Practical aspects of SPECTCT imaging

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Introduction
Hybrid imaging with SPECTCT, combining functional single photon emission computed tomography (SPECT) with anatomic computed tomography (CT), has evolved over the last decade with advances in both technology and clinical application. While overshadowed by the phenomenal success of PETCT, there has been increasing accessibility to multi-slice SPECTCT aided by a wide range of clinically available radiotracers, lower cost and existing infrastructure within most nuclear medicine and/or radiology departments.

In this article, we will discuss the evolution of SPECTCT technology, list the wide range of clinical applications and explore some of the practical aspects of incorporating multi-slice SPECTCT into clinical practice.

Technical overview and advances
The first commercially available integrated SPECTCT (GE Hawkeye) was launched in 1999 with the low-dose (fixed mA) CT component used for attenuation correction and gross anatomic localisation. Current SPECTCT machines incorporate multislice, diagnostic quality CT that can be acquired in a fraction of the time. Most vendors include equivalent CT components as found on stand-alone mid-range CT machines. Several 64-slice SPECTCT machines have been installed at institutions around the world, predominantly at research sites, but commercially available SPECTCT cameras offer up to 16-slice, which is adequate for almost all current clinical uses. Multislice CT offers additional benefits of accurate localisation and lesion characterisation, multiplanar reconstructions and 3D displays including maximum intensity projection (MIP) and surface/volume rendering.

Alongside developments in CT technology, SPECT hardware innovations include new detector materials and collimator designs. Solid-state detector (SSD) materials such as cadmium zinc telluride (CZT) coupled with multiple pinhole collimators allow much faster dynamic acquisitions by exploiting the high count rate capability of high sensitivity CZT detectors, which in turn has resulted in improved resolution and shorter acquisition times compared to traditional dual-head cameras using sodium iodide detector photomultiplier array. CZT detectors have been utilised in small field of view cardiac cameras (GE Discovery NM530c) to date, as the high cost of these SSDs remain a major limitation to its incorporation into general SPECTCT use. A cheaper alternative is focused collimation that allows shorter acquisition times in cardiac imaging, by up to two-thirds less, and available on a wide range of SPECTCT cameras.

Perhaps the greatest advance has been in image processing and reconstruction algorithms, facilitated by faster and more powerful computers. These include:

i) iterative reconstruction techniques such as OSEM (ordered-subset expectation maximisation) replacing filtered back projection

ii) correction processes that are more sensitive to photon dynamics (ie absorption and scattering)

iii) depth-dependent resolution recovery, resulting in superior image quality, shorter acquisition times and lower radiation doses.

More recently, a novel reconstruction algorithm (sxSPECT, Siemens Intevo) has been introduced for bone imaging, which uses the higher resolution CT matrix as the frame of reference rather than traditional SPECT matrix, producing higher resolution and sharper contrast images.

Clinical applications
The incremental benefit of SPECTCT has been demonstrated in a wide range of clinical applications and these are well described in multiple review articles. Improved sensitivity from SPECT and specificity from accurate CT localisation/characterisation are common findings that are reflected in a positive clinical impact and reporter confidence. We briefly list some of the common and emerging oncologic and non-oncologic applications of SPECTCT.

Oncologic applications
The role of SPECTCT in oncology has been eclipsed by the rapid expansion of 18F FDG PETCT, but these are complementary techniques at present due to the limited availability of non-FDG tracers in the UK. The incremental value of SPECTCT has been extensively described in the imaging of neuroendocrine tumours (NET) using the somatostatin receptor analogue 

In-octreotide (figure 1) as well as 

18F-mIBG scintigraphy. There is an increasing evidence-base for the use of SPECTCT in sentinel node lymphoscintigraphy, where accurate nodal mapping and localisation for surgery can have a positive impact on the management of breast cancer, melanoma (figure 2) and head and neck cancers.

More recently, the use of SPECTCT for therapeutic assessment of radiolabelled therapy has facilitated more accurate three-dimensional dose quantification of dose.

During the work-up of selective internal radiation therapy (SIRT), using Yttrium-90 microspheres for the treatment of non-resectable liver metastatic disease, pre-treatment “Te-MAA SPECTCT can identify potential extra-hepatic radiation toxicity, specifically to the lungs and gastric mucosa, and help calculate any dose adjustments. Post-treatment bremsstrahlung SPECTCT imaging can confirm tumoural uptake of the radiolabelled microspheres (figure 3).

Non-oncologic applications
There are a wide variety of uses for SPECTCT in the evaluation of benign diseases, particularly for problem solving or localising findings on planar imaging, for example, gastrointestinal bleeding sites during red cell scintigraphy.
or active segments of inflammatory bowel disease during white cell scintigraphy.1 One of the major benefits of SPECT/CT is in the evaluation of primary hyperparathyroidism where it has been shown to be superior to planar SPECT imaging for identifying and localising solitary parathyroid adenomas and selecting patients for minimally-invasive surgery (figure 4).2,3,5 Similarly, the use of SPECTCT in the evaluation of musculoskeletal diseases has been well documented (figure 5) including bone and joint infections, arthropathy and trauma (eg carpal bone fractures).5,6 Finally, the well-established role of SPECT for evaluating myocardial perfusion can be improved with the addition of CT to reduce attenuation-related artefacts and increase specificity.7,8 Furthermore, multislice CT allows contemporaneous calcium scoring and potentially CT coronary angiography, providing a one-stop approach to investigating coronary artery disease.

**Practical considerations**

**Training issues**

There are key training and competency issues to be considered when introducing multislice SPECT/CT, particularly within a nuclear medicine department which may be staffed by nuclear medicine technologists, radiographers and physicians with no prior training in CT. Skill mix between nuclear medicine personnel and CT radiographers is essential to bridge the gap in experience. Similarly, nuclear medicine physicians will need to collaborate with radiologists or undertake formal CT training to facilitate reporting of the diagnostic CT component of the study.

**Radiation dose**

The additional dose burden of the CT component is an important consideration, for example the effective dose can range from 1.5mSv for a low dose CT acquisition of the abdomen and pelvis, to 3-5mSv for a full diagnostic examination.9 Dose reduction technology on modern SPECTCT cameras mirror those on stand-alone CT machines including dose modulation and iterative reconstruction algorithms that can significantly reduce dose and improve CT image quality even at low mA by reducing image noise. Importantly, departments need SPECTCT protocols to guide the appropriate use of the CT component, ie localisation of activity can be achieved with low dose CT whereas higher quality images may be required for morphological characterisation in the abdomen and pelvis.10,11 Limited dose savings can also be made by reducing the injected dose of radionuclide, in lieu of shortening acquisition time, when using newer iterative SPECT reconstruction and resolution recovery algorithms.

**Workflow issues**

Traditional workflow patterns and patient scheduling are likely to be disrupted by the availability and use of SPECTCT, especially for ad-hoc problem solving of abnormalities on planar imaging (eg on bone scintigraphy). However, some studies will require SPECTCT regardless of planar findings, such as parathyroid scintigraphy, and can be scheduled accordingly. Nevertheless, SPECTCT will have a significant impact on departmental efficiency and patient throughput. Typically, a whole-body planar bone scan can be acquired in 20-25 minutes whereas a single section (40cm) SPECTCT can take a similar period of time. Iterative reconstruction and resolution recovery algorithms, as discussed earlier, can help reduce SPECT acquisition times but new workflow, vetting and decision-making processes need to be set in place to maximise patient benefit and throughput while minimising longer waiting times.

Potential benefits for radiology departments with lower volume nuclear medicine workloads will be the availability of an additional CT scanner and indeed the possibility to streamline patient pathways. For example, breast cancer patients could have a staging bone scan and CT performed at the same time rather than two separate attendances.

Finally, additional reporting time for radiologists/physicians and reimbursement are important considerations when transitioning from gamma camera or low-dose SPECTCT work to more complex multislice SPECTCT, where the diagnostic CT images require formal reporting. This is particularly topical in the current period of budgetary constraints and service level agreements between hospital departments and NHS trusts.

**Future prospects**

PET/CT is a whole-body imaging technique that offers greater resolution and faster acquisition times with a range of potential tracers that can replace almost all current gamma camera work (eg 18Fluoride for bone imaging, 123Iodine for neuroendocrine tumours). However, the limited availability of these non-FDG tracers and uncertain funding sources remain a significant hurdle to overcome in the short to medium term. Currently, SPECTCT offers a wider range of clinically-available tracers, lower cost and greater accessibility in most nuclear medicine departments around the UK. There is continuing development of new SPECT tracers for clinical and research purposes (eg angiogenesis, drug receptor and binding ligands), and SPECTCT offers the unique advantage of multi-parametric nuclear medicine imaging, eg dual-tracer imaging to simultaneously evaluate two processes at the same time using different radioisotopes, eg Technetium and 111Indium.

**Conclusion**

Modern day SPECTCT is a true multimodality technique that combines functional and morphologic imaging and has been shown to be of clinical benefit in a wide variety of oncologic and non-oncologic applications. Several practical issues around training, radiation dose and workflow need to be addressed when transitioning to multislice SPECTCT, although some of these can be offset by technological advances in hardware and software design, many taken from PET/CT. Hopefully the replacement of older gamma cameras with new SPECTCT machines will provide greater accessibility and benefit of this valuable technique that is currently overshadowed by the success of PET/CT.

**References**


Figure 1
111In-octreotide-avid neuroendocrine tumour of the terminal ileum. Coronal MIP reconstruction of the SPECT. (A) shows an octreotide-avid focus in the right side of the pelvis. The fused SPECTCT (B) localises this to the terminal ileum (arrow), and identified further octreotide-avid nodules in the distal small bowel not apparent on the planar image (not shown). Contemporaneous contrast-enhanced, high resolution CT confirms the presence of hyper-enhancing nodules (arrow) at these locations in the distal small bowel.

Figure 2
99Tc-nanocolloid lymphoscintigraphy for a right shoulder melanoma. Radiotracer was injected at the site of the melanoma excision in the right posterior shoulder. Anterior and right-lateral planar views (A,B) demonstrated tracer uptake at the melanoma excision site and multiple adjacent lymph nodes which are difficult to localise. SPECTCT accurately localises these to sentinel nodes in right neck level V and right axilla (other sites not shown), providing a clear road map for the surgeon.
Figure 3
Bremsstrahlung imaging post-selective internal radiation therapy (SIRT) with intra-arterial \(^{90}\)Yt resin microspheres for infiltrative cholangiocarcinoma. Following selective \(^{90}\)Yt microsphere radio-embolisation, the SPECT (A) and SPECTCT (B) images confirm isolated activity at the known tumour site in the right lobe of liver, as demonstrated on the pre-treatment contrast-enhanced CT (C).

Figure 4
\(^{99}\)Tc-sestamibi scintigraphy showing an ectopic parathyroid adenoma on low-dose SPECTCT compared to high resolution, contrast-enhanced SPECTCT. The 90-minute delayed planar (A) and SPECT (B) demonstrate a focus of persistent tracer uptake in the superior mediastinum compatible with an ectopic parathyroid adenoma (black arrow) as well as an incidental left thyroid nodule (white arrowhead). The low-dose CT and fused SPECTCT (C, D) localise the adenoma as a small nodule in the right tracheo-oesophageal groove (white arrow). Whereas a subsequent high resolution contrast-enhanced CT (E) and software fused SPECTCT (F) more accurately localise an elongated retro-tracheal parathyroid adenoma (white arrow).
Figure 5

$^{99}$Tc-HDP SPECTCT using high resolution CT for anatomic localisation and characterisation in active enthesopathy. Young female athlete with left buttock and hip pain referred for a bone scan following negative morphologic imaging. Axial SPECT (A) and fused SPECTCT images (B) demonstrate an asymmetric increase in tracer uptake in the left ischial tuberosity in keeping with hamstring enthesopathy. The high resolution CT images and earlier T2-fat saturated MRI (C) did not show any associated bony abnormality.