

SPECT-CT and its role in imaging and oncology

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Introduction

Nuclear medicine has been engaged in considerable transformational change; this is particularly true in the current decade. In part, this is due to developing technology, software algorithms, disease management pathways and models, and evidence based medicine. The merging of functional and anatomical technologies ('hybrid imaging', for example, SPECT-CT) is beginning to provide a more focused approach to disease management.

Within current clinical practice, various types of computed tomography (CT) configurations are available for purchase with a SPECT system, and the workload of a department as well as its financial constraints will have an influencing factor on the final specifications of such a purchase¹. Historically, low resolution/dose, single slice CT units (eg GE Hawkeye) provided an initial platform to undertake routine clinical hybrid SPECT-CT imaging; more recently the advent of multi slice high resolution (diagnostic quality) CT has resulted in nuclear medicine centres utilising this technology in routine SPECT-CT clinical practice.

This article focuses on several aspects of SPECT-CT that appear to have particular importance within clinical practice. First, through case illustrations, an indication of where SPECT-CT has value is given; a debate is then raised about the added radiation dose that is incurred through CT. Building on this, the scope of practice of radiographers is considered in light of practitioner and referrer status² for the CT component of SPECT-CT and, finally, education and training and business planning matters are considered.

Areas in which SPECT-CT has value

Attenuation Correction

An obese 43 year-old female who had experienced left sided chest pain underwent an exercise tolerance test (with ECG); no ST depression was noted. The origin of her cardiac related pain was required and, consequently, the patient underwent stress and rest myocardial perfusion imaging (MPI; see figure 1). The images shown are rest only; row A is not attenuation corrected (AC); row B is with CT AC applied. On comparing rows A and B, the attenuation induced photon deficient artefact (on the non AC images) is corrected on the CT AC images, so ruling out potential myocardium infarction (the stress study demonstrated similar photon deficient areas on the non AC images). This is an interesting case as the resting CT AC images rule out any problem in the inferior wall but pinpoint the problem in the anterior wall. This case illustrates that the use of attenuation correction in MPI should only be used as a tool to support decision making in relation to establishing the presence of attenuation artefacts³.

For certain SPECT studies non-homogeneous photon attenuation within the chest

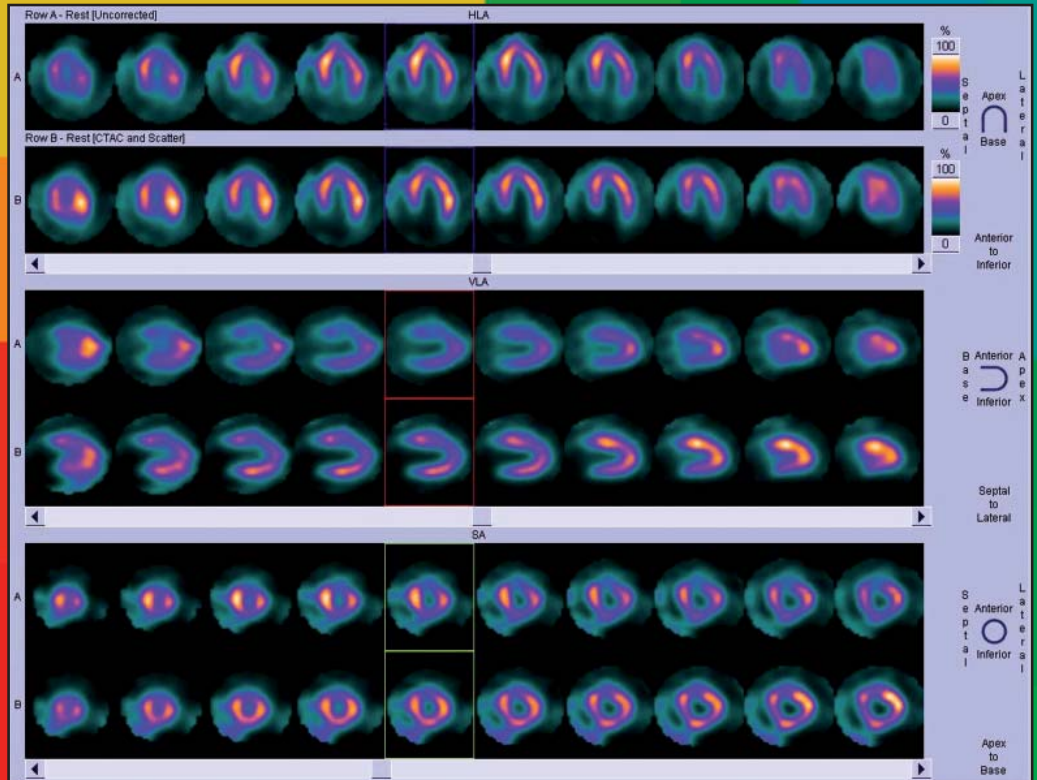


Figure 1. Myocardial perfusion scan, rest images only. Row A = no AC; row B = CT AC applied.

and abdomen has made diagnosis difficult. Non-homogenous attenuation can affect sensitivity and specificity. To counteract this, AC can be used to counteract attenuation artefacts. Attenuation is an exponential process (linear attenuation coefficient); when measured, the value depends upon the proportion of scatter included in the measurement⁴. In SPECT imaging, the spatial distribution of the linear attenuation coefficient data and impact upon the raw projection data is unknown, and additional information (such as the information provided from CT) is required to correct for the effects of attenuation and/or scatter³.

Evidence suggests a necessity to interpret attenuation corrected studies as part of an overall quality control process³. This may include various steps but the added value of attenuation corrected images should be considered as part of the complete imaging process, and to aid the overall clinical decision making process. In terms of clinical studies which have utilised AC for cardiac imaging, the majority include small to medium sample sizes. Although Ficaro et al's study in 1995⁵ included a limited number of patients (n=10), lateral-to-posterior and basal-to-apical wall ratios of near unity value were demonstrated using AC. The use of AC is further supported in more recent research, also undertaken by Ficaro et al in 2002⁶.

CT can be used with SPECT to localise cold or hot areas

Additional studies by Prvulovich et al in 1997 and Hendel et al in 1999 demonstrated improvements in diagnostic specificity in patients with follow-up angiography, in comparison with non-attenuation corrected images^{7,8}. It should, however, be noted that these studies were all conducted using radioisotope and transmission based attenuation correction units, not CT. In terms of the impact of attenuation correction on diagnostic sensitivity of MPI, Duvernoy et al's study on 28 patients with left main coronary artery disease in 2000⁹ showed this to be present on 64 per cent of AC images versus seven per cent of uncorrected images.

In the 1980s, the use of external transmission sources such as Ba-133 and Gd-153 were utilised to provide attenuation correction data. However, issues related to poor statistical quality has resulted in a limited use of such sources within modern clinical practice. Nevertheless, in clinical instances whereby only AC is being performed, as in nuclear cardiology for example, the use of a transmission-based system may be justified. Acquiring the required AC data using a transmission based system such as Gd-153 takes longer than a CT based method due to the large difference in available photon flux and the fact that transmission based systems have a limited field of view coverage³.

CT data may be used to create linear attenuation coefficients based upon anatomical detail specific to each patient. This data (attenuation map) may be used to correct for the effects of photon attenuation within the subject and, if only AC is being undertaken (eg myocardial perfusion imaging), the CT may be acquired with a lower statistical quality. Although this reduces the spatial resolution, this technique reduces the radiation dose to the patient.

With reference to oncology-based applications, CT AC has particular values. SPECT imaging is increasingly used to quantify the uptake of a particular radiopharmaceutical within tumours/organs. Such targets are quantified in SPECT as volumes of interest (VOI); these are defined around the region to integrate the number of counts, which is directly proportional to the activity (expressed as MBq or mCi) in the volume defined¹⁰.

Accurate quantitative measurement of radioactivity from a SPECT study can be compromised by the effects of attenuation (and scatter). Such factors may be corrected by the use of CT AC data. The use of SPECT-CT is beginning to create a new role for nuclear medicine in terms of accurately quantifying radionuclide uptake within targets, compared to measurements undertaken with SPECT alone. Results from clinical studies^{11,12} have demonstrated the value of SPECT-CT in terms of measuring response to radiotherapy treatment for patients with non-Hodgkin's lymphoma and radioimmunotherapy. The use of SPECT-CT within oncology is beginning to replicate clinical experience with PET-CT, in terms of improving localisation and extent of disease, and differentiation of physiological and pathological uptake.

Localisation

CT (low resolution or diagnostic quality) can be used in conjunction with SPECT to help localise cold or hot areas seen on SPECT imaging. This has particular value in cases where there are limited or no anatomical landmarks present on SPECT imaging and/or when such landmarks are present but greater anatomical spatial resolution is required. Examples with the registration of SPECT with CT for localisation purposes could include: to aid definitive diagnosis and to give more precise lesion localisation as part of surgical work up, such as sentinel lymph nodes¹³, radiotherapy treatment planning¹⁴ or initial patient treatment work up¹⁵ (eg neuroendocrine tumours (NET)).

Advancements in computing power and software algorithms have also impacted upon the ability to compensate for the errors in SPECT imaging. In particular the inclusion of an iterative reconstruction model (eg OSEM) for the correction of attenuation with SPECT data and providing quantitative information is becoming more common within clinical practice¹⁰. Numerous studies have identified the improved diagnostic accuracy of SPECT/CT over conventional SPECT imaging and the empirical evidence points toward the following areas of clinical practice which have benefited from the emerging hybrid imaging technology, for example:

- Lymphoma¹⁶
- Lung Cancer¹⁶
- Primary and secondary malignant bone disease¹⁷
- Infection and inflammation¹⁸
- Abdominal disease¹⁹
- Endocrinology^{15,20}

A comprehensive list of potential clinical applications for SPECT-CT has previously been published¹⁰ and the majority of applications relate to the anatomical localisation of tumours using various radiopharmaceuticals. Published research by Koral et al identified the added value of SPECT-CT in terms of providing valuable tumour organ uptake and dosimetry data, enabling accurate patient workup prior to treatment for lymphoma^{11,12}. This research involved a range of professional fields and provides evidence of multiprofessional working.

Case study

An eight-year-old male presented with a painful right tibia; the clinical question surrounded whether this patient had an osteoid osteoma or leukaemia. A whole body bone scan was conducted (anterior and posterior) and a focal area of uptake was noted within the right femur. Subsequently, localised SPECT images of pelvis and femora were acquired; the poor resolution could not differentiate the high uptake between cortex and medulla and CT imaging was undertaken (see figure 2). Correlation with plain films and a SPECT-CT acquisition of the area show a localised area of thickening and sclerosis of the medial cortex of the upper right

femoral shaft, and a small central lucent nidus with a surrounding sclerotic rim. The features are consistent with an osteoid osteoma.

Surgical resection of certain pathologies often requires quite precise localisation of lesions prior to surgery. This helps the surgeon locate the area to be removed more quickly; it also helps the surgeon plan more accurately which areas need

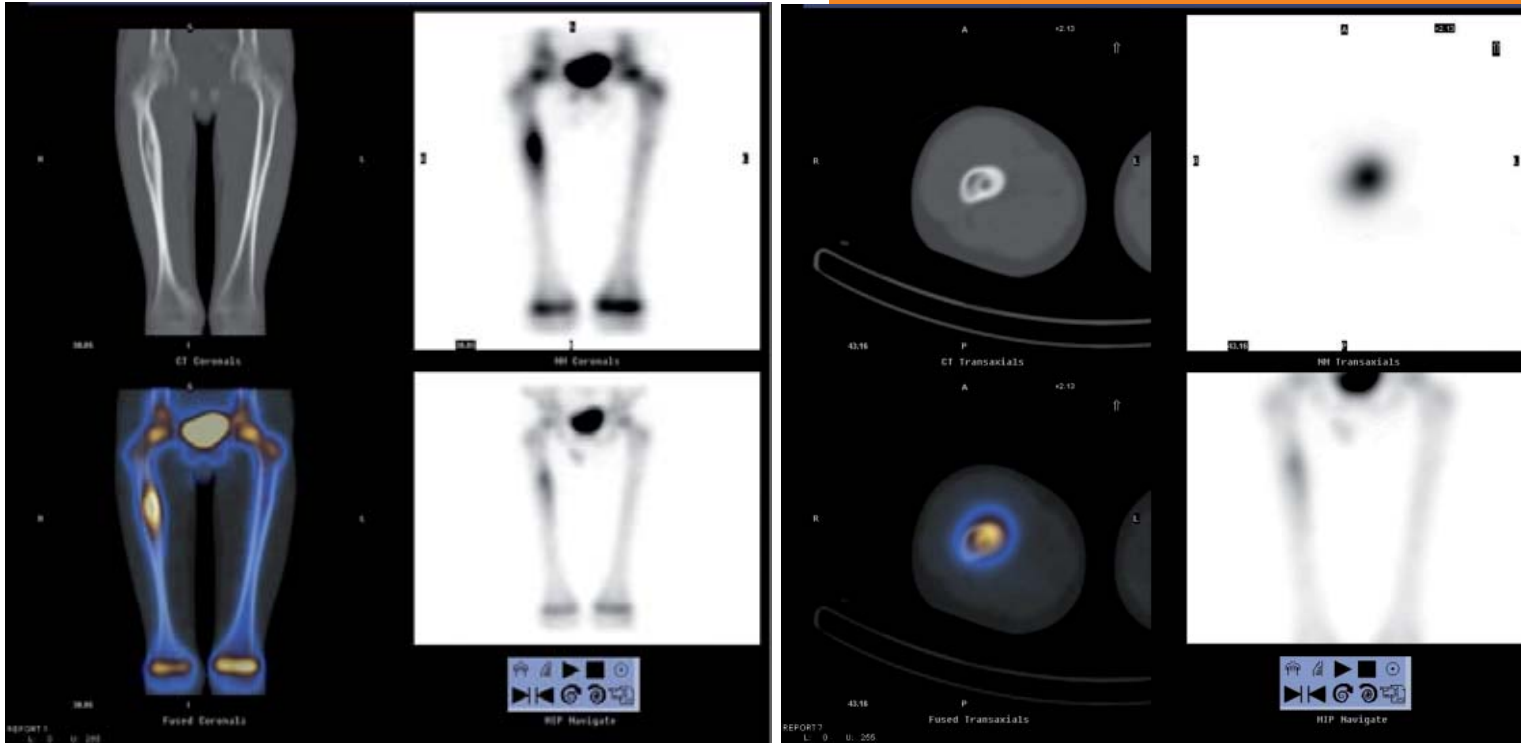


Figure 2.

to be removed. Better intelligence prior to and during surgery results in increased probability of removing the affected tissue and reduced operating time. Both can have an impact on post-operative recovery and, ultimately, patient outcome.

Low dose/resolution and high dose/resolution can both play a part in localising lesions seen on SPECT studies, and the precise overlay of regional anatomy, together with co-registered SPECT-CT (structural and functional aspects) of the lesion make for better surgical localisation, possible radiotherapy treatment or, even, extraction of tumour tissue. For example, SPECT-CT of brain tumours using a range of Tc99m based radiopharmaceutical agents, such as Sestamibi and Tetrofosmin and In-111 Pentetreotide, may be utilised to provide accurate functional and anatomical diagnosis, and monitor patients' responses to

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radiotherapy/chemotherapy treatment. CT used in isolation cannot always distinguish tumour progression from radiotherapy damage/necrosis, even up to several months after the patient has received treatment¹⁴.

Various empirical studies and critical reviews have demonstrated the additional value of SPECT-CT over stand alone SPECT systems, particularly in cases such as lymphoma^{21,22}, infection and bone disease¹⁷. However, there appears to be a debate relating to the appropriate use of low dose CT for attenuation correction and/or basic localisation purposes (which were the parameters of a low performance x-ray scanning device) and higher quality CT data for improved anatomical image quality. Roach et al's study in 2006²³ was conducted using a multislice SPECT-CT unit which permitted greater spatial resolution for the anatomical data. Although the overall final diagnosis and reporter confidence was improved using a multislice SPECT-CT unit, the increase over first generation low-performance SPECT-CT units was minimal.

Diagnosis using diagnostic quality CT

SPECT-CT has a role in diagnosis, particularly when 'targeted' SPECT imaging reveals lesions with no surrounding discernable anatomical landmarks (for localisation) and also when the internal structure of the SPECT lesion needs additional radiological (high resolution CT) scrutiny to determine its nature. An example could be differentiated thyroid cancer, using whole body imaging with iodine 123 or 131. Here, the precise localisation of lesions is often not possible because of the absence of anatomical landmarks in nuclear medicine data. Co-registered SPECT-CT allows for differentiation between artefactual and normal uptake, and pathological uptake.

Research conducted by Roach et al highlighted the value of SPECT-CT in terms of diagnostic accuracy and reporter confidence within clinical practice²³. This evaluation of the impact of SPECT/CT on common areas of clinical practice, such as bone scintigraphy, infection imaging (Gallium-67), Indium-111 octreotide scans, I-123/1-131 MIBG scans/treatment monitoring, and Tc-99m Sestamibi parathyroid scans, reflected a typical nuclear medicine department workload. Overall, the utilisation of SPECT-CT added extra confidence to the final diagnosis, and reporter confidence was also increased in particular cases where anatomical landmarking would have been an issue without the CT data. The following case study demonstrates the clinical value of diagnostic accuracy using SPECT-CT.

Case Study

A 78 year old female had known multiple liver metastases from a carcinoid tumour and Yttrium-90 therapy was being considered. An In-111 octreotide SPECT-CT scan was conducted (see figure 3). As can be seen, the images demonstrate liver metastases, incidental adrenal gland findings and hydronephrosis. The

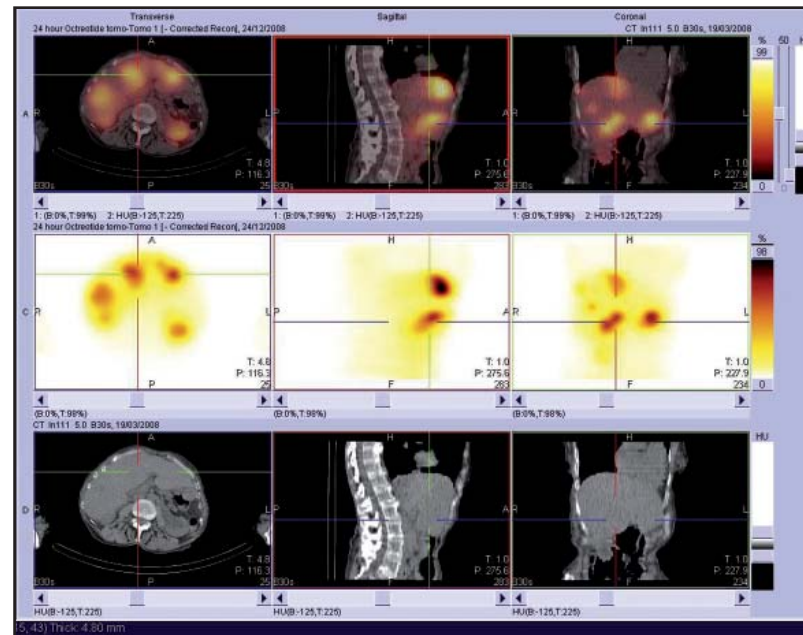


Figure 3. Radiation dose from CT

morphological appearance of the metastases can be clearly located on the diagnostic quality CT image series, giving heightened confidence for areas of radiopharmaceutical uptake.

One of the biggest considerations of using low resolution or high dose CT scans in addition to SPECT is the additional radiation dose to the patient and whether or not the extra dose from using high-resolution CT is justified, bearing in mind the extra clinical information that may be obtained. Table 1 illustrates radiation doses that a patient will typically receive from SPECT, low-resolution and high-resolution CT, and plain radiography for reference. As can be seen, the CT component adds a significant amount to the total dose the patient receives; this is particularly true for high resolution CT. It is interesting to compare plain film and high resolution CT and the dose differential. This brings into sharp focus the need to consider carefully whether CT or plain film imaging would give the same radiological information and, if so, whether the lower dose alternative (plain film) would be better justified.

Professional responsibilities and legislative considerations

Depending upon local circumstances in clinical imaging departments, radiographers can be referrers, practitioners and operators within the context of the Ionising Radiation (Medical Exposure) Regulations² (IR(ME)R). Within nuclear medicine and with regard to radiopharmaceuticals, this is not the case. Radiopharmaceuticals are regulated

Radiographers have adopted the roles of referrer, practitioner and operator

	Imaging and Dose (mSv)							
	SPECT [i]		Low-Res CT ^[ii]		High-Res CT ^[iii]		Plain Film ^[iv]	
Pulmonary Nodes	Tc-99m Depreotide	6	Chest	1	Chest	5.8	Chest	0.02
Lumber Spine Metastases	Tc-99m phosphonate	5	Abdo + pelvis	1.5	Abdo + pelvis	7.1	Lumber Spine	1.3
Myocardial Imaging	Tc-99m sestamibi	4	Chest	1	Chest	5.8	Chest	0.02

Table 1.

[i] Notes for Guidance on the Clinical Administration of Radiopharmaceuticals and Use of Sealed Radioactive Sources Health Protection Agency, Administration of Radioactive Substances Advisory Committee, March 2006 (Revised 20 April 2006).

[ii] Effective doses to patients from CT acquisitions on the GE Infinia Hawkeye: a comparison of calculation methods. Sawyer, L et al. Nuclear Medicine Communications. 29(2):144-149, February 2008.

[iii] Doses from computed tomography (CT) examinations in the UK – 2003 review Shrimpton PC et al. NRPB-W67 March 2005.

[iv] RADIATION PROTECTION 118 Referral guidelines for imaging, European Commission 1999.

under both medicines and ionising radiation legislation and the former mandates that only a registered dental or medical practitioner may direct the clinical service and, as such, provide the clinical justification required under IR(ME)R. For nuclear medicine examinations, with regard to IR(ME)R, only the ARSAC licence holder may justify clinical examinations. Radiographers working within nuclear medicine and with specific reference to radiopharmaceuticals may only act as operators.

Within nuclear medicine departments, legislative arrangements permit radiographers to act as practitioners and referrers for x-ray examinations and acting as referrer for plain x-ray examinations, in association with nuclear medicine procedures, has become common practice. Using the same legislative arrangements, radiographers can, indeed should, act as referrer and practitioner for the CT component of SPECT-CT. There is logic for both as SPECT-CT has limited routine applications. For many patients, the decision to make a CT exposure (low or high resolution) will depend on factors such as the clinical background, physical make up and the nuclear medicine images themselves. Hence, the decision to refer for CT may only be made at the point of care within the nuclear medicine department. Therefore, the radiographer is ideally placed to fulfil the role of referrer. In full knowledge of the evidence base and the clinical background, a radiographer can act as practitioner, thereby protecting the patient from unnecessary x-radiation exposure. On discussion with several nuclear medicine departments, it was found that radiographers have already adopted formally the roles of referrer, practitioner and operator for the CT component of the SPECT-CT studies.

Business, practical and educational considerations when purchasing a SPECT-CT system

A department should consider the physical footprint required for a hybrid SPECT-CT system. This is especially true if the existing gamma camera has a small footprint. Some clinical departments within the United Kingdom are

replacing first generation SPECT systems with SPECT-CT units, which generally require a larger physical space. The space required for a SPECT-CT system will depend on the type of unit being installed and the nature of the examinations conducted. The quoted minimum room size for a GE Hawkeye/Hawkeye-4 is 14 feet x 16 feet and the amount of lead shielding required for this environment may be less than a dedicated CT unit. Some departments utilise mobile lead shielding devices for the GE Hawkeye devices which permits some flexibility with the organisation of the imaging environment. The exposure rate from low performance CT units is approximately 20 times less than that from a multislice CT unit²⁴ and the use of mobile shields are common in departments with these units.

A larger physical room environment (minimum 15 feet x 24 feet) is required for SPECT-CT systems employing a dedicated multislice CT unit, and thicker protective shielding is required for the use of multislice SPECT/CT units. The weight bearing parameters of the floor should also be considered²⁴, especially if the unit is not being installed on the ground level within a hospital. Separate operator console environments are also becoming common within SPECT-CT rooms, although this does remove an element of patient interaction normally associated with nuclear medicine.

Currently the cost of the high end CT components (eg 64 slice) may exceed the cost of the SPECT device and the justification for such units will depend upon the clinical workload of a nuclear medicine department. With current shifts in imaging tools for certain conditions (eg pulmonary embolism), a SPECT-CT unit with multislice capabilities may be positioned to undertake contrast enhanced CT scans, such as pulmonary angiography and the assessment of coronary calcification^{10,25} and, potentially, providing a 'one stop' approach for patients undergoing their diagnostic CT and physiological scans, if required.

Nuclear medicine departments may wish to evaluate the feasibility of undertaking CT examinations during periods where access to radiopharmaceuticals is limited (eg early morning/late afternoon), or utilising the CT component of the hybrid unit for out-of-hours work to alleviate some of the demands on the radiology department's main CT unit. This may require some degree of cross pollination of training requirements²⁶ and the development of appropriate educational curriculum within the workplace and at academic institutions. Educational programmes for nuclear medicine technologists in North America and Australia provide focused academic and clinical training specifically related to the utilisation of CT within the nuclear medicine environment.

In the USA, working relationships between the Society of Nuclear Medicine Technologists and the American Society for Radiologic Technologists are considered to be a good example of a synergistic approach to the training requirements between professions. The University of Sydney in Australia also offers a dedicated distance based CT module aimed at nuclear medicine technologists who are involved in using CT within a nuclear medicine environment. In the UK, there is limited scope for the provision of a dedicated hybrid imaging programme. However, short courses for technologists related to the safe use of CT, and hybrid imaging modules of study have emerged from two academic institutes over the last couple of years. Currently, it is unclear what CT training requirements are needed officially by a technologist working within the hybrid nuclear medicine field, especially if the CT unit has a multislice configuration and the imaging parameters are interchangeable. A clear educational strategy is required for the safe and optimal use of CT within a hybrid nuclear medicine environment, to minimise patient dose and optimise disease detection, aiding patient management.

Conclusion

Following the inception of SPECT-CT hybrid technology, there appears to be an evolution in the useful applications associated with this modality. Initial 'low-end' systems introduced over a decade ago provided a platform for improved anatomical localisation and high photon-flux attenuation co-efficient data, potentially improving the sensitivity and specificity of existing imaging techniques. Beyond the existing techniques, SPECT-CT has the potential for mirroring the success of PET-CT in terms of radiotherapy planning, dosimetry calculations and multi-imaging approaches, which include coronary artery calcium scoring and myocardial perfusion imaging.

As detector technology also continues to evolve, the overall design and utilisation of future SPECT/CT units may further develop. The use of solid state materials such as cadmium-zinc-telluride will provide a single detector interface and, potentially, improve the functional count rate and spatial resolution further. The training and

education of the hybrid imaging workforce is crucial to the future utilisation of this important area of clinical practice.

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