2.2 SINGLE PHOTON EMISSION COMPUTED TOMOGRAPHY (SPECT)

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Images of the biodistribution in the body of injected radiotracers created using a gamma camera (figure 1) can provide information about the function of tissues. Such 2D images, known as planar scintigrams, are degraded by the superposition of non-target activity from the 3D body which restricts the measurement of organ function and prohibits accurate quantification of that function. Single photon emission computed tomography (SPECT) is a technique whereby cross-sectional images of tissue function can be produced allowing the removal of the effect of overlying and underlying radioactivity (Larsson 1980, Williams 1985, Croft 1986, Ott 1986).

Fig.1. Schematic diagram of the production of radionuclide images using a gamma camera

SPECT involves the use of radioisotopes such as $^{99m}$Tc, where a single $\gamma$-ray is emitted per nuclear disintegration. This is in contrast to positron emission tomography (PET) which makes use of radioisotopes such as $^{18}$F, where two $\gamma$-rays, each of 511 keV, are emitted simultaneously when a positron from a nuclear disintegration annihilates in tissue. SPECT images are produced from multiple 2D projections by rotating one or more gamma cameras around the body to achieve complete 360° angular sampling of photons from the body. Reconstruction using methods similar to those used in x-ray CT provides 3D data sets allowing the tracer biodistribution to be displayed in orthogonal planes. The advantages of SPECT over planar scintigraphy can be seen in the improvement of contrast between regions of different function, better spatial localisation, improved detection of abnormal function and, importantly, greatly improved quantification. In general SPECT images have poorer spatial resolution than the 2D images used to produce them.
Clinical applications of SPECT include evaluation of function of the brain, heart, skeleton, liver, lung and kidneys.

Fig. 2. Transaxial sections through a $^{99m}$Tc Ceretech brain scan of a normal brain

In the brain SPECT is used to measure cerebral blood flow and brain patency in patients with stroke and tumour. Figure 2 shows the uptake of the blood flow tracer $^{99m}$Tc Ceretech in the normal brain indicating the differential blood flow in grey and white matter which is known to be ~4:1. In a patient with reduced blood flow after stroke, the size of the abnormal region and the level of residual blood flow may help to differentiate between ischaemic and infarcted tissue.

In figure 3, the uptake of the same tracer in the brain of a patient with cerebral glioma is illustrated, showing an ill-defined lesion with some peripheral enhancement on x-ray CT which is clearly well-perfused from the SPECT scan, indicating viable tumour in the region of low x-ray contrast. This result will affect the treatment of the lesion which is expected to be more sensitive to radiotherapy than if it was poorly perfused. Radiolabelled receptor ligands have also been used in SPECT to evaluate receptor density and the effect of drugs in the treatment of patients with psychiatric diseases such as schizophrenia.

In cardiology, SPECT using either $^{201}$TlCl or $^{99m}$Tc sestamibi is used to assess the viability of the heart muscle to help differentiate between ischaemia and infarction. Both these tracers mimic the perfusion of the left ventricle and the use of SPECT highlights regions of poor flow during stress. These regions of the heart will reperfuse post stress if the tissue is ischaemic rather than infarcted. Figure 4 shows uptake in the left ventricle of a normal heart (bottom) in comparison to the top image which
shows the effect of poor perfusion in the posterior wall of the ventricle. This type of
information is important in aiding the treatment of patients with cardio-vascular
disease – especially to determine if a bypass grafting is warranted for those patients
with ischaemic disease in contrast to transplant which might be indicated for the
seriously infarcted heart. These studies are also used in patients with suspected
stenosis, hypoxia, aneurism or cardiomyopathy.

Fig.4. Perfusion of the left
ventricle of (top) a heart showing
a posterior wall perfusion defect
and (bottom) a normal heart
showing relatively uniform uptake
of $^{99m}$Tc sestamibi.

Skeletal radioisotope imaging is
most often performed as
anterior/posterior whole-body
scans as the tracer used, $^{99m}$Tc
MDP, provides excellent contrast for 2D imaging. However there are many areas
where 2D contrast is insufficient to make a diagnosis and SPECT can then help the
diagnosis by providing the necessary improved contrast. Radioisotope imaging is
indicated for a wide range of skeletal diseases including Paget’s disease,
spondylolysis, sacroiliitis, ankylosing spondylitis, avascular necrosis, metastases,
synovitis, arthritis and osteomyelitis. Whilst the images are not specific to any
particular skeletal disease the sensitivity is excellent. Figure 5 shows how SPECT can
provide accurate anatomical location within the vertebra of a patient with a suspected
stress fracture. Similar results can be obtained if the patient has metastatic disease in
the skeleton. Such scans are used to stage the treatment of patients with breast or
prostate cancer.

Fig.5. Sagittal, transaxial and coronal
sections of the lower spine showing
the enhanced uptake of $^{99m}$Tc MDP in
part of a vertebra corresponding to a
stress fracture

Liver disease can be imaged using SPECT to determine the existence of sarcoma,
hepatic tumour, haemangioma, metastases, cyst, glycogen storage disease,
Menetrier’s disease, etc. In figure 6 we see the uptake of $^{99m}$Tc colloid in the liver of a
patient with suspected metastatic disease. This tracer is extracted by normal Kupfer
cells in the liver. In the planar image there is an indication of reduced uptake of the
colloid in the right lobe of the liver. This is clearly delineated in the transaxial SPECT
images which also show the existence of disease extending into the left lobe. The
same tracer can be used to examine the status of the spleen which is shown on the
right side of the images in figure 6. By using an alternative tracer such as labelled red-
blood cells it is possible to visualise increased uptake in liver lesions, indicative of
haemangioma.
In the lung, the most common radioisotope imaging is carried out to measure the ventilation and perfusion status of the lung using $^{99m}$Tc labelled tracers. These scans can be used to differentiate space-occupying disease from other pulmonary abnormalities such as obstructive airways or embolism. SPECT can sometimes help the diagnosis and can also be used to quantify treatment outcome.

Other applications include the evaluation of tumour in the lung to determine the perfusion status which may help treatment. Figures 7 and 8 show the uptake of $^{99m}$Tc Ceretech in the lungs of two patients with metastatic disease. In Figure 7 the SPECT image shows high perfusion in a right lung lesion which is barely visible in the planar scan.

Fig. 6. Liver SPECT showing the uptake of $^{99m}$Tc colloid in the normal liver and space occupying lesions in the left and right lobes.

Fig. 7. $^{99m}$Tc Ceretech planar view and SPECT image of the lung of a patient with metastatic disease in the liver and lung showing high uptake indicating a well-vascularised lesion in the right lung.
Figure 8 shows the perfusion of a large tumour again in the right lung. In this case the lesion has a well perfused periphery with poor perfusion in the central region possibly indicating necrosis. In both these patients the SPECT images provide a much more detailed picture of the functional status of the disease which may well affect the way the patients are treated.

There are many other applications of SPECT which can help the diagnosis of disease and in some cases be an aid to therapy. Targeted radionuclide therapy is a method of expanding interest for cancer treatment and SPECT has a very important role to play in quantifying radionuclide-tissue concentration which cannot be achieved as well using planar imaging. An example of this is the use of SPECT to image the biodistribution of $^{123}$I-mIBG in patients with neural crest tumours such as childhood neuroblastoma, (figure 9). In this case the images are used to determine if the uptake of the tracer in the tumour warrants treatment with $^{131}$I-mIBG. The quantitative information from the $^{123}$I-mIBG image can be used to estimate the activity of $^{131}$I-mIBG needed and subsequent $^{131}$I images can be used to estimate radiation dose to the tumour and normal tissues.