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CARDIOVASCULAR IMAGING FOR NUCLEAR CARDIOLOGISTS −REVIEW ARTICLE

Cardiovascular Imaging for Nuclear Cardiologists: First Step of Cardiac Magnetic Resonance Imaging for Nuclear Cardiologists

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Abstract

Cardiac magnetic resonance (CMR) is a rapidly evolving technology that is increasingly being used for the noninvasive imaging in the diagnosis of cardiac diseases. CMR allows for the accurate and reproducible assessments of anatomy, function and tissue characterization of the heart. It is important for cardiologists to know the advantages and the clinical applications of CMR examination. This review article describes the essentials of CMR study and the key points of the interpretation in patients with cardiac disease.
Keywords: Cardiac function, Cardiac sarcoidosis, Cardiovascular magnetic resonance, Myocardial infarction, Myocardial viability
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As a result of the rapid technical progress in hardware and software, cardiac magnetic resonance (CMR) plays an increasingly important role in managing patients with cardiac disease (1-3). A unique feature of CMR is the availability of multiple types of pulse sequences for evaluating cardiac anatomy, function, and tissue characterization. CMR is regarded as a gold standard imaging technique to assess myocardial regional and global function (4, 5), and myocardial infarction and fibrosis (6). CMR images can be acquired without application of ionizing radiation or the administration of radioactive isotopes or iodinated contrast. The noninvasive feature of the imaging facilitates the diagnosis and the subsequent monitoring of cardiac diseases. Now, it is important for cardiologists to become familiar with the advantages and the clinical applications of CMR examination. This review article would focus on three topics regarding CMR clinical applications, including myocardial function, myocardial infarction, and cardiac sarcoidosis (CS).

Assessment of myocardial function with cine CMR

In contrast to echocardiography, CMR has the ability to image in any desired plane and with a nearly unrestricted field of view. This feature of CMR is attractive particularly in patients who may have body habitus limitations with other imaging modalities, such as obesity and pulmonary emphysema in echocardiography (1, 3). For CMR measurement of ventricular volumes and ejection fraction, consecutive 6- to 10-mm tomographic cine short-axis cross-sections of the heart are obtained, and the summation of discs method is then applied to determine the total ventricular volumes (Fig. 1). In a typical application, the temporal resolution of cine CMR for myocardial function determination is 45 ms or less (7). Breath-hold time for each cross-sectional slice is approximately 5 to 10 s. The functional information with cine CMR can be obtained without the need to make any geometric assumptions or calculations based on incomplete sampling of the cardiac volumes. Thus, cine CMR can provide an excellent reproducibility for the assessment of ventricular volume and ejection fraction (4, 9). Left ventricular (LV) size and systolic function are precisely determined by cine CMR imaging with standard errors of about 5% (9, 10). The inherent 3-dimensional nature of CMR makes it particular well suited to studying the right ventricle (RV), which is difficult to assess with echocardiography because of its complex and variable morphology (11).

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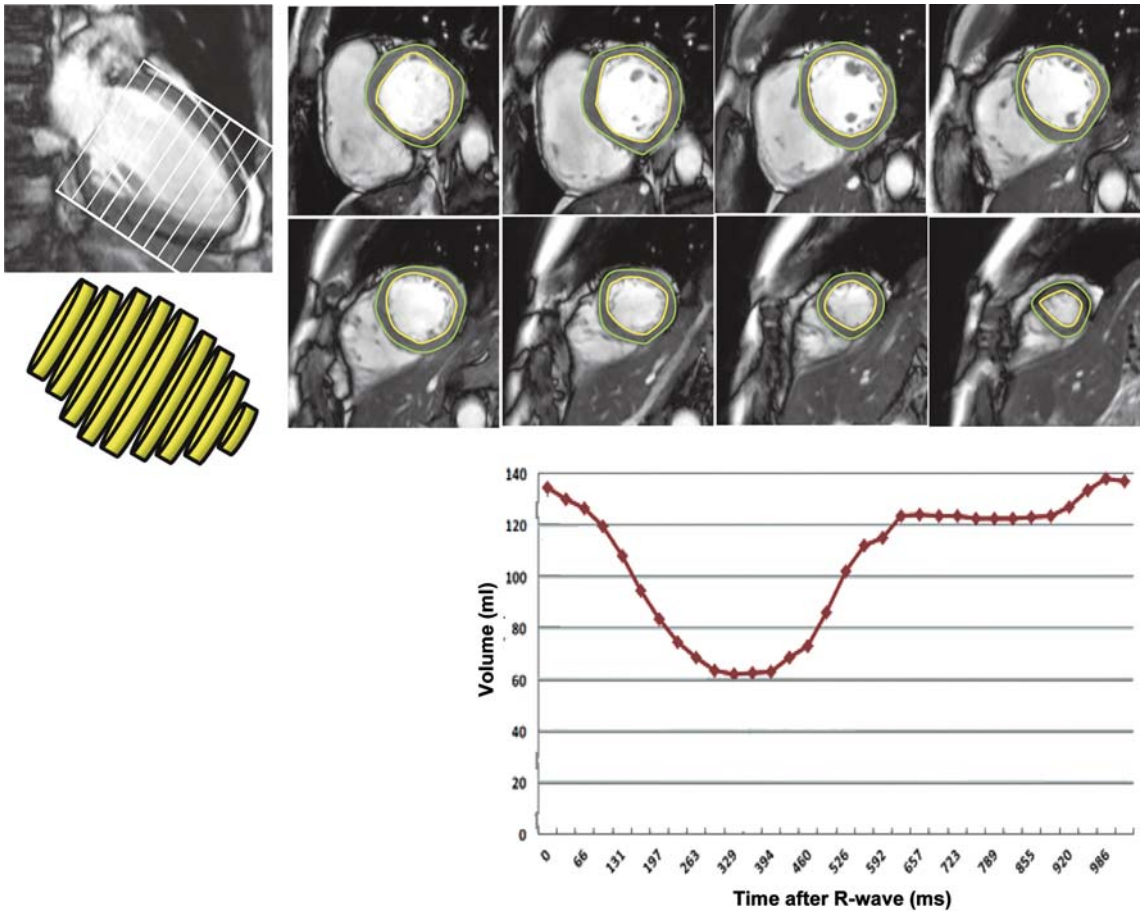

Fig. 1 For the measurement of myocardial volumes and mass, endo- and epicardial border is contoured on consecutive 6- to 10-mm tomographic cine short-axis cross-sections of the heart, and the summation of discs method is then applied. Right lower column shows time-volume curve during a cardiac cycle generated from cine magnetic resonance images.

Cine CMR can also measure the diastolic function. Time-volume curves generated from cine CMR provide indexes of global diastolic function, such as peak filling rate and time to peak filling rate (12). With regard to regional ventricular function, cine CMR enables the accurate identification of even subtle regional contractile abnormalities, since cine CMR can provide an excellent delineation of the blood-myocardial interface without use of contrast medium (6).

Assessment of myocardial infarction and viability with late gadolinium enhancement CMR

In contrast to radioactive tracers used for myocardial perfusion scintigraphy, conventional gadolinium contrast media non-specifically distributes in the extracellular space. Approximately 10 minutes after intravenous administration of gadolinium contrast medium, distribution of the contrast medium in the intravascular and extra-cellular space reaches equilibrium state. In patients with myocardial infarction, concentration of the contrast medium in necrotic or fibrotic myocardium is substantially higher than that in normal myocardium due to increased extra-cellular space (Fig. 2). This is typically referred to as“delayed enhancement”or“late gadolinium enhancement (LGE)”(13). LGE accurately delineates infarcted tissue as defined by histology, with high spatial resolution and contrast-to-noise ratio (14). Thus, LGE CMR is more reliable in detecting subendocardial infarction when compared with single photon emission computed tomography (15, 16). In addition, LGE CMR improves the detection of RV infarction (17).

Previous studies demonstrated that transmural extent of LGE (percent transmural extent) is correlated with a lack of improvement of regional contractile function in patients with acute myocardial infarction (18, 19). In the setting of old myocardial infarction, percent transmural enhancement has been shown to be predictive of recovery of regional contraction after revascularization (20, 21). The best predictor of improved wall thickening and global function after revascularization was the extent of the dysfunctional myocardium that had either no LGE or less than 25% transmurality of LGE (20). By contrast, the likelihood of regional functional recovery was very limited in the myocardial segment with a 76% to 100% transmurality of LGE in patients with old

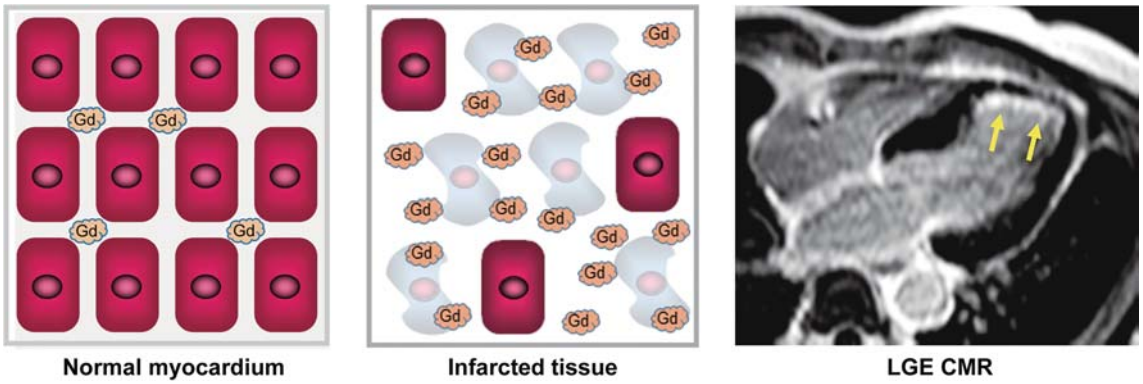

Fig. 2 Mechanisms of late gadolinium enhancement (LGE) in myocardial infarction. Gadolinium distributes in the extracellular space. In normal myocardium, majority of the volume is myocyte intracellular space (≈80%). Thus, the distribution volume of gadolinium in normal myocardium is relatively small. In the setting of myocardial infarction, there is myocyte membrane rupture or replacement with collagenous scar. This in turn results in increased gadolinium concentration in the infarcted tissue. The right column displays 4 chamber image of LGE cardiac magnetic resonance (CMR) obtained 10 minutes after the intravenous administration of 0.15mmol/kg of gadolinium. Note subendocardial infarction is clearly depicted in the anteroseptal wall of the left ventricle (arrows).

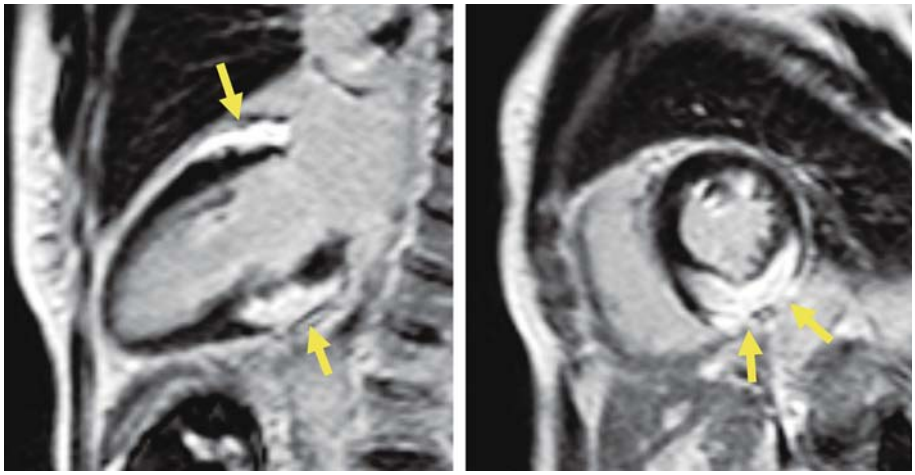

Fig. 3 Late gadolinium enhancement in a patient with cardiac sarcoidosis. Note the epicardial hyperenhancement, suggesting a"non-ischemic"etiology, is depicted in the anterior and inferior wall of the left ventricle (arrows).

myocardial infarction (20).

Evidence suggests that LGE CMR can also provide a valuable information for predicting major adverse cardiac events and cardiac mortality in patients with suspected coronary artery disease. Previous studies also demonstrated that the presence of LGE was found to be the strongest predictor of major or adverse cardiac events, independent of LV ejection fraction and other conventional clinical markers (22, 23).

Role of CMR in the evaluation of cardiac sarcoidosis (CS)

Sarcoidosis is a multisystem disorder of unknown cause, and CS affects at least 25% of patients and accounts for substantial mortality and morbidity from this disease. CS may present with heart failure, atrioventricular block, atrial or ventricular arrhythmias, and sudden cardiac death. An early identification of CS is crucial to install immunosuppressive therapy and thereby prevent the development of severe cardiomyopathy and heart failure symptoms (24).

Recent studies demonstrated LGE CMR can readily identify individuals with CS that are not otherwise clinically recognized because of its ability to accurately detect even small areas of granuloma and scar by CS (25). In fact, >15% of patients with sarcoidosis have cardiac involvement based on CMR, despite the absence of significant LV dysfunction (26). A recent study demonstrated that LGE is associated with an increased risk of death or ventricular tachycardia, even with preserved LV function (27). These observations suggest that LGE CMR is a valuable tool for the cardiac risk stratification of patients with extracardiac sarcoidosis, as well as for ruling out CS in patients with suspected CS. Updated guidelines have evidence of regional cardiac fibrosis and/or wall motion abnormalities on CMR studies as minor criteria (28). In CS patients, LGE is frequently found isolated to the mid-

Table 1 Summary of the CMR characteristics and clinical implications described in this article

CMR scan	Technical characteristics	Clinical indications/implications
Cine	・High accuracy and reporducibility ・High temporal resolution	・Cardiac morophological assessment ・LV and RV volumes and ejection fraction, such as in heart failure ・LV and RV regional wall motion
LGE	・Sensitive for necrosis, fibrosis, and granuloma in the myocardium	・Identification of the extent and location of myocardial necrosis ・Transmurality of LGE is associated with regional contractile recovery after revascularization ・Identification of granuloma and scar by cardiac sarcoidosis

CMR: cardiac magnetic resonance; LGE: late gadolinium enhancement; LV: left ventricular; RV: right ventricular

myocardial wall or epicardium, indicative of a non-ischemic type of pattern (Fig. 3). However, we should acknowledge the facts that subendocardial or transmural hyperenhancement is also observed in sarcoidosis, mimicking the pattern of myocardial infarction.

It should be also noted that activity of CS lesion and effectiveness of therapy cannot be assessed by LGE CMR, since scar tissue as well as granulation exhibits LGE. Cardiac ^{18}F-fluorodeoxyglucose positron emission tomography plays a decisive role to not only detect the presence of CS but also to potentially guide immunosuppressive therapy (24, 29, 30). The relationship between positron emission tomography and CMR for the evaluation of CS has not yet to be fully elucidated, but the two modalities are likely complementary with each provide unique information in the care of CS patients.

Conclusion

This review described the roles of CMR study and the key points of the CMR findings in patients with myocardial infarction and cardiac sarcoidosis. The summary of the CMR techniques and their clinical implications is shown in Table 1. CMR is an imaging modality that provides a mean to assess cardiac anatomy, function, and tissue characteristics in a highly reproducible manner during a single examination. The authors hope that this article serves as a first step to recognize the clinical applications and interpretation of CMR study.

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Conflicts of interest

None

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References

1. Hundley WG, Bluemke DA, Finn JP, et al. ACCF/ACR/NASCI/SCMR 2010 Expert consensus document on cardiovascular magnetic resonance: A report of the American College of Cardiology Foundation Task Force on Expert Consensus Documents. Circulation 2010; 121: 2462-508.
2. Wolk MJ, Bailey SR, Doherty JU, et al. ACCF/AHA/ASE/ASNC/HFSA/ HRS/SCAI/SCCT/SCMR/STS 2013 Multimodality appropriate use criteria for detection and risk assessment of stable ischemic heart disease. J Am Coll Cardiol 2014; 63: 380-406.
3. Karamitsos TD, Francis JM, Myerson S, et al. The role of cardiovascular magnetic resonance imaging in heart failure. J Am Coll Cardiol 2009; 54: 1407-24.
4. Ichikawa Y, Sakuma H, Kitagawa K, et al. Evaluation of left ventricular volumes and ejection fraction using fast steady-state cine MR imaging: comparison with left ventricular angiography. J Cardiovasc Magn Reson 2003; 5: 333-42.
5. Markiewicz W, Sechtem U, Kirby R, et al. Measurement of ventricular volumes in the dog by nuclear magnetic resonance imaging. J Am Coll Cardiol 1987; 10: 170-7.
6. Kim RJ, Fieno DS, Parrish TB, et al. Relationship of MRI delayed contrast enhancement to irreversible injury, infarct age, and contractile function. Circulation 1999; 100: 1992-2002.
7. Kramar CM, Barkhausen J, Flamm SD, et al. Standardized cardiovascular magnetic resonance (CMR) protocol2 2013 update. J Cardiovasc Magn Reson 2013; 15: 91-100.
8. Walsh TH, Hundley WG. Assessment of ventricular function with cardiovascular magnetic resonance. Cardiol Clin 2007; 25: 15-33.
9. Natori S, Lai S, Finn JP, et al. Cardiovascular function in multi-ethnic study of atherosclerosis: normal values by age, sex, and ethnicity. AJR Am J Rouentgenol 2006; 186: S357-65.
10. Grothues F, Smith GC, Moon JC, et al. Comparison of

interstudy reproducibility of cardiovascular magnetic resonance with 2-dimensional echocardiography in normal subjects and in patients with heart failure or left ventricular hypertrophy. Am J Cardiol 2002; 90: 29-34.
11. Grothues F, Moon JC, Bellenger NG, et al. Interstudy reproducibility of right ventricular volumes, function, and mass with cardiovascular magnetic resonance. Am Heart J 2004; 147: 218-23.
12. Paelinck BP, Lamb HJ, Bax JJ, et al. Assessment of diastolic function by cardiovascular magnetic resonance. Am Heat J 2002; 144: 198-205.
13. Rewald WG, Fieno DS, Chen EL, et al. Myocardial magnetic resonance imaging contrast agent concentrations after reversible and irreversible ischemic injury. Circulation 2002; 105: 224-9.
14. Fieno DS, Kim RJ Chen EL, et al. Contast-enhanced magnetic resonance imaging of myocardium at risk: distinction between reversible and irreversible injury throughout infarct healing. J Am Coll Cardiol 2000; 36: 1985-91.
15. Wagner A, Mahrholdt H, Holly TA, et al. Contrast-enhanced MRI and routine single-photon emission computed tomography (SPECT) perfusion imaging for detection of subendocardial infarcts: an imaging study. Lancet 2003; 361: 374-9.
16. Ibrahim T, Bulow HP, Hackl T, et al. Diagnostic value of contrast-enhanced magnetic resonance imaging and sigle-photon emission computed tomography for detection of myocardial necrosis early after acute myocardial infarction. J Am Coll Cardiol 2007; 49: 208-16.
17. Krumar A, Abdel-Aty H, Kriedemann I, et al. Contrast-enhanced cardiovascular magnetic resonance imaging of right ventricular infarction. J Am Coll Cardiol 2006; 48: 1969-76.
18. Choi KM, Kim RJ, Gubernikoff G, et al. Transmural extent of acute myocardial infarction predicts long-term improvement in contractile function. Circulation 2001; 104: 1101-7.
19. Ichikawa Y, Sakuma H, Suzawa N, et al. Late gadolinium-enhanced magnetic resonance imaging in acute and chronic myocardial infarction: improved prediction of regional myocardial contraction in the chronic state by measuring thickness of nonenhanced myocardium. J Am Coll Cardiol 2005; 45: 901-9.
20. Kim RJ, Wu E, Rafael A, et al. The use of contrast-enhanced magnetic resonance imaging to identify reversible myocardial dysfunction. N Engl J Med 2000; 343: 1445-53.
21. Mahrholdt H, Wagner A, Parker M, et al. Relationship of contractile function to transmural extent of infarction in patients with chronic coronary artery disease. J Am Coll Cardiol 2003; 42: 505-12.
22. Kwong RY, Chan AK, Brown KA, et al. Impact of unrecognized myocardial scar detected by cardiac magnetic resonance imaging on event-free survival in patients presenting with signs or symptoms of coronary artery disease. Circulation 2006; 113: 2733-43.
23. Yoon YE, Kitagawa K, Kato S, et al. Prognostic significance of unrecognized myocardial infarction detected with MR imaging in patients with impaired fasting glucose compared with those with diabetes. Radiology 2012; 262: 807-15.
24. Osborne MT, Hulten EA, Singh A, et al. Reduction in 18F-fluorodeoxyglucose uptake on serial cardiac positron emission tomography is associated with improved left ventricular ejection fraction in patients with cardiac sarcoidosis. J Nucl Cardiol 2014; 21: 166-74.
25. Patel MR, Cawley PJ, Heitner JF, et al. Detection of myocardial damage in patients with sarcoidosis. Circulation 2009; 120: 1969-77.
26. Patel AR, Klein MR, Chandra S, et al. Myocardial damage in patients with sarcoidosis and preserved left ventricular systolic function: an observational study. Eur J Heart Fail 2011; 13: 1231-7.
27. Murtagh G, Laffin LJ, Beshai JF, et al. Prognosis of myocardial damage in sarcoidosis patients with preserved left ventricular ejection fraction: risk stratification using cardiovascular magnetic resonance. Circ Cardiovasc Imaging 2016; 9: 3003738.
28. Soejima K, Yada H. The work-up and management of patients with apparent or subclinical cardiac sarcoidosis: with emphasis on the associated heart rhythm abnormalities. J Cardiovasc Electrophysiol 2009; 20: 578-83.
29. Schindler TH, Solnes L. Role of PET/CT for the identification of cardiac sarcoid disease. Ann Nucl Cardiol 2015; 1 (1): 79-86.
30. Yoshinaga K, Manabe O, Ohira H, et al. Focus issue on cardiac sarcoidosis from international congress of nuclear cardiology and cardiac CT (ICNC 12) symposium: Improving the detectability of cardiac sarcoidosis − practical aspects of 18F-fluorodeoxyglucose positron emission tomography imaging for diagnosis of cardiac sarcoidosis −. Ann Nucl Cardiol 2015; 1 (1): 87-94.