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Importance Of Delayed Enhanced Cardiac MRI In Idiopathic RVOT-VT: Differentiating Mimics Including Early Stage ARVC And Cardiac Sarcoidosis

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Abstract

A detailed understanding of cardiac anatomy and pathophysiology is necessary to optimize catheter ablation procedural success for patients with symptomatic ventricular tachycardia (VT)/premature ventricular contractions (PVCs) of outflow tract origin. Comprehensive imaging with cardiac magnetic resonance imaging (cMRI) is now at the forefront of procedural planning for complex ventricular arrhythmia ablation for patients with structural heart disease, but is increasingly used in patients with presumed "idiopathic" outflow VT/PVCs as well.

cMRI with late gadolinium enhancement (LGE) can localize small regions of myocardial scar from previous myocardial infarction, fibrosis from non-ischemic cardiomyopathy, or edema/fibrosis from inflammatory disorders and help define targets for ablation. LGE, in combination with structural assessment, can help differentiate true idiopathic outflow VT/PVCs from those caused by early stage disease secondary to more significant pathology, such as arrhythmogenic right ventricular cardiomyopathy or cardiac sarcoidosis.

We review the benefits of cMRI with LGE for patients with VT/PVCs of outflow origin.

Introduction

Pre-procedure imaging is a well established practice in clinical electrophysiology prior to catheter-based cardiac ablation, with the majority of patients having a transthoracic echocardiogram (TTE) as the initial imaging modality. While TTE provides an assessment of biventricular function, cardiac chamber size and valvular function and excludes most congenital heart disease, it falls short of providing high-resolution assessment of regions of scar/fibrosis.

Cardiac magnetic resonance imaging (cMRI) has been increasingly used in the last decade for cardiac ablation pre-procedure imaging, and is no longer reserved for complex cases.[1-2] cMRI with late gadolinium enhancement (LGE), with excellent soft-tissue visualization, is unsurpassed in defining cardiac anatomy and function while characterizing regions of scar that correlate with low voltage areas seen on electroanatomic mapping (EAM) during diagnostic electrophysiologic study.[3-4]

The most frequent use of cMRI within cardiac electrophysiology remains prior to ablation for arrhythmias such as atrial fibrillation (AF) or ventricular tachycardia (VT) in the setting of structural heart disease. However, as more data becomes available on the ability of cMRI to differentiate early stage pathology, it has become an increasingly useful tool in presumed "normal heart" arrhythmias to differentiate truly idiopathic arrhythmias from pathologic conditions such as arrhythmogenic right ventricular cardiomyopathy (ARVC) and cardiac sarcoidosis (CS).

Potential detection of these pathologic conditions in patients thought to have an idiopathic arrhythmia not only changes ablation strategy and potentially allows for a more focused ablation approach, but also may completely alter the overall treatment strategy.

Disclosures:
None.

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Review

cMRI For VT In Structurally Normal Hearts

VT with left bundle branch (LBBB)/inferior axis morphology, in the setting of a preserved ejection fraction (EF) is most consistent with idiopathic outflow VT and associated scar/fibrosis is not typically expected in this clinical scenario. (Figure 1) The use of cMRI for pre-procedure imaging and planning in patients with VT has until recently predominantly focused on the left ventricle (LV). While cMRI has been used for patients with known or high suspicion for ARVC, cMRI has not been routinely used in presumed structurally normal hearts due to resolution limitations for the relatively thin-walled right ventricle (RV). However, as imaging techniques continue to improve and the availability of cMRI increases, the utility of RV imaging has become more evident. This is important as many patients with RV outflow (RVOT) arrhythmias, previously identified as having normal cardiac structure by TTE and resting 12-lead electrocardiogram (ECG), may in fact have underlying

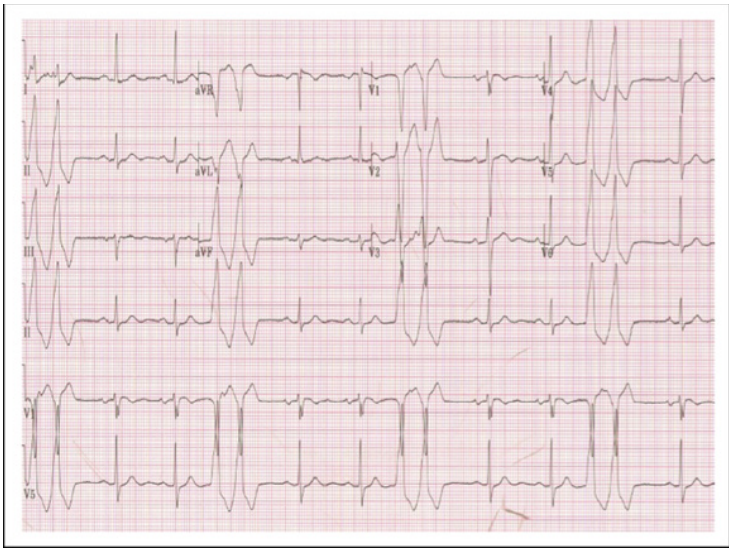

Figure 1: 12-lead ECG of a patient with frequent outflow origin PVCs referred for catheter ablation.The PVCs display a left bundle, inferior axis morphology.

undiagnosed early-stage pathology. (Figure 2)

Regions of low voltage/scar and fibrosis can be reliably identified non-invasively with cMRI as well as invasively during electroanatomic mapping (EAM) performed at the time of diagnostic electrophysiologic testing. While cMRI with LGE is not meant to substitute for comprehensive EAM during electrophysiologic testing, it has been shown to reliably detect areas of low voltage (scar) corresponding to different cardiomyopathic substrates when compared to EAM[5-7] and is not subject to detection of pseudo-scar due to poor catheter contact during EAM acquisition.

The majority PVCs originating from the outflow tracts will not increase ones risk of sudden cardiac death (SCD), however the clinical risk may vary based on the coupling interval (CI) as described by Viskin and colleagues.[8] They demonstrated that ultra-short and intermediate CI PVCs conveyed increased risk for ventricular fibrillation (VF) and polymorphic VT when compared with the longer CI of true idiopathic RVOT PVCs. Further evidence suggests that not only absolute CI, but also potentially the variability of the CI of presumed idiopathic VT/PVCs may affect risk of cardiac events.[9,10] Variable coupling, more frequently seen in VT/PVCs originating from the coronary cusps/aortic sinus of valsalva and from the epicardial venous system, were more likely to be associated with syncope and cardiac arrest in this study.

The underlying mechanism for the increased risk of a subset of presumed idiopathic outflow ventricular arrhythmias remains unclear. Possible mechanisms have been postulated including lack of restraining effect from surrounding myocardium in relatively anatomically isolated foci,[10] as well as underlying peri-valvular fibrosis.[11] Nagashima and colleagues found that some presumed idiopathic outflow arrhythmias may in fact be reentrant in mechanism (Figure 3) and related to peri-aortic fibrosis. cMRI with LGE can provide a detailed anatomic and functional assessment of the RV for dilation, fat infiltration, subtle changes in wall motion and scar/fibrosis that may aid in risk stratifying these PVC cases. In a study by Aquaro and colleagues, the composite end point of cardiac death, aborted cardiac arrest and appropriate shock from an implantable cardiac-defibrillator (ICD) was higher in patients with anatomical and functional findings on cMRI when compared to a cohort with truly normal structure VT/PVC patients.[12]

cMRI may have intra-procedural benefits as well. The benefits of catheter ablation for idiopathic RVOT VT/PVCs are clear and generally associated with a low risk for a major complication[13-14] However, the relative close proximity of these right-sided cardiac structures to the left main coronary artery and the potential for coronary injury with ablation in the septal RVOT is often underestimated.[15] Fusion of cMRI images intra-procedurally with EAM can be performed using proprietary software such as CartomergeTM (Biosense Webster, Diamond Bar, CA USA), which allow assessment of proximity to the coronary vasculature or other areas of interest seen on cMRI during mapping and radiofrequency delivery.

Advanced imaging may also provide beneficial information after successful ablation, if not done pre-procedure. In cases when outflow VT/PVCs are diagnosed in the setting of depressed left ventricular EF, the concern for tachycardia-induced cardiomyopathy (TIC) is often raised. In patients with a high burden of VT/PVCs, there is evidence that successful ablation can improve EF.[16-18] After successful ablation, cMRI can be used to evaluate for the presence of ventricular LGE outside of the region of focal ablation. LGE at sites distant from regions of ablation is indicative of concomitant pathology causing ventricular dysfunction, as LGE has rarely been found in patients with true idiopathic VT leading to TIC.[19]

cMRI In Arrhythmogenic Right Ventricular Cardiomyopathy

ARVC is an inherited cardiomyopathy characterized by ventricular arrhythmias and slowly progressive ventricular dysfunction. Although ARVC can progress to have biventricular involvement, there is a predilection for the disease to primarily affect certain regions of the RV: the RVOT, the RV apex, and the subtricuspid region. These anatomical regions together give rise to what is known as the triangle of dysplasia.[20-21] Therefore, in the early-stages ARVC, VT/PVCs from the superior aspect of the triangle of dysplasia can have a similar morphology to VT/PVCs of idiopathic origin, and should be considered in the differential diagnosis of outflow origin arrhythmias.

When considering a diagnosis of ARVC-induced VT/PVCs, TTE may fall short in recognizing subtle wall motion abnormalities early in the disease process. Resting ECGs can provide additional

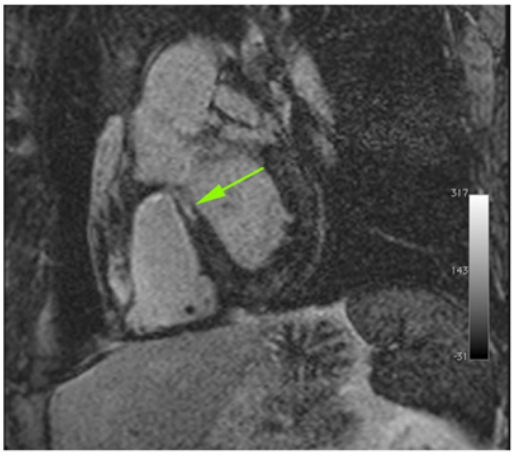

Figure 2: cMRI of a patient with presumed idiopathic RVOT-VT. A mid-septal region of LGE is noted (green arrow). The LGE site correlated with the VT origin found during diagnostic electrophysiologic study.

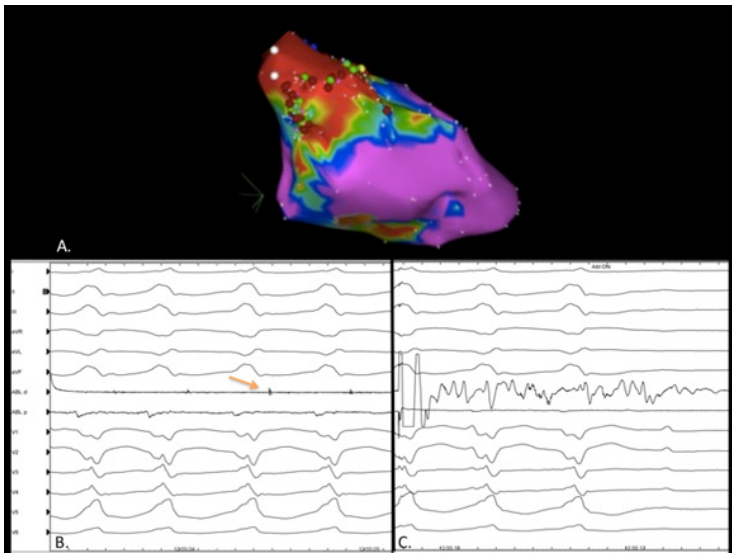

Figure 3: Electroanatomic Map (EAM) of reentrant RVOT-VT. (A) Right anterior oblique (RAO) view of an EAM demonstrating scar in the RVOT (red) with superimposed radiofrequency (RF) ablation delivery sites (red dots), pace mapping sites (green dots) and pulmonary valve annulus (white dots). (B) 12-lead and ablation catheter recording during VT induced with evidence of diastolic potentials (arrow) providing evidence that this VT was not focal or triggered, but rather reentrant. (C) The VT was successfully ablated with immediate termination with ablation in this region of diastolic potentials.

insight as to the etiology of LBBB/inferior axis VT/PVCs leading to a further increased suspicion for ARVC as the etiology.[22-23] However, TTE and ECG alone may be insufficient, as not all patients in whom the diagnostic index of suspicion is high will meet non-MRI Task Force Criteria for the diagnosis of ARVC.

cMRI may identify previously undiagnosed wall motion abnormalities and regional areas of scar and with continued improvement in cMRI imaging resolution, its sensitivity for the early detection and diagnosis of ARVC will likely increase. cMRI is not only important for initial diagnosis and to rule out other previously undiagnosed cardiac pathology,[24-26] but it can also assess progression of disease from dysplasia to cardiomyopathy.[27-28] Further, cMRI can provide additional risk stratification information in patients with documented LBBB morphology VT/PVCs (Figure 4) and can be useful for peri-procedural planning for future radiofrequency ablation procedures, should one be required.

cMRI In Cardiac Sarcoidosis

When considering the differential diagnosis of RV origin VT/PVCs, cardiac sarcoidosis (CS) (with or without non-cardiac involvement) should be considered among the possible diagnoses. Sarcoidosis is a multisystem granulomatous disease of unknown etiology characterized by noncaseating granulomas in involved organs. Organs involved include the lymphatic system, heart, lung, central nervous system and the eyes.

When comparing ARVC to CS, RV involvement favors ARVC, though in the later stages of the illness, ARVC can have a higher incidence of biventricular involvement.[29] In comparison, it is generally accepted that in CS, the pattern of ventricular involvement will favor an LV distribution. However, isolated RV involvement can occur in CS and therefore it must be considered in the differential diagnosis. Extra-cardiac involvement such as chronic inflammatory findings with thoracic lymphadenopathy will be almost exclusively seen in CS.[29]

CS is an under-diagnosed disorder, with only half of the patients diagnosed during autopsy known to have carried the diagnosis in vivo.[29-30] Clinical effects of sarcoidosis on the heart include electrical conduction disturbances,[31-32] tachy-arrhythmias,[33-34] specifically sustained monomorphic VT,[35] heart failure and increased risk of sudden cardiac death (SCD).[18] Prompt diagnosis is essential to ensure early initiation of systemic immunosuppressive therapy and therefore minimize the risks of end-organ damage.[30,35]

Reports on the frequency of cardiac involvement in patients with systemic disease vary significantly with evidence that up to a third of patients with systemic sarcoidosis will have cardiac involvement in some studies, with other series reporting cardiac foci in as low as 5%[36-37] with isolated CS regarded as a relatively rare entity. However, in patients who present with sustained monomorphic VT in whom idiopathic and ischemic etiology are excluded as many as a third of cases may be related to previously undiagnosed as CS.[36-37] While the incidence of SCD is not known in CS, the five-year all cause mortality has been estimated between 25-66%.[38] SCD in CS is most commonly a result of conduction abnormalities (heart block) or VT.[35-39]

cMRI is an important management tool for patients with CS, as those in whom LGE has been documented will have a survival benefit from implantable cardioverter defibrillator (ICD) implantation.[40] An increased incidence of death, aborted SCD and appropriate ICD shock have been associated with the presence of LGE on cMRI, independent of LV ejection fraction, LV end diastolic volume and heart failure.[38] The use of integrated positron emission tomography/computed tomography (PET/CT) with the glucose analogue 2-F-fluoro-2-deoxy-D-glucose (FDG) has been validated for the diagnosis of patients with sarcoidosis[39] and has become the primary imaging modality for CS. (Figure 5) However, the combination of simultaneous PET and MRI demonstrating increased FDG uptake and LGE is indicative of not only the diagnosis of CS with associated scar, but also implies active cardiac inflammation, which if left untreated may progress to further myocardial fibrosis. The

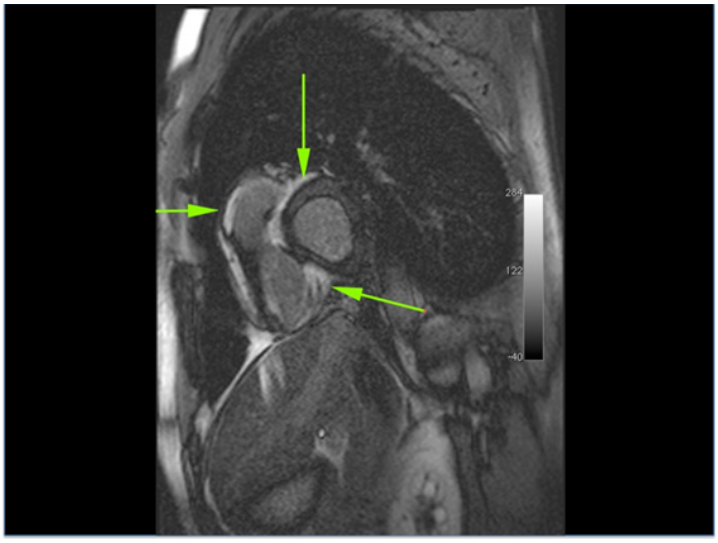

Figure 4: cMRI of patient with ARVC. cMRI Short Axis view demonstrating LGE (arrows) in a patient with ARVC involving the RV free wall and the interventricular septum.

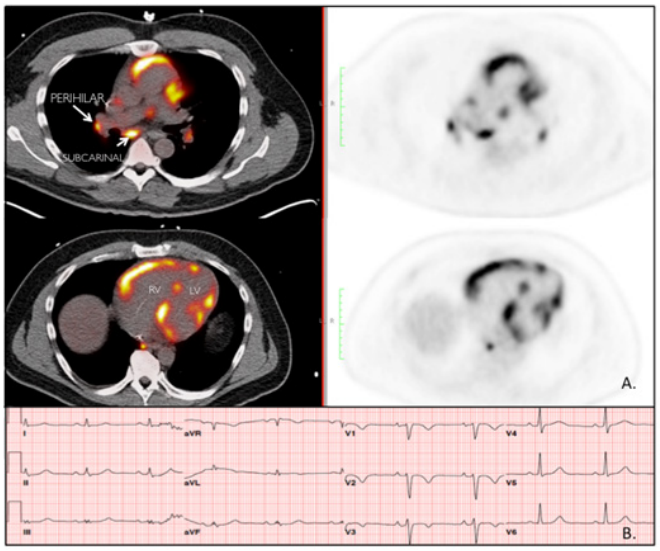

Figure 5: **Example of a patient referred for VT ablation with presumed ARVC found to have Cardiac Sarcoidosis(CS). (A) Axial PET scan view demonstrates patchy focal uptake throughout both ventricles and hilar lymphadenopathy consistent with active CS and not ARVC. (B) ECG showing precordial T wave inversions in leads V1-V3. Up to 90% of patients with ARVC will have abnormalities in the resting 12-lead ECG but these findings are non-specific for ARVC**

hybridization of PET and MRI within a single imaging system is a significant advance in noninvasive imaging for CS. Co-registration of metabolic and structural imaging with morphological, functional and tissue imaging is at the forefront of non-invasive cardiac diagnosis.[41]

MRI In Patients With Implanted Cardiac Devices

One potential limitation of utilizing cMRI for differentiating the etiology of outflow origin VT/PVCs, is that cMRI has not been widely used in patients with implanted cardiac devices due to concerns for lead/generator damage.[42] However, while there are clear contraindications to cMRI imaging in certain cases such as retained/abandoned leads due to lead heating with potential for myocardial injury, and device dependency in case of a catastrophic device failure, cMRI has been demonstrated to be safe in individuals with ICDs. The overall risk to the ICD system and the patient is low and the results may significantly impact patient care.[43-46]

Furthermore, use of cMRI in patients with implantable devices was limited by artifact due to the ICD or pacemaker generator that was produced by conventional cMRI acquisition sequences, which limited image interpretation. Stevens and colleagues have reported a wideband LGE MRI pulse sequence for device artifact removal, thus permitting for almost unperturbed imaging of the myocardium.[47]

Therefore, our hypothesis is that vWF plasma levels show variability in patients with NVAF and that this variability is influenced by risk factors and by AF type. The aim of the present study is to identify these ranges of variability in patients with AF.

Conclusion:

Structural and functional findings on cMRI may provide important information to help guide the management of ventricular arrhythmias. In a recent series reported by Corrado et al, when EAM was performed in patients with sustained VT consistent with RVOT origin (LBBB inferior axis), as may as 20% had findings consistent with early concealed ARVD with EAM.[48] Pre-procedural MRI, if performed, may suggest non-idiopathic RV VT origin and may significantly change the treatment course for an individual patient. We anticipate cMRI imaging will continue to improve and will be an invaluable tool in the diagnostic workup of patients with VT/PVCs of outflow origin and should be considered as part preprocedure work up when ever possible.

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