Electroanatomic mapping in atrioventricular junction ablation and pacemaker implantation for permanent atrial fibrillation associated with persistent left superior vena cava

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Introduction

Atrioventricular (AV) junction ablation and permanent pacemaker implantation, commonly referred to as "ablate and pace," is an effective therapy for patients with atrial fibrillation (AF) with rapid ventricular rate that is refractory to medical management. Persistent left superior vena cava (PLSVC) is a thoracic venous anomaly that has an estimated prevalence of 0.3%.[1] Resulting from continued patency of the left anterior cardinal vein during the early developmental period, the PLSVC typically joins the confluence of the left jugular and subclavian veins to the right atrium via the coronary sinus.[1,2] Compared to those with normal anatomy, invasive electrophysiology procedures in patients with PLSVC may be associated with lower success rates and higher complications rates.[3–5] This is the first report illustrating the use of an electroanatomic mapping (EAM) system to assist in AV junction ablation and permanent pacemaker implantation in a patient with permanent AF associated with PLSVC.

Case report

In April 2021, a 76-year-old man with a 10-year history of AF and a known left ventricular ejection fraction (LVEF) of 30%–35% presented to the emergency department with shortness of breath. An electrocardiogram demonstrated what was believed to be a macroreentrant atrial tachycardia with a ventricular rate of 131 beats per minute (bpm). This transitioned into AF during his hospitalization. He was on metoprolol tartrate 12.5 mg twice daily as an outpatient. He elected to undergo AV junction ablation with placement of a cardiac resynchronization therapy-pacemaker (CRT-P).

Regarding his arrhythmia history, he was first diagnosed with AF in 2011. A PLSVC had been diagnosed on computed tomography of the chest (Supplemental Figure S1) in July 2015 after transesophageal echocardiography, performed prior to cardioversion, noted a vascular abnormality. The computed tomography report stated that contrast was injected into a right upper extremity vein and "The opacified blood crosses the midline to a left superior vena cava."

In early 2016, antiarrhythmic drug trials with dofetilide and sotalol were unsuccessful owing to intolerable side effects. In July 2016, he underwent cryoballoon ablation (Arctic Front Advance; Medtronic, Minneapolis, MN), achieving bidirectional block in all 4 pulmonary veins. He had no recurrences of atrial arrhythmias until August 2020, when he presented to the emergency department with a suspected macroreentrant atrial tachycardia and underwent successful cardioversion.

During a clinic visit in September 2020, he was noted to be in AF at 112 bpm. He declined oral anticoagulation, other medications, and redo catheter ablation. An echocardiogram in January 2021 demonstrated an LVEF of 30%–35%, a left ventricular end-diastolic diameter of 5.1 cm, a left atrial volume index of 22 mL/m^2, and mild-to-moderate tricuspid regurgitation. This was the first time his LVEF was estimated as less than 55%. He again declined oral anticoagulation, other medications, redo catheter ablation, and CRT-P plus AV junction ablation. Following a 3-day hospitalization for rapid AF and heart failure exacerbation in February 2021, he agreed to CRT-P plus AV junction ablation to be arranged as an outpatient. He was not interested in an implantable cardioverter-defibrillator. The procedure was scheduled in late April 2021, but he had worsening symptoms, which led to hospitalization.

In the electrophysiology laboratory, the CARTO 3 System (Biosense Webster, Diamond Bar, CA) was used for EAM given knowledge of his unconventional anatomy. Bilateral upper extremity venograms confirmed absence of a right

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KEY TEACHING POINTS

- For patients with persistent left superior vena cava (PLSVC), electroanatomic mapping (EAM) systems, used in conjunction with coronary sinus cannulation sheaths, may enhance secure placement of active-fixation endocardial pacing leads in the right ventricle.
- Targeting the interventricular septum for pacing site selection may be accomplished with coronary sinus cannulation sheaths and active-fixation endocardial pacing leads.
- Reconstruction of cardiac chambers and tagging of His bundle electrogram recording locations with EAM systems may offer insights for planning atrioventricular junction ablation when anatomy is distorted owing to the presence of a PLSVC, with or without tachycardia-induced cardiomyopathy from atrial fibrillation with rapid ventricular rate.
- Higher costs and longer preparation times associated with EAM systems should be balanced with the potential benefit of increasing procedural success.

superior vena cava and presence of a PLSVC. Access was obtained via the left axillary vein. Through a peel-away sheath, a Tendril STS Model 2088TC-65, 65 cm length, active-fixation endocardial pacing lead (Abbott Laboratories, Abbott Park, IL) was inserted. Owing in part to the large right atrium, the lead was only able to be advanced just beyond the tricuspid valve annulus despite using C-shaped and J-shaped stylets, as previously described.[6] Available sites were not felt to be stable and the lead was removed. The tricuspid annulus diameter was markedly enlarged and measured as 6.5 cm on the EAM system.

An externally irrigated 3.5-mm-tip THERMOCOOL SMARTTOUCH Catheter (Biosense Webster) was inserted and the PLSVC, coronary sinus, and right atrium were reconstructed using the EAM system. The THERMOCOOL catheter was removed and reinserted within a 10.06 French (3.4 mm diameter) CPS Direct Universal slittable outer guide catheter with 115° curve and 50.6 cm length (Abbott Laboratories) to facilitate reconstruction of portions of the right ventricle (Figure 1). The inner lumen of this sheath is 8.00 French (2.67 mm diameter). Exchanging the THERMOCOOL catheter for a less stiff 5 French deflectable decapolar electrophysiology catheter allowed for maneuvering of the sheath to point towards the septum, where the lead could be deployed. The Tendril STS Model 2088TC-65 lead requires a minimum introducer size of 6 French, or 2 mm diameter. The coronary sinus cannulation sheath was slit in a conventional fashion.

Attempts to place a left ventricular pacing lead into a coronary sinus branch were unsuccessful. Interrogation of the coronary sinus with a Worley Vein Selector (Merit Medical, South Jordan, UT) and contrast injection did not reveal any suitable branches. The right ventricular pacing lead was connected to an Allure RF Model PM3222 CRT-P generator (Abbott Laboratories). Right atrial and left ventricular ports were plugged. The left ventricular port was an IS-1 configuration to accommodate an epicardial lead, if necessary, for the future.

AV junction ablation was performed through right femoral venous access. The THERMOCOOL catheter was advanced into the right atrium. Refinement of the anatomical reconstruction was performed, including tagging of points around the tricuspid annulus (Figure 2). His bundle electrograms were recorded in the superior segment of the tricuspid AV junction (Supplemental Figure S2).[7] Atrial electrograms were not visible at these locations.

Ablation lesion #1, which did not impact AV nodal conduction, was delivered where His bundle electrograms were recorded. Because this location, or any locations with His bundle electrograms recorded, did not have any discernible atrial electrograms, the ablation catheter was repositioned. Lesion #2, where low-amplitude atrial and ventricular electrograms were recorded, was delivered 20.8 mm away from the nearest His bundle electrogram point (Supplemental Figure S3). Transient slowing of AV conduction was observed. Ultimately, ablation lesion #5 achieved complete heart block within 10 seconds (Figure 3) and was continued for a total of 120 seconds. At this site, no atrial electrograms and only low-amplitude ventricular electrograms were recorded. The average contact force at the successful site was approximately 9 grams. A 15-minute wait time was allowed to elapse to confirm persistence of complete heart block. The total procedure time was 3 hours and 14 minutes with a fluoroscopy time of 16.9 minutes. The pacemaker was set at VVIR-80 bpm. Final chest radiographs and electrocardiogram are shown in Supplemental Figure S4.

An echocardiogram in July 2021 demonstrated LVEF 55%–60%, a left ventricular end-diastolic diameter of 4.7 cm, a left atrial volume index of 35 mL/m^2, and trace tricuspid regurgitation. Seven months after "ablate and pace," he remained free of rehospitalization.

Discussion

This is the first report of an EAM system assisting in AV junction ablation and pacemaker implantation in a patient with permanent AF associated with PLSVC. LVEF recovery supported tachycardia-induced cardiomyopathy as the etiology of his cardiomyopathy. LVEF recovery may have been facilitated by placement of the right ventricular lead in a septal position, as opposed to an apical position.[8] There were 2 primary benefits of the EAM system. First, in conjunction with the coronary sinus cannulation sheath, it facilitated secure positioning of the active-fixation pacing lead on the right ventricular septum. Second, it provided

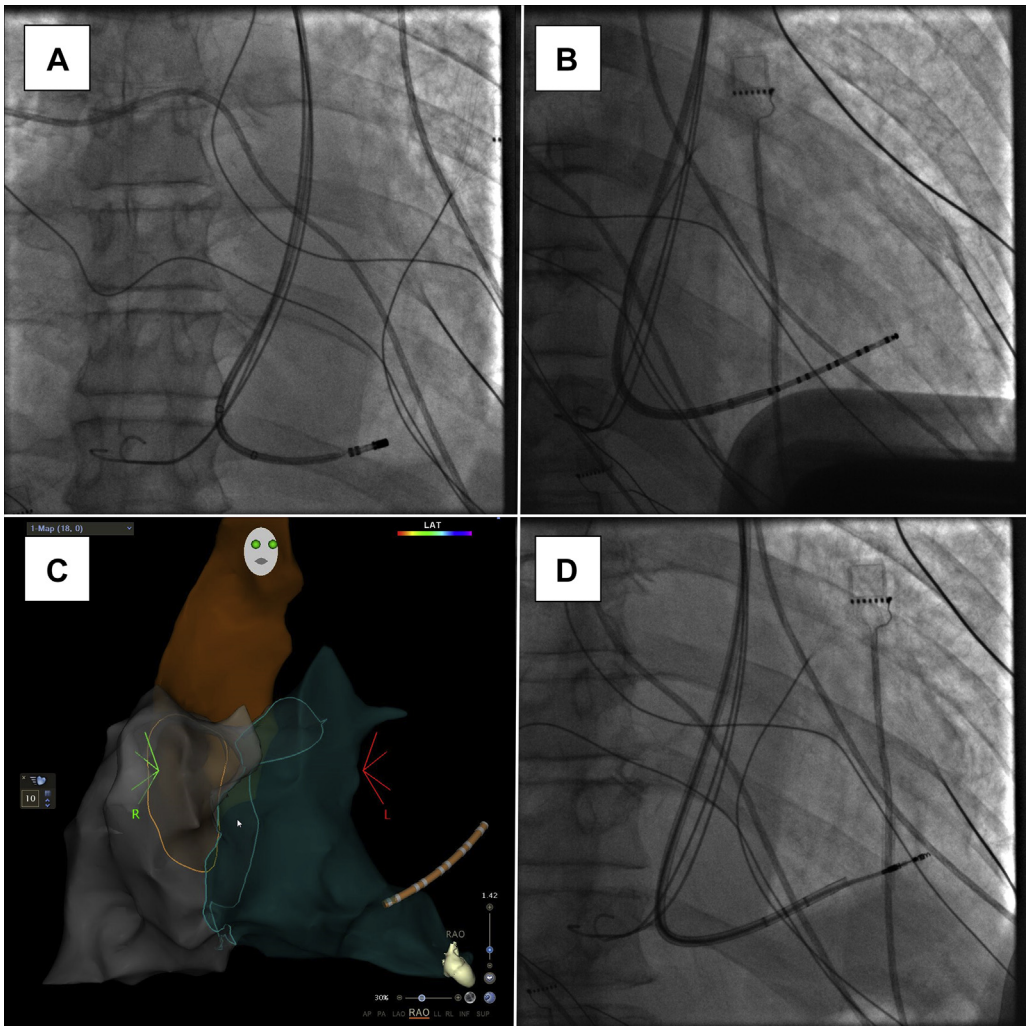

Figure 1 Electroanatomic mapping (EAM) for right ventricular pacing lead placement. **A:** Anterior-posterior projection demonstrating maneuvering of the coronary sinus cannulation sheath into the right ventricle using the ablation catheter. **B:** Right anterior oblique (RAO) projection demonstrating refinement of the sheath position using a decapolar catheter. **C:** RAO projection of the EAM system reconstruction of the coronary sinus and persistent left superior vena cava (*orange*), right atrium (*gray*), and right ventricle (teal). The decapolar catheter is displayed. **D:** RAO projection demonstrating deployment of an active-fixation pacing lead through the sheath to the right ventricular septum.

clarity to the His bundle location, which guided catheter ablation.

AV junction ablation and permanent pacemaker implantation was first performed in a human by Dr Melvin Scheinman and colleagues.[9] Reported in 1982, it established proof of concept for closed-chest catheter ablation as a treatment for arrhythmias, particularly AF with rapid ventricular rate.[9] Nevertheless, there is little published on this therapy in patients with PLSVC. A PubMed search, without limitation for publication year, on September 1, 2021 using Medical Subject Headings (MeSH) terms "ablation," "atrial fibrillation," and "persistent left superior vena cava" yielded 36 articles. None described AV junction ablation and permanent pacemaker implantation. To the best of my knowledge, the only detailed publication for "ablate and pace" in a patient with AF and PLSVC is by Deshmukh and colleagues,[10] where a permanent His bundle pacemaker was used.

Articles on cardiovascular implantable electronic device procedures in patients with PLSVC are mostly case reports, with larger series only published in recent years.[3,4,6] Despite limited data, it is clear that adjustments to standard techniques must be made when placing leads through the PLSVC. Failure to achieve successful lead placement has been attributed to atypical anatomy. Secure lead placement is of particular importance in patients undergoing AV junction ablation given resultant complete heart block.

Daccarett and colleagues[11] reported use of a coronary sinus cannulation sheath to deliver an active-fixation lead for right ventricular apical pacing. Certain sheath shapes may be more advantageous than others if targeting specific areas for lead placement. Use of a deflectable catheter within the sheath, as performed in this case report, may enhance maneuvering to desired areas. Some sheaths may theoretically be used to deliver 7 French active-fixation implantable

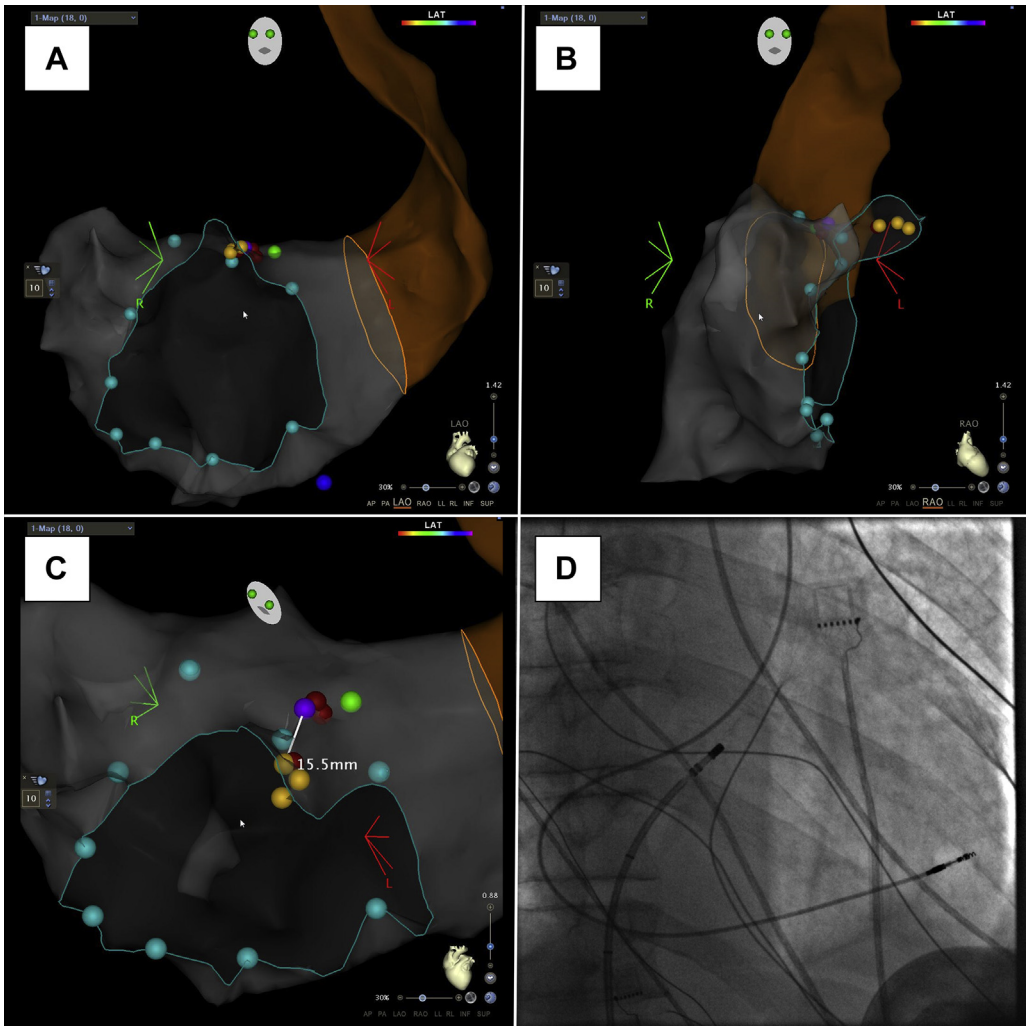

Figure 2 Electroanatomic mapping (EAM) for atrioventricular junction ablation. The coronary sinus and persistent left superior vena cava are colored orange. EAM points indicate His bundle recordings (*yellow*), tricuspid annulus (*teal*), ablation lesions with no effect (*red*), ablation lesion #2 (*green*), and ablation lesion #5 (*purple*). See text for details. **A:** Left anterior oblique projection. **B:** Right anterior oblique (RAO) projection. **C:** Lesion #5 was 15.5 mm from the closest His bundle recording. Lesion #1, which did not have any effect, was delivered at the site of His bundle recordings. **D:** RAO cine image with the ablation catheter in the successful position, or lesion #5.

cardioverter-defibrillator leads in a similar fashion, if needed. Voltage mapping with the EAM system may guide optimal lead placement and has been described in a patient with complex congenital heart disease.[12]

PLSVC may lead to massive distortion of the triangle of Koch. In the presented case report, the His bundle electrograms were localized to the superior segment of the right AV junction. The AV node and His bundle are typically located in the superoparaseptal segment.[7] Prior cases of patients with AV nodal reentrant tachycardia who underwent EAM mapping also demonstrated His bundle electrogram recordings at the superior segments.[13,14]

Traditional bipolar intracardiac electrogram features for radiofrequency catheter ablation to target the compact AV node include distinct atrial and ventricular signals (1:1 amplitude ratio) where the His bundle electrogram is early.[15] As illustrated in the presented case, lack of distinct signals at the successful site presented challenges. Indeed, after tagging of His bundle electrogram sites with the EAM system, the ablation strategy was mostly based on anatomic location and contact force. Whether these factors may come into play for other patients undergoing AV junction ablation in the presence of a PLSVC, with or without tachycardia-induced cardiomyopathy, requires further study.

Use of an EAM system generally requires diagnosis of the PLSVC prior to the patient entering the electrophysiology laboratory. Most operators probably do not routinely use EAM systems for "ablate and pace" given higher costs and longer preparation times.

Conclusion

An EAM system with a coronary sinus cannulation sheath during AV junction ablation and pacemaker implantation

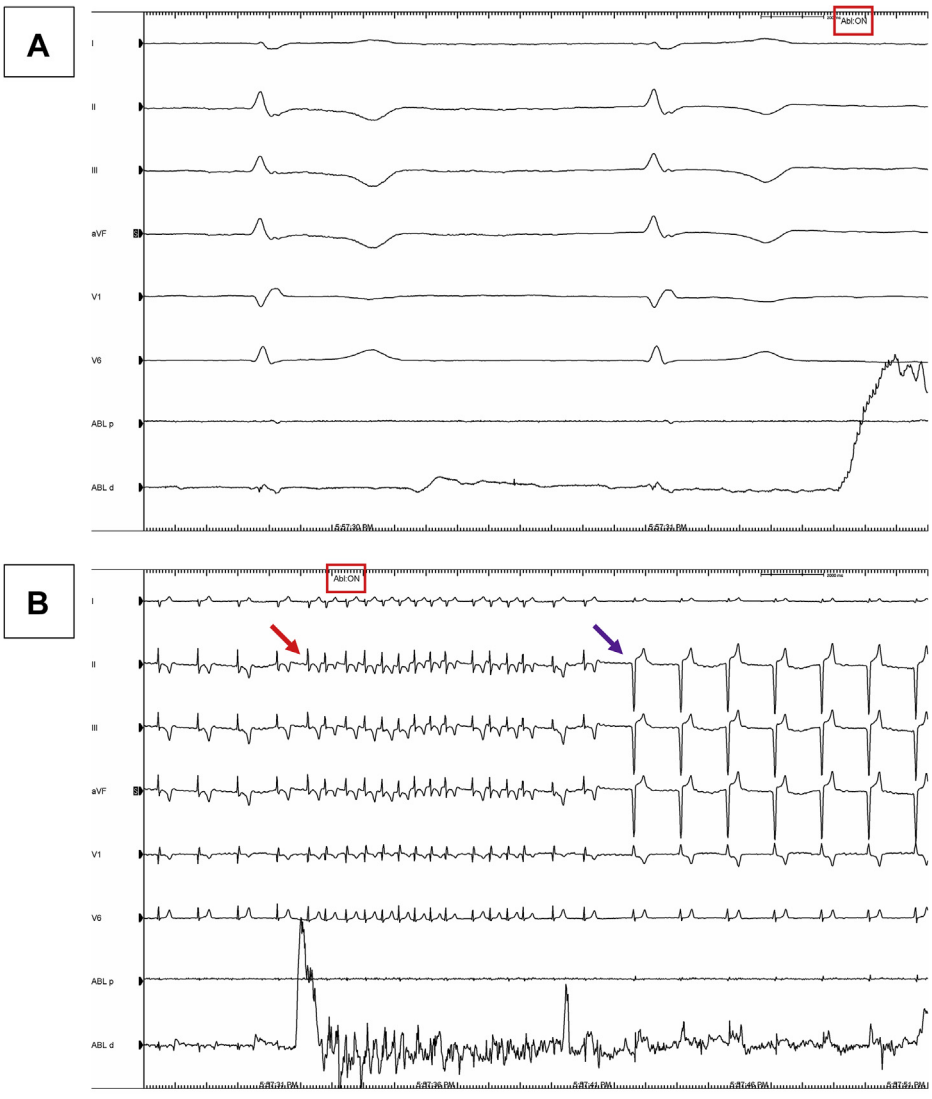

Figure 3 Ablation onset at the successful site, lesion #5 (*purple dot* in Figure 2), is demonstrated by an abrupt change on the ablation catheter recording and indicated by "Abl: ON" (*boxed in red*). **A:** The ablation catheter distal electrode (ABL d) recorded no atrial signals and low-amplitude ventricular signals. Recording speed 100 mm/second. **B:** An accelerated junctional rhythm appeared with ablation onset (*red arrow*). Complete heart block with pacing at 40 beats per minute occurred within 10 seconds (*purple arrow*). Recording speed 10 mm/second.

for permanent AF associated with PLSVC may facilitate procedural success by guiding right ventricular lead placement and clarifying AV junction anatomy.

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Appendix

Supplementary data

Supplementary data associated with this article can be found in the online version at https://doi.org/10.1016/j.hrcr.2021.11.007.

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