# Cardiovascular magnetic resonance imaging

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## Abstract

Magnetic resonance imaging (MRI) uses the magnetic properties of the hydrogen nucleus, radiowaves and powerful magnets to provide high-quality still and cine images of the cardiovascular system, with and without the use of exogenous contrast (gadolinium). Cardiovascular MRI (CMR) is the gold standard method for three-dimensional analysis of cardiothoracic anatomy, assessment of global and regional myocardial function and viability imaging (late gadolinium enhancement technique). Using first-pass perfusion imaging under vasodilator stress, CMR has high diagnostic accuracy for identifying myocardial ischaemia. Oedema imaging using T2-weighted techniques is useful for the identification of acute coronary syndromes and myocardial inflammation. Coronary MRI is feasible, and indicated particularly for visualizing anomalous coronaries. Its spatial and temporal resolution is inferior to computed tomography or conventional angiography, and the identification and grading of stenoses remains challenging. Molecular imaging may in future allow visualization of unstable plaque. Novel techniques such as T1 and T2 mapping offer a quantitative measure of tissue characteristics. CMR also provides important prognostic data for many cardiovascular diseases. CMR is now an essential component of an advanced cardiovascular imaging service, and it is anticipated that its role will continue to grow.

**Keywords** Cardiac anatomy; cardiac function; coronary angiography; diffuse fibrosis; magnetic resonance imaging (MRI); mapping; MRCP; oedema; perfusion; viability

## Introduction

Cardiovascular magnetic resonance imaging (CMR) has undergone major technical progress over the last decade. CMR scanning has become faster and more patient-friendly, and image quality has further improved. A study of cardiac anatomy, (left and right ventricular) function and fibrosis with a modern CMR scanner can be performed in <30 minutes by an experienced operator. These improvements have led to the widespread adoption of CMR in clinical practice.

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## Key points

- Cardiovascular magnetic resonance imaging (CMR) has further advanced in the last 4 years, becoming faster and more patient-friendly
- CMR is considered the gold standard technique for assessing cardiac anatomy, function and viability
- First-pass perfusion imaging with CMR allows assessment of the presence and extent of perfusion abnormalities, which, in conjunction with infarct imaging, provides important information for planning revascularization strategies
- The application of T1 and T2 mapping to quantitatively measure tissue characteristics has undergone further improvement and is now a robust technique applied in everyday clinical practice in many centres
- In the clinical scenarios of potential iron overload, amyloidosis, Anderson—Fabry disease and myocarditis, parametric mapping provides unique clinical information
- Overall, CMR has a growing clinical role in ischaemic heart disease and various non-ischaemic cardiomyopathies, with a rapidly expanding pool of prognostic data
- Coronary imaging is feasible with CMR, but the identification and grading of stenoses remains challenging
- Although still at the research stage, molecular imaging may in future allow specific detection of unstable plaque

## Background

Magnetic resonance imaging (MRI) is typically based on the magnetic properties of the hydrogen nucleus, although other nuclei can be used.[1] In an MRI examination, the patient is placed in a powerful magnetic field that acts to align the body's protons. Radiowaves in the form of a radiofrequency pulse transmitted into the patient cause the proton alignment to change, for example by 90°. When this radiofrequency pulse is turned off, the protons in the patient's body return to their neutral position, emitting their own weak radiowave signals, which are detected by receiver coils and used to produce an image. The phase and amplitude of each returning radiowave signal can be determined using powerful computers and additional magnetic field gradients, and used to map the position of the excited protons. The resulting image reflects not only proton density, but also the highly complex manner in which protons resonate in their local environment.

CMR requires advanced technology, including a high-field magnet (typically 1.5 Tesla (T), although recently 3.0 T systems have increasingly been used), fast-switching gradient coils and coils for transmission and signal reception. Compared with other imaging techniques, MRI has a unique ability to perform tissue characterization. Image contrast is influenced by proton




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density and T1 and T2 relaxation times, which vary substantially for different tissues (Appendix Table 1). Another way to modify image contrast is by modulating how radiofrequency pulses are played out (the MRI sequence; Appendix Table 2).

During an MRI scan, subjects and operators are not exposed to ionizing radiation, and there are no known detrimental biological adverse effects of MRI if safety guidelines are followed. The scanner attracts ferromagnetic objects, turning them into projectiles that could lead to significant patient or operator injury and also damage the scanner. The presence of certain medical implants and devices (e.g. pacemakers, defibrillators, cochlear implants, cerebrovascular clips) is a contraindication for routine MRI scanning, but nearly all prosthetic cardiac valves, coronary and vascular stents, and orthopaedic implants are safe in a 3 T (or less) MRI environment. Claustrophobia is a problem in a small percentage of patients, and mild sedation usually helps to overcome this.

Gadolinium-containing contrast agents have been linked with the development of a rare systemic disorder called nephrogenic systemic fibrosis. Patients at risk of developing this disease are those with acute or chronic severe renal insufficiency (glomerular filtration rate $<30$ ml/minute/1.73 $m^2$), or acute renal dysfunction of any severity caused by hepato-renal syndrome or in the perioperative liver transplantation period. To date, there is no evidence that other patient groups are at risk. Many MRI centres use gadolinium agents that are tightly bound to a cyclic chelate, which have an incidence of nephrogenic systemic fibrosis of nearly zero. However, it is not known whether immediate haemodialysis protects against nephrogenic systemic fibrosis, so gadolinium-based contrast media should be avoided in high-risk patients unless the diagnostic information sought using contrast-enhanced CMR is essential and not available with non-contrast-enhanced CMR or other imaging modalities.

## Applications of CMR

### Normal and pathological anatomy

Historically, the first application of CMR was the three-dimensional analysis of cardiothoracic anatomy. By providing excellent soft tissue contrast, cardiovascular anatomy can be assessed in virtually any imaging plane (coronal, transverse, sagittal), including individualized double–oblique planes. The latter are particularly valuable in complex congenital heart disease. CMR has a very high degree of sensitivity and specificity for detecting diseases of the thoracic aorta such as aneurysm, acute dissection and intramural haemorrhage. It also allows investigation of the consequences of dissection (e.g. thrombosis, aortic incompetence, pericardial effusion) (Figure 1). Thoracic masses found on chest radiography or echocardiography are also indications for CMR, which can reveal their anatomical relationship to the normal cardiac and thoracic structures. In some cases, CMR allows tissue characterization of such masses.

CMR is currently the most accurate method for diagnosing arrhythmogenic right ventricular cardiomyopathy, characterized by regional wall motion abnormality, regional wall thinning and, in advanced cases, fibrofatty infiltration.[1] In hypertrophic cardiomyopathy, CMR can diagnose and determine the distribution and extent of hypertrophy and fibrosis.[1] Myocardial and liver iron overload in thalassaemia can be assessed quantitatively by measuring myocardial T2*.[1] CMR also helps to differentiate constrictive from restrictive cardiomyopathy; in constriction, thickened pericardium on anatomical images and abnormal motion of the septum resulting from increased interventricular dependence can be readily recognized using real-time imaging during inspiration. By contrast, some patients with restrictive cardiomyopathy (e.g. from amyloidosis or endomyocardial fibrosis) can have areas of fibrosis on late gadolinium enhancement (LGE) CMR.

**Figure 1** A follow-up surveillance scan in a 75-year-old man who had previously undergone repair of a type A aortic dissection (ascending aorta interpositional graft). There is a small residual dissection in the aortic root. The chronic dissection continues distal to the graft, around the aortic arch and into the abdominal descending aorta. Source: Myerson S and Neubauer S, University of Oxford Centre for Clinical Magnetic Resonance Research.

### Myocardial function and mass

CMR is the accepted gold standard for quantification of myocardial mass and function. Using steady-state free precession techniques, double-angulated short-axis cine views can be obtained during all phases of the cardiac cycle (cine-MRI). Planimetry of each slice and summation of slice volumes allow precise determination of systolic and diastolic left and right ventricular volumes, stroke volumes, ejection fraction and myocardial mass, with high reproducibility (Figure 2). This is particularly important in patients with deformed hearts that have lost symmetry (e.g. after myocardial infarction), in whom M-mode and two-dimensional echocardiographic measurements (which assume left ventricular symmetry) are invalid. Because of the higher reproducibility, use of CMR instead of echocardiography in longitudinal clinical research studies of cardiac volumes and mass allows a several-fold reduction in patient group sizes.

Analysis of regional myocardial function is feasible both at rest and during pharmacological stress, typically using dobutamine. Dobutamine stress CMR produces better quality images and thus has a higher sensitivity and specificity for detecting coronary artery disease than dobutamine stress echocardiography, particularly in patients with difficult acoustic windows. New CMR techniques (e.g. tagging, tissue phase-mapping) allow




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