Pulsed field ablation of a persistent left superior vena cava in recurrent paroxysmal atrial fibrillation and its effect on the mitral isthmus: A case report

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Introduction

Persistent left superior vena cava (LSVC) is the most common congenital malformation of the thoracic veins, with an overall incidence of 0.3%–1%,[1] and has a well-established arrhythmogenic potential in the context of paroxysmal and persistent atrial fibrillation (AF).[2] Traditionally, catheter ablation of this anatomic variant is performed using radiofrequency (RF) lesions, aiming either at the ablation of focal triggers within the LSVC or at the creation of circumferential lesions to achieve electrical disconnection of the vein. Nevertheless, these strategies are often challenging and pose a non-negligible risk of cardiac perforation, tamponade, and damage to adjacent structures, especially when extensive ablation is needed in the absence of discrete triggers.[3,4]

Pulsed field ablation (PFA) is a novel, nonthermal ablation energy source based on the application of high-voltage electric fields to induce cell death. It is characterized by high myocardial selectivity, thus exhibiting a favorable safety profile while retaining an efficacy rate comparable to that of thermal ablation sources.[5] Additionally, it has a short operator learning curve and, thanks to the relatively large size of the currently commercially available PFA catheter, large lesions can be achieved in a short time.[5] Not surprisingly, its clinical use has rapidly expanded from pulmonary vein isolation to a range of different ablation procedures.[6–8]

In this report, we present the first case of LSVC and mitral isthmus ablation using PFA, in the setting of recurrent paroxysmal AF.

KEY TEACHING POINTS

- Persistent left superior vena cava (LSVC) is a common anatomic variant that is associated to an increased risk of atrial fibrillation and poses significant challenges during ablation with traditional thermal energy sources.
- Pulsed field ablation may be a safe, fast, and effective strategy to ablate a persistent LSVC that overcomes the limitations of the currently available thermal energy sources.
- Ablation of an LSVC may have transmural effect and therefore result in the formation of a potentially arrhythmogenic incomplete line of block at the level of the mitral isthmus. Therefore, endocardial mapping of the mitral isthmus should always be taken into consideration following this procedure and, when appropriate, additional endocardial applications may be performed to achieve a complete line of block.

Case report

A 60-year-old male patient was referred to our institution owing to highly symptomatic recurrences of paroxysmal AF. An index cryoenergy pulmonary vein isolation had been performed 13 years before and was followed by 2 RF ablation procedures owing to clinical recurrences 6 and 10 years later, respectively. During the last procedure, persistent electrical disconnection of the pulmonary veins was confirmed; however, a highly active LSVC was noted. Because of its considerable size and the widespread presence of fragmented potentials throughout its length, the operator decided not to target the LSVC and the procedure was limited to a wider antral ablation at the level of the pulmonary veins.

KEYWORDS Persistent left superior vena cava; Pulsed-field ablation; Mitral isthmus block; Atrial fibrillation; Anatomic variant
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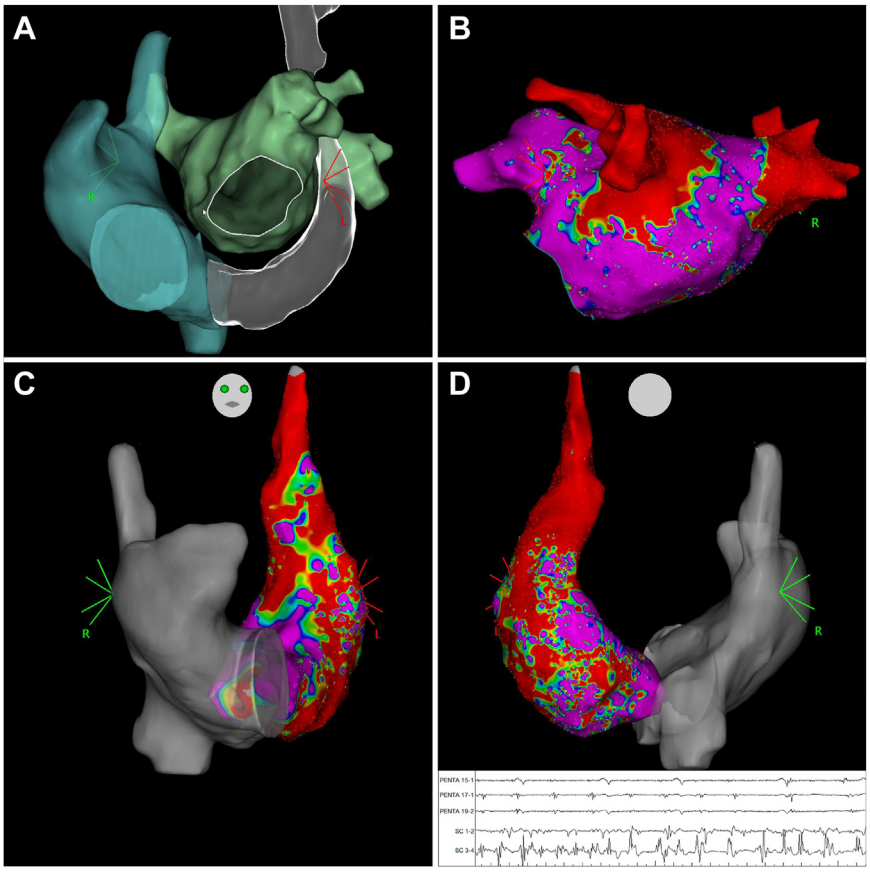

Figure 1 **A:** Three-dimensional reconstruction of computed tomography scan imaging showing the left atrium (blue), right atrium (green), and left superior vena cava (LSVC) (white). **B:** Baseline voltage map of the left atrium showing previous effective pulmonary vein isolation and normal mitral isthmus signals. **C, D:** Baseline voltage map of the LSVC showing widespread heterogenous signals throughout the entire length of the vein and endocardial recordings showing electric activity with higher frequency and amplitude in the coronary sinus (SC) than on the endocardial surface of the left atrium (PENTA).

At the time of the referral, the patient was treated with amiodarone and bisoprolol.

Considering the negative impact of the arrhythmia recurrence on the patient's quality of life and the availability of the novel ablation energy source, the patient was scheduled for a re-intervention.

The procedure was performed under general anesthesia. Using computed tomography scan imaging, a 3-dimensional reconstruction of the anatomical structures was performed, which confirmed the presence of an LSVC and a dilated coronary sinus, with a maximum diameter of 34 mm at the level of the ostium (Figure 1A). A 3-dimensional electroanatomic map (EAM) was performed using the CARTO 3 mapping system (Biosense Webster, Diamond Bar, CA) and confirmed the presence, throughout the entire course of the LSVC, of widespread, fragmented potentials characterized by a higher frequency and voltage amplitude compared to those on the left atrium endocardium (Figure 1C and 1D); on the contrary, pulmonary veins were effectively isolated and no other areas of low voltages could be identified on the endocardium of the left atrium (Figure 1B).

Under fluoroscopy, a 31 mm Farawave catheter (Boston Scientific, Menlo Park, CA) was deployed in the basket configuration at the most distal and electrically active part of the LSVC (Figure 2A and 2B). High-output stimulation (ie, 10 mV) in that region resulted in effective capture of the phrenic nerve. Prior to the first application, 1 mg of isosorbide dinitrate was given by intracoronary injection to prevent coronary artery spasm. Four PFA applications at 2.0 kV were delivered with a 90° catheter rotation after the second application. Subsequently, the catheter was retracted and the same sequence of 4 applications was repeated whenever electrical activity was seen along the LSVC. In total, 20 applications were delivered throughout the entire length of the vein until the coronary sinus ostium was reached. Post-ablation, no differences in diaphragmatic contraction strength were noted during high-output stimulation of the phrenic nerve.

A new EAM revealed the complete abolition of potentials along the LSVC (Figure 2C and 2D). Since the LSVC is in close proximity to the left atrium, we performed a new EAM that revealed a significant impact of the PFA applications on the endocardial aspect of the mitral isthmus (Figure 3A). Despite the presence of an extensive area of low voltage, persistent conduction along the mitral isthmus was noted (Figure 3B). To mitigate the potential arrhythmogenic effects of an incomplete ablation line, 8 additional

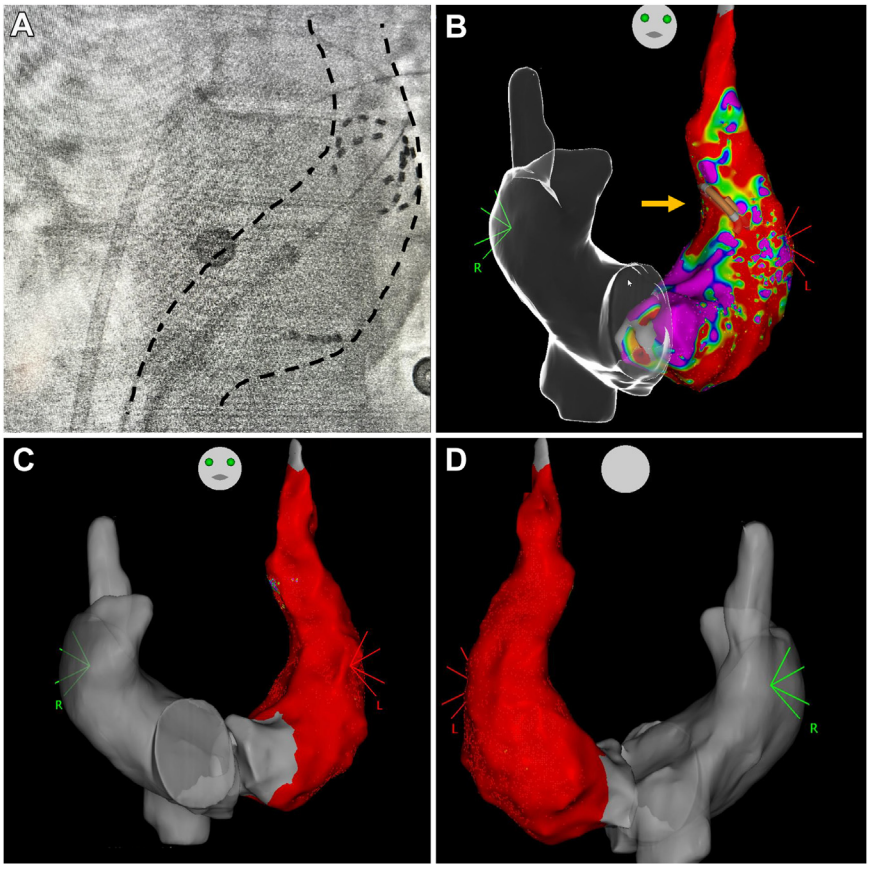

Figure 2 **A:** Fluoroscopic visualization of the Farawave catheter (Boston Scientific, Menlo Park, CA) in the basket position in the left superior vena cava (LSVC) (*black dotted lines*). **B:** Visualization of the Farawave catheter in the CARTO mapping system (Biosense Webster, Diamond Bar, CA) represented as a Lasso catheter (*yellow arrow*). **C, D:** Voltage map of the LSVC following 20 applications of pulsed field energy.

applications were delivered on the endocardial side of the mitral isthmus using the Farawave catheter in the flower configuration. A complete conduction block across the mitral isthmus was confirmed by the recording of a considerable prolongation in the interval between stimulation and recording of a signal on the opposite site of the isthmus (Figure 3C and 3D). The procedure was then completed with 8 additional applications to isolate the posterior wall of the left atrium.

The following day, given the absence of acute procedural complications, the patient was discharged at home and the amiodarone was discontinued. At the 4-month follow-up visit, the patient remained in sinus rhythm without any arrhythmia recurrences.

Discussion

In this report, we describe the first case of persistent LSVC and mitral isthmus ablation using PFA for recurrent AF.

The arrhythmogenic potential of persistent LSVC is well described and, like for the vein of Marshall, it can be attributed to its embryological origin from the common cardinal vein.[2,9] Unfortunately, the potential benefits of LSVC ablation in the context of AF have been impaired by nonnegligible safety concerns. Indeed, different reports highlight the risk of coronary sinus perforation, cardiac tamponade, and coronary sinus stenosis resulting in superior vena cava syndrome following RF ablation of LSVC.[3,4] Thanks to its tissue selectivity, PFA may overcome this limitation: as cardiomyocytes exhibit a unique susceptibility to the effects of pulsed electric fields, it is possible to modulate this nonthermal energy source to minimize, and theoretically eliminate, the risk of damage to surrounding structures, such as vascular smooth muscle cells, fibroblasts, and nervous tissue.[10]

Disconnection of the LSVC by traditional point-by-point ablation catheters is often challenging. Indeed, the LSVC and the coronary sinus share multiple electrical connections with the left atrium in the form of funnel-shaped or spiraliform muscular sleeves propagating distally from the coronary sinus ostium.[11] Therefore, targeting these connections often requires multiple RF applications, resulting in prolonged procedures. Owing to this fact, some centers have used a cryoballoon to perform LSVC isolation.[12] This approach is reported to be fast and effective but carries a considerable risk of thermally mediated phrenic nerve palsy. The PFA Farawave catheter prevents such a complication, while retaining the advantages of a large-interface, single-shot catheter. These benefits become even more evident when, as in the presented case, electrical activity is recorded over a large part of

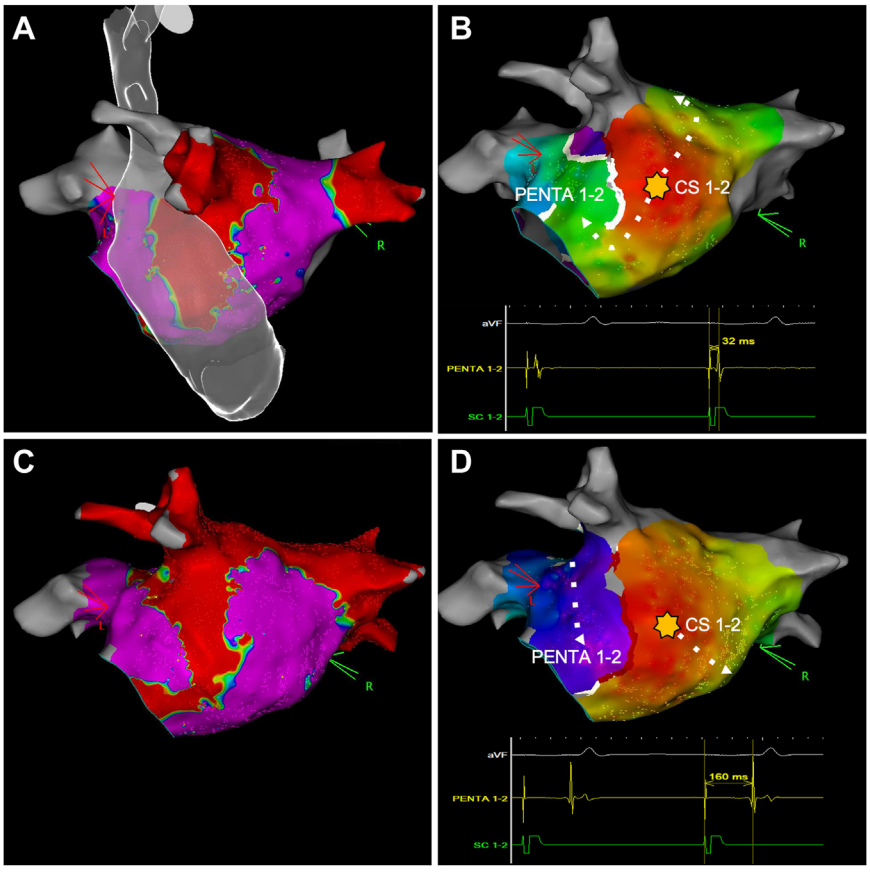

Figure 3 **A, B:** Voltage and activation map of the left atrium following pulsed field ablation in the left superior vena cava showing low endocardial voltages and an incomplete line of block. **C, D:** Voltage and activation map of the left atrium following 8 additional endocardial applications of pulsed field energy showing complete mitral isthmus block (counterclockwise activation with long stimulus-to-signal interval).

the vein and would therefore require extensive ablation, further increasing the risk of thermally mediated complications.

To our knowledge, there is a single case report of a persistent LSVC ablation using PFA in the scientific literature.[13] However, in this report, ablation was limited to the pulmonary veins and LSVC. Keeping in mind the anatomical relation between the LSVC and the mitral isthmus, we sought to investigate the potential effects of the PFA applications on this anatomic structure. Indeed, despite the presence of normal voltages at the beginning of the procedure, a considerable impact on the endocardial voltage map of the mitral isthmus was noted following applications in the LSVC. This is not surprising, as lesion transmurality is a typical and desirable effect of PFA.[14] Nevertheless, as only a portion of the mitral isthmus is in direct contact with the LSVC, this resulted in an incomplete ablation line, which has a well-established arrhythmogenic role.[15] For this reason, we decided to deliver additional endocardial PFA applications, until a complete mitral isthmus block was achieved. In our opinion, evaluation of the mitral isthmus should always be performed after LSVC ablation and, in case of incomplete ablation, a bidirectional block should be pursued with additional applications.

Conclusion

The first case of persistent LSVC ablation with mitral isthmus block using PFA is presented. This strategy may reduce the risk of complications associated with RF ablation of the LSVC, while minimizing the arrhythmogenic susceptibility posed by an incomplete mitral isthmus block.

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