Multimodality imaging to guide cardiac interventional procedures

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Impact of pulmonary vein anatomy and left atrial dimensions on the outcome of circumferential radiofrequency catheter ablation for atrial fibrillation

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ABSTRACT

Background: Multi-slice computed tomography (MSCT) is commonly acquired prior to radiofrequency catheter ablation (RFCA) for atrial fibrillation (AF) in order to plan and guide the procedure. Importantly, MSCT allows accurate measurement of left atrial (LA) and pulmonary vein (PV) dimensions and classification of PV anatomy.

Objective: The aim of this study was to investigate the impact of LA dimensions, PV dimensions and PV anatomy on the outcome of circumferential RFCA for AF.

Methods: One hundred consecutive patients undergoing RFCA for AF (paroxysmal 72%, persistent 28%) were studied. Left atrial dimensions, PV dimensions and PV anatomy were assessed in multiple directions on MSCT. Pulmonary vein anatomy was classified as normal or atypical based on the absence/presence of a common trunk or additional vein(s).

Results: After a mean follow up of 11.6 ± 2.8 months, 65 patients (65%) maintained sinus rhythm. Enlargement of the LA in anterior-posterior direction on MSCT was related to a higher risk for AF recurrence. No relation was found between PV dimensions and outcome of RFCA. In contrast, the presence of atypical right-sided PV anatomy was related to a reduced risk for AF recurrence. Multivariate analysis showed that anterior-posterior LA diameter on MSCT (OR=1.083, p=0.027), atypical right-sided PV anatomy (OR=0.149, p=0.006), and persistent AF (OR=3.004, p=0.035) were independent predictors of AF recurrence after RFCA.

Conclusions: Enlargement of anterior-posterior LA diameter and presence of atypical anatomy of the right PVs are independent risk factor for AF recurrence.

INTRODUCTION

Radiofrequency catheter ablation (RFCA) is considered a reasonable treatment option for patients with symptomatic drug-refractory atrial fibrillation (AF) (1). However, this treatment modality is associated with a considerable recurrence rate and a small risk for serious complications (2). Identification of pre-procedural risk factors for AF recurrence is mandatory to improve the outcome of RFCA.

Multi-slice computed tomography (MSCT) is nowadays commonly acquired prior to RFCA for AF. It provides important information about left atrial (LA) and pulmonary vein (PV) anatomy which can be used to plan and guide the RFCA procedure (3). Moreover, MSCT allows accurate multidirectional assessment of LA and PV dimensions (4,5). It has been demonstrated that LA and PV dimensions are enlarged in patients with AF (6,7). However, whereas LA size is a well-known risk factor for AF recurrence after RFCA (8-11), little is known about the prognostic importance of PV dilatation. Similarly, the impact of PV anatomy on the outcome of RFCA has not been studied extensively. Potentially, different anatomical drainage patterns could be accompanied by different tissue characteristics of the surrounding myocardium rendering the PV area more or less resistant to electrical isolation. Moreover, certain anatomical variants could pose a technical difficulty to achieve stable catheter position during ablation thereby compromising effective lesion formation. The aim of this study was to investigate the impact of multidirectional LA dimensions, PV dimensions and PV anatomy assessed by MSCT on the outcome of circumferential RFCA for AF.

METHODS

Study population

The study population comprised 100 consecutive patients with symptomatic drug-refractory AF, undergoing circumferential RFCA. After RFCA, all patients were evaluated on a regular basis at the outpatient clinic during a 12-month follow-up period. Routine electrocardiograms (ECG) were recorded each visit and 24-hour Holter registrations were scheduled at 3, 6 and 12 months after the ablation. All medications were continued for at least 3 months. Afterwards, anti-arrhythmic drugs were discontinued at the discretion of the physician. After a post-ablation blanking period of 3 months, recurrence of AF was defined as any recording of AF on ECG or an episode longer than 30 seconds on 24-hour Holter monitoring (1). After 12-month follow-up, the study population was divided into two groups: patients with maintenance of sinus rhythm (SR) (non-recurrence group) and patients who had recurrence of AF (recurrence group).

Multi-Slice Computed Tomography

Multi-slice computed tomography data were acquired prior to the ablation in order to guide the procedure (3). The MSCT scan was performed with a 64-slice Toshiba Aquilion 64 system (Toshiba Medical Systems, Otawara, Japan). A bolus of 70 ml nonionic contrast material (Iomeron 400, Bracco, Milan, Italy) was infused through the antecubital vein at a rate of 5 ml/s followed by 50 ml saline solution flush. Automatic detection of the contrast bolus in the descending aorta was used to time the start of the scan. Craniocaudal scanning was performed during breath-hold, without ECG-gating. Collimation was 64 x 0.5 mm, rotation time 400 ms and the tube voltage 100 kV at 250 mA. After acquisition, the raw MSCT data were exported, post-processed and analyzed on a dedicated workstation (Vitrea 2, Vital Images, Minnetonka, Minnesota, USA).

Pulmonary vein ostium dimensions were evaluated using a two-dimensional viewing mode. To allow accurate assessment, multiplanar reformatting was used by placing two orthogonal planes parallel to the course of the vein (Figure 1, panel A and B). The third orthogonal plane, orientated perpendicular to the course of the vein, was then used to measure the diameter of the PV ostium in anterior-posterior (AP) and superior-inferior (SI) direction (Figure 1, panel C). The ratio between the largest and smallest diameter was calculated in order to obtain information on the oval shape of the ostium. Similarly, multiplanar reformatting was used to assess LA dimensions in 3 orthogonal directions: AP, longitudinal and transversal direction (Figure 2).

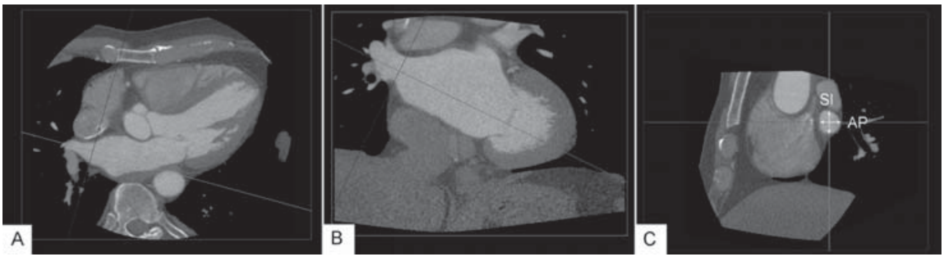

Figure 1. To assess pulmonary vein diameters, two orthogonal planes were placed parallel to the course of the vein (panel A and B). A third orthogonal plane (panel C), oriented perpendicular to the course of the vein, was then used to measure the anterior-posterior (AP) and superior-inferior (SI) pulmonary vein diameter (white arrows).

Pulmonary vein anatomy was analyzed from an external view using a 3D volume-rendered reconstruction. Pulmonary vein classification was based on the presence or absence of a common trunk and/or additional vein(s) (Figure 3). A common trunk was defined as a conjoined part of more than 5 mm in which both superior and inferior PV drain before entering the LA. An additional vein was defined as a supernumerary vein directly entering the LA.

To evaluate the impact of PV anatomy on the outcome of RFCA for AF, left- and right-sided anatomy was additionally classified as normal or atypical. Atypical anatomy was defined as the presence of a common trunk or an additional PV.

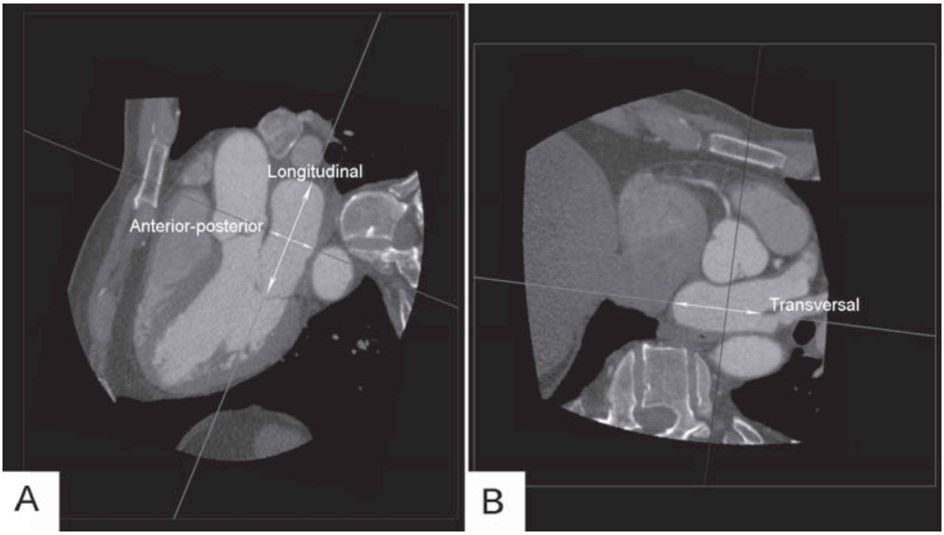

Figure 2. The left atrial (LA) dimensions (white arrows) were assessed in three orthogonal directions by using multiplanar reformatting. Panel A: LA dimensions in anterior-posterior (AP) (red line) and longitudinal direction (green line). Panel B: LA dimension in transversal direction (green line). Panel B is a cross-section of panel A at the level of the crosshair and parallel to the red line.

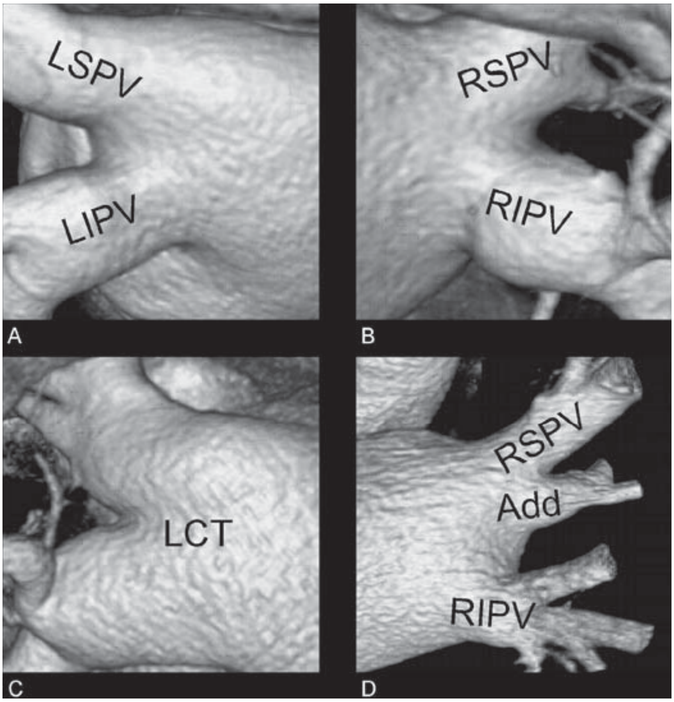

Figure 3. Panel A: Separate ostia of the left-sided pulmonary veins; Panel B: Separate ostia of the right-sided pulmonary veins; Panel C: Common trunk of the left-sided pulmonary veins (defined as a conjoined part of more than 5 mm); Panel D: Additional right-sided pulmonary vein (defined as a supernumerary vein directly entering the left atrium). Add = additional pulmonary vein, LIPV = left inferior pulmonary vein, LSPV = left superior pulmonary vein, RIPV = right inferior pulmonary vein, RSPV = right superior pulmonary vein.

Radiofrequency catheter ablation

The RFCA procedure was aimed at creating two circumferential lesions around the left- and right-sided ipsilateral PVs approximately 1 cm outside the ostia. All patients received intravenous heparin to maintain an activated clotting time of 300-400 s. Intracardiac echocardiography was used to guide the transseptal puncture. To guide the ablation, a non-fluoroscopic electroanatomical mapping system with MSCT integration was used (CARTO XP^{TM} with Cartomerge^{TM}, Biosense Webster, Diamond Bar, California, USA). Contact mapping and ablation was performed using a 4-mm quadripolar open-loop irrigated mapping/ablation catheter (7Fr Navistar^{TM}, Biosense Webster). A 6Fr quadripolar diagnostic catheter placed inside the right atrium served as a temporal reference. Radiofrequency current was applied at 30-35 W with a maximum temperature of 45°C and an irrigation flow of 20 ml/min until a bipolar voltage of <0.1 mV was achieved, with a maximum of 60 s per point. The end-point of the procedure was PV isolation as confirmed by recording entrance block during SR or pacing from inside the coronary sinus (1).

Statistical analysis

Data are presented as mean ± SD or as number (percentage). Statistical comparisons for continuous variables were performed with the two tailed Student's t-test, paired or unpaired as appropriate. Statistical comparisons for categorical variables were performed with the Chi-square test. Univariate and multivariate logistic regression analyses were performed to study the impact of PV anatomy, PV dimensions, LA dimensions and clinical characteristics on the incidence of AF recurrence after RFCA. Variables with a p-value <0.05 in the univariate analyses were included into the multivariate analysis. Multivariate analysis was performed using an 'enter' method. All statistical analyses were performed with SPSS software (version 16.0, SPSS Inc., Chicago, Illinois, USA). A p-value of <0.05 was considered statistically significant.

RESULTS

One hundred consecutive patients were included (77 men, mean age 56 ± 9 years), from an ongoing clinical registry (12). Atrial fibrillation was paroxysmal in 72 patients and persistent in 28 patients according to American College of Cardiology/American Heart Association/European Society of Cardiology guidelines definitions (13). None of the patients had previously undergone RFCA for AF. Median duration of AF was 48 months (interquartile range: 24-84) and the mean number of anti-arrhythmic drugs used was 3.1 ± 1.3 per patient. The mean AP diameter of the LA was 43 ± 6 mm and the mean left ventricular ejection fraction was 58 ± 8% on transthoracic echocardiography (Table 1). The procedural end-point of PV isolation was achieved in all patients.

After a mean follow-up of 11.6 ± 2.8 months, 65 patients (65%) had maintained SR (non-recurrence group), whereas 35 patients (35%) had recurrence of AF (recurrence group). In

Table 1. Baseline characteristics

	Total study population (n = 100)
Age (years)	56.4 ± 8.6
Gender (male/female)	77/23
Body Surface Area (m^2)	2.1 ± 0.2
Type of AF (paroxysmal/persistent)	72/28
Duration of AF (months)	64 ± 60
Anti-arrhythmic drugs used per patient	3.1 ± 1.3
Hypertension, n (%)	53 (53)
Coronary artery disease, n (%)	8 (8)
Diabetes, n (%)	8 (8)
Echocardiography	
Anterior-posterior LA diameter (mm)	43 ± 6
Left ventricular ejection fraction (%)	58 ± 8

AF = atrial fibrillation; LA = left atrium.

the recurrence group a higher prevalence of persistent AF was found compared to the non-recurrence group (14 [22%] vs 14 [40%], p=0.049).

Left atrial dimensions

Left atrial dimensions were measured in three orthogonal directions on MSCT: AP, longitudinal and transversal (Figure 2). Mean AP diameter was 41 ± 7 mm, mean longitudinal diameter was 65 ± 8 mm and mean transversal diameter was 59 ± 7 mm. Anterior-posterior LA diameter was significantly larger in the recurrence group than in the non-recurrence group (43 ± 6 mm vs. 39 ± 7 mm, p=0.02). Interestingly, no differences were found between the recurrence group and non-recurrence group in longitudinal (64 ± 7 mm vs. 65 ± 9 mm, p=0.45) and transversal (59 ± 7 mm vs. 60 ± 7 mm, p=0.57) LA diameter.

Pulmonary vein dimensions

Pulmonary vein ostial dimensions were assessed in AP and SI direction on MSCT (Table 2). Pulmonary vein dimensions were larger in SI direction than in AP direction (21.1 ± 2.3 mm vs. 16.3 ± 2.5 mm, p<0.001). Overall, right-sided PVs had a larger diameter than left-sided PVs (20.0

Table 2. Pulmonary vein measurements on MSCT

	AP diameter (mm)	SI diameter (mm)	Mean diameter (mm)	Ratio
RSPV	18.8 ± 4.2	23.3 ± 4.5	21.0 ± 4.0	0.80 ± 0.11
RIPV	17.7 ± 2.9	20.3 ± 3.2	19.0 ± 2.8	0.87 ± 0.10
LSPV	14.3 ± 2.6	21.1 ± 3.6	17.7 ± 2.4	0.67 ± 0.13
LIPV	12.1 ± 2.7	18.8 ± 2.5	15.4 ± 2.0	0.65 ± 0.15
ADD	8.9 ± 3.1	10.1 ± 2.4	9.5 ± 2.5	0.82 ± 0.11
LCT	19.5 ± 4.5	33.5 ± 4.7	26.5 ± 3.4	0.59 ± 0.15
All RPV	18.2 ± 2.5	21.8 ± 2.8	20.0 ± 2.4	0.83 ± 0.08
All LPV	13.2 ± 2.5	19.9 ± 2.0	16.6 ± 1.6	0.66 ± 0.11
All PV	16.3 ± 2.5	21.1 ± 2.3	18.7 ± 2.2	0.77 ± 0.09

ADD = additional pulmonary vein; AP = anterior-posterior; LCT = left common trunk; LIPV = left inferior pulmonary vein; LPV = left pulmonary veins; LSPV = left superior pulmonary vein; RIPV = right inferior pulmonary vein; RPV = right pulmonary veins; RSPV = right superior pulmonary vein; SI = superior-inferior

± 2.4 mm vs. 16.6 ± 1.6 mm, p<0.001). Similarly, superior PVs had a larger diameter than inferior PVs (19.6 ± 3.8 mm vs. 17.5 ± 3.1 mm, p<0.001). With regard to the shape of the PV ostium, left-sided PVs had a more pronounced oval shape than right-sided PV ostia indicated by a lower ratio between the largest and smallest PV diameter (ratio 0.65 ± 0.09 vs. 0.84 ± 0.09, p<0.001).

In contrast to AP LA dimension, PV dimensions were not related to the recurrence of AF during follow-up: no differences were found in mean PV diameter between the recurrence and non-recurrence group (18.8 ± 2.2 mm vs.18.6 ± 2.2 mm, p=0.74). In addition, a similar oval shape of the PV ostia was found in the both groups (non-recurrence group vs. recurrence group: 0.77 ± 0.09 vs. 0.77 ± 0.09, p=0.73).

Pulmonary vein anatomy

Pulmonary vein anatomy was classified based on the presence or absence of a common trunk and/or additional PV. A total of 174 left-sided PVs and 226 right-sided PVs were identified on MSCT. Separate ostia of the left superior PV and left inferior PV were present in 74 patients (74%) and a common trunk of the left PVs was present in the remaining 26 patients (26%). Separate ostia of the right superior PV and right inferior PV were observed in 78 patients (78%), an additional right-sided PV in 18 patients (18%) and 2 additional right-sided veins in 4 patients (4%). Accordingly, atypical anatomy of the left-sided PVs was present in 26 patients (26%) and atypical anatomy of the right-sided PVs was observed in 22 patients (22%).

Atypical anatomy of the right-sided PVs was associated with a significantly lower risk for AF recurrence than normal anatomy of the right-sided PVs (unadjusted OR: 0.136, p=0.010). In contrast, the presence of atypical anatomy of the left-sided PVs had no significant impact on the outcome of RFCA (unadjusted OR: 0.466, p=0.14).

Predictors of AF recurrence

Univariate logistic regression analyses were performed to study the impact of LA dimensions, PV dimensions and PV anatomy, as well as clinical risk factors (e.g. type of AF, hypertension) on the outcome of RFCA for AF (Table 3). A large AP LA diameter was related to a higher risk for recurrent AF after RFCA (unadjusted OR: 1.082, p=0.021). Similarly, patients with persistent AF had a higher risk for AF recurrence (unadjusted OR: 2.429, p=0.049). In contrast, the presence of atypical right-sided PV anatomy was related to a lower risk for AF recurrence (unadjusted OR: 0.136, p=0.010). Subsequent multivariate analyses demonstrated that AP LA diameter, type of AF and right-sided PV anatomy were independent predictors of AF recurrence (OR: 1.083, p=0.027, OR: 3.004, p=0.035 and OR: 0.149, p=0.006, respectively) (Table 4).

Table 3. Univariate logistic regression analysis of clinical and anatomical characteristics on MSCT as risk factors for recurrence of AF after RFCA

	OR	95% CI	P-value
Clinical characteristics			
Age (years)	1.027	0.978-1.079	0.28
Male gender	1.012	0.381-2.691	0.98
AF duration (months)	1.032	0.952-1.118	0.45
Failed anti-arrhythmic drugs (n)	1.109	0.802-1.532	0.53
Persistent AF	2.429	0.989-5.963	0.05*
Hypertension	0.908	0.399-2.067	0.82
Left atrial AP diameter (TTE)	1.042	0.966-1.125	0.29
Left ventricular ejection fraction (%)	0.971	0.920-1.026	0.30
MSCT characteristics			
Right atypical anatomy	0.136	0.030-0.624	0.010*
Left atypical anatomy	0.466	0.167-1.297	0.14*
Mean PV diameter	1.033	0.856-1.247	0.73
Left atrial diameter			
AP (mm)	1.082	1.012-1.156	0.021*
Longitudinal (mm)	1.021	0.967-1.078	0.45
Transversal (mm)	1.018	0.958-1.082	0.57

* included in multivariate logistic regression analysis; ECV = electrocardioversion; TTE = transthoracic echocardiography; other abbreviations as in Table 2.

Table 4. Multivariate logistic regression analysis of clinical and anatomical characteristics on MSCT as risk factors for recurrence of AF after RFCA

	OR	95% CI	P-value
Clinical characteristics			
Persistent AF	3.004	1.082-8.345	0.035
MSCT characteristics			
Right complex anatomy	0.149	0.038-0.576	0.006
Left atrial AP diameter (mm)	1.083	1.009-1.162	0.027

DISCUSSION

The present study investigated the impact of LA dimensions, PV dimensions and PV anatomy on the outcome of circumferential RFCA for AF. The main findings can be summarized as follows: enlargement of the LA in AP direction on MSCT is an independent predictor of AF recurrence after RFCA. In contrast, PV dimensions are not related to the outcome of RFCA. Finally, atypical anatomy of the right-sided PVs is independently associated with less recurrences of AF after RFCA.

Left atrial dimensions

Left atrial enlargement is an important risk factor for the development of AF in the general population (14) and has been identified as an independent predictor of AF recurrence after RFCA (8-11). Heavily dilated atria are thought to contain a large extent of atrial remodeling thereby limiting the efficacy of RFCA. Multislice CT allows accurate measurement of LA dimensions and is commonly acquired prior to RFCA in order to plan and guide the procedure (3). The present study evaluated LA dimensions in three orthogonal directions on MSCT: AP, longitudinal and transversal. Anterior-posterior LA diameter on MSCT was identified as an independent predictor of AF recurrence, whereas longitudinal and transversal LA diameters were not. Interestingly, atrial dilatation is thought to be predominantly oriented in longitudinal and transversal direction and not in AP direction (15). A potential explanation for our finding is that dilatation of the LA in AP direction occurs at a more advanced stage of atrial enlargement and reflects a higher extent of atrial remodeling, thereby explaining its prognostic value. Importantly, AP LA diameter was a strong predictor of AF recurrence even after correction for type of AF.

Pulmonary vein dimensions

Similar to LA dimensions, PV dimensions are enlarged in patients with AF (6,7). However, little is known about the prognostic importance of PV dilatation in patients undergoing RFCA for AF. The present study evaluated the impact of PV ostial dimensions assessed by MSCT on the outcome of RFCA for AF. No differences were found in PV dimensions or shape between patients with AF recurrence and patients without AF recurrence during follow-up. These results suggest that PV dilatation has no prognostic importance for the outcome of circumferential RFCA. Most likely, PV dilatation is caused by the presence of AF and can be best considered an epiphenomenon.

Pulmonary vein anatomy

The observations by Haïssaguerre et al. that ectopic beats originating from the PVs can initiate AF, have led to an increasing interest in the PVs as target for RFCA (16). Nowadays, isolation of the PV region is the cornerstone for most ablation strategies (1). However, the relation between the anatomy of the PV region and the efficacy RFCA for AF has not been studied extensively. Several studies have shown that large variations in pulmonary venous drainage pattern into the LA exist (5,17-20). Potentially, certain anatomical variants could pose a technical challenge to achieve stable catheter position thereby influencing the outcome of RFCA. Moreover, different venous drainage patterns could be accompanied by different tissue characteristics of the surrounding myocardium rendering the PV area more or less resistant to electrical isolation.

In the present study, the relation between PV anatomy and outcome of AF ablation was studied in 100 consecutive patients undergoing circumferential RFCA. Pulmonary vein anatomy was analyzed on MSCT and classified according to the presence or absence of a common trunk and/or additional PV as either normal or atypical. Atypical anatomy of the right-sided PVs was associated with a decreased risk for AF recurrence after RFCA. After correction for AP LA diameter and type of AF, right-sided PV anatomy remained an independent predictor of AF recurrence after RFCA. Potential explanations for these results include that an atypical PV drainage pattern may be accompanied by an increased susceptibility of the surrounding myocardial tissue for electrical isolation or a lower likelihood for PV ectopy originating from the right-sided PVs. Furthermore an atypical PV drainage pattern may pose less technical difficulty to achieve stable catheter position, resulting in a more effective lesion formation and a lower risk for electrical reconnection.

Recently, Hof et al reported on the impact of PV anatomy on the efficacy of RFCA in 146 patients (9). Interestingly, no relation was found between PV anatomy and outcome of RFCA. However, several differences can be identified between their work and the present study that could have caused this discrepancy. Most importantly, the definition of outcome used by Hof et al included three categories (failure, improvement of AF burden and complete success) (9), whereas the present study only considered two (AF recurrence and non-recurrence). The use of this definition of outcome may also explain why type of AF, which is a commonly accepted risk factor for AF recurrence (1) was not related to outcome in their study (9).

Clinical implications

Despite the introduction of new devices to perform PV isolation, circumferential RFCA remains a widely used ablation strategy. Multi-slice computed tomography is commonly performed prior to these procedures. The present study demonstrates that AP LA dimension and PV anatomy on MSCT have an important impact on the likelihood to maintain SR after RFCA. In patients undergoing RFCA for AF, information about LA size and PV anatomy on MSCT can be used to decide whether circumferential RFCA alone is sufficient or additional ablation lesions (e.g. PV carina ablation) may be needed to improve outcome.

Limitations

The present study represents a single center experience. In addition, the number of evaluated patients is relatively small; nonetheless, statistical significance was reached. The applicability of MSCT as a pre-procedural patient selection tool is limited by the radiation exposure of this technique. However, since MSCT is commonly acquired prior to RFCA to plan and guide the procedure, the present results may help determine whether additional ablation is needed in patients who are undergoing circumferential ablation.

CONCLUSIONS

Right-sided PV anatomy is an independent predictor of AF recurrence after circumferential RFCA for AF. In addition, enlargement of the LA in AP direction and type of AF are independent pre-procedural risk factors for recurrence of AF after circumferential RFCA.

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