The role of cardiac MRI in clinical practice

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Cardiac MRI has emerged as an established tool for the investigation of many cardiovascular disorders, with a growing number of clinical applications. These include assessment of patients with cardiomyopathy or aortic or congenital heart disease, where it yields prognostic data that are likely to improve clinical outcomes.

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With advances in MRI technology over the past 20 years, cardiac MRI (CMR) has emerged as a robust noninvasive imaging technique for patients with cardiovascular disorders. The utility of CMR for the assessment of cardiac disease stems largely from its ability to:

- generate high-resolution dynamic cine imaging of the beating heart
- generate three-dimensional data sets with gadolinium-based contrast
- detect myocardial scar or fibrosis
- precisely quantify cardiac blood flow.

A clear advantage of CMR is the ability to image using large fields of view with unrestricted imaging planes and without the need for ionising radiation or iodinated contrast. These capabilities have established CMR as the noninvasive reference standard for the accurate quantification of cardiac volumes and ejection fraction, in addition to tissue characterisation of cardiomyopathy and infiltrative diseases.

Myocardial viability studies using CMR combined with high-resolution imaging of regional wall motion are ideal to aid in decisions about coronary revascularisation. CMR is also widely used for the evaluation of congenital heart and aortic diseases, where high-resolution anatomical imaging and flow quantification are often used to guide potential intervention.

Magnetic resonance imaging

MRI involves the application of a strong magnetic field (1.5 or 3 T) and radiofrequency pulses to induce 'resonance' of tissue protons. The heart is well suited to this form of imaging as the blood pool, myocardium and epicardial fat produce signals with distinct characteristics. CMR sequences can be used to generate different

Key points

- **Cardiac MRI (CMR) provides high-resolution dynamic imaging of the beating heart and is the reference standard for assessing ventricular systolic function.**
- **CMR is the only imaging modality that can identify myocardial fibrosis and inflammation, which aids in diagnosis and prognostication for patients with cardiomyopathy.**
- **CMR is widely used for the assessment of aortic and congenital heart disease, where anatomical imaging and quantification of blood flow help guide potential interventions.**
- **Access to CMR is limited to specialised centres and currently Medicare rebates are available only for investigation of congenital heart disease, aortic disease and cardiac tumours.**

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patterns of tissue contrast (T1- and T2-weighted imaging) and to quantify blood flow (phase-contrast imaging). Further, the contrast agent gadolinium is widely used in CMR for angiography and the identification of myocardial fibrosis.

Comparison of CMR with other noninvasive cardiac imaging modalities

CMR *vs* echocardiography

Echocardiography remains the first-line imaging modality for assessment of cardiac function. For many patients no further investigation is required. Echocardiography has a higher temporal resolution than CMR and more adequately assesses valve function. It is also effective for identifying left ventricular (LV) dysfunction via the Simpson's biplane method. However, CMR quantifies ventricular function more accurately through volumetric analysis, with no geometric assumptions. Specifically, CMR is superior for the assessment of right ventricular (RV) function, the LV apex and extracardiac anatomy. Furthermore, CMR can uniquely identify myocardial fibrosis and inflammation to help diagnose in patients with different cardiomyopathies. At present CMR is available only in specialised or tertiary centres, whereas echocardiography is widely accessible, portable and available at lower cost.

CMR *vs* CT angiography

CT angiography has emerged as an important tool for the assessment of aortic and coronary artery disease because of its high temporal and spatial resolution. Importantly, vascular calcification is readily identified using CT but not CMR, where coronary imaging is largely limited to delineation of the proximal coronary course rather than assessment of luminal stenosis. However, the radiation exposure associated with CT, unlike CMR, limits its utility for cardiac functional assessment.

Applications of CMR

Assessment of ventricular function and volumes

CMR has high reproducibility for the assessment of ventricular volumes and function.[1] Whereas echocardiography relies on geometric assumptions, CMR generates multiple contiguous slices through the heart, resulting in precise quantification of LV/RV volumes and ejection fraction.

Assessment of great vessel anatomy and flow

CMR combines high-resolution imaging of vascular anatomy using gadolinium three-dimensional angiography with large fields of view and accurate flow quantification using phase-contrast data. As such, CMR is superior to echocardiography and CT for imaging great vessel anatomy and the outlet valve function of the heart, which are especially relevant in patients with complex congenital heart diseases.

Assessment of cardiomyopathy

CMR allows the characterisation of intramyocardial pathology through assessment of myocardial fibrosis, scarring, inflammation and oedema.

Late gadolinium enhancement (LGE) is used for the assessment of myocardial fibrosis and scarring and involves imaging 10 to 30 minutes after administration of gadolinium. Cardiomyopathies have differing patterns of fibrosis according to their aetiology. Specifically, ischaemic cardiomyopathies have a transmural pattern of LGE, indicating fibrosis (from subendocardium to epicardium), and nonischaemic cardiomyopathies have a mid-wall pattern of LGE.[2]

A hyperintense signal on T2-weighted myocardial imaging allows further tissue characterisation of both the myocardium (oedema or inflammation) and cardiac tumours (vascularity).

Ischaemic cardiomyopathy

CMR is the reference standard for determining the viability of heart muscle after myocardial infarction. LGE in infarcted myocardium typically has a subendocardial or transmural pattern and follows a coronary distribution (Figures 1a and b). Segments with systolic dysfunction but no or minimal LGE are presumed viable and likely represent hibernating myocardium. These areas are likely to recover function after revascularisation.[3] Myocardium with more than 75% transmurality of LGE is considered nonviable.

Nonischaemic cardiomyopathy

Hypertrophic cardiomyopathy. CMR has a role in characterising the phenotype (pattern of wall thickness) of hypertrophic cardiomyopathy and assessing for myocardial fibrosis and scarring (Figures 2a and b). Variants such as apical hypertrophic cardiomyopathy are also easier to detect using CMR compared with echocardiography. The presence of LGE is associated with adverse outcomes, including sudden cardiac death.[4]

Arrhythmogenic right ventricular cardiomyopathy. CMR is the reference standard for the assessment of RV volumes, structure and function and as such has been incorporated into diagnostic algorithms for arrhythmogenic RV cardiomyopathy, which is an inherited condition with a definite association with sudden death.[5,6]

Left ventricular noncompaction. This cardiomyopathy is morphologically characterised by excessive LV trabeculations, leading to cardiac dysfunction, arrhythmia and systemic thromboembolism. Using the higher spatial resolution of CMR, our group has demonstrated a relation between the extent of LV noncompaction and adverse consequences.[7]

Idiopathic dilated cardiomyopathy. Up to 30% of patients with idiopathic dilated cardiomyopathy have mid-wall myocardial fibrosis. Its presence is often associated with reduced functional recovery after medical therapy and hence the need to progress to device-based therapies and/or cardiac transplantation.

Assessment of infiltrative diseases

Sarcoidosis and amyloidosis can result in focal T2 hyperintensity caused by myocardial oedema or inflammation in a noncoronary distribution, and focal wall thickening is often identified (Figures 3a and b).[8] Epicardial and mid-myocardial LGE is characteristic and an independent predictor of adverse outcomes. The site of LGE can be used to guide biopsy. Resolution of LGE often denotes a response to therapy.

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Assessment of congenital heart disease

Atrial and ventricular septal defects

Complete anatomical evaluation with echocardiography (transthoracic or transoesophageal) is usually possible. Beyond this, CMR offers precise shunt evaluation using phase-contrast imaging, robust ventricular volumes (especially RV volume) and assessment of extracardiac anatomy, such as anomalous pulmonary venous drainage.

Aortic disease

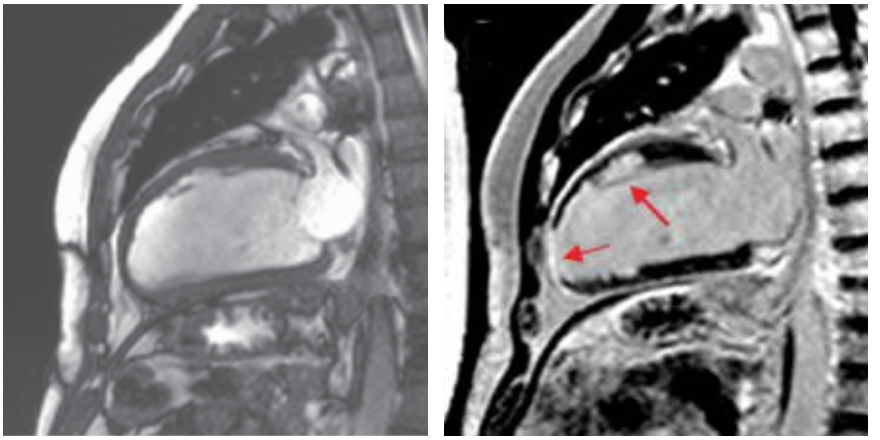
CMR is well suited for the serial assessment of patients with surgically corrected coarctation of the aorta as re-coarctation is not uncommon in adulthood. The severity of re-stenosis and pathological dilatation distal to the defect can be detected (Figures 4a and b).[9] This region may not be easily identified on echocardiography. Patients with connective tissue diseases (e.g. Marfan's syndrome) or bicuspid aortic valves tend to be younger, and CMR offers reproducible serial three-dimensional measurements of aortic dimensions with noniodinated contrast and no exposure to ionising radiation.

Tetralogy of Fallot

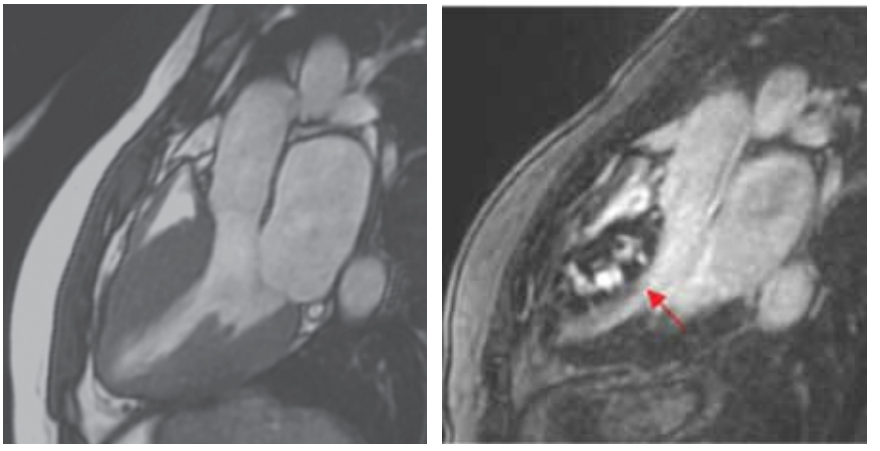
Tetralogy of Fallot is the most common cyanotic congenital heart defect, and pulmonary regurgitation remains a common late postoperative complication, determining the long-term functional outcome. Precise quantification of RV volumes has become a key determinant for the timing of pulmonary valve replacement and is best assessed with CMR because of the complex tripartite anatomy of the RV, with inlet, apex and outlet (Figure 5a). Accurate quantification of pulmonary regurgitation with phase-contrast MRI and delineation of RV outflow tract anatomy will guide either transcatheter or surgical repair.[9] MR angiography also allows accurate imaging of central and branch pulmonary artery pathology (Figure 5b) in addition to detection of aortopulmonary collateral vessels.

Transposition of the great arteries

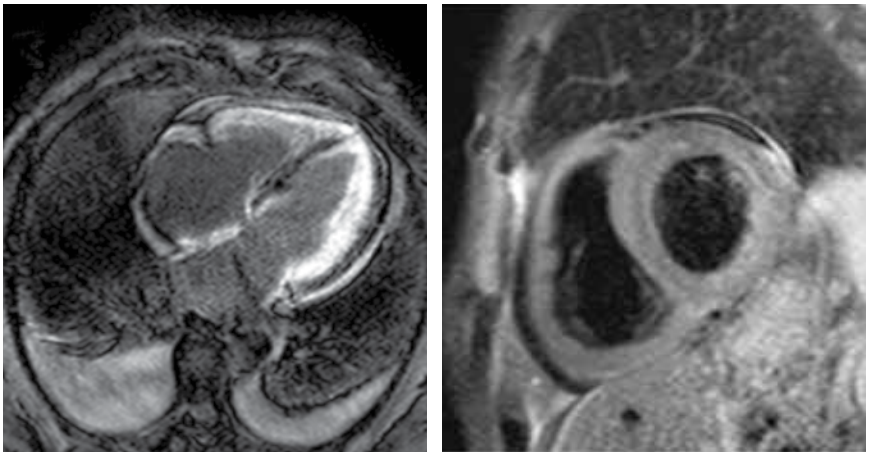
CMR importantly detects postoperative complications of surgically corrected



Figures 1a and b. MRI in a patient after a left anterior descending territory myocardial infarction. MRI images can be generated in any anatomical plane. a (left). Long axis cine image of the left ventricle. b (right). Areas of late gadolinium enhancement indicative of transmural apical and subendocardial mid-anterior wall myocardial infarction (arrows).



Figures 2a and b. MRI in a patient with hypertrophic cardiomyopathy. a (left). Three-chamber view of the heart. b (right). Patchy fibrosis in the anteroseptal wall (arrow).



Figures 3a and b. MRI in a patient with cardiac amyloid. a (left). Diffuse subendocardial late gadolinium enhancement. b (right). Diffusely increased T2-weighted signal indicating inflammation or oedema.

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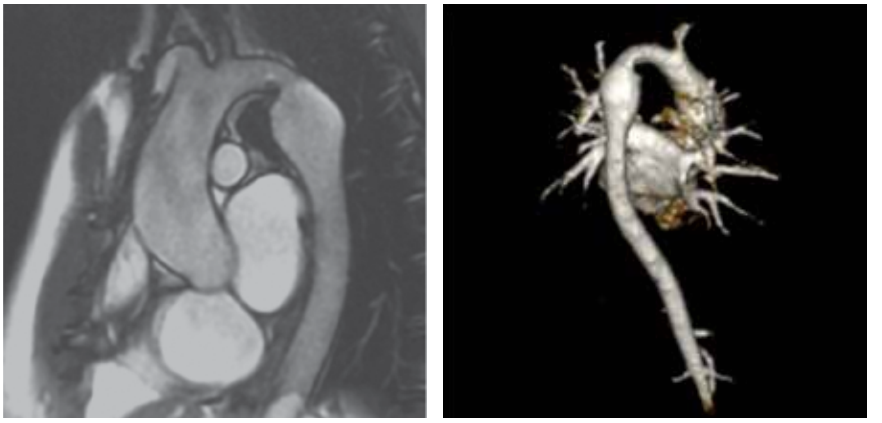
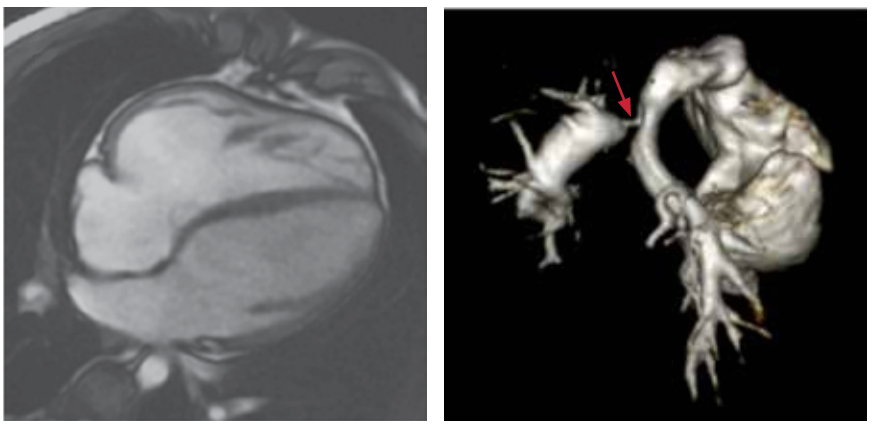
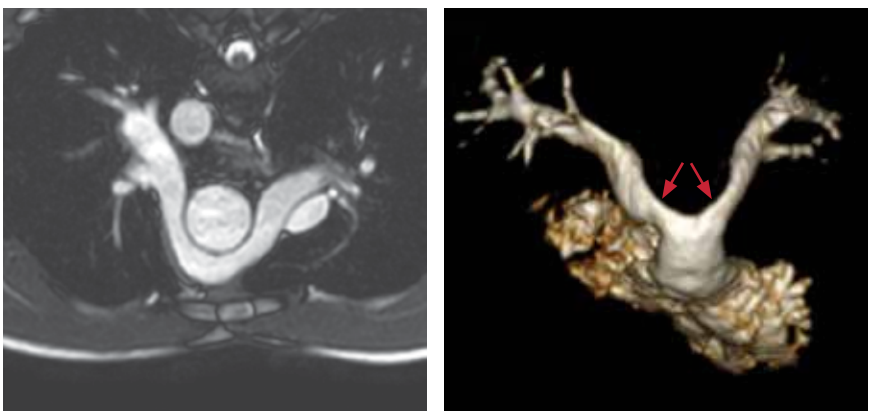


Figures 4a and b. Patient who underwent surgical repair of aortic coarctation many years previously. a (left). MRI cine imaging of the aortic arch. b (right). Three-dimensional MR angiographic reconstruction of the aorta showing mild narrowing in the distal arch and aneurysm formation in the proximal descending aorta.



Figures 5a and b. Patient with surgically repaired tetralogy of Fallot and right ventricular dilatation. a (left). Four-chamber MRI view. b (right). Three-dimensional MR angiographic reconstruction showing severe stenosis at the origin of the left pulmonary artery (arrow).



Figures 6a and b. Patient with transposition of the great arteries treated with an arterial switch operation. a (left). Oblique axial MRI view of the branch pulmonary arteries showing typical Lecompte configuration of the pulmonary arteries after surgery. b (right). MR angiography shows flattening of the branch pulmonary arteries (arrows).

transposition of the great arteries. In these patients, CMR is useful for the assessment of RV outflow tract and branch pulmonary artery pathology in addition to aortic and proximal coronary anatomy following an arterial switch operation (Figures 6a and b).

Single ventricle

Increasing numbers of patients born with a single functioning ventricle have had a modern Fontan procedure, where the superior and inferior vena cava are anastomosed directly to the branch pulmonary arteries, bypassing the need for a subpulmonary ventricle. CMR allows for precise interrogation of complex anatomy, ventricular function and shunt calculations beyond that possible through echocardiography.

Assessment of cardiac tumours

Although rare, cardiac tumours are best assessed by CMR because of the ability to define tissue characteristics through T1- and T2-weighted imaging, with perfusion of the mass and postcontrast enhancement indicating increased vascularity.[10] Prognostication and treatment surveillance are easier than with echocardiography or CT, and CMR often has better resolution than total body positron emission tomography.

Limitations of CMR

Limitations of CMR include a relatively low temporal resolution and susceptibility to arrhythmia and respiratory motion artefacts. Some patients are generally not suitable for MRI, including those with extreme claustrophobia, cerebral aneurysm clips or older generation implantable cardiac devices (pacemakers or defibrillators) and those who are unable to hold their breath. Patients with significant renal dysfunction (estimated glomerular filtration rate less than 30 mL/min) are generally not ideal for administration of gadolinium because of the risk of nephrogenic sclerosing fibrosis.

At present, Medicare rebates for CMR are available only for the following indications:

- congenital disease of the heart or a great vessel

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- abnormality of the thoracic aorta
- tumour of the heart or great vessel.

Medicare rebates are not available for MRI assessment of acquired cardiomyopathy or ischaemia (perfusion imaging), which are validated techniques that are currently being assessed by the MBS.

Conclusion

The strengths of CMR include the ability to define cardiac anatomy, function and physiology noninvasively and precisely using a single modality. Importantly, this high-resolution cardiac imaging is achieved without ionising radiation or iodinated contrast. The prognostic impact of CMR is being consolidated by accumulating prospective data, which are likely to result in its increasing incorporation into diagnostic and management guidelines for cardiovascular disease. **CT**

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