

Coronary Venous Mapping and Catheter Ablation for Ventricular Arrhythmias

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ABSTRACT: Catheter ablation is an effective treatment method for ventricular arrhythmias (VAs). These arrhythmias can often be mapped and targeted with ablation from the left and right ventricular endocardium. However, in some situations the VA site of origin or substrate may be intramural or epicardial in nature. In these cases, the coronary venous system (CVS) provides an effective vantage point for mapping and ablation. This review highlights situations in which CVS mapping may be helpful and discusses techniques for CVS mapping and ablation.

ANATOMIC DISTRIBUTION OF THE CORONARY VENOUS SYSTEM

The coronary venous system (CVS) is a network of veins that drains blood from myocardial tissues and confluences at the coronary sinus (CS), which empties into the right atrium. The CVS is in part an epicardial structure but also reaches into the myocardium in the form of perforator veins. The CVS therefore offers access to the basal left ventricular (LV) epicardium via the great cardiac vein (GCV) and to the septal aspects of the anterior and posterior epicardium via the anterior interventricular and middle cardiac veins, respectively. Furthermore, the intramural aspect of the septum can be accessed via perforator veins. Preprocedural cardiac imaging with cardiac computed tomography (CT) angiography can also be helpful to visualize the course of the CS branches and identify anatomic anomalies.^{1,2}

TECHNIQUES FOR MAPPING THE CORONARY VENOUS SYSTEM

In patients with atrial arrhythmias, CS access for ethanol ablation of the vein of Marshall is often obtained via the right internal jugular vein.³ Meanwhile, mapping and ablation for ventricular arrhythmias (VAs) via the CVS is usually possible using a femoral venous approach. There are several methods that employ this approach. For example, the CS ostium can be cannulated using a deflectable catheter over which a long sheath is advanced into the body of the CS; it also can be accessed directly with a long wire through a steerable sheath (deflected towards the CS ostium guided by intracardiac echocardiography and fluoroscopy), which can then be advanced over the wire into the CS. The sheath is then advanced as distally as possible in the CS, at which point a multipolar mapping catheter can be advanced into the CVS. It is important to recognize that the body of the CS is protected by muscle only from the CS ostium to the takeoff of the vein of Marshall; as such, care must be taken when manipulating a catheter or sheath beyond this point to avoid perforation or laceration of the CS, which can result in cardiac tamponade requiring pericardiocentesis or emergent surgery.

For this reason, it may be prudent to place the CS catheters at the beginning of the case, prior to administering systemic heparin. Inadvertent dissection of the CS can also occur, which typically does not result in pericardial effusion and cardiac tamponade but can limit further mapping and ablation within the CVS. Once the outer sheath is advanced to a stable position in the CS body, balloon occlusive contrast venography of the CS can be performed to delineate the anatomy of the coronary venous branches and identify target vessels to cannulate.

TOOLS FOR MAPPING THE CORONARY VENOUS SYSTEM

Mapping the CVS can be done using an irrigated-tip ablation catheter because it also permits ablation if a VA target site is identified during mapping. However, the ablation catheter often cannot be advanced all the way to the presumed site of interest because the coronary veins taper more distally. In these cases, smaller multielectrode mapping catheters and specialized wires can be used to access the distal CVS branches for mapping. The Map-iT™ catheter (Access Point Technologies EP) is a 120-cm 4/3.3F nonsteerable catheter with either 10 or 20 electrodes, and the EP Star catheter (Baylis Medical) is a 130-cm 2F nonsteerable catheter with 8 electrodes. Both catheters can be advanced either directly through an outer sheath or guided to a vessel of interest through an inner vein selector catheter. In certain cases that require cannulation of even smaller-caliber branches, the use of a mapping wire may be preferred since it can be advanced through an inner vein selector catheter. The VisionWire (Biotronik) is one such mapping wire. This wire is a 175-cm by 0.014-inch guidewire that is insulated throughout except at the distal 15 mm that is noncoated and flexible. By connecting one alligator clip to the proximal 40-mm noncoated end of the wire and the other clip to a needle in the skin, unipolar signals can be obtained from the distal tip of the VisionWire for mapping and pacing.⁴ These microcatheters and wires can be connected to the mapping system so they can be visualized during mapping and ablation, thereby allowing the ablation

catheter to be placed close to target sites that can only be reached with small mapping catheters or wires.

Transient suppression of premature ventricular contractions (PVCs) after injection of cold saline can be a helpful diagnostic technique to identify the intramural septal site of origin (SOO).⁵ In one prior series, room temperature normal saline was injected through the tip of an irrigated ablation catheter positioned deep within the coronary venous system at the junction of the GCV and anterior interventricular vein and within perforator veins during ongoing ventricular ectopy. Out of 26 total patients who received the saline injection, PVCs were temporarily suppressed in 11, and 9 of these (82%) had intramural PVC focus (versus only 1 of 15 of those who did not experience PVC suppression).⁵

CATHETER ABLATION WITHIN THE CORONARY VENOUS SYSTEM

Importantly, ablation in the CVS can be limited by rapid impedance rise as well as proximity to coronary arteries. For these reasons, lower power settings are often used during CVS ablation, starting as low as 5 W to 10 W and titrating the power up gradually to achieve an impedance drop of 10 ohms. It has been shown that lesions delivered from the distal CVS versus the right ventricular outflow tract (RVOT) or left ventricular outflow tract (LVOT) are less likely to result in detectable late gadolinium enhancement on cardiac magnetic resonance imaging (CMR) performed 3 months post ablation.⁶ Rapid impedance rises can limit power delivery during ablation within the CVS. As such, the use of half normal saline can potentially increase lesion size during ablation in this region, although care must be taken to avoid steam pops, which could have catastrophic effects. Due to the close proximity of the epicardial coronary arteries that tend to run alongside the CVS, care must be taken to avoid coronary arterial injury when performing ablation in the CVS.

A study by Nagashima examined 30 patients who underwent ablation for focal VA with early activation in the GCV. Out of 27 patients who received coronary angiography, 20 (74%) showed the earliest site in the GCV to be within 5 mm from an epicardial coronary artery. Ablation could only be performed safely at the earliest site in 7 of these patients and was performed within 2 to 3 cm of the earliest site in 8 patients. The study authors reported coronary artery occlusion of a marginal branch of the left circumflex artery in 2 patients who underwent ablation within the GCV.⁷ Preprocedural cardiac CT and CMR can help define the course of the coronary arteries in relation to the CVS, and coronary angiography should be considered prior to ablation in the CVS in all patients. Cryoablation (-80 C° for 4-8 minutes) can be considered in patients in whom radiofrequency ablation is limited due to impedance or proximity to coronary arteries.⁷

MAPPING AND ABLATION OF FOCAL INTRAMURAL AND EPICARDIAL VENTRICULAR ARRHYTHMIAS

Historically, common sites of successful ablation for idiopathic VAs have included the RVOT, the LVOT including the aortic sinuses of Valsalva, and the papillary muscles because these are sites typically accessible with endocardial ablation.⁸ However, there is increasing recognition that idiopathic VAs can have an epicardial or intramural SOO—especially when originating from the LV summit, basal anteroseptum, mitral annulus, or inferior crux region—and these VAs can often be successfully mapped and targeted with ablation using branches of the CVS for access.⁹⁻¹² In a consecutive series of 189 patients with idiopathic VAs who were referred for ablation, 27 (14%) had their earliest site mapped to the CVS, and 20 (74%) had successful elimination of their VA.¹⁰ Another series found that 47 of 511 patients (9.2%) with idiopathic VAs had the earliest activation time in the CVS.¹¹

Targeting arrhythmias from the epicardial LV summit has proven to be challenging if using a subxiphoid approach due to the presence of epicardial fat and proximity to coronary arteries.^{7,13,14} However, the majority of these arrhythmias can be successfully targeted from within the CVS and from adjacent anatomic structures.^{10,11,15} Identifying the SOO from within the CVS is key to reaching the anatomic surface closest to the origin if radiofrequency energy cannot be delivered from within the CVS—for example, because of too close proximity to coronary arteries or the phrenic nerve.⁵ A distance of ≤ 1 cm from an adjacent anatomical surface to the SOO is often required to allow for successful ablation from adjacent sites. If located close to the LV summit, it may help to assess whether the arrhythmia might actually originate from an intramural source since ablation close to the coronary arteries from the CVS aspect may not be possible and since the closest anatomical structure is often > 1 cm away from the SOO.

Mapping and ablation of intramural VAs is particularly challenging. Different approaches have been proposed to target intramural VA origins, including targeting the breakout sites, the use of simultaneous unipolar or bipolar catheter ablation or infusion needle ablation, baseline impedance modulation, altering the ionic content of the local milieu by using half normal saline as the catheter irrigant, coronary venous or arterial ethanol ablation, coiling of coronary arteries, or stereotactic body radiation therapy.¹⁶⁻²⁴ The use of these different ablation techniques depends on the experience of the operator and the availability of the required equipment or systems. Since most of these treatment options are fairly new, efficacy and safety data are limited and comparative studies have not been done.

In a recent study of 83 patients, we demonstrated that prioritizing the identification of an intramural arrhythmia SOO can be an effective strategy.²⁵ The SOO was identified by mapping from

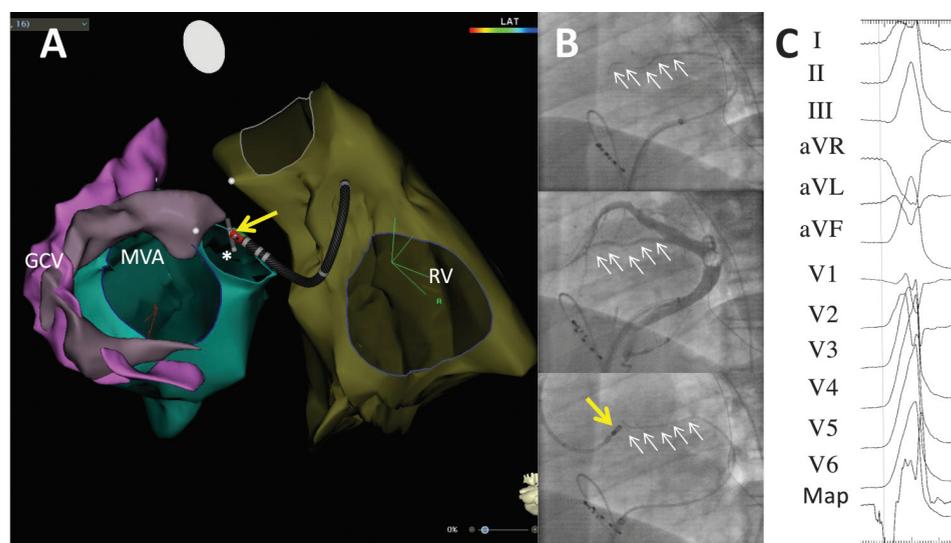


Figure 1.

Intramural premature ventricular complex where the ablation catheter failed to reach the site of origin (SOO) and radiofrequency catheter ablation was carried out at a site located close to the SOO in the left ventricular outflow tract (LVOT). (A) 3-dimensional reconstruction of echocardiographic contours obtained by intracardiac echocardiography with posterior views of the right ventricle (RV), the left ventricle with the mitral valve annulus (MVA), and the great cardiac vein (GCV). The GCV and its continuation into the anterior interventricular veins (AIVs) is pink while the perforator vein is lavender. The ablation catheter is located in the LVOT (yellow arrow). A mapping wire (grey icon) is located in the distal perforator vein (asterisk). (B, top) Left anterior oblique (LAO) view showing selective cannulation of a perforator vein with a unipolar mapping wire (series of white arrows). (B, center) LAO view of an occlusive venogram showing the GCV, the AIV, and a perforator vein (series of white arrows). (B, bottom) LAO view with the mapping wire located in the proximal perforator vein (series of white arrows). The ablation catheter (yellow arrow) is placed in the LVOT in close proximity to the tip of the mapping wire that is indicating the location of the SOO. (C) A recording from the mapping wire that precedes the onset of the PVC-QRS complex by 40 msec. Radiofrequency ablation was successfully performed from the ablation catheter located in the LVOT (yellow arrow). Reprinted with permission from Ghannam et al.²⁵

within the CVS and specifically from perforator veins that drain the intramural myocardium. For this purpose, patients underwent occlusive venography imaging, and an ablation catheter, multipolar mapping catheter, or mapping wire was placed into their CVS branches. In 19 patients with intramural focal VAs, the SOO could be identified and the VA was eliminated. In 3 patients, an ablation catheter was advanced to the SOO and ablation was carried out. The ablation catheter also reached the SOO in 7 other patients, and radiofrequency ablation was delivered there and at a site in a different anatomical chamber but close to the SOO. In 9 patients, the SOO was not

reached with the ablation catheter, but a mapping catheter or mapping wire was placed there (Figure 1), and the SOO was targeted with radiofrequency ablation from an anatomically adjacent site. If the SOO could not be reached, as was the case in 64 of the 83 patients, the earliest breakout sites were targeted although the success rate was significantly lower in this group (67%).

It is interesting to note that the SOO in most of these patients was significantly farther away from the endocardial breakout sites than the closest anatomical sites and was actually located in another anatomic

chamber than the site anatomically closest to the SOO. Furthermore, the activation time at the site anatomically closest to the SOO was significantly later than at the endocardial breakout site due to preferential conduction. This explains why the traditional approach of activation mapping for focal, intramural arrhythmias is less effective than an approach targeting the SOO.

If ablation from the CVS is not possible because of the SOO's proximity to the coronary arteries or the inability to advance the ablation catheter distally in the CVS, ablation from adjacent sites using an anatomical approach can be effective. In patients with outflow tract VAs where the earliest sites are mapped to the CVS, an anatomic approach with ablation from neighboring sites (eg, endocardial LVOT, aortic sinuses of Valsalva, and RVOT) can be beneficial, particularly when the targeted anatomic site is within 12.8 mm from the earliest site within the CVS.²⁶ Preprocedural imaging can help determine if ablation from the CVS will be successful in targeting the presumed VA SOO.¹³ In such patients, the CVS can often provide an effective vantage point with which to target LV summit VAs.

VENTRICULAR TACHYCARDIA IN THE SETTING OF NONISCHEMIC CARDIOMYOPATHY

Myocardial scarring is the arrhythmogenic substrate of VT in patients with nonischemic cardiomyopathy (NICM). In these patients, two major scar patterns frequently exist: anteroseptal (usually basal intramural septum) and inferolateral (often basal epicardial free wall).²⁷ The VT substrate in NICM tends to have a basal perivalvular predilection adjacent to the mitral and aortic valves, near the course of the coronary vessels in the atrioventricular groove. CMR is helpful to visualize the precise location of the scar and the course of the CVS. If the scar is located close to the CVS, it is possible that the arrhythmogenic substrate can be

reached via the CVS. The CVS provides a more effective access route for ablation along the basal epicardial LV than direct percutaneous epicardial access due to the presence of epicardial fat along the atrioventricular and interventricular grooves, which can make ablation of an underlying epicardial substrate difficult. In these patients, mapping the large coronary venous branches (the middle cardiac vein, inferolateral and lateral ventricular branches, great cardiac vein, and anterior interventricular vein) in addition to smaller septal branches can be very helpful to identify a critical VT substrate.⁴ Coronary CT can help assess the thickness of the epicardial fat pad and help estimate whether an ablation might be beneficial if an arrhythmia originates from the basal epicardial myocardium.²⁸

Since a perivalvular VT substrate in patients with NICM can often be accessed from the CVS that runs along the AV groove and down the top and bottom of the interventricular septum, we routinely use a stepwise approach for mapping and ablating a VT substrate in these patients. We start by mapping the endocardial aspect of the LV, RV, and then CVS and only obtain percutaneous epicardial access if VT remains inducible after mapping and ablation from the endocardium and CVS. Among 41 consecutive patients with NICM and a mean ejection fraction of 38%, a stepwise approach was performed to target inducible VTs from the endocardium, CVS, and eventually the epicardium using a subxiphoid approach if required.²⁹ VT target sites could be identified in the endocardium of all 41 patients, in the CVS in 15 patients, and in the epicardium in 8 patients. Ablation within the CVS eliminated VT in 8 patients who did not require an epicardial approach (Figure 2). CMR indicated that the scar was closer to the CVS in patients with VT target sites within the CVS, and a cut-off of ≤ 9 mm separated patients with VT targets within the CVS from those outside the CVS. Furthermore, in two patients who underwent epicardial ablation with

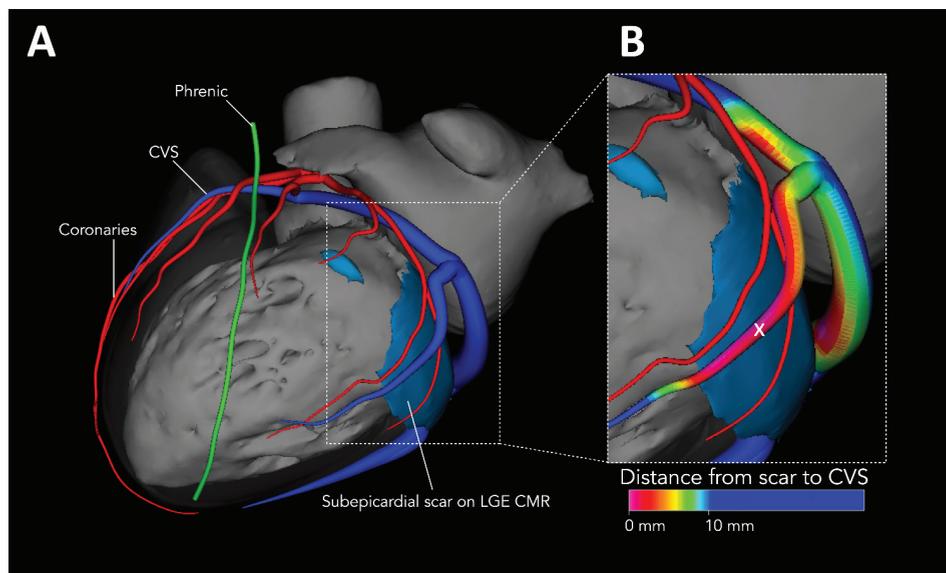


Figure 2.

A) Combined 3-D reconstruction of cardiac anatomy by cardiac magnetic resonance imaging and computed tomography in a patient with epicardial scarring in the basal left ventricle. (B) Distance mapping using the MUSIC software where the distance of the scar (blue) to the coronary venous system (CVS) is color coded, red indicating the closest proximity of the CVS to the scar. The CVS is in direct contact with the scar and is 0 mm from the scar. Radiofrequency ablation from a marginal venous branch (x) eliminated the patient's VT. Reprinted with permission from Ghannam et al.²⁹

subxiphoid access, ablation within the CVS was necessary to render the patients non-inducible since the VT origin was sheltered under an epicardial fat pad that could not be penetrated with ablation from the epicardial space alone. Similarly, a stepwise approach can be helpful for mapping and ablation in patients with VAs involving intramural scar detected on cardiac imaging.³⁰

CONCLUSION

The CVS can provide an access route to effectively map and target VAs, particularly in patients with NICM and idiopathic VAs in whom epicardial or intramural substrates or sites of origin may exist. Preprocedural imaging with CT and CMR can help delineate the CVS and define its proximity to the suspected VA substrate or SOO. Operators must have a clear understanding of the anatomy of nearby structures to avoid potential complications when ablating VAs from within the CVS.

KEY POINTS

- The coronary venous system provides an effective route of access for mapping and catheter ablation of intramural and epicardial ventricular arrhythmias.
- Idiopathic ventricular arrhythmias and ventricular tachycardia in patients with nonischemic cardiomyopathy with an intramural or epicardial substrate can often be effectively targeted with radiofrequency catheter ablation from the coronary venous system.
- Preprocedural cardiac imaging can help delineate the anatomy of the coronary venous branches in relation to the suspected ventricular arrhythmia substrate.

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