Pulmonary vein isolation: The impact of pulmonary venous anatomy on long-term outcome of catheter ablation for paroxysmal atrial fibrillation

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BACKGROUND Circumferential pulmonary vein (PV) isolation is the cornerstone of catheter ablation for atrial fibrillation (AF); however, PV reconnection remains problematic.

OBJECTIVE To assess the impact of PV anatomy on outcome after AF ablation.

METHODS One hundred two patients with paroxysmal AF underwent cardiac magnetic resonance (60%) or computed tomography (40%) before AF ablation. PV anatomy was classified according to the presence of common PVs, accessory PVs, PV branching pattern, and the dimensions of the PV ostia, intervenous ridges (IVRs), and the left PV-left atrial appendage ridge.

RESULTS Four discrete PVs were present in 48(47%) of the patients: a left common PV in 38(37%), a right common PV in 2 (2%), an accessory right PV in 20(20%), and left PV in 4(4%). At a mean follow-up of 12 ± 4 months, 75 of 102 (74%) patients were free of recurrent AF. A LCPV was associated with an increase in freedom from AF (87% vs 66% for 4 PV anatomy; $P = .03$). Greater left IVR length (16.9 ± 3.5 mm vs 14.0 ± 3.0 mm; $P \leq .001$) and width (1.4 ± 0.6 mm vs 1.1 ± 0.6 mm; $P = .02$) were associated with increased AF recurrence. After multivariate analysis, abnormal anatomy (LCPV or accessory PV) and left IVR length were found to be the only independent predictors of freedom from AF.

CONCLUSIONS Four discrete PVs are present in the minority of patients with paroxysmal AF undergoing PV isolation. The presence of a LCPV is associated with an increased freedom from AF after catheter ablation. PV anatomy may in part explain the variable outcome to electrical isolation in patients with paroxysmal AF.

KEYWORDS Atrial fibrillation; Pulmonary vein isolation; Ablation; Intervenous ridge; Anatomy

ABBREVIATIONS **AAD** = antiarrhythmic drug; **AF** = atrial fibrillation; **CMR** = cardiac magnetic resonance; **CT** = computed tomography; **IVR** = intervenous ridge; **LA** = left atrium/atrial; **LAA** = left atrial appendage; **LCPV** = left common pulmonary vein; **MRI** = magnetic resonance imaging; **PV** = pulmonary vein; **PVI** = pulmonary vein isolation

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Introduction

Circumferential pulmonary antral ablation is a commonly used technique to achieve pulmonary vein isolation (PVI) in patients with atrial fibrillation (AF). However, PVI is limited by AF recurrence in up to 30% of the patients with paroxysmal AF.[1] Despite advances in catheter-based technology and operator experience, pulmonary vein (PV) reconnection continues to thwart the success of catheter ablation.

Pulmonary venous anatomy demonstrates considerable inter- and intraindividual variation with common PVs, accessory PVs, and significant difference in the dimensions of the intervenous ridge and PV-appendage ridge. With advances in catheter contact technology, we have gained new insights into

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the challenges of tissue contact at these locations that may in part translate to the variable outcomes after PVI. The intervenous ridge (IVR) and the left PV-left atrial appendage (LAA) ridge are preferential sites of not only acute PV isolation but also chronic PV reconnection.[2,3] Interestingly, adequate catheter contact is difficult to achieve in these locations[4,5] and may translate to sites of PV reconnection at the time of repeat procedure for recurrent AF.[4]

Prior studies have explored the impact of pulmonary venous anatomy on the outcomes of catheter ablation with conflicting results. Pulmonary venous anatomy demonstrates considerable diversity with a left common pulmonary vein (LCPV) present in 9%–83% of the patients and accessory PVs in 17%–29% of the patients undergoing catheter ablation.[6,7] Right-sided accessory PVs have been associated with improved success after PVI,[8] though other series did not demonstrate an association between atrial anatomy and procedural outcomes.[9,10]

We conducted a prospective study to determine the impact of pulmonary venous anatomy on outcome after catheter ablation for paroxysmal AF.

Methods

Study population

Patients with highly symptomatic paroxysmal AF resistant to at least 1 antiarrhythmic drug (AAD) were prospectively recruited before first time PVI between January 2010 and January 2012. Patients underwent preprocedural cardiac magnetic resonance (CMR) imaging or computed tomography (CT) for the assessment of LA anatomy. AF was classified as paroxysmal if episodes were self-terminating within 7 days or cardioverted within 48 hours of onset. Patients were required to have normal renal function and no history of claustrophobia or metallic implant as contraindication to magnetic resonance imaging (MRI). Baseline demographic characteristics, comorbidities, and medications were recorded. This multicenter study included patients from Alfred Hospital, Royal Melbourne Hospital, and Melbourne Private Hospital in Melbourne, Australia, and was approved by ethics committees of the relevant institutions.

CMR protocol

The CMR protocol has been described previously by our institution.[11] Participants underwent CMR within 48 hours of AF ablation by using a clinical 1.5-T MRI scanner. Sequences were acquired during breath-holds of as long as 15 seconds. Left atrial (LA) anatomy was assessed via axial contrast–enhanced magnetic resonance angiography acquired after an intravenous injection of gadolinium-diethylenetriamine pentaacetic acid timed to maximal opacification of the LA (52 slices with 2-mm thickness).

CT protocol

Participants underwent CT left atriogram on a 64-slice CT scanner within 48 hours of AF ablation. A region of interest was placed in the LA and an 80–100 mL bolus of iodinated intravenous contrast was administered at a rate of 4 mL/s, followed by 40 mL of saline flush. All scans were acquired after minimal delay following contrast at the time of maximal LA opacification. A maximal resolution of the left atriogram was $0.625 \times 0.625 \times 0.625$ mm.

Three-dimensional reconstruction and analysis of LA anatomy

Left atriograms acquired at CT or MRI were reconstructed with 3-dimensional (3D) segmentation software using NavX (St Jude Medical, St Paul, MN) or CARTO 3 (Biosense Webster, Diamond Bar, CA). LA anatomy was assessed by a reviewer blinded to outcome for the following (Figure 1):

1. presence of a common pulmonary venous trunk defined when the inferior and superior PVs coalesce before insertion into the LA. A short common PV was defined when the distance from the IVR to the common orifice was 5–15 mm and a long common PV when this distance was >15 mm[12];
2. accessory PVs;
3. early branching of the PVs was defined as an origin of the first PV branch within 1 cm of the PV ostium[7];
4. PV ostium—area and dimension (superior-inferior and transverse) of each PV
5. IVR dimensions were measured after defining the superior and inferior PV orifices as depicted schematically in Figure 2 with representative examples in Figure 3. All measurements were taken along the surface of the 3D reconstruction, rather than straight lines between points;
6. Left PV-LAA ridge dimensions (Figures 2 and 3)—narrowness of the left PV-LAA ridge was measured by the length along this ridge, which was less than 5 mm wide, as described previously[13]; and
7. LA volume was calculated by using the biplane dimension-length formula, as described previously.[8]

The venoatrial junction was measured on the epicardial aspect at the inflection point where the PV inserted into the atrium.[14]

Catheter ablation

In brief, all AADs except amiodarone were discontinued 5 half-lives before the procedure, with amiodarone ceased 2 weeks prior. All patients underwent general anesthesia with transesophageal echocardiography. A decapolar catheter was positioned in the coronary sinus, and a quadripolar catheter was positioned in the His bundle position via femoral venous access. Two 8- or 8.5-F long sheaths were introduced into the LA, with transseptal puncture performed with a BRK-1 needle. A circular mapping catheter was introduced through the SL1 sheath into the LA for electrical mapping of the PVs. An irrigated ablation catheter was advanced into the LA under therapeutic heparinization. LA geometry was created by using a 3D electroanatomic mapping system and merged with the segmented CT or CMR.

A wide encirclement of the ipsilateral PV pairs was delivered at the PV antrum proximal to the PV-LA junction until electrical isolation was achieved. PVI (defined by PV