Diagnostic and Prognostic Role of Cardiac Magnetic Resonance Before Implantable Cardioverter Defibrillator

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The use of cardiac magnetic resonance (cMR) to assess remodeling and tissue characterization in primitive and secondary cardiomyopathies has progressively increased, and it carries important prognostic informations. The aim of this study was to assess the overall clinical value of cMR before implantable cardioverter defibrillator (ICD). All patients referred to our center for an ICD implantation and submitted to cMR (n = 134) were analyzed. All the cMR diagnostic findings and following clinical events were reviewed to assess clinical relevance in patients care. The use of cMR before ICD implantation has progressively increased during the decade studied (13% to 53%, p <0.001). Subjects who underwent cMR were younger, more often female, with lower NYHA class and higher ejection fraction (p <0.05 for all). Unexpected diagnostic findings were observed in 34 patients (25%), resulting in an immediate therapeutic strategy modification in 13%. A pattern of fibrosis leading to a change in the disease's etiology and thrombus detection were the most frequent cMR findings, followed by anatomical incidental findings. Any grade of fibrosis carried a higher annual incidence of combined death or ventricular arrhythmias (9.92% vs 1.83%, p = 0.02). Annual event rate was related to the extent of scarring. In conclusion, we observed a progressively increase of cMR utilization before ICD implantation during the last decade. This practice has yielded a significant increase of new diagnostic findings, carrying unique prognostic information linked to tissue characterization.

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Cardiac magnetic resonance (cMR) has become important in the management of patients who have met criteria for an implantable cardioverter defibrillator (ICD). Left ventricular (LV) remodeling and reduction of ejection fraction (EF) represent the major structural changes linked to heart failure [1−3]and the most important criteria for ICD implantation.[2,3] Nevertheless, EF is only one macroscopic element of myocardial injury, and several data indicate that myocardial fibrosis is an independent prognostic predictor of arrhythmic events in both ischemic (IC) and nonischemic cardiomyopathies.[4−6] A myocardial scar has a prognostic role also in subjects with nonsevere LV dysfunction.[4,5] Fibrosis pattern provides important diagnostic information since it is often a marker of a specific type of injury[7−10] and indicates the presence of viable myocardium.[10,11] Tissue characterization is one of the most important diagnostic dilemmas becoming difficult to be obtained after ICD implantation due to possible artifacts.[12] The main hypothesis of the proposed analysis is that cMR offers an immediate clinical gain in several situations, providing adequate information to develop an appropriate management of this complex group of patients. Hence, we investigated the utilization and the clinical impact of cMR in randomized patients before ICD implantation.

Methods

We prospectively registered patients referred to our center for a first ICD implantation. Our hospital is a secondary center with cMR facility. This service is provided by specialized radiologists (CT and LS) and cardiologists (JDM and GC). The study was approved by the Institutional Review Boards and informed consent was obtained for each patient. We included subjects with indication for an ICD for primary or secondary prevention. Exclusion criteria included patient's decision to receive treatment from another center, significant valvular heart disease, indication for LV assistant device, suspected acute myocarditis or acute coronary syndrome, and inability to give consent.

After ICD implantation, the first follow-up visit was conducted at 6 months, followed by 6 monthly visits at our clinic. In case patients did not come back for their appointment, follow-up was conducted by telephone interview. Survival data were collected for all included patients. Information about deaths was recorded by telephone interview with the patient's relatives or from the administrative database. The present analysis focused on patients who underwent cMR before implantation. Contraindication to cMR imaging included claustrophobia, hemodynamic instability,

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metallic implants, significant arrhythmias, and estimated glomerular filtration rate <30 ml/min.

Devices were implanted with the standard technique. Single, dual chamber or resynchronization device choice was at discretion of the physician based on sinus bradycardia, atrial fibrillation, QRS, clinical, and imaging findings.

Ischemic (IC), dilated (DC), hypertrophic (HC), and infiltrative cardiomyopathy were defined according to the European Society of Cardiology recommendations.[13] Patients with idiopathic ventricular tachycardia or fibrillation (VT/VF), arrhythmogenic right ventricular dysplasia, channelopathies, or other conditions were grouped in the miscellaneous etiologies. All subjects underwent coronary assessment with coronary angiography or CT scan as appropriate. Early conclusions regarding the pathology's underlying etiology were first suspected on the basis of clinical and familial history, visit, ECG, and standard echocardiogram.[13] In subjects who underwent cMR, etiology was confirmed or disproved according to cMR findings. Radiologists and cardiologists analyzed these images and agreed on the etiology classification in every case. Patients with multiple findings were classified as having dual pathology (usually a combination of IC and HC or DC features).

CMR exams were performed using two 1.5 T MR systems (MAGNETOM Symphony, Siemens Healthcare, Erlangen-Germany from 2006 to 2011 and MAGNETOM Avanto, Siemens Healthcare, Erlangen, Germany since 2011). Cine images of the heart were acquired in 2-chamber and 4-chamber views of the left ventricle and in short-axis view, using TrueFISP sequences.

Ten minutes after intravenous administration of 0.2 mmol/kg of gadolinium DTPA (Magnevist, Schering), late gadolinium enhancement (LGE) images were acquired in the same views as those used for cine imaging using PSIR sequences with the inversion time adjusted to null normal myocardium.

The quantification of LV function, volumes, and mass was performed using the Argus Ventricular Function software (Siemens Healthcare). Two senior radiologists (CT and LS) and 1 senior cardiologist (JDM) visually analyzed, discussed, and collectively agreed on the interpretation of all the images. The transmural extent of contrast enhancement within each segment was defined visually according to the following scheme: 0 = no enhancement, 1 = 1% to 25%, 2 = 26% to 50%, 3 = 51% to 75%, and 4 = 76% to 100% enhancement extent referred to the myocardial wall thickness.[14] A total scar score was obtained by summing the score of each segment (each weighted by the midpoint of the range of enhancement for the given segmental score; i.e., 1 = 13%, 2 = 38%, 3 = 63%, 4 = 88%) and dividing by 17.[15,16]

Statistical analysis was performed using SPSS for Windows 15.0 (SPSS Inc., Chicago, IL). Continuous variables are expressed as the mean ± standard deviation (SD). Baseline categorical data were compared by means of the chi-square test. To compare continuous variables, the Student's *t* test for normally distributed paired and unpaired data was used. Nonparametric data were analyzed using the Mann-Whitney or Wilcoxon test. Logistic regression was utilized to isolate univariate cMR referral predictors. The log-rank test was used to compare survival distributions (mortality rates) between subjects with or without LGE. Receiving operating curves were constructed for the comparison of EF and LGE score performance to predict ICD activation. Youden method was used to calculate the optimal cutoff for LGE score. For all tests, a p value <0.05 was considered statistically significant.

Results

A total of 378 subjects referred for ICD implantation for a primary (87%) or secondary (13%) prevention were prospectively registered between 2006 and 2017. A total of 139 patients (37%) underwent cMR before the intervention. In 5 patients, images were suboptimal mainly for excessive irregular rhythm, patients' intolerance, or other artifacts. The final population with pre-ICD cMR scan was of 134 patients. The percentage of subjects with preimplantation cMR changed significantly with time, ranging from 13% in the 2010 to 53% in the last year (Figure 1). Including only subjects without contraindications to gadolinium or cMR, the percentage of subjects who underwent cMR in the last year was 63%.

Baseline population characteristics with or without cMR are showed in Table 1. Patients who underwent cMR compared with those without cMR were younger with lower NYHA class at implantation and a higher EF (p <0.001). A higher number of women were present in the cMR group (p 0.03). Ischemic etiology was comparable between patients with or without cMR. Prevalences of different etiologies were however significantly different between the 2 groups due to higher percentage of HC within the cMR group. Univariate predictors of cMR referral are presented in Table 2. Incidence rate of ICD intervention for sustained ventricular arrhythmias was 3.01%/year in patients without cMR and 3.33%/year in patients with cMR (p 0.394).

Out of the 134 subjects referred for cMR, a total of 34 patients (25%) had new diagnostic findings. The most relevant cMR conclusions that were able to be drawn were about pathology's etiology according to the observed LGE pattern, thrombus detection, and anatomical incidental findings (Figure 2). In 25 patients (19%), the original etiology was

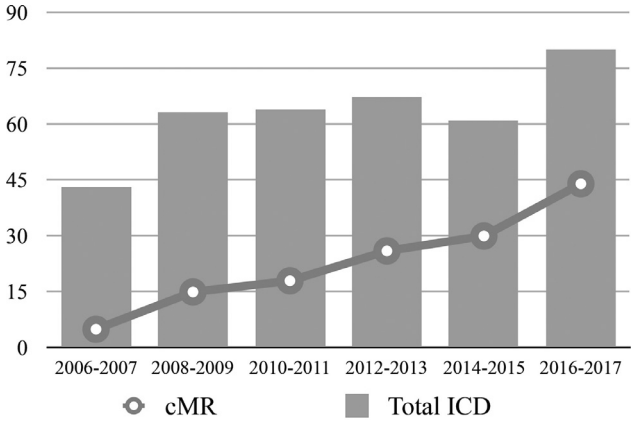

Figure 1. The bars represent the number of implantable cardioverter defibrillator (ICD) implanted. Overimposed are the number of cardiac magnetic resonance (cMR) scans performed before ICD implantation in the same period. Percentage of subjects with cMR pre-ICD implantation gradually increases during the follow-up period.

Table 1
Demographic characteristics of patients who underwent defibrillator implantation with or without cMR before the procedure

Variables	cMR (n = 134)	no cMR (n = 244)	p Value
Age (years)	65.04 ± 12.18	70.07 ± 10.65	<0.001
Women	32 (24%)	36 (15%)	0.03
Primary prevention	119 (89%)	210 (86%)	0.52
Atrial fibrillation	31 (23 %)	—	
Etiology			
Ischemic	54 (40%)	93 (38%)	0.017
Dilated	43 (32%)	111 (45%)	
Hypertrophic	25 (19%)	23 (9%)	
Miscellaneous	12 (9%)	17 (7%)	
NYHA class	1.98 ± 0.72	2.17 ± 0.73	0.026
Resynchronization	32 (24%)	91 (37%)	<0.001
Ejection fraction (%)	36.65 ± 17.91	31.49 ± 9.02	<0.001
End diastolic volume (ml)	221.82 ± 89.25	—	
End systolic volume (ml)	151.03 ± 88.92	—	
Medication			
Beta blockers	125 (93%)	—	
ACE-I/ARBs	114 (85%)	—	
Anti-aldosterone	57 (42%)	—	
Amiodarone	38 (28%)	—	

Table 2
Univariate predictors of undergoing cardiac magnetic resonance before defibrillator implantation

Variables	Hazard ratio	95% CI	p Value
Age (years)	0.946	0.923-0.971	<0.001
Female	2.143	1.096-4.189	0.026
Primary prevention	1.206	0.520-2.801	0.662
Ejection fraction	2.147	0.068-67.79	0.630
Year of implant	1.329	1.223-1.444	<0.001
NYHA ≥3 vs <3	0.630	0.321-1.235	0.178
Etiology (vs ischemic)			
Dilated	0.662	0.380-1.153	0.145
Hypertrophic	1.146	0.465-2.827	0.767
Miscellaneous	0.482	0.097-2.399	0.373

changed after cMR. In 20 out of them, multiple LGE patterns were observed thus suggesting a dual pathology. In 9.3% of patients with a diagnosis of DC and in 8.3% of cases with HC, an ischemic LGE distribution was diagnosed. All these subjects had nonobstructive Coronary Artery Disease (CAD). A pattern suggestive of infiltrative disease was present in 2 HC cases (1.5% of overall population).

Overall due to these findings, a total of 11% of subjects with initial nonischemic etiology had an immediate therapeutic modification. A nonischemic pattern was revealed in 22% (n = 12) of patients with previous Acute Myocardial Infarction (AMI) and CAD. Eight of these showed significant LV hypertrophy with a final diagnosis of simultaneous HC and IC.

LV or auricular thrombosis, which was not highlighted by standard echocardiography, was evident in 6% of overall population (8 of 134). In 1 patient, a ventricular thrombus was suspected by echocardiography but was not confirmed by cMR. New thromboses were detected in 9% of IC patients and 5% of DC. One patient had evidence of auricular thrombosis albeit in sinus rhythm. Oral anticoagulation

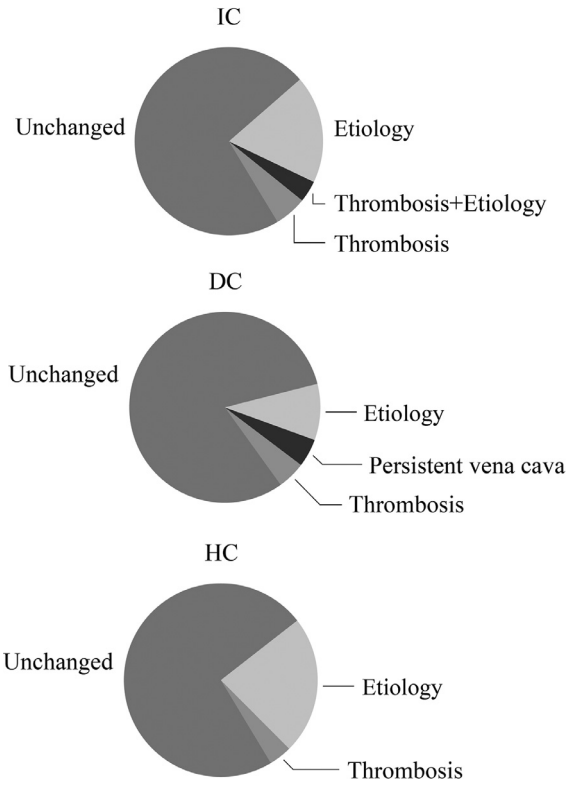

Figure 2. Graphical representation of diagnostic findings within 3 most represented etiologies. Roughly, 1 of 4 investigations had at least a new diagnostic finding.

was introduced in 5% of patients and ceased or modified (INR range) in 1.5%.

Overall, in 18 of 134 subjects (13%), we observed an immediate therapeutic modification due to etiology description and thrombosis detection post-cMR findings. Two cases of left persistent superior vena cava were detected.

During a mean follow-up of 3.15 years (range 3 months to 11 years), we observed a death rate of 5.38%/year and an arrhythmias's incidence rate of 3.33%/year. Three patients (2.2%) were lost to follow-up. Combined event rates were 1.8%/year in patients without LGE and 9.9%/year in patients with LGE (hazard ratio [HR] 5.48, 95% confidence interval [CI] 1.31 to 22.98, p 0.02). Incidence rate of VT/VF was 0.9%/year in patients without LGE and 4.3%/year in subjects with LGE (HR 4.38, 95% CI 0.57 to 33.63, p 0.15). Annual even rate was related to the extent of scar reported by LGE score analysis (Figure 3). Receiving operating curves analysis showed that an LGE score higher than 4.5 had 86% sensitivity and 49% specificity to predict ICD activation. Area under curve was higher albeit not significant for LGE score as compared with EF (0.605 vs 0.469, p 0.2).

Discussion

The main finding of our study is that cMR can identify unique diagnostic and prognostic information in patients referred for ICD. One of 4 of these investigations had some clinical consequences. Our experience showed that the use of cMR in clinical practice progressively increases, in a

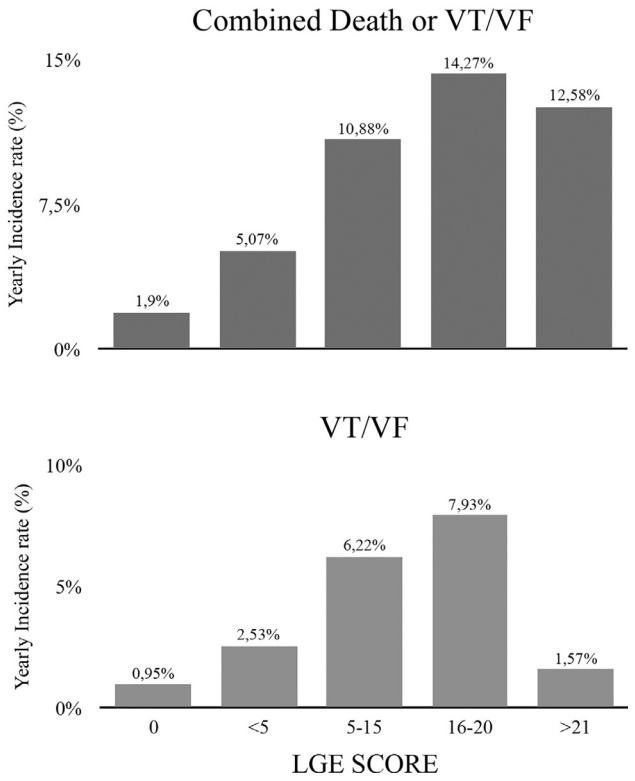

Figure 3. Events organized according to scar extension. The incidence of combined outcome or ventricular arrhythmias progressively increased in patients with larger scars. VF = ventricular fibrillation; VT = ventricular tachycardia.

center with cMR service it can be feasibly performed in the majority of ICD recipients.

The role of cMR as a gatekeeper to coronary angiography has been previously shown to be effective in patients with heart failure of uncertain aetiology.[7,9] Our analysis showed that cMR can also be an important step in ICD recipients. The progressive higher rate of utilization can be due to several aspects. First, previous data highlighted that cMR has better prognostic value than echocardiography in predicting adverse events.[17] Second, loss of myocardium and its replacement with fibrosis which forms different patterns may be pathognomonic of a specific etiology.[7−10] The presence and scar extent revealed by cMR was significantly and independently associated with lower overall and cardiac survival, included SCD.[4,5,18,19]

In our study, we demonstrated the immediate clinical implications of LGE assessment before ICD implantation. In both dilated and hypertrophic cardiomyopathies, we observed an ischemic pattern indicative of previous unknown AMI. The prevalence of this finding was similar in the etiologies and promoted the initiation of secondary prevention therapies. The unique cMR ability to identify ischemic and nonischemic etiologies in patients with HF has been previously demonstrated.[7,9] Of note in our series, more than 10% of patients with IC showed also a mid-wall LGE pattern (i.e., nonischemic) in the context of LV hypertrophy. Indeed, a diagnosis of dual pathology (HC and IC) was achieved in these patients after cMR scan. The observation of multiple patterns is a prerogative of cMR, even if a dual pathology comprising HC can be suspected with echocardiography.[20,21] The diagnostic information obtained was obviously meaningful for relatives' prompt diagnosis and clinical screening.

Finally, our data demonstrated the presence of infiltrative disease in a low percentage of subjects with hypertrophy and clinical-suspected cardiac amyloidosis. Of importance, the possibility to achieve specific tissue characterization before ICD implantation can represent the last chance for a correct diagnosis. In a study by Sasaki et al, about 50% of segments (and up to 70% in the anterior wall) showed significant LGE artifacts resulting in uninterpretable scans in the usual left-side ICD implantation.[12]

We highlighted other major clinical issues. An unknown left atrial or ventricular thrombosis could be observed in about 6% of patients with negative routine echocardiography. The high diagnostic accuracy of cMR has been demonstrated,[22] and it is mainly linked to the improved sensitivity of the scan. Previous data on intracavitary thrombus assessment showed a large variability of prevalence between studies according to different population and etiologies.[22−24] Left atrial thrombus can also be observed in subjects in sinus rhythm[25] as our study detected in 1 subject. Of note, cMR has also the ability to exclude the presence of thrombus previously suspected with bedside echocardiography.[24] This promotes an obvious immediate clinical gain of oral anticoagulation management in this complex group of patients that might translate into maximization of ICD benefit. Two cases of left persistent superior vena cava were observed, piece of information that was important in planning the device implantation procedure.

The overall result of our study was that 1 in 4 patients referred for cMR had a new diagnostic finding, and more than 1 in 10 subjects had a meaningful clinical change in pathology's etiology and management.

Our experience also confirmed previous data about the prognostic importance of fibrosis assessment before ICD implantation. The absence of fibrosis is a strong predictor of good outcome and is associated with very low percentage of arrhythmic events (<1%/year) in our subset. The scar extension is directly related to the outcome. This has already been clearly established in the literature.[4−6,26−28]

Our study has some limitations. First, since the observational nature of the study, our conclusions are hypothesis generating and cannot be definitive. Details of patients who underwent cMR are carefully recorded, whereas this is not the case for patients with other conditions such as atrial fibrillation and medications. Therefore, selection bias and lack of homogenous control information could be 2 limitations of our study. Nevertheless, the similar incidence rate of arrhythmias in all our patients suggested a low impact that selection bias could play in this study. Second, since a control group is lacking, we cannot conclude that the observed diagnostic findings have internal validity. Third, the lack of core laboratory and the unblinded nature of the study could give rise to detection bias. Nevertheless, some aspects of cMR (such as LGE scoring) are semiquantitative and less prone to interpretation. Fourth, subgroups are small and inadequate to explore the role of fibrosis. Scar and its extension may have a different clinical meaning within

different etiologies. Finally, we have detailed a prognostic analysis to better describe population; however, prognostic data are not new and prone to bias due mode of collection and outcome assignment.

Disclosures

The authors have no conflicts of interest to disclose.

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Supplementary materials

Supplementary material associated with this article can be found, in the online version, at https://doi.org/10.1016/j.amjcard.2018.11.036.

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