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Advances in Technologies to Improve Ventricular Ablation Safety and Efficacy

Shu Chang[1] · Wendy S. Tzou[1]

Abstract

Purpose of Review This review focuses on advances within the field of cardiac electrophysiology that have helped to improve the safety and efficacy of ventricular arrhythmia ablation.

Recent Findings Improvements in three-dimensional electroanatomic mapping systems and catheters allow providers to generate high-resolution maps in less time while identifying critical areas of arrhythmogenic substrate with greater efficiency and possibly better accuracy. Advanced imaging integration into the mapping systems have improved pre- and periprocedural planning and safety. Novel ablation catheters and techniques have improved the ability to target and deliver effective lesions to areas that are critical in sustaining ventricular arrhythmias. Risk prediction algorithms have been developed to improve the ability to determine those undergoing VA ablation that are at highest risk for acute hemodynamic decompensation, and for whom hemodynamic mechanical support should be instituted, allowing for this therapy to be able to be more safely performed in even those with advanced heart failure. Finally, emerging techniques undergoing development may further improve the safety and efficacy of ventricular arrhythmia management.

Summary Recent advancements in the field of cardiac electrophysiology now enable us to approach ablation of ventricular arrhythmias with increasing precision, safety, and success. With the increasing tools available to the electrophysiologist, ventricular arrhythmia ablations can be offered to increasing larger scope of patients with positive outcomes.

Keywords Ventricular arrhythmia · Ventricular arrhythmia ablation · Ablation technology · Ventricular ablation safety · Ventricular ablation outcomes

Introduction

Dr. Mel Scheinman and his colleagues performed the first catheter ablation in humans in 1981 by delivering DC shocks through an electrode positioned adjacent to the His bundle [1]. Since that first ablation procedure, the field has benefited from numerous advances that now allow us to safely and effectively perform ablations of increasingly complex arrhythmias involving all chambers of the heart (inside and out) [2–5].

✉ Wendy S. Tzou
wendy.tzou@ucdenver.edu

Shu Chang
shu.chang@ucdenver.edu

[1] Division of Cardiology, Cardiac Electrophysiology Section, University of Colorado, Anschutz Medical Campus, 12401 E. 17th Avenue, B-132, Aurora, CO 80045, USA

Despite these advances, inherent risks and challenges exist in ablation of ventricular arrhythmias, especially when performed in the context of structural heart disease or in patients with significant other comorbidities [6, 7, 8•]. Risks of major complications range from 6 to 8% in literature reported from clinical studies conducted at tertiary referral centers and from 8 to 13% in observational studies of "real-world" experiences [6, 7, 8•, 9, 10•]. However, a number of recent technological advances have helped to optimize pre-procedural planning, as well as peri- and post-procedural safety and efficacy [11].

Improved mapping technology, integration of cardiac imaging modalities, and contact force-sensing ablation catheters have all helped to optimize ablation safety, although their direct impact on ventricular ablation efficacy has been less clear [11–14]. What has seemed to incrementally improve ablation outcomes, particularly in the area of post-infarction VT, has been developments in and greater utilization of substrate-based ablation approaches, all of which minimize the need for extensive mapping and ablation during VT [15–21].

Targeted utilization of mechanical hemodynamic support options, when needed, have been refined by risk stratification schemes that assist in better predicting and therefore pre-empting acute procedural hemodynamic collapse—a circumstance that has carried a far worse prognosis [22]. This progress has made ventricular ablation procedures more readily available at most tertiary referral centers [17]. This review aims to highlight some of the recent technological advances that have improved ventricular ablation safety and efficacy.

Advances in Mapping

Cardiac mapping has evolved from a fluoroscopy-based process of correlating electrophysiologic data with anatomic position to a more precise method of simultaneously collecting intracardiac electrogram (EGM) data and corresponding three-dimensional anatomic locations within an electroanatomic mapping (EAM) system [23]. Commercially available EAMs most commonly used currently are CARTO (Biosense Webster, Diamond Bar, CA), EnSite (Abbott, Minneapolis, MN), and Rhythmia (Boston Scientific, Minneapolis, MN). Each system incorporates either use of a localized magnetic field, detection of impedance changes, or a combination, in order to localize the position of roving catheters within the range of detection and assign EGM information to each geographic location [24].

The CARTO system employs a low-level magnetic field to triangulate the position of compatible diagnostic and ablation catheters; although most catheters can be visualized within the system, active mapping can only be performed using catheters with specialized sensors and which are proprietary to the CARTO system. The latest version of the EnSite mapping system (Precision) incorporates electromagnetic localization along with impedance field assessments to localize catheters and re-create three-dimensional anatomy. The open platform of the EnSite system allows for any catheter to be visualized and be used for mapping, as long as impedance can be actively measured from the connected electrodes. Finally, the Rhythmia system also utilizes both impedance- and magnetic field-based technologies for catheter visualization [11, 24, 25].

These mapping systems allow for virtual three-dimensional color-coded displays to be created of the endocardium or epicardium that can highlight areas of potentially abnormal myocardium acquired in sinus or non-tachycardia rhythm (e.g., voltage or late potential maps, as described below) or activation timing specific to location during tachycardia [14, 25]. These tools have become critical in successful VT ablation in many patients, particularly in those patients with structural heart disease.

Mapping, as originally developed with standardly used, bipolar ablation catheters has limitations. The relatively large electrodes in the latter (3.5- to 4-mm tip electrode and 2-mm ring electrode, separated by 1-mm spacing) may not detect diseased myocardium if it is surrounded by surviving tissue or, conversely, surviving myocardial strands of tissue within regions of dense infarction or scar [11]. These limitations exist when performing sinus rhythm/substrate mapping as well as when performing activation mapping during tachycardia [25]. In efforts to improve sensitivity of detection, especially of potential conduction channels within heterogeneous tissue, multielectrode catheters with smaller electrode sizes, closer bipolar spacing, and various shapes have been developed by each major EAM company. These multielectrode catheters have improved the mapping resolution by allowing higher-density maps to be created and in often shorter amounts of time than are feasible with standard ablation catheters (Table 1) [10•, 26–28]. High-density maps not only facilitate discovery of potentially critical ventricular arrhythmia elements that would be underdetected using single bipolar mapping, but they also increase the speed with which detailed maps can be acquired [26, 27].

In order to process the amount of data that is acquired by these multielectrode catheters in making a high-density map, current electroanatomic mapping systems have also undergone continued updates. The Biosense Webster system is currently in its third iteration, CARTO3, St. Jude Medical (now Abbott) released EnSite Precision in the USA in 2017, and Boston Scientific acquired Rhythmia HDX in 2012. These current mapping software tools are capable of rapidly synthesizing large sets of data and converting them into complex multifaceted maps. Each of these mapping systems can accommodate multielectrode catheters that contain as many as 64 electrodes. [23, 25, 29]

Utilizing advanced mapping software and novel catheters, contemporary algorithms to integrate increasingly massive volumes of data acquired with high-density mapping have also evolved to help improve identification of potentially most critical sites of reentry or to identify relevant, low-amplitude bipolar signals that might be otherwise missed. Examples of proprietary software or improved data acquisition algorithms include Ripple mapping with CARTO, AutoMap Module available with EnSite, and Intelligent Annotation Algorithm with the Rhythmia system. Automated annotation algorithms help to minimize the time needed to create comprehensive, high-density maps, especially with up to thousands of points collected, but accepting the data must still be done with circumspection. At least intermittent personal assessment of EGMs and associated annotations is still important, given how dramatically the displayed information may change based on subtle changes in annotation windows (Fig. 1). Though each of these and other software advances offer promising improvements to current methods of rhythm mapping, further investigation is necessary [23, 30].

Advanced Imaging Integration

Another critical function incorporated in contemporary mapping systems is cardiac imaging integration. Advanced cardiac

Table 1 Characteristics of commonly used multielectrode catheters

Catheter	Mapping System	Number of Electrodes	Electrode Size	Inter-electrode Spacing
PentaRay®	CARTO®	20	1 mm	3 mm
DecaNav®	CARTO®	10	1 mm	2-8-2 mm
Lasso®	CARTO®	10-20	1 mm	4-8 mm
HD Grid®	EnSite®	16	1 mm	3 mm
LiveWire™ Duo-decapolar	Ensite®	20	1 mm	2-2-2 mm 2-5-2 mm 5-5-5 mm 2-10-2 mm
Reflexion™ Spiral	Ensite®	10	1 mm	6.3 mm
		20	1 mm	1-4-1 mm
Orion™	Rhythmia®	64	0.4 mm^2	2.5 mm

Fig. 1 Note the change in color annotation based on timing of local signal acquisition when the window of interest is changed only slightly. In the top activation map, the location of the local signal is "early" (red dotted circle and arrow) within the designated window of interest. In the bottom activation map, the same signal (and others around it, yellow dotted circle and arrow) appears "late"
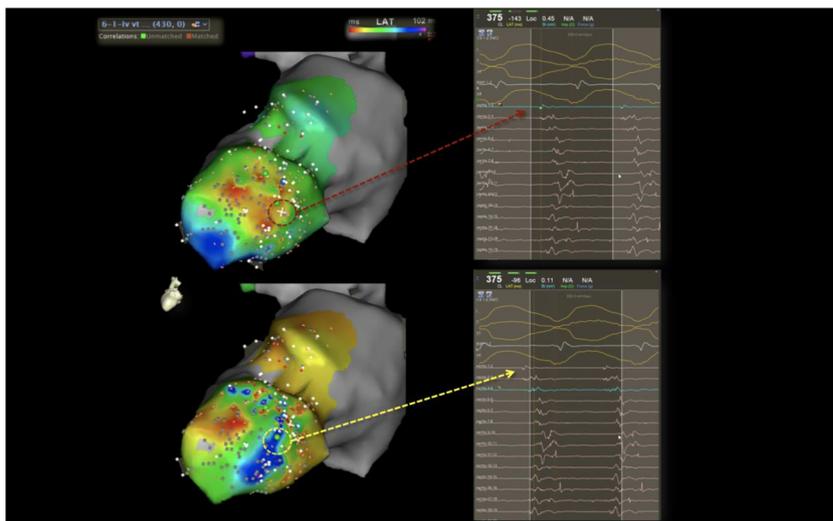
imaging is now being increasingly employed for both pre- and periprocedural planning and for helping with procedural efficacy and safety. The imaging modalities currently most employed for ventricular ablations are cardiac magnet resonance imaging (MRI), contrast-enhanced multi-detector cardiac computed tomography (MDCT), and intracardiac echocardiography (ICE).

Cardiac MRI has gained increasing popularity as a tool for pre-procedural planning. Cardiac MRI can identify and characterize areas of scar through late gadolinium enhancement which often correlate with areas of arrhythmic substrate [31, 32]. This characterization can be particularly helpful in patients with non-ischemic cardiomyopathy where scar substrate formation may not follow as predictable a pattern as in ischemic cardiomyopathy and may also often involve the midmyocardium and epicardium (Fig. 2) [33]. Cardiac MRI in these cases may help the operator plan ablation approach, access, and help refine which mapping tools and catheters may be advantageous for use [34]. Also, pre-procedural cardiac MRI can identify high-risk structures such as coronary arteries that may be in close approximation to substrates of interest. In these cases, further pre-procedural planning and further discussions with the patient may be warranted. The limitations of cardiac MRI include long image acquisition times requiring relatively stable patients, reliance on slow stable rhythms for proper cardiac gating, image distortion or incompatibility in patients with certain implantable devices, limited availability, and inability to obtain real-time images periprocedurally [34].

MDCT has been increasingly utilized to assist in ventricular ablation procedures. Like cardiac MRI, pre-procedural MDCT can give the operator detailed information regarding the patient's cardiac anatomy, which may help in procedural planning. In addition, current generation mapping systems can integrate cardiac CT images, which provides a surrogate to real-time assessment of

cardiac (such as coronary arteries) and anatomically adjacent extracardiac (i.e., phrenic nerve, esophagus) structures that help the operator to optimize safety and efficacy in mapping and ablation. Cardiac images acquired using contrast-enhanced MDCT have demonstrated superior spatial resolution compared to cardiac MRI and are more universally available in most institutions, especially those in which performing MRI in patients with pre-existing cardiac devices is not possible. A notable specialized image-processing platform (MUSIC, Liryc Institute, Bordeaux, France) has been developed with which three-dimensional MDCT reconstructions can be created to include color coding for wall thickness, which can then be integrated into the electroanatomic mapping system. Using this platform, correlations between wall thickness, scar, and arrhythmogenic myocardium have been well demonstrated in post-infarction VT studies [35, 36]. The utility of MDCT in identification of substrate has been best demonstrated in post-infarction substrates, however, and has been of less use in identifying substrate in NICM [31, 32, 35].

Additional limitations of MDCT are that it does expose patients to additional ionizing radiation as well as intravenous contrast, which may be avoided with use of other imaging modalities. Another important detail to note with each of these pre-procedural imaging modalities is that images acquired pre-procedurally must be imported into and appropriately registered within the electroanatomic mapping system, a process that also requires additional time and does not always correlate perfectly with intraprocedural anatomy (for instance, in the setting of altered volume status) [36]. Nevertheless, these imaging modalities are of increasing relevance in management of refractory ventricular arrhythmias, especially as innovative, non-invasive techniques for cardiac ablation, including stereotactic body radiation therapy, emerge [37].

ICE has been increasingly used as an intraprocedural imaging modality and has been especially useful in cases in which pre-procedural imaging as described above are not
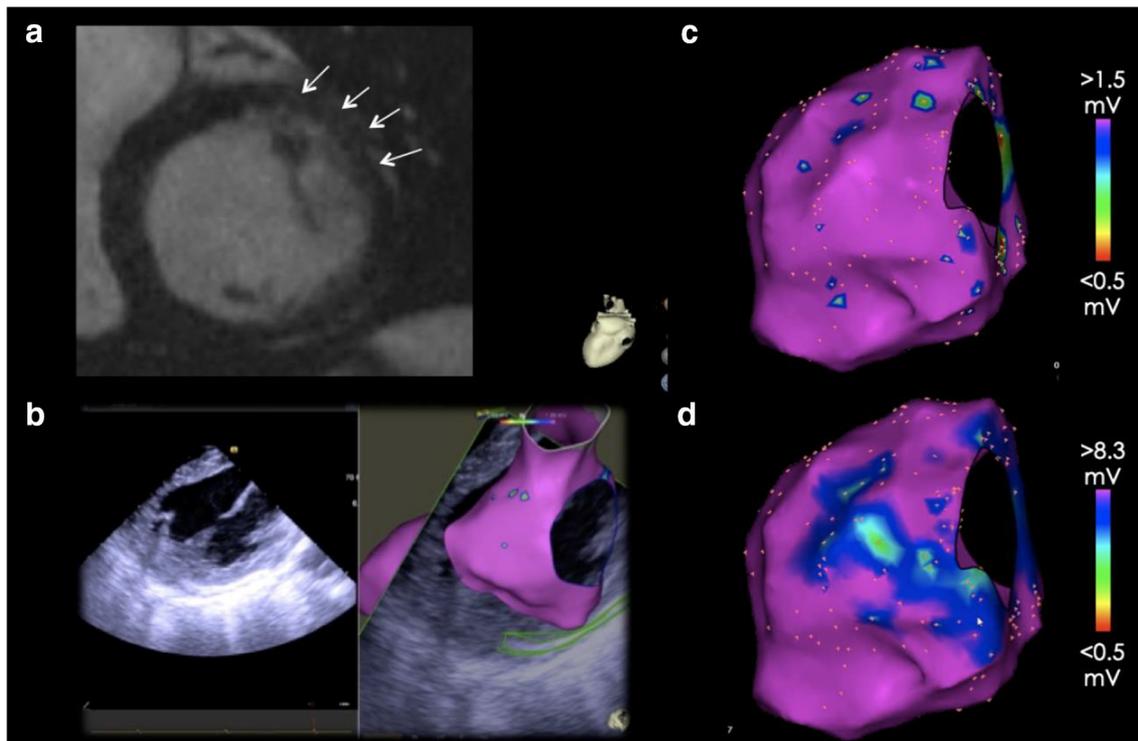
Fig. 2 Example of midmyocardial substrate (arrows) identified on cardiac MRI (**a**) and intracardiac echocardiography (**b**) in a patient with NICM and ventricular tachycardia. Electroanatomic LV voltage map corroborated imaging findings, with normal LV endocardial bipolar voltage (**c**) but abnormal LV endocardial unipolar voltage (**d**) in the distribution of lateral mitral annular substrate

available or limited in quality. A unique advantage of the Biosense Webster CARTO EAM is that ICE images are fully integrated within the EAM, and three-dimensional reconstruction of cardiac structures can be easily created and fully integrated into the electroanatomic maps (Fig. 2). This feature assists not only with providing real-time images of the cardiac structures, but also for early identification and expeditious management of procedural complications, such as pericardial effusion and cardiac tamponade. ICE can additionally be employed to identify catheter positions with manipulation and during ablation and can assist with adequate but safe radiofrequency ablation delivery. Additionally, skilled operators can use ICE images to identify potential scar and arrhythmogenic substrate, manifesting as hyperechogenicity, often with wall motion abnormalities [14, 27, 38].

Advances in Ablation Tools

With advances that have been made in mapping technology, cardiac imaging, and substrate localization, sustained success in ablation of ventricular arrhythmias remains limited, although mostly in the setting of structural heart disease or in targeting of intramural ventricular arrhythmias [6, 7, 8•, 9•, 10•, 39]. Central to the problem of at least some recurrences of ventricular arrhythmias following ablation is the inability to deliver durably effective ablation lesions and, more immediate to any procedure, to determine which lesions are more likely to be durable and of sufficient depth. These issues can be particularly problematic when trying to target midmyocardial substrate [33]. Contemporary VA catheter ablation is performed using open-irrigated catheters that deliver radiofrequency (RF) energy in unipolar configuration [40]. Unipolar RF ablation directs the current flow from the catheter to a large surface area grounding patch placed on the patient's skin. RF ablation lesions that are generated by this technique typically can achieve a maximum depth of about 11 mm, depending on the power, duration, and contact with which the lesion is applied. In ablation cases where the target is localized closer to the surface to which RF is being applied, unipolar ablation is often sufficient in achieving positive end results [41]. However, a substantial proportion of arrhythmogenic substrate is not localized to the endocardial surface particularly in patients with non-ischemic substrate. In these instances, conventional unipolar ablation may be less effective [33, 42].

Multiple adjunctive ablation techniques have been developed in response to these challenges in an effort to generate deeper or more targeted ablation lesions, either with alternative configurations for delivery of standard RF energy or other energy sources (cryoablation) or use of myotoxic substances, such as ethanol, delivered through coronary vasculature [43, 44].. The remainder of this discussion on adjunctive ablation will focus on alternative delivery methods of RF energy.

Delivery of bipolar ablation is feasible by replacing the large surface area and remotely positioned impedance patch

with another catheter. This configuration, when the active and ground electrodes are positioned within 10–15 mm of one another, has led to increased likelihood of transmural lesions compared to either sequential unipolar or even simultaneous unipolar ablation [41, 44•, 45•]. Bipolar ablation configurations have typically been achieved, using existing ablation equipment, but with construction of a custom-made cable, to connect the "ground" catheter to the impedance port on the RF generator [44•, 45•]. An investigational device exemption (IDE) trial (ClinicalTrials.gov Identifier: NCT02374476), in which bipolar ablation specifically configured within the CARTO EAM, is underway to assess safety and efficacy; using this platform, both active and ground catheters can be simultaneously visualized, with inter-catheter distances and active catheter force registered. These features are not available using the configuration described above, in absence of participation in the IDE trial. We recently developed a configuration using preexisting, manufactured cables, obviating the need for creation and use of custom-made cables in which both catheters could be visualized simultaneously within the Precision EAM (Abbott, Minneapolis, MN) [46]. Regardless of how it was achieved, bipolar RF ablation has demonstrated efficacy in targeting substrate in the midmyocardium [32, 41, 44•].

Another method that has been developed to improve the size and depth of ablation utilizing standard RF energy is to alter the ionic content of the irrigant used to cool the RF electrode. Open-irrigated RF ablation catheters allow for active cooling at the interface between the electrode and myocardium, thus preventing char formation and allowing for deeper lesions to be created compared to non-cooled RF ablation. However, the standard irrigant used is normal saline (NS), which contains an ionic charge and lower impedance relative to myocardium that can produce dispersion of RF energy to the surrounding blood pool and away from myocardium. By decreasing the ionic concentration and thus increasing the impedance of the irrigant, with use of half-normal saline (HNS) or 5% dextrose in water (D5W), we found that less energy is dispersed and more is directed to the tissue of interest, producing larger lesions [47]. Its utility in effective ablation of refractory ventricular arrhythmias has also been demonstrated [33, 46]. However, with the capacity to create larger lesions, increased vigilance about safety should also always accompany use of adjunctive techniques. At our institution, use of D5W as the cooling irrigant (unless used in the epicardial space) is often avoided due to an increased incidence of steam pops in pre-clinical studies [47]. We also use ICE to monitor lesion formation with use of these adjunctive techniques to monitor for and prevent steam pops, which can be visualized as acute and rapid increase in echogenicity, often with bubble formation (Fig. 3) [48•, 49•, 50•].

Another advance in RF energy delivery is the creation of the needle RF catheter. The needle catheter is an investigational tool that allows operators to target deep intra-mural substrate that may otherwise be unattainable with traditional ablation catheters [51]. The needle catheter is manufactured as an endocardial catheter with an extendable and retractable needle. The needle catheter allows deep intra-mural pacing, recording of potentials, and delivery of radio-frequency energy for ablation in addition to traditional endo-cardial mapping and ablation functions [41]. A study by Abdelwahab et al. showed that in 8 consecutive patients who had at least one previous failed ventricular ablation attempt, the use of a needle catheter successfully terminated at least one VT in 6 of those 8 patients studied [52]. Though promising, the safety and efficacy of a retractable needle ablation catheter still requires further investigation, and its availability is currently restricted to only a few centers.

Advances in Ablation Strategies

Beyond novel catheters, ventricular ablation efficacy and safety has also benefited from better understanding of ablation approaches. Although entrainment and activation mapping remain important in identifying critical VT circuitry elements in structural heart disease patients, mapping for prolonged periods in VT is often not hemodynamically tolerated or feasible. Identification of substrate and ablation of substrate, primarily in sinus rhythm, has emerged as the preferred technique for efficacious and safe ablation of ventricular arrhythmias in patients with structural heart disease [53]. The mapping technology discussed above has certainly allowed for increasingly efficient and accurate identification of arrhythmogenic myocardium.

Substrate-based ventricular ablation starts with complete substrate mapping which entails identifying all areas of fibrous tissue intermixed with bundles of viable myocardium; varied conduction characteristics of these tissues connected in sequence allow for reentry, which is the most common mechanism for VT in structural heart disease. These areas are typically identified by low-amplitude, fractionated electrograms, often of long duration and with late potentials. Pacemapping is often employed in these regions to garner additional support regarding the participation of the abnormal region in the clinical arrhythmias. Hallmarks of important pacemap sites, in addition to matching the QRS morphology observed during VT, are long stimulus-QRS time (> 40 ms) and alternating morphologies (with or without "perfect" pacemap match to VTs observed, Fig. 4).

Various strategies have been developed over the last decade for substrate modification, including targeting of entrance conduction channels (scar dechanneling), direct ablation of all local abnormal ventricular activities (LAVA ablation or scar homogenization), ablation of regions with greatest change in conduction time, as estimated by isochronal activation maps, and electrical isolation of the relevant substrate (core isolation), confirmed with both entrance and exit blocks of the isolated region [14, 54]. Although these techniques vary slightly in terms of identification
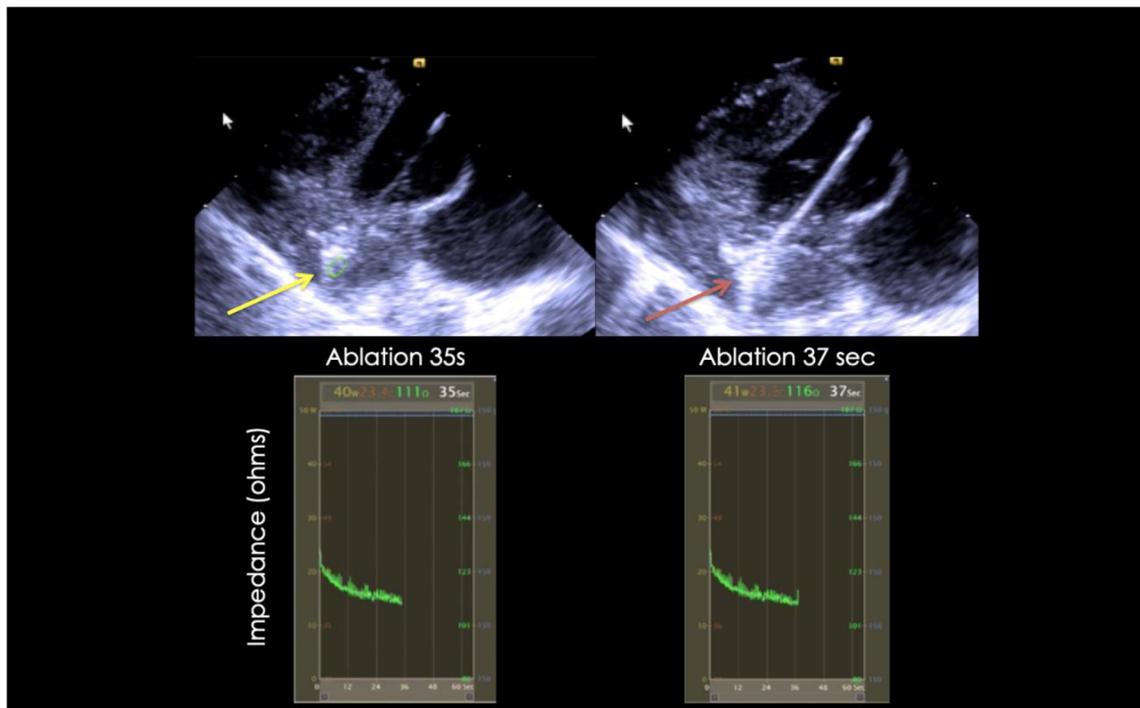
Fig. 3 Example of imminent steam pop visualized on intracardiac echocardiography (ICE) during radiofrequency (RF) ablation, during a 40-W RF application from 35 to 37 s. Effective RF ablation typically produces a decrease in impedance $> 10\ \Omega$ and focally increased echogenicity on ICE (yellow arrow), but note the rapid rate of rise in hyperechogenicity over 2 s, along with bubble/steam formation (red arrow). These features are observed milliseconds before an abrupt impedance rises, which typically correlates with steam pop, especially in the absence of catheter movement and when immediately preceded by decline in impedance
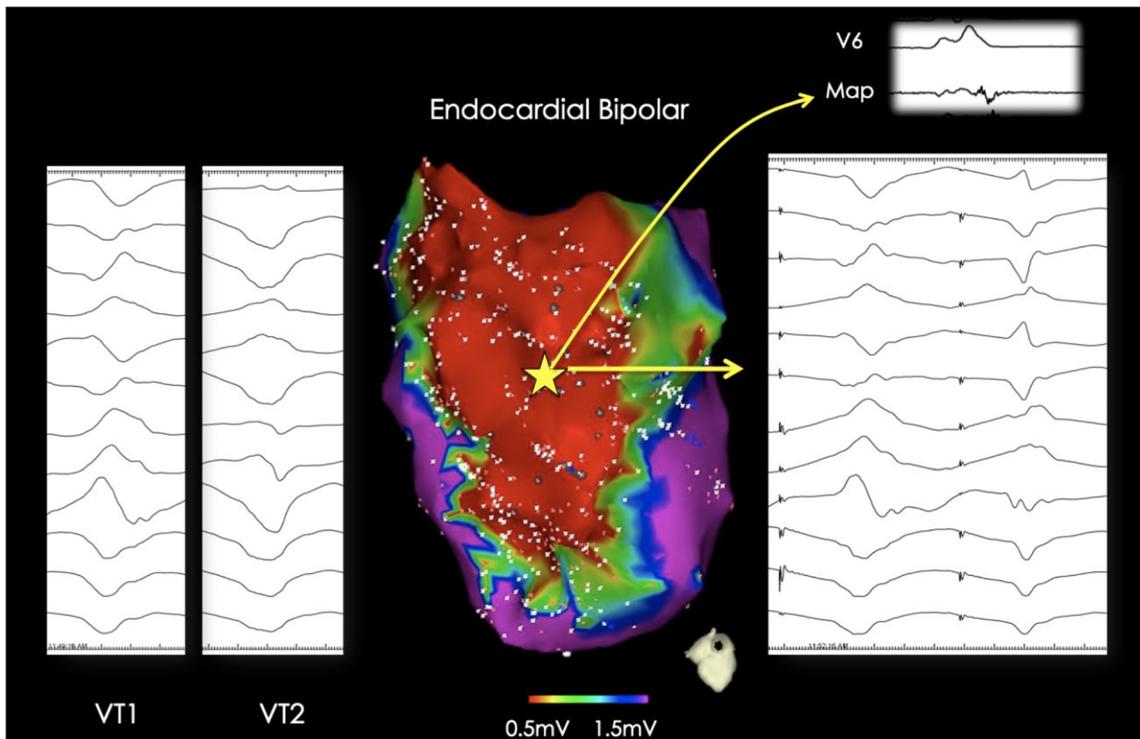

Fig. 4 Example of patient with prior inferior myocardial infarction and two predominant ventricular tachycardia (VT) morphologies. The electroanatomic bipolar voltage map of the endocardial left ventricle demonstrates an area of extensive abnormality, with low voltage as well as late potentials and fractionated, long-duration local electrograms (example, yellow curved arrow). Pacing at that site (yellow star) produces pacemaps of alternating morphologies, similar to the morphologies of the relevant VTs

of substrate, they all have substantial overlap in final ablation regions, as well as in safety and efficacy outcomes [54]. Also importantly, although these contemporary strategies involve more extensive ablation than what has traditionally been performed, and they often incorporate epicardial as well as endocardial mapping and ablation, long-term efficacy is improved with acceptable safety profile in comparison to more limited ablation approaches [55].

One of the drawbacks of the substrate-based ablation approach is that procedure and ablation times may be prolonged with extensive ablation. Additionally, when epicardial ablation or more complex techniques are considered, referral to a tertiary care or high-volume ablation center should be considered to optimize outcomes [8]. In addition, substrate-based ablation approach may be less efficacious in patients with non-ischemic cardiomyopathy as areas of substrate may be more patchy, diffuse, and, in cases of purely intramural substrate, can be difficult to identify [56]. Another limitation may be mapping of substrate to areas near critical cardiac structures which may limit its efficacy [54].

Hemodynamic Support During Ventricular Ablation

Patients with significant heart failure may not tolerate long procedure times due to hemodynamic instability, even in absence of active ventricular arrhythmia [57]. Periprocedural hemodynamic decompensation has been shown to be associated with higher long-term mortality; thus, proactively identifying methods to prevent it are essential in procedural planning [16]. There are instances in which some mapping during VT may be beneficial in refining or modifying the ablation approach, including to determine whether an alternative cardiac chamber or the epicardium should be additionally mapped. For those patients in whom baseline hemodynamic stability is tenuous, or in whom more prolonged periods of mapping during VT may be anticipated, various hemodynamic support options have been investigated and utilized to prevent decompensation. The goal of hemodynamic support is to maintain cardiac output during periods of VT, thereby sustaining end-organ perfusion and preventing multi-organ dysfunction [15, 58, 59].

Multiple percutaneous hemodynamic support options are available to help cardiac output during poorly tolerated ventricular arrhythmias. Most commonly used percutaneous support options include the intra-aortic balloon pump, TandemHeart (Cardiac Assist Inc., Pittsburgh, PA), and Impella (Abiomed Inc., Danvers, MA). Each of these options presents unique advantages and disadvantages (Table 2) [58]. Relative contraindications for each of the percutaneously placed devices include significant peripheral vascular disease, significant aortic insufficiency, ventricular septal defect, LV thrombus, and, for TandemHeart and Impella, RV failure [15, 58]. Extracorporeal membrane oxygenation (ECMO) is a surgical support option which provides the greatest degree of support, for both the left and right ventricles; however, in the USA, implementation of this therapy is limited by the need for cardiothoracic surgeon to place the device and a perfusionist to maintain the circuit while it is in place [60]. Importantly, although they provide hemodynamic support and allow for more comprehensive mapping during VT, their use has not been associated with improved VT-free survival. Therefore, their use is generally limited to those with high-risk features for decompensation (see below).

High-Risk Features and Procedural Planning

Despite all the advances discussed above, ventricular arrhythmia ablation still poses significant risks and challenges. Appropriate patient selection is still critical when determining

Table 2 Hemodynamic support options for ventricular ablation

Support modality	Mechanism	Anticipated support	Advantages	Disadvantages
Intra-aortic balloon pump	Counterpulsation	0.5 L/min	- Wide availability - Ease of use - Familiarity - Small vascular access size	- Minimal support - Timed by ECG which may be difficult in VT
TandemHeart	External centrifugal pump with LA to femoral artery bypass	3.5–5 L/min	- High degree of LV support	- Requires large bore venous and arterial access - Requires transseptal puncture
Impella	Axial flow pump that delivers blood from LV to aorta	2.5–5.0 L/min	- Directly offloads work of LV - Increasing familiarity and availability	- May interfere with magnetic field-based mapping systems - LV position may interfere with catheter manipulation
ECMO	External centrifugal pump and oxygenator	> 4.5 L/min	- Highest level of support - Can provide RV and LV support	- Limited availability in many centers - Requires large bore venous and arterial access - Requires trained surgeon - Requires perfusionist

if a patient is a candidate for ventricular ablation. In addition, evaluating a patient's procedural risk is important in determining ablation approach and need for hemodynamic support. Over time, varying combinations of patient characteristics have been used to estimate a patient's procedural risk. One algorithm developed at the University of Pennsylvania has been useful in mitigating the risk of acute periprocedural hemodynamic decompensation. The set of patient characteristics were published in the form of a risk score calculator, called PAINESD, that tallies pulmonary disease, age, anesthesia, ischemic cardiomyopathy, NYHA class III or IV, ejection fraction < 25%, storm, and diabetes [16].

Using the PAINESD risk score, operators can anticipate a patient's need for hemodynamic support. In a validation study by Muser et al., they showed that prophylactically placing a percutaneous left ventricular assist device in patients with high PAINESD scores leads to improved periprocedural hemodynamic complication rates. Seven percent of patients with a high PAINESD score and a prophylactic left ventricular assist device placement suffered acute hemodynamic decompensation, versus 23% of patients with a high PAINESD score without a prophylactic hemodynamic support [61•].

Non-invasive Ablation?

Regardless of how much care and time is spent planning and preparing for a ventricular ablation procedure, potential risks always will exist. A novel, non-invasive approach to ventricular ablations has now been described. Cuculich et al. performed a feasibility study of catheter-free non-invasive cardiac radioablation for refractory ventricular tachycardia in five high-risk patients. They combined a cardiac MRI, CT, SPECT, or a combination of these imaging modalities with multielectrode body-surface electrocardiography and induced VT using the patients' pre-existing ICD devices. In VT, the authors mapped the critical isthmus of the VT circuit and delivered a total dose of 25 Gy in a single fraction to the point of interest. In these five high-risk patients with refractory ventricular tachycardia, they reported a significant reduction of ventricular arrhythmia events by over 99%. In addition, the mean ablation time was 14 min for the five patients studied. Though results are encouraging, the small cohort and lack of long term followed warrant further investigation [62•].

Conclusion

Advances in mapping and ablation technologies and techniques have improved the safety and efficacy of catheter ablation for ventricular arrhythmias over the last several decades. Since the first ablation procedure conducted in man in 1981, the field of ventricular ablation has seen rapid growth and technological advancements. Improved electroanatomic

mapping software and multielectrode catheters allow electrophysiologists to map ventricular substrate and arrhythmia circuits in great detail. Advanced ablation tools and techniques allow operators to ablate substrate that has previously been out of reach. As understanding of arrhythmia substrate and procedural risks have grown, we can now utilize risk calculators and anticipate the need for hemodynamic support devices. Investigational techniques in non-invasive cardiac ablation are still evolving, and they are unlikely to entirely replace intracardiac mapping and ablation, but they may certainly augment our capacity to better manage patients with ventricular arrhythmias with even greater safety and efficacy.

Compliance with Ethical Standards

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