Nuclear imaging

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Abstract

Nuclear cardiology is a well-established technique that provides physiological information regarding myocardial perfusion and function. Three techniques are described: myocardial perfusion scintigraphy (MPS — the most widely used), radionuclide ventriculography (RNV) and positron emission tomography (PET). MPS is used chiefly in the diagnosis or exclusion of coronary artery disease, and is an option for the functional assessment of suspected coronary disease in those at an intermediate risk, as specified in the NICE guidance of 2010. It has also been validated in patients undergoing non-cardiac surgery, before and after coronary revascularization, and in the assessment of myocardial viability. MPS relies on the changes in cellular uptake of radioactive tracers at rest and during myocardial stress. Matched defects represent sites of infarction, whereas mismatch between normal perfusion at rest and reduced perfusion during stress indicates ischaemia. Cardiac risk is proportional to the size of the perfusion defect. RNV relies on blood pool labelling to assess regional ventricular function with excellent reproducibility. Cardiac PET has seen a recent surge in interest, with improved techniques and new tracers leading to an expansion of its use. It uses positron-based tracers that closely resemble physiologically occurring compounds, so it can characterize myocardial metabolism, assess cardiac perfusion and viability, and assist the diagnosis of intracardiac infection and sarcoid.

Keywords Cardiovascular disorders; coronary artery disease; gamma camera; hibernating myocardium; left ventricular function; myocardial perfusion scintigraphy; nuclear cardiology; positron emission tomography; radionuclide ventriculography; SPECT

What's new?

- The recent introduction of cadmium—zinc—telluride (CZT) gamma cameras has revolutionized the acquisition time and image quality of myocardial perfusion scintigraphy studies. Typical imaging times are now only 2—3 minutes
- SPECT/CT and PET/CT hybrid imaging allows the addition of cardiac anatomy to perfusion and function; essentially a complete one-stop assessment for patients with suspected coronary artery disease
- ^{82}Rubidium imaging allows myocardial perfusion to be assessed on a PET camera without the need for a cyclotron
- Specific A_{2A} adenosine receptor agonists have demonstrated efficacy with good tolerability
- ^{18}F-Flurpiridaz tracer shows promise at investigational stage as a PET perfusion tracer. It appears to increase sensitivity, and has fewer artifacts at a lower radiation dose. No cyclotron is required

Nuclear imaging comprises myocardial perfusion scintigraphy (MPS), radionuclide ventriculography (RNV), and positron emission tomography (PET). All of these procedures involve the use of radioactive isotopes that are injected intravenously and detected using specific cameras. MPS is the most commonly used and is discussed in some detail within this article.

Myocardial perfusion scintigraphy (MPS)

Indications

MPS is a widely available investigation for the assessment of coronary artery disease (CAD). It is recommended by the UK National Institute for Health and Care Excellence (NICE) as a first line diagnostic investigation for the assessment of those at intermediate risk of suspected CAD.[1] MPS is also recommended in patients with established CAD, to assess residual ischaemia after myocardial infarction and to guide the planning of revascularization procedures in patients with multivessel disease. The American Heart Association guidelines support MPS as a validated tool in patients for whom electrocardiographic stress testing has proved suboptimal.[2] Similarly the European Society of Cardiology guidelines support MPS as a validated, cost-effective tool for the early detection and risk stratification of obstructive coronary artery disease.[3]

Other uses include risk stratification in heart failure (including viability assessment) and before elective non-cardiac surgery, and as an early 'at the door' investigation for triage of emergency attendees with chest pain.

Technique

MPS consists of two parts; the rest scan and the stress scan. Different protocols exist depending on the tracer used and local preference. Stress may be achieved physiologically (treadmill or bicycle exercise), or using pharmacological coronary vasodilators (adenosine or dipyridamole) or inotropes (dobutamine).

Adenosine acts to cause coronary artery vasodilatation, whereas dipyridamole increases endogenous adenosine concentration by inhibiting its breakdown and increasing uptake. Both agents can cause bronchospasm and should be avoided in patients with reversible airways disease. Adenosine can cause significant bradycardia and should be withheld in patients with underlying second/third degree heart block. Newer, more specific A_{2A} adenosine receptor agonists, such as regadenoson, have significantly reduced these adverse effects. Dobutamine is an alternative agent, which causes vasodilatation indirectly via an increase in myocardial oxygen demand. Relative contraindications to its use include recent myocardial infarction or unstable coronary disease.

At peak stress, a radioactive tracer (^{201}thallium, ^{99m}technetium sestamibi or ^{99m}technetium tetrofosmin) is injected into the peripheral circulation. The technetium-based agents bind to

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myocytes and single photon emission CT (SPECT) imaging follows after 30 minutes. Protocols involve either 1 or 2 days. ^{201}Thallium redistributes rapidly and stress imaging may be undertaken 5–10 minutes after isotope injection.

Acquisition of images

Standard MPS scanning uses a gamma camera and ECG-gated SPECT to image uptake of radiopharmaceutical tracer into the myocardium at rest and during stress (Figure 1). The use of gating to match underlying cardiac rhythm has significantly reduced artefact and improved the accuracy of MPS. New ultrafast cameras (UFC), using novel semiconductor-based cadmium–zinc–telluride (CZT) detectors, have further reduced acquisition times and radiation exposure. The image quality and its ability to distinguish multivessel disease compare favourably with standard acquisition.[4,5]

Reporting

Tracer uptake and left ventricular dilatation are compared during rest and stress acquisitions. Abnormalities of uptake are reported to describe the number, location, inducibility, extent and severity of the perfusion defects – the total ischaemic burden. Some centres use the validated *summed stress score* to predict prognostic risk.[6] A normal scan predicts an annual rate of adverse cardiac events less than 1%, even in patients with medium-to-high risk pre-test probabilities.[7] In low-to-medium pre-test probabilities, this annual event rate remains low (around 0.6%) for up to 5 years of follow-up.[8]

The risk of a cardiac event can also be estimated from an abnormal scan (Figure 2). In broad terms, an abnormal MPS predicts a 7% annual risk of a significant cardiac event.[8] In patients with suspected CAD, this annual risk rises by 7% for every 1% increase in inducible perfusion defects and by 3% for every 1% increase in resting myocardial ischaemia.[9] Gated scanning allows accurate and reproducible estimation of left ventricular ejection fraction (LVEF), an additional indicator of risk. An LVEF <45% or end-systolic volume >70 ml indicates poorer outcomes in the presence of any inducible perfusion defect.[10]

Studies using MPS following myocardial infarction suggest an increased risk of a further event if >10% of reversible ischaemia is demonstrated, supporting the use of MPS to target and monitor

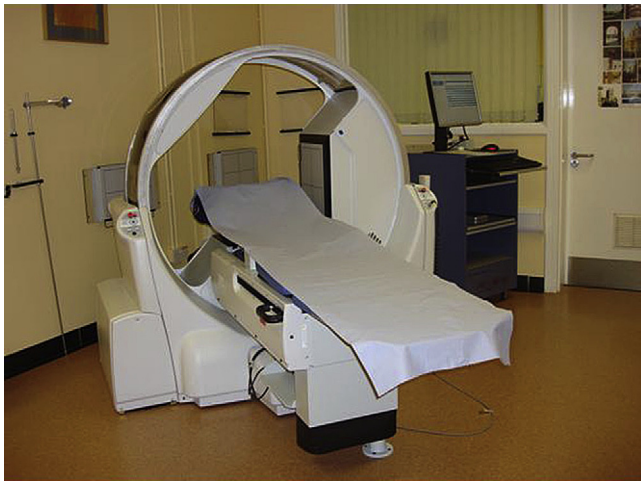

Figure 1 Typical modern sodium iodide gamma camera designed for dedicated cardiac work. The sodium iodide crystal heads are perpendicular to each other and rotate around the patient's heart in 32 steps. Collimators in front of the heads allow only perpendicular photons through to the crystals. The resulting scintillation is amplified by photomultiplier tubes and converted to an electrical signal that is gated to the patient's ECG. Transaxial slices are created, reconstructed to standard orthogonal planes and displayed on the computer workstation. Fixed planar imaging (non-rotating camera heads) is no longer used for MPS work; SPECT (single photon emission CT) is preferred especially as this allows functional assessment.

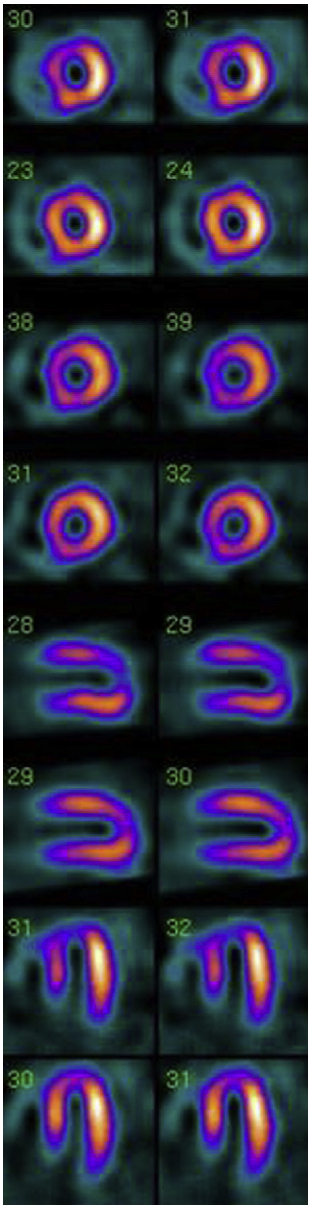

Figure 2 Standard MPS imaging. Stress images are orientated above the corresponding resting perfusion images. The top four slices represent short axis slices through the LV. The next two slices demonstrate the anterior, apical and inferior walls (2-chamber echo view). The final two slices represent the septal, apical and lateral walls (4-chamber echo view). At rest there is normal uptake of tracer throughout the LV. At peak stress reduced perfusion is identified in the anterior, apical and septal walls. There is also a small amount of stress-induced LV cavity dilatation. The gated images (not shown) confirm normal LV systolic function at rest. The ischaemic burden is calculated as 13% of the entire myocardium and the scan predicts flow-limiting LAD disease; this is a higher risk scan and revascularization should be considered for this patient.