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Clinical Usage of Cardiovascular Magnetic Resonance Imaging: Single-Center Experience in the New Era of Cardiovascular Imaging

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ABSTRACT

Introduction: Utilization of cardiac magnetic resonance imaging (CMRI) has been increasing year by year for the most cardiovascular diseases. In this paper, we documented a real-life experience of our center as a high-volume CMRI performing center.

Methods: We have retrospectively analyzed the 100 patients who have undergone CMRI at our center during the last 1 year. All the preliminary diagnoses, specialty or subspecialty of referring physicians, patient characteristics and CMRI findings were analyzed.

Results: In 87 of 100 scans, a gadolinium-based contrast agent was used and in none of these procedures neither complications nor adverse events related to the contrast agent has occurred. Among these 100 consecutive CMRIs were referred to by a clinical cardiologist, invasive cardiologists, heart failure specialist, cardiovascular imaging specialists, electrophysiologists, and other specialists. On referral from a clinical cardiologist, the CMRI findings were high consistency. In these patients, the biggest number of preliminary diagnoses belongs to hypertrophic cardiomyopathy. The most common MRI finding was reduced left ventricular ejection fraction. In 25 patients we observed extracardiac findings.

Conclusion: CMRI is increasingly occurring in cardiovascular imaging and diagnosis of various cardiovascular diseases. CMRI not only produces high-resolution morphological images but also provides quantitative information on the severity of regurgitant or stenotic lesions in valvular diseases or cardiac shunts with the velocity and flow measurements.

Keywords: Cardiovascular imaging, cardiac magnetic resonance, cardiovascular diseases

Introduction

Imaging in human medicine is one of the fastest developing areas in the medical practice and cardiovascular imaging has also entered a period of rapid development by showing a parallel course to this general development with various novel methods. The utilization of cardiac magnetic resonance imaging (CMRI) has been increasing year by year, and it has emerged as the "gold standard" diagnostic test for most cardiovascular diseases. Despite numerous randomized controlled trials on CMRI, the use of this method in clinical practice is still disappointing. Some of the most important reasons for this are the insufficient number of trained physicians and technicians, high cost and lack of MR machines in several centers.

In this paper, we documented a real-life experience of our center as a high-volume CMRI performing center compared to with other centers in our country and serve a descriptive data about the clinical usage of CMRI.

Methods

Study Population

We have retrospectively analyzed the last 100 consecutive patients who have undergone CMRI in our center during the last 1 year. The study protocol was approved by the Local Ethics Committee of Memorial Bahçelievler Hospital (approval number: 19, date: 13.09.2021). Written consent was obtained from all patients. All the preliminary diagnoses, specialty or subspecialty of referring physicians, patient characteristics and CMRI findings were analyzed. All images were reviewed by an experienced and European Association of Cardiovascular Imaging (EACVI) CMR exam certified cardiovascular multimodality imaging specialist. Detailed patient characteristics are given in Table 1. Mean age of the patients was 42.9±15.3. In 87 of 100 scans, a gadolinium-based contrast agent was been used and in none of these procedures neither complications nor adverse events related to contrast agent occurred. Ninety-three patients were referred from an outpatient clinic, and 7 of

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them were the patients who were already hospitalized due to different etiologies (Table 1).

Statistical Analysis

Statistical Package for the Social Sciences (v.24., Chicago, Ill., USA) program was used in this study. As the statistical analyzes were based on categorical data, they were described as frequency and percentage.

CMR Setting

All CMR exams were performed on the same 1.5 T scanner (Magnetom Avanto, Siemens Healthcare, Erlangen, Germany). Our CMR services were provided for both outpatients and inpatients. The principal referring departments were our hospital's cardiology in- and outpatient departments, as well as other university and public hospitals outpatient departments from different cities of our country. CMR protocols were planned as follows: For CINE imaging steady-state free-precession, for myocardial edema triple-inversion T2-weighted spin-echo, for late enhancement T1-weighted inversion-recovery turbo fast low-angle shot sequence, for flow study two-dimensional (2D) phase contrast acquisition was used. Each exam and report was supervised by one cardiologist who trained at a level 3 certificated center and passed the EACVI board exam and an experienced radiologist.

A dedicated software was used for all qualitative and quantitative evaluations (CVI 42, Version 5.1, Circle Cardiovascular Imaging, Calgary, Canada).

Results

Among these 100 consecutive CMRIs, 27 were referred by a clinical cardiologist. Invasive cardiologists took the second place with 26 referrals. Other specialties in order are as follows, heart failure (HF) specialists (N:15), cardiovascular imaging specialists (N:12), electrophysiologists (N:10), sports cardiologists (N:4). After them; pulmonologist, oncologist, cardiovascular surgeon, pediatric cardiologist, neurologist, and rheumatologist came with 1 referral for each (Table 2).

As the most referral from a clinical cardiologist, 18 of 27 referrals, the CMRI findings were consistent with clinically suspected diagnosis (66.67%) with a high consistency. The second most referred specialty was invasive cardiologists by 26, and among these 26 patients, 20 patients' CMRI findings were consistent with clinically suspected diagnosis, which made the invasive cardiologists the highest consistency ratio (76.92%) except from the departments who have referred to 1 patient. Electrophysiologists referred 10 patients and 2 were consistent with clinical suspected diagnosis and 8 were not, which made them have the least consistency ratio by 20% (except from the departments who have referred single patient). Additional findings are below (Table 2).

Table 1. Patient characteristics

	Patients (n=100)
Year, age	42.9±15.3
Height, cm	172.28±11.23
BSA, kg/m^2	1.98±0.23
Hospitalized patients	7 (7%)
Contrast agent usage	87 (87%)

In these 100 patients, the biggest number of preliminary diagnoses belongs to hypertrophic cardiomyopathy (HCM) (26 referrals). After HCM, myocarditis, dilated cardiomyopathy (DCM) and etiology of ventricular tachycardia (VT) caused 10 referrals for each clinical situation. Five referrals have were made due to reduced ejection fraction (EF) and myocardial viability investigation. Other findings are below in Table 3.

Table 4 demonstrates the CMRI findings of these 100 patients. The most common MRI finding was reduced left ventricular EF [42], followed by mitral regurgitation [23]. In 25 patients we observed extracardiac findings. Nineteen patients were diagnosed with HCM and 15 with DCM. A total of 7 had pericardial effusion, and 11 had myocarditis. 10% of the patients (N:10) had completely normal CMRI findings. Additional findings are below Table 3.

The CMRI findings of patients are listed in Table 4, 5 shows the extracardiac findings that are detected in these scans. The most common extracardiac finding was pleural effusion [7] followed by renal and liver cysts (4 for each). Two patients had mediastinal lymphadenomegaly and two had pulmonary nodules.

Lastly, among the patients referred to CMRI, Table 6 demonstrates the consistency of preliminary diagnosis to final diagnosis. Twenty-six patients have been referred to CMRI with a preliminary diagnosis of HCM. Seventeen of them (65.38%) were diagnosed with HCM and showed the highest rate of consistency with the preliminary diagnosis. Ten patients were referred for DCM investigation and other 10 for myocarditis. For DCM, 8 patients have been diagnosed consistently (80%), and 7 for myocarditis (70%). Also, a notable point, among 10 patients who referred to CMRI to investigate the etiology of VT-such as arrhythmogenic substrate or scar tissue- none of them (0%) was diagnosed with preliminary diagnosis as arrhythmogenic right ventricular dysplasia and myocardial non-compaction, which were suspected in 3 patients for each and diagnosed in none of them with 0% consistency.

Table 2. Referred specialty and consistency of MRI findings with clinical diagnosis

	Patients (n=100)	Clinical diagnosis and MRI findings consistency	
Referred specialty		**Consistent**	**Inconsistent**
Clinical cardiologist	27 (27%)	18 (66.67%)	9 (33.33%)
Invasive cardiologist	26 (26%)	20 (76.92%)	6 (23.08%)
Heart failure specialist	15 (15%)	9 (60%)	6 (40%)
Cardiac imaging specialist	12 (12%)	9 (75%)	3 (25%)
Electrophysiologist	10 (10%)	2 (20%)	8 (80%)
Sports cardiologist	4 (4%)	2 (50%)	2 (50%)
Pulmonologist	1 (1%)	1 (100%)	0 (0%)
Oncologist	1 (1%)	1 (100%)	0 (0%)
Cardiovascular surgeon	1 (1%)	1 (100%)	0 (0%)
Pediatric cardiologist	1 (1%)	1 (100%)	0 (0%)
Neurologist	1 (1%)	0 (0%)	1 (100%)
Rheumatologist	1 (1%)	1 (100%)	0 (0%)

MRI: Magnetic resonance imaging

Table 3. Preliminary diagnosis

	Patients (n=100)
Hypertrophic cardiomyopathy	26 (26%)
Etiology of ventricular tachycardia	10 (10%)
Dilated cardiomyopathy	10 (10%)
Myocarditis	10 (10%)
Reduced ejection fraction	5 (5%)
Myocardial viability	5 (5%)
Mitral valve prolapsus	4 (4%)
Arrhythmogenic right ventricular dysplasia	3 (3%)
SLE myocarditis and pericarditis	3 (3%)
Aortic stenosis	3 (3%)
Myocardial non-compaction	3 (3%)
Sarcoidosis	2 (2%)
Amyloidosis	2 (2%)
Aort coarctation	2 (2%)
Mitral regurgitation	2 (2%)
Aortic regurgitation	2 (2%)
Operated tetralogy of fallot	2 (2%)
Left ventricular thrombus	1 (1%)
Aortic root dilatation	1 (1%)
Myocardial infarction with non-obstructive coronary arteries	1 (1%)
Tricuspid regurgitation	1 (1%)
Mitral annular disjunction	1 (1%)
Cardiac involvement in scleroderma	1 (1%)

SLE: Systemic lupus erythematosus

Table 4. Cardiac MRI findings

MRI finding	Patients (n=100)	MRI finding	Patients (n=100)
Reduced LVEF	42 (42%)	Tricuspid regurgitation	6 (6%)
Extracardiac findings	25 (25%)	Myocardial viability	5 (5%)
Mitral regurgitation	23 (23%)	Aortic stenosis	3 (3%)
HCM	19 (19%)	Pericarditis	3 (3%)
DCM	15 (15%)	LV non-compaction	3 (3%)
Pericardial effusion	14 (14%)	Amyloidosis	3 (3%)
Myocarditis	11 (11%)	Papillary muscle hypertrophy	2 (2%)
Normal findings	10 (10%)	Cardiac involvement in sarcoidosis	2 (2%)
Aortic regurgitation	8 (8%)	Operated tetralogy of Fallot	2 (2%)
Bicuspid aortic valve	7 (7%)	ARVD	1 (1%)
Mitral valve prolapsus	7 (7%)	Left ventricular thrombi	1 (1%)
Aortic root dilatation	7 (7%)	Subaortic aneurysm	1 (1%)
Ascending aort dilatation	7 (7%)	SLE Myocarditis	1 (1%)
History of MI	7 (7%)	SLE Pericarditis	1 (1%)
Reduced RVEF	6 (6%)	Scleroderma	1 (1%)
Mitral annular disjunction	6 (6%)	-	-

MRI: Magnetic resonance imaging, LVEF: Left ventricular ejection fraction, HCM: Hypertrophic cardiomyopathy, DCM: Dilated cardiomyopathy, LV: Left ventricular, MI: Myocardial infarction, RVEF: Right ventricular ejection fraction, ARVD: Arrhythmogenic right ventricular dysplasia, SLE: Systemic lupus erythematosus

Table 5. Extracardiac findings

	Extracardiac findings (n=25)		Extracardiac findings (n=25)
Pleural effusion	7 (7%)	Pectus excavatum	1 (1%)
Renal cysts	4 (4%)	Muscular atrophy	1 (1%)
Liver cysts	4 (4%)	Liver metastasis	1 (1%)
Mediastinal LAM	2 (2%)	Tumoral thickening of stomach	1 (1%)
Pulmonary nodule	2 (2%)	Splenic cyst	1 (1%)
Axillary LAM	1 (1%)	Eventration of diaphragm	1 (1%)
Splenomegaly	1 (1%)	-	-

LAM: Lymphadenomegaly

Discussion

Over the past few years, CMRI has been increasingly recognized as a valuable cardiovascular imaging modality in the evaluation of heart diseases. CMRI is generally evaluated and reported by radiologists, while in centers such as ours, cardiology and radiology collaborate with a multi-disciplinary approach from an anatomical, functional, and clinical perspective. There are many articles on CMRI physics and cardiovascular diseases prepared for clinicians (1) and the European Society of Cardiology has a practical pocket guide for cardiologists for CMR as well (2). In other words, CMRI is increasingly occurring in cardiovascular imaging and diagnosis of various cardiovascular diseases and the experience of cardiologists, who provide additional clinical information on this subject, is gradually increasing.

CMRI not only produces high-resolution morphological images compared with transthoracic echocardiography (TTE) but also provides quantitative information on the severity of regurgitant or stenotic lesions in valvular diseases or cardiac shunts with the velocity and flow measurements (3-5).

CMRI is widely used for the diagnosis and diagnosing of many cardiomyopathies. Particularly in HCM, the use of CMR is recommended to determine the sudden cardiac death (SCD) risk (6,7). In our study, the most common preliminary diagnosis was HCM, while in the articles sharing the experiences of other centers, it may be ischemic cardiomyopathy or myocarditis. It may vary according to the interests of the physicians in these centers or the interests of the centers to which they are referred (8,9). Patients with HCM may be asymptomatic and have a normal life expectancy, or they may present with more severe clinical manifestations and prognoses with ventricular arrhythmia, SCD, or HF (10-12).

CMRI is a very useful imaging method both in diagnosing HCM and in determining HCM phenotypes because it can clearly show cardiac

morphologies. The most accurate measurement of left ventricular wall thickness can also be measured by CMRI. CMRI helps risk stratification as it detects "high-risk" phenotypes and defines myocardial fibrosis as well. It is also highly valuable for differentiating HCM from other causes of left ventricular thickening (13,14).

Therefore, CMRI is of great importance in clinical practice in patients with or suspected of having HCM. In our clinic, CMRI was requested mostly with the pre-diagnosis of HCM (26%), and in 65.3% of these patients, the clinical pre-diagnosis and the CMRI result were compatible.

Having HCM as the most frequent referred pre-diagnosis, the most common finding was reduced EF in our study. In our daily clinical practice, 2D TTE is the most widely used method to determine systolic cardiac dysfunction. For this purpose, LV end-diastolic and end-systolic volumes and EF are commonly used. However, TTE is quite user-dependent and intra- and interobserver variability is high, especially in patients with poor image quality. The fact that EF is affected by many parameters creates limitations and reduces reliability as well (15). CMRI is a more reliable method to evaluate cardiac functions, chamber volumes compared with TTE, and it also allows to evaluate cardiac structure and provides tissue caharcterization such as inflammation, edema and fibrosis (16).

Table 6. Consistency of preliminary diagnoses and cardiac MRI findings

	Consistent	Inconsistent
HCM	17 (65.38%)	9 (34.62%)
DCM	8 (80%)	2 (20%)
Myocarditis	7 (70%)	3 (30%)
Myocardial viability	5 (100%)	0 (0%)
Mitral valve prolapsus	4 (100%)	0 (0%)
Reduced EF	4 (80%)	1 (20%)
Aortic stenosis	3 (100%)	0 (0%)
Amyloidosis	2 (100%)	0 (0%)
Mitral regurgitation	2 (100%)	0 (0%)
Aortic regurgitation	2 (100%)	0 (0%)
Operated tetralogy of fallot	2 (100%)	0 (0%)
Left ventricular thrombi	1 (100%)	0 (0%)
Sarcoidosis	1 (50%)	1 (50%)
Aort coarctation	1 (50%)	1 (50%)
Aortic root dilatation	1 (100%)	0 (0%)
MINOCA	1 (100%)	0 (0%)
Tricuspid regurgitation	1 (100%)	0 (0%)
SLE myocarditis or pericarditis	1 (33.33%)	2 (66.67%)
Mitral annular disjunction	1 (100%)	0 (0%)
Scleroderma	1 (100%)	0 (0%)
ARVD	0 (0%)	3 (100%)
Etiology of VT	0 (0%)	10 (100%)
Suboptimal echogenity	0 (0%)	0 (0%)
Pericarditis	0 (0%)	0 (0%)
Myocardial non-compaction	0 (0%)	3 (100%)

MRI: Magnetic resonance imaging, HCM: Hypertrophic cardiomyopathy, DCM: Dilated cardiomyopathy, EF: Ejection fraction, MINOCA: Myocardial infarction with non-obstructive coronary arteries, SLE: Systemic lupus erythematosus, ARVD: Arrhythmogenic right ventricular dysplasia, VT: Ventricular tachycardia

Another advantage of CMRI over TTE is the detection of extracardiac findings. Extracardiac findings such as pleural effusion, renal and hepatic cyst, lymphadenopathy, pulmonary nodule, etc. are the common ones. As CMRI cases assessed by both radiologist and cardiologist together in our center, it allows for an accurate evaluation of extracardiac findings in the image field, thus helping in early detection of conditions such as pulmonary nodules or malignant masses, where early diagnosis is vital.

Study Limitations

The main limitation of our study is its single-center nature, which would cause a bias regarding patient referral, selection of imaging procedures. Another limitation of the study is its retrospective nature, but it also overcomes the patient referral bias. It should also be noted as a limitation, that all images were reviewed by only two cardiovascular imaging specialists (one radiologist and one cardiologist), rather than multiple reviewers due of lack of CMRI specialists experienced in the field.

Conclusion

In the results of the study, despite the limited time and the small number of patients, it has been shown that the diagnoses that are not often considered in clinical practice, such as mitral annular dysjunction, papillary muscle hypertrophy, which haven't been noted to be associated with arrhythmia previously, can be clearly and easily detected by CMRI. In the era of multimodality cardiovascular imaging, where the use of CMR is the gold standard in some heart diseases and is increasingly widespread, we wanted to share our experience in the compatibility of the diagnosis of CMRI with the clinical prediagnosis, the extracardiac findings we determined, and the compatibility rate of the diagnoses according to the subspecialty in our clinic.

Ethics Committee Approval: The study protocol was approved by the Local Ethics Committee of Memorial Bahçelievler Hospital (approval number: 19, date: 13.09.2021).

Informed Consent: Written consent was obtained from all patients.

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