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

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Short Title: Impact of Atrial Anatomy on AF Ablation Outcome

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ABSTRACT

Background:

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

Objective:

We assessed the impact of PV anatomy on outcome post AF ablation.

Methods:

102 patients with paroxysmal AF underwent CMR (60%) or CT (40%) prior to AF ablation. PV anatomy was classified according to: presence of common PVs; accessory PVs; PV branching pattern; and the dimensions of the PV ostia, intervenous ridges (IVR) and the left atrial appendage (LAA)-left PV ridge.

Results

Four discrete PVs were present in 47% of patients, a left common PV in 37%, a right common PV in 2% and an accessory right PV in 20% and left PV in 4%. At 12±4 months follow-up 75 of 102 (74%) patients were free of recurrent AF. A left common PV was associated with an increase in freedom from AF (87% vs 66% for 4 PV anatomy; p=0.03). Greater left IVR length (16.9±3.5mm vs. 14.0±3.0mm; p=<0.001) and width (1.4±0.6mm vs. 1.1±0.6mm; p=0.02) were associated with increased AF recurrence. On multivariate analysis abnormal anatomy (left common PV or accessory PV) and left IVR length were the only independent predictors of freedom from AF.

Conclusion

Four discrete pulmonary veins are present in the minority of patients with paroxysmal AF undergoing PVI. The presence of a left common PV is associated with an increased freedom from AF following catheter ablation. Pulmonary vein anatomy may in part explain the variable outcome to electrical isolation in patients with paroxysmal AF.

Key Words

Atrial fibrillation, pulmonary vein isolation, ablation, intervenous ridge, anatomy

Abbreviations

AF Atrial Fibrillation

CPVI circumferential pulmonary vein isolation

PV pulmonary vein

IVR intervenous ridge

LAA left atrial appendage

HT hypertension

LVH left ventricular hypertrophy

IHD ischaemic heart disease

CCF congestive cardiac failure

LA left atrium

LVEF left ventricular ejection fraction

CMR Cardiac Magnetic Resonance

CT Computed Tomography

TTE transthoracic echocardiogram

INTRODUCTION

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

Pulmonary venous anatomy demonstrates considerable inter and intra individual variation with common PVs, accessory PVs and significant difference in the dimensions of the intervenous and PV/appendage ridges. With advances in catheter contact technology we have gained new insights into the challenges of tissue contact at these locations which may in part translate to the variable outcomes following pulmonary vein isolation. The intervenous ridge and LAA/LPV ridge are preferential sites of 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 present in 9-83%[6, 7] and accessory pulmonary veins in 17-29% of patients undergoing catheter ablation[6, 7]. Right sided accessory PVs have been associated with improved success following PVI[8] though other series did not demonstrate an association between atrial anatomy and procedural outcomes[9,10].

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

METHODS

Study Population

Patients with highly symptomatic paroxysmal AF resistant to at least one anti-arrhythmic medication were prospectively recruited prior to first time PVI between January 2010 and January 2012. Patients underwent pre-procedural Cardiac Magnetic Resonance imaging (CMR) or Computed Tomography (CT) for assessment of LA anatomy. Atrial fibrillation 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 MRI. Baseline demographics, comorbidities and medications were recorded. This multi-centre study included patients from Alfred Hospital, Royal Melbourne Hospital and Melbourne Private Hospital in Melbourne, Australia and was approved by the relevant institutions ethics committees.

CMR Protocol

CMR protocol has been previously described by our institution[11]. Participants underwent CMR within 48 hours of AF ablation using a clinical 1.5-T MRI scanner. Sequences were acquired during breath-holds of as long as 15 seconds. Left atrial anatomy was assessed via axial contrast enhanced magnetic resonance angiography acquired following intravenous injection gadolinium-diethylene triamine penta-acetic acid timed to maximal opacification of the left atrium (52 slices, 2mm slice thickness).

CT Protocol

Subjects underwent CT left atriogram on a 64-slice CT scanner within 48 hours of AF ablation. A region of interest was placed in the left atrium and an 80-100 ml bolus of iodinated IV contrast was administered at a rate of 4 ml per second, followed by a 40 ml saline flush. All scans were acquired after minimal delay post contrast at the time of maximal LA opacification. Maximal resolution of the left atriogram was 0.625 x 0.625 x 0.625mm.

3-Dimensional Reconstruction and Analysis of Left Atrial Anatomy

Left atriograms acquired at CT or MRI were reconstructed with 3D segmentation software using NavX (St. Jude Medical, St. Paul, MN, USA) or CARTO3 (Biosense Webster, Diamond Bar, CA, USA). Left atrial 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 prior to insertion into the LA. A short common PV was defined when the distance from the IVR to the common orifice was 5-15mm and a long common PV when this distance was >15mm[12];

(2) Accessory pulmonary veins;

(3) Early branching of the pulmonary veins was defined as an origin of the first PV branch within one cm of the PV ostium[7];

(4) PV ostium - area and dimension (superior-inferior and transverse) of each PV

(5) Intervenous ridge 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) LPV/LAA ridge dimensions (figures 2 and 3) - narrowness of the left PV-LAA ridge was measured by the length along this ridge that was less than 5mm wide, as previously described[13].

(7) Left atrial volume was calculated as described previously[8] using the biplane dimension-length formula.

The veno-atrial junction was measured on the epicardial aspect at the inflection point where the pulmonary vein inserted into the atrium[14].

Catheter Ablation

In brief, all antiarrhythmic medications except amiodarone were stopped 5 half-lives before the procedure with amiodarone ceased two weeks prior. All patients underwent general anesthesia with transesophageal echocardiography(TEE). 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 left atrium with trans-septal puncture performed with a BRK-1 needle. A circular mapping catheter was introduced through the SL1 sheath into the left atrium for electrical mapping of the pulmonary veins. An irrigated ablation catheter was advanced into the left atrium under therapeutic heparinisation. Left atrial geometry was created using a 3-dimensional electroanatomic mapping system and merged with the segmented CT or CMR.

Wide encirclement of the ipsilateral pulmonary vein pairs was delivered at the pulmonary vein antrum proximal to the PV–LA junction until electrical isolation was achieved. Pulmonary vein isolation (defined by PV entrance and exit block) was confirmed 30 minutes after initial isolation including intravenous adenosine 18mg to assess for acute reconnection. Ablation strategy was consistent across the time period of this study.

Follow up

Arrhythmia recurrence was defined as any documented atrial arrhythmia lasting more than 30seconds after an initial 3 month blanking period[15]. Post procedure patients were followed up in clinic at 1, 3, 6 and 12 months with ongoing review 6 monthly. Patients underwent a 7 day Holter monitor at six and twelve months, with ongoing ambulatory electrocardiographic monitoring beyond 12 months performed at the discretion of the treating electrophysiologist. Participants were given instructions to contact the arrhythmia research nurse for immediate assessment and event monitors were performed in patients with recurrent symptoms.

Statistics

Continuous variables are expressed as a mean ± SD with comparisons between groups performed with either an unpaired Student's t-test, or where a normal distribution could not be assumed the Mann-Whitney U-test. Categorical variables are expressed as numbers and percentages, and were compared with a chi-square test. Bland-Altman plots were performed to define agreement of IVR measurements between imaging modalities (CT vs. MRI), between segmentation software (CARTO vs. NavX), and between observers. Freedom from AF was assessed with Cox Regression analysis in univariate and multivariate models. Kaplan-Meir analysis was utilised to assess the impact of normal vs. abnormal anatomy, left common PV vs. no left common PV and accessory PV vs. no accessory PV on freedom from AF. A two sided P value <0.05 was considered statistically significant. All statistical analysis was performed using SPSS software version 21.0 (SPSS, Chicago, IL, USA).

RESULTS

Baseline Characteristics and procedural outcomes (see table1)

102 patients with paroxysmal AF (age 59±9 years, male 67%) underwent CMR or CT prior to AF ablation (MRI in 60% and CT in 40%). Segmentation of the left atriogram for LA anatomy was performed with NavX in 85% and CARTO3 in 15%. Acute procedural success defined as pulmonary vein isolation was achieved in all patients. At a mean follow up of 12±4 months, 75 of 102 (74%) patients were in sinus rhythm off antiarrhythmic medication after a single procedure.

Impact of pulmonary venous anatomy on AF ablation outcomes

Common or accessory pulmonary veins (see figure 4, table 2)

Four discrete pulmonary veins were identified in 47% of patients, a left common pulmonary vein in 37%, and a right common PV in 2% of patients. An accessory right sided PV was identified in 20% and an accessory left PV in 4% of patients.

In patients with a common or accessory PV freedom from AF following PVI was 85% compared with 60% in patients with a typical 4 vein arrangement (p=0.005). Specifically a left common PV was associated with freedom from AF in 87% compared with 66% in patients without a left common PV (p=0.03). A right sided accessory PV was not significantly associated with procedural outcome (85% vs. 70%; p=0.15).

Ablation on the intervenous ridge was performed if electrical isolation could not be achieved with antral ablation despite an apparently complete antral ring and positioning of the circular mapping catheter suggests breakthrough at the intervenous ridge. Ablation on the left IVR was required in 25% with 2 separate left PVs and not in patients with a left common PV (LCPV). There was no significant difference in freedom from AF in patients who underwent IVR ablation in the presence of dual left sided PV (71%) compared with a left common PV (87%; p=0.38). Patients who did not receive ablation on the left IVR had reduced freedom from AF in the presence of two left sided PVs (57%) compared to patients with a LCPV (87%; p=0.03).

The presence of dissociated left sided pulmonary vein potentials (PVPs) after index pulmonary vein isolation was present in 17 patients (46%) with a LCPV vs. in 19 patients (31%) who did not have a LCPV (p=0.13).

Pulmonary vein branching

Early PV branching defined as a distance to 1st PV branch of < 1.0cm was present in 23% of RSPV, 43% of RIPV, 4% of LSPV and 4% of LIPV. Early PV branching was not associated with outcome in patients undergoing PVI (see table 2).

Dimensions of IVR and left PV-LAA ridges (see table 2)

The findings of the left and right IVR and left PV-LAA dimensions are presented in table 2. The left IVR was significantly longer and the area larger in patients with recurrent AF following PVI compared with those without recurrent AF (table 2).

Differences in the dimensions of the left IVR may be attributable to the presence of a left common PV. The left IVR was significantly smaller in width (4.0±2.7mm vs. 6.1±3.0mm; p=0.001), area (0.8±0.4cm^2 vs. 1.4±0.6cm^2; p<0.001) and length (13.2±2.8mm vs. 15.7±3.4mm; p<0.001) in patients with a left common PV compared to two discrete left sided PVs.
After excluding patients with a left common PV, the left IVR remained significantly greater in length (17.6±3.5mm vs. 14.9±3.0mm in no recurrent AF; p=0.003) although not in area (1.5±0.6cm^2 vs. 1.3±0.5cm^2; p=0.14) in patients with AF recurrence.

There was no significant difference in the dimensions of the pulmonary veins, right IVR or left PV-LAA ridges between patients with and without AF at follow up (table 2).

Inter-observer correlation and agreement

We report very good correlation (R^2 from 0.81 to 0.97) and Bland-Altman assessment showing high agreement between measurements of IVR area, width and length made between imaging modalities, between segmentation software and between observers (see supplementary figures 1-3).

Univariate and multivariate analysis

Baseline comorbidities, LA area and volume, and LVEF were not associated with freedom from AF following PVI (tables 1 and 2). A longer duration of AF prior to ablation was associated with an increase in recurrent AF following PVI (78±61months vs. 50±55months in patients free of AF recurrence; p=0.03, table 1). Longer radiofrequency ablation times were associated with AF recurrence (48±16mins vs. 39±11mins in patients free of AF recurrence; p=0.01, table 3).

Univariate predictors of AF recurrence included normal anatomy, length and area of the left IVR and RF duration. After multivariate analysis, the only significant predictors of freedom from AF were the presence of left common PV or accessory PV and length of the left IVR (table 4).

Redo Procedures and Follow up

Sixteen patients in the cohort underwent a redo procedure (13 patients (20%) without a left common pulmonary vein (LCPV) vs. 3 patients (8%) with a LCPV; p=0.095). 14 of 16 patients had reconnection of at least one PV, with non PV atrial tachycardia in 2. At the repeat procedure reconnection of the left sided PVs was present in 1 of 3(33%) for LCPV vs 11 of 13(85%) without a LCPV (p=0.06).

In patients who had freedom from AF 57 of 75 patients (74%) were on no antiarrhythmic drugs (AAD) and 18 (24%) were on one AAD. In patients with AF recurrence 23 (85%) were on AADs (p<0.001).

DISCUSSION

Atrial and pulmonary vein anatomy demonstrates considerable variation between patients. 3D mapping with image integration has improved our appreciation of the anatomic diversity and assisted our ability to complete pulmonary vein isolation despite often challenging terrain. In the present study we demonstrated that pulmonary venous anatomy is an important determinant of outcome in patients undergoing pulmonary vein isolation for paroxysmal AF. The main findings were:

(i) Typical four pulmonary vein anatomy is present in 47% of patients, with a left common PV in 37% and an accessory right sided PV in 20%;

(ii) Typical four pulmonary vein anatomy is associated with a significant increase in AF recurrence following PVI compared to patients with a common PV

(iii) Larger dimensions of the left IVR was associated with an increase in AF recurrence including after exclusion of patients with a left common PV

Impact of a left common PV on AF ablation outcomes

In the present study a common pulmonary vein was reported in 39% consistent with earlier studies[9]. In 473 patients undergoing cardiac MR prior to AF ablation common and accessory PVs was more frequent than so called “normal” four PV anatomy[16] . The reported incidence of a left common PV varies significantly largely dependent on the anatomic definition[17]. In the present study we employed the definition described by cardiac pathologists Cabrera and coworkers[12] where a common PV is present when the inferior and superior PVs coalesce at least 5mm prior to insertion into the left atrium.

We report a significant improvement in the outcome of catheter ablation in patients with paroxysmal AF with a left common PV compared with two discrete left PVs. In patients with a left common PV the left intervenous ridge was significantly smaller in width (4.0±2.7mm vs. 6.1±3.0mm; p=0.001), area (0.8±0.4cm^2 vs. 1.4±0.6cm^2; p<0.001) and length (13.2±2.8mm vs. 15.7±3.4mm; p<0.001) compared to patients with two discrete left sided PVs.

A greater length of the left intervenous ridge was associated with increased AF recurrence after excluding patients with left common PVs.

Prior studies investigating the implications of PV anatomy on the outcomes of catheter ablation have reported conflicting results. Anselmino et al did not demonstrate a relationship between PV anatomy and the outcomes of catheter ablation in patients with paroxysmal and persistent AF[9]. While the incidence of common or accessory PVs was similar to the present study important differences included a lower freedom from AF of 53% compared to 74% in the current study likely explained by the inclusion of patients with persistent AF. As catheter ablation incorporated atrial substrate modification beyond the pulmonary veins in persistent AF patients this may have diluted the impact of pulmonary venous anatomy on catheter ablation outcomes[18]. Similarly Hof et al did not demonstrate a relationship between PV anatomy and freedom from AF following catheter ablation[10]. Persistent AF was present in 45% of patients with an ablation strategy extending beyond PVI and the reported incidence of a left common PV was significantly lower (16%) than in the present study.

Catheter contact may in part explain how PV anatomy can impact on ablation outcomes. The availability of catheter contact technology has provided new insights into the challenges of catheter ablation and achieving durable ablation lesions. Kumar et al demonstrated lower contact force on the left PV-LAA ridge and on the intervenous ridges[5]. Neuzil et al extended these findings and correlated sites of inadequate contact force with sites of PV-LA recovery at follow up procedures[4]. We speculate that a left common PV may facilitate greater contact force along the left PV/left atrial appendage ridge as the intervenous ridge does not interfere with catheter ablation, and the minimal risk of PV stenosis allows slightly deeper ablation on the venous aspect of the LPV/LAA ridge. In addition left common pulmonary veins may more frequently harbor triggers responsible for AF episodes. In the present study there was a non-significant trend to more frequent spontaneous pulmonary vein potentials to originate from left common PVs. Only a limited number of patients underwent repeat procedures with reconnection rates lower for left common pulmonary veins (33%) compared with two discrete left pulmonary veins (85%). A combination of anatomic and arrhythmogenic factors may in part explain better outcomes following PVI in patients with a left common PV.

In contrast a left common PV may be associated with an increase in recurrent AF[19] with alternate ablation technologies. Obtaining complete occlusion of a large left common with the cryoballoon may be more challenging than conventional two vein anatomy and translate to reduced success. An increase in recurrent AF has also been reported in patients with a left common PV undergoing catheter ablation guided by remote magnetic navigation (RMN)[20] likely related to the technical aspects of this technology.

Freedom from AF – IVR and Left PV-LAA Ridge

In the present study a longer left IVR was associated with a significant increase in recurrent AF. Previous anatomical studies have described complex endocardial and epicardial connections bridging the superior and inferior PVs involving the left IVR only in 53%, right IVR only in 33% and both IVRs in 14%[21]. The myocardial tissue at the IVR was significantly thicker on the left compared with the right IVR. The thicker more complex arrangement of myofibres of the left IVR may pose greater challenges to durable vein isolation in the presence of a more extensive ridge.

While freedom from AF was significantly improved in patients with a left common PV compared with two left sided PVs subgroup analysis demonstrated this was no longer apparent when intervenous ridge ablation was performed.

STUDY LIMITATIONS

The results are confined to patients with paroxysmal AF undergoing pulmonary vein isolation using a point by point approach with RF ablation. The findings in the present study may not be extrapolated to patients with persistent AF or where alternate balloon based technologies are used. In the present study a left common pulmonary vein was associated with a higher freedom from recurrent AF following PVI compared with 4 vein anatomy. The present study does not offer insights as to how the electrophysiologist may tailor the ablation strategy to improve the outcome of patients with standard 4 vein anatomy but rather demonstrates the potential impact of PV anatomy on AF ablation outcomes. Atriograms were segmented and analyzed with commercially available software (NavX or CARTO3) as in previous studies rather than using the raw MRI or CT images[22]. Contact catheter technology may help provide insights into the observations in the present study however only became available toward the end of the study period.

CONCLUSION

Four discrete pulmonary veins are present in the minority of patients with paroxysmal AF undergoing pulmonary vein isolation. The presence of a left common PV is associated with an increased freedom from AF following catheter ablation. Pulmonary vein anatomy may in part explain the variable outcome to electrical isolation in patients with paroxysmal AF.

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Table 1: Baseline patient characteristics

	AF Recurrence NO (n=75)	**AF Recurrence YES** (n=27)	**P value**
Age	59±9	61±9	0.29
Gender, male n (%)	46 (68)	15 (65)	0.83
AF duration (years)	50±55	78±61	0.03
CCS-SAF	3.1±0.6	3.1±0.6	0.48
Diabetes n (%)	5 (7)	1 (4)	0.58
Hypertension	29 (39)	11 (41)	0.85
IHD	6 (8)	3 (11)	0.63
CCF	2 (3)	0	0.39
Number of failed AAD	1.5±0.7	1.7±0.7	0.14

Table 2: Pulmonary vein anatomy

	AF Recurrence NO (n = 75)	AF Recurrence YES (n = 27)	P value
MRI n (%) of scans vs. CT	46 (61)	15 (56)	0.42
NavX n (%) of segmentation	67 (89)	20 (74)	0.06
CARTO n (%) of segmentation	8 (11)	7 (26)	0.06
Normal anatomy n (%)	29 (39)	19 (70)	<0.01
Left common PV	33 (44)	5 (19)	0.02
Right common PV	2 (3)	0	0.39
Accessory Right	17 (23)	3 (11)	0.19
PV area			
LSPV (cm^2)	2.1±0.7	2.3±0.6	0.28
LIPV	1.8±0.5	1.8±0.4	0.96
RSPV	3.0±2.3	2.9±0.7	0.86
RIPV	2.4±0.6	2.5±0.5	0.33
Left IVR			
Length mm	14.0±3.0	16.9±3.5	<0.001
Width	5.0±2.8	6.2±3.6	0.09
Area cm^2	1.1±0.6	1.4±0.6	0.02
Right IVR			
Length	19.9±3.1	20.7±2.6	0.26
Width	8.4±4.6	8.5±4.1	0.93
Area	2.0±0.5	2.0±0.5	0.96
Left PV-LAA ridge			
Length	35.3±5.6	37.7±9.9	0.14
Width	3.8±1.9	3.8±1.5	0.99
Area	1.6±0.8	1.6±0.6	0.93
Length<5mm #	13.4±9.7	10.6±9.4	0.20
Distance to 1st PV Branch			
LSPV	27.7±11.2	28.6±9.5	0.72
LIPV	22.6±7.4	22.8±6.5	0.88
RSPV	17.3±8.7	18.5±11.0	0.60
RIPV	11.6±6.7	11.8±5.4	0.93
Left atrium/ left ventricle			
Left atrial volume cm^3	60.3±17.3	58.7±13.0	0.67
LA area (cm^2)	24.9±6.3	26.9±4.2	0.27
LVEF	58.4±6.4	62.2±7.7	0.07

Table 3: Procedural characteristics

	AF Recurrence NO (n = 75)	AF Recurrence YES (n = 27)	P value
Procedure time (min)	163.4±35.4	172.8±36.0	0.25
Fluoroscopy time (min)	24.7±7.8	26.1±7.2	0.44
Radiation Dose (mGy/cm²)	45797±27652	48016±37253	0.76
Total RF time (min)	39.3±11.0	48.2±15.7	0.01
PV isolation	100%	100%	1.0
Acute reconnection	24 (32)	12 (44)	0.27

Table 4: Cox Regression Analysis

	Univariate		Multivariate	
	B	**P value**	**B**	**P value**
Age	0.015	0.520	-	-
Gender	0.067	0.878	-	-
AF duration	0.005	0.072	-	-
IHD	0.282	0.647	-	-
CCF	-3.039	0.596	-	-
Hypertension	0.047	0.909	-	-
DM	-0.501	0.623	-	-
LA size	0.026	0.538	-	-
LA volume	-0.005	0.713	-	-
LVEF	0.074	0.091	-	-
Procedure Duration	0.006	0.267	-	-
RF Duration	0.040	0.004	0.021	0.165
Acute Reconnection	0.459	0.255	-	-
Normal vs. Abnormal anatomy	1.095	0.011	1.022	0.038
Left common PV	-0.975	0.051	-	-
Right accessory PV	-0.820	0.183	-	-
Left IVR width	0.090	0.103	-	-
Left IVR length	0.202	<0.001	0.164	0.021
Left IVR area	0.659	0.024	0.020	0.958
Right IVR width	-0.005	0.913	-	-
Right IVR length	0.076	0.243	-	-
Right IVR area	-0.024	0.923	-	-
Left PV-LAA width	-0.019	0.863	-	-
Left PV-LAA length	0.060	0.097	-	-
Left PV-LAA area	-0.052	0.843	-	-

Figure legend

Figure 1: Representative postero-anterior projections: normal PV anatomy in A; left common PV in B; right middle PV in C and right common PV in D.

Figure 2: Schematic of intervenous ridge measurement: red represents left IVR area (hashed line) with arrows representing IVR width (vertical line) and length; green represents right IVR area (hashed line), width (vertical line) and length; blue represents left PV-LAA ridge area (hashed line), width (horizontal line) and length.

Figure 3: Representative examples of measurement of the IVRs and left PV-LAA ridge. A is an external view of the left IVR and left PV-LAA ridge (red represents the left IVR and blue represents the left PV-LAA ridge); B is an internal view of the left IVR/ left PV-LAA ridges; C is an external view of the right IVR (green hashed line represents the right IVR); D is an internal view of the right IVR.

Figure 4: Kaplan Meier analysis: Freedom from recurrent AF post procedure for normal vs. abnormal anatomy, and for left common PV vs. no left common PV.