INNOVATIVE TECHNIQUES

Innovative Techniques Stem from Classical Electrophysiology: Completing the Circle

1BRIAN D. POWELL, MD and 1,2SAMUEL J. ASIRVATHAM, MD

1Division of Cardiology, Department of Medicine, Mayo Clinic, Rochester, MN
2Division of Pediatric Cardiology, Department of Pediatric and Adolescent Medicine, Mayo Clinic, Rochester, MN

ABSTRACT. Pulmonary vein isolation (PVI) is an important and frequently employed component for atrial fibrillation (AF) ablation procedures. Although generally thought of as an “anatomic” approach, classical electrophysiological principles need to be innovatively employed in order to determine whether the pulmonary veins (PVs) are indeed electrically isolated. We present two instances in which variants of recently described PVI diagnostic maneuvers were employed. The rationale, technique, and limitations for these maneuvers are discussed.

KEYWORDS. ablation, atrial fibrillation, maneuvers, pulmonary vein, superior vena cava, wide area circumferential ablation.

ABBREVIATIONS. AF—atrial fibrillation, CS—coronary sinus, LA—left atrium, LAA—left atrial appendage, LAO—left anterior oblique, PV—pulmonary vein, PVI—pulmonary vein isolation, PVP—pulmonary vein potential, RA—right atrial, RAO—right anterior oblique, RSPV—right superior pulmonary vein, SVC—superior vena cava.

Introduction

Ablation procedures for atrial fibrillation (AF) have now become an established option for managing drug-refractory patients with symptomatic AF. Although a variety of ablation paradigms are being used, including targeting fragmented signals, the autonomic ganglia, cryoablation, and balloon-based ablation procedures, an integral component for most operators involves electrical isolation of the pulmonary veins (PVs). At times, pulmonary vein isolation (PVI) is considered to be an “anatomic” ablation, suggesting that knowledge and implementation of classical electrophysiology principles and diagnostic techniques are not required for successful ablation. However, PVI is not always a straightforward procedure. It is essential for the operator to determine whether the PVs are, in fact, electrically isolated. To determine this, abolition of the pulmonary vein potential (PVP) following circumferential atrial ablation around the ostia of the veins is used. Inaccurate identification of the presence or absence of PVPs impacts success and safety of these procedures. For example, if the presence of PVPs is not identified, then under-ablation is performed, and the arrhythmogenic substrate may remain. On the other hand, if contaminant non-PV signals are diagnosed as PVPs, unnecessary over-ablation may be done, increasing the risks of PV stenosis, cardiac perforation, or esophageal injury.

Rather than always employing a purely anatomic approach, operators need to be aware of simple applications of classic electrophysiological diagnostic maneuvers to aid correct identification of PVPs. We present below two brief cases in which innovative variants of such described maneuvers were required for exact diagnosis, thus avoiding over-ablation.

A patient with drug-refractory AF was referred for radiofrequency ablation. Wide area circumferential ablation was performed to isolate the PVs. Because of the proximity of the esophagus to the posterior atrial wall near the left-sided PVs, a particularly wide area ablation was performed to avoid potential esophageal injury. The right-sided PVs were isolated. However, because of continued conduction into the left superior PV, an additional “carina” line between the left upper and lower vein was performed. As this line crossed the...
location of the esophagus, only cryo energy was applied at regions of esophageal proximity.\textsuperscript{16–18}

In Figure 1, the electrical signals seen on a circumferential mapping catheter (Lasso, Biosense Webster, Diamond Bar, CA) placed in the left upper vein during distal coronary sinus (CS) pacing are shown. Despite rechecking previous ablation sites for continuity of the wide area ablation as well as the carina line, these potentials persisted.

CS pacing was done as a surrogate for the left atrium (LA), and, in this instance, both near- and far-field signals were found. These usually represent left atrial and PVPs, and further ablation is required.

Peri-vein and intra-vein pacing are additional maneuvers that can be employed to ascertain whether the two components of the retrieved electrograms represent origin from the LA and PV, as has been described.\textsuperscript{14,15}

Figure 2 illustrates the principle of this concept. When pacing from site A in the LA, the left atrial component (far-field) of the signal is drawn in towards the pacing site, as the LA is captured first. After a delay, PV activation is noted. On the other hand, when pacing from site B within the PV, the PVP is drawn into the spike and often obscured within the stimulation artifact and saturation. Following a delay, activation of the LA is seen. Although these maneuvers were performed, there clearly remained both near- and far-field components for the electrograms shown in Figure 1, despite what appeared to be adequate circumferential and carina ablation.

Prior to performing further ablation, particularly given the specific risk for esophageal injury in this case, alternate sources for these remnant signals were considered. The left atrial appendage (LAA) lies in close proximity to the left upper PV, and electrical activation of the LAA may be mistaken for left superior PVPs.\textsuperscript{14,19,20}

In Figure 3, we show the difference in the circumferential mapping catheter signals when pacing the CS only (first beat) and then simultaneously adding pacing with capture with a catheter placed in the LAA (echocardiographic and fluoroscopic guidance). Note that the far-field component of the complex signal (arrow) is drawn in towards the pacing spike, signifying that this component of the signal is from LAA activation.

Left atrial pacing outside of the circumferential ablation line did not significantly affect the signals retrieved. What then, is the cause of the remaining, relatively near-field signal? Is further isolation required?

A unique situation arises with wide area circumferential ablation that previously was not considered when devising PV diagnostic maneuvers for ostial ablation of the PVs. That is, two different areas of potential conduction delay or block need to be considered. The
Figure 2: Diagrammatic representation of peri-vein (left atrial pacing site A) and intra-vein (site B) to diagnose and distinguish between left atrial and pulmonary vein activation contributing to the pulmonary vein potential. LSPV = left superior pulmonary vein.

Figure 3: Illustrating the effect of pacing from the left atrial appendage (LAA) with coronary sinus (CS) pacing, complex signal with far- and near-field components is noted. With added simultaneous LAA pacing, one set of this complex signal (arrow) is drawn into the pacing artifact, signifying that this component of the complex signal represented LAA activation. P1 ART = arterial line recording; II and V1 = EKG leads; Lasso = circumferential mapping catheter in the left upper pulmonary vein; ABL = ablation catheter.
wide area circle may not be complete, but subsequent ablation nearer the vein, including the carina line, may result in PV isolation. However, because conduction delay from the rest of the LA into the antrum (area between the PV ostium and the wide area circle) may exist, the antral (LA) signals may be so delayed as to mimic delayed conduction into a PV.

Figure 4 illustrates this principle. Shown in red dots are the wide circle and linear, including carina, ablation. The blue dots show where cryo energy was applied, and the black dots the course of the esophagus. The pacing site within the antrum, but not within the PV, is also marked.

Figure 5 shows the result of pacing from this location. In the first beat, CS pacing only is shown with the complex signal present. When pacing from the antrum, the near-field (arrows) but delayed signals are drawn towards the pacing spike, signifying that these signals are from delayed left atrial activation around the ostium of the PV but within the wide area circle. As the other, relatively far-field component was already diagnosed to be LAA in origin, the vein is now determined to be isolated, and no further ablation was required or performed.

Figure 6 is obtained from another patient, where again an innovative variant of PV diagnostic pacing maneuvers was required. Following wide area right-sided PV ablation, potentials remained on the circumferential catheter placed in the right superior pulmonary vein (RSPV). Although the signals suggested continued activation of the RSPV, complete circumferential ablation had been done, and ectopy (arrow) from the vein was noted to occur with apparent exit block. Although possible, it is generally rare for exit block to occur in the absence of entrance block (complete isolation) of the PV. After further verifying the integrity of the circumferential ablation (absence of local electrograms at each ablated site), the same phenomenon remained. Therefore, alternate contaminant sources for the recorded signals on the circumferential mapping catheter were considered.
Figure 5: Addition of anteral pacing to coronary sinus (CS) pacing. The near-field components (arrows) are drawn into the pacing spike. The other component was already determined to be left atrial appendage in origin, and thus the vein was determined to be isolated and no further ablation required. P1 ART = arterial line recording; II and V1 = EKG leads; Lasso = circumferential mapping catheter in the left upper pulmonary vein; ABL = ablation catheter.

Figure 6: Continued complex signals recorded from the right superior pulmonary vein despite what appeared to be adequate wide area ablation. In addition, ectopy (arrow) from the vein was noted to occur with apparent exit block with and without coronary sinus (CS) pacing. P1 ART = arterial line recording; II and V1 = EKG leads; Lasso = circumferential mapping catheter; ABL = ablation catheter.
The importance of the actual pacing site has been emphasized when determining whether PV conduction is still occurring. For example, as illustrated in Figure 7, when recording in the RSPV, pacing from the CS may result in wavefronts that simultaneously activate the neighboring right atrium and the PV itself, resulting in obscuring of the PV signal within the contaminant proximate right atrial (RA) signals. Therefore, with the RSPV, RA pacing may help to distinguish whether the RSPV conduction is still occurring. In this instance, however, RA pacing did not significantly affect the observed signals, suggesting that complex PVPs remained. However, because of the exit block observed and the already significant ablation performed, we considered another electrically active source as the cause of the remaining signals.

Figure 8 shows the right anterior oblique (RAO) and left anterior oblique (LAO) images. The pacing catheter...
Figure 8: Right anterior oblique (RAO) and left anterior oblique (LAO) projections showing the circumferential mapping catheter in the right superior pulmonary vein. The pacing/ablation catheter (arrow) is in the superior vena cava. Note the close proximity of the superior vena cava and right superior pulmonary vein.

Figure 9: Disappearance of the previously recorded potentials in the right superior pulmonary vein when pacing from the superior vena cava, diagnosing the origin of the previously recorded signals as arising from the superior vena cava. P1 ART = arterial line recording; II and V1 = EKG leads; Lasso = circumferential mapping catheter; ABL = ablation catheter; CS = coronary sinus.
Is the Pulmonary Vein Isolated?

The SVC may have venous potentials in some patients that can be recorded in the neighboring RSPV. Figure 9 shows that, with pacing from the SVC, the potentials are pulled into the pacing site, diagnosing the origin of the signals as being from the SVC. The SVC was subsequently isolated, and the “PVPs” previously recorded in the RSPV were no longer seen. No further left atrial ablation was required.

**Conclusion**

We have presented two brief cases illustrating an innovative variant of electrophysiological maneuvers to correctly identify isolation of the PVs, obviating the need for further unnecessary ablation. Although approaches to AF ablation are sometime mistakenly considered anatomic, assuming that the principles of electrophysiology are not required for successful or safe ablation, these cases illustrate the contrary. These innovative approaches, however, are only variations of maneuvers and principles that have been described for decades and utilized for a variety of arrhythmia diagnostic purposes. Thus, present students of electrophysiology and ablation will no doubt have the opportunity to modify and innovate when applying classical principles to complete the wide circle of learning.

**References**