Nuclear imaging

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Abstract

Nuclear cardiology provides physiological information on 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 to diagnose or exclude ischaemic heart disease, and is an option for functional assessment of suspected coronary disease, as specified in NICE guidance in 2016. It is validated in patients undergoing non-cardiac surgery, before and after coronary revascularization, and for assessment of myocardial viability. MPS relies on 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 ventricular function, and has excellent reproducibility. Cardiac PET has seen a recent increase in use due to improved techniques and new tracers. It employs positron-based tracers that resemble physiologically occurring compounds, to characterize myocardial metabolism, assess cardiac perfusion and viability, and assist diagnosis of intracardiac infection and sarcoid. Combining functional data from nuclear imaging with anatomical data from CT or MRI produces hybrid imaging, which improves diagnostic yield.

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

Key points

- Myocardial perfusion scintigraphy (MPS) provides evidence-based data relating to myocardial perfusion and function
- MPS is also indicated in preoperative risk stratification, viability assessment and the guidance of revascularization decisions
- The extent of abnormalities (e.g. ischaemia/infarction) detected by MPS is proportional to the rate of subsequent cardiac events; a normal scan predicts a very low cardiac event rate (<1% per year) over 5-year follow-up in non-diabetic patients
- The use of positron emission tomography has expanded to include assessment of viability and inflammation, including infection (endocarditis, device-related)

Introduction

Nuclear imaging comprises myocardial perfusion scintigraphy (MPS), radionuclide ventriculography (RNV) and positron emission tomography (PET). These all 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 here.

Myocardial perfusion scintigraphy

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 as one of the modalities for functional testing of myocardial ischaemia. 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. Similarly, the European Society of Cardiology guidelines support MPS as a validated, cost-effective tool for the early detection and risk stratification of obstructive CAD. 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 can be achieved physiologically (treadmill, bicycle exercise), or using pharmacological coronary vasodilators (adenosine, regadenoson, dipyridamole) or inotropes (dobutamine). Physiological stress is preferred where possible.

Adenosine and regadenoson act to cause coronary artery vasodilatation, whereas dipyridamole increases endogenous adenosine concentration by inhibiting its breakdown and increasing uptake. These agents can cause bronchospasm and should be avoided in patients with significant reversible airways disease. Adenosine can cause significant bradycardia and should be withheld in patients with underlying second-/third-degree heart block. Regadenoson is a newer, more specific A_{2A} adenosine receptor agonist. It causes significantly less bronchospasm and bradycardia, and can be used in patients with mild or moderate airways disease. Dobutamine is an alternative agent that causes vasodilatation indirectly via an increase in myocardial oxygen demand. Relative contraindications to its use include recent myocardial infarction and unstable coronary disease.

At peak stress, a radioactive tracer (^{201}thallium, ^{99m}technetium sestamibi, ^{99m}technetium tetrofosmin) is injected into the

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peripheral circulation. ^{201}Thallium rapidly redistributes within the blood pool, and stress imaging can be undertaken 5–10 minutes after isotope injection, with redistribution imaging performed 4 hours later. Technetium-based agents bind to myocytes rather than redistributing, and stress imaging follows after 30–60 minutes. Depending on protocols, MPS using technetium can be performed over 1 or 2 days, with the rest scan performed later the same day or the following day.

Acquisition of images

Standard MPS scanning uses a gamma camera (Figure 1) and electrocardiogram (ECG)-gated single-photon emission computed tomography (SPECT) to image uptake of radiopharmaceutical tracer into the myocardium at rest and during stress. Use of dual-headed cameras positioned at 90° to each other halves the acquisition time. The use of gating to match underlying cardiac rhythm has significantly reduced artefact and improved the accuracy of MPS. New ultrafast cameras, using semiconductor-based cadmium–zinc–telluride detectors, have further reduced acquisition times and radiation exposure. Image quality and the ability to distinguish multivessel disease compare favourably with standard acquisition.

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. A normal scan predicts an annual rate of adverse cardiac events of <1%, even in patients with medium- to high-risk pre-test probabilities. In low to medium pre-test probabilities, this annual event rate remains low (around 0.6%) for up to 5 years' follow-up.[1]

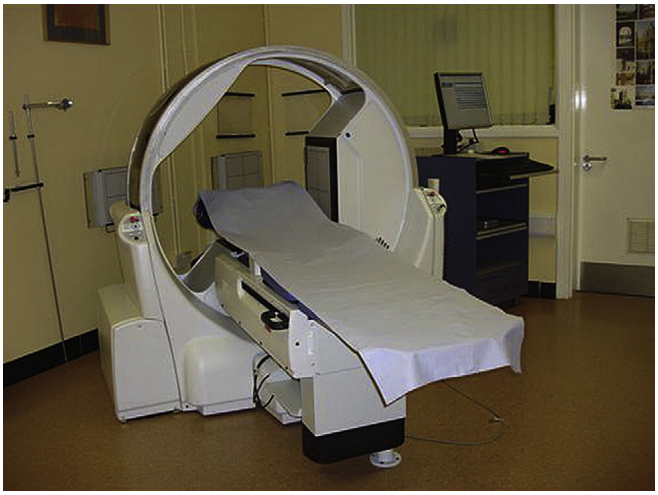

Figure 1 Sodium iodide gamma camera designed for dedicated cardiac work. The sodium iodide crystal heads lie perpendicular to each other and rotate around the patient's heart in 32 steps. Collimators in front of the heads allow only perpendicular photons through to the crystals. The resulting scintillation is amplified by photomultiplier tubes and converted to an electrical signal that is gated to the patient's ECG. Trans-axial 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 is preferred, especially as it allows functional assessment.

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. 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.[2] Gated scanning allows accurate and reproducible estimation of left ventricular ejection fraction (LVEF), an additional indicator of risk. LVEF <45% or end-systolic volume >70 ml indicates poorer outcomes in the presence of any inducible perfusion defect.[3] Studies suggest that >10% reversible ischaemia on MPS after myocardial infarction increases the risk of a further event. This supports the use of MPS to target and monitor patients treated with either revascularization or intensive medical therapy.

Radioactivity and safety

The radioactivity burden is dependent on the tracer and protocol used. A typical dose required for a 1-day technetium study involves 1000–1500 Mbq (equivalent to exposure of around 8–12 mSv). This is higher than a diagnostic coronary angiogram (2–8 mSv) and a modern 64 coronary CT scan (1–5 mSv).

Recent advances in acquisition using cadmium–zinc–telluride and ultrafast camera technology have seen radiation exposure drop to around 1 mSv for a stress-only scan. The dose associated with background environmental radiation exposure in the UK is 2.6 mSv. The overall 10-year increased risk of a malignancy associated with radiation is approximately 1 in 2000 per 10 mSv exposure, superimposed upon the 1 in 3 background risk of developing cancer in the general population. The risk of a serious complication, death, myocardial infarction or sustained ventricular tachycardia is 1.2 in 10,000 for adenosine and physiological stress tests.

Comparison with non-SPECT techniques

A meta-analysis of MPS using all tracers and types of stress reported a sensitivity of 87% and specificity of 73% for detection of angiographically significant (>70%) coronary artery stenoses.[4] This compared with a sensitivity of 78% and specificity of 70% for exercise ECG testing, and 76% sensitivity and 88% specificity in smaller studies of stress echocardiography. Recent comparison of cardiac magnetic resonance to MPS demonstrated no statistically significant difference in major adverse cardiac events or rates of unnecessary coronary angiography.[5]

Cost

MPS is a cost-effective strategy for investigation of CAD in selected groups, such as individuals who have or are likely to have an equivocal exercise stress test, and those with an intermediate pre-test probability of CAD, to avoid unnecessary further investigation.

MIBG

^{123}Iodine-meta-iodobenzylguanidine (MIBG) imaging can be used to identify patients with known left ventricular dysfunction who are at high risk of sudden cardiac death. MIBG is a radioactive iodine tracer that acts as a false neurotransmitter in the sympathetic nervous system. After myocardial injury or ischaemia, myocardium is denervated, and this persists after revascularization. Reduced uptake of MIBG is linked with left ventricular sympathetic denervation and a poorer prognosis.

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