Sustained monomorphic ventricular tachycardia (MVT) is characterized by regular, typically wide QRS complexes with uniform morphology at a rate greater than 100 beats/min for greater than 30 s if hemodynamically tolerated, or less if associated with hemodynamic collapse. The incidence of sustained MVT after acute myocardial infarction (MI) is approximately 3.5% for MVT alone and 6.2% for both MVT and ventricular fibrillation. Sustained MVT typically occurs in the chronic phase after MI and is associated with left ventricular dysfunction and scarring. The risk of sudden cardiac death (SCD) from sustained MVT depends on the hemodynamic tolerance of the arrhythmia. Faster MVTs are typically less tolerated and more likely to lead to hemodynamic collapse and cardiac arrest. The incidence of SCD in patients with tolerated, sustained MVT without an implantable cardioverter-defibrillator (ICD) is approximately 2.4%/year, with an overall mortality that is much higher, approximately 20% over the first year.

Treatment for VT generally includes one or more of the following options: antiarrhythmic therapy, an implantable cardioverter-defibrillator and/or catheter ablation. Catheter ablation is performed with an electroanatomic mapping system to define the heart’s 3D anatomy, as well as regions of scar. Radiofrequency energy is then applied to areas of abnormal substrate within which are located channels critical to the VT circuit. Cardiac magnetic resonance (CMR) imaging is a non-invasive modality that provides high-resolution images of cardiac structure and function. CMR has become a very useful tool for sudden cardiac death risk stratification and to facilitate successful radiofrequency ablation of VT in patients with abnormal cardiac substrate. The role of CMR in the management and treatment of VT in patients with structural heart disease is reviewed here.

**Risk Stratification for Ventricular Arrhythmias and SCD**

SCD accounts for up to 400,000 deaths annually in the United States, the majority of which are attributable to prior MI. In patients with structural heart disease, with or without accompanying coronary artery disease, the left ventricular ejection fraction (LVEF) is the most widely used predictor of SCD. Several multicenter randomized controlled trials have demonstrated a mortality benefit in patients with low LVEF who receive an ICD for primary prevention. However, not all patients with low LVEF suffer SCD and not all SCDs occur in patients with low LVEF. Our risk predictive models for SCD need to be improved and evidence suggests that CMR may play an additive role to conventional risk stratification techniques.

It was initially demonstrated that in patients with prior MI, infarct size by contrast-enhanced CMR (CE-CMR) was a better predictor for inducibility of MVT than low LVEF. Infarct size was later shown to be an independent predictor of adverse outcomes and mortality, even when compared with con-
Procedural Planning for VT Ablation

ICD placement can help prevent SCD and improve patient survival but it does not prevent the recurrence of MVT. Antiarrhythmic therapy and catheter ablation are necessary for MVT prevention. Catheter ablation procedures are often complex and procedural planning is critical for safe and effective outcomes. Two of the main challenges in current procedural planning for MVT ablation are whether to proceed with an epicardial approach and identification of interventricular septal scar. The epicardial approach was first described by Sosa et al., but can be technically challenging and result in significant procedural complications such as cardiac laceration, hepatic injury, bowel perforation and pneumothorax. Consideration must also be given to the anticoagulation status of the patient should operative repair of an injury be required. Although most patients with prior MI and resultant ischemic scar can undergo successful catheter ablation via an endocardial approach, a combined endo- and epicardial approach is occasionally necessary to improve efficacy. Conversely, although a combined endo- and epicardial approach is often necessary for successful MVT ablation in patients with non-tractile reserve., Further differentiation of infarct tissue demonstrated the size of the peri-infarct zone to have incremental value for prediction of SCD than LVEF alone. Infarct tissue heterogeneity was also shown to be a stronger predictor of MVT inducibility, as well as spontaneous ventricular arrhythmias and appropriate ICD shocks than LV function and volume. More recently, high-resolution CE-CMR in an animal study demonstrated that regions of tissue heterogeneity were helpful to identify critical isthmus sites in patients with ischemic MVT and elimination of regions with tissue heterogeneity correlated with less inducibility of MVT (Figure 1). The additive role of CE-CMR in risk stratification has been corroborated in patients with hypertrophic cardiomyopathy, non-ischemic cardiomyopathy, cardiac sarcoidosis, and in patients who were candidates for cardiac resynchronization therapy with defibrillation capabilities (CRT-D).

Once a patient is identified as having an increased risk of SCD, ICD placement is an important treatment modality to improve survival. LVEF has been the conventional methodology to guide ICD placement. However, myocardial scarring as defined by CE-CMR has been shown to be an independent predictor of death or ICD shock in patients being considered for ICD placement. In patients with LVEF >30%, the presence of scar by CE-CMR identified patients at similarly high risk as those with LVEF <30% and no scar; and in patients with LVEF <30%, the absence of scar identified patients at similarly low risk as those with LVEF >30%.

![Figure 1](image-url)

**Figure 1.** In vivo and ex vivo (high resolution) magnetic resonance tomography (MRI) in animals that were inducible (Left) and not inducible (Right) at 1 week after ablation. Upper row: Pre-ablation user of semiautomatic algorithm for detection of the heterogeneous zone (HZ). Red=scar, green=HZ. Second row: 1 week post-ablation, the in vivo MRI shows substantial remnants of the HZ still present in inducible animals (Left) but minimal HZ present in non-inducible animals (Right). Third row: Post-ablation MRI confirms more remnants of tissue heterogeneity present in inducible animals (Left), than in non-inducible animals (Right). Reprinted with permission from Estner HL, et al.
Epicardial ablation was necessary in 3 (6.1%) ischemic and 12 (42.9%) non-ischemic patients. The presence of subepicardial scar in the successful ablation segment had 84.6% sensitivity and 100% specificity for predicting an epicardial site of MVT origin, further validating the utility of CE-CMR in guiding the decision for an epicardial approach. Identification of septal substrate as a site of origin can be challenging with conventional bipolar electroanatomic voltage mapping (EAVM) techniques.

Of the 8 (10.4%) patients that had mid-myocardial scar in the study by Andreu et al, 6 were septal in origin, of which 4 were successfully ablated from the left ventricular endocardium and 2 from the both the right and left ventricular endocardium. In all cases, the successful ablation site (right vs. left ventricular septum) was that with the shortest distance to the center of the scar, suggesting that CE-CMR can also be helpful in identifying and targeting septal substrate for MVT ablation.

Although bipolar EAVM can be limited in identifying intramural septal scar, unipolar EAVM may have better accuracy in identifying such substrate and appears to correlate with CE-CMR findings (Figure 2).

**CMR-Guided VT Ablation**

EAVM to identify scar for substrate modification is the current standard to guide MVT catheter ablation in patients with non-inducible or poorly tolerated arrhythmias. CE-CMR can provide useful supplementary information for scar identification. Recent studies have shown correlation of scar identified by CE-CMR and that identified by EAVM in patients with ischemic cardiomyopathy, epicardial ablation is not always necessary. Several ECG criteria have been developed to help identify epicardial sites of origin for MVT but all of them have some limitations. Additional information to guide the necessity and timing of an epicardial approach to MVT catheter ablation can be very helpful.

A larger study by Andreu et al performed CE-CMR in 29 patients with non-ischemic cardiomyopathy; 14 patients were found to have scar, of which 9 had MVT and 5 had premature ventricular contractions. All 14 patients underwent catheter ablation, of which 9 had a successful outcome. In these 9 patients, 5 had only endocardial scar and required only endocardial ablation. In the other 4 patients, scar was either intramural and epicardial or epicardial alone. All 4 of those patients required an epicardial approach for effective therapy. The results of that study suggest the location of scar as identified by CE-CMR can help guide the decision of whether or not to proceed with epicardial access for catheter ablation of MVT.

Bogun et al performed CE-CMR in 29 patients with non-ischemic cardiomyopathy; 14 patients were found to have scar, of which 9 had MVT and 5 had premature ventricular contractions. All 14 patients underwent catheter ablation, of which 9 had a successful outcome. In these 9 patients, 5 had only endocardial scar and required only endocardial ablation. In the other 4 patients, scar was either intramural and epicardial or epicardial alone. All 4 of those patients required an epicardial approach for effective therapy. The results of that study suggest the location of scar as identified by CE-CMR can help guide the decision of whether or not to proceed with epicardial access for catheter ablation of MVT.
identification of epicardial scar. However, both endocardial and epicardial bipolar EAVM may miss the presence of intramural scar. Regions of confluent unipolar abnormality that do not overlap with low bipolar voltage may be helpful to identify regions of intramural scar as defined by CE-CMR (Figure 3).

Future of CMR

Prospective observational data have demonstrated that CE-CMR provides additional information with respect to LVEF for risk stratification of SCD. However, further study is needed to assess whether the absence of scar by CE-CMR can allow safe deferment of ICD placement in patients with LVEF <35%. Conversely, further data are needed to assess whether the presence of scar by CE-CMR warrants ICD placement in patients with LVEF >35%. An attempt to study this hypothesis, the Defibrillators to Reduce Risk by Magnetic Resonance Imaging Evaluation (DETERMINE) study, was unfortunately stopped after limited enrollment, in part because of difficulty with reimbursement for CMR studies. Although scar identification by CE-CMR can provide useful adjunct information to
EAVM, use of CE-CMR is limited in patients with ICDs. Scar correlation with EAVM, especially in patients with non-ischemic cardiomyopathy who have intramural and/or epicardial scar, needs to be improved. Limited data suggest that algorithms incorporating unipolar voltage and computed tomography can help improve the correlation for epicardial scar, and that CE-CMR can safely be performed in patients with ICDs while still allowing incorporation into EAVM. However, this needs to be further assessed.

If CE-CMR and EAVM scar correlation can be improved, it is conceivable that CMR could be integrated into live use. Animal studies have demonstrated that real-time CMR data potentially can be used to guide atrial fibrillation ablation. Limited assessment of real-time CMR use in 5 patients for simple ablations demonstrated that it can be done safely but much work needs to be done with respect to surface and intracardiac electrogram recordings, catheter manipulation and defibrillation capabilities before the real-time integration of CMR procedures is ready for more widespread use.

The superior resolution of CMR with respect to anatomic definition is well established, as is the capability for identification of scar by contrast-enhanced imaging techniques. There is tremendous potential for better risk stratification of SCD, procedural planning for MVT ablation and even the possibility of live use in procedures. However, more data are needed to systematically assess the utility of CE-CMR for each of these applications.

References

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