Cardiac venous system mapping for ventricular arrhythmia localization

Matthew Hanson, MD,[1] Carli Peters, MD,[2] Andres Enriquez, MD,[2] Fermin Garcia, MD[2]

From the [1]Division of Cardiology, Queen's University, Kingston, Ontario, Canada, and [2]Section of Cardiac Electrophysiology, Hospital of the University of Pennsylvania, Philadelphia, Pennsylvania.

The coronary venous system offers a route for mapping and ablation of ventricular arrhythmias with suspected epicardial or intramural origins. Coronary venous mapping helps the operator to select the best ablation approach, decide when percutaneous epicardial access may be necessary and provides an opportunity for therapeutic interventions, including radiofrequency application inside the coronary veins or ethanol infusion. In this article we review the anatomy of the coronary venous system, the scenarios in which coronary venous mapping can be helpful and the technical aspects involved in coronary venous mapping.

KEYWORDS Catheter ablation; Coronary venous system; Mapping; Premature ventricular complex; Ventricular tachycardia

(Heart Rhythm O^2 2025;6:70–77)

Introduction

Catheter ablation is a highly effective therapy for idiopathic and scar-related ventricular arrhythmias (VAs), but outcomes are less favorable when the arrhythmia substrate is epicardial or intramural. Detailed and thorough mapping is key to select the best ablation target in these cases and the coronary venous system provides an invaluable opportunity to map areas of the heart that are otherwise inaccessible with standard techniques.

Coronary venous mapping may help to determine if percutaneous epicardial access is necessary in a patient and may also allow mapping of epicardial VAs that can potentially be ablated from endocardial structures or from the coronary veins themselves. When mapping septal VAs, the coronary venous system provides direct access to the intramural aspect of the interventricular septum, which cannot be accessed via conventional endocardial or epicardial mapping. Often, elimination of intramural VAs requires ablation from multiple sites or the use special ablation techniques including bipolar ablation, simultaneous unipolar ablation, or transvascular ethanol ablation.[1–8] Venous mapping in these cases helps to select the best ablation strategy.

In this article, we review the anatomy of the coronary venous system and the indications and techniques of coronary venous mapping.

Address reprint requests and correspondence: Dr Fermin Garcia, Hospital of the University of Pennsylvania, 1 Convention Avenue, Philadelphia, PA 19104. E-mail address: Fermin.Garcia@pennmedicine.upenn.edu; Twitter: @DrFerminGarcia.

KEY FINDINGS

- Mapping of the coronary venous system is a valuable adjuvant strategy for ventricular arrhythmias with presumed intramural or epicardial origin.
- The coronary veins are useful sites for advanced ablation techniques including ablation from within the veins, bipolar ablation, and ethanol ablation in select patients.
- Coronary venous system mapping is a safe and accessible technique that can be accomplished using dedicated mapping catheters or angiography wires.

Coronary venous anatomy

The coronary venous system comprises 2 main groups of veins: the tributaries of the greater coronary veins ultimately terminating in the coronary sinus (CS) as it drains into the right atrium (RA), accounting for 60% of cardiac venous return,[9] and the Thebesian veins, which are thin-walled veins that open directly into the cardiac chambers. There is substantial anatomic variation with the following serving as a general outline of common anatomy of the coronary venous system as it pertains to mapping and ablation (Figure 1).

Coronary sinus

The CS lies in the sulcus between the left atrium (LA) and left ventricle (LV) and extends between the RA orifice or CS ostium and the valve of Vieussens, where it is continued by the great cardiac vein (GCV). The CS varies in length from 3 to 5.5 cm and is the only portion of the epicardial venous

 https://doi.org/10.1016/j.hroo.2024.10.008

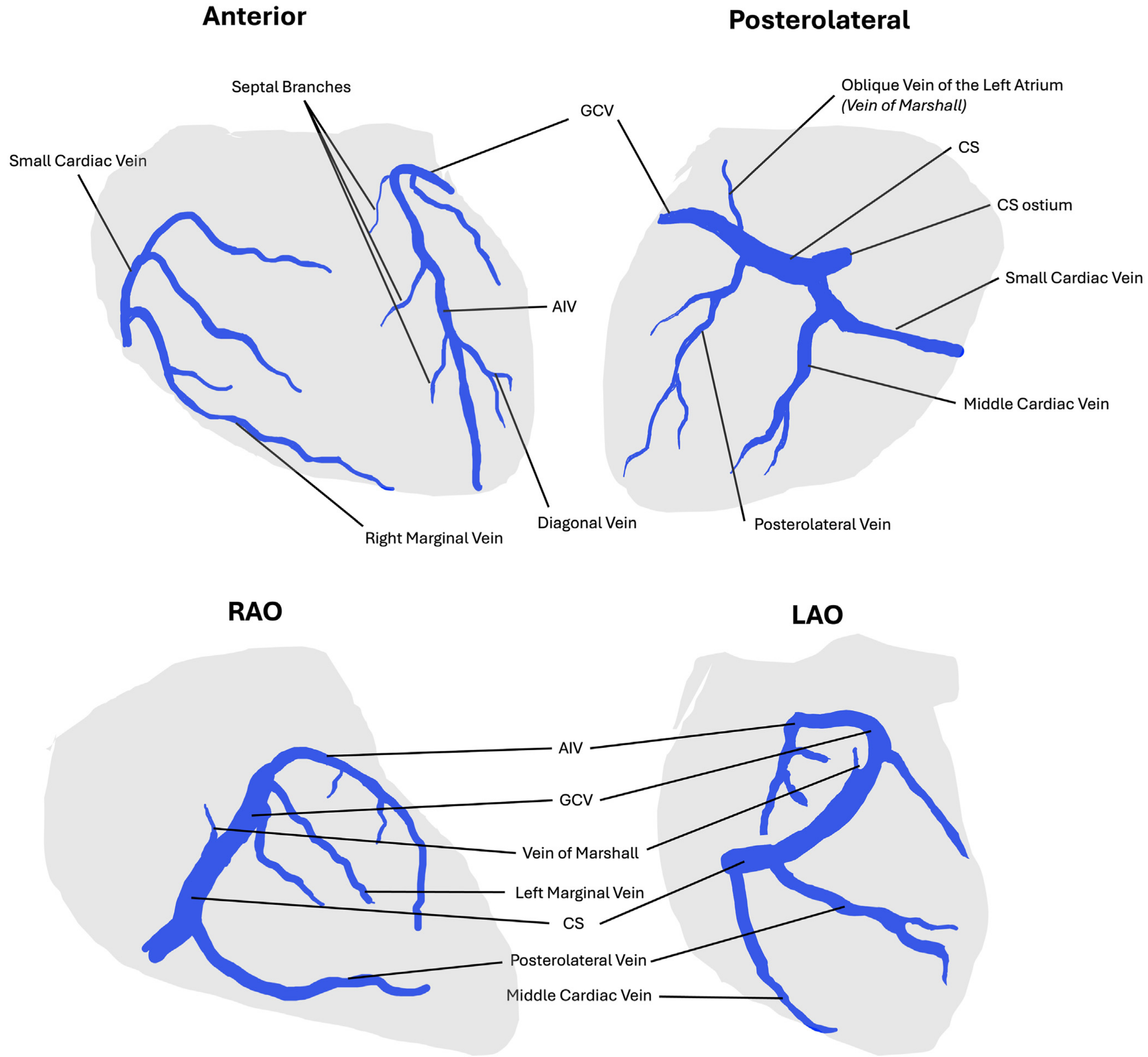

Figure 1 Cardiac venous system anatomy. The top images show the anatomy as seen from typical anatomic views of the anterior and posterolateral cardiac surfaces. In the bottom images, the anatomy is viewed from standard fluoroscopic angles, delineating the expected course for the major epicardial veins. AIV = anterior interventricular vein; CS = coronary sinus; GCV = great cardiac vein; LAO = left anterior oblique; RAO = right anterior oblique.

system contained within a muscular sheath.[9,10] The CS ostium is located on the posterior interatrial septum, anterior to the Eustachian ridge and posterior to the tricuspid annulus. The CS ostium is partially obscured by the Thebesian valve, an embryologic remnant of the right sinoatrial valve, a crescent-shaped structure that usually covers the superior and posterior aspect of the ostium.[9] The CS receives drainage from most epicardial coronary veins, including the GCV, the left marginal vein, the oblique vein of the LA (vein of Marshall), the posterior vein of the LV, and the posterior interventricular vein.

GCV and anterior interventricular vein

The GCV is the continuation of the CS and runs between the LA and LV in the atrioventricular groove before taking a sharp inferior turn toward the anterior interventricular groove, where it is continued by the anterior interventricular vein (AIV). Because of their location, the distal GCV and AIV provide direct access to the basal LV epicardium, and earliest activation at this region is the hallmark of LV summit VAs. The AIV has a highly variable relationship with respect to the left anterior descending artery, as it can be located right, left, superficial, or deep relative to the artery.[10]

LV annular vein and septal veins

The LV annular vein (present in 36% of cases)[11] is a branch of the GCV that originates before the GCV-AIV junction. It travels septally between the aortic and pulmonary annulus and ends in the aortomitral continuity, communicating in some cases with the LV septal veins via collaterals.[12] Because of its location in the mitral annulus, a mapping catheter in this vein typically records atrial and ventricular electrograms.

The LV septal veins, also called perforator veins, are branches of the AIV that arise at or below the GCV-AIV junction and run deep in the interventricular septum. The number of septal veins fluctuates between 1 and 4 (1.7 ± 0.8 on average).[11] Mapping of these veins will typically show ventricular electrograms, but the first septal vein may also show far-field atrial electrograms.

Middle cardiac vein

The middle cardiac vein (MCV), or inferior interventricular vein, originates from the CS at the level of the cardiac crux, approximately 1 cm from the CS ostium, and runs in the inferior interventricular sulcus, receiving drainage from the inferior septal veins. In rare cases, it drains directly into the RA. In addition, it can become aneurysmal or have a diverticulum at its junction with the CS. The MCV drains the inferior walls of the ventricles, as well as the apical area and the posterior two-thirds of the septum.

Lateral cardiac veins

The territory between the MCV and AIV is drained by several veins. The largest and most constant is the posterolateral vein, which drains the lateral and diaphragmatic walls of the LV.[13] Most patients also have a left marginal vein that drains the lateral portion of the LV and courses superficial to the marginal branch of the circumflex artery, emptying into the GCV (80%) or CS (20%).[14] An anterolateral vein may also be present.

Small cardiac vein

The small cardiac vein runs in the coronary sulcus between the RA and RV, parallel to the RCA, and usually drains into the CS, but may also drain directly into the RA or the MCV. It is responsible for draining the posterior RA and RV via the right marginal vein and anterior veins of the RV.

Atrial veins

The largest atrial vein and the most relevant from a clinical perspective is the vein of Marshall, which is an embryological remnant of the left superior vena cava. Its runs within the Marshall's ligament coursing obliquely between the LA appendage and the left pulmonary veins draining into the CS just proximal to the valve of Vieussens. The vein of Marshall has an average diameter of 1.0 mm and a mean length of 20 to 30 mm.[14] Complete fibrosis or obliteration in the form of a cord is seen in 5% to 12% of cases.

Table 1 Tools required for coronary venous mapping.

Deflectable sheath (Agilis [Abbott], Preface [Biosense Webster], or SupraCross [Baylis])
180-cm 0.032-inch guidewire
4-F or 5-F Glidecath or LIMA catheter
Multielectrode catheter (EPstar [Baylis] or Map-iT [Access Point Technologies])
Coronary angioplasty wire (BMW 0.01400 [Abbott] or VisionWire [Biotronik])
Contrast dye and angiography syringe
Alligator clips

LIMA = left internal mammary artery.

Patient selection

When planning an ablation of ventricular tachycardia (VT) or a premature ventricular complex (PVC), several elements may suggest an epicardial or intramural origin, in which case mapping of the coronary venous system can be revealing. Some of these include the following:

- Electrocardiographic (ECG) features of epicardial origin/exit: these include a pseudo-delta wave ≥34 ms, a maximum deflection index >0.55, overall QRS duration with shortest RS complex ≥121 ms, and intrinsicoid deflection time >85 ms.[7]
- Nonischemic etiology.
- Previous failed endocardial ablation.
- Pre- or intraprocedural imaging (computed tomography, magnetic resonance, intracardiac echocardiography) demonstrating the presence of epicardial or intramyocardial scar.[15]

In our opinion, the main indications for coronary venous mapping can be summarized as the following:

- Idiopathic VT or PVCs from the left ventricular outflow tract (LVOT), especially if the ECG suggests an LV summit origin: right bundle branch block (RBBB) pattern or left bundle branch block (LBBB) pattern with early transition (V2 or V3), taller R-wave in III than II, more negative Q-wave in aVL than aVR, and a pseudo-delta wave (with maximum deflection index >0.55).
- Idiopathic VT or PVCs from the inferoseptal LV, especially if the ECG suggests a cardiac crux origin: LBBB pattern with left superior axis, early transition (lead V2), and QS pattern in inferior leads, usually with maximum deflection index >0.55.
- Nonischemic or ischemic cardiomyopathy with VT of likely septal origin (LBBB pattern with left inferior or left superior axis), especially if preprocedural imaging indicates the presence of septal substrate.
- Ischemic cardiomyopathy when an epicardial VT is suspected based on ECG or imaging (eg, intracardiac echocardiography), but epicardial access is contraindi-

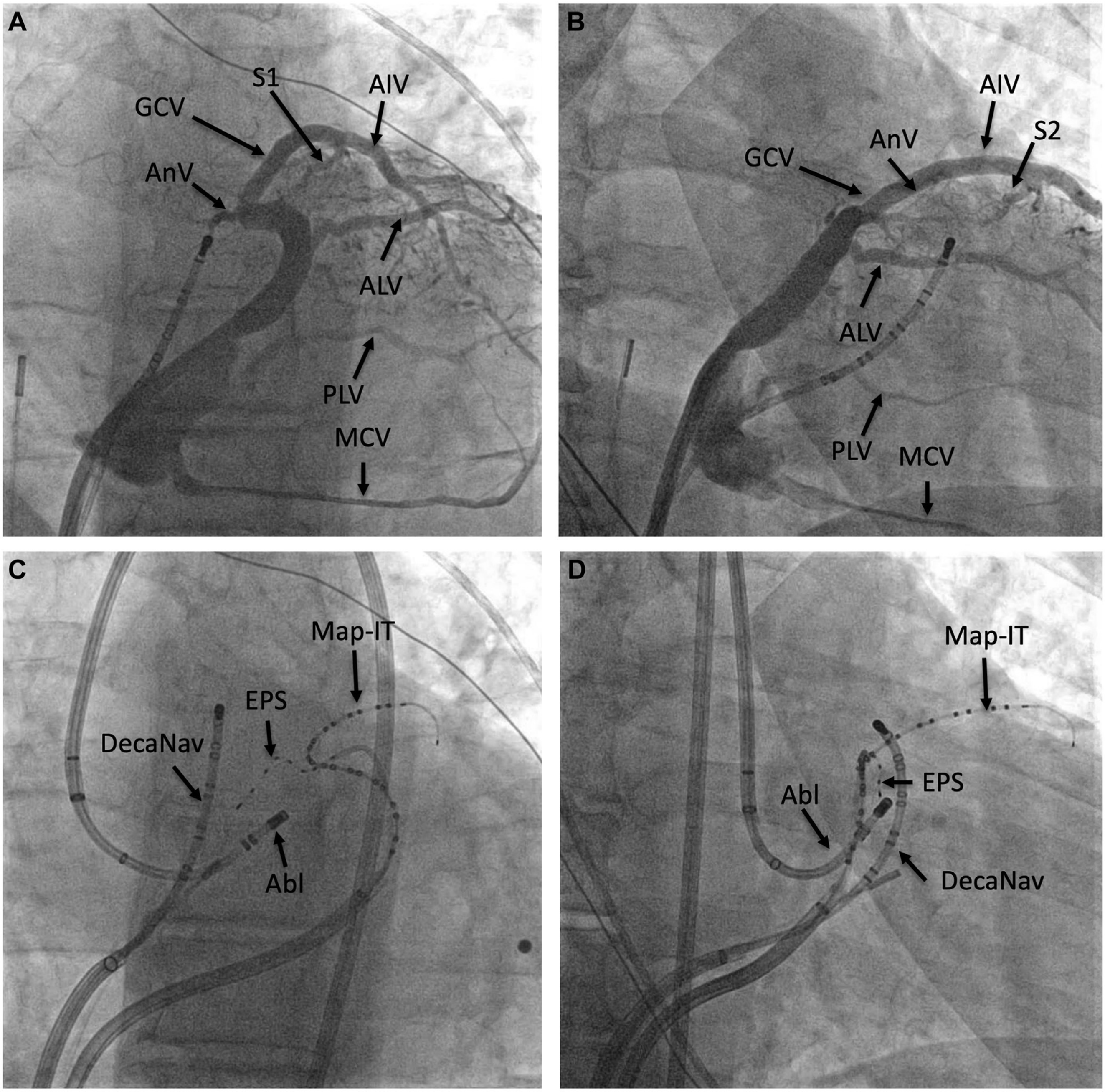

Figure 2 Triangulation approach to mapping of left ventricular (LV) ostial ventricular arrythmias. A, B: Coronary sinus (CS) venography in left anterior oblique and right anterior oblique projections. C, D: A 4-F duo-decapolar catheter (Map-iT) is placed at the great cardiac vein (GCV)/anterior interventricular vein (AIV) to record epicardial activation, a 2-F decapolar catheter (EPstar [EPS]) is positioned into an annular LV vein to assess the intramural space, and an ablation catheter is advanced into the LV via retrograde aortic approach to map the LV endocardium. In this case, an additional decapolar catheter (DecaNav) is located in the right ventricular outflow tract to map the right side of the septum. Abl = ablation catheter; ALV = anterolateral vein; AnV = annular vein; MCV = middle cardiac vein; PLV = posterolateral vein; S1 = first septal vein.

cated by previous cardiac surgery or presence of pericardial adhesions.

Coronary venous mapping technique

The first step of coronary venous mapping is the cannulation of the CS using a long deflectable sheath (Agilis [Abbott], Preface [Biosense Webster], or SupraCross [Baylis]) over a J-tip guidewire, a deflectable decapolar catheter, or an ablation catheter (Table 1). Once stable CS access is achieved, the next step is a good-quality venogram, which is crucial to define the anatomy of the coronary venous system and select the branches that are suitable for mapping. The venogram can be occlusive using a ballon wedge pressure catheter or nonocclusive, and the latter is preferred by us to minimize the risk of CS dissection. The level of the venogram depends

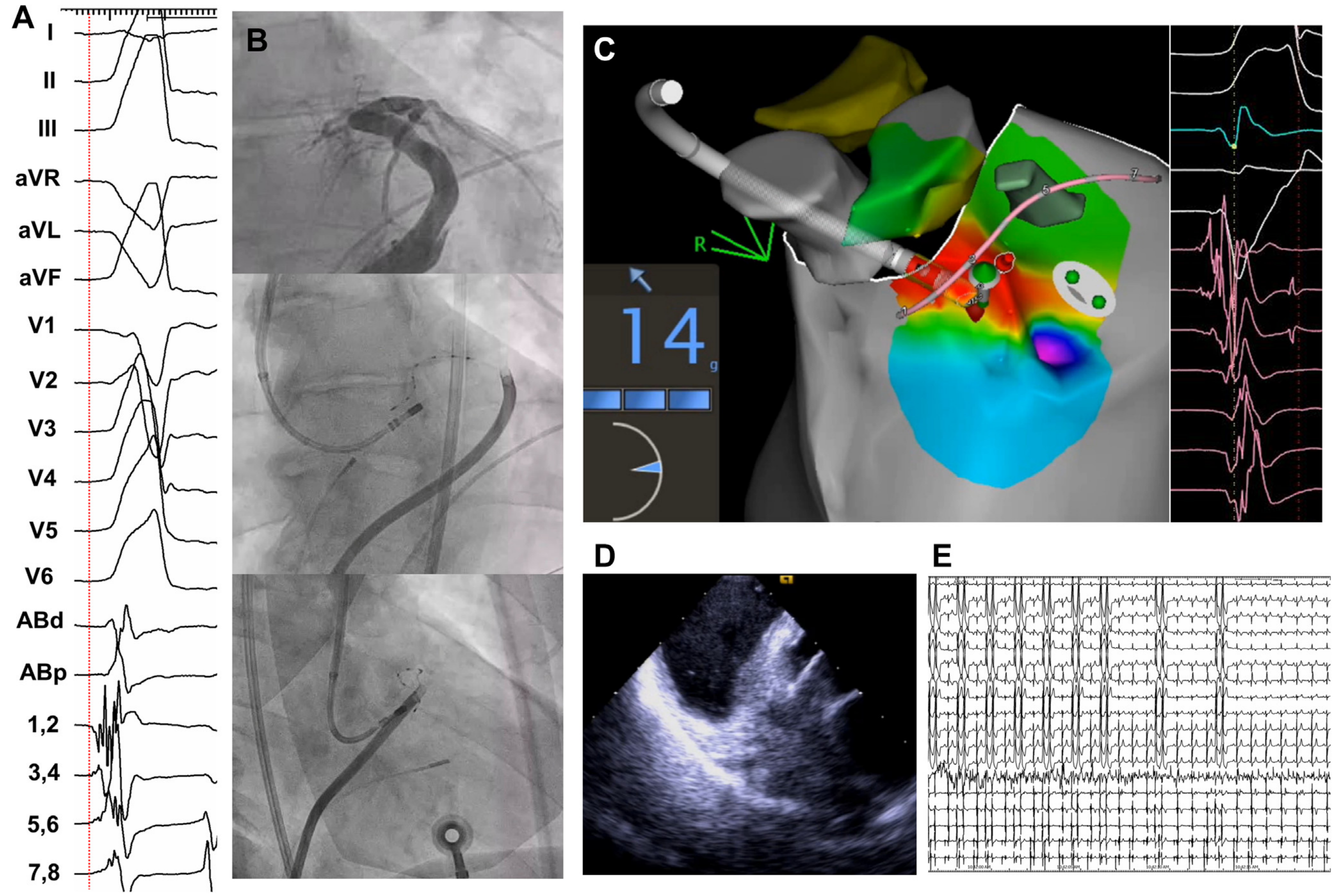

Figure 3 MCV mapping. A 12-lead ECG of the clinical VT shows a LBBB pattern with left superior axis, reverse V2 pattern break and QS in inferior leads, consistent with an epicardial exit (**A**). A multipolar catheter (MAPit) advanced into the MCV showed diastolic signals in the distal portion of the vein and percutaneous epicardial access was obtained (**B**). Voltage mapping showed a small area of epicardial scar adjacent to the MCV catheter (**C**), where sharp diastolic electrograms were recorded during VT (*red arrows*) (**D**). After a coronary angiogram showed a safe distance from the RCA, ablation resulted in immediate VT termination.

on the location of the target. For mapping of the LV summit or septum, the sheath should be advanced as close as possible to the GCV/AIV junction, while a proximal or mid injection is used when mapping a posterolateral or lateral branch is considered. For mapping of the inferoseptal/crux region, the sheath is placed close to the ostium of the CS while stabilized by a J-tip guidewire, and contrast is injected to localize the origin of the MCV, which is then cannulated with the deflectable sheath.

Once identified by the venogram, a small multielectrode catheter (EPstar [Baylis] or Map-iT [Access Point Technologies]) or an angioplasty wire (BMW 0.01400 [Abbott or VisionWire [Biotronik]) is advanced into the vein of interest. Sometimes, this requires selective cannulation of the vein using an angiography catheter (4- or 5-F Glidecath or left internal mammary artery catheter). The multielectrode catheter can be used for activation mapping, pace mapping, or entrainment depending on the arrhythmia mechanism. When the EnSite mapping system (Abbott) is used, the multipolar catheter can be integrated into the electroanatomic map and used to acquire geometry of the veins. Mapping of particularly small coronary veins can also be performed by advancing an angioplasty wire connected to an alligator clip in a unipolar configuration with a needle inserted in the skin as reference electrode. The guidewire can be preloaded into a 2.6-F microcatheter (FineCross MG; Terumo), which should cover the guidewire, leaving only the distal tip exposed. This avoids a large antenna effect and limits electrogram recording to the tip of the guidewire.

For mapping focal PVC/VTs of suspected LV summit origin, we typically follow a triangulation method that involves positioning a 4-F multielectrode catheter (Map-iT) in the AIV for epicardial mapping, a second 2-F multielectrode catheter (EPstar) in the LV annular or first septal perforator vein, and an ablation catheter or multipolar mapping catheter in the endocardial aspect of the LVOT via retrograde aortic or transseptal approach (Figures 2 and 3). This allows to discriminate if the VT/PVC is epicardial (true LV summit), endocardial, or intramural and allows to choose the best ablation site.

Mapping of the crux region is performed by cannulating the MCV with the Agilis sheath and advancing a multielectrode catheter (Map-iT) with or without the aid of a 5-F angioplasty catheter, with simultaneous mapping of the LV

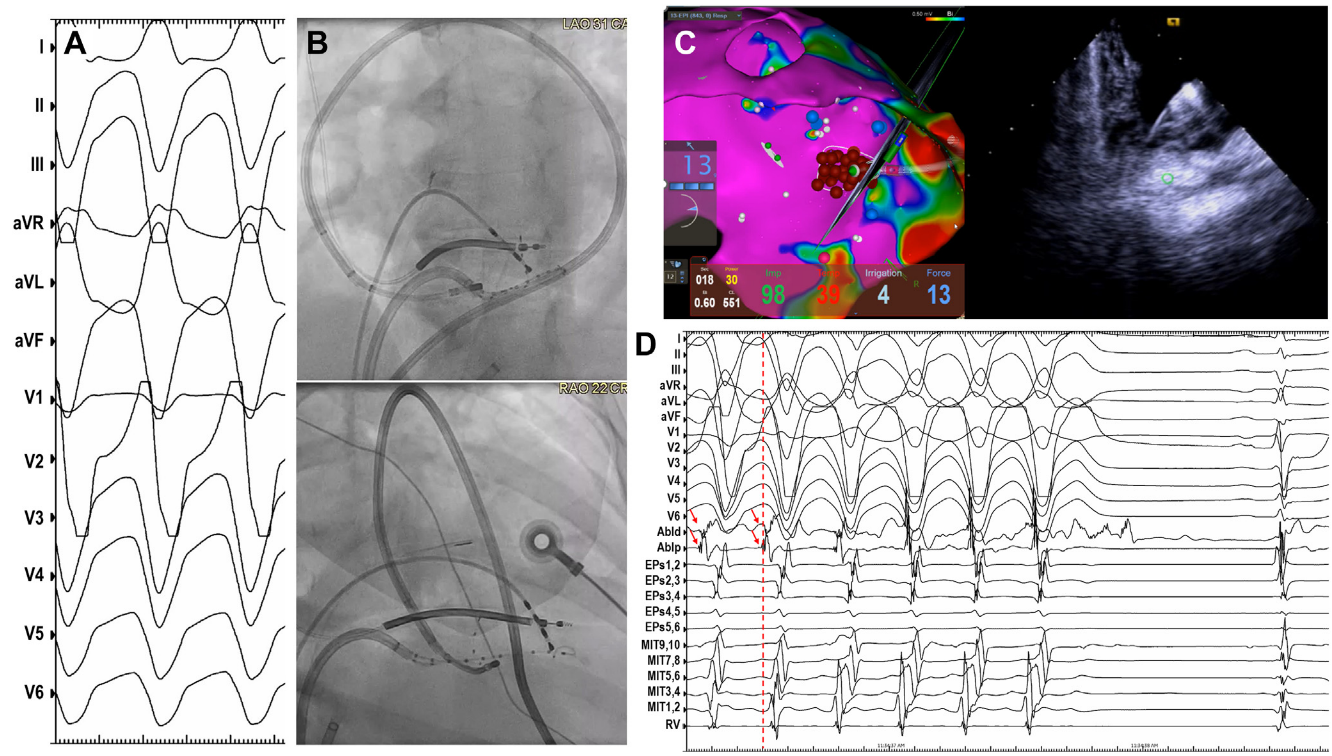

Figure 4 Intramural PVC. The 12-lead ECG shows a LBBB morphology with right superior axis and V3 transition (**A**). After comprehensive mapping of the coronary venous system, earliest ventricular activation is recorded from a multipolar catheter (EPStar) positioned inside an annular vein (earlier than LV endocardium and GCV/AIV), confirming an intramural origin (**B**). An ablation catheter is advanced into the LV via retrograde aortic approach and placed immediately adjacent to the earliest pole of the multipolar catheter (**C**, **D**). Ablation at this site guided by anatomy terminates the PVC despite relatively later activation time (**E**).

endocardium using an ablation or a multipolar catheter (Figure 4). This allows differentiation of VAs from the inferoseptal LV endocardium from true cardiac crux VAs, characterized by earliest activation in the epicardial vein.

Finally, mapping of posterolateral, lateral, or anterolateral branches of the CS can be performed if the substrate distribution or the ECG morphology suggests an origin from these regions.

Ablation considerations

Most intramural VAs and some epicardial VAs can be successfully eliminated by radiofrequency ablation from the endocardium. We recommend an organized approach to ablation of LV ostial VAs that can also be applicable for other arrhythmia localizations. Briefly, if activation mapping demonstrates earliest ventricular activation in the endocardium, ablation is performed at the earliest endocardial site. If the earliest ventricular activation is recorded in a septal coronary vein representing an intramural source, an initial endocardial ablation approach is used targeting the site that is anatomically closest to the intraseptal catheter. Often, activation at this endocardial site is not particularly early, representing an unlikely target if septal venous mapping is not conducted. Finally, if earliest activation is recorded in the GCV or AIV indicating an epicardial origin (LV summit), ablation is performed in the epicardium via the GCV/AIV following a coronary angiography to confirm a safe distance (>5 mm) from major coronary arteries. In these cases, ablation should be started with low power (20 W) and uptitrated to achieve a >10% impedance drop. When the distance between the earliest site in the GCV/AIV and the closest endocardial vantage point is <1.3 cm, endocardial ablation may be successful to eliminate an LV summit arrhythmia and should be the preferred strategy when epicardial ablation is limited by proximity to a coronary artery.

Intramural VAs can be challenging to ablate, often requiring prolonged lesions (2–5 minutes), ablation from multiple sites, and/or special ablation techniques (Figure 5). The use of half-normal (0.45%) saline or 5% dextrose in water as irrigant solutions can increase current delivery to achieve deeper lesion formation and may also have a role when ablating within the coronary venous system.[16,17] Transvenous ethanol ablation is a valuable option when an intramural target is identified by activation, entrainment, and/or pace mapping, depending on the arrhythmia mechanism.[18] If a suitable intramural vein is identified, an over-the-wire angioplasty balloon is advanced to the target vein, the balloon is inflated and contrast is injected to determine the extent of myocardial staining. Then, several 1-cc injections of 98% ethanol are applied until the desired therapeutic response is achieved. Sometimes, the intramural veins are too large or may have collaterals that could divert ethanol away from

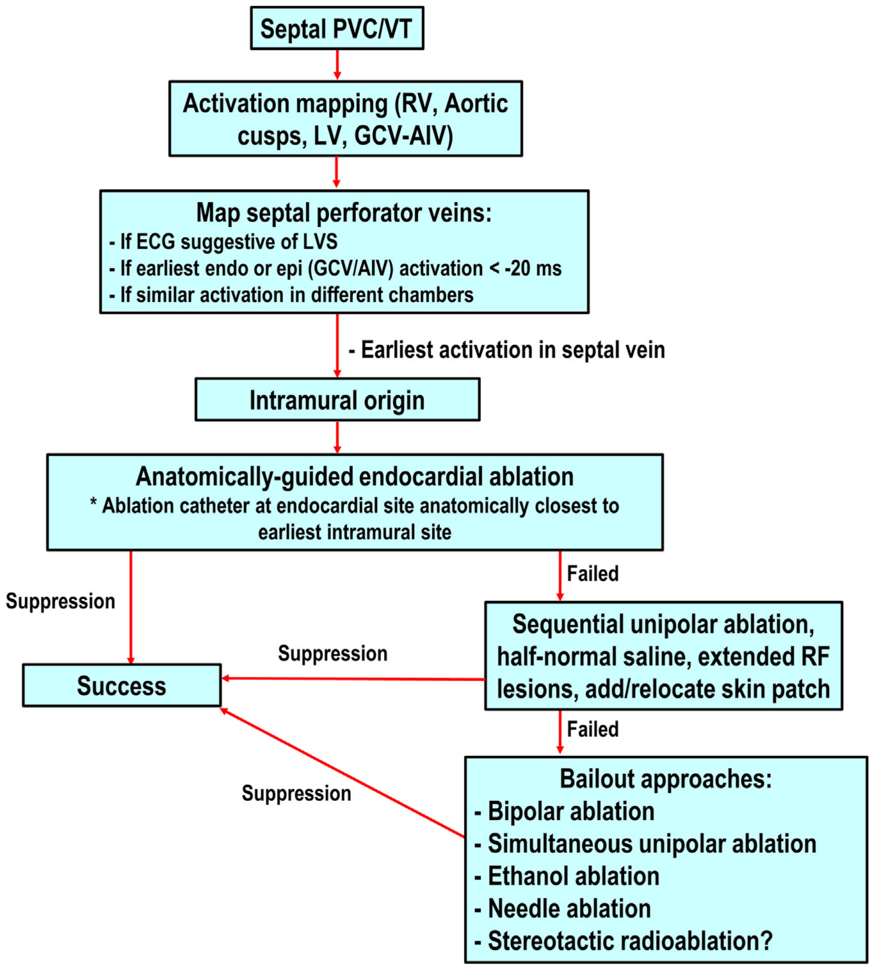

Figure 5 Our approach to mapping and ablation of intramural septal ventricular arrhythmias. AIV = anterior interventricular vein; ECG = electrocardiogram; GCV = great cardiac vein; LV = left ventricular; LVS = left ventricular septum; MCV = middle cardiac vein; PVC = premature ventricular complex; RF = radiofrequency; RV = right ventricle; VT = ventricular tachycardia.

the targeted myocardium. These cases may require the use of double balloon techniques for distal protection in case of large veins or to occlude collateral venous flow.[19]

Bipolar ablation and simultaneous unipolar ablation using 2 ablation catheters are alternative bailout techniques when standard ablation fails.[1,20,21] In these cases, the catheters are placed at adjacent endocardial or epicardial sites in order to maximize energy delivery to the myocardium encompassed by the catheters (eg, right ventricular outflow tract–LVOT, LVOT-GCV/AIV).

Complications of venous system mapping

Complications of coronary venous mapping are rare, with the most common being dissection of the CS or its branches resulting in pericardial effusion and tamponade.[22,23] To prevent this complication, we recommend always advancing sheaths and guiding catheters over a guidewire and to avoid the use of occlusive balloons to minimize the risk of dissection during inflation. Effusions related to coronary vein mapping or ablation are usually self-resolving after drainage and rarely have long-term sequelae, seldom requiring emergent cardiac surgery. When performing ablation within the coronary veins, consideration of the surrounding arterial system is of great importance to minimize the risk of coronary artery vasospasm or thrombosis. A coronary angiography is always recommended to confirm a safe distance from major coronary arteries. Should these complications occur, vasospasm can be managed with intravenous or intracoronary nitroglycerin administration and coronary thrombosis should be treated with percutaneous coronary intervention. During ablation, careful power titration must be used due to rapidly changing impedance, increasing the risk of damage to surrounding structures and perforation.[23,24] Intravascular ethanol infusion in the septal veins can result in right bundle branch block and, rarely, heart block requiring pacemaker implantation.[19]

Conclusion

Mapping of the coronary venous system is a valuable adjuvant strategy when an epicardial or intramural VA is suspected. The coronary venous circulation may exhibit significant variation, and a detailed characterization of the individual patient's anatomy is the first critical step, followed by selective cannulation of the vein(s) of interest. Coronary venous mapping helps the operator to select the best ablation site and strategy and decide when percutaneous epicardial access is indicated, and also provides an opportunity for therapeutic interventions, such us radiofrequency delivery in the venous system or ethanol ablation.

Funding Sources: This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

Disclosures: The authors have no conflicts to disclose.

Authorship: All authors attest they meet the current ICMJE criteria for authorship.

References

1. Enriquez A, Hanson M, Nazer B, et al. Bipolar ablation involving coronary venous system for refractory left ventricular summit arrhythmias. Heart Rhythm O2 2024;5:24–33.
2. Nguyen DT, Tzou WS, Sandhu A, et al. Prospective multicenter experience with cooled radiofrequency ablation using high impedance irrigant to target deep myocardial substrate refractory to standard ablation. JACC Clin Electrophysiol 2018; 4:1176–1185.
3. Di Biase L, Romero J, Zado ES, et al. Variant of ventricular outflow tract ventricular arrhythmias requiring ablation from multiple sites: intramural origin. Heart Rhythm 2019;16:724–732.
4. Nguyen DT, Zheng L, Zipse MM, et al. Bipolar radiofrequency ablation creates different lesion characteristics compared to simultaneous unipolar ablation. J Cardiovasc Electrophysiol 2019;30:2960–2967.
5. Yamada T, Doppalapudi H, Litovsky SH, McElderry HT, Kay GN. Challenging radiofrequency catheter ablation of idiopathic ventricular arrhythmias originating from the left ventricular summit near the left main coronary artery. Circ Arrhythm Electrophysiol 2016;9:e004202.
6. Santangeli P, Marchlinski FE, Zado ES, et al. Percutaneous epicardial ablation of ventricular arrhythmias arising from the left ventricular summit. Circ Arrhythm Electrophysiol 2015;8:337–343.
7. Hanson MG, Enriquez A. Deductive electrocardiographic analysis of left ventricular summit arrhythmias. Card Electrophysiol Clin 2023;15:9–14.
8. Neira V, Santangeli P, Futyma P, et al. Ablation strategies for intramural ventricular arrhythmias. Heart Rhythm 2020;17:1176–1184.
9. Hołda MK, Klimek-Piotrowska W, Koziej M, Mazur M. Anatomical variations of the coronary sinus valve (Thebesian valve): implications for electrocardiological procedures. Europace 2015;17:921–927.
10. Sirajuddin A, Chen MY, White CS, Arai AE. Coronary venous anatomy and anomalies. J Cardiovasc Comput Tomogr 2020;14:80–86.
11. Tavares L, Fuentes S, Lador A, et al. Venous anatomy of the left ventricular summit: therapeutic implications for ethanol infusion. Heart Rhythm 2021; 18:1557–1565.
12. Komatsu Y, Nogami A, Shinoda Y, et al. Idiopathic ventricular arrhythmias originating from the vicinity of the communicating vein of cardiac venous systems at the left ventricular summit. Circ Arrhythm Electrophysiol 2018; 11:e005386.
13. Habib A, Lachman N, Christensen KN, Asirvatham SJ. The anatomy of the coronary sinus venous system for the cardiac electrophysiologist. Europace 2009; 11(Suppl 5):eup270.
14. Kassem MW, Lake S, Roberts W, Salandy S, Loukas M. Cardiac veins, an anatomical review. Transl Res Anat 2021;23:e100096.
15. Desjardins B, Yokokawa M, Good E, et al. Characteristics of intramural scar in patients with nonischemic cardiomyopathy and relation to intramural ventricular arrhythmias. Circ Arrhythm Electrophysiol 2013;6:891–897.
16. Dong Y, Wang H, Ma K, et al. Half versus normal saline irrigation during catheter ablation of outflow tract ventricular arrhythmias (HALF): a multi-center, parallel, open-label, randomized controlled study. J Interv Card Electrophysiol 2023; 66:2143–2151.
17. Sandhu A, Schuller JL, Tzou WS, Tumolo AZ, Sauer WH, Nguyen DT. Use of half-normal saline irrigant with cooled radiofrequency ablation within the great cardiac vein to ablate premature ventricular contractions arising from the left ventricular summit. Pacing Clin Electrophysiol 2019;42:301–305.
18. Tavares L, Lador A, Fuentes S, et al. Intramural venous ethanol infusion for refractory ventricular arrhythmias: outcomes of a multicenter experience. JACC Clin Electrophysiol 2020;6:1420–1431.
19. Patel A, Nsahlai M, Flautt T, et al. Advanced techniques for ethanol ablation of left ventricular summit region arrhythmias. Circ Arrhythm Electrophysiol 2022; 15:519–529.
20. Yang J, Liang J, Shirai Y, et al. Outcomes of simultaneous unipolar radiofrequency catheter ablation for intramural septal ventricular tachycardia in nonischemic cardiomyopathy. Heart Rhythm 2019;16:863–870.
21. Kany S, Alken FA, Schleberger R, et al. Bipolar ablation of therapy-refractory ventricular arrhythmias: application of a dedicated approach. Europace 2022; 24:959–969.
22. Mountantonakis SE, Frankel DS, Tschabrunn CM, et al. Ventricular arrhythmias from the coronary venous system: prevalence, mapping, and ablation. Heart Rhythm 2015;12:1145–1153.
23. Liang JJ, Bogun F. Coronary venous mapping and catheter ablation for ventricular arrhythmias. Methodist Debakey Cardiovasc J 2021;17:13–18.
24. Ghannam M, Siontis KC, Cochet H, et al. Value of mapping and ablation of ventricular tachycardia targets within the coronary venous system in patients with nonischemic cardiomyopathy. Heart Rhythm 2020;17: 520–526.