Current applications and controversies in bone SPECT/CT imaging

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Introduction

Bone scintigraphy is the largest single volume area in nuclear medicine, while PETCT is a close second. Most bone imaging is planar imaging for oncology. Indications for scintigraphy are listed in figure 1. Bone SPECT/CT is a dual modality imaging test that has not gained as high a profile as other nuclear medicine techniques such as PETCT, despite recent significant advances in both SPECT/CT technology and availability. There is a remarkable lack of data regarding its indications, potential utility and accuracy. In addition, there is a lack of knowledge among referring clinicians as to how to optimally utilise this technique. SPECT/CT brings challenges in terms of staff training, radiation protection, imaging protocols and interpretation time, but offers significant advantages in terms of diagnostic accuracy. Many nuclear medicine and radiology departments have upgraded to this technology, without a clear plan for putting the equipment to use, but rather evolving a plan over time. This article is a brief discussion of the utility and indications for bone SPECT/CT.

New technology

The affordability of SPECT/CT equipment has greatly increased and this is a major factor in the wider availability of the technology. The cost differential between SPECT/CT and gamma camera equipment has decreased, which means that when replacing equipment, departments commonly upgrade from a conventional gamma camera to a SPECT/CT system. Furthermore, in a lot of cases little additional room shielding is needed, so the add-on costs of upgrading are minimal. However, a technical point that must be considered is the electrical supply to an imaging room that is for upgrade to SPECT/CT.

The specification of the CT component determines most of the additional cost and some of the service contract costs of equipment. Typical specification considerations include ranging from 2 to 16 slices. Original systems employed slow 1 to 4 slice rotating CT, but the speed and quality of current systems are equivalent to the corresponding conventional CT component. The conversion of gamma camera equipment to SPECT/CT is similar to the move from PET to PETCT imaging systems.

Another option when purchasing equipment is to install an upgradeable gamma camera to future proof a department. Some nuclear medicine imaging techniques do not significantly benefit from SPECT/CT and departments may choose to maintain a gamma camera for thyroid and renal imaging. In centres where there is high volume of bone imaging, the additional expense of SPECT/CT is justified, for orthopaedic indications and in oncology for detection of metastatic disease.

Role of CT component of SPECT/CT

The CT component has three functions (figure 2): Attenuation correction is a most fundamental function and is common to all SPECT/CT imaging, replacing some of the algorithms used in conventional SPECT.

Localisation is particularly important in situations where there is little background activity, for example in infection imaging of bone, with Indium-111 scintigraphy. Often, background activity adjacent to peripheral joints is limited and SPECT/CT helps to localise activity within a specific joint. Localisation and attenuation correction can be performed with low dose or LDCT SPECT.

Bone SPECT can confirm whether a lesion or finding is present, while CT can characterise the lesion and help confirm what it actually is. Characterisation of lesions is usually but not always performed with full dose CT. Full dose CT is less of a radiation protection issue in the peripheral skeleton but is an important issue in assessment of the axial skeleton, where LDCT may be used to help to characterise lesions. Furthermore, characterisation improves the specificity of bone SPECT which has always been a weakness of planar and SPECT imaging. In certain locations the type of pathology can be predicted, however in other locations, for example in the spine or long bones, the type of lesion may not be as predictable and without a CT component, additional imaging with CT or MRI may be required.

When to perform SPECT/CT

The decision as to when to perform CT is important and is often made at the time of imaging by the nuclear medicine radiographer. Individual imaging departments make policies surrounding the use of SPECT/CT. Options include scanning any single ‘hot spot’ identified on planar imaging. Another approach is limited SPECT/CT imaging of any lesion that would have ‘qualified’ for plain radiograph correlation previously. Some departments operate a reading room approach where all planar images are reviewed by a nuclear medicine fellow, physician or radiologist as they are acquired. Images are evaluated for image quality and the need for additional or focused imaging. However, this approach may only be feasible in larger departments. Specific regional imaging protocols are used for peripheral joint imaging, incorporating multiphase imaging, and low or full dose CT and SPECT where appropriate (figure 3). Most cases can be protocolled in advance. Oncology imaging, however, often needs a decision made on each individual scan (figure 4). Currently in our department, approximately one in every two patients for either oncologic or orthopaedic indications has a SPECT or SPECT/CT performed as part of their imaging assessment.

Having an audit system to regulate radiographer-directed additional SPECT/CT imaging is important, particularly with new staff, to ensure appropriate use of radiation. Feedback should be through formal audit or quality assurance meetings. QA systems attached as a drop-
down menu option are available on PACS systems and can be used to accumulate cases that may be instructive at a QA meeting. Departmental imaging policies may need to be rewritten and reapproved by a radiation safety committee.

**Challenges to radiology and nuclear medicine departments**

SPECT/CT increases the reading time needed for nuclear medicine studies. This is significant enough to form part of the business plan for a new unit. Dual trained radiography staff are the ideal. The challenge is similar to the move from conventional PET to PETCT.

Conventional PACS systems are not suitable for reporting SPECT/CT examinations. Images cannot be windowed correctly and measurements are not possible. Many readers also consider the images ‘pixelated’. The solution is to use a proprietary add-on nuclear medicine application launched through PACS or a separate dedicated vendor or independent nuclear medicine workstation. This can add further to reporting times.

**Clinical applications**

**Oncology**

Identifying the first bone metastasis is an important task and unfortunately indicates incurable disease in many cases. Sensitivity and specificity of SPECT/CT for diagnosis of bone metastases is higher than with planar or SPECT imaging. SPECT/CT can also help with identification of the ‘flare’ phenomenon, confirming healing sclerosis on associated CT imaging, or identify benign findings mimicking metastases (figure 5).

Typically, a limited regional examination of a hot spot identified on planar imaging is performed. Most patients for staging have had a contemporaneous CT thorax abdomen and pelvis. Comparison with these staging studies is performed on the PACS system, and CT need not be repeated if performed recently. In these cases, SPECT alone can be used, with the option of software fusion with a prior CT. For those who have not had recent CT imaging, the CT component of SPECT/CT can help assess fracture risk or spinal compromise. This is important for those cancer staging protocols that involve bone scintigraphy only.

**Evaluation of prostheses**

The advances in gamma camera CT integration have coincided with improvements in software reconstruction technology, with iterative reconstruction significantly improving image quality while potentially reducing scan times. Three phase imaging is no longer needed, but two phase planar or SPECT imaging is very useful to evaluate for inflammation, including infection. Now, two phase imaging is standard in the evaluation of metal prostheses of the hip or spine. The advances in gamma camera CT integration have indirectly and measurements are not possible. Many readers also consider the images ‘pixelated’. The solution is to use a proprietary add-on nuclear medicine application launched through PACS or a separate dedicated vendor or independent nuclear medicine workstation. This can add further to reporting times.

This is an ever-expanding area in nuclear medicine imaging in our department, particularly over the past two years. SPECT/CT imaging offers significant advantages in assessment of hind foot pain, particularly in the setting of previous metal fixation (figure 7). Plain radiographs may have limited ability to evaluate the hind foot in the setting of moderate degenerative change or previous surgery. In patients with widespread joint abnormalities, often marked degenerative changes are seen in multiple joints at CT, which can make identification of the symptomatic joint or region difficult. SPECT imaging can identify focal inflammation which, when fused with the CT imaging, localises the activity to indicate the symptomatic joint.7 This is a major advantage for foot surgeons, hence the high referral rate. SPECT imaging can confirm stress reaction or bone turnover of mechanical origin adjacent to metal, while the CT component can confirm bony joint fusion post surgery (figure 8).

**Infection imaging**

SPECT/CT is an ideal complement to bone infection imaging, along with Tc99m-leukoscan, Tc99m-granulocyte and In111 white cell scans. These imaging techniques are often more costly and time consuming than conventional imaging and the use of additional CT radiation exposure is often also justified to increase specificity. The consequences of a diagnosis of osteomyelitis are significant, typically needing six weeks of antibiotics and PICC line access for treatment. All imaging modalities, including MRI, suffer from imperfect accuracy in the diagnosis of infection. The first imaging test to use is plain radiography. In the setting of normal plain radiographs and where infection is suspected, a negative SPECT/CT examination is accurate in excluding infection.8 However, a positive study may require further confirmation with other isotope studies or MRI. In the setting of abnormal baseline radiographs due to structural or degenerative bone disease, leukoscan imaging, MRI or FDG PETCT may be more appropriate investigations.

**Research**

This modality offers opportunities for research as there are many unanswered questions surrounding protocols, and the clinical benefit of establishing a diagnosis. There is a dearth of research studies for SPECT/CT in comparison with other modalities. There are opportunities for individual departments to lead and exploit this gap in the research. SPECT/CT is important in dosimetry for experimental bone seeking radioisotope therapies, however dosimetry is not needed for radium-223 therapy.
The future

SPECT/CT is an underutilised modality in our opinion. To expand appropriate usage, more research is needed. In addition, imagers should consider attending and contributing at multidisciplinary team meetings. As always in nuclear medicine and radiology, one of the best ways to encourage utility of a modality is to produce high quality, detailed, relevant reports. However, the lack of studies showing the effect on patient outcomes is a limiting factor when promoting the modality.

Conclusion

Bone SPECT/CT referral volumes are rising, and the technology is more widely available due to reduced equipment costs. However, this evolving technique brings with it a number of challenges, including radiation protection issues, the need for new imaging protocols and appropriate training of staff. Furthermore, the resultant studies take longer to read than conventional planar imaging, which has implications for resource allocations and workload. Overall, it is a highly effective imaging modality when it comes to identification and characterisation of metastases, hardware associated complications and trauma-related pathology, among others, and is an under-exploited imaging modality.

References


Figure 1

Indications for bone scintigraphy.

Figure 2

Indications/functions of the CT component of SPECT/CT.

Figure 3

Sagittal SPECT/CT of a patient with hindfoot pain. The CT component of SPECT/CT commonly demonstrates prominent degenerative findings, but without significant radiotracer uptake, indicating asymptomatic abnormality. (A) demonstrates a moderate sized degenerative plantar spur, with no tracer uptake. (B) shows prominent focal uptake at a similar sized osteophyte indicating a symptomatic finding relating to plantar fascitis or a fractured osteophyte. CT showed no fracture. Plantar fascitis is straightforward to diagnose clinically without imaging. Imaging may have a value in excluding an autoimmune fascitis or a fracture. In this patient, additional foot and ankle abnormalities were present and a diagnosis of plantar fascitis could be overlooked.

Figure 4

Posterior imaging from a whole body bone scan for restaging of prostate adenocarcinoma. Increased tracer uptake apparently at the level of a spinous process in the lower lumbar spine is, in fact, a bone metastasis. A second metastasis is in the left iliac bone subsequently proven at CT biopsy. Based on the planar imaging, the nuclear medicine radiographer made a correct decision to proceed to SPECT/CT, therefore establishing the diagnosis. In the absence of SPECT/CT imaging an incorrect diagnosis of interspinous degenerative change would have been made (Baastrup’s disease).
Planar imaging and SPECT/CT of a right-sided 10-year-old cemented hip prosthesis and a one-year-old left-sided uncemented prosthesis in a patient with bilateral symptoms, worse on the right side. Planar imaging demonstrates bilateral abnormalities. SPECT/CT improves specificity by localising and characterising the abnormalities. On the right side moderate protrusio with an undisplaced acetabular fracture with focal intense uptake. There is significant lucency surrounding the acetabular component on the CT component indicating loosening. Assessment of the femoral stem on fused images is limited by metal artefact and review of the coronal non-fused SPECT images may be more useful. Uptake adjacent to an uncemented femoral stem is normal for up to two years post placement. On the left side medial stem uptake is mildly increased. Focal uptake at the ischial tuberosity at the hamstring insertion indicating microavulsion or degenerative change, was thought a likely explanation of symptoms.

MRI for neck pain demonstrated intermediate non-specific signal in the T2 vertebral body in a 55-year-old. Whole body scintigraphy with focused LDCT SPECT/CT of the upper spine demonstrated a single site of intense tracer uptake without significant bone abnormality on CT. A decision was made not to proceed to CT-guided biopsy based on a suspected diagnosis of Paget’s disease. Follow-up MRI and whole body scintigraphy demonstrated no change at six months. It is not unusual for patients to have SPECT/CT imaging after MRI imaging, where MRI cannot confirm a diagnosis.

Evaluation of the post-operative foot or ankle is a strong indication for SPECT/CT imaging. MRI may have limited use in this situation due to metal artefact despite artefact reduction sequences. In this patient with plate fixation and intramedullary nail fixation, abnormality of the distal fibular plate fixation was suspected. SPECT/CT shows varus angulation with joint space narrowing and intense tracer uptake at the tibiotalar articulation, indicating the source of pain (A). No significant tracer uptake in relation to the fibular plate, but immature heterotopic ossification is noted above the distal tibiofibular syndesmosis (B).

Figure 6
Planar imaging and SPECT/CT imaging of a right-sided 10-year-old cemented hip prosthesis and a one-year-old left-sided uncemented prosthesis in a patient with bilateral symptoms, worse on the right side. Planar imaging demonstrates bilateral abnormalities. SPECT/CT improves specificity by localising and characterising the abnormalities. On the right side moderate protrusio with an undisplaced acetabular fracture with focal intense uptake. There is significant lucency surrounding the acetabular component on the CT component indicating loosening. Assessment of the femoral stem on fused images is limited by metal artefact and review of the coronal non-fused SPECT images may be more useful. Uptake adjacent to an uncemented femoral stem is normal for up to two years post placement. On the left side medial stem uptake is mildly increased. Focal uptake at the ischial tuberosity at the hamstring insertion indicating microavulsion or degenerative change, was thought a likely explanation of symptoms.

Figure 7
Evaluation of the post-operative foot or ankle is a strong indication for SPECT/CT imaging. MRI may have limited use in this situation due to metal artefact despite artefact reduction sequences. In this patient with plate fixation and intramedullary nail fixation, abnormality of the distal fibular plate fixation was suspected. SPECT/CT shows varus angulation with joint space narrowing and intense tracer uptake at the tibiotalar articulation, indicating the source of pain (A). No significant tracer uptake in relation to the fibular plate, but immature heterotopic ossification is noted above the distal tibiofibular syndesmosis (B).

Figure 8
Suggested protocols for orthopaedic bone SPECT/CT imaging.