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Magnetic resonance imaging in ischaemic heart disease

磁共振成像對於缺血性心臟病的評估

Magnetic resonance imaging has an increasing role in the assessment of ischaemic heart disease. Its superb spatial and temporal resolution currently allows accurate assessment of cardiac function, regional wall motion, and the extent of myocardial infarction. Regional myocardial perfusion can also be assessed, most commonly by a first-pass technique. Non-invasive imaging of the coronary arteries by various magnetic resonance imaging techniques represents a major advance in recent years. In the foreseeable future, magnetic resonance imaging may become a single, comprehensive examination for the assessment of ischaemic heart disease.

磁共振成像在評估缺血性心臟病方面的重要性日益提高。此技術在空間及時間方面的解像極佳，並可以準確地評估心臟功能、局部心肌運動，以及心肌梗塞的嚴重程度。此外，磁共振成像亦可被用作局部心肌灌注的評估，這通常是用首過技術來作檢查。透過不同的磁共振成像技術為冠狀動脈進行非侵入性的成像是近年來醫學界的一大進步。在可見的將來，磁共振成像有可能成為全面評估缺血性心臟病的單一檢查方法。

Key words:
Magnetic resonance imaging;
Myocardial ischemia

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Introduction

Ischaemic heart disease is one of the leading causes of death in many developed countries, including the US.[1] Hospitalisations resulting from ischaemic heart disease impose a significant economic burden on society. Conventionally, ischaemic heart disease has been assessed on clinical signs and symptoms, electrocardiographic findings, biochemical tests, echocardiography, cardiac scintigraphy, and conventional coronary artery angiography. Magnetic resonance imaging (MRI) of the heart has been performed since the 1980s.[2-4] Given continuous heart and breathing motion, the resulting suboptimal image quality and long scanning time have limited the popularity of MRI in this setting. In recent years, technological improvements have enabled ultrafast image acquisition. Images with good contrast, and spatial and temporal resolution are routinely obtained. Magnetic resonance imaging of the cardiovascular system is now feasible as part of routine clinical practice. For patients with ischaemic heart disease, MRI can be used to assess cardiac function, regional wall motion, regional myocardial perfusion, and the viability of the myocardium. Magnetic resonance angiography of the coronary arteries, although still research based, has shown promising results and its application to clinical practice is anticipated.

Cardiac function and regional wall motion

For those patients with heart failure or myocardial infarction due to ischaemic heart disease, assessment of cardiac function is important prior to commencement and for monitoring of therapy. Cardiac function can be assessed using echocardiography, which is an easily accessible technique. Bedside scanning can be performed due to the ease of transporting equipment. Non-invasiveness, easy accessibility, and low cost account for the popularity of echocardiography in day-to-day practice. However, echocardiography is considered to be operator-dependent,[5] and the availability of an accessible acoustic window depends on the patient's body build. It is not an ideal technique for serial measurement and monitoring of cardiac function due to relatively high intra- and inter-observer variation. In serial measurement, only changes of at least 10% to 20% are considered to represent genuine change.[6] Further, calculation of ejection fraction and ventricular mass by echocardiography is based on a geometrical assumption about the shape of the left ventricle.[7] This contributes to inaccuracy, especially post-infarction, with ventricular remodelling occurring. Real-time three-dimensional echocardiography is an alternative way to measure left ventricular function and may be preferable to the biplane method.[8]

Cardiac scintigraphy is another technique widely used in the assessment of cardiac function. Thallium and technetium 99m sestamibi are the two most popular radiopharmaceuticals used for this purpose.[9,10] Measurement of ejection fraction in an infarcted heart by nuclear scintigraphy can be performed, but the accuracy is likely to vary with the site and size of the infarct. For example, in the presence of a large, anterior left ventricular aneurysm, the ejection fraction can be underestimated.[11] Low spatial resolution in cardiac scintigraphy also leads to unreliable volumetric measurement of myocardial mass. Further, radiation exposure during the procedure makes serial examinations for monitoring of therapy undesirable.

Magnetic resonance imaging provides good spatial and temporal resolution, allowing imaging of the systolic and diastolic phases of both right and left ventricles to be performed. Cine short-axis images, from base to apex, yield reproducible data for myocardial mass and ventricular size.[12,13] Regional wall thickness of the ventricle (Fig 1), valvular motion (Fig 2), and regional wall motion can be clearly defined, and accurately assessed. The tomographic aspect of this tool allows multiplanar assessment of ventricular remodelling after myocardial infarction. Commercially available software yields calculations of the end-diastolic volume, end-systolic volume, stroke volume,

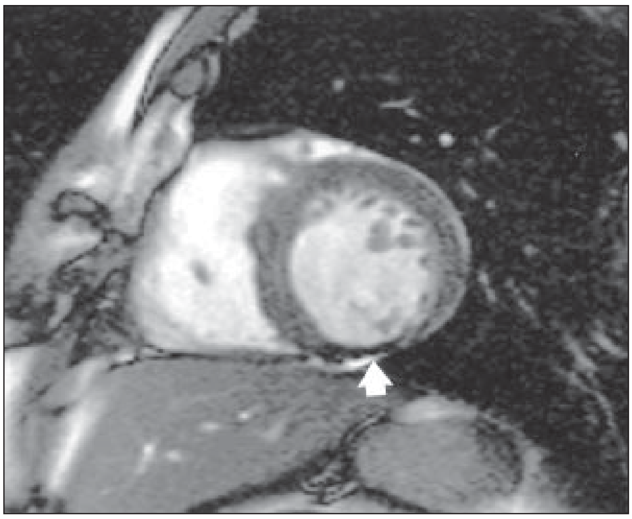

Fig 1. Magnetic resonance image of the short axis of the left ventricle shows thinning of the post-infarcted inferior wall (arrow)

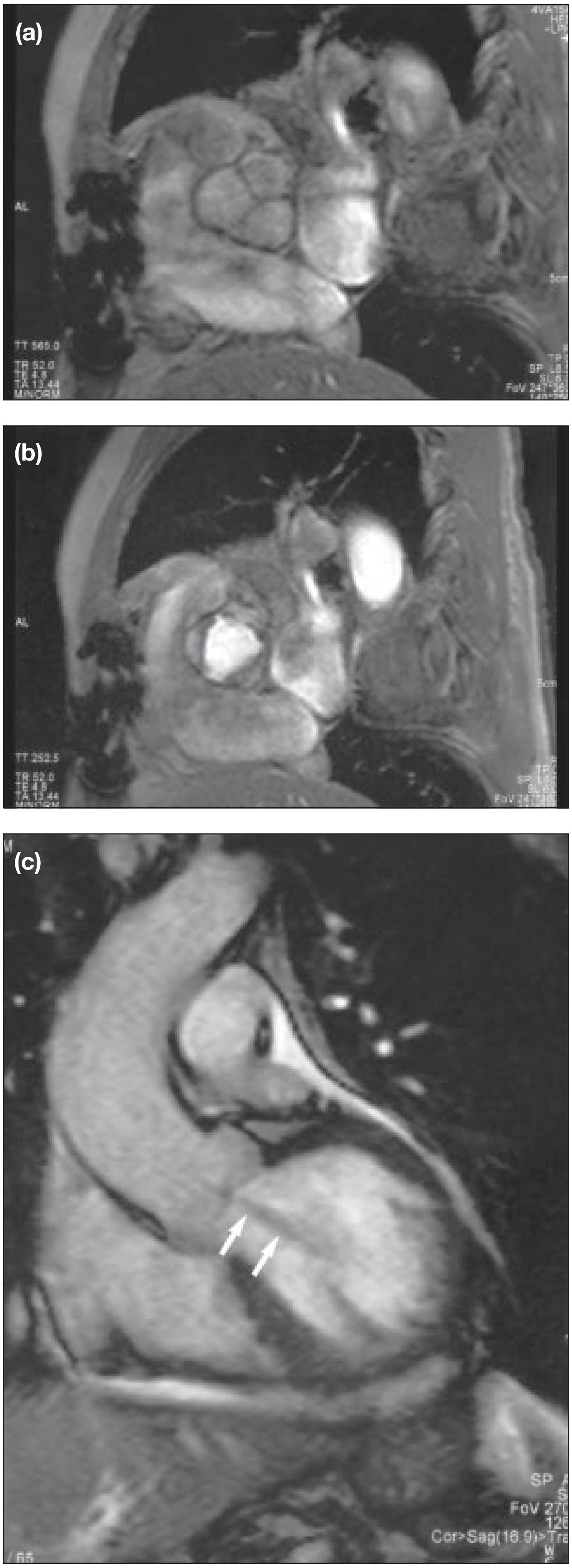

Fig 2. Magnetic resonance images (a) showing the closure of the tricuspid and aortic valves; (b) showing the opening of the tricuspid and aortic valves; (c) with left ventricular outflow view showing mild regurgitation of the aortic valve (arrow)

ventricular mass, and ejection fraction, within a few minutes, making clinical application of this imaging technique efficient and effective. With the use of new pulse sequences, the complete heart can be scanned within 15 seconds, without the need for electrocardiographic triggering.[14] The advantages of MRI include non-invasiveness, no irradiation, high reproducibility, and high repeatability of results. These characteristics have made it an ideal tool for serial measurement and monitoring of cardiac function alongside therapy.[15]

Regional perfusion techniques

The gold standard for detection of regional myocardial perfusion is positron emission tomography.[16] This gives images of good spatial resolution with in-plane resolution of 6 x 6 mm, and quantification of regional perfusion is possible. The radio-pharmaceuticals used for this purpose are ^{15}O-labelled water and ^{13}N-labelled ammonia.[16,17] Limited access to the scanner and the necessity of an on-site cyclotron for the production of radio-pharmaceuticals are the major limitations to the use of this technique. Single photon emission computed tomography (SPECT) imaging can also be used in the assessment of regional myocardial perfusion. Thallium- and technetium-labelled compounds are utilised for this purpose. In the detection of coronary artery disease, sensitivities of 80% to 90% have been achieved.[18-20] However, assessment of the inferior wall of the left ventricle can be difficult, because of the high tracer uptake by the liver. The low spatial resolution and the irradiation involved are other disadvantages of this imaging technique. A relatively new technique to evaluate regional myocardial perfusion involves contrast echocardiography, using intermittent harmonic imaging and intravenous perfluorocarbon containing microbubbles. However, the clinical utility of this technique has yet to be assessed in a large-scale study in a multicentre setting.[21]

Evaluation of regional myocardial perfusion with MRI is possible, either by the introduction of exogenous contrast, or by the presence of endogenous contrast. The most commonly used exogenous contrast agents are paramagnetic gadolinium compounds, which are usually administered intravenously. Endogenous contrast, such as deoxyhaemoglobin, can also be used for the detection of regional ischaemia. This is known as the blood oxygen level–dependent or BOLD MRI technique.[22]

When exogenous contrast is administered, a fast dynamic sequence is acquired at systole, triggered by the electrocardiogram. The sequence represents a balance between the total acquisition time, temporal resolution, spatial resolution, and the number of slices obtained. It is usually acquired at a rate of one or more images per second. Assessment of the temporal enhancement of myocardium at rest and during stress enables the detection of regional ischaemia. In the setting of MRI, exercise-induced stress is practically difficult. Consequently, pharmacological stress is employed. Pharmacological stress is most commonly induced by administration of dipyridamole at a dose of 0.56 mg/kg given intravenously within 4 minutes,[23] or adenosine at 140 μg/kg/min intravenously for 6 minutes.[24] These drugs decrease vascular resistance and therefore increase flow in the coronary arteries. In normal coronary arteries, the increase in coronary flow usually reaches four to five times baseline values.[25] Myocardium receiving blood supply from a significantly stenosed coronary artery will show hypoperfusion compared with normal myocardium, supplied by maximally dilated coronary arteries. Normally perfused myocardium will show greater enhancement at a faster rate than hypoperfused myocardium. Comparison of rest and stress perfusion imaging can thus allow detection of regional reduction in vasodilated flow (Fig 3).[26,27] Comparative studies of stress perfusion performed by MRI and stress radionuclide scintigraphy have been performed. Agreement between these two examinations is reasonable, varying from 73% to 90% across different studies.[28-30] Most of these studies were small, however, and the imaging techniques used varied. Large-scale multicentre studies are required to determine which examination has the best sensitivity and specificity, and greatest reliability.

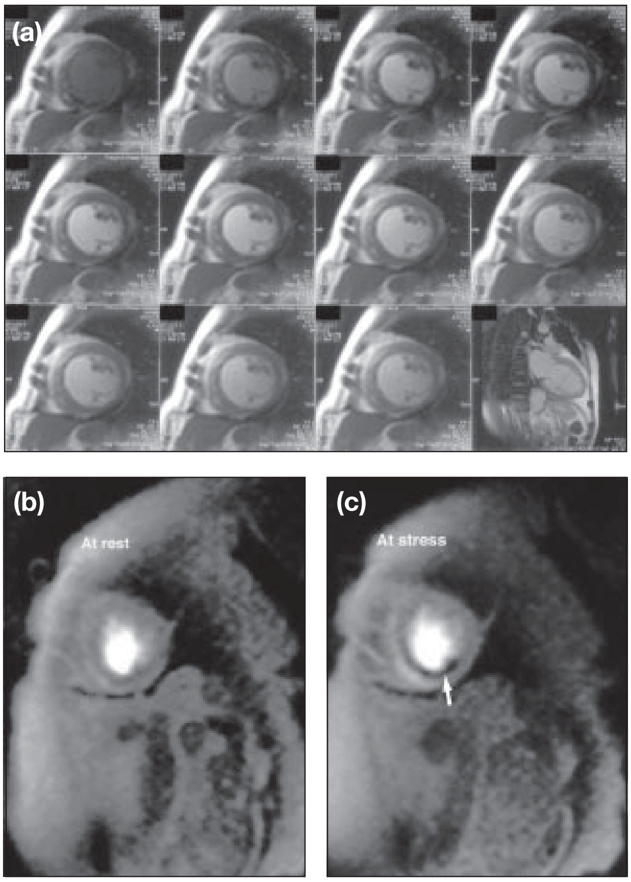

Fig 3. Magnetic resonance imaging at rest and during pharmacologically induced stress: (a) dynamic sequence of the left ventricle showing contrast entering the chamber of left ventricle and then subsequent enhancement of the myocardium; (b) perfusion at rest: short-axis view of the left ventricle shows normal perfusion of the myocardium; (c) perfusion during stress: short-axis view shows hypoperfusion of the inferior wall (arrow)

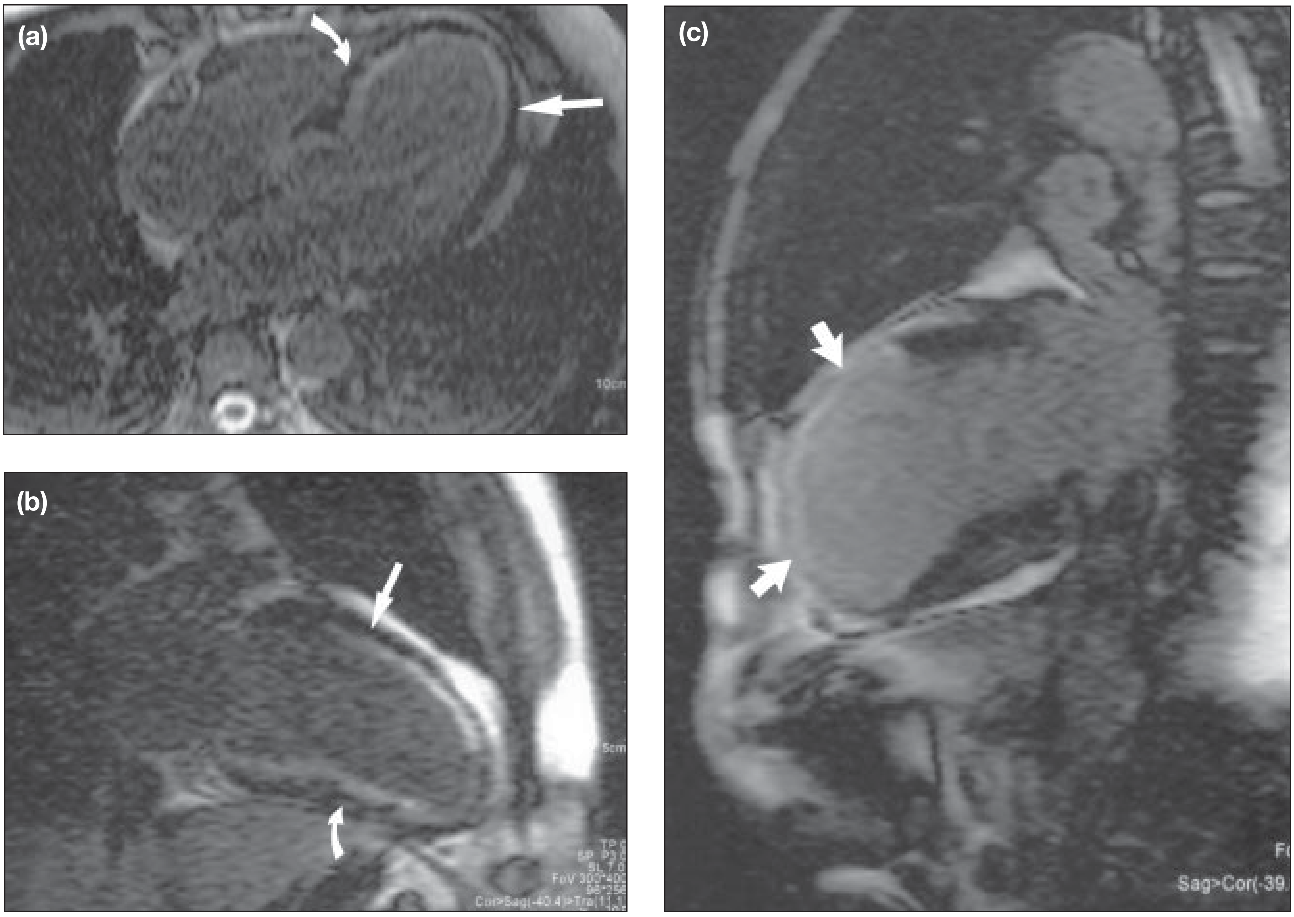

Fig 4. Magnetic resonance images: (a) four-chamber view shows non-transmural infarction of the lateral (arrow) and septal walls (curved arrow) of the left ventricle. About 50% of myocardial thickness shows enhancement representing myocardial infarction; (b) two-chamber view showing non-transmural infarction of the anterior (arrow) and inferior walls (curved arrow) of the left ventricle; (c) two-chamber view showing transmural infarction of the anterior wall of the left ventricle, extending to the apex (arrowhead)

Myocardial infarction

Determination of the extent of myocardial infarction is worthwhile, as it is of prognostic value (Fig 4).[31] Viable myocardium may benefit from revascularisation.[32] It is important to differentiate between stunned myocardium, hibernating myocardium, and non-viable myocardium, for optimal decision-making with respect to reperfusion and therapy. Stress echocardiography may have a role in differentiating viable from scarred myocardium before coronary artery bypass graft.[33] On MRI, injured myocardium shows delayed enhancement after injection of gadolinium chelates. The infarct size may be overestimated or underestimated, depending on multiple factors including the extent of the infarct, collateral circulation, and the timing and dose of contrast given. Infarct avid MRI contrast agents have been developed. These agents are calcium avid and thus bind strongly to infarcted myocardium, allowing a long temporal window for imaging. However, they may also disturb calcium homeostasis and subsequent ventricular contractility.[34]

Simonetti et al[35] have demonstrated a good correlation between delayed enhancement of myocardium and ischaemic injury. There has been some controversy as to whether delayed gadolinium–diethylenetriamine pentaacetic acid enhancement might overestimate infarct size. Fieno et al's study[36] using a dog model showed that the enhanced area on MRI closely matched the infarcted area identified on triphenyltetrazolim chloride staining at all stages of healing after infarction. The delayed enhanced MRI allows differentiation between viable and non-viable regions within the myocardium, and thus, the exact extent of myocardial infarction can be demonstrated.[37]

Coronary artery angiography

Coronary artery disease is conventionally diagnosed by angiography on cardiac catheterization. Non-invasive imaging techniques such as computed tomography (CT) coronary artery angiography and MRI coronary artery angiography have been developed recently. Computed tomography angiography, both ultrafast CT and multidetector CT, give clinically useful images of the coronary artery and are superior to MRI in the detection of coronary artery calcification. However, these imaging

Fig 5. Contrast-enhanced magnetic resonance angiography showing a normal right coronary artery (arrow)

techniques require administration of iodinated contrast and radiation is involved. Repeated examination on the same day is not possible. These techniques are also unsuitable for serial follow-up and general screening.

Magnetic resonance coronary artery angiography can be performed, with or without the administration of intravenous gadolinium. Magnetic resonance angiography of the coronary arteries can be performed by a first-pass angiography technique, involving the administration of exogenous contrast (Fig 5). Non-contrast coronary artery angiography can be performed using breath-hold and free breathing methods (Fig 6). The choice of technique to achieve the best result is dependent on the clinical situation of the individual patient. Contrast-enhanced and non–contrast enhanced coronary artery angiography each have specific advantages and disadvantages. Administration of contrast

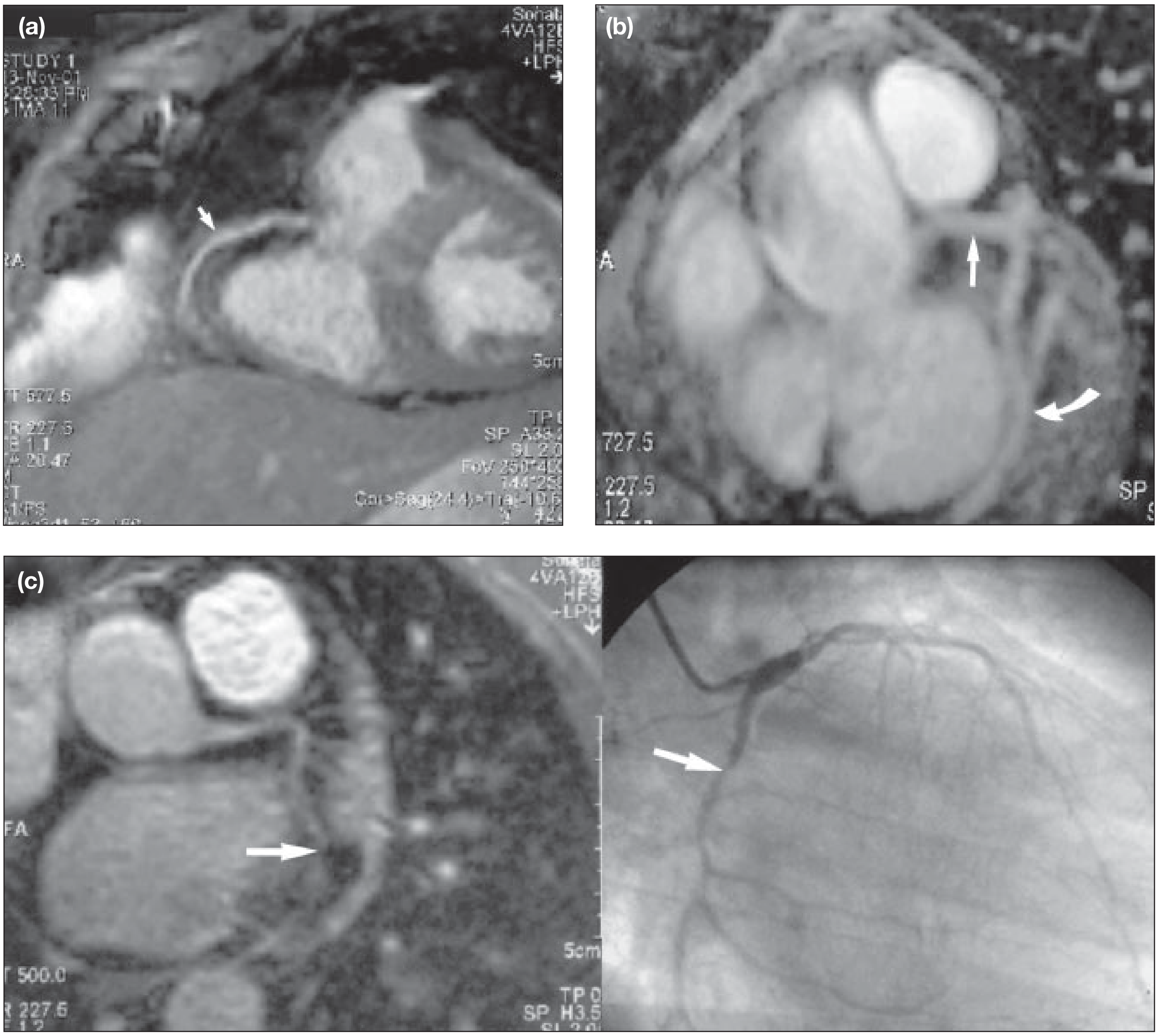

Fig 6. Non-contrast magnetic resonance angiography using breath-hold method: (a) normal right coronary artery (arrow); (b) normal left main coronary artery (arrow) and left circumflex artery (curved arrow); (c) significant stenosis of the left circumflex artery can be seen (left arrow) which was confirmed on digital subtraction angiography (right arrow)

Table. Advantages and disadvantages of different imaging modalities in the evaluation of coronary artery disease*

	Computed tomography	Magnetic resonance imaging	Echocardiography (+/- stress, +/- contrast)	Nuclear medicine (PET† or SPECT‡)
Assessment of myocardial mass	√√	√√	√	√
Assessment of ejection fraction	√√	√√	√	√
Assessment of regional perfusion	√	√	√	√√
Assessment of site and size of myocardial infarction	√	√√	√	√
Detection of coronary artery calcification	√	NA§	NA	NA
Assessment of coronary artery stenosis	√	√	√	√
Repeatability of examination	√√	√√	√	√√
Radiation exposure	√√	NA	NA	√√

* √ denotes good, √√ denotes very good
† PET positron emission tomography
‡ SPECT single photon emission computed tomography
§ NA not applicable

increases the cost of the examination, and possible side-effects associated with the contrast have to be considered. Moreover, first-pass angiography requires the patient's full cooperation. Any movement will degrade the image quality significantly and the possibility of repeat scans is limited by the maximum dose of contrast recommended for the patient's clinical situation and body weight. Contrast-enhanced angiography, however, gives better spatial resolution and signal-to-noise ratio than non–contrast enhanced angiography. Non–contrast enhanced scans can be performed using both breath-hold and free breathing techniques. Screening of an anomalous origin of a coronary artery can therefore be performed without injection of contrast. Breath-hold techniques usually require the patient to hold his/her breath for about 15 to 20 seconds. This is an attractive technique because of rapid imaging and little time penalty when repeated scanning is required. The signal-to-noise ratio is limited, however, by the short acquisition time. Two-dimensional sequences have a further disadvantage in that any slice registration error will result in an apparent signal void in the coronary arteries, causing a false positive result for significant coronary artery stenosis. Three-dimensional acquisition, allowing multiplanar reconstruction, is therefore a preferable technique.[3] Free breathing methods do not require patients to hold their breath, and are therefore feasible for patients with poor cardiac function and shortness of breath. Multiple averages can be taken to improve the signal-to-noise ratio. A major disadvantage lies in the relatively long acquisition time required.

In the past, magnetic resonance coronary artery angiography has been predominantly of research interest. A recent multicentre trial of the use of coronary artery angiography for the detection of coronary artery stenosis found an overall accuracy of 72%. However, the sensitivity, specificity, and accuracy of detection of left main coronary artery disease or three-vessel disease was 100%, 85%, and 87%, respectively.[39] It should be noted that the in-plane spatial resolution achieved by magnetic resonance coronary artery angiography can be 700 to 1000 µm, with the slice thickness varying from 2 to 3 mm. This is still inferior to the resolution of 300 µm achieved on conventional angiography. Distal small branches of the coronary arteries cannot be adequately assessed by this technique. Magnetic resonance coronary artery angiography cannot therefore replace conventional angiography at present. However, it may have a role in general screening of proximal coronary artery disease and serial follow-up in patients who refuse conventional coronary artery angiography. Demand for such a non-invasive method will certainly increase with further improvements in the accuracy of the technique. A summary of the advantages and disadvantages of various imaging techniques discussed in the assessment of coronary artery disease are listed in the Table.

Conclusion

Magnetic resonance imaging has a definite role in the assessment and management of patients with ischaemic heart disease. Its significance and popularity in clinical practice will increase with continuous improvements in technology and accessibility. It is an ideal imaging technique for serial follow-up and screening due to being non-invasive. In the future, MRI may allow a single examination for the assessment of patients with ischaemic heart disease. Assessment of cardiac function, regional wall motion, regional perfusion, the extent of infarction, and the status of the coronary arteries may in the future be determined using MRI.

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