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Radionuclide Bone Scintigraphy in Sports Injuries

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Bone scintigraphy is one of the mainstays of molecular imaging. It has retained its relevance in the imaging of acute and chronic trauma and sporting injuries in particular. The basic reasons for its longevity are the high lesional conspicuity and technological changes in gamma camera design. The implementation of hybrid imaging devices with computed tomography scanners colocated with the gamma camera has revolutionized the technique by allowing a host of improvements in spatial resolution and anatomical registration. Both bone and soft-tissue lesions can be visualized and identified with greater and more convincing accuracy. The additional benefit of detecting injury before anatomical changes in high-level athletes has cost and performance advantages over other imaging modalities. The applications of the new imaging techniques will be illustrated in the setting of bone and soft-tissue trauma arising from sporting injuries.
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The uptake characteristics of the bone-seeking radiopharmaceuticals are highly conducive to the localization of trauma to bone or its attached soft-tissue structures. Bone scintigraphy has an inherently high contrast-resolution, which enables the detection of the pathophysiology of trauma at a nascent stage. Such changes precede structural abnormalities, and therefore can be detected earlier than conventional radiology and with a similar temporal course to magnetic resonance imaging (MRI). Scintigraphy is an ideal method for detecting complications, such as the chronic regional pain syndrome (Reflex sympathetic dystrophy) and nonunion. The recent advent of hybrid imaging devices has allowed the coregistration of high contrast–resolution bone scintigraphy with the high spatial resolution of computed tomography (CT), permitting a new imaging paradigm of immense potential.

Pathophysiology and Definitions

Tissue damage is stereotypically characterized by hemorrhage, necrosis, and calcification. These processes bind the phosphate complexes used in scintigraphy with high affinity. Scintigraphy is also capable of detecting bone bruising, an acute injury resulting from direct trauma that leads to trabecular microfractures without frank cortical disruption.[1] The greater force transmission involved in cortical fracture ensures early detection by three-phase scintigraphy.

Acute injury to the articular cartilage usually occurs in the knee or talar dome and may lead to osteochondral fractures. Repetitive or prolonged muscular action on bone that has not accommodated to the applied stress may lead to stress fracture.[2,3] Repeated stress can lead to periosteal resorption that outstrips the rate of remodeling, weakening the cortex, and resulting in fracture.[4] Response to such injury is stereotypic and characterized by hyperemia, formation of callus, and remodeling, thus leading to avid uptake of the scintigraphic agents.

Clinical Presentation

Clinical presentation of fractures is almost always with pain that worsens with the intensity of activity. Eventually, pain can become so severe that activity will be completely curtailed. Examination may reveal point tenderness or diffuse tenderness. Anatomical variants that may predispose to stress injuries, such as pes planus or spastic flat foot may be apparent. The possibility of predisposing factors for reduced bone mineral content should be elicited.

Studies have confirmed that regardless of the care with which the history and examination is conducted, the average time for a firm diagnosis after sporting injury remains at approximately 16 weeks.[5]

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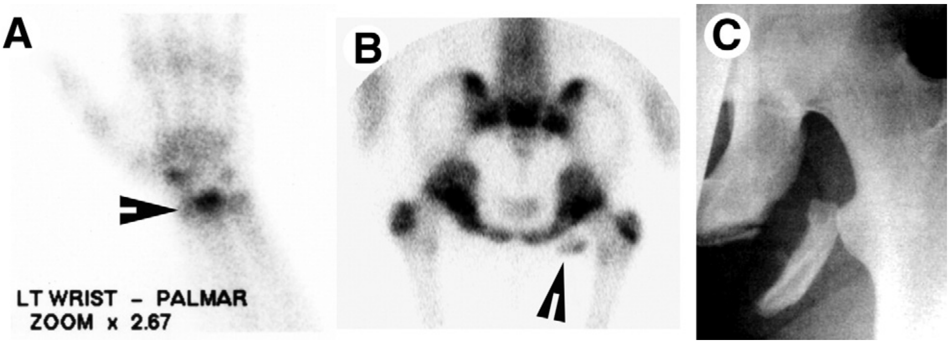

Figure 1 Childhood injuries. (A) Fracture of scaphoid and radial growth plate injury (arrowhead) in a young soccer player who landed heavily on an outstretched left arm. (B, C) Avulsion of the ischial apophysis, sustained by a young hurdler who felt acute pain in the right buttock after coming out of the starting blocks. The fragment is significantly displaced in the plain film.

Patterns and Prevalence of Injuries by Age and Site

The incidence of stress fractures increases with age and approximately 75% occur before the age of 40 years.[5] Nine percent of fractures occur in children of age <15 years, 32% in the age group of 16-19 years, and 59% in patients older than 20 years.[6] In the pediatric population, pooled data indicate that 51% occur in the tibia, 20% in the fibula, 15% in the pars interarticularis, 3% in the femur, and 2% in the metatarsals.[7] In adults, 50% occur in the tibia and 14% in the metatarsals with <1% in the pars interarticularis. Approximately 17% of fractures will be bilateral.[5]

Imaging of Sporting Injuries

The natural history of imaging has a rhythm that is dictated by advances in technology and the affordability and availability of new devices. The history of imaging continues to evolve in parallel with technological advances that appear to have an ever-decreasing focal length to clinical implementation. Thus, the simple plain radiograph was augmented by scintigraphy in the 1970s, with the addition of x-ray CT by the end of the decade. MRI revolutionized imaging of sporting injuries in the late 1980s with its exquisite contrast resolution for soft-tissue injury. It supplanted bone scintigraphy, particularly as it detected injury with good spatial resolution and was able to detect soft-tissue injury and grade severity. A major shortcoming of MRI was in the imaging of cortical bone injury in which CT was more sensitive. This decade has seen the advent of hybrid imaging devices, combining CT with gamma cameras capable of single-photon emission computed tomography (SPECT). Technological advances in SPECT include statistical methods of reconstruction, attenuation and scatter correction, and collimator modelling, which have allowed significant improvements in spatial resolution. When these scintigraphic images are coregistered with CT data, the potential for accurate diagnoses is enhanced and the technique made more attractive for layman and referrer alike. Preliminary assessment of the hybrid modality has shown a ~41% improvement in diagnostic accuracy over scintigraphy alone.[8] Specific results in musculoskeletal imaging remain to be assessed, particularly with outcome and cost-benefit data. It is noteworthy that a computerized search of the National Library of Medicine database under the search heading of SPECT/CT or hybrid imaging produced only 4 relevant publications from over 500 "hits." There are no existing published prospective studies examining pertinent scientific questions about this new technology in the musculoskeletal setting.

Childhood Sporting Injuries

Acute trauma or chronic stress may involve growth plate injury as the physis is the weakest portion of the immature skeleton (Fig. 1A). Such injuries usually occur through the zone of provisional calcification and although this zone heals well, extension into the germinal zones has the potential for growth arrest.[9] Included in this group of injuries is trauma to the apophysis (Figs. 1B and C), a growth plate that does not contribute to longitudinal growth. Important sites of growth plate injury are the distal radial and proximal humeral physis in the upper limb and the distal femoral and distal tibial physis in the lower limb. The most commonly affected apophyses are located in the medial epicondyle (Little leaguer's elbow), olecranon, coracoid, acromion, vertebrae, and around the pelvis. The osteochondroses are a disparate group of disorders characterized by a number of eponyms, such as Kohler disease (navicular), Freiberg infraction (second metatarsal head), and Sever disease (calcaneal apophysitis). Others include Osgood–Schlatter disease (tibial tubercle), Sinding-Larsen-Johansson disease (inferior pole of patella), and Panner disease (capitellum).

Injuries in the Lower Limb

Ankle and Foot

The blood pool phase is critical in soft-tissue injuries as it shows hyperemia in the affected structure with delayed uptake appar-

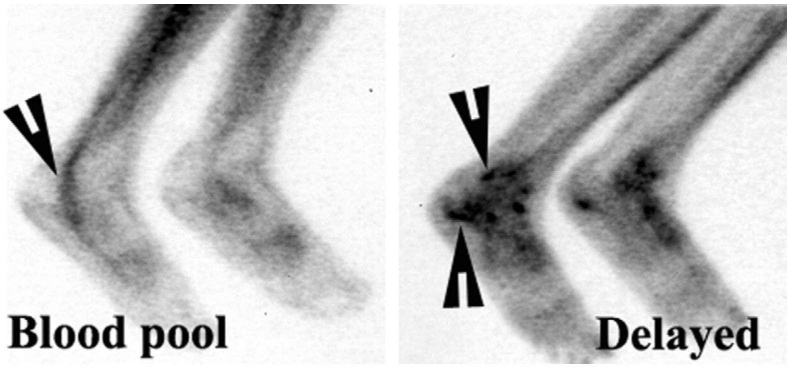

Figure 2 Peroneus brevis tendonitis. The blood pool image shows hyperemia in the distribution of the peroneus brevis tendon as it courses around the lateral malleolus (arrowhead). The delayed study shows increased uptake where the inflamed tendon is in close apposition with the bony structures around the lateral malleolus (arrowheads).

ent in bony structures in close apposition as in Figure 2 (other examples include tibialis posterior tendinosis/medial malleolus). Occasionally, soft tissues show increased uptake in the delayed phase of the study if there is significant necrotic tissue. SPECT/CT permits identification of such injuries with great accuracy, particularly on the soft-tissue windows in the CT study.

Injury to Tendons, Bursae, and Capsular Structures

Injuries to the soft tissues involve the tendons, joint capsule, and bursae. Scintigraphy can show either enthesitis or traction injury of the Achilles tendon, the most commonly injured tendon (Fig. 3). The second most frequently injured tendon is tibialis posterior, usually occurring in ballet dancers and gymnasts. Tibialis posterior tendinosis may also be seen in association with increased uptake in the accessory navicular bone, constituting the accessory navicular syndrome.[10] A similar pattern of blood pool activity in the distribution of the tendon has also been described with the peroneal tendons (Fig. 2).[11]

Impingement Syndromes

Posterolateral pain usually occurs due to posterior impingement syndrome, impingement of the os trigonum (Fig. 4), or peroneal tendonitis (Fig. 2). An os trigonum is present in approximately 3%-13% of the population. Posterior impingement may occur with forced plantar flexion of the ankle, as happens in ballet dancers. Posterior impingement can also be caused by an enlarged posterior talar process, prominent posterior calcaneal process, loose bodies, or avulsion of the posterior tibiotalar ligament.[12] The scintigraphic appearance is characterized by intense uptake in the posterior talus.[13]

The anterior impingement syndrome is caused by repeated traction of the anterior ankle joint capsule and impingement

Figure 3 (A) Achille's tendinosis (arrow), retrocalcaneal bursitis (arrowhead), and probable retro-Achille's bursitis in a long-distance runner. (B) In addition to retrocalcaneal bursitis and Achille's tendinosis there is also evidence of plantar aponeurosis enthesitis that is associated with plantar fasciitis (arrowhead). (C) Medial epicondylitis in a tennis player.

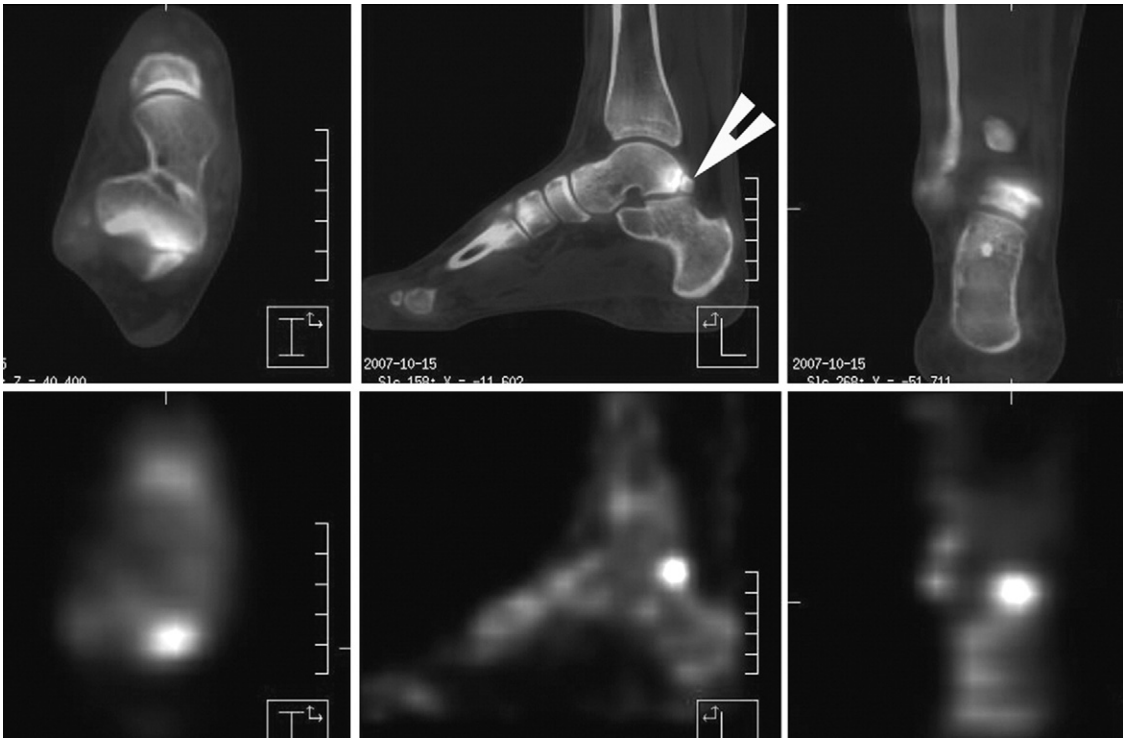

Figure 4 Posterior impingement syndrome. Cricketer with pain in the posterior ankle. The study shows increased uptake in association with an os trigonum on the CT images (arrowhead).

of the talus against the tibia. The chronic process leads to calcific deposits along the lines of the capsular fibers and spur formation on the dorsum of the anterior talus and tibia.[12] A pattern of intense increase in uptake of tracer is seen in the anterior aspect of the ankle.

Plantar Fasciitis

Heel pain is one of the most common presentations in sports medicine, plantar fasciitis being the most common cause.[14] Other causes of heel pain that may be elucidated by scintigraphy (Fig. 3) include Achilles tendonitis and bursitis, retrocalcaneal bursitis, apophysitis of the calcaneum, and calcaneal stress fracture (Fig. 5).

Bony and Ligament Injury

Ankles are the most common site of acute injury and have been reported in up to 75% of participants in sports.[15] Approximately 15% will have more serious sequelae.[16] About 70% of acute injuries are inversion "sprains" with injury to the lateral ligamentous complex of the ankle. The medial ligamentous complex is injured less often. In a small proportion, serious injuries will occur to the talus, tibiofibular syndesmosis, cuboid, calcaneus, or navicular bones.

Talar Dome Fractures

Osteochondral fractures of the talus occur in up to 6% of acute ankle sprains (Fig. 6), most commonly in the posteromedial aspect followed by the anterolateral talar dome.[17] Plain radiographs may miss up to 33% of fractures.[18] Scintigraphy is a good screening test in the presence of a normal radiograph, as was shown in a small series of 24 patients.[19] In a larger series of 122 patients, bone scintigraphy was shown to have a sensitivity of 94% and specificity of 76% for detect-

Figure 5 Calcaneal stress fracture. Intense uptake and sclerosis in a vertical distribution through the posterior calcaneum in a long-distance runner, with increasing pain in the posterior heel.

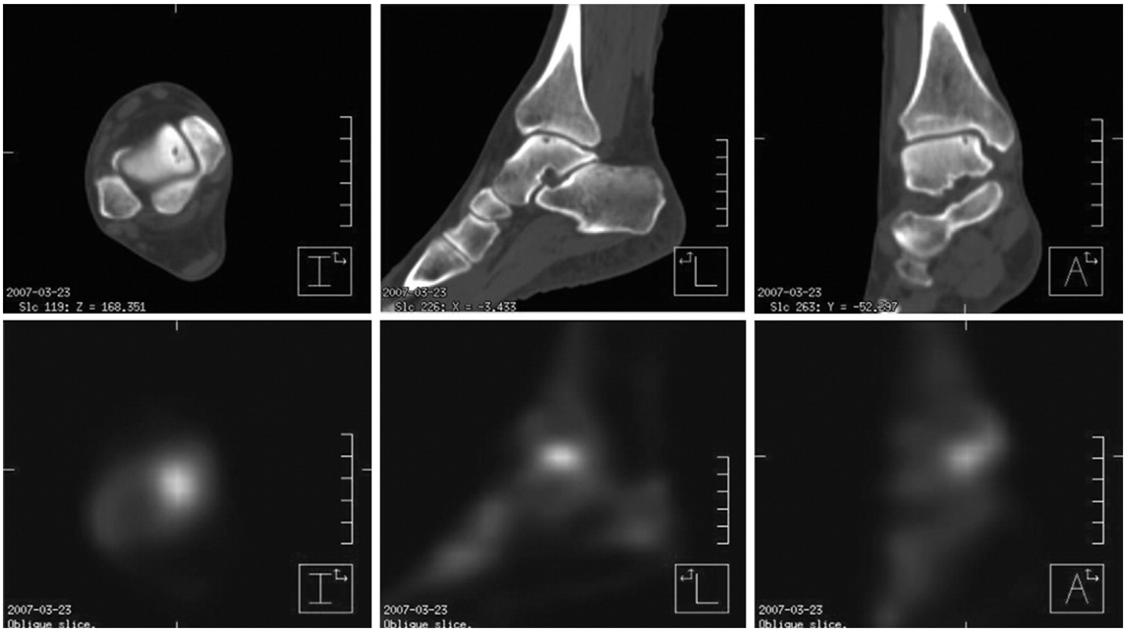

Figure 6 Osteochondral fracture of the talar dome in a basketball player who sustained a complex sprain of the ankle. There is intense uptake in the talar dome in association with sclerosis and erosion on the CT study.

ing talar dome fractures. Blood pool abnormalities were associated with higher grade fractures.

Fractures of the Plafond and Interosseous Membrane

In one study of 639 cases of ankle sprain, 15% had either avulsion or compression fractures and 5% had significant injuries to the interosseous membrane.[16] Scintigraphically, this is evident as hyperemia in the posterior aspect of the ankle, extending superiorly into the syndesmosis and interosseous membrane. Delayed images demonstrate increased uptake in the posterior plafond (avulsion or chip fracture), medial edge of the posterior fibula (avulsion fracture), and extension into the distal syndesmosis (Fig. 7).[20] This injury is often associated with a fracture of the proximal fibula (Maisonneuve fracture).

Fractures of the Tarsal Bones

Although rare in overall terms, acute navicular fractures are the most common midfoot fracture (Fig. 8A) and require careful treatment to avoid long-term morbidity. The dorsal ligament avulsion fracture is the most common navicular fracture and presents with pinpoint tenderness after eversion

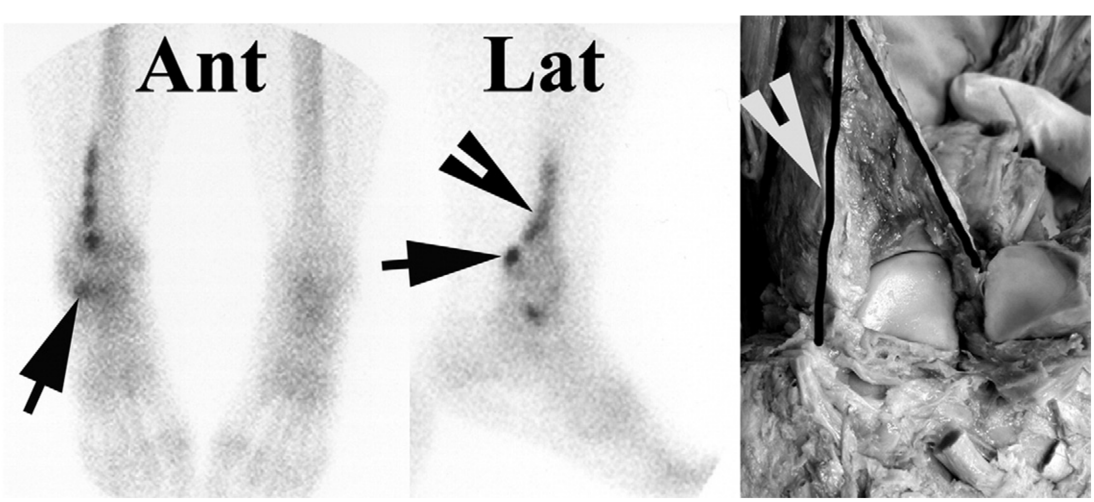

Figure 7 Injury to the interosseous membrane of the ankle. A soccer player who sustained a complex injury to the ankle while running at high speed and being tripped. The scintigraphic study shows intense uptake at the posterior aspect of the ankle and at the tip of the lateral malleolus (arrows) in keeping with injuries to the ligaments. In addition, there is intense uptake extending through the posterior part of the triangular syndesmosis between the distal tibia and fibula (arrowhead) and extending into the attachment of the interosseous membrane proximally. This is further illustrated in the anatomic dissection of the syndesmosis, boundaries of which are shown in solid black lines.

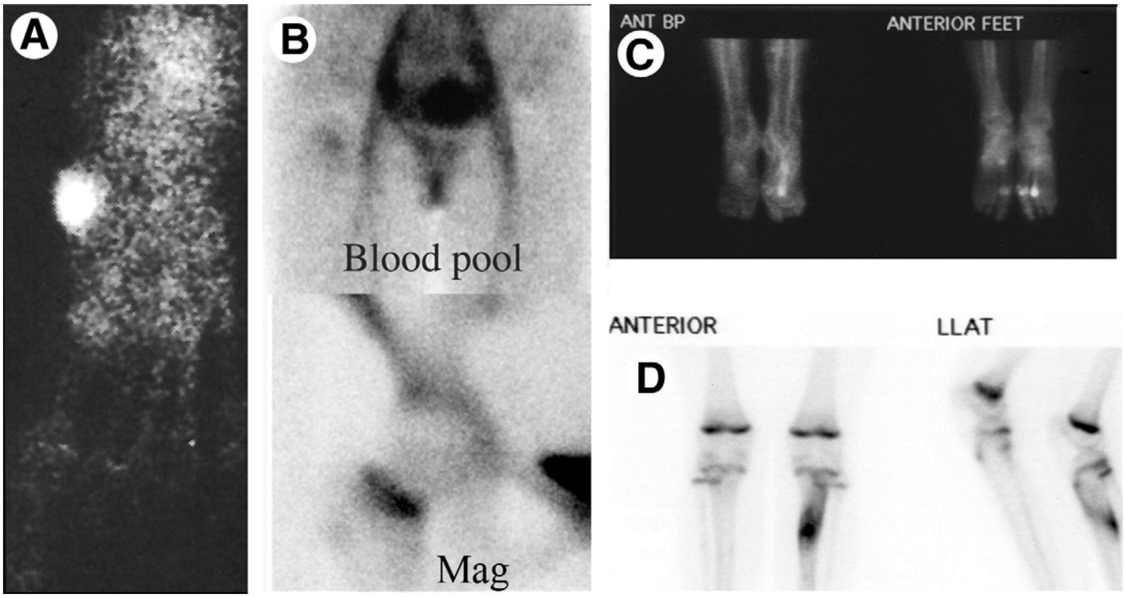

Figure 8 Various stress fractures. (A) Navicular stress fracture in an Australian rules footballer. Intense uptake is evident in the medial aspect of the right navicular bone. (B) Stress fracture of right femoral neck in a long-distance runner. The blood pool shows intense focal hyperemia extending across the right femoral neck with intense uptake in the magnified delayed image. Note: the fracture is more intense medially at the edge of the lesser trochanter, where most stress fractures begin, on the compression side of the femoral neck. (C) Second metatarsal fracture in a power walker. Intense hyperemia and uptake are evident in the proximal shaft of the second metatarsal bone on the left. (D) Tibial stress fracture in a young footballer. Note extension of uptake posteriorly.

or inversion injury on a plantar-flexed foot. Navicular stress fractures are being seen with increasing frequency due to the increasing participation of women and adolescents in various sports. Fractures are easily detected by scintigraphy, CT, and MRI in nearly all cases.[21,22] Acute fractures of the anterior process of the calcaneus have been reported to account for up to 15% of all calcaneal fractures.[23]

Stress fractures of the calcaneus have been reported in approximately 20% of male and 40% of female military recruits undergoing basic military training (Fig. 5).[24,25] The most common site of fracture is the posterior calcaneal tubercle.

Metatarsal Stress Fracture

Fracture of the metatarsals is a common form of stress injury in the foot and ankle (Fig. 8C). In a large series of 295 subjects with 339 stress fractures, 28% fractures occurred in the metatarsals.[26] These injuries occur in athletes who participate in high-impact sports involving mainly running and jump-

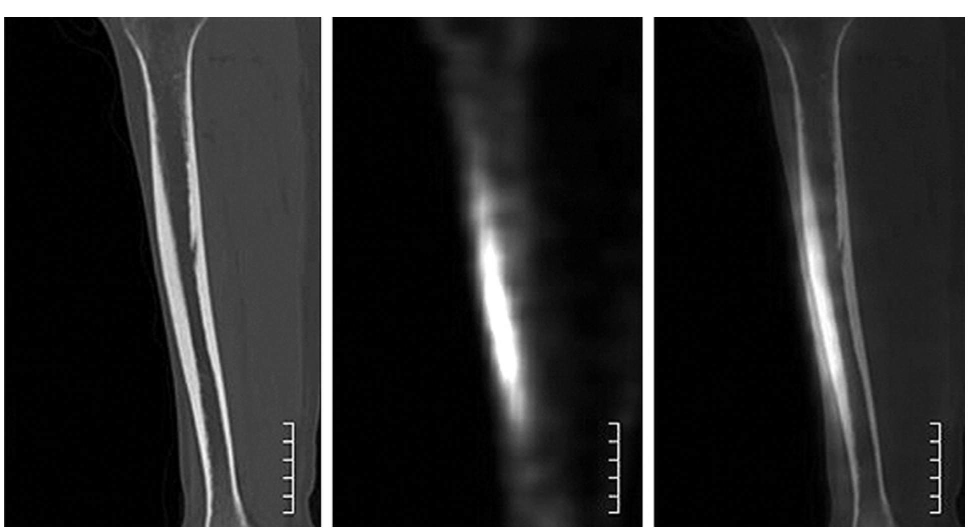

Figure 9 Shin splints. Moderately intense uptake is present along approximately one-third of the length of the posteromedial tibial shaft. There is no focal abnormality in the CT study in keeping with shin splints in a long-distance runner. Notice that activity flares into the adjacent soft-tissues.

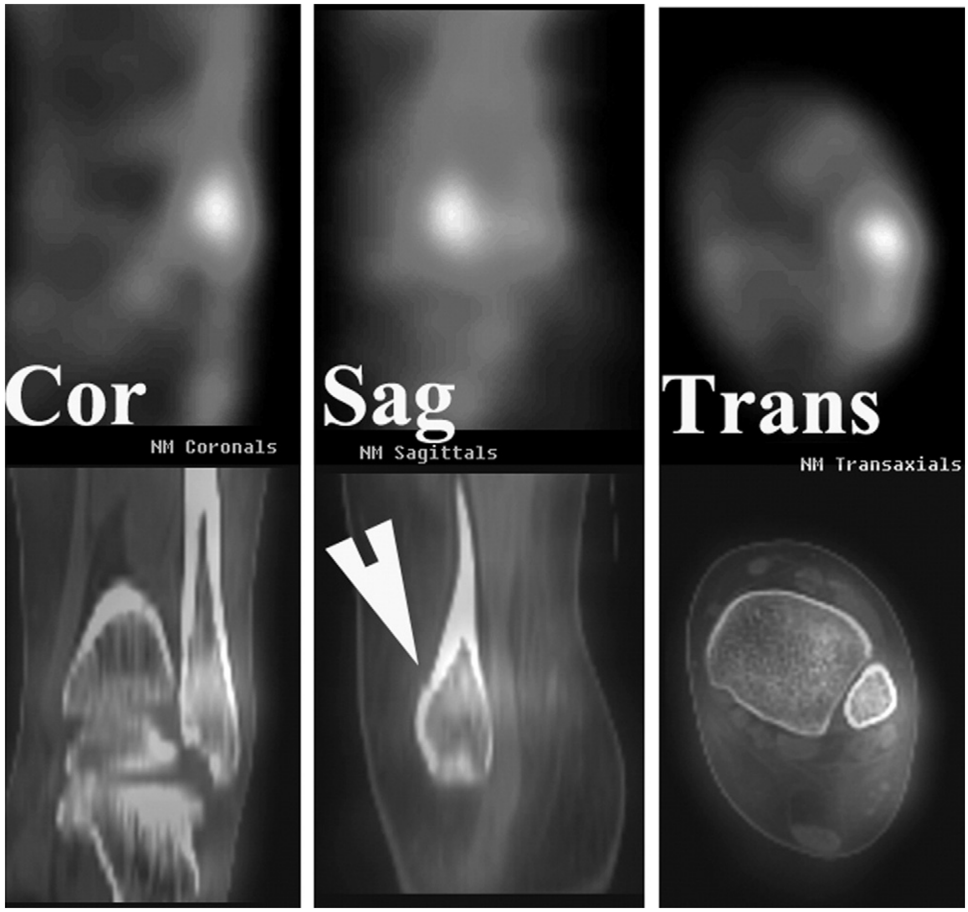

Figure 10 Fibula stress fracture. Intense uptake in association with a cortical breach (arrowhead) in a patient presenting with right ankle pain 3 weeks after accelerating her training program for a triathlon.

ing. Stress fractures predominantly (90%) occur in the second and third metatarsal bones. There is also a high level of stress through the fifth metatarsal, although less than in the second.[27] Fractures of the fifth metatarsal are usually through the shaft and more rarely, proximally located (Jones fracture).[28]

Tarsal Coalition

A failure in segmentation of the mesenchymal anlage of the hindfoot bones in the embryo is thought to be the cause of tarsal coalition. An autosomal dominant inheritance pattern has been established and tarsal coalitions occur in approximately 1% of the population. Fifty percent of coalitions are bilateral and a significant proportion has multiple coalitions.[29] Coalitions of the talocalcaneal and calcaneonavicular bones are the most common. Coalitions may be fibrous, cartilaginous, or bony. Symptoms usually occur when the coalitions ossify and present with pain in the early to middle teens with ankle pain in the lateral and anterolateral aspects of the ankle.

The Tibial Region

Stress fractures of the tibia are the single most common fracture in sports medicine.[2,30,31] The diagnosis must be distinguished from shin splints and compartment syndrome. Stress fractures of the fibula are less common than tibial fractures, but may occur in association with other injuries.

Soft-Tissue Injuries

Major chronic soft-tissue injuries are shin splints and the chronic compartment syndromes. Other causes of pain include entrapment of arteries and nerves, deep venous thrombosis, rupture of the gastrocnemius muscle, fascial herniations, and muscle strains. Muscle strains are probably the single most common cause of acute pain in the lower limbs.[32]

Shin Splints

Shin splints have been called the medial tibial stress syndrome due to the localization of exercise-induced pain to the posteromedial aspect of the distal two-thirds of the tibia.[32] Considerable controversy surrounds the etiology of so-called shin splints. Biopsy evidence shows inflammation of the crural fascia and increased bony metabolism with vascular ingrowth in the majority.[32] The triple-phase bone scan appearance was well described by Holder and Michael[33] as showing low-grade uptake in the distal posteromedial tibia on the delayed phase only (Fig. 9), with no alterations in blood flow. Scintigraphic studies currently define the diagnosis.

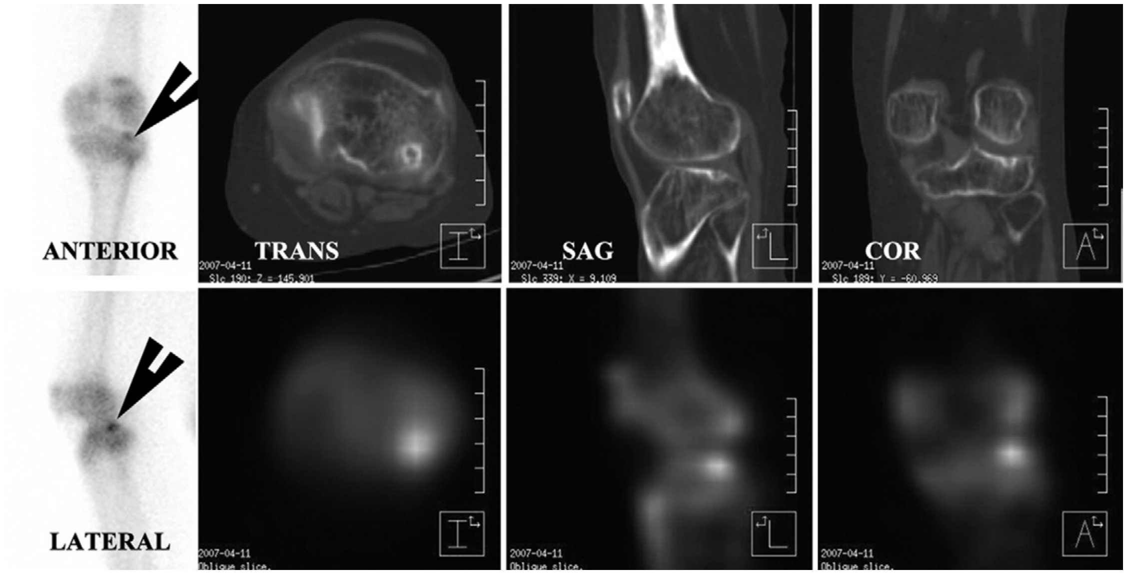

Figure 11 Osteochondral fracture of the knee. The planar images demonstrate a focally intense lesion in the posterior and lateral aspect of the tibial plateau. This is confirmed on SPECT and the corresponding CT images show sclerosis and focal erosion of the plateau at this site.

Bony Injuries

Tibial Stress Fractures

The incidence of tibial stress fractures has been reported to range from 4% to 31%, but accounts for over 50% of all stress fractures, particularly in military recruits.[2,31] Predisposing factors include altered biomechanics in the lower limb, changes in foot-wear, or rapid acceleration in the level of activity.

The utility of bone scintigraphy in the early diagnosis of tibial stress fractures has been well established since the description of early detection compared with plain radiology in the mid-1970s.[34] The usual scan appearance is of hyperemia with intense transverse uptake at the site of fracture (Fig. 8D). More recent published reports have shown an equivalence with MRI for early diagnosis,[35,36] with MRI findings of periosteal and bone-marrow edema. The posterior aspect of the upper third of the shaft is the most common site of fracture in children and the elderly. The distal third is the most common site in long-distance runners.

Zwas et al[37] confirmed that 164 of 280 fractures occurred in the midshaft and was able to grade fractures from poorly defined cortical uptake (grade I) to well-defined intramedullary trans-cortical uptake (grade IV). The scintigraphic grade of uptake provided valuable prognostic information on the time to healing.

Fibula Stress Fractures

Stress fractures of the fibula account for 20% of pediatric[7] and up to 30% of adult stress fractures.[38] The vast majority develop in the distal third (Fig. 10), with the proximal and middle third being uncommon. Scintigraphy has been established as a reference standard since the earliest experiences with athletic injuries.[34]

Knee Injuries

Because of its complex range of motion, the knee is prone to injury in any activity involving rapid changes in direction. The menisci separate the femoral condyles from the tibial plateau while the cruciate ligaments, medial and lateral collateral ligaments, joint capsule, and muscles afford joint stability. Planar imaging can yield a number of diagnoses, such as bursitis, enthesopathy, osteochondritis dissecans, bone bruises, or fractures of the tibial plateau. Complex internal derangements may be detected by SPECT imaging.

Acute and Chronic Injury

Although knee SPECT has a defined role in the assessment of both acute and chronic knee pain,[39–43] it is rarely used as MRI provides more direct and definitive anatomical information as a single imaging assessment. In contrast, the bone scintigram reflects the altered biomechanics in the adjacent bone, resulting from injury to the stabilizing or "shock-absorbing" soft tissues. Notwithstanding this "shortcoming," good to excellent performance has been shown in a variety of knee disorders in 158 patients in which knee SPECT made the correct diagnosis in 89%.[42] Although SPECT may not provide a specific diagnosis, it is helpful in directing arthroscopy and shortening the examination.[40,43]

Meniscal Injury

Knee SPECT has been evaluated in the setting of chronic and acute meniscal tears.[39,40,42–45] Meniscal tears are characterized by peripherally increased uptake in a crescent in the tibial plateau as well as focal posterior femoral condylar uptake.[42,43,45] Ryan et al[42] in a study of 100 patients with undiagnosed knee pain showed a sensitivity of 84%, specificity of

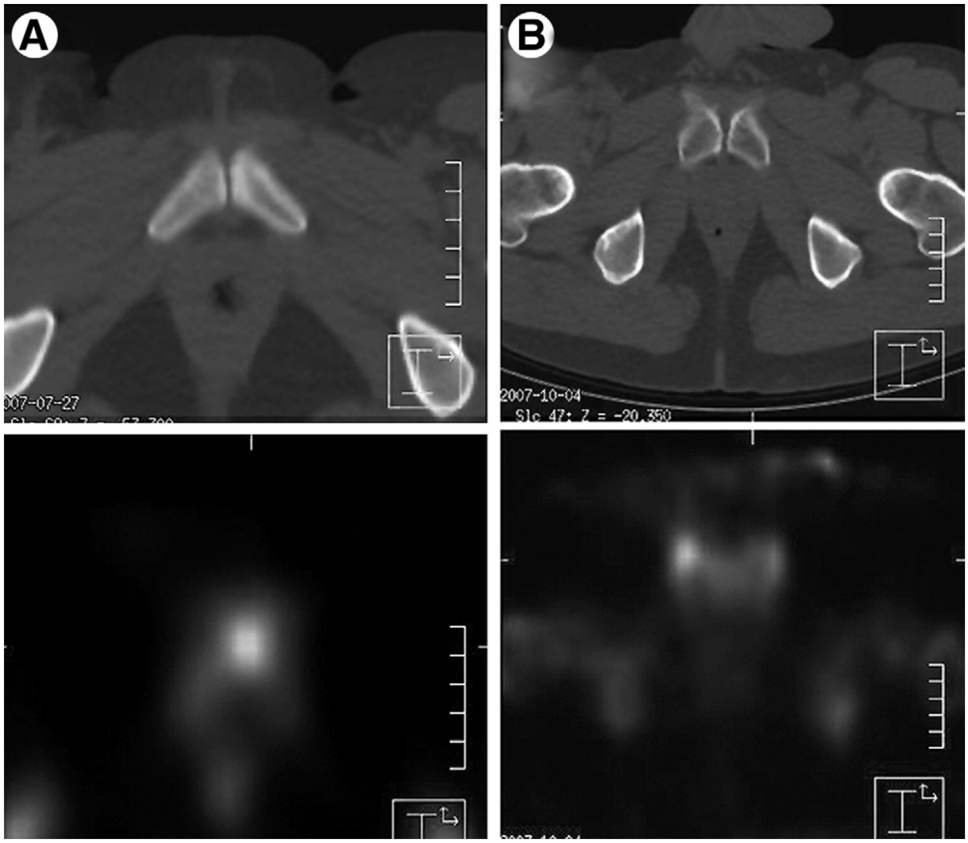

Figure 12 Osteitis pubis and adductor enthesopathy. (A) Osteitis pubis with increased uptake around the pubic symphysis. (B) Adductor enthesopathy with increased uptake at the sites of adductor insertion into the pubic bones. These patterns may coexist and are inter-related in biomechanical terms.

80%, positive predictive value of 88%, and negative predictive value of 76% for SPECT, with similar values for MRI.

Cruciate Ligament Injury

Knee SPECT can detect cruciate ligament injuries. The characteristic feature providing primary evidence of anterior cruciate ligament (ACL) injury is focal uptake at the insertion sites, more commonly at the femoral than the tibial attachment.[41,45] Corollary evidence is provided by uptake in the lateral femoral condyle or posterolateral tibial plateau due to bone bruising at these sites, which often occurs during the process that produces ACL injury.[41,45,46] So et al[41] showed relatively poor results in ACL injury, using primary or corollary evidence alone, but a sensitivity of 84% and positive predictive value of 81% when the evidences were combined.

Miscellaneous Injuries

Collateral ligament injuries are characterized by focal uptake at both attachments of the ligament, often accompanied by an arc of blood pool activity around the center of the knee.[43,45,47] Avulsion may lead to focal uptake in the proximal attachment, and is called Pellegrini–Stieda disease. Osteochondritis and focal condylar erosions are easily visualized with knee SPECT (Fig. 11), perhaps better than by MRI.[45] Osteochondritis dissecans occurs at different sites, most frequently at the lateral aspect of the medial femoral condyle, to subchondral infractions that occur in weight-bearing regions, usually in the lateral compartment.[48]

Thigh, Hip, and Pelvis

Soft-Tissue Injuries of the Thigh, Hip, and Pelvis

A variety of soft-tissue injuries have been reported in the thigh. Adductor splints are an overuse injury of the adductor muscles, manifested by a periosteal reaction at the insertion into the cortex of the femur as with shin splints.[49] A similar pattern of uptake may also be seen at the proximal insertion around the pubic symphysis and contributes to the pathophysiology of osteitis pubis (Fig. 12).[50] Direct muscular trauma with or without hematoma formation may also be detected due to muscular uptake at the sites of damage. In patients with symptomatic muscle pain after ultramarathon competition, up to 90% will have evidence of rhabdomyolysis.[51]

Many other pathologic causes of scintigraphic alterations in the region include bursitis of the iliopsoas, greater trochanteric, and ischial bursae. Enthesopathy may be evident, involving the gluteus medius tendon, adductor tendons, and a variety of other tendon insertions (Fig. 13).

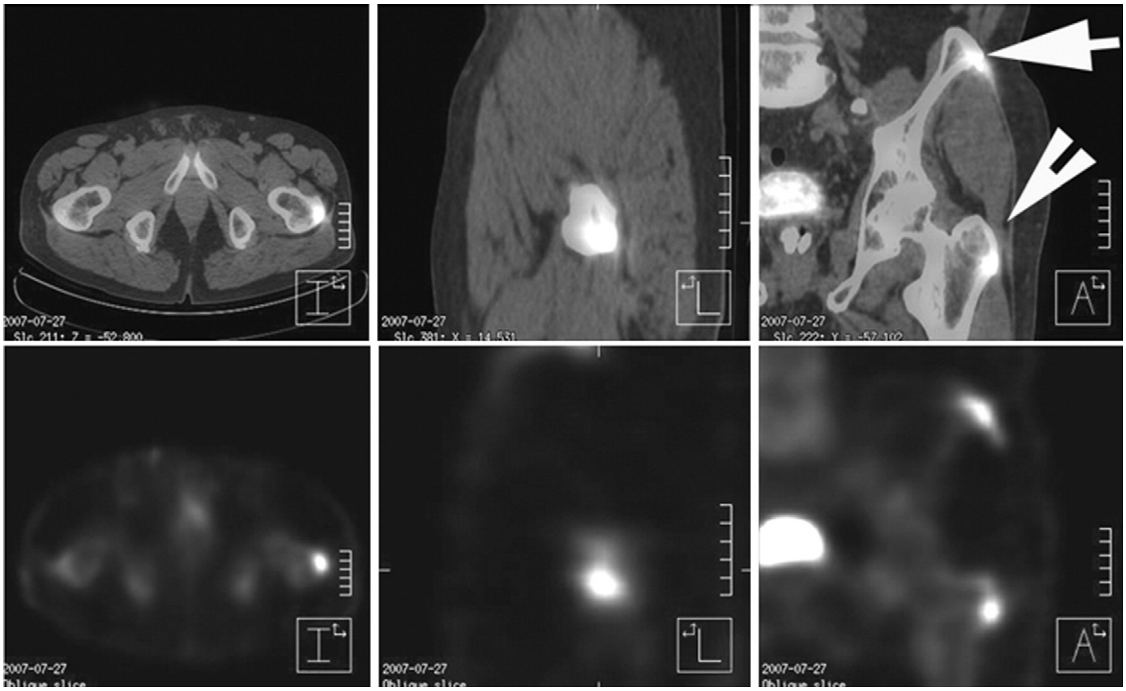

Figure 13 Gluteus medius tendinopathy and iliotibial enthesopathy. Increased uptake is evident in the lateral aspect of the left greater trochanter at the site of insertion of the gluteus medius tendon, as is evident in the corresponding CT (arrowhead). Increased uptake is also present at the insertion site of the iliotibial tendons into the iliac crest (arrow).

Bony Injuries of the Hip and Pelvis

Stress Fractures of the Hip

Stress fractures of the hip account for approximately 4.5% of all stress fractures.[52] Two patterns have been described: transverse and compression. Transverse fractures are in the superior or tension side of the femoral neck and occur in older individuals. The rate of complications is much higher with these fractures.[53] Compression fractures occur on the medial side in younger patients (Fig. 8B). Such fractures heal well with rest when undisplaced, but requires more aggressive therapy if displaced.[53]

Avulsion Fractures of the Pelvis

Avulsion fractures are a common injury in adolescent athletes. These injuries occur through the apophysis and are equivalent to physeal fractures (Fig. 1B). The usual mechanism involved is a sudden violent contraction of a large muscle attached to bone, resulting in tearing of the attached tendon and bone through its weakest point, the provisional zone of calcification.[53]

Pelvic Stress Fracture

Pelvic stress fracture are rare but positive when tested with bone scintigraphy.[54] Fracture of the inferior pubic ramus has been reported in female military recruits[55] and is thought to be due to repetitive strain of the large muscles on the pubic bones.[53]

Osteitis Pubis

This injury is mainly reported in runners, and soccer and football players and presents with groin, pubic, perineal, or scrotal pain. The mechanism is thought to be due to the action of the large adductor muscles on the pubic bones as weight is transferred from one leg to the other during running. The diagnosis is easily made by scintigraphy[56] (Fig. 12) and is often diagnosed in the asymptomatic elite athlete.[57]

Injuries of the Chest

Rib stress fractures occur in 5.3% of all injuries in female and male rowers and account for 39.5% of chronic chest injuries in female rowers.[58] These injuries are readily apparent on bone scintigraphy.

Injuries of the Vertebral Column

Cervical and Thoracic Spine

SPECT/CT will almost certainly revolutionize imaging of the cervical spine. The normal anatomical pattern of uptake has been defined[59,60] and the utility assessed in the setting of acute neck trauma in a small series.[60] In 16 patients with abnormal results, SPECT detected occult fractures in 7 of 35 patients (27%), including 3 with normal radiographs and 4 with equivocal radiographs. Recent fractures were excluded in 6 of 9 patients (67%). None of the patients with normal SPECT studies had CT or MRI evidence of recent fractures. SPECT/CT permits a precise window into lesions of the cervical spine and allows the diagnosis of previously unrealized sources of trauma, such as the uncovertebral joints[61] (Fig. 14D) in addition to the standard delineation of pathology in the facet joints.

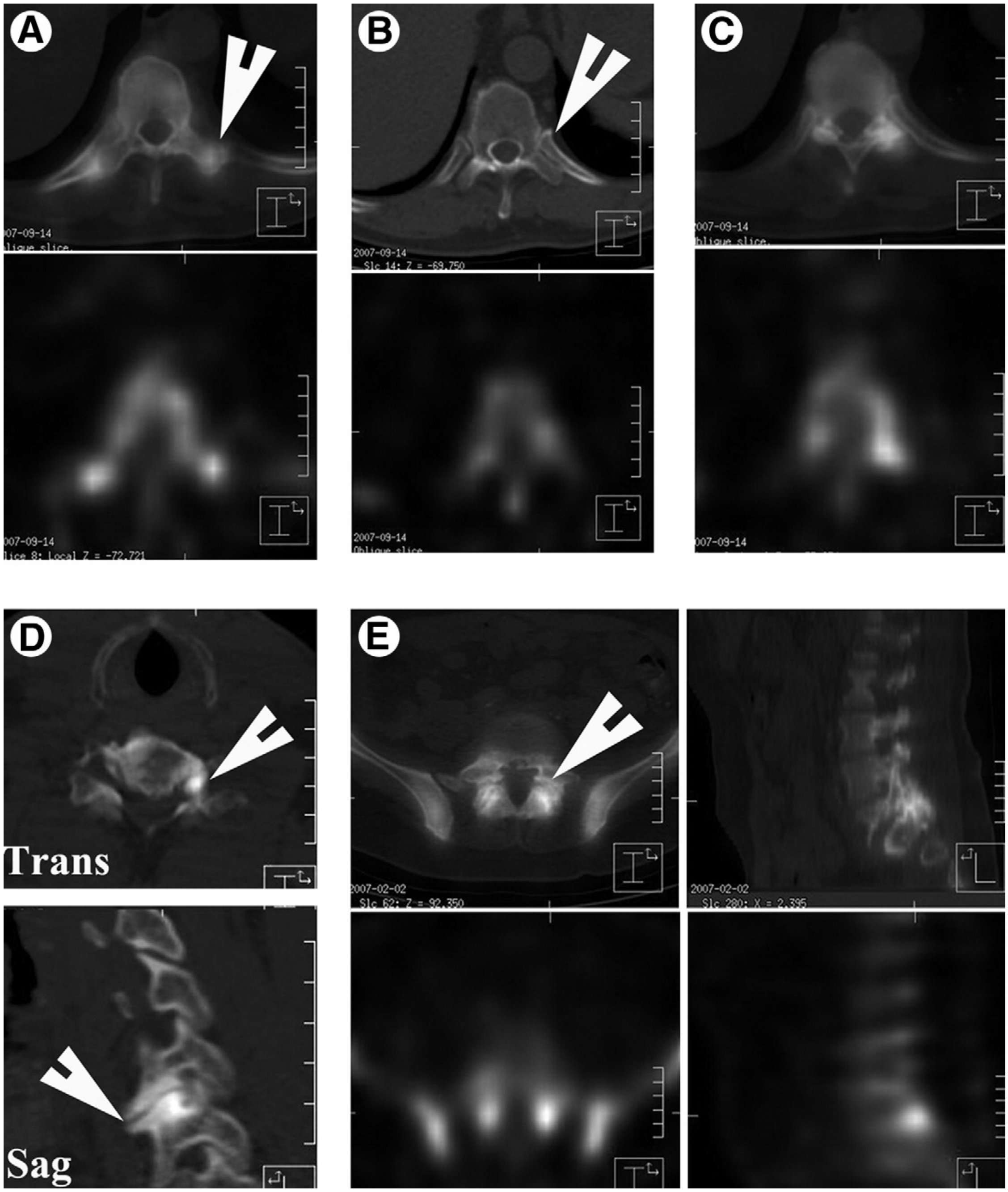

Figure 14 Spinal pathology. (A) Costotransverse degenerative change (arrowhead). (B) Costovertebral degenerative change (arrowhead). (C) Bilateral facet joint degenerative change. (D) Uncovertebral degenerative change in the anterior aspect of the cervical vertebra (arrowheads). (E) Bilateral facet joint degeneration and scintigraphically inactive spondylolysis of L5 (arrowhead).

Thoracic Spine

Pain in the interscapular region is difficult to assess, particularly after minor trauma in various traumatic settings. Early studies indicate a defined role for diseased joints in production of typical pain patterns.[62] SPECT/CT has the potential to identify such joints with precision, as we have shown in preliminary studies of patients with posterior thoracic pain after the injection of such joints with corticosteroids and local anesthetic.

Lumbar Spine

Low back pain is common among athletes. Its causes vary and must be distinguished from stress fracture of the pars interarticularis (Fig. 14E), which has an incidence of 6% in the general population and accounts for about 15% of pediatric stress fractures. Most pars fractures occur at the L5 and to a lesser degree, at L4 levels of the spine. Young athletes are at most risk, particularly those involved in tennis, gymnastics, cricket (fast bowling), and throwing. Careful scinti-

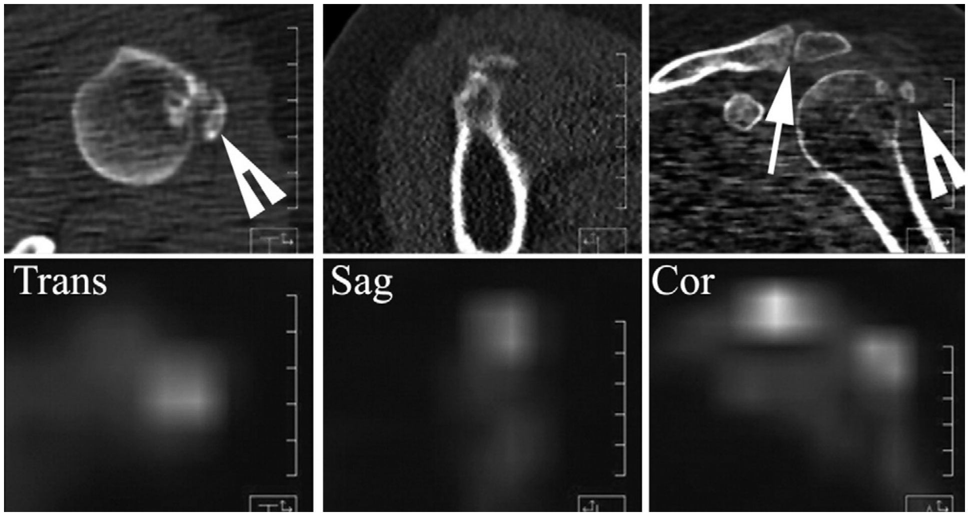

Figure 15 Supraspinatus tendinosis and degenerative change in the acromioclavicular (AC) joint. Intense uptake is present at the site of insertion of the supraspinatus tendon into the lateral humeral head and in the AC joint in the SPECT study. This is associated with calcification in the distal tendon (arrowhead) and sclerosis and erosive change of the AC joint (arrow) in the CT images.

graphic imaging is important as 15% of evolving fractures may not be evident on CT scanning.[63] Pars lesions are easily distinguished from facet joint pathology with SPECT/CT (Fig. 14E).

A major utility of bone scintigraphy is in deciding whether a pars fracture is of long standing and has no potential for healing (Fig. 14E), or is metabolically active and has capability for healing.[64] A study that examined surgical outcomes for spondylolysis based on preoperative SPECT, showed that those with positive studies had a better outcome than those with negative SPECT.[65] Rarely, rotational movements may lead to avulsion/traction injuries of the multifidus muscles of the lumbar spine, presenting as increased uptake in the spinous processes and posterolateral vertebral bodies.[66] A role for SPECT/CT is currently being explored in the condition involving a failure of load transfer across the sacroiliac joints.

Shoulder and Upper Limb

Shoulder Injuries

The shoulder is a difficult joint to study with scintigraphy due to its size and the dominance of soft-tissue injuries. Little systematic scintigraphic study has been attempted due to the dominance and accuracy of MRI. An early attempt at systematic study was by Clunie et al.[67] Using a number of positioning techniques, they were able to iden-

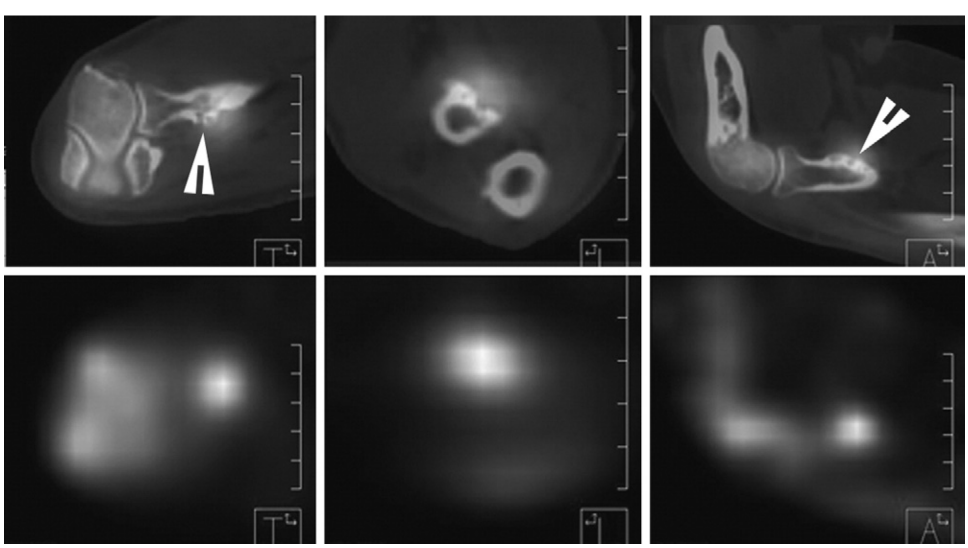

Figure 16 Bicipital tendon avulsion injury. Intense uptake is evident at the bicipital tuberosity of the proximal radius in the SPECT image, with sclerosis and fragmentation (arrowhead) of the tuberosity in the corresponding CT study.

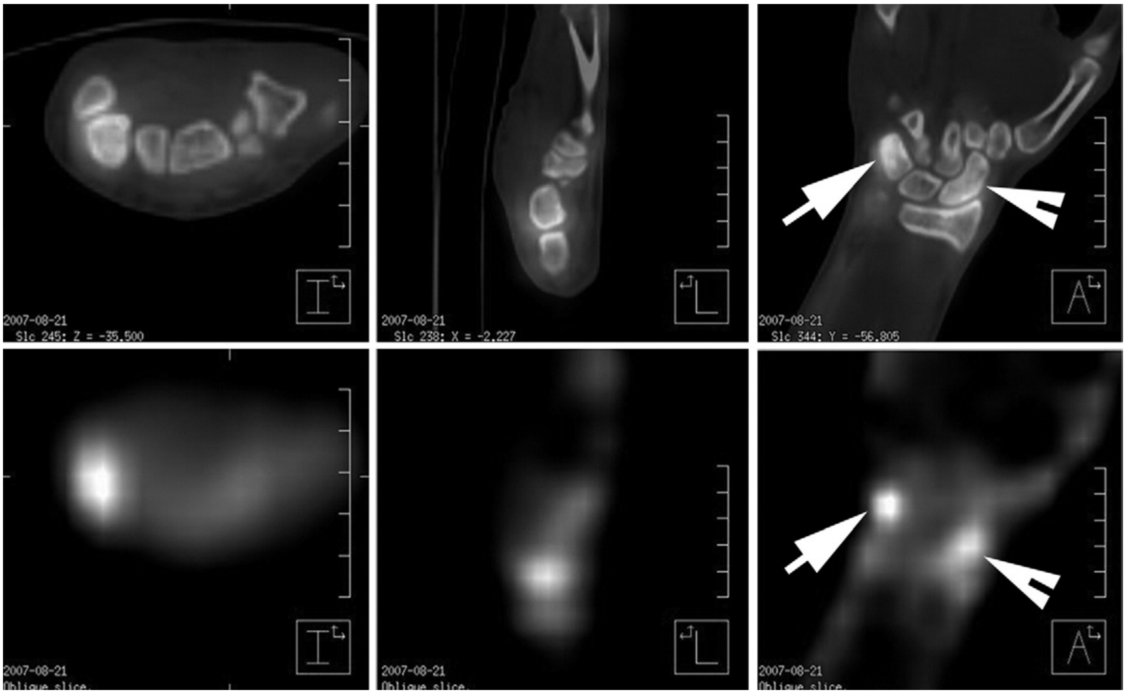

Figure 17 Fracture of the scaphoid and triquetrum. Injury sustained in a heavy fall onto the hand in a baseball game. The SPECT study demonstrates intense focal uptake in the scaphoid and triquetrum, both of which are easily identifiable in the fused CT images. Mild increase in uptake in the distal radius may well reflect bone bruising.

tify a cause of the painful shoulder in 79% of patients. Although it is possible to diagnose a variety of pathologies afflicting tendons, bursae, joint capsule, and even rotator cuff disease, the major utility is in the diagnosis of supraspinatus tendinosis (Fig. 15).

Arm and Forearm

Injuries other than acute fractures are infrequently reported in the humerus, with occasional reports of muscle insertion splints at the proximal insertion of the brachioradialis.[68] In-

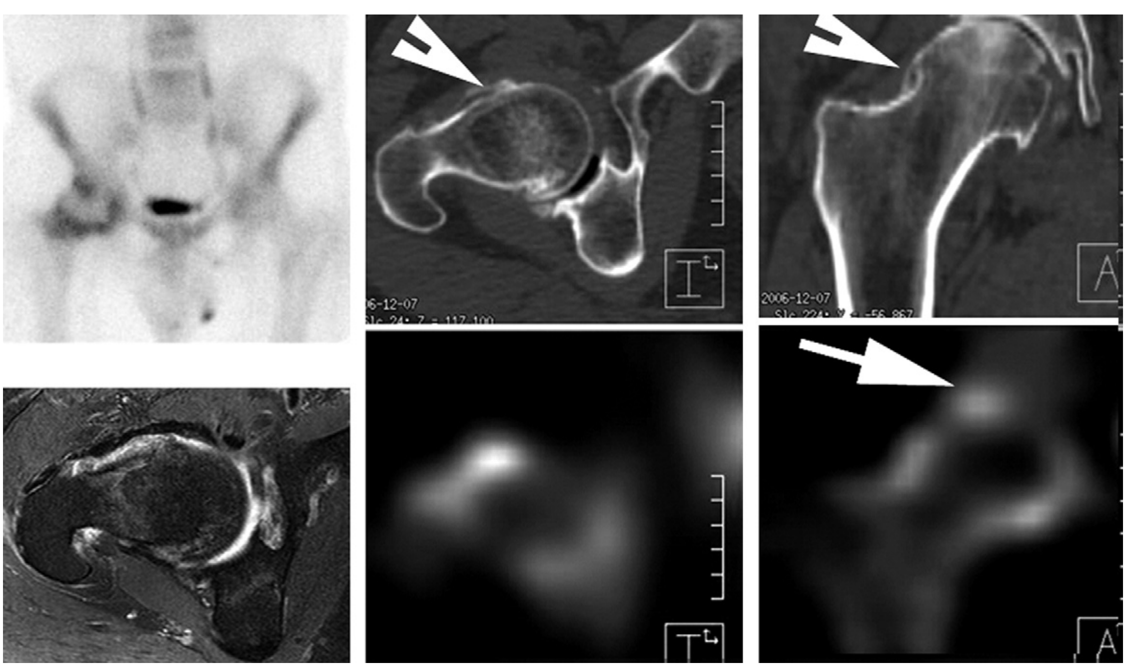

Figure 18 Impingement of the hip, incidentally diagnosed in a runner with lower back pain. The planar study demonstrates crescentic uptake extending across the right femoral head and increased uptake in the acetabulum. SPECT/CT and MRI images confirm increased uptake in the "bump" in the lateral aspect of the femoral head and neck (arrowheads) and increased acetabular uptake (arrow) in association with a torn acetabular labrum. This is the cam variant of hip impingement.

juries around the elbow are more common, with scintigraphic reports of a number of soft-tissue manifestations, such as triceps avulsion from the olecranon process, olecranon bursitis, medial (Fig. 3) and lateral epicondylitis, and distal biceps avulsion injury (Fig. 16).[69] Most forearm injuries are due to acute or chronic fractures. Distal radial fractures are reported to account for one-sixth of all acute fractures presenting to the emergency room,[70] with 50% involving dislocation and over 60% involving the radiocarpal or radioulnar joint.

Wrist and Hand

Soft-Tissue Injury

Scintigraphy can demonstrate evidence of soft-tissue and bony injury in the wrist. It can demonstrate tenosynovitis of the tendons of the wrist. De Quervain's tenosynovitis has been described as showing elongated hyperemia in the distribution of the tendons in the radial compartment of the wrist with delayed uptake in the radial styloid.[71] Posttraumatic pain due to the complex regional pain syndrome (reflex sympathetic dystrophy) may be diagnosed accurately.

Bony Injury

The scintigraphic detection of fractures of every bone in the carpus and hand has been reported.[72,73] Scaphoid fractures are the most common, accounting for 60%-70% of all carpal injuries (Fig. 17).[74] Fractures of the lunate are rare but prone to avascular necrosis if not treated, as 20% of the population have only a single blood supply to the bone.[74] Injuries to the hamate usually affect the hook, although any portion of the bone may be involved.[74] Fractures of the hook are usually seen in sports that involve bats, clubs or racquets. SPECT/CT has the potential to improve the early detection of fractures in the hand and wrist.

Conclusion

Bone scintigraphy has extensive applications in the diagnosis and monitoring of bony and soft-tissue trauma sustained during sporting injury. Such an assessment requires a good history, understanding of the mechanisms of the injury and a good working knowledge of anatomy to reach an accurate diagnosis. The advent of SPECT/CT makes the identification of the precise site of injury obvious. Hybrid imaging also opens up the serendipitous diagnosis of incidental abnormalities of clinical consequence in the search for other pathologies (Fig. 18). As the gamut of diagnostic possibilities encompasses soft-tissue and bony injuries, the acquisition of high-quality blood pool images is mandatory. When imaging children, special consideration needs to be given to positioning and anatomical variations.

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