

Cardiac magnetic resonance in clinical cardiology

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Abstract

Over the last decades, cardiac magnetic resonance (CMR) has transformed from a research tool to a widely used diagnostic method in clinical cardiology. This method can now make useful, unique contributions to the work-up of patients with ischemic and non-ischemic heart disease. Advantages of CMR, compared to other imaging methods, include very high resolution imaging with a spatial resolution up to 0.5 mm × 0.5 mm in plane, a large array of different imaging sequences to provide *in vivo* tissue characterization, and radiation-free imaging. The present manuscript highlights the

relevance of CMR in the current clinical practice and new perspectives in cardiology.

Key words: Cardiac magnetic resonance; Gadolinium enhancement; Myocarditis; Myocardial; Cardiomyopathy

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Core tip: The present manuscript highlights the relevance of cardiac magnetic resonance in the current clinical practice and new perspectives in cardiology.

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INTRODUCTION

Over the last decades, cardiac magnetic resonance (CMR) has transformed from a research tool to a widely used diagnostic method in clinical practice. While other imaging modalities like echocardiography and cardiac computed tomography depend solely on tissue density, the most important feature that CMR affords to the diagnostic toolset of the clinic cardiologist, is its ability to provide with a very-high spatial resolution, up to 0.5 mm × 0.5 mm in plane, a large array of different imaging sequences in order to assess *in-vivo* tissue characterization, in addition to radiation-free imaging. These imaging sequences investigate the presence of protons in different chemical environments, thereby allowing conclusions on the presence of fat, water (edema), blood or myocardium among other tissues. The addition of a contrast agent enhances the diagnostic capabilities to assess perfusion, fibrosis and necrosis as well as identify thrombus. Exploiting these different imaging sequences, in addition to the capability of performing high spatial resolution imaging in any desired imaging plane in 3-dimension (3D)

space, CMR provides what could be also called “*in-vivo* pathology”. Therefore, this has led to substantial progress in the assessment of patients with ischemic and non-ischemic heart disease^[1].

ISCHEMIC HEART DISEASE

Acute ischemic disease

After the development of electrocardiographic-triggered fast CMR imaging using gradient-echo sequences, the late gadolinium enhancement (LGE) imaging technique opened new horizons for CMR at the beginning of the century^[2-4]. The method exploits the fact that gadolinium-based contrast agents have a much higher volume of distribution in necrotic and fibrotic tissue, when the cardiomyocytes have lost their cell wall integrity or have been replaced by collagen. Late enhancement imaging therefore allows for an assessment of viability with unprecedented image contrast and very-high spatial resolution. Clinical applications included the detection, when the diagnosis is unclear, the differences between acute myocardial infarction (AMI) and chronic ischemic cardiomyopathy^[5,6]. The assessment of viability predicts functional recovery in acute myocardial infarction based on the transmural extent of the necrosis^[7].

The use of CMR in this setting was subsequently enhanced by the development of water-sensitive T2-STIR sequences, allows the assessment of tissue edema. Of note, since only acute infarction has edema, the combination with LGE imaging, T2-STIR helps to differentiate acute from chronic myocardial infarction^[6,8,9]. The edematous tissue in AMI is thought to reflect the area-at-risk, allowing for quantitative assessment of salvaged myocardium after reperfusion therapy^[10-12]. This can be measured as the difference between edematous tissue minus necrotic tissue, where the latter is seen on LGE.

Microvascular obstruction (MVO) as a consequence of ischemia and reperfusion injury in AMI is reliably detected with first-pass perfusion imaging or the LGE sequence applied early after contrast injection. The presence of MVO is an independent predictor of adverse outcome, independent of infarct size and left ventricular systolic function^[13,14]. Severe microvascular injury can be complicated by reperfusion hemorrhage, which again can be visualized and also quantified with a specific CMR sequence (T2*-weighted imaging)^[15]. It is currently unclear whether hemorrhage has independent prognostic effects beyond MVO, since insufficient sample size and flaws in study design, limited most of the clinical studies trying to address this question.

Chronic ischemic disease

Newer imaging approaches are emerging to fine-tune risk assessment in chronic ischemic heart disease, and help, for example, with patient's selection for implantable cardioverter-defibrillators (ICD) implantation. Several authors have shown that the peri-infarct zone between

chronic infarction tissue and healthy myocardium displays an intermediate contrast signal. The extent of this “grey-zone” has been associated with ventricular arrhythmia and major adverse cardiac events, probably due to electrical re-entry circuits being located in this area^[16]. Prospective studies are under way to assess, whether advanced tissue characteristics such as the LGE grey-zone would be helpful to better select patients for ICD implantation, thereby switching selection criteria from the current left ventricular systolic function to a tissue characteristic. Hence, an improved patient's selection could be of tremendous help, allowing for better selection of patients at higher risk, and also avoiding potentially unnecessary ICD implantations.

In stable coronary artery disease, CMR perfusion imaging with and without stress agents (predominantly adenosine) can detect myocardial ischemia with high accuracy. Depending on the reference standard, it has been reported a sensitivity and specificity of about 90% and 70%-90%, respectively, for the detection of myocardial ischemia^[17,18]. Advantages of CMR in this setting include a higher spatial resolution than nuclear imaging methods, allowing the diagnosis of sub-endocardial perfusion defects and microvascular disease^[19]. Research efforts are under way to detect ischemia without using contrast agents. Indeed, blood-oxygen-level-dependent (BOLD) sequences are able to create image contrast-based on the tissue's oxygen content in the brain, and initial reports have suggested that modified BOLD sequences could also be applied in the heart^[20,21]. This approach, once developed to a clinically applicable tool, promises to revolutionize the ischemia detection field by measuring myocardial oxygen directly, and moving away from perfusion as a surrogate marker.

NON-ISCHEMIC HEART DISEASE

Cardiac magnetic resonance has allowed significant progress in understanding of non-ischemic cardiomyopathies. Beyond accurate assessment of ventricular volume and function, tissue characterization using T1, T2, T2*, perfusion and contrast-enhanced sequences allows for comprehensive tissue characterization as a non-invasive pathology^[22-24]. This further contributes to identify the etiology of heart failure, and initial studies have started to identify CMR-based tissue characteristics as prognostic markers^[25-28]. In fact, CMR is now the reference diagnostic tool to diagnose myocarditis, as recommended by the Lake Louise consensus criteria^[29]. Importantly, T2-weighted imaging identifies edema as a marker of inflammation in acute/active disease, and late gadolinium enhancement is typically present in a “patchy”, thus, a non-ischemic pattern. Of note, the combined imaging sequences yield a diagnostic power to assess myocarditis with a sensitivity of 76% and specificity of 96%^[30]. Noteworthy, patients with LGE in myocarditis have a worse prognosis than patients

without LGE^[31]. Moreover, infiltrative cardiomyopathies such as amyloidosis are reliably diagnosed based on their typical pattern of signal change on T2 and LGE, usually involving the entire myocardium as an organ^[32]. The diagnostic power of CMR is especially well exploited in iron deposition disease like thalassemia and hemochromatosis. In fact, CMR can semi-quantitatively assess iron deposition by measuring the T2* value of myocardium. The latter highly correlates with myocardial iron content^[33,34]. Furthermore, it is of prognostic value as can be used to monitor the effect of iron chelation therapy, let's say, to start, titrate or finish iron chelation therapy.

THE FUTURE OF CMR

Cardiac magnetic resonance is still a relatively “young” imaging technique, and new technical developments are continuously entering the clinical arena. While current imaging sequences mostly provide a contrast suited for visual analysis, imaging methods that quantitatively map T1, T2 and T2* characteristics are under evaluation^[35]. Moving away from qualitative assessment to semi-quantitative or quantitative image analysis will allow increased diagnostic accuracy and reduced observer bias, as well as improve inter-study variability. Normal values will have to be established for different field strengths, and differences in sequence programming between different CMR vendors as a source of variability of normal values will have to be addressed. Eventually, advanced tissue characterization with mapping sequences could reduce (but probably not eliminate) the dependence on gadolinium-based contrast agent. New imaging sequences that apply self-triggering may eliminate the need for electrocardiographic tracing and breath-hold maneuvers^[36], further increasing patient comfort and reduce scan time.

CONCLUSION

Cardiac magnetic resonance has become a basic diagnostic tool in cardiovascular medicine. The next decade will be marked by clinical trials investigating the prognostic value of the detailed imaging findings that can be obtained today, and may guide therapy and improve patient prognosis.

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