SPECT – CT physics and instrumentation

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This presentation will build on the previous talk given by Prof. Peter Hogg on "Is SPECT-CT the new gamma camera?" It will focus on the physics and equipment of SPECT-CT with particular emphasis on CT and its use in functional imaging. Prior knowledge of nuclear medicine principles and SPECT imaging techniques will be assumed.

Basic Principles of SPECT Imaging

SPECT allows visualisation of the functional information about a patient's specific organ or body system. It is a tomographic nuclear medicine imaging technique that produces cross-sectional images from gamma ray emitting radiopharmaceuticals.

The emitted gamma rays are detected by a gamma camera, the gamma camera then rotates as data is collected. The collected data is then reconstructed via filtered back projection or iterative reconstruction to obtain 3-dimensional images of the bio-distribution of the radiopharmaceutical within the patient.

Basic Principles of CT Imaging

All x-ray imaging is based on the differential absorption of x rays as they pass through the different parts of a patient's body. Depending on the amount absorbed in a particular tissue such as muscle or lung, a different amount of x rays will pass through and exit the body. The transmitted x-rays are detected by an image receptor and provide a 2-dimensional projection image of the tissues within the patients' body.

CT is also based on the variable absorption of x-rays by different tissues; however CT provides 2-dimensional axial, or cross-sectional, images. These cross-sectional slices are images that are taken along the body, and are then added together to create a 3-dimensional image.

The main housing of a CT scanner is known as a gantry. This contains the X-Ray tube which rotates through 360° at a typical speed of 1 rotation per second. Also housed within the gantry is a bank of detectors that detect the amount of x-rays that are transmitted through the patient.

The x-ray tube produces a narrow, fan-shaped beam of x rays which irradiates a section of the patient's body. If we consider the X-ray tube stationary at the top of the gantry (0°), the X-rays emitted from the X-ray tube are variably absorbed, depending on what tissue the x-ray beam has passed through. The amount transmitted is detected by the row of detectors. This information is known as a projection. The X-ray tube then moves to the next rotation point and another projection is taken, and so on around the patient, building up projections around the 360° rotation.

These projections are then reconstructed via filtered back projection to give a 2 dimensional map of the attenuation coefficients within a cross sectional slice of the patient. Each element of the attenuation map is known as a voxel, and has a grey scale value that represents the attenuation properties of the tissue contained within that voxel. The value within the voxel is known as the CT number, which is then compared to the CT number for water to give a number known as a Housfield unit (HU).

Another important part of the CT scanner is the patient table, which moves through the gantry as the x-ray tube is rotated which means that the projections create a "spiral" or "helix" around the patient. Hence the terms spiral or helical CT. Further developments in CT include multi-slice which obtains multiple projections along the length of the patient simultaneously. Both spiral and multi-slice developments have lead to CT being an incredibly fast imaging modality, with examinations being acquired within a single breath hold.

Basic Principles of Hybrid SPECT-CT

In hybrid SPECT-CT a CT unit and a gamma camera share the same patient table. This combination allows the acquisition of the SPECT and CT information sequentially in a single patient study with the patient ideally in a fixed position.

Attenuation Correction

One of the main uses of CT when combined with SPECT is for a process known as attenuation correction. When structures lie deep within tissues the tracer concentration will appear reduced due to absorption of the photons by the tissue. Approximately 70% of 140keV photons are absorbed in 10cm of tissue. For example, if two structures have equal concentration, but one is located on the surface and one is located at depth, the one at depth will appear to have a lower concentration of tracer compared to the one at the surface. Additionally, if the attenuation of tissues around a structure varies, the structure will be spatially distorted, seemingly having higher concentration in areas of lower attenuating tissues. This could mean that measurement of lesion sizes become unreliable.

To overcome these issues, the attenuation coefficient values obtained from the CT scan are incorporated into the reconstruction algorithms of the SPECT images, this corrects for the absorption of the photons emitted by the tracer.

Image Registration and Fusion

Image registration is the process in which the two image data sets (the SPECT images and the CT images) are brought into geometric alignment. The aim of image registration is to find the transformation between the two coordinate systems. In other words, the question is: how much must the SPECT images be rotated (3 rotations about the orthogonal axes) and how far must they be shifted (3 translations) until it is in agreement with the CT images?

As the images are taken sequentially within the same unit, the image registration in a hybrid SPECT-CT scanner is automatic, based on parameters set during the calibration of the unit.

Image fusion is the combination of the images to give one image dataset to provide both anatomical and structural information. The images can be fused in several ways. They can be overlaid, where the images are displayed one on top of the other. The image on top has to be selected carefully, as if there are high counts in one area, this will cover the data from the other image.

The images can be merged, where a single image is created with a single pixel value that is generally a weighted sum of the two corresponding pixel values. The images can also be interlaced, where alternate pixels are taken from the images to build up the new image. The image will seem merged, as the resolution capability of the human eye cannot differentiate the pixels. The images can also be simply displayed side by side, with markers indicating structures to enable localisation.

Quality Control (QC)

There are general quality control procedures of the gamma camera and CT scanner separately as described below.

The regular CQ tests for SPECT include: Energy peak, uniformity, resolution, centre of rotation.

For CT, there are tests performed at acceptance and during annual QC, and daily QC test. The acceptance/annual test are listed below, they will not be discussed in this talk.

Parameter	Test
Tube	kV
	Half Value Layer
Image Quality	Noise
	Uniformity
	CT number (HU) accuracy
	Contrast detectability
	Resolution
	Mechanical Registration
Patient Dose	Slice Thickness accuracy
	CTDI

Daily QC tests on a CT scanner involve the use of a water or water equivalent cylindrical phantom.

The first test involves calibrating the detectors using single slice taken in air and a single slice taken in the water phantom. From these measurements the Housfield units can be calculated.

The single slice in water is also used to check the noise levels, which is the variation in pixel values, and also the uniformity, where the pixel values should be the same across the whole phantom.

In addition to performing quality assurance of the CT scanner and gamma camera, it is important to routinely verify the accuracy of the image registration. Errors in registration will cause inaccuracies in attenuation correction and improper fusion of anatomy and function. All manufacturers recommend the scanning of an image registration phantom at a recommended weekly or monthly frequency.

Phantoms commonly used are of a cylindrical construction containing section, or syringes, filled with radioactivity. The phantom is scanned sequentially with the CT scanner and gamma camera, and errors are calculated between the measured centre locations of the syringes. These measurements are then compared with the acceptable errors for the system (typically 3–5 mm) to verify that the registration accuracy is sufficient for clinical applications. For some systems, it is recommended that the table is weighted down to simulate a clinical situation.

Problems related to SPECT-CT

As the images are taken sequentially and not simultaneously, there is the potential for patient movement to occur during the time between the two modalities.

Also, the acquisition times are vastly different between the two modalities. A CT scan can take seconds and can be acquired within a breath hold, whereas a SPECT scan can take 15-20 minutes, and the images are averages over the respiratory cycle. This can create a misalignment of the SPECT and CT information, especially in the diaphragm region. This leads to problems not only with image registration/fusion, but also with attenuation correction.

These issues can potentially be overcome by using a slower CT scanning system, however this would create long scanning times, which causes discomfort for the patient and increases risk of patient movement.

Motion modelling and 4D gated CT are suggested ways of overcoming this issue in the future.

Doses in SPECT-CT

One of the biggest considerations of using low resolution or high dose CT scans in addition to SPECT is the dose to the patient and the justification of the extra dose, bearing in mind the extra information obtained.

Below is a table of doses that a patient will typically receive from SPECT, low-resolution and high-resolution CT, and plain radiography for reference.

	Imaging and Dose (mSv)							
	SPECT[1]		Low-Res CT		High-Res CT[2]		Plain Film[3]	
Pulmonary Nodes	Tc-99m Depreotide	6	Chest	1	Chest	5.8	Chest	0.02
Lumber Spine Metastases	Tc-99m phosphonate	5	Abdo + pelvis	1	Abdo + pelvis	7.1	Lumber Spine	1.3
Myocardial Imaging	Tc-99m sestamibi	4	Chest	1	Chest	5.8	Chest	0.02

[1]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)

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

[3]RADIATION PROTECTION 118 Referral guidelines for imaging European Commission 1999

References

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2. Farr's Physics for Medical Imaging 2nd Edition by Penelope J. Allisy-Roberts and Jerry Williams, Saunders Ltd, Nov 2007
3. Hybrid SPECT/CT Imaging in Clinical Practice by Ora Israel (Editor), Stanley J. Goldsmith (Editor), Marcel Dekker Ltd, May 2006