Chapter 171

Cutting Edge 3 Tesla Cardiac MRI: How can it Benefit to Patients and Physicians?

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Cardiac magnetic resonance imagine (CMRI) has slowly crawled its way into current cardiology and cardiac surgical practice in India, though it has been utilized for more than a decade in the Western world. The CMRI has now grown from a research and experimental tool in imaging the heart to becoming a well-established new modality for visualizing cardiac pathophysiology, which was till date seen only on autopsy. The CMRI has significant advantages over currently available cardiac imaging tools such as echocardiography, nuclear imaging and computed tomography (CT). It combines evaluation of both structure as well as function of the heart and has now established itself as the most accurate tool for the evaluation of ejection fraction, and for assessment of myocardial scarring. Cardiac MRI has become an important diagnostic tool and the new reference standard for the assessment of cardiac function. Figures 1A and B show the functional parameters assessed on CMRI by tracing the endocardial and epicardial borders of the heart on the short axis image of an athlete. Various flow parameters can also be assessed as shown in Figures 2A and B, of another patient, where the aorta is traced to give various flow parameters. Flow quantification can be done in all major vessels, such as the aorta, main or branch pulmonary arteries; as well as across shunts vessels, in congenital heart disease patients.

Many limitations of echocardiography, such as user dependence, small field of view and restriction of echo window—a common problem in the evaluation of the cardiac apex and right heart, are not encountered in CMRI; which therefore provides comprehensive cardiac evaluation, irrespective of the patient size, bony anomalies or emphysema, which would seriously limit echo evaluation. The MRI allows a reproducible and accurate evaluation of myocardial morphology, function, perfusion, and tissue damage in a noninvasive and “one-stop shop” way. The CMRI is also the only modality to directly visualize myocardial scar tissue. A nuclear imaging study, on the other hand, infers the presence of scar tissue on the basis of lack of tracer uptake, but does not directly show the scarred myocardium. A small rim of viable myocardium can often be missed on nuclear scan due to its inherently poor resolution. The CMRI will not only show the scar tissue, but also accurately assess the thickness of the surrounding viable myocardium. The percentage of scarring is therefore more accurately provided on CMRI. This would be of huge benefit in the evaluation of ischemic heart disease (IHD) and in its prognostication.

A brief outline of various heart diseases and aortic root diseases in adults is summarized below.

**ISCHEMIC HEART DISEASE AND ISCHEMIC CARDIOMYOPATHY**

India bears a large cardiovascular disease burden and it is increasing at an alarming rate. Cardiovascular disease causes more than 25% of deaths in India and by the next 15 years it is postulated to host more than half the cases of heart disease in the world. We now have various treatment options available for IHD; medical, interventional as well as surgical. Often the choice of management may be straightforward, but many a times the question is whether it is worthwhile to intervene; and if so, how much. Nuclear imaging is often sought for in such situations. However, various clinical trials and research work now conclusively prove that CMRI is more accurate than nuclear studies, especially in detection of subendocardial infarction. In addition, it is completed in a shorter duration, requires no glucose overload, has no radiation and can be used for repeated follow-ups. The biggest advantage that CMRI offers is actual visualization of scar tissue and accurate determination of the viable versus non-viable scarred myocardium. A thin rim of viable myocardium may be missed on nuclear studies due to lack of adequate resolution, but is easily picked up on CMRI. Imaging of the myocardium is done both at rest and after dobutamine stress, to look for wall motion abnormalities and perfusion defects; with and without adenosine infusion. Around 15-20 minutes after injecting the dye, a delayed enhancement sequence is performed, to look for subendocardial scarring. A subendocardial scar, pertaining to a vascular territory, is the hallmark of ischemic damage to the myocardium (Figures 3A and B). Lamellar thrombi are routinely missed on 2D echocardiography, due to lack of adequate tissue differentiation on the echo, and cannot be detected on nuclear imaging studies; but are very well seen on CMRI. Chronically ischemic hibernating and stunned myocardium can also be shown on CMRI. Surgical and interventional outcomes can be suggested once an accurate assessment of ischemic (stunned or hibernating) myocardium is done, along with the ratio of viable to non-viable myocardium.

The lack of ionizing radiation and lesser scan time, as compared to nuclear imaging makes CMRI a tool that can be used not only for diagnosis, but also for repeated follow-up.

**NONISCHEMIC CARDIOMYOPATHIES**

This comprises of a whole spectrum of diseases where the myocardial function deteriorates due to an identifiable or un-identifiable cause other than ischemia. The different patterns of scarring in various cardiomyopathies are seen only on cardiac MRI.

**Dilated Cardiomyopathy**

Dilated cardiomyopathy (DCM) is the commonest cardiomyopathy. The DCM can occur due to ischemic damage, may be idiopathic, genetic, due to post-myocardial infection or inflammation. Excluding ischemia as a cause of DCM can guide treatment options and provide good prognostic information. The CMRI, by virtue of its ability to depict scar tissue, can differentiate ischemic from non-ischemic causes of DCM; both in the absence of significant coronary
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Figures 1A and B: Evaluation of a Triathlon Athlete’s Heart—endocardial (green circle) and epicardial (yellow circle) tracing during systole and diastole illustrating various functional parameters of the heart

artery disease, as well as in the presence of diffuse coronary artery disease. As opposed to ischemic scars, scarring in DCM is usually mid-myocardial, i.e. between the epicardial and endocardial layers. The epicardial layer is the outermost and subendocardial region is the innermost layer closest to blood pool. The scarring is not limited to any particular vascular territory (Figure 4). Presence of scarring suggests foci of fibrosis, which lead to increased electrical instability in these patients with a increased risk of sudden death. The CMRI thus helps in risk stratification in cases of DCM. Such scar tissue is only seen on CMRI. The CMRI is also the gold standard for evaluation of ejection fraction (EF), not being operator dependent. It is therefore more worthwhile to have basic CMRI follow-up in all such cases.

Hypertrophic Cardiomyopathy

Hypertrophic cardiomyopathy (HCM) is the commonest cause of sudden death in young and otherwise healthy adults, resulting in episodes of collapse on the field, especially in athletes. A genetic heart disease with dominant transmission results in an abnormal myocardial thickening without any underlying cause, such as aortic stenosis or systemic hypertension. Usually, the ventricular septum is involved, although various forms affecting different parts or the entire LV myocardium either in diffuse or asymmetrical forms are known (Figures 5A and B). Septal hypertrophy results in obstruction of the aortic outflow tract and also causes a drag on the anterior mitral leaflet, causing mitral regurgitation. This can be easily appreciated on CMRI. The typical mid-myocardial enhancement due to fibrosis resulting from microvascular insufficiency caused in the hypertrophied myocardium are also clearly shown by CMRI. Left ventricular outflow tract (LVOT) obstruction due to myocardial hypertrophy is treated either by surgical resection, or by alcohol ablation of the obstructing myocardium. Post-operatively, the CMRI reveals the extent of scarring as well as the relief of LVOT obstruction, without any user bias and helps in prognosis. Apical hypertrophy, a form of HCM, can often be missed on 2D echocardiography due to limitation in near-
field evaluation. These however, are well seen on CMRI, due to the larger field of view available for evaluation.

**Restrictive Cardiomyopathy**

Restrictive cardiomyopathy (RCM) and constrictive pericarditis are often difficult to differentiate on echocardiography, as both would present with bi-atrial enlargement and poor ventricular filling. On CMRI, the pericardium is well seen and so are the myocardial inflammation/scarring (Figures 6 and 7). The two entities can thus be easily differentiated on CMRI. This would greatly impact management strategies. Diastolic dysfunction can be well studied on CMRI in cases of both constrictive pericarditis and restrictive cardiomyopathy. Pericarditis is most commonly tuberculosis in our institution while restrictive cardiomyopathy is most commonly due to amyloidosis.

**ARRHYTHMOGENIC RIGHT VENTRICULAR DYSPLASIA**

Often these are young patients presenting with seemingly non-specific ECG changes, with or without a history of sudden death in the family. This is also an important cause of sudden death in young individuals. The disease is genetic and characterized by replacement of the right ventricular myocardium with fibro-fatty tissue. The CMRI can pick up the characteristic fatty infiltration of the right ventricular wall, along with thinning, wall motion abnormalities and aneurysm formation. The 2D echo fails to differentiate fatty infiltration, due to lack of tissue characterization; in contrast to CMRIs excellent tissue characterization. Myocardial delayed enhancement MR imaging may help to improve the specificity of MR imaging for arrhythmogenic right ventricular dysplasia (ARVD) diagnosis (Figure 8).
**Figure 3A and B:** (A) IHD—short axis view (star represents the normal black myocardium, white arrow—full thickness infarct). Note full-thickness involvement limited to the right coronary artery territory; (B) The white lines on the line-diagram represent the scan plane.

Abbreviations: LV, Left ventricle; RV, Right ventricle.

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**Figure 4:** Dilated cardiomyopathy. Known case of dilated cardiomyopathy shows severely dilated left ventricle (LV) on the short axis image with typical scarring of the mid-myocardium at the site of septal insertion.

Abbreviations: LV, Left ventricle; White arrow, Scar tissue in LV myocardium.

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**DRUG-INDUCED CARDIOMYOPATHY**

Alcohol, other substance abuse and drug-induced cardiomyopathy are often missed due to a lack of clinical suspicion. Alcoholic cardiotoxicity often causes dilated cardiomyopathy, which may be reversible once alcohol consumption is stopped. With adequate clinical and laboratory data, we can demonstrate the effects drugs can have on the myocardium. Recently, acute chloroquine induced myocardial scarring was seen at our institute (Figure 9); in a patient suffering from malaria, who had been treated with intravenous chloroquine earlier, at another center. Correlating ECG patterns of prolongs QRS complex, repeated arrhythmias and a high dose of intravenous chloroquine, it was concluded that the presence of myocardial scarring was due to drug toxicity.

Autoimmune cardiomyopathy, such as due to sarcoidosis or scleroderma may show a characteristic pattern of scarring, or granulomas. The CMRI can detect the onset of cardiac disease in these cases much before functional deterioration sets in. Early diastolic dysfunction can be detected by functional cardiac MRI much earlier than echocardiography. Granulomas and scars of sarcoidosis can be clearly seen and their extent well defined. Acute sarcoidosis causes myocardial edema and sub-epicardial or mid-myocardial enhancement whereas chronic sarcoidosis is often seen as myocardial thinning due to granulomatous scarring.
INFECTIVE DISEASES OF THE HEART AND PERICARDIUM

Infective diseases affecting the heart are common in India and often present as difficult and conflicting findings on 2D echo, as well as on MRI; especially where myocardial and pericardial tuberculosis (TB) is concerned. Rheumatic heart disease with valvular vegetation is usually best assessed on echo and rarely needs a CMRI reference, unless there is a suspicion of thrombosis. Tuberculosis on the other hand often presents with pericarditis (Figures 10A and B) or a picture of an infiltrating mass lesion which is difficult to differentiate from malignancy (Figure 11).

In our CMRI experiences, many of these sinister looking lesions have turned out to be tuberculosis. We have found complex forms of cardiac affections due to tuberculosis, ranging from diffuse, well-defined pericardial enhancement to nodular pericardial thickening, to complex affection, where it was difficult to differentiate pericardial from myocardial disease. We describe the latter as complex myocardial-pericardial disease pattern of tuberculosis. This “Myocardial-Pericardial Complex” sign is a good pointer of cardiac TB and has helped us significantly in differentiating sinister looking, infiltrating tumor-like tuberculous lesions of the heart; from true malignant affection of the heart.15 Whenever any infiltrating cardiac mass lesion in accompanied by evidence of pericarditis, TB should be the first differential.

The CMRI can also play a vital role in identifying on going inflammation in infective myocarditis, which may be vital in diagnosis, treatment, as well as in follow-ups.
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STORAGE DISORDERS AND IRON OVERLOAD
Iron overload is a significant cause of morbidity and mortality in patients undergoing repeated blood transfusions. These comprise of a huge subset of thalassemics in our country, along with those with hematological malignancies. The CMRI is the only modality that can quantify iron deposition non-invasively in these patients. Chelation therapies can be modulated based on these iron overload estimates much before cardiac dysfunction sets in.

CARDIAC AND PARACARDIAC TUMORS
Cardiac tumors though rare are best characterized on CMRI. Often echo cannot differentiate a thrombus from a tumor, whereas CMRI would invariably provide valuable differentiation features. It not only differentiates a tumor from a thrombus, but will reveal the spread of a malignant lesion as it infiltrates the surrounding myocardium. The CMRI plays a vital role in confirming the presence of the tumor, defining its extent, its tissue characterization and impact on the cardiac hemodynamics. Various cardiac tumors can be further characterized as benign or malignant based on tissue characteristics, location and the enhancement pattern noted on CMRI (Figure 12).
The common tumors of the heart are distinguish from each other; such as myxomas, angiofibromas, leukemia, lymphomas, etc by CMRI. Infiltration of paracardiac tumors is also well seen on CMRI. The global perspective that is available, which includes the tumor along with its surrounding anatomical structures, is unique to CMRI.

**VALVULAR HEART DISEASE**

The CMRI can depict vegetation, stenosis and regurgitations, and quantify the flow dynamics secondary to valvular diseases. It can depict valve leaflets; accurately show valve areas and congenital anomalies, such as Ebstein's anomaly and various aortic valvular diseases (dysplastic, uni/bi/tri/quadrucuspid aortic valves, valvular stenosis, ruptured sinus of Valsalva, regurgitation) and its effects on the hemodynamics of the left ventricle and its outflow tract (Figure 13).

**THE FUTURE**

Newer imaging techniques, such as non-contrast free breathing coronary MR angiography and MR spectroscopy are under way. These promise to give information on coronary arteries without the use of contrast agents; and the extent of myocardial dysfunction and infiltration, respectively. The CMRI is being used in stem cell tracking as well as in assessing benefits of stem-cell therapies in various cardiac diseases, especially cardiomyopathies and IHD.

The CMRI has revolutionized the way we see cardiac pathologies and dysfunction in a living heart and provides insight to the ongoing disease process and how best we can manage them. It is a new age, cutting edge technology and indeed a new frontier in cardiac imaging with a huge potential to benefit the physician and the patients. Its utility is widely accepted in good centers abroad, its only a matter of time before our part of the world embraces this wholeheartedly.

**REFERENCES**