ORIGINAL ARTICLE

The Contribution of Cardiac Magnetic Resonance Imaging to the Diagnosis of Cardiac Diseases

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ABBREVIATIONS
ARVC = arrhythmogenic right ventricular cardiomyopathy
CAD = coronary artery disease
CHD = congenital heart disease
CM = cardiomyopathy
ECG = electrocardiogram
MRI = magnetic resonance imaging

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ABSTRACT

BACKGROUND: Cardiac magnetic resonance imaging (MRI) has been established in clinical practice as a valid imaging modality for the diagnosis of various cardiovascular disorders.

OBJECTIVES: To underline the importance of cardiac MRI as an alternative non - invasive imaging method for the diagnosis and follow-up of cardiac patients based on findings from our own recent experience.

PATIENTS AND METHODS: The study included all cardiac patients referred for cardiac MRI over a period of one year. Cardiac MRI studies were performed with the use of a 1.5-Tesla scanner using a body phased-array coil, breath and ECG-triggering. Almost all cardiac sequences were gated to the patient's cardiac cycle. Cine imaging for the evaluation of cardiac volumes and heart motion was performed using a cine breath-hold true short-axis and true four-chamber sequence with whole left ventricular coverage. Black blood imaging for the assessment of morphology was acquired on a true short-axis and true four-chamber view. Depending on the pathology under investigation, special sequences were added to the imaging protocol, such as late-enhancement imaging after gadolinium administration.

RESULTS: The study cohort comprised 114 patients who were referred for cardiac MRI with the following indications and clinical diagnoses: myocarditis (n=29), arrhythmogenic right ventricular cardiomyopathy (ARVC; n=27), valvular heart disease (n=23), history of myocardial infarction (n=13; seeking myocardial viability), hypertrophic (n=12), or dilated (n=2), or tako-tsubo (n=1), or non-compaction (n=2) cardiomyopathy, pericardial effusion (n=2) and various intracardiac masses (n=3). Cardiac MRI confirmed the clinical diagnosis and gave further specific information in 52% of myocarditis cases, in 37% of suspected ARVC cases, in 38% of coronary artery disease patients regarding myocardial viability, while it confirmed all other clinical diagnoses (100% match).

CONCLUSIONS: Cardiac MRI represents a clinically useful imaging method for the diagnosis of various cardiac disorders since it has the capability of providing highly accurate and reproducible measurements of cardiac hemodynamics in addition to the detailed demonstration of cardiac anatomical structures.

INTRODUCTION

Cardiac magnetic resonance imaging (MRI) has been established in clinical practice for the diagnosis and management of cardiovascular diseases. It is a rather safe examination since no long-term ill effects have been reported.´H

Considerable technical advances, in both hardware and software, have been achieved over the recent years and many techniques are currently available for performing cardiac MRI. This imaging modality was introduced into clinical routine for the assessment of cardiac morphology more than 10 years ago. The multiplanar cross-sectional nature inherent to cine-MRI, coupled with high spatial and temporal resolution, has been shown to provide highly accurate and reproducible measurements of cardiac hemodynamic parameters in both acquired and congenital heart diseases. Indeed, it has been considered as the most precise technique for the quantification of ventricular volumes, function and mass, representing this way a standard of reference method for the assessment of the ejection fraction of both ventricles and of regional wall motion abnormalities.[2-4]

Cardiac MRI is also the optimal method to assess therapeutic response with regards to geometrical and dynamic ventricular parameters.[3,4] Moreover, delayed contrast enhancement is an accurate and robust method used in the diagnosis of ischemic and non-ischemic cardiomyopathies (CM) and of less common diseases, such as cardiac sarcoidosis and myocarditis.[5,6] Finally, first-pass magnetic contrast myocardial perfusion is becoming an alternative to radionuclide techniques for the detection of coronary artery disease (CAD) and/or assessment of myocardial viability. In this article we present our experience with cardiac MRI in patients with various cardiovascular diseases referred to us during the past 12 months.

PATIENTS AND METHODS

The study included all cardiac patients referred over a period of one year for cardiac MRI. Cardiac MRI studies were performed with a 1.5-Tesla scanner (Signa Excite, GE Healthcare) using a body phased-array coil, breath and ECG-triggering. Various measures were taken before or during image acquisition. At first, patients were informed about the procedure and the importance of breath holding during the examination was underlined to them. Image acquisition at end-expiration was preferred since it is highly reproducible. Almost all cardiac sequences were gated to the patient's cardiac cycle; to accomplish gating, electrocardiographic leads were applied and the electrocardiographic waveform was evaluated before image acquisition begins. Since the placement of surface coils in relation to the heart is crucial to achieve a good signal-to-noise ratio, the centers of both the anterior and the posterior surface coils were then well aligned with the center of the heart. After the patient was positioned within the magnet, multiplanar scout images were obtained and reviewed to ensure that the surface coils were properly placed over the heart and that the patient was positioned so that the heart was at or near the magnet isocenter.

After the initial gradient echo had been localized in the three orthogonal planes, the following sequences were acquired: vector cardiogram triggered balanced Fiesta in single-slice, multiphase mode in the long axis, pseudo-short axis and four-chamber plane. Cine imaging for the evaluation of cardiac volumes and heart motion was performed using a cine breath-hold true short-axis and true four-chamber sequence with whole left ventricular coverage (axial SSFP bright blood cine Image -FIESTA, true 4-chamber-view cine images, and true short-axis cine images; cover the entire left ventricle; TR = 3.5 msec; TE = minimum, flip angle = 45–70°, slice thickness = 8 mm, interslice gap = 2 mm, FOV = 36–40 cm, 16–20 views per segment). Black blood imaging for the assessment of morphology was acquired on a true short-axis and true four-chamber view (axial black blood images: double inversion recovery TSE/FSE starting from the diaphragm to the pulmonary artery, TR = 2 R-R intervals, TE = 5 msec GE; slice thickness = 5 mm Interslice gap = 5 mm FOV = 28 cm). Black blood Images with fat suppression on a true short-axis and true four-chamber view were also obtained. Cardiac triggered, flow sensitive phase-contrast gradient echo sequences were obtained at levels perpendicular to the long axis of the ascending aorta and the main pulmonary artery. Depending on the pathology under investigation special sequences were added to the imaging protocol, such as late-enhancement imaging in a short-axis inversion-recovery sequence performed 10 and 15 min after gadolinium administration (TI scout 4-chamber view, using TI scout sequences or trial TI times to suppress normal myocardium; delayed gadolinium short axis images 10–15 min delay; same slice coverage as short axis cine images, TI : 250-270, flip angle = 20–25°, slice thickness = 8 mm, interslice gap = 2 mm, FOV = 36–40 cm).

In order to study regional myocardial contraction, tagging sequence was used, which superimposes a grid of dark lines across the image in diastole. These tags subsequently deform through the cardiac cycle allowing the calculation of regional myocardial strain. Cardiac magnetic resonance angiography was performed with three-dimensional (3D) coverage of the vessel during a short breath-hold and after intravenous injection of a *gadolinium*-based contrast agent. In some cases non-contrast magnetic resonance angiographic techniques were also used.

Image analysis was performed on a workstation (report-card GE) using the cardiac analysis package. Evaluation included biventricular mass, dimensions and end-diastolic, end-systolic volumes, ejection fraction and stroke volume as well as aorta and pulmonary artery flow measurements.

Left ventricular and right ventricular end-diastolic volumes, end-systolic volumes, ejection fractions, and stroke volumes were calculated throughout the cardiac cycle by defining the endocardial and epicardial borders at end-diastole and end-systole in the short-axis FIESTA images and evaluated with a computer aided analysis package for planimetry.

Flow and volume measurements in the pulmonary artery and aorta and their ratio were obtained throughout the cardiac cycle by manually tracing the respective vessel contours on the phase images from the phase contrast gradient echo sequences. All volume and flow values were indexed to body surface area. The evaluation of biventricular mass was achieved by determination of the epicardial and endocardial contour of the free wall on the same set of end-diastolic short-axis images. The obtained volume was multiplied by 1.05 g/cc. Papillary muscles and trabeculae were included in the mass measurement and excluded from the volume analysis.

R E S U L T S

One-hundred fourteen patients were examined in the MRI unit of our Radiology department over the last one year (Table 1). Twenty-nine patients were referred with symptoms suggestive of myocarditis, 27 with ventricular arrhythmias suggestive of arrhythmogenic right ventricular cardiomyopathy (ARVC), 23 with valvular heart disease to assess the severity of valvular regurgitation, 13 with coronary artery disease (history of myo-

cardial infarction) to detect viable myocardial tissue, 12 with hypertrophic cardiomyopathy (CM) to assess left ventricular outflow tract gradient, 2 with dilated CM to measure left ventricular ejection fraction, two with non-compaction CM, one with Tako-Tsubo CM, 2 with pericardial effusion, and 3 with various intracardiac masses.

In 15 out of the 29 patients (51.7%) with possible myocarditis the diagnosis was established based on the finding of late enhanced images (Fig. 1). Of the 27 patients with ventricular arrhythmias and suspected ARVC, evidence strongly indicating the presence of ARVC (localized aneurysms, right ventricular dilation with low ejection fraction, late enhancement images positive for fibrosis) was documented in 10 of them (37%). In the 23 patients with valvular heart disease, an accurate estimate of the severity of regurgitation was achieved in all of them. Moreover, viable myocardium was detected in 5 out of the 13 (38.4%) patients with CAD examined. An accurate measurement of the pressure gradient in the left ventricular outflow tract was achieved in all patients with hypertrophic CM referred for cardiac MRI (Fig. 2). In addition,
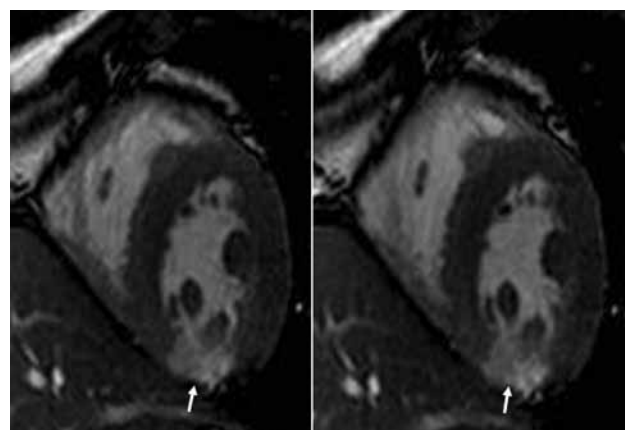

FIGURE 1. Acute Myocarditis. Delayed enhancement imaging, short-axis view, 5 minutes after intravenous Gadolinium infusion. Gadolinium enhancement in the lower part of the left ventricle (arrow).

TABLE 1. Patients in whom a Cardiac MRI was Performed and Respective Diagnoses

Cardiac Disease	Referral Diagnosis	Final Diagnosis (No./ %)
Myocarditis	29	15 (51.7%)
ARVC	27	10 (37%)
Valvular heart disease	23	23
CAD (myocardial viability)	13	5 (38.4%)
Hypertrophic CM	12	12
Idiopathic dilated CM	2	2
Non-compaction CM	2	2
Tako-Tsubo CM	1	1
Pericardial disease	2	2
Intracardiac masses	3	3
Total	114	75

ARVC= arrhythmogenic right ventricular cardiomyopathy; CAD= coronary artery disease; CM= cardiomyopathy; MRI= magnetic resonance imaging
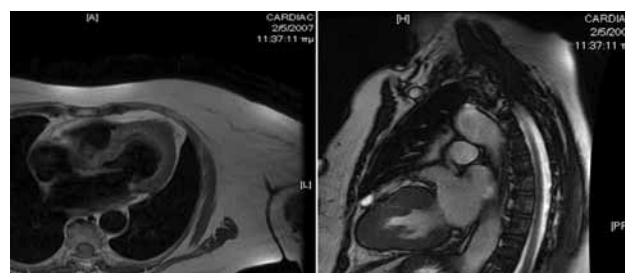

FIGURE 2. Hypertrophic cardiomyopathy. Double-IR sequence (left), FIESTA cine-sequence (right).

left ventricular ejection fraction was accurately measured in the 2 patients with dilated CM. Finally, fine anatomic details of their underlying pathology were delineated in the rest of the patients (Fig. 3), while in the 2 patients with pericardial effusion cardiac MRI excluded the diagnosis of tuberculous pericarditis based on the absence of gadolinium enhancement as well as on the lack of both pericardial anomalous thickening and of nodules suggestive of tuberculomas.

DISCUSSION

We herein presented out experience in 114 patients with the use of cardiac MRI during the time span of one year. Our findings strongly support the important role of this relatively new imaging technique in the diagnosis of various cardiovascular disorders. Indeed, recent technologic advances have allowed cardiac MRI to enter the mainstream imaging practice for many disease entities. The development of increasing magnet strengths and surface coil channels, rapid k-space sampling and post-processing techniques and sophisticated myocardial soft-tissue characterization sequences have made cardiac MRI a powerful tool in the workup of many complex cardiac conditions. The clinical use of this imaging technique continues to expand because of the increasing experience and proliferation of cardiac MRI centers. As the worldwide prevalence of cardiovascular disease continues to rise, the use of cardiac MR imaging provides an opportunity for improved and cost-effective noninvasive cardiac assessment. Continued progress in cardiac MRI technology promises to further widen its clinical application in the diagnosis and management of diseases of the cardiovascular system.

The most important current clinical applications of this imaging technique are detailed below. Evaluation of patients with congenital heart disease (CHD) is a significant strength of cardiac MRI because 3-dimensional contiguous data sets are very effective for the complete depiction of the pathological anatomy of both simple and complex CHD (Fig. 4). Moreover, the lack of ionizing radiation is an important consideration when performing sequential studies in children and young adults. Thus, cardiac MRI is usually performed following, and as an adjunct to, transthoracic echocardiography in neonates and infants. In contrast, it becomes the first-line technique in older children, in adolescents or adults, in diseases with complex anatomy and at any age after surgery because the body habitus as well as the interposition of scar tissue and lungs become an increasing problem for transthoracic echocardiography.[7]

Cardiac MRI is well established for the evaluation of a wide variety of acquired vascular diseases. It is particularly useful for vascular lumen imaging with its ability to generate projection angiograms. In addition to morphologic imaging of blood vessels, velocity mapping can be used to assess and measure the blood flow.[1] It is well suited for use in patients with contraindications to X-ray contrast.

Cardiac MRI has opened new avenues for assessing coronary artery disease (CAD) and its consequences. It provides valuable information which may not be available from other diagnostic tools such as echocardiography and nuclear cardiology currently dominating non-invasive diagnosis in patients with CAD. Its superb spatial and temporal resolution combined with excellent soft tissue contrast allow for accurate assessment of cardiac morphology, global cardiac function, regional wall motion, and the extent of myocardial infarction (Fig. 5).[5,8]
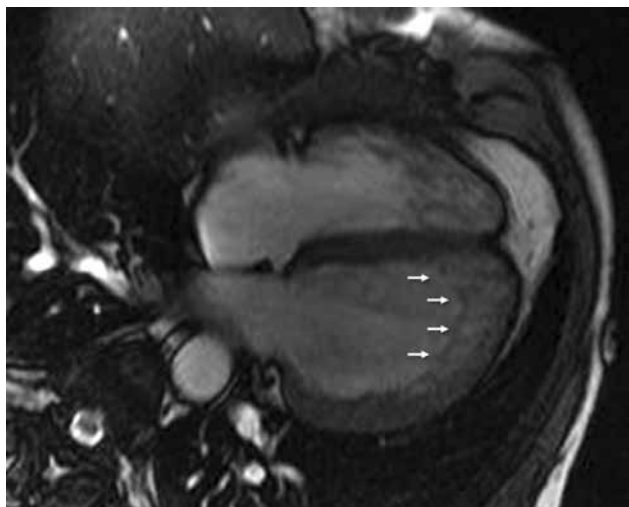

FIGURE 3. Non-compaction cardiomyopathy (arrows) (four-chamber view; cine).
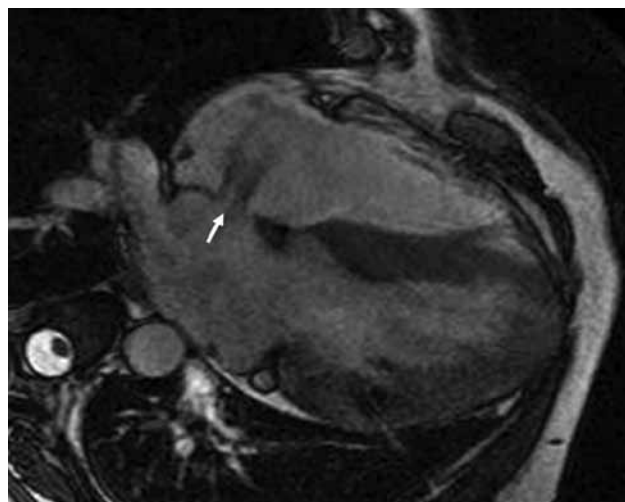

FIGURE 4. Atrial septal defect with left to right shunt (arrow) (four chamber view; cine).

FIGURE 5. Left ventricular apex aneurysm (arrow).

The cardiomyopathies include a variety of diseases where the primary pathology directly involves the myocardium excluding CAD. Cardiac MRI is proving increasingly valuable in the identification and management in these conditions.[5,8] As shown in the present series, a particularly difficult to diagnose CM with use of echocardiography is the ARVC, in which cardiac MRI has immensely contributed and has helped arrhythmologists to properly manage these patients; in 10 out of 27 (37%) patients in our cohort suspected of having been afflicted by ARVC, cardiac MRI confirmed the diagnosis. Cardiac MRI was also very helpful in other rare types of CM, such as the non-compaction (n=2) and tako-tsubo (n=1) variety. Another type of myocardial disease is the case of myocarditis, in which again cardiac MRI has the potential to assist in the diagnosis. This can be accomplished by its tissue characterization capabilities[9] with the early and delayed gadolinium enhancement with its subepicaridal, as opposed to subendocardial (seen in CAD) distribution; this was achieved in ~52% of our own cases referred for cardiac MRI with a potential diagnosis of myocarditis.

Cardiac MRI is a valuable tool for individual follow-up of the severity of regurgitant lesions and for quantification of the effects of valvular lesions on ventricular volumes, function and myocardial mass. Cardiac MRI may play a complementary role when transthoracic acoustic windows are poor and a transesophageal approach is undesirable, or when results of echocardiography and catheterization are conflicting.[10-12]

Cardiac MRI is particularly helpful in patients with cardiac masses determining the relationship to normal intracardiac structures and the tumour extension to adjacent vascular and mediastinal structures, infiltration into the pericardium, and surgical planning. In addition several other MRI features can assist in tumour characterization.[13]

Both cardiac MRI and computed tomography (CT) are well suited to define anatomic abnormalities of the pericardium including pericardial thickening and effusions. Cardiac MRI has the advantage of being able to depict and quantify the functional abnormalities which may be associated with pericardial disease. The large field of view of CT and MRI is helpful in providing a better overview of the extent of pericardial disease, and to define the relationship with surrounding anatomic structures. For suspected pericardial thickening, MRI and CT are primary imaging modalities, with CT having an advantage for identification of pericardial calcium.[1,4,8,14]

CONCLUSION

Recent technological advances have led cardiac MRI to enter the practice of mainstream cardiac imaging. Cardiac MIR is currently used in clinical practice for the evaluation of congenital heart disease, of the aorta, of cardiac tumors, of the pericardium, of cardiomyopathies, of valvular heart disease, of CAD, and for the assessment of ventricular function and mass. We underlined the importance of cardiac MRI as an alternative non-invasive imaging method for diagnosis and follow-up of 114 patients with various cardiovascular disorders, based on data from our own recent experience with this modern technique over the period of one year.

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