Bone SPECT/CT of the Foot and Ankle: Potential Clinical Application for Chronic Foot Pain

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Abstract

Diseases of the foot and ankle are common but relatively difficult to diagnose because of the complexity of the anatomy and the frequent occurrence of multiple diseases at the same time. For these reasons, management of chronic foot pain is often clinically challenging. MRI is the imaging modality of choice in many types of diseases causing chronic foot pain, due to high resolution and excellent soft tissue contrast. However, in the postoperative state, the use of MRI can be limited by artifact from metallic devices, and it may be difficult to confirm whether the pathology detected on the MRI is the actual cause of the pain. As bone scintigraphy provides metabolic information, it can help to find the origin of pain, and SPECT/CT can further improve the specificity by adding anatomical information. In daily clinical practice for management of foot and ankle pathologies, the use of bone SPECT/CT is gradually increasing. However, there has been limited evidence of usefulness of SPECT/CT in evaluating chronic foot pain. In this review article, the potential application of bone SPECT/CT for chronic foot pain is illustrated, and the role of SPECT/CT in the management of the foot and ankle diseases in clinical practice is described.

Keywords SPECT/CT · Foot · Ankle · Chronic foot pain

Introduction

Structural imaging studies including plain radiography, computed tomography (CT), magnetic resonance imaging (MRI), and ultrasound (US) are generally used for diagnosing various musculoskeletal diseases including those of the foot and ankle. Single-photon emission computed tomography/computed tomography (SPECT/CT) can be used to diagnose the abnormalities of the skeletal system by combining the advantages of two imaging modalities functional information from SPECT and precise morphological information from CT. Bone scintigraphy is highly sensitive for detecting bone pathology, but the relatively poor specificity is a major drawback. SPECT imaging can overcome the suboptimal specificity of planar images by improving lesion localization [1–3]. Besides, these tomographic images facilitate comparison with other sectional images such

as CT and MRI [4]. The development of hybrid SPECT/CT with high-resolution multislice CT images further increased the diagnostic accuracy [5]. Using bone SPECT/CT in patients with suspected bone diseases other than malignancy showed good performance in 76 patients, as shown by Even-Sapir et al. [6]. In 59% of the patients, final diagnosis for previously unspecified lesions was reached with SPECT/CT, and in another 30% of the patients, it guided the choice of the next imaging modality.

To obtain high-resolution images in the CT portion, reconstruction with thin slice, sufficient pixel matrix, appropriate field of view, dedicated bone kernel, and iterative reconstruction algorithms are required [7]. Furthermore, by virtue of advances in SPECT/CT hardware, algorithms for image reconstruction, and techniques for correcting photon attenuation and scattering, quantification using SPECT/CT became possible with considerable accuracy [8, 9]. Measurement of standardized uptake value of the bone lesions with SPECT/CT can enable longitudinal assessment for bone pathologies [10]. Also, quantitative bone SPECT/CT could be used in prognostication and differential diagnosis of various bone and joint disorders [11]. Additional blood pool imaging prior to SPECT and CT acquisition can be helpful in the assessment of inflammatory condition or disease activity in various bone and joint diseases such as diabetic foot [12].

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Although there is insufficient evidence to achieve consensus on appropriate indication of bone SPECT/CT, quite a number of studies and case reports focusing on the usefulness of bone SPECT/CT for diseases in the foot and ankle have been published [3, 5, 13, 14]. The utility of SPECT/CT for degenerative disease, osteochondral lesions, stress fracture, postoperative evaluation of joint fusion of foot, tarsal coalition, diabetic foot, and soft tissue pathologies such as Achilles tendonitis has been reported. Despite the relatively high incidence of foot pain, the evaluation of chronic foot pain is often challenging in clinical practice, because the anatomy and function of the foot are complex, and various kinds of bone and soft tissue pathologies could involve the foot and ankle. Unlike acute pain, which is most often caused by traumatic injury, the underlying diseases of chronic foot pain are diverse and often difficult to diagnose clinically. Thereby, various imaging modalities can be used and it is necessary to select appropriate imaging modalities. MRI is known as the favored imaging modality for evaluation of the musculoskeletal system including the foot because of its high resolution and superior soft tissue contrast, but metallic device from previous surgery, claustrophobia, and obesity could hamper the use of the MRI. In addition, when multiple lesions of the foot and ankle are detected on MRI, it may be difficult to identify the culprit lesion associated with the patient's symptoms. In the study by Ha et al. comparing bone SPECT/CT to MRI for foot and ankle lesions, the specificity was limited for joint lesions with bone SPECT/CT, and low for ligament or tendon lesions with MRI [15]. So, the authors suggested that SPECT/CT could be an effective complementary imaging tool to the MRI in patients with ankle and foot pain. Since SPECT/CT allows accurate anatomical correlation with high-resolution CT to functional information from SPECT in all three orthogonal planes, it can improve the diagnostic accuracy for traumatic injury, degenerative disease, inflammation, or tumor of the foot and ankle. Also, bone SPECT/CT may be particularly useful in cases where the results from anatomical imaging are equivocal or not feasible. Mohan et al. suggested diagnostic algorithm for assessment of patients with chronic foot pain [3]. According to this algorithm, bone SPECT/CT has been found to be the most useful in patients who have previously undergone surgery and retained metallic hardware, or who had inconclusive MRI findings, with clinical suspicion of bone pathology rather than soft tissue pathology.

The aims of this review were to contribute to the appropriate use of bone SPECT/CT according to various clinical indications in the disease of the foot and ankle though validation is a work in progress, and to further expand the list of potential indications of bone SPECT/CT.

Potential Application of SPECT/CT in the Foot and Ankle

Osteoarthritis

In bone scintigraphy, osteoarthritis is the most common cause of increased activity in the extremities. The foot and ankle are also common locations of degenerative arthritis [14]. In osteoarthritis, the precise assessment of disease extent and pain localization is very important for therapeutic planning, such as corticosteroid injections or arthrodesis [16]. Higher response rates to anesthetic injections in the hind- and midfoot can be achieved by ^{99m}Tc -dicarboxypropane diphosphonate (DPD)-SPECT/CT guidance, compared to CT-guided injections [17] (Fig. 1).

Bone scintigraphy has the limitations of low spatial resolution and lack of anatomic information. Furthermore, CT scans cannot always depict the increased bone remodeling activity of the lesions. SPECT/CT enhances the accuracy of the localization of active osteoarthritis by providing both functional and morphological information. In the study by Singh et al. [18], SPECT/CT showed a diagnostic accuracy of 94% in 50 patients, most of whom had osteoarthritis, and the treatment plan was changed in 78% of patients because of SPECT/CT findings. In addition, bone SPECT/CTs showed higher inter-observer agreement in image analysis for osteoarthritis, compared to CT scans or bone scintigraphy [16]. Therefore, the importance of using bone SPECT/CT stands out, especially for small or complicated anatomical locations and interpreters with limited clinical experience.

Stress Fracture

Stress fractures of the foot are not rare, especially in athletes, and also in the middle aged or elderly following sporting activities. Metatarsal bones are the most common sites in the foot, and in small numbers, stress fractures occur in the tarsal bones [19, 20]. Radiographs are often inconclusive in diagnosing fractures, especially stress or insufficiency fractures that could be well visualized on radionuclide bone scintigraphy. Although MRI is known to be highly sensitive for stress injuries demonstrated as bone marrow edema, bone scintigraphy is also a very sensitive diagnostic modality for early stress fractures [3]. Moreover, SPECT/CT can diagnose stress fractures with higher accuracy by the combination of CT findings, such as fracture lines or linear sclerotic areas, and SPECT findings of increased metabolic activity [4, 7] (Fig. 2).

Osteochondral Lesions

Osteochondral lesions or defects (OCLs or OCDs) of the ankle joint are a common condition related to sports injuries, especially in young, sports-active patients with a history of

Fig. 1 Osteoarthritis of the left subtalar and talonavicular joints. ^{99m}Tc -hydroxymethylene-diphosphonate (HDP) bone SPECT/CT of a 51-year-old female with left foot pain for 4 years showed prominent focal activity in the left hindfoot on planar spot images (a). There were focal hot uptakes in subtalar (arrows) and talonavicular (short arrow) joints of the left foot on coronal (b) and sagittal (c) SPECT/CT fusion images. Following arthrodesis for both joints, the patient's foot pain was alleviated

ankle sprains, chronic ligament instability, and fractures [14, 21, 22]. Devitalization of the subarticular region by disruption of the blood supply to the joint area induces the separation of

Fig. 2 Stress fracture of the left navicular bone. A 17-year-old male who had a history of repeated ankle sprains underwent ^{99m}Tc -HDP bone SPECT/CT to evaluate the cause of left ankle pain for 2 years. Focally increased activity was noted in the left midfoot on both planar spot (a) and blood pool (b) images (arrows). SPECT/CT fusion images (c, d) showed increased metabolic activity along the fracture line of the left navicular bone (arrows). Fracture line and diffuse bone marrow edema were also seen in the navicular bone on fat-saturated T2-weighted (e) MR image (short arrow). The patient's symptom was relieved after internal fixation of the navicula

bone and cartilage fragments, which causes pain [23]. Talus is the most often affected bone and shows defect of the cartilaginous surface and subchondral bone in the dome portion. Talar OCL is one of the treatable causes of unclear chronic ankle pain [3]. Despite the advantage of nuclear medicine images to delineate the exact origin of the pain, MRIs entirely replace the other image modalities for the diagnosis of OCLs with superior image quality. However, in the study of 15 patients with ankle OCLs, Wiewiorski et al. [22] reported a highly significant correlation between pain and pathologic uptake on bone SPECT/CT. This correlation indicates that pathologically increased bone remodeling in OCLs might be an

important cause of pain. Since the management of OCLs is based on the stage of the lesions, precise assessment is also important. Increased activity at the corresponding area of the talar dome on additional blood pool images may help diagnose talar OCLs (Fig. 3). In the study by Meftah et al., the authors assessed the role of bone SPECT/CT compared to MRI for the management of talar OCLs in 22 patients [24]. The role of SPECT/CT was especially useful in complex or equivocal cases where the patients had already undergone surgery or when MRI could not suggest the cause of persistent pain. Leumann et al. recommended performing both MRI and SPECT/CT because SPECT/CT provided additional information and influenced OCL treatment decisions [21].

Tarsal Coalition

Tarsal coalition is a painful deformity of the foot with motion restriction, resulting from the abnormal fusion of tarsal bones

Fig. 3 Osteochondral defect of the left talus. A 37-year-old male underwent ^{99m}Tc -HDP bone SPECT/CT for evaluation of left ankle pain developed following fall down 5 years ago. Plain radiograph (a) of left ankle showed no definite bony abnormality. Planar spot (b) and blood pool (c) images demonstrated focal hot uptake in the corresponding area of the left medial ankle (arrows). SPECT/CT fusion images (d, e) revealed the exact location of the focal activity at the medial talar dome (arrows), with subtle cystic and sclerotic changes on CT portion. The patient no longer experienced symptoms during the 4-year follow-up period after talar curettage and drilling

through bridging of the fibrous tissue, cartilage, or bones. The most frequently involved are the calcaneonavicular and talocalcaneal joints. About half of the patients with tarsal coalition show bilateral foot involvement. CT and MRIs are not the imaging modalities of choice for this condition, albeit MRI is reasonably effective for diagnosing tarsal coalition. The ability of anatomical imaging to differentiate between symptomatic and asymptomatic lesions is limited. Since bone SPECT/CT can demonstrate abnormally increased activity at the affected joint due to shearing forces on the fused joint, it can be used to identify the origin of pain and guide intra-articular injections [20] (Fig. 4). SPECT/CT can also detect lesions missed on other imaging modalities by the combination of functional and structural information it provides [14, 23].

Postoperative Evaluation of Arthrodesis

Joint fusion (arthrodesis) is used for the treatment of several conditions that cause foot pain, such as severe arthritis, joint destruction following inflammation in arthritis, trauma-related complications such as misalignment, and neuropathic osteoarthropathy [3, 25]. SPECT/CT can be used for the

Fig. 4 Underlying talocalcaneal coalition with osteoarthritis of both feet. A 21-year-old male complained of right ankle pain for 5 months. Planar spot (a) and blood pool (b) images of ^{99m}Tc -HDP bone SPECT/CT showed focal hot uptakes in the medial aspect of both hindfeet (arrows), and symmetrically increased activity was noted in the typical site of talocalcaneal joint of both feet on SPECT/CT (c, d) images (arrows). There was a nonosseous bridging at the corresponding site in the right foot (short arrow) on fat-saturated T2-weighted MR image (e). The patient's pain was relieved after right subtalar fusion surgery

evaluation of postoperative foot if the pain remains or redevelops. Fusion is usually achieved within 6 months after surgery. Delayed union is defined as a fusion that occurs more than 9 months after surgery. Nonunion is also one of the major reasons for persistent pain after arthrodesis (Fig. 5). Simple mechanical stress, subsequent osteoarthritis of the joints adjacent to the arthrodesis, and infection can also be source of pain. A large proportion of patients complain of foot pain within 1 year after surgery. Radiographs and CT scans are widely used for patients with pain after arthrodesis, however,

Fig. 5 Nonunion of right first tarsometatarsal joint arthrodesis. A 55-year-old male with posttraumatic arthritis underwent joint fusion surgery for the left first tarsometatarsal joint 10 months ago. ^{99m}Tc -HDP bone SPECT/CT performed for persistent right foot pain showed focally increased activity at the medial aspect of the right midfoot on planar spot (a) and blood pool (b) images (arrows). On SPECT/CT fusion images (c, d), increased metabolic activity was noted in the first tarsometatarsal joint (arrows), corresponding to the area of joint fusion with metallic pins (short arrows) seen on CT portion (e), as well as plain radiograph (f)

these modalities are not able to reveal the cause of the pain in many cases. Optimal quality images cannot be obtained with MRI in patients with metal hardware. Therefore, in this clinical setting, SPECT/CT may be a useful modality, improving the diagnostic accuracy for the cause of pain by correlating altered metabolic activity seen in SPECT with CT findings and is especially useful for demonstrating nonunions, malunions, or subjacent osteoarthritis [3, 14]. Kampen et al. suggested that bone SPECT/CT was the method of choice for postoperative foot and ankle pain in cases of metal implants, and bone SPECT/CT was especially helpful in patients with normal or equivocal findings on anatomical imaging [25].

Painful Accessory Bones

Accessory bones are common skeletal variations in the foot and ankle. Accessory navicular bones and os trigonum are the most common accessory bones. An accessory tarsal navicular is located adjacent to the medial and posterior margin of the navicular bone, and os trigonum is seen adjacent to the posterior margin of the talus. In addition, over ten kinds of accessory bones, such as os versalianum pedis and os subfibulare, have been reported in the foot area [26].

The pain from accessory ossicles can be caused by many types of pathologies, but the major mechanism of pain is traumatic or degenerative changes at the synchondrosis, or soft tissue inflammation [3]. While both MRI and bone scintigraphy show signal changes or increased activity across the synchondrosis [27], SPECT/CT is an excellent technique for diagnosing painful accessory bone syndrome, because it can demonstrate both altered metabolic activity and anatomical localization [7, 14] (Fig. 6).

Inflammation and Infection

Only a few studies have evaluated the value of SPECT/CT in inflammation and infection of the foot and ankle [14, 28]. Radionuclide bone scintigraphy is highly sensitive for the diagnosis of bone infection, but its relatively low specificity lowers the diagnostic accuracy. Since SPECT can provide more accurate localization of lesions and combined CT may identify the finding of infection, such as cortical destruction, a foreign body, or a sequestrum, the relatively low specificity of bone scintigraphy can be overcome by using SPECT/CT [4]. In addition, knowing the exact location of the lesion depicted by SPECT/CT is useful for guiding surgery (Fig. 7). In a case report by Al-Jafar et al. of a patient with sickle cell anemia complaining of foot pain, bone SPECT/CT was an important diagnostic tool for the diagnosis of hidden Brodie's abscess of the talus [28].

SPECT/CT with radiolabeled leukocytes can be useful in differentiating bone from soft tissue infection by precise

Fig. 6 Painful accessory navicular bone of the left foot. On ^{99m}Tc -HDP bone SPECT/CT of a 25-year-old female with left foot pain for 4 years, focal hot uptake was noted in the medial aspect of the left hindfoot on planar spot image (a). SPECT/CT fusion images (b, c) showed increased metabolic activity in accessory navicular bone and synchondrosis with navicular bone, suggesting degenerative change (arrows). Only the accessory navicular bone (short arrow) was seen on plain radiography (d). Left foot pain was relieved following surgery, excision of navicula

localization of sites of leukocyte accumulation [29]. Heiba et al. investigated a SPECT/CT fusion method that combined the imaging of dual isotopes (DI) of ^{99m}Tc -hydroxymethylene-diphosphonate (HDP) and In-111 leukocyte for an accurate diagnosis and precise localization of diabetic foot infection [12]. Blood pool images were obtained with ^{99m}Tc -HDP, followed by white blood cell (WBC) reinjection and DI planar and SPECT/CT images the next day. The results proved the superiority of DI SPECT/CT imaging over bone scintigraphy or WBCS SPECT/CT alone to confirm or exclude foot infection and determine the nature of the infected tissue. Bone SPECT/CT and WBC SPECT/CT have complementary roles in clinically suspected posttraumatic osteomyelitis, so combining both modalities can enhance the diagnostic accuracy [30].

Soft Tissue Abnormalities

SPECT/CT may be useful in evaluating soft tissue pathology and impingement syndrome in the foot and ankle [31]. Achilles tendonitis and plantar fasciitis are potential causes of hindfoot pain [14]. MRI is regarded as the choice of imaging modalities because of its ability to detect changes in soft

Fig. 7 Chronic osteomyelitis of the left medial cuneiform bone. A 36-year-old male who had unclear history of trauma in the left foot underwent ^{99m}Tc -HDP bone SPECT/CT to evaluate the cause of left foot pain for 7–8 years. Intensely increased focal activity was noted in the medial portion of the left midfoot on both planar spot (a) and blood pool (b) images (arrows). SPECT/CT fusion images (c, d) showed increased metabolic activity in the left medial cuneiform bone (arrows). Irregular radiolucent area surrounded by sclerotic change was seen on corresponding CT portion (sequester). Increased T2 signal intensity with enhancement was present in the medial and intermediate cuneiform and second metatarsal base on fat-saturated T2-weighted (e) MR image (short arrow). The patient's pain was subsided following curettage and drilling and second tarsometatarsal joint fusion. Pathologic findings from surgery showed chronic inflammation and fibrosis with sclerotic bony fragments

tissue, such as thickening and edema [3, 20]. In the case of false-negative results from MRI, high-resolution ultrasound can be useful in evaluating tendinopathies [32]. Although bone scintigraphy has a limited role in diagnosing soft tissue abnormalities, bone SPECT/CT facilitates the diagnosis of these soft tissue lesions by showing abnormal metabolic activity at the typical site (postero-superior or inferior aspect) of the calcaneus (Fig. 8). The CT portion can also help provide more accurate diagnoses by directly depicting the associated soft tissue abnormalities.

Fig. 8 Enthesopathy of right Achilles tendon. A 71-year-old female who had a history of DM neuropathy and plantar fasciitis presented with chronic right heel pain. ^{99m}Tc -HDP bone SPECT/CT fusion images (a, b) showed focally increased activity at the cortical insertion site of the Achilles tendon of right calcaneus with bony spurs and a few small bone fragments (arrows). On plain radiograph (c), subtle bony spur was seen in the right calcaneal tuberosity (short arrow)

Conclusion

Bone scintigraphy is rated low for diagnosing chronic foot pain in the American College of Radiology (ACR) Appropriate Criteria, and MRI is the generally preferred imaging modality for various diseases of the foot and ankle. However, bone SPECT/CT combines metabolic activity of bone scintigraphy with highly enhanced anatomical information from CT, resulting in significantly improved diagnostic accuracy for bone diseases. Although the evidence to support the usefulness of bone SPECT/CT in the diagnosis of chronic foot pain is still not fully established, there is growing body of evidence for the clinical role of bone SPECT/CT in various pathologies in the foot and ankle. Especially in cases with complicated or equivocal findings on anatomical images, the role of SPECT/CT stands out. According to the empirical clinical experience and review of the literatures, bone SPECT/CT is highly useful in determining the cause of foot pain and planning the management, especially if there are multiple pathologies coexisting in the foot and ankle of the patient. It is also useful whether there is an anatomical deformation from surgery or trauma, regardless of the presence of metallic hardware.

Albeit SPECT/CT has all the advantages of hybrid imaging, the exact diagnosis for bone diseases may not always be possible. Therefore, it is important to understand indications for bone SPECT/CT in the comprehensive spectrum of foot and ankle diseases. Recommendations in the form of expert

opinion coming from those with clinical experience could refine the selection of appropriate indications. Although the use of SPECT/CT in chronic foot pain is gradually increasing in clinical practice, there is still much to be validated. Therefore, large and prospective studies assessing the role of SPECT/CT in foot and ankle diseases are required.

Compliance with Ethical Standards

Conflict of Interest Je Ryung Yoo declares that she has no conflict of interest.

Ethical Approval This article does not contain any studies with human participants or animals performed by the author.

Informed Consent For this type of study, formal consent is not required.

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