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Research Article

Utility of Cardiac Magnetic Resonance Imaging and Follow-Up of Defibrillator Events to Identify the Etiology and Natural History of Sudden Cardiac Arrest

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Abstract

Background: In patients with sudden cardiac arrest (SCA) cardiac MRI (CMR) can be useful to evaluate ischemic, inflammatory, infiltrative and degenerative processes. Correlation of initial CMR findings with future events recorded by automatic implantable cardiac defibrillators (AICD) can characterize the natural history of these life-threatening cardiac conditions.

Methods: We examined the CMR studies of 83 patients with SCA. In all patients, initial cardiac work-up was non-revealing for potential etiology, and CMR with late gadolinium enhancement (LGE) was performed. Following CMR, most of these patients underwent clinically indicated AICD placement. The interrogated AICD events were followed up for 1-4 years to monitor significant arrhythmias.

Results: Of the 83 patients resuscitated from SCA of otherwise unknown etiology, CMR identified a possible substrate in 41%. Presence of major diagnostic findings in CMR in SCA patients had 67% sensitivity for significant AICD-events during the follow-up.

Conclusions: Beyond standard diagnostic algorithm, CMR can identify potential cause of SCA in over 40% of the patients. Presence of LGE or other major diagnostic findings on CMR can uniquely identify patients with significant AICD events.

Keywords: AICD; Cardiac MRI; Sudden Cardiac Arrest

Introduction

Evaluation of cardiac arrhythmias begins with documentation of the arrhythmia type and investigation for underlying etiology [1]. Current clinical guidelines recommend the use of echocardiography and coronary angiography following sudden cardiac arrest (SCA) [2,3]. Cardiac MRI (CMR), an emerging non-invasive imaging modality, is increasingly being utilized to identify the potential causes of malignant ventricular arrhythmias and conduction abnormalities [4-10]. However, there is no data to clearly establish the clinical utility of CMR for patients presenting with malignant ven-

tricular arrhythmias. More importantly, the predictive role of initial CMR findings for the progression of primary myocardial pathology, and thus identification of recurrent arrhythmias are unknown [11-15].

CMR with tissue characterization examines the pathologic substrate for lethal ventricular arrhythmias for a defined cross-section of time. CMR also has the ability to discern acute from chronic forms of myocardial disease. These attributes are equally based on the clinical course of the myocardial disease, in addition to initial imaging findings [16]. Therefore, in this study, we have first evaluated the diagnostic utility of CMR for the identification of potential substrate for SCA. We have then followed up the automatic implantable cardiac defibrillator (AICD) events in these patients to examine whether the presence of late gadolinium enhancement (LGE) or other major diagnostic findings on CMR would predict the onset of lethal ventricular arrhythmias recorded by AICD.

Materials and Methods

Study Design and Follow-Up: This is a retrospective study that reviewed the clinical CMR data obtained from 2004 to 2012. This study was approved by the Massachusetts General Hospital Institutional Review Board. We examined 83 SCA-resuscitated patients who underwent CMR with gadolinium administration to evaluate possible etiology of SCA. At the time of CMR, patients were in-house and expected to undergo AICD placement procedure before hospital discharge.

CMR Protocol: CMR was performed in a standardized fashion using the methods described previously [17-20]. The CMR protocol used in the SCA-resuscitated patients was specifically tailored to the clinical question. We used GE 1.5-T scanner with technical parameters recommended by the manufacturer, with the following scanning protocol: Scout images in coronal, sagittal and axial planes; fast spin-echo (FSE) axial slices; short-axis, and two, three and four-chamber steady-state free precession (SSFP) sequences; T2-weighted triple-inversion recovery images; T1-weighted FSE sequence before and after intravenous (IV) Gadolinium injection, and delayed enhanced images 7–10 minutes after Gadolinium injection. Semi-automated data analysis and volume quantification software (CMR42, Cir International; Calgary, Alberta, Canada) was used for the evaluation of ventricular volumes, dimensions and function.

Data Interpretation/Diagnosis: The major and minor CMR diagnostic criteria for arrhythmogenic right ventricular cardiomyopathy/dysplasia (ARVC/D) are utilized according to the current modifications of the Task Force Criteria which represent a working framework to improve the diagnosis and management of this disease [21,22]. For the patients with suspected myocarditis, a combined CMR approach using T2-weighted imaging, early and late gadolinium enhancement was used as reported previously (presence of abnormal LGE), increased myocardial early gadolinium enhancement ratio and regional edema visible on T2-weighted CMR images) [23]. For the patients with possible sarcoidosis, positive findings included- intramyocardial focal zones with increased signal intensity on both T2-weighted and early gadolinium images, focal myocardial thickening and abnormal LGE reflecting accumulation of gadolinium chelates in the myocardium [24].

Statistical Analyses: The associations between presence of LGE on CMR and events recorded by AICD were assessed with the two-sided chi-square test. We also included datasets showing the right ventricular ejection fraction (RVEF). Analyses were performed with the Statistical Analysis System software package, version 9 (SAS Institute Inc., Cary, NC).

Results

Baseline Characteristics

We studied a total of 83 patients who were resuscitated following SCA. In agreement with overall incidence of SCA in general populations, the mean age of presentation was 50±17 years. Patients had preserved left ventricular (left ventricular ejection fraction [LVEF], 56±12) and right ventricular (RVEF, 50±10) functions, except in the ARVC/D subgroup that had reduced RV function (RVEF %, 29±6) (Table 1).

Table 1. Comparison of baseline clinical characteristic and CMR findings in resuscitated patients following SCA

	All Patients (N=83)	Focal Fibrosis (N=10)	Potential Ischemia (N=9)	Myocarditis (N= 5)	ARVD (N=3)	HCM (N=3)
Age, y	50±17	58±18	62±13	55±5.3	46±22	**66±6**
Female sex	22 (24%)	1 (10%)	0 (0%)	2 (40%)	0 (0%)	**2 (67%)**
MRI Parameters						
LV EF, %	56±12	56±9	55±5	53±23	59±3	**55±6**
RV EF, %	50±10	50±4	50±7	48±18	29±6	**52±8**
LV EDV	160±61	184±72	180±64	139±26	59±3	**167±39**
RV EDV	**161±51**	**177±70**	**179±60**	**152±32**	**194±79**	**160±25**

In this group of resuscitated patients, initial work up did not reveal a clear etiology for SCA. These patients then underwent clinically indicated CMR with LGE.

Major Diagnostic Findings in CMR: CMR with LGE provided important diagnostic information in 41% of the patients with SCA of otherwise unknown etiology. The largest proportion of the patients (N=10, 12%) had LGE in the myocardium, which suggests myocardial fibrosis or scarring. Nine patients (11%) had LGE in well-defined coronary artery territories, with a subendocardial distribution, indicative of ischemia. Myocar-

ditis was reported in 6% of the patients. Other myocardial pathological conditions including ARVD (4%), hypertrophic cardiomyopathy (4%), and other etiologies (4%) attributed to remaining cases.

Follow-up of AICD Events: Of these 83 resuscitated patients, 63 received AICD for the secondary prevention of SCA. Remaining 20 patients either did not qualify or declined the procedure. Of the 63 patients in AICD subgroup, no follow up data could be obtained from 13 patients. Only 50 patients had documented AICD interrogation studies. The significant AICD events were considered as appropriate AICD discharge due to ventricular fibrillation or ventricular tachycardia (3 patients had non-sustained ventricular tachycardia). Within a follow-up period of 1 to 4 years (median, 2 years), 16 of the 24 patients with ≥1 major diagnostic findings in CMR had a sensitivity of 67% to develop a significant AICD event. Since the presenting etiologies were diverse, the major findings discovered by CMR were arbitrarily presented as ≥1 major diagnostic findings (Table 2). The diagnostic criteria represents the different pathological conditions found in our retrospective study, including, focal fibrosis (visualized by LGE), ARVD (right ventricle dyskinesia and dysfunction), chronic ischemia (subendocardial/transmural fibrosis), etc.

Table 2. Sensitivity, specificity and predictive values of CMR findings to identify ICD events on follow-up

	Sensitivity (%)	Specificity (%)	PPV (%)	NPV (%)
SCA→AICD (N=50)				
Presence of ≥1 major diagnostic finding(s) in CMR and significant AICD events	**67**	**38**	**50**	**55**

PPV, positive predictive value; NPV, negative predictive value

Discussion

The results of this study show an incremental diagnostic utility of CMR in SCA beyond the algorithm established by current guidelines. CMR can be used as a part of non-invasive but comprehensive evaluation of common and potentially life-threatening cardiac arrhythmias. Our results add to the existing body of information on the utility of CMR to identify unknown and potentially reversible myocardial or electrical abnormalities, and to define the prognostic use of CMR for the prediction of AICD events.

CMR methodology is evolving at a rapid pace. Previous small-scale studies and case reports have reported the clinical utility of CMR for the diagnosis of SCA [4,10,25-27]. Among numerous interesting developments in the sensitivity and diagnostic accuracy of CMR, many can be expected to be directly useful for the evaluation of SCA. As hardware and coil technology are improving, image quality and diagnostic yield will be more consistent for small and focal areas of tissue infiltration, inflammation and fibrosis [16,28,29]. Our study highlights the use of CMR not only as an additive comprehensive diagnostic tool, but also as a model and marker to predict the clinical outcomes resulting from the initial myocardial pathology identified by CMR.

Due to abrupt and unexpected clinical presentations, SCA remains to be a challenging clinical entity to execute prospective or randomized studies. Therefore, large body of literature for the clinical management of SCA is based on retrospective and observational studies [30-32]. Overall, these factors make it difficult to conduct large scale prospective clinical studies. Consequently, existing diagnostic algorithms for the determination of the potential etiologic substrate of these processes are largely based on the identification of common risk factors which include myocardial ischemia/injury, inflammation and different forms of cardiomyopathies [3]. CMR with comprehensive tissue characterization allows us to understand their pathologic and functional implications, safely and non-invasively.

In our follow-up analysis of AICD in SCA patients, we have made intriguing observations. Presence of major abnormal findings in CMR in SCA patients had 67% sensitivity for significant AICD-events during the follow-up. Overall, these findings highlight the importance of prognostic utility of CMR and warrant larger clinical studies or registries to evaluate the significance of presence of focal LGE or other major diagnostic findings on CMR for future AICD events.

Study Limitations

This is a retrospective study based on chart review data and AICD interrogation database. Due to rapid evolution of this field and frequent updates of management guidelines, heterogeneity of the study database is possible. Relatively small study size precludes a systematic and powered analysis of LGE or other major diagnostic findings in different myocardial territories to pinpoint the source, location and electromechanical significant of these findings.

Conclusions

This study shows that CMR can be a useful diagnostic modality for the identification of potential causes of SCA resulting from sustained VT or VF. A potential and previously unraveled utility of CMR to monitor and possibly predict the future cardiac events in a subgroup of patients with presence of focal LGE and other major diagnostic findings at the presentation has been discussed. Combination of CMR data with other clinical parameters including the AICD events will help understand both eti-

ology and natural history of such common and life-threatening cardiac arrhythmias.

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