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Cardiac magnetic resonance for prediction of arrhythmogenic areas

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ABSTRACT

Catheter ablation has been widely used to manage recurrent atrial and ventricular arrhythmias. It has been established that contrast-enhanced magnetic resonance can accurately characterize the myocardium. In this review, we summarize the role of cardiac magnetic resonance in identification of arrhythmogenic substrates, and the potential utility of cardiac magnetic resonance for catheter ablation of complex atrial and ventricular arrhythmias.

Introduction

Catheter ablation is a well-established therapeutic strategy for patients with recurrent arrhythmia. Scar-related sustained monomorphic ventricular tachycardia (VT) is most commonly seen after myocardial infarction. Although implantable cardioverter defibrillators offer the best protection against sudden cardiac death, catheter ablation for VT suppression is occasionally required. Atrial fibrillation (AF), the most common cardiac arrhythmia, is also amenable to catheter ablation. Together, these arrhythmias offer the most complex and gratifying challenges for electrophysiologists today.

Successful ablation requires the correct identification of underlying critical arrhythmogenic substrates. In the commonly used technique of electroanatomic mapping, substrates are identified indirectly, by collecting local voltage amplitudes as a surrogate of the state of nearby myocardium. This method is time consuming, lacks sensitivity for scar substrates deep to the surface being mapped, and lacks specificity for scar especially in the setting of poor catheter contact or thinner myocardium. Therefore, development of improved strategies to define arrhythmogenic scar substrates is warranted.

Cardiovascular magnetic resonance (CMR) is a non-invasive imaging modality with high contrast resolution that lacks ionized radiation. CMR has been used extensively in the recent decade due to its ability to characterize cardiac anatomy and function. As validated histopathologically, CMR can visualize fibrosis by delayed imaging of gadolinium-based contrast agents that accumulate within the extracellular space and have slower washout from scar than from healthy myocardium [1].

Today, with the help of evolving mapping technologies, CMR images can be merged with electrograms derived from the electrophysiologic study, thus creating an anatomic roadmap for the electrophysiologist [2]. Myocardial scar, the most common substrate for reentrant arrhythmias, can be easily displayed by late gadolinium-enhanced (LGE) CMR [3]. Incorporation of the LGE derived scar anatomy shortens the procedure time devoted to substrate identification and enables VT ablation in the setting of hemodynamic instability

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that precludes conventional electrophysiologic mapping and dense point-by-point voltage mapping. However, the technique of LGE CMR promises to do more than that. A thorough understanding of the physiologic conduction characteristics associated with various anatomic scar substrates may improve patient selection for arrhythmia therapies and facilitate ablation even in cases that are amenable to conventional electrophysiologic mapping.

In this review, we summarize the role of CMR in prediction of arrhythmogenic substrates, focusing on 2 arrhythmias: scar-related VT and AF.

Ventricular tachycardia

Despite significant advances in technology and therapeutics; cardiac disease is still the leading cause of mortality in the industrialized world. Many deaths are attributable to ventricular arrhythmia, especially in patients with structural heart disease. Scar-related sustained monomorphic VT is a common arrhythmia after myocardial infarction. Although mortality is best prevented with implantable defibrillators in such patients, many require catheter ablation for VT suppression. Due to continuing improvements in electrophysiology techniques, catheter ablation is now a validated option for treatment of scar-related VT to reduce the morbidity associated with structural heart disease. A crucial step for successful VT ablation is detailed characterization of the underlying arrhythmogenic substrate.

Early fundamental studies by Josephson et al. [4] showed that surgical resection of critical regions of the endocardium and subendocardium could terminate sustained VT [5]. Post-myocardial infarct-related VTs that were resistant to medical therapy, were successfully treated by resecting fibrotic endocardial tissue and infarct border zone regions. Patients that underwent such daring procedures were VT free during a follow-up period of 6–24 months [5]. These findings inspired the consequent histopathological studies, which evaluated the resected endocardium and subendocardium specimens as a potential substrate for VT [6,7].

Fenoglio et al. [6] defined the morphologic characteristics of arrhythmogenic substrates derived from surgical resections of the endocardium in patients with recurrent VT. In the resected specimens, bundles of viable myocardial fibers within dense fibrous tissue extended to the margins of the surgical resection. The authors concluded that the abnormal structure and arrangement of the surviving cardiac fibers in the endocardium might be the critical substrate for VT. A following study by de Bakker et al. [7] included subjects with sustained VT, to describe the electrophysiologic and histologic findings in the resected endocardium of patients with previous myocardial infarction. The electrophysiologic signs of arrhythmogenic substrates such as fractionated electrograms and slow conduction were detected in areas where viable muscle fibers and fibrous tissue were mixed heterogeneously; and where muscle fibers were organized and isolated by connective tissue. Presystolic activity was located intramurally and subendocardially, supporting the concept that reentry occurred via isolated bundles of surviving myocytes within the infarct and the larger subendocardial muscle mass.

After validation of LGE for identification of scarred myocardium, numerous studies have sought to define VT substrates noninvasively [2,3]. Peri-infarct zones are located between normal and infarcted tissue, surrounding the core scar. They appear as regions of intermediate intensity on LGE CMR, thus also referred to as gray or heterogeneous zones. Although some intermediate intensity regions may represent volume averaging of adjacent regions with dense scar and viable tissue, histological studies have verified that intermediate intensity regions usually represent a mixture of viable myocardium and scar [8]. It has been shown that the extent of the heterogeneous zone is associated with spontaneous and inducible VT, and predicts mortality after myocardial infarction [9–11]. In a study that enrolled 235 ischemic and nonischemic cardiomyopathy patients, the extent of the heterogeneous zone was independently associated with appropriate implantable defibrillator shocks for ventricular arrhythmias or cardiac death [12]. Additionally, Perez-David et al. [13] showed that post-infarction VT conducting channels were associated with heterogeneous zones detected by LGE CMR.

To understand the pathophysiologic basis of these observations, Estner et al. [14] used LGE CMR in animal studies to show that heterogeneous zones were located at successfully ablated VT sites, and that incomplete ablation of these zones was associated with VT recurrence. Ashikaga et al. also studied swine hearts and defined arrhythmogenic substrates by using LGE CMR. Critical VT sites were identified as viable myocardial fibers adjacent to the scar tissue in the peri-infarct region [15]. Other studies based on electroanatomic substrate mapping, have found that successful ablation of scar-related VTs can be performed from the scar border zone [16]. Animal based CMR studies and previous surgical studies indicate that the infarct border contains viable tissue, and close contact of normal and abnormal conduction pathways as well as viable and fibrotic tissue interactions may form the VT substrate [6–8,14,15].

On the other hand, several studies point to the scar core on CMR as the substrate for VT. Desjardins et al. [17] performed electroanatomic mapping and LGE CMR in patients post-myocardial infarction. The authors found that critical VT cites were located predominantly within the core infarct region. Sasaki et al. [18] from our group performed LGE CMR in patients with ischemic cardiomyopathy prior to catheter ablation for VT. In this study, all critical VT sites were located in regions with >25% scar transmurality, but central pathway sites were located in regions with >75% scar transmurality. Many sites that exhibited isolated potentials and were identified as central circuit sites via entrainment mapping resided in regions with 100% transmural scar by LGE CMR (Fig. 1). These findings are in agreement with the early surgical work by Fenoglio et al. [6] that defined the arrhythmogenic VT substrates as bundles of viable myocardial fibers within dense fibrous tissue. A recent article from Piers et al. [19] also evaluated the characteristics of VT substrates with LGE CMR in ischemic and nonischemic patients who underwent VT ablation. Critical VT sites were associated with high scar transmurality and the majority of the critical VT sites were