An introduction to non-invasive cardiac imaging

Introduction

According to the World Health Organization (2009), an estimated 17.1 million people died from cardiovascular disease in 2005 (29% of global deaths), 7.2 million from coronary heart disease. It is the number one killer globally and with new and more complex ways of investigating the heart non-invasively, it is important to understand what is available and when to use each modality. This article explains how the different forms of non-invasive cardiac imaging work, their advantages and disadvantages (*Table 1*), when to use each one and finally what developments are likely in the future. Some may not be available in all hospitals, but access and availability to cardiac imaging is likely to change significantly in the future.

The important questions to ask before selecting an investigation are:

1. What is the clinical question? (Does this patient have a vegetation on a valve? Is there a stenosis in one of the patient's coronary arteries?)
2. Which part of the heart is to be focused on?
3. How stable and mobile is the patient?

Echocardiography

Echocardiography is the most widely used non-invasive cardiac imaging modality. It has advantages of being portable (the smallest machines are the size of a laptop) and of having no ionizing radiation dose to the patient. However, it can be highly dependent on the skill and experience of the echosonographer, with potentially variable results each time it is performed. Also, tachycardia and patient body habitus, for example obesity or hyperinflated lung fields in chronic obstructive pulmonary disease, can make acquiring images difficult. Transthoracic and transoesophageal are the main two formats and contrast agents, Doppler studies and dobutamine can be used in conjunction with these modalities to gain extra information.

Transthoracic echocardiography

Transthoracic echocardiography (*Figures 1* and *2*) is the standard and most common form of this modality and can be performed with no preparation and at the bedside in patients who are unstable. Transthoracic echocardiography allows assessment of systolic and diastolic function (including regional wall motility), dyssynchrony, valve morphology and function, pericardial effusions, intracardiac masses (vegetations, thrombi, tumours) and structural defects as well as other abnormalities, including aortic coarctation and dissection.

Table 1. Advantages and disadvantages of different investigations

Investigation	Advantages	Disadvantages
Echo	Readily available at all hospitals and sometimes out of hours	Operator dependent
	Ability to test dynamically with dobutamine	Limited by body habitus and in chronic obstructive pulmonary disease
Cardiac magnetic resonance	Accurate for quantification of muscle and chamber volumes	Not readily available
		Not possible with cardiac pacemakers
Computed tomography angiography	Accurate and reproducible assessment of vessels	Not readily available
	Fast	Radiation dose
Myocardial perfusion scintigraphy	Accurate functional assessment of myocardium	Need synthesis of radioisotope on day of test

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Transoesophageal echo

In transoesophageal echocardiography (*Figure 3a*) a probe is inserted through the mouth into the oesophagus and stomach, where it scans the heart. It is more invasive than transthoracic echocardiography which is typically performed first. It can often provide better images of the basal portions of the heart than transthoracic echocardiography, in particularly the valves, atria, aorta and pulmonary artery, atrial septum and left atrial appendage as these are much closer to the oesophagus

Figure 1. Two-dimensional transthoracic echo image of arrhythmogenic right ventricular cardiomyopathy. RV = right ventricle.

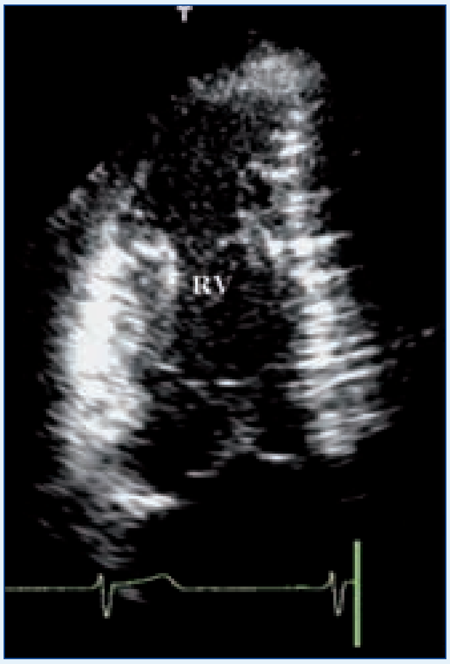
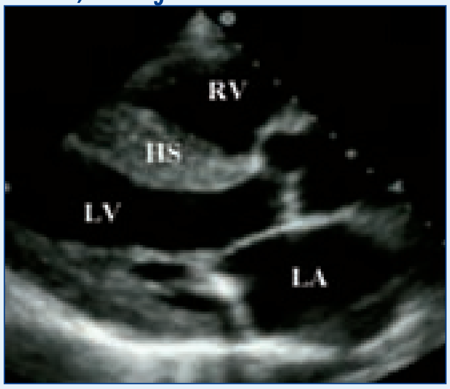


Figure 2. Two-dimensional transthoracic echo image of hypertrophic cardiomyopathy. HS = hypertrophied septum; LA = left atrium; LV = left ventricle; RV = right ventricle.



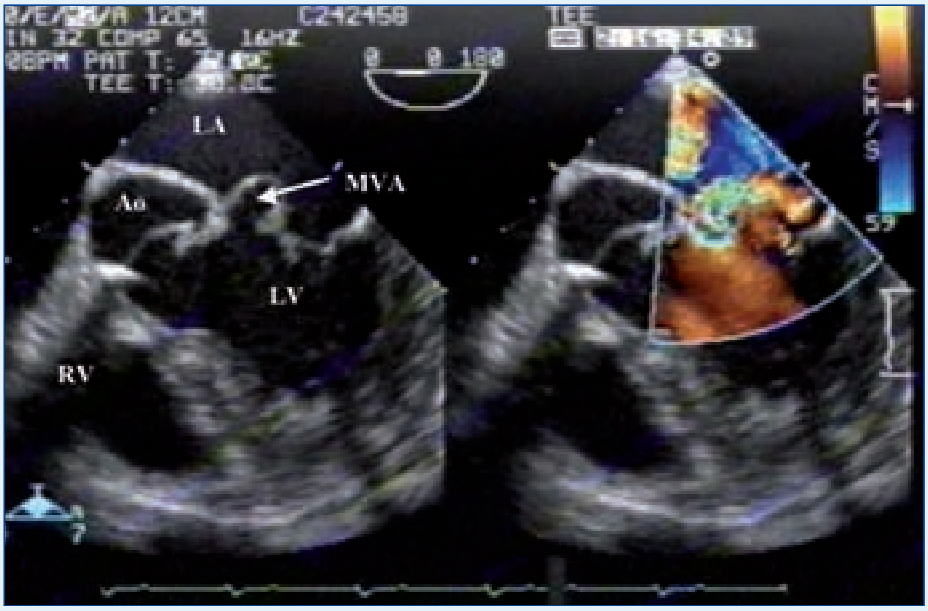


Figure 3. a. Transoesphageal echo, with (b) Doppler demonstrating a mitral valve abscess and the associated turbulent flow around it. Ao = aorta; MVA = mitral valve abscess; LA = left atrium; LV = left ventricle; RV = right ventricle.

and the ultrasound waves do not have to pass through the aerated lungs which distort the signal.

One of its more common uses is to look for valve vegetations in infective endocarditis or a thrombus in the left atrium. However, it carries a 1 in 10 000 risk of oesophageal perforation, requires a fasted patient who is usually sedated, is less readily available and is much more uncomfortable to the patient than transthoracic echocardiography. Two studies comparing transthoracic and transoesophageal echocardiography for the diagnosis of infective endocarditis demonstrated a sensitivity of 44–58% and 90–94%, and a specificity of 98% and 100% respectively (Mügge et al, 1989; Shively et al, 1991).

Doppler

When ultrasound waves hit a moving target, such as blood flowing through the heart, the frequency of the ultrasound wave is altered by the movement. If the flow is towards the probe the frequency change is positive and vice versa (*Figure 3b*). There are several different ways of using Doppler, colour flow imaging overlays a spectral Doppler display over a two-dimensional echo image of the heart where different colours represent flow towards or away from the probe (by convention: red–blue). Continuous wave Doppler summates all Doppler signals down a single channel of interrogation and is good for measuring peak velocities. Pulse wave Doppler analyses only a selected sample volume and is good for measuring flow in defined regions of the heart. One of the limitations of Doppler is that it can only measure flow towards or away from the probe and any flow off axis will be measured incorrectly. This issue increases inter- and intra-operator variability, especially in inexperienced users.

Contrast agents

Contrast agents can be used to aid delineation of the endocardial wall and assessment of left ventricle parameters (*Figure 4*). Contrast agents oscillate in the ultrasound wave producing bubble-specific harmonic signals requiring specific modes to detect them. These agents light up the solution-filled chambers and vessels more clearly, making identification of clot or tumour easier. The contrast also has a role when investigating a possible right-to-left shunt; contrast can be seen in the left-hand side of the heart earlier than would be expected if it were travelling through the pulmonary circulation.

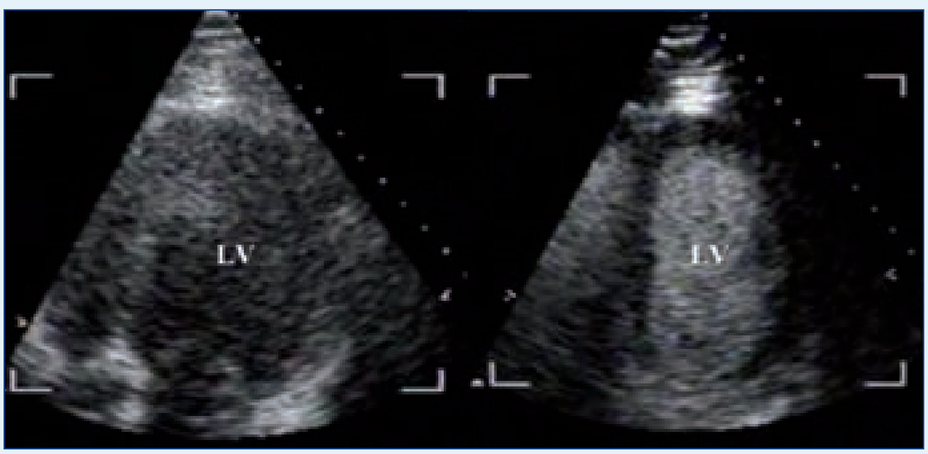
Three-dimensional echocardiography

This is a natural development of two-dimensional echo which can aid interpretation and analysis of cardiac structures; it also allows more accurate calculation of areas and volumes, which are useful in measuring chamber and valve sizes. It is more time consuming than two-dimensional imaging, but future developments in three-dimensional echo are likely to lead to it becoming the standard modality for echocardiography (Binder, 2002).

Stress echocardiography

This is a functional test which gives anatomical information about the heart when stressed. It is an alternative to stress electrocardiography (treadmill test) and also nuclear scans. It can be performed during exercise and in those who cannot exercise, dobutamine, a pharmacological agent mimicking exercise, may be administered to stress the heart. It has benefits of visualizing the heart under strain, which tends to be more accurate than electrocardiography analysis in interpreting regional defects.

Figure 4. Two-dimensional transthoracic echo (a) without contrast enhancement, (b) with contrast. LV = left ventricle.



It can also demonstrate areas of the heart with reversible ischaemia or viability. The process involves:

1. Baseline transthoracic echocardiography
2. Low dose intravenous dobutamine infusion (vasodilating inotrope) – this demonstrates regions which would improve in contracting ability should the blood supply improve. This is known as 'viability' and is indicated by regions which do not move at rest but which are stimulated by low dose dobutamine (Krahwinkel et al, 1997)
3. High dose intravenous dobutamine – this demonstrates ischaemic regions by reduction in wall contraction.

A biphasic response is often seen, where an initial improvement in wall thickening at low dose dobutamine is followed by reduced wall thickening at high dose dobutamine, demonstrating both viability and ischaemia.

Cardiac magnetic resonance

Cardiac magnetic resonance with gadolinium contrast is highly accurate at measuring ventricular dimensions and myocardial mass; it can then calculate chamber volumes, ejection fraction and cardiac output. It is very reproducible and combined with its lack of ionizing radiation becomes useful to investigate and monitor congenital cardiac abnormalities, such as hypertrophic cardiomyopathy. It is also able to measure flow across valves but not as accurately as other modalities. It is contraindicated in patients with a pacemaker.

Gadolinium labelling can also be used to highlight areas of ischaemia and infarction. Myocardial scars have expanded the extravascular extracellular space compared to healthy myocardium and the gadolinium accumulates in this space and shows up brighter on the scan. It also has greater uptake in acutely ischaemic myocardium which has increased permeability in its cell membranes, although it is not a recommended technique to diagnosing acute myocardial infarction. Magnetic resonance angiography has largely been abandoned since computed tomography coronary angiography has moved to the fore. It is limited to evaluating proximal coronary arteries only, because of the size of the vessels, together with cardiac motion and the time taken to scan (Finn et al, 2006).

Computed tomography angiography

Multislice spiral computed tomography scanners have improved in recent years with narrower and more numerous rows of detectors and faster gantry rotation speeds, which have led to an increase in temporal resolution and reduced motion artefact respectively. Developments in several areas, including software for image acquisition and analysis, and advances in injector technology have also led to improvements in this modality.

In preparing a patient for this investigation an 18G or larger venflon in a right cubital vein is recommended to aid fast administration of contrast and avoid artefact from contrast in the left subclavian vein. Beta blockers are used to improve accuracy and sensitivity of scans and also reduce the amount of radiation required to acquire the images. Oral and intravenous agents are used depending on the centre. The ideal heart rate for scanning is between 50 and 65 beats per minute to achieve the best quality images but higher heart rates do not prevent scanning. At higher heart rates projections from consecutive heart cycles can be combined, however, variations in movement between cycles means this pay off is only beneficial at heart rates greater than 80 beats per minute (depending on the scanner) (Martin et al, 2005). Irregular heart rhythms, such as atrial fibrillation, also reduce scan quality.

Sublingual nitrates can also be administered which improve the diagnostic pictures by vasodilating coronary vessels and thus increasing the contrast density within them (Klass et al, 2009).

Advantages of this technique are that it can acquire images very quickly, with less risk of vascular injury. Disadvantages of this technique include radiation (dose dependent on scanner and heart rate) and need for a contrast agent (risk of nephropathy and allergic reactions).

Multislice spiral computed tomography is indicated for intermediate risk patients, as those at low risk have a higher chance of false-positive results and those at high risk are more likely to benefit from an invasive angiogram. A study of 61 patients using 64-slice multislice spiral computed tomography evaluating ≥50% luminal stenoses demonstrated a sensitivity of 85% and specificity of 97% compared to invasive coronary angiography (Schuijf et al, 2006).

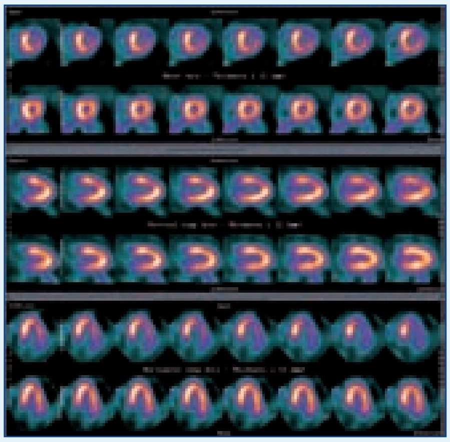
Nuclear scans

These include multi-gated acquisition scans which show flow through the heart by using a radioactive isotope (e.g. technetium) which is carried in the blood and the radiation signal picked up on a gamma camera. This test can be carried out both as a 'rest' and 'stress' test to make a functional assessment.

There is also myocardial perfusion scintigraphy using single photon emission computed tomography (*Figure 5*) which uses radioactive isotopes (e.g. thallium) which are absorbed into the myocardium. The amount of radioisotope in any region of the heart is determined by the blood flow and myocardial viability. A scan at a resting heart rate is followed, or preceded, by a 'stressed' scan using exercise or drugs such as adenosine, dipyridamole or dobutamine. Ischaemia is indicated when a myocardial segment fails to take up tracer during stress but returns to normal at rest.

Myocardial perfusion scintigraphy is more sensitive (84% compared to 80%) but less specific than stress echos (77% compared to 86%) (Schinkel et al, 2003). However, the equipment is less portable and more expensive, and only certain centres offer these scans. The radioisotopes need to be synthesized on the day of the

Figure 5. Myocardial perfusion imaging, showing three different cross-sectional images of the heart (one short axis and two different long axes), with comparable slices at stress and rest (above and below respectively). The reduced enhancement during stress demonstrates reversible ischaemia in the anterior and lateral regions.



scan as they degrade quickly. Myocardial perfusion scintigraphy using single photon emission computed tomography is recommended by the National Institute for Health and Clinical Excellence (2010) for investigation of patients with stable chest pain and estimated likelihood of coronary artery disease between 30 and 60%, or in patients with higher likelihood (up to 90%) but when invasive coronary angiography is either not appropriate or not acceptable.

The future

In the future there is likely to be increased use of contrast and three-dimensional echo as a way of enhancing an already effective and readily available investigation. As magnetic resonance imaging and multislice spiral computed tomography scanners become more prevalent these are likely to become used increasingly to image the heart. In particular, multislice spiral computed tomography is likely to grow as a technique to stratify coronary artery disease and identify those patients who would benefit from invasive coronary angiography. It is also likely that increasingly specific markers and labelling techniques will be used to highlight high risk vessels and areas of myocardium which would benefit from revascularization (Marwick and Schwaiger, 2008).

Conclusions

There is no single test which is superior to all the others: each has their merits and disadvantages. Not all hospitals will have all the modalities mentioned above available and radiologists (occasionally cardiologists) will usually be the gatekeepers to all modalities barring echos. As with most investigations the more information about the patient and the more specific the question on the request forms the more likely you are to get the most appropriate test and the speediest answer. BJHM

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KEY POINTS

- Echocardiography is an easily accessible technique for assessing overall cardiac systolic and valvular function.
- Stress echo, myocardial perfusion scintigraphy and computed tomography angiography are useful in patients with intermediate risk of coronary artery disease.
- Cardiac magnetic resonance imaging is good at investigating structural myocardial disease.
- Use of non-invasive imaging is likely to increase in the near future, particularly for stratifying risk in groups of patients.