Imaging of Stress Fractures: Specific Sites of Injuries

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Iris Eshed, Tuvia Schlesinger, Eugene Kots, and Gideon Mann

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Further details on specific sites are included in chapter "Overview: Stress Fractures."

I. Eshed (✉)
Orthopedic Department, Meir Medical Centre, Kfar Saba, Israel

Department of Diagnostic Imaging, Sheba Medical Center, Tel Hashomer, Israel
e-mail: iriseshed@gmail.com

T. Schlesinger
The Sheri and Arnold Schlesinger Radiation Protection Information, Training and Research Center, Ariel University, Ariel, Israel
e-mail: Schlesinger@ariel.ac; Schlesinger@ariel.il; tuviasch@inter.net.il; tuvia@ndc.soreq.gov.il

E. Kots
Department of Diagnostic Radiology, Meir Medical Center, Kfar Saba, Israel
e-mail: eukots.@clalit.org.il; kotze@clalit.org.il

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Abstract

The current chapter elaborates on the appearance of stress injury in specific upper and lower extremity body parts and on various imaging modalities as well as advantages and disadvantages of the different imaging modalities in diagnosing stress fracture.

Lower Extremity

Stress injuries can affect almost any bone, but the vast majority (up to 90 %) affect the lower extremity (Matheson et al. 1987).

Femur

The clinical diagnosis of a hip stress fracture may be difficult. Often the pain pattern is atypical and

G. Mann
Sackler Faculty of Medicine, Tel Aviv University, Tel Aviv, Israel

Department of Orthopaedic Surgery, Service of Sports Injuries, Meir University Hospital Medical Center, Kfar-Saba, Israel

Department of Orthopaedic Surgery, Sapir Medical Center, Kfar Saba, Israel

Orthopedic Department, Meir Medical Centre, Kfar Saba, Israel
e-mail: gideon.mann.md@gmail.com; gideon.mann@gmail.com

pain may be referred to the groin or the knee. The insidious nature of femoral neck stress fracture presentation combined with a low clinical suspicion commonly leads to serious complications. Possible complications include fracture completion, malunion, nonunion, avascular necrosis, and arthritic changes (DeFranco et al. 2006; McCormick et al. 2012).

Femoral stress fractures are associated with specific activities, such as long-distance running, jumping, and ballet dancing (Matheson et al. 1987; Arendt et al. 2003). The most common sites are the femoral neck and shaft, while distal femur fractures are rare (Shin and Gillingham 1997; Harrast and Colonno 2010). In athletes, femoral shaft stress fractures are more common in the medial femoral cortex (Hershman et al. 1990; Johnson et al. 1994). Other sites of hip stress fracture were also described, including subchondral fracture of the femoral head (Song et al. 2004) and the lateral cortex of the femoral neck (Provencher et al. 2004); however, these are uncommon.

Most femoral stress fractures require imaging studies to confirm the diagnosis. Plain radiographs are usually normal in the acute presentation and do not aid in the diagnostic workup. Several studies used scintigraphy for the diagnosis of femoral stress fracture and its sensitivity is of use for localizing the nonspecific symptoms to the femur (El-Khoury et al. 1981; Bryant et al. 2008). Although femoral neck stress fractures can show significant uptake on planar scintigraphy, most low-grade stress fractures and some high-grade stress fractures show only subtle radiotracer uptake. Bryant et al. showed that SPECT imaging was superior to planar scintigraphy in these instances (Bryant et al. 2008). MRI is, however, still considered a favorable modality that is both sensitive and specific for diagnosing early femoral stress injury. The use of MRI has led to earlier diagnosis of femoral neck stress fractures that could alter treatment (Shin et al. 1996).

Bone marrow edema can be identified on MRI and demonstrate the location of the fracture, classifying the fracture as a compression type (on the inferior aspect of the neck) or a tension type (on the superior aspect of the neck), of which the latter is considered to be more unstable (Moran et al. 2008).

The typical finding is a rounded area of bone marrow edema along the compressive side of the femoral neck, adjacent to the lesser trochanter seen initially on T2-weighted with fat saturation or STIR sequences with a small field of view focusing on the hip. Fracture line will be seen in more advanced stages on the T1-weighted sequence as a line of decreased signal intensity perpendicular to the cortical margin (Fig. 1).

Tibia and Fibula

Tibial shaft stress injuries are the most common cause of lower leg pain in the athlete or soldier and may account for up to 73 % of all stress fractures, the majority being transverse or, less frequently, oblique (Umans and Kaye 1996; Iwamoto et al. 2012). Tibial stress injury usually involves the middle and distal one-third of the tibia and is typically seen in runners (Hulkko and Orava 1987; Lempainen et al. 2012). Anterior tibial stress fractures are tension-side fractures and, as such, are at risk for delayed healing and nonunion. Classically, anterior tibial shaft stress fractures present in runners as anterior leg pain or poorly localized discomfort (McCormick et al. 2012). Initial radiographic workup, though usually negative, is warranted. MRI is very sensitive and allows for evaluation of the bone and soft tissue. A horizontal line hypodense on X-ray or hypointense on MRI on the anterior tibia at the middle–distal third junction of the anterior tibia is pathognomonic for a stress fracture (Fig. 2).

Medial malleolar stress fractures are rare accounting for only 0.6–4.1 % of all stress fractures (Sherbondy and Sebastianelli 2006). These fractures occur most often in track and field athletes, long-distance runners, and basketball players, that is, in sports where running and repeated jumping is frequent. Radiographs in these fractures are usually insignificant and remain normal despite increasing pain, possibly because the medial malleolus consists mainly of cancellous bone. Due to these reasons and the fact that this injury may have a tendency to dislocate

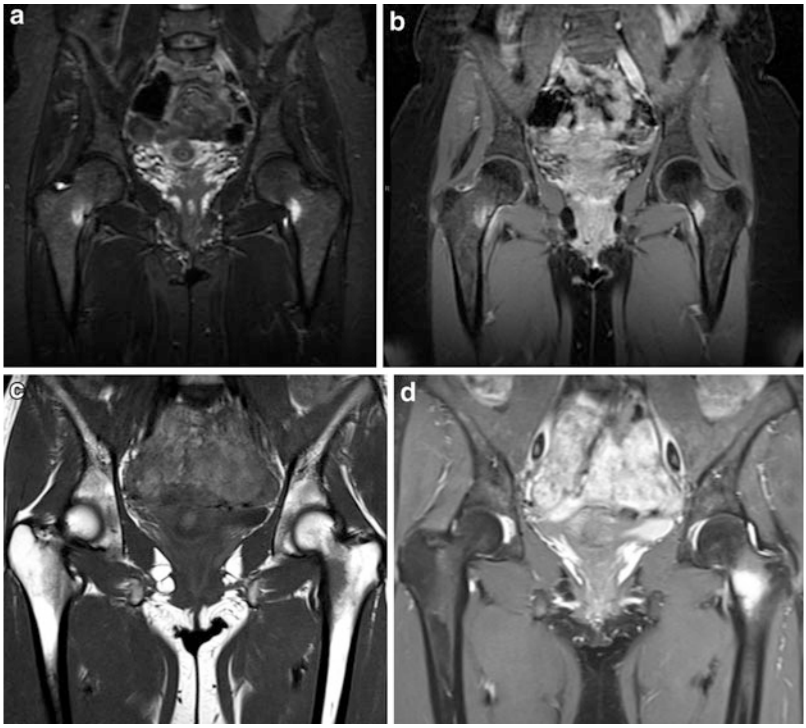

Fig. 1 Stress fracture of the femoral neck as seen on MRI. (**a**, **b**) Bilateral femoral neck stress reaction seen on coronal (**a**) STIR and (**b**) T1 after gadolinium injection. (**c**, **d**) A more advanced fracture in a different athlete seen on coronal (**c**) T1 and (**d**) STIR sequences. Fracture line can be detected on the STIR image

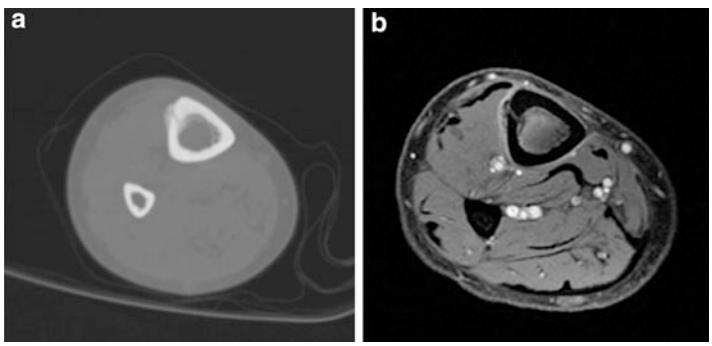

Fig. 2 Stress fracture of the anterior cortex of the tibia, on axial (**a**) CT and (**b**) on T1-weighted post gadolinium MRI

and cause severe complications, MRI is the recommended modality for diagnosis (Lempainen et al. 2012).

Medial tibial stress syndrome or shin splints is not fully understood. It is considered, however, by many as a prodrome for stress reaction, the lowest on the stress reaction–fracture continuum, and is thought to be caused by stress reaction of the fascia, periosteum, and bone (Mammoto et al. 2012; Reshef and Guelich 2012).

Shin splints are not detected on plain radiographs and traditionally triple-phase bone scintigraphy has been the imaging modality of choice with a sensitivity of 74–84 % (Batt et al. 1998; Gaeta et al. 2005). On the delayed phase of this exam, a longitudinal lesion at the posterior aspect of the tibia involving one-third of the tibia can be seen in patients with shin splints (Fig. 3). Gaeta et al. have shown that with overloaded remodeling, the cortex appears osteopenic on a CT on which cortical bone abnormalities were seen on the anterior or posterior cortex (Gaeta et al. 2005). CT was superior in this study compared to scintigraphy and MR regarding the detection of these cortical findings.

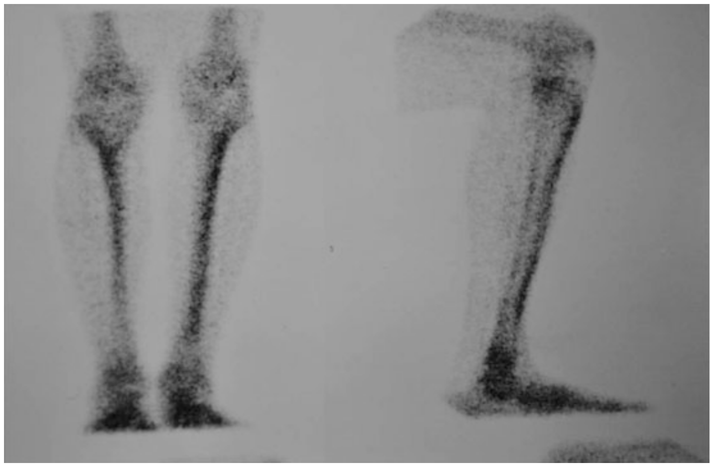

Fig. 3 Bilateral cortical longitudinal uptake on the medial side of the tibia, known as shin splints, as seen on the bone scan

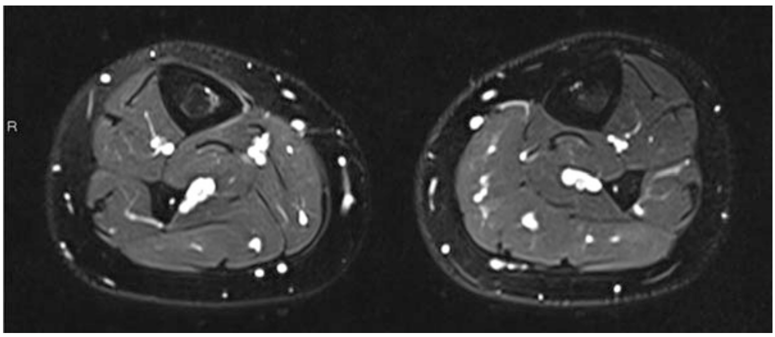

Fig. 4 Periosteal edema and posterior bone marrow edema of the tibia as seen by axial T2 weighted with fat suppression MRI in shin splint of the *right* leg

On MRI periosteal and bone marrow edema are reported in 83–89 % of patients with symptomatic tibial pain (Fredericson et al. 1995; Batt et al. 1998; Gaeta et al. 2005). Periosteal edema is seen as peri-cortical high signal intensity on fluid-sensitive sequences and can be detected on the antero- or posteromedial tibial border (Fig. 4; Fredericson et al. 1995; Moen et al. 2012). Clinical parameters were shown to significantly correlate with the presence of bone marrow edema on MRI, and the presence of bone marrow edema in this study correlated with recovery time (Moen et al. 2012).

Fibular stress fractures account for 1.3–12.1 % of stress fractures in athletes (Matheson et al. 1987). The most common site is the lower fibula, just proximal to the tibiotalar syndesmosis, but fractures of the proximal fibula have also been reported (Devas and Sweetnam 1956; Blair and Hanley 1980; Sherbondy and Sebastianelli 2006; Woods et al. 2008). In the early stages, radiographic findings are absent or subtle with minimal hazy periosteal reaction. With progression, callus or a fracture line may be detected. It is nowadays recommended to continue evaluation with MRI. Woods et al. evaluated 20 patients with fibular stress injury by both radiographs and MRI (Woods et al. 2008). None of these patients had findings compatible with stress reaction on initial radiographs, but all had a periosteal reaction and bone marrow edema within the fibula on MRI (Fig. 5).

Foot and Ankle

Stress fractures of the metatarsal bones were first described in military recruits as march fractures, and most often involve the neck and distal shafts of the second and third metatarsals. Metatarsal

Fig. 5 Stress fracture of the fibula seen on (**a**) sagittal T1-weighted and (**b**) coronal T2-weighted sequences

stress fractures account for 9–25 % of stress fractures in athletes and up to 63 % in dancers (Matheson et al. 1987; Kadel et al. 1992; Goulart et al. 2008). Initial radiographs may be negative, but subsequent imaging usually demonstrates callus formation in the area of the fracture followed by the appearance of the fracture line (Ashman et al. 2001). Stress fractures can be commonly seen on ultrasound at the metatarsal heads. Ultrasound features include: periosteal reaction appearing as a hyperechoic band along the cortex; periosteal hemorrhage, in which the hyperechoic periosteum is elevated from the cortex by a hypoechoic band; and cortical interruption (Gregg et al. 2008; Fig. 6). MR imaging shows stress fractures as very-low-signal-intensity linear lesions on T1-weighted images, representing the fracture line, surrounded by bone marrow edema seen on T2-weighted sequences. There may be surrounding soft tissue edema and periosteal reaction which appears as a low-signal stripe paralleling the cortical bone, occasionally separated from it by high signal edema on fluid-sensitive sequences (Ashman et al. 2001; Gregg et al. 2008; Fig. 7).

Jones' fracture is a stress fracture of the fifth metatarsal base occurring approximately 1.5 cm distal to the tubercle, at the junction of the metaphysis and diaphysis (Torg et al. 1984). Delayed or nonunion occurs more commonly in these fractures and may require early operative intervention (Rosenberg and Sferra 2000). Torg et al. described three radiographic appearances of a Jones' fracture: acute fractures characterized by a narrow fracture line and absence of intramedullary sclerosis, fractures with delayed union characterized by widening of the fracture line and evidence of intramedullary sclerosis, and fractures with nonunion characterized by complete obliteration of the medullary canal by sclerotic bone (Torg et al. 1984).

Stress fractures affecting the tarsal bones account for 10–25 % of stress fractures in athletes (Matheson et al. 1987). Of these, the calcaneus is the most affected, manifesting as heel pain aggravated by running and jumping and posterosuperior calcaneal tenderness on examination (Berger et al. 2007). Plain radiographs are often unremarkable and therefore advanced imaging studies such as bone scan or MRI are required to differentiate calcaneal stress fractures from other pathology such as Achilles tendinosis, retrocalcaneal bursitis, or plantar fasciitis (Fig. 8; Goulart et al. 2008). Plain radiographs in the more advanced cases often depict a sclerotic line at the posterosuperior aspect of the calcaneus that is parallel to the posterior cortex and perpendicular to the trabecular bone.

Navicular stress fractures are relatively rare, accounting for up to 2.4 % of all stress fractures (Khan et al. 1994) often resulting from impact activities. These stress fractures are regarded as high-risk injuries with high incidence of delay or nonunion, particularly at the relatively avascular central third of the bone (Coris et al. 2003; McCormick et al. 2012).

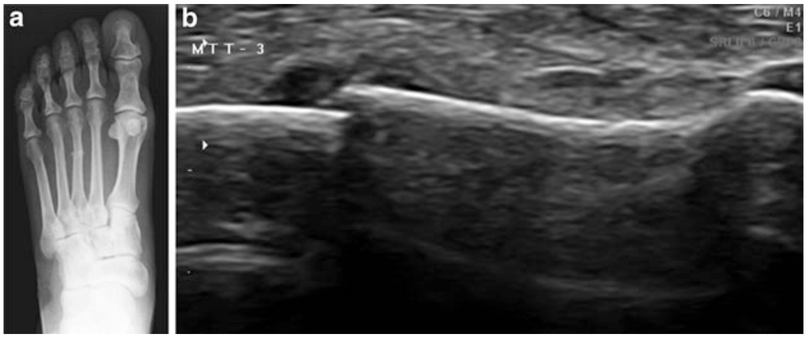

Fig. 6 Stress fracture of the third metatarsal bone as seen on (**a**) X-ray and on (**b**) US. Fracture line and periosteal reaction can be easily detected on both modalities

Fig. 7 MRI of the foot demonstrating a stress fracture of the second metatarsal bone on (**a**) T1- and (**b**) T2-weighted sequences

Navicular stress fractures are difficult to diagnose both clinically and radiographically, and therefore, a strong index of suspicion should be maintained in athletes presenting with midfoot or arch pain. Plain radiographs are not sensitive enough 1 to depict the fracture (Khan et al. 1994), while MRI is the recommended modality for the assessment of athletes with midfoot pain and suspected navicular fracture (Liong and Whitehouse 2012).

Pelvis

Stress fractures of the pelvis account for 1.3–8.4 % of stress fractures seen in athletes (Matheson et al. 1987; Iwamoto et al. 2012). Femoral neck and the pubic ramus are most frequently involved but sacral fractures are also reported.

Pubic rami fractures were reported in runners (Pavlov et al. 1982; Noakes et al. 1985). They usually occur on the inferior rami, adjacent to the symphysis pubis. Stress fractures at this anatomic site are thought to result from repetitive tensile stresses of the adductor magnus at its origin on the inferior pubic ramus (Ha et al. 1991). Superior ramus stress reaction has also been described, specifically in football players (Verrall et al. 2001; Cunningham et al. 2007). Pubic rami fractures may manifest as undisplaced fracture lines on radiographs in the more advanced stages. Negative radiographs in patients with high

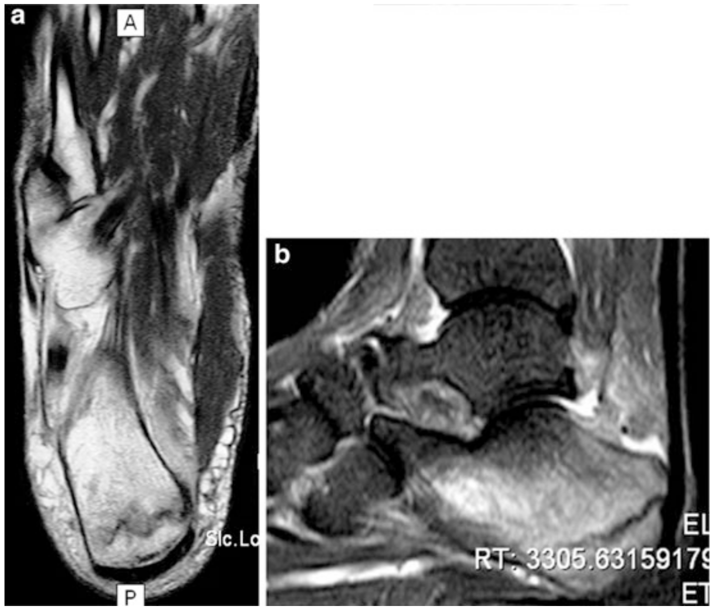

Fig. 8 Stress fracture of the calcaneus as seen on MRI

clinical suspicion warrant further study with MRI in which marrow edema is evident before the appearance of a fracture line (Fig. 9).

Athletic pubalgia is the term used to describe exertional pubic or groin pain. The differential diagnosis in the active athlete is wide and may result from tendon (rectus abdominis or adductors) or bone dysfunction. The concepts regarding etiology of osteitis pubis and the broader topic of athletic pubalgia continue to evolve, but osteitis pubis is probably a chronic overuse injury that results from stress related to sheer force from unbalanced traction on the symphysis pubis. It is seen in adults and late adolescence runners, fencers, soccer, hockey, and football players (Hotchkiss et al. 2007).

MRI in osteitis pubis demonstrates generalized and, often, symmetrical symphyseal bone marrow edema which classically extends into the soft tissues with intact adjacent muscle and tendons (Fig. 10). The symphyseal bone marrow edema is probably the result of a stress reaction in that area.

Fractures of the sacrum are not frequent but have predominantly been described in long-distance runners, particularly females, and have also been reported in hockey, basketball, and volleyball players (Southam et al. 2010; Major and Helms 2000; Fredericson et al. 2003). Patients with sacral stress fractures present with nonspecific symptoms of lower back and buttock pain mimicking sciatica, so the differential diagnosis at the time of presentation may include disk disease, spinal stenosis, musculotendinous strain, and tumors. Diagnosis may be thus overlooked and appropriate treatment delayed. Imaging workup begins with radiography, which is helpful in excluding tumors, but otherwise radiographs are of limited value due to overlaying bowel gas and the geometry of the sacrum. Indeed a sacral stress fracture was missed on radiographs in more than 80 % of patients (Liong and Whitehouse 2012). CT, scintigraphy, and SPECT may enable earlier visualization of a fracture line (linear sclerosis with cortical disruption on CT and increased uptake parallel to the sacroiliac joint on scintigraphy) but entails radiation in a cohort of relatively young patients. The cross-sectional imaging capabilities and the ability to diagnose subtle marrow changes of MRI can help identify osseous abnormalities in areas not readily visualized with conventional radiography. Therefore, MRI is the preferable modality for further workup. Findings on MRI include bone marrow edema usually linear and vertical. When a fracture is present, linear abnormal signal intensity paralleling the sacroiliac joint will be identified (Fig. 11).

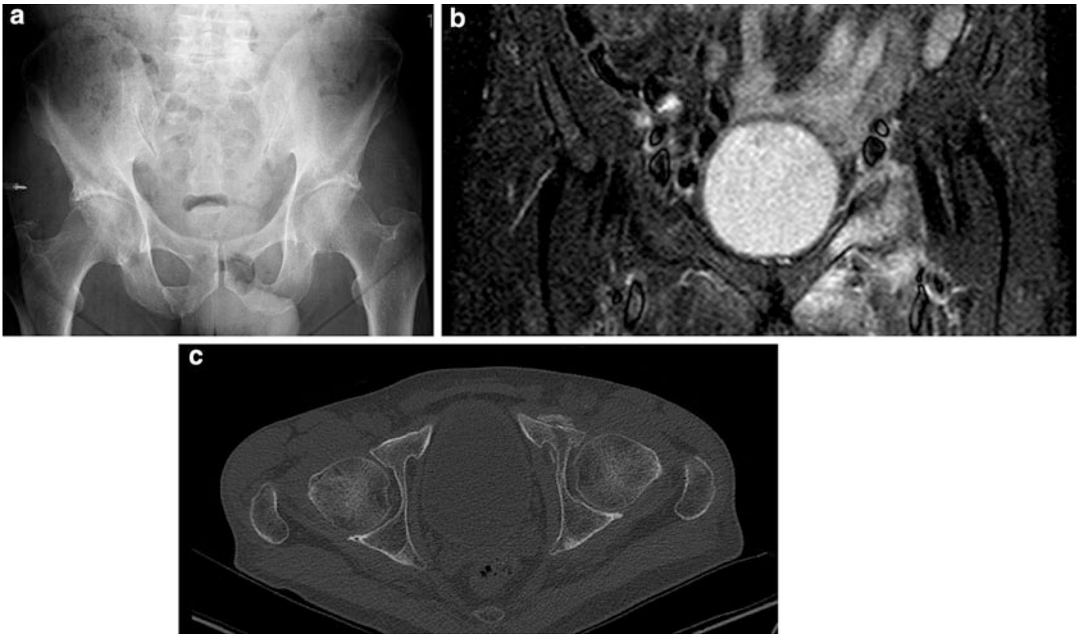

Fig. 9 A marathon runner with left pubis pain. (**a**) Unremarkable X-ray. (**b**) Bone marrow edema compatible with stress reaction in the *upper left* pubic bone in a coronal STIR image. (**c**) Fracture line and callus formation are evident on CT performed in a later stage

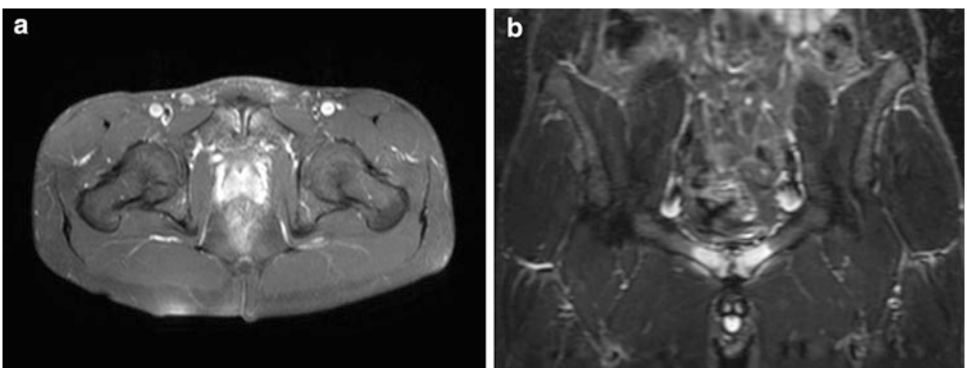

Fig. 10 Osteitis pubis as seen on MRI (**a**) axial T2-weighted image demonstrating relatively mild bone marrow edema and adductor tendinosis and (**b**) a more advanced case with bilateral stress reaction seen on coronal STIR image

Upper Extremity

Upper-extremity stress fractures account for less than 10 % of all stress fractures and are commonly found in throwing athletes and rowers. Stress fractures have been reported to occur at multiple sites in the upper extremity. These fractures occur either as a result of repetitive loading at the point of muscular attachments to the bone or as a result of impact loading, as seen in upper-extremity weight-bearing athletes so that the two most common sport activities associated with these injuries are gymnastics and throwing sports, such as baseball and softball (Brukner 1998).

Fig. 11 Stress fracture of the left sacrum in a long-distance runner seen on (**a**) T1- and (**b**) T2-weighted images

Elbow

Two types of olecranon stress fractures have been described in the skeletally mature athletes: fractures of the olecranon tip and oblique fractures through the midportion of the olecranon (Sinha et al. 1999; Schickendantz et al. 2002). Tip fractures prone to nonunion occur in the proximal third of the olecranon and are seen typically in throwers (Nuber and Diment 1992). Stress injury involving the middle third of the olecranon has been reported in baseball pitchers, javelin throwers, and weight lifters (Hulkko et al. 1986; Nuber and Diment 1992; Rao et al. 2001). Patients usually present with posteromedial elbow pain during the acceleration and follow-through phases of the throwing motion (Jones 2006). Plain radiographs are often negative or show very subtle findings such as periosteal reaction over the medial olecranon (Anderson 2006; Jones 2006). Tip fractures result in a small, triangular-shaped fracture fragment that may be evident on a lateral radiograph. MRI findings range from poorly defined, patchy areas of bone marrow edema if an acute stress reaction is present to more focal linear areas of intermediate signal throughout the cortex and subjacent cancellous bone of the proximal ulna compatible with a fracture line. This has been shown, for example, in a group of professional baseball players presenting with posterior elbow pain who revealed focal marrow edema at the posteromedial margin of the proximal olecranon (Schickendantz et al. 2002). Authors in this study suggested that findings are related to the steady valgus overload produced with throwing.

Periostitis of the ulnar diaphysis has been demonstrated in the forearm as a result of strength-training activities. This condition was described as a case of “forearm splints,” equivalent to shin splints in the tibia (Wadhwa et al. 1997; Haupt 2001). The more advanced stage of a stress fracture in the ulnar shaft is not common, but when present radiographs demonstrate either a small crack in the cortex or subtle periosteal reaction at the site of the fracture (Jones 2006). Radionuclide imaging or MRI is used to confirm the diagnosis.

Ribs

Although they are not part of the upper extremity proper, stress fractures of the ribs are discussed here because these are often secondary to activities involving the upper extremities. Rib stress fractures have been reported in several sports, including rowing and wind surfing (Holden and Jackson 1985; Karlson 1998; Connolly and Connolly 2004). Muscular forces are predominately responsible for these stress fractures (Boden et al. 2001). The most common sites of fracture include the first rib anterolaterally, the fourth through ninth ribs posterolaterally, and the upper ribs posteromedially (Boden et al. 2001).

First-rib stress fractures occur most commonly in athletes whose sports involve repetitive overhead positioning of the arm such as baseball or basketball pitching, while rowers, golf, and tennis athletes present with stress fractures of predominantly the middle and lower ribs. Patients with first-rib fractures present with an insidious onset of a dull, vague pain in the anterior cervical triangle (Connolly and Connolly 2004).

As with stress fractures in other locations, radiographs are insensitive at the initial stage while scintigraphy can be quite sensitive. MRI of the ribs is challenging due to their thin and curvilinear configuration. In addition, breathing motion artifacts inevitable during the long MRI sequence acquisition reduce image quality. Bone marrow edema can be detected in the stress-related location within the rib with dedicated, high-quality, low field of view MRI; however, the fracture itself can be sometimes overlooked or not visible. Therefore, high clinical suspicion and correlation with clinical history is mandatory for diagnosis.

Stress Injuries in the Pediatric and Adolescent Population

Sport injuries affecting the skeletally immature skeleton are often different to those suffered by adult athletes due to the unique anatomy and physiology of the developing musculoskeletal system. The pediatric musculoskeletal system is particularly susceptible to overuse injuries because of the relatively weak bones especially during growth spurts and the open growth plates at the end of the bones and the apophyses. Apophyseal physes represent a weak link in the growing athlete because they are weaker than the bone and the musculotendinous unit (Fig. 12). Traction apophysitis is relatively common in the setting of pediatric overuse injuries. Apophysitis is a diagnosis that is unique to the growing skeleton, occurring when forces placed by a tendon on an apophysis are submaximal but repeated and chronic (Davis 2010a, b). These injuries cause tenderness and swelling and result in painful motion and gait (Ryu and Fan 1998).

Pelvis and Hips

Apophyseal avulsion injuries of the pelvis in adolescent competitive athletes are seen in soccer players, gymnasts, runners, and baseball players (Rossi and Dragoni 2001; Hebert et al. 2008). Prevalence of apophyseal overuse or stress injury to the pelvis is increasing because of the increase in participation of adolescents in highly competitive athletic activities. Sites of apophyseal injury around the pelvis include the ischial tuberosity, anterior–inferior iliac spine, anterior–superior iliac spine, pubic symphysis, and iliac crest (Rossi and Dragoni 2001). On radiographs, the physis may have a normal appearance or appear mildly widened, but not displaced (Frank et al. 2007). This can similarly occur in other apophyses such as the greater and lesser trochanters (Fig. 13; Vazquez et al. 2013).

Avulsion injuries of the anterosuperior (sartorius and tensor fasciae latae) and anteroinferior (rectus femoris) iliac spines are most commonly seen in the sprinting phase of running and hurdling and in kicking sports such as soccer. Avulsion injury of the ischial apophysis by the hamstrings is common in runners, dancers, and gymnasts, with pain typically referred to the buttock region. At the ischial tuberosity, the apophysis may not be ossified yet, in which case traction apophysitis will cause the margins of the bone to appear irregular and sclerotic, with lucent defects (Kozlowski et al. 1989). These findings may be mistaken for an aggressive periosteal reaction due to a space occupying lesion; thus, close correlation with the patients' history and sometimes even MRI are necessary to exclude this differential diagnosis. MRI has greater sensitivity and can depict marrow edema in patients in whom radiographs are normal. MR imaging of traction apophysitis in the pelvis reveals abnormally increased signal of the bone and sometimes the attached tendon on the water-sensitive sequences. Low signal of avulsed cortical fragments may be difficult to identify either because the fragments may not contain bone marrow or because of the bone marrow edema within these fragments which is masked by the intense surrounding soft tissue edema. Thus high-quality MRI as well as

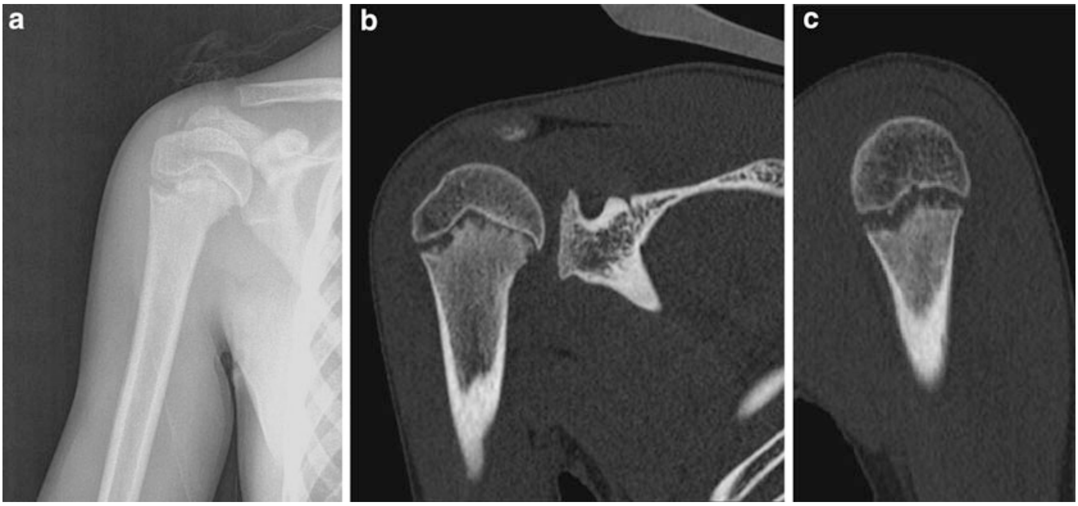

Fig. 12 Epiphysiolysis of the humerus in a 14-year-old tennis player seen on X-ray and on CT

Fig. 13 A 17-year-old artistic gymnast with pain of the *right* hip. Widening of the greater trochanter's growth plate on the *right* (**a**) at the time of pain and (**b**) half a year later

reading of an experienced radiologist is warranted. Unlike other types of stress injuries, here ultrasound can play a role in the imaging workup. Here, soft tissue thickening about the enthesis and thickening and increased echogenicity of the tendon at the attachment site can be observed by ultrasound (Carty 1998; Pisacano and Miller 2003).

Elbow

Traction apophysitis of the medial epicondyle is said to be the most frequent component of Little League elbow (Saperstein and Nicholas 1996). The medial epicondyle is the origin of the flexor pronator tendon group, which places tension on the medial epicondyle when strong valgus forces are in effect. This condition affects children and adolescent pitchers who engage in heavy throwing regimens and also tennis players and javelin throwers (Gomez 2002; Davis 2010b). Radiographs demonstrate variable irregularity of ossification, fragmentation, and sclerosis of the apophysis as well as widening and indistinctness of the physis (Saperstein and Nicholas 1996; Auringer and Anthony 1999). MR imaging demonstrates widening of the physis and increased T2 signal intensity within and possibly adjacent to the physis. The apophysis may be segmented and partially resorbed (Sugimoto and Ohsawa 1994).

Spine

Low back pain is a common complaint among adolescent athletes across various sports. The origin of back pain in young athletes is significantly different from that in adults, requiring a differing radiologic approach to workup. Adolescent

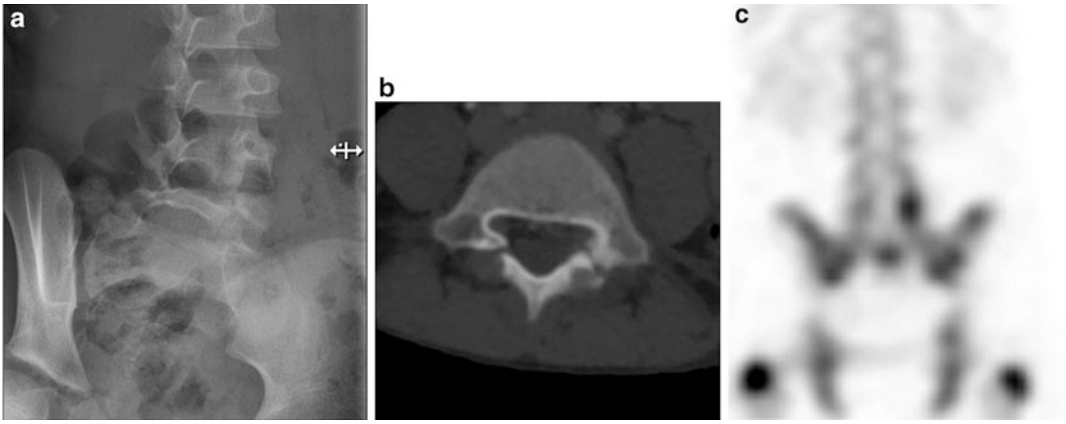

Fig. 14 Spondylolysis with a pars interarticularis defect in the spine at the level of L5 as seen on (**a**) an oblique radiograph, (**b**) CT, and (**c**) scintigraphy

athletes with their natural periods of rapid growth of the spine are at highest risk for spine injury (Micheli and Wood 1995). The most striking difference from adults is the high incidence of symptomatic spondylolysis, a defect of the pars interarticularis of the vertebral posterior elements, seen in 47 % of adolescent athletes complaining of low back pain in contrast to only 5 % in adult controls (Micheli and Wood 1995). Spondylolysis is seen among athletes participating in many common sports, including football, gymnastics, and swimming (Nyska et al. 2000; Caine and Nassar 2005; Giza and Micheli 2005). Due to its high rate, early imaging of the lumbar spine is required in adolescent athletes complaining of back pain. Plain radiographs of the lumbar spine should be performed including anterior–posterior–anterior and lateral views though some authorities still require four views of the lumbar spine: frontal, lateral, and bilateral oblique images. In the oblique projection, the posterior elements and pars interarticularis of the lumbar vertebrae mimic the profile of a Scottish terrier or "Scottie dog." Spondylolysis seen on these oblique radiographs is described as a dog's collar or a break in the dog's neck (Fig. 14a). Approximately 20 % of pars defects are seen only on oblique radiographs. Spondylolisthesis can be appreciated on the lateral views of the spine. Though it may occur

Fig. 15 Spondylolysis as seen on sagittal STIR image of the spine. Bone marrow edema is seen in the pars affected at the level of L3

at any vertebral level in pediatric patients, spondylosis is most commonly seen in L5 vertebra followed by L4, and pars defects above L4 vertebra are uncommon (Maxfield 2010). If radiographs are normal but clinical suspicion is high, further imaging is indicated. Both CT and scintigraphy (Fig. 14b, c) have been shown to be sensitive in the detection of radiographically occult pars defects (Bellah et al. 1991). CT has the advantage of greater anatomic details and thus higher specificity showing the actual place of involvement and scintigraphy the advantage of physiologic information in which increased uptake suggests symptomatic spondylolysis. One has to use those modalities with caution due to the involved ionizing radiation, specifically harmful to the pediatric population. MR imaging may be useful in detecting bone marrow edema seen early in the course of stress reaction lesions (Fig. 15; Sairyo et al. 2006, 2011).

Cross-References

▶ Elbow Injuries in Pediatric Pitchers
▶ Navicular Stress Fractures of the Foot
▶ Soccer and Associated Sports Injuries
▶ Sport-Related Elbow Problems
▶ Stress Fractures Around Hip

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