and with IV contrast

MRI with IV contrast may be useful in identifying complications of stress fracture such as osteonecrosis or in suspected osteoid osteoma or tumor causing persistent symptoms or delayed healing after conservative therapy for suspected stress fracture.

Variant 6: Adult. Positive stress fracture on radiographs, excluding vertebrae. Need for determining extent (ie, for surgical planning, return to activity) or associated complication (ie, osteonecrosis or delayed healing). Next imaging study.
E. MRI area of interest without IV contrast

MRI is useful in identifying complications of stress fracture such as osteonecrosis or in suspected osteoid osteoma or tumor causing persistent symptoms or delayed healing after conservative therapy for suspected stress fracture. In athletes, MRI can be used to predict time to return to play on initial diagnosis. Fredericson et al [71] 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 [13,72,73], including that the finding of abnormal cortical signal intensity or a fracture line was of prognostic value [73] and that MRI performed better in predicting return to activity than radiographs, bone scintigraphy, or CT [72,74].

A recent prospective study in university athletes found that MRI grading severity, total-body bone mineral density evaluated by dual-energy X-ray absorptiometry, and location of injury (ie, cortical or trabecular bone) were important variables for predicting time to full return to sport [42]. In this study, periosteal edema as described by Fredericson et al [71] 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 [42]. 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 [42]. 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 [42]. 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.

Variant 6: Adult. Positive stress fracture on radiographs, excluding vertebrae. Need for determining extent (ie, for surgical planning, return to activity) or associated complication (ie, osteonecrosis or delayed healing). Next imaging study.
F. Radiography area of interest repeat in 10-14 days

Follow-up radiographs in patients at high risk for completion of stress fractures can be helpful in the long bones but are of limited benefit for pelvic or femoral head fractures. Cross-sectional imaging (ie, CT or MRI) is more sensitive and specific in identifying extent of fracture and/or other causes of persistent pain after conservative therapy (eg, metastatic disease). Radiographs are typically not useful for assessing a patient's "return to play."

Variant 6: Adult. Positive stress fracture on radiographs, excluding vertebrae. Need for determining extent (ie, for surgical planning, return to activity) or associated complication (ie, osteonecrosis or delayed healing). Next imaging study.
G. US area of interest

Although there is increasing evidence of the usefulness of US in the early diagnosis of stress fractures of the extremities [44,45], later US findings of stress fractures, including subcutaneous edema, periosteal thickening, cortical bone irregularity, local hyperemia [44-46], and periosteal callus are often nonspecific and may suggest ongoing healing. However, because US cannot evaluate the subcortical bone, the status of endosteal callus formation, the true indicator for fracture healing, cannot be assessed, nor any intraosseous complication (eg, osteonecrosis, tumor, or abscess).

Summary of Highlights

- **Variant 1**: Radiography is usually appropriate for the initial imaging of a suspected stress fracture, excluding the vertebrae. Although the panel did not agree on recommending bone scan whole body with SPECT or SPECT/CT because there is insufficient medical literature to conclude whether these patients would benefit from the procedure, its use may be appropriate.
- **Variant 2**: In the setting of a suspected stress fracture with negative or indeterminate radiographs, MRI without IV contrast is usually appropriate as the next imaging of the area of interest excluding the vertebrae.

- **Variant 3**: In the setting of suspected pelvis, hip, or sacrum fracture with negative or indeterminate radiographs, MRI without IV contrast is usually appropriate as the next imaging study in pregnant patients.
- **Variant 4**: In the setting of a suspected stress fracture with negative or indeterminate radiographs, MRI without IV contrast is usually appropriate as the next imaging of the area of interest excluding the vertebrae for "need to know" situations or patients at high-risk for fracture completion. Although the panel did not agree on recommending bone scan whole body with SPECT or SPECT/CT because there is insufficient medical literature to conclude whether these patients would benefit from the procedure, its use may be appropriate.
- **Variant 5**: MRI area of interest without IV contrast is usually appropriate for the initial imaging of a suspected subchondral stress fracture at an extremity joint.
- **Variant 6**: In the setting of a positive stress fracture by radiographs, MRI area of interest without IV contrast or CT area of interest without IV contrast is usually appropriate as the next imaging of the area of interest excluding the vertebrae for determining extent or associated complication. These procedures are equivalent alternatives (ie, only one procedure will be ordered to provide the clinical information to effectively manage the patient's care).

Supporting Documents

The evidence table, literature search, and appendix for this topic are available at https://acsearch.acr.org/list. The appendix includes the strength of evidence assessment and the final rating round tabulations for each recommendation.

For additional information on the Appropriateness Criteria methodology and other supporting documents, please go to the ACR website at https://www.acr.org/Clinical-Resources/Clinical-Tools-and-Reference/Appropriateness-Criteria.

Gender Equality and Inclusivity Clause

The ACR acknowledges the limitations in applying inclusive language when citing research studies that predates the use of the current understanding of language inclusive of diversity in sex, intersex, gender, and gender-diverse people. The data variables regarding sex and gender used in the cited literature will not be changed. However, this guideline will use the terminology and definitions as proposed by the National Institutes of Health.

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 the Safe and Optimal Performance of Fetal Magnetic Resonance Imaging (MRI)
· ACR-SPR Practice Parameter for Imaging Pregnant or Potentially Pregnant Patients with Ionizing Radiation
· ACR-ACOG-AIUM-SMFM-SRU Practice Parameter for the Performance of Standard Diagnostic Obstetrical Ultrasound
· ACR Manual on Contrast Media
· ACR Manual on MR Safety

Appropriateness Category Names and Definitions

Appropriateness Category Name	Appropriateness Rating	Appropriateness Category Definition
Usually Appropriate	7, 8, or 9	The imaging procedure or treatment is indicated in the specified clinical scenarios at a favorable risk-benefit ratio for patients.
May Be Appropriate	4, 5, or 6	The imaging procedure or treatment may be indicated in the specified clinical scenarios as an alternative to imaging procedures or treatments with a more favorable risk-benefit ratio, or the risk-benefit ratio for patients is equivocal.
May Be Appropriate (Disagreement)	5	The individual ratings are too dispersed from the panel median. The different label provides transparency regarding the panel's recommendation. "May be appropriate" is the rating category and a rating of 5 is assigned.
Usually Not Appropriate	1, 2, or 3	The imaging procedure or treatment is unlikely to be indicated in the specified clinical scenarios, or the risk-benefit ratio for patients is likely to be unfavorable.

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, because of both 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 with 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 (e.g., region of the body exposed to ionizing radiation, the imaging guidance that is used). The RRLs for these examinations are designated as "Varies."

References

1. Matcuk GR Jr, Mahanty SR, Skalski MR, Patel DB, White EA, Gottsegen CJ. Stress fractures: pathophysiology, clinical presentation, imaging features, and treatment options. [Review]. Emergency Radiology. 23(4):365-75, 2016 Aug.EMERG. RADIOL.. 23(4):365-75, 2016 Aug.
2. Aparisi Gomez MP.. Nonspinal Fragility Fractures. [Review]. Semin Musculoskelet Radiol. 20(4):330-344, 2016 Sep.
3. Abbott A, Bird M, Brown SM, Wild E, Stewart G, Mulcahey MK. Part II: presentation, diagnosis, classification, treatment, and prevention of stress fractures in female athletes. [Review]. Phys Sportsmed. 48(1):25-32, 2020 02.
4. Knapik JJ, Reynolds K, Hoedebecke KL. Stress Fractures: Etiology, Epidemiology, Diagnosis, Treatment, and Prevention. J Spec Oper Med. 17(2):120-130, Summer 2017.
5. Saunier J, Chapurlat R. Stress fracture in athletes. [Review]. Joint Bone Spine. 85(3):307-310, 2018 05.
6. Tenforde AS, Carlson JL, Chang A, et al. Association of the Female Athlete Triad Risk Assessment Stratification to the Development of Bone Stress Injuries in Collegiate Athletes. Am J Sports Med. 45(2):302-310, 2017 Feb.
7. DeFroda SF, Cameron KL, Posner M, Kriz PK, Owens BD. Bone Stress Injuries in the Military: Diagnosis, Management, and Prevention. [Review]. Am J Orthop. 46(4):176-183, 2017 Jul/Aug.
8. Hayashi D, Jarraya M, Engebretsen L, et al. Epidemiology of imaging-detected bone stress injuries in athletes participating in the Rio de Janeiro 2016 Summer Olympics. BJSM online. 52(7):470-474, 2018 Apr.
9. Lambert BS, Cain MT, Heimdal T, et al. Physiological Parameters of Bone Health in Elite Ballet Dancers. Med Sci Sports Exerc. 52(8):1668-1678, 2020 08.
10. Bazire L, Xu H, Foy JP, et al. Pelvic insufficiency fracture (PIF) incidence in patients treated with intensity-modulated radiation therapy (IMRT) for gynaecological or anal cancer: single-institution experience and review of the literature. [Review]. Br J Radiol. 90(1073):20160885, 2017 May.
11. Png MA, Mohan PC, Koh JSB, Howe CY, Howe TS. Natural history of incomplete atypical femoral fractures in patients after a prolonged and variable course of bisphosphonate therapy-a long-term radiological follow-up. Osteoporos Int. 30(12):2417-2428, 2019 Dec.
12. Sapienza LG, Salcedo MP, Ning MS, et al. Pelvic Insufficiency Fractures After External Beam Radiation Therapy for Gynecologic Cancers: A Meta-analysis and Meta-regression of 3929 Patients. Int J Radiat Oncol Biol Phys. 106(3):475-484, 2020 03 01.
13. 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;31:959-68.
14. 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;15:46-58.
15. 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. 35(4):643-9, 2007 Apr.

16. Tamaki Y, Nagamachi A, Inoue K, et al. Incidence and clinical features of sacral insufficiency fracture in the emergency department. Am J Emerg Med. 35(9):1314-1316, 2017 Sep.

17. 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. 36(3):186-91, 2011 Mar.

18. 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.

19. McCormick F, Nwachukwu BU, Provencher MT. Stress fractures in runners. Clin Sports Med. 2012;31(2):291-306.

20. 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.

21. 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.

22. Muthukumar T, Butt SH, Cassar-Pullicino VN. Stress fractures and related disorders in foot and ankle: plain films, scintigraphy, CT, and MR Imaging. [Review] [139 refs]. Semin Musculoskelet Radiol. 9(3):210-26, 2005 Sep.

23. 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. 235(2):553-61, 2005 May.

24. 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;44:255-63.

25. Hatem SF, Recht MP, Profitt B. MRI of Little Leaguer's shoulder. Skeletal Radiol. 2006;35(2):103-106.

26. Liong SY, Whitehouse RW. Lower extremity and pelvic stress fractures in athletes. [Review]. Br J Radiol. 85(1016):1148-56, 2012 Aug.

27. 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.

28. 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.

29. Ahovuo JA, Kiuru MJ, Visuri T. Fatigue stress fractures of the sacrum: diagnosis with MR imaging. Eur Radiol. 2004;14(3):500-505.

30. Anderson MW.. Imaging of upper extremity stress fractures in the athlete. [Review] [56 refs]. Clin Sports Med. 25(3):489-504, vii, 2006 Jul.

31. Berger FH, de Jonge MC, Maas M. Stress fractures in the lower extremity. The importance of increasing awareness amongst radiologists. [Review] [48 refs]. Eur J Radiol. 62(1):16-26, 2007

Apr.

32. Campbell SE, Fajardo RS. Imaging of stress injuries of the pelvis. [Review] [60 refs]. Semin Musculoskelet Radiol. 12(1):62-71, 2008 Mar.

33. 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.

34. Krestan C, Hojreh A. Imaging of insufficiency fractures. Eur J Radiol. 2009;71(3):398-405.

35. 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.

36. 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.

37. Sofka CM.. Imaging of stress fractures. [Review] [19 refs]. Clin Sports Med. 25(1):53-62, viii, 2006 Jan.

38. 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.

39. Sormaala MJ, Niva MH, Kiuru MJ, Mattila VM, Pihlajamaki HK. Bone stress injuries of the talus in military recruits. Bone. 39(1):199-204, 2006 Jul.

40. 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. 81(12):3813-23, 2012 Dec.

41. Fottner A, Baur-Melnyk A, Birkenmaier C, Jansson V, Durr HR. Stress fractures presenting as tumours: a retrospective analysis of 22 cases. Int Orthop. 33(2):489-92, 2009 Apr.

42. 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;41:1930-41.

43. Lassus J, Tulikoura I, Konttinen YT, Salo J, Santavirta S. Bone stress injuries of the lower extremity: a review. Acta Orthop Scand 2002;73:359-68.

44. 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. 36(8):1715-9, 2009 Aug.

45. Bianchi S, Luong DH. Stress fractures of the ankle malleoli diagnosed by ultrasound: a report of 6 cases. Skeletal Radiol. 43(6):813-8, 2014 Jun.

46. Banal F, Etchepare F, Rouhier B, et al. Ultrasound ability in early diagnosis of stress fracture of metatarsal bone. Ann Rheum Dis 2006;65:977-8.

47. Tsiridis E, Upadhyay N, Giannoudis PV. Sacral insufficiency fractures: current concepts of management. Osteoporos Int 2006;17:1716-25.

48. 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.

49. 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.

50. 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.

51. Lin JT, Lutz GE. Postpartum sacral fracture presenting as lumbar radiculopathy: a case report. Arch Phys Med Rehabil. 2004;85(8):1358-1361.

52. Rousiere M, Kahan A, Job-Deslandre C. Postpartal sacral fracture without osteoporosis. Joint Bone Spine. 2001;68(1):71-73.

53. Thein R, Burstein G, Shabshin N. Labor-related sacral stress fracture presenting as lower limb radicular pain. Orthopedics. 2009;32(6):447.

54. Thienpont E, Simon JP, Fabry G. Sacral stress fracture during pregnancy--a case report. Acta Orthop Scand. 1999;70(5):525-526.

55. 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;18:2502-6.

56. Beltran LS, Bencardino JT. Lower back pain after recently giving birth: postpartum sacral stress fractures. Skeletal Radiol. 2011;40(4):461-462, 481-462.

57. Steib-Furno S, Luc M, Pham T, et al. Pregnancy-related hip diseases: incidence and diagnoses. Joint Bone Spine. 2007;74(4):373-378.

58. Behrens SB, Deren ME, Matson A, Fadale PD, Monchik KO. Stress fractures of the pelvis and legs in athletes: a review. Sports Health 2013;5:165-74.

59. Fullerton LR, Jr., Snowdy HA. Femoral neck stress fractures. Am J Sports Med 1988;16:365-77.

60. Monteleone GP, Jr. Stress fractures in the athlete. Orthop Clin North Am 1995;26:423-32.

61. DeFranco MJ, Recht M, Schils J, Parker RD. Stress fractures of the femur in athletes. Clin Sports Med 2006;25:89-103, ix.

62. 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.

63. Goolsby MA, Barrack MT, Nattiv A. A displaced femoral neck stress fracture in an amenorrheic adolescent female runner. Sports Health 2012;4:352-6.

64. 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;24:228-47.

65. Boden BP, Osbahr DC. High-risk stress fractures: evaluation and treatment. Journal of the American Academy of Orthopaedic Surgeons. 8(6):344-53, 2000 Nov-Dec.J Am Acad Orthop Surg. 8(6):344-53, 2000 Nov-Dec.

66. Bencardino JT, Kassarjian A, Palmer WE. Magnetic resonance imaging of the hip: sports-related injuries. Top Magn Reson Imaging. 2003 Apr;14(2):145-60.

67. 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;30:165-9.

68. Brenner AI, Koshy J, Morey J, Lin C, DiPoce J. The bone scan. Semin Nucl Med 2012;42:11-26.

69. Ha AS, Chang EY, Bartolotta RJ, et al. ACR Appropriateness Criteria® Osteonecrosis: 2022 Update. J Am Coll Radiol 2022;19:S409-S16.

70. Yu JS, Krishna NG, Fox MG, et al. ACR Appropriateness Criteria® Osteoporosis and Bone Mineral Density: 2022 Update. J Am Coll Radiol 2022;19:S417-S32.

71. 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;23:472-81.

72. 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.[Erratum appears in Radiology. 2012 Sep;264(3):920]. Radiology. 263(3):811-8, 2012 Jun.

73. Yao L, Johnson C, Gentili A, Lee JK, Seeger LL. Stress injuries of bone: analysis of MR imaging staging criteria. Acad Radiol 1998;5:34-40.

74. 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;198:878-84.

75. American College of Radiology. ACR–SPR Practice Parameter for the Safe and Optimal Performance of Fetal Magnetic Resonance Imaging (MRI). Available at: https://gravitas.acr.org/PPTS/GetDocumentView?docId=89+&releaseId=2.

76. American College of Radiology. ACR–SPR Practice Parameter for Imaging Pregnant or Potentially Pregnant Patients with Ionizing Radiation. Available at: https://gravitas.acr.org/PPTS/GetDocumentView?docId=23+&releaseId=2.

77. American College of Radiology. ACR-ACOG-AIUM-SMFM-SRU Practice Parameter for the Performance of Standard Diagnostic Obstetrical Ultrasound. Available at: https://gravitas.acr.org/PPTS/GetDocumentView?docId=28+&releaseId=2.

78. American College of Radiology. ACR Committee on Drugs and Contrast Media. Manual on Contrast Media. Available at: https://www.acr.org/Clinical-Resources/Clinical-Tools-and-Reference/Contrast-Manual.

79. American College of Radiology. ACR Committee on MR Safety. 2026 ACR Manual on MR Safety. Available at: https://edge.sitecorecloud.io/americancoldf5f-acrorgf92a-productioncb02-3650/media/ACR/Files/Clinical/Radiology-Safety/Manual-on-MR-Safety.pdf.

80. American College of Radiology. ACR Appropriateness Criteria® Radiation Dose Assessment Introduction. Available at: https://edge.sitecorecloud.io/americancoldf5f-acrorgf92a-productioncb02-3650/media/ACR/Files/Clinical/Appropriateness-Criteria/ACR-Appropriateness-Criteria-Radiation-Dose-Assessment-Introduction.pdf.

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