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CLINICAL RESEARCH
Ablation for atrial fibrillation

Duty-cycled bipolar/unipolar radiofrequency ablation for symptomatic atrial fibrillation induces significant pulmonary vein narrowing at long-term follow-up

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Aims A novel duty-cycled bipolar/unipolar ablation catheter pulmonary vein ablation catheter (PVAC) has been developed to achieve pulmonary vein (PV) isolation in patients with atrial fibrillation (AF). Ablation with PVAC was recently found to induce PV narrowing at 3 months follow-up. The long-term effects of this catheter on PV dimensions are however unknown and were evaluated with this study.

Methods and results Patients ($n = 62$, 71% male, age 60 ± 7 years) with drug-refractory AF scheduled for a first ablation procedure were evaluated. A multi-slice computed tomography (MSCT) scan was performed before and 1 year after the initial procedure. Pulmonary vein dimensions and left atrial (LA) volume were measured on MSCT. To correct for reverse remodelling of the LA, the ostial area/LA volume ratio before and after PVAC was calculated. As reverse remodelling may depend on procedural outcome, patients were divided in two groups depending on sinus rhythm (SR) maintenance or AF recurrence 1 year after ablation. Baseline characteristics were comparable between the SR group ($n = 41$) and the AF recurrence group ($n = 21$). At one year follow-up, ostial area of the PVs ($n = 219$) was significantly reduced from 236 ± 7.0 to 173 ± 7.4 mm^2 (27% narrowing, $P < 0.01$), independent of ablation outcome. Pulmonary vein narrowing was mild in 37% of PVs (25–50%), 9% was moderate (50–70%), and 3% severe (>70%).

Left atrial volumes were found to be significantly reduced after ablation (14 and 5% for the SR group and AF recurrence group, respectively, $P < 0.01$). After adjustment for LA volume reduction, narrowing of PV ostial area remained significant in these patients ($P < 0.01$).

Conclusion Ablation with PVAC results in a significant decrease in PV dimensions after long-term follow-up. In line with previous literature, PV narrowing was mild and patients did not develop any clinical symptoms.

Keywords Atrial fibrillation • Radiofrequency ablation • PVAC-catheter • Multi-slice CT scan • Pulmonary vein narrowing • Pulmonary vein notching

Introduction

Catheter ablation is an established therapy for drug refractory symptomatic atrial fibrillation (AF).[1] As ~90% of AF originates from ectopic foci in the pulmonary veins (PVs), the primary goal of the ablation procedure is electrical isolation of the PVs.[2] The standard method for pulmonary vein isolation (PVI) is applying radiofrequency (RF) energy using an irrigated-tip catheter in a point-by-point manner. Although this approach has an acceptable efficacy, the procedure is complex and time-consuming.[3] In addition, a complication rate of ~6% has been described, including 1.3% PV stenosis (>50% PV narrowing).[4]

A novel circular decapolar catheter pulmonary vein ablation catheter (PVAC, Medtronic AF solutions) serving as both mapping and

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What's new?

- Ablation with the duty-cycled bipolar/unipolar PVAC catheter leads to significant pulmonary vein (PV) narrowing (mean 27%) on multi-slice computed tomography scan after 12 months follow-up
- Pulmonary vein remodelling remains significant after correction for left atrial reverse remodelling
- In 18% of patients, local stenosis or notching of one PV was described, which related to 5.0% of treated PVs. Local notching was mild in 4.0% of these PVs (25–50% narrowing)

ablation device has been developed to shorten procedural time and simplify the ablation technique. Through the electrodes of the catheter, duty-cycled unipolar energy (from the poles to the backpatch) and bipolar energy (between the poles) can be delivered.[5] The efficacy of PVAC, defined as restoration and maintenance of sinus rhythm (SR), has been observed to be ~70% after 12 months.[6,7]

Besides complications related to ablation procedures in general, specific complications associated with the use of the PVAC catheter are largely unknown.[8] Potentially, the design of the catheter leads to a more distal location at the ostium of the PVs during ablation compared with circumferential PVI with an irrigated-tip catheter.[9] As the electrodes of the PVAC catheter are non-cooled, local temperatures of up to 60° may be reached, leading to endothelial damage.[10] Both the position of the catheter during ablation and the high local temperatures reached may cause local PV notching at the side of RF energy application or uniform PV narrowing, which has recently indeed been described by de Greef *et al.*[11] 3 months after ablation. Pulmonary vein dimensions may, however, also decrease as part of the physiological reverse remodelling of the entire left atrium (LA), which has been observed after point-by-point ablation.[12,13]

Severe PV stenosis, defined as narrowing of PV diameter of >70%, can lead to a serious clinical condition, potentially inducing dyspnoea, thoracic pain, and right-sided heart failure due to decreased venous drainage of the lungs.[14] Until now, it is unclear as to whether PV stenosis remains stable more than 3 months after an ablation procedure.

The aim of the current study was to investigate the long-term effect of ablation with PVAC on PV dimensions and local notching, which was assessed on multi-slice computed tomography (MSCT) before and 12 months after ablation. Furthermore, LA reverse remodelling and the effect of ablation outcome, defined as SR maintenance or AF-recurrence, was evaluated. The hypothesis was that the PVAC catheter causes significant PV narrowing, independent of LA reverse remodelling.

Methods

Patients

The population consisted of consecutive patients with symptomatic paroxysmal or persistent drug refractory AF scheduled for a first catheter-guided PVI. Patient data were prospectively collected in the departmental Cardiology Information System (EPD-Vision®, Leiden University Medical Center, Leiden, The Netherlands) and subsequently analysed. According to the standard clinical evaluation protocol, all patients underwent an MSCT scan prior to ablation to evaluate PV and LA anatomy and 1 year after ablation to rule out PV stenosis.[9] Patients who underwent a second ablation procedure had their follow-up scan performed just before this procedure. Patients were followed up at the outpatient clinic 3, 6, and 12 months after the procedure. Evaluation included three 24 h Holter registrations. Patients with diagnosed local PV notching >50% underwent a pulmonary ventilation/perfusion scan to detect possible perfusion deficits of the lungs due to reduced venous drainage.

All patients provided oral informed consent for the ablation procedure and subsequent follow-up.

Exclusion criteria included contra-indications for CT including contrast allergy and claustrophobia and previous (catheter-guided) ablation for AF.

Ablation procedure

During hospitalization, oral anticoagulation was continued in order to maintain an international normalized ratio between 2.0 and 3.0. The ablation procedure was performed under local anaesthesia and intravenous analgesia. After venous access, 5000 IU heparin was administered. Additional heparin was given during the procedure to maintain an activated clotting time between 300 and 400 s. A reference catheter was placed in the coronary sinus (CS). Under fluoroscopic and intracardiac echocardiography (ICE) guidance, the PVAC catheter was subsequently placed at the ostia of the PVs. A multi-channel RF generator delivered RF energy in a duty-cycled manner in a bipolar : unipolar ratio of either 4 : 1 or 2 : 1, creating both adjoining and transmural lesions (Genius, Medtronic Ablation Frontiers). Depth of the created ablation lines differs from 3 to 4 mm when using 4 : 1 energy to 7 mm using 2 : 1 energy delivery.[15] Each RF application was continued for 60 s. Temperature increased until a maximum power of 8 W was reached in case of 4 : 1 energy delivery and 10 W in case of 2 : 1 energy delivery.

Procedural outcome

Success of the ablation procedure was defined as isolation of all PVs, which was checked immediately after ablation of each PV. Isolation was confirmed by verification of the signals with and without CS pacing using the reference catheter and by the existence of an exit block with pacing from the PVAC catheter. Pulmonary vein isolation was checked again 30 min after isolation of all PVs to exclude early reconnection.

Atrial fibrillation recurrence was defined as any recording of AF on electrocardiogram or an AF episode >30 s on 24 h Holter registration after a blanking period of 3 months. Anti-arrhythmic medication was continued until a minimum of 3 months after the procedure.

Multi-slice computed tomography scan

An MSCT scan (Aquilion ONE) was performed before and 12 months after the ablation to establish LA anatomy and to calculate PV dimensions. Patients received 90 ml of iodinated contrast during the MSCT-scan. Craniocaudal scanning was started after automatic detection of contrast in the left ventricle with a threshold of +180 Hounsfield units. The scan was performed during breath hold, with a rotation time of 350 ms. Tube voltage, adjusted for body mass index, was 100, 120 or 135 kV at 400–580 mA. The phase window was 70–80% of the R-R interval if the heart rate was stable and <65 b.p.m. If the heart rate was over 65 b.p.m. or irregular, the phase window was set at 30–80%. Reconstruction of the images was at 75% of the R-R interval and in case of motion artefacts at multiple other phases as well to obtain optimal image quality. The raw data were exported to the Vitrea work-station for further analysis (Vitrea 2).

A two-dimensional (2D) model of the MSCT scan was used to assess PV diameters and ostial area. Cross-sections of PV ostia were obtained by applying two orthogonal planes to PV on a transversal slice of LA (*Figure 1*). One plane was placed parallel to the long-axis of the vein, the other was placed at the ostium perpendicular to the long-axis of the vein. Diameters and cross-sectional area were measured manually and automatically calculated by Vitrea.

Pulmonary vein narrowing was defined as either the presence of an apparent circumscriptive notch in the lumen (*Figure 2A*) or a uniform reduction in PV dimensions (*Figure 2B*).

Left atrial volumes were also measured on MSCT scan before and 1 year after ablation with PVAC. The change in LA volume 1 year after ablation was calculated, since it can be expected that LA reverse remodelling includes the PV ostia. The modified Simpson's method was applied for the measurement of LA volumes.[16] Volumes were automatically calculated by Vitrea and manually corrected to secure exclusion of PVs.

Statistical analysis

Statistical analysis was performed using SPSS (version 17.0, SPSS Inc.). Continuous data were expressed as mean ± standard error of the mean, tested for normality and compared with linear mixed model analysis, clustering PV dimensions of each individual patient and evaluating the influence of ablation and procedural outcome. Dichotomous variables were expressed as numbers and percentages and analysed with the χ^2 test or Fisher's exact test as appropriate. The relation between changes in LA volume and PV ostial area was investigated with Pearson correlation. A P value of <0.05 was considered statistically significant.

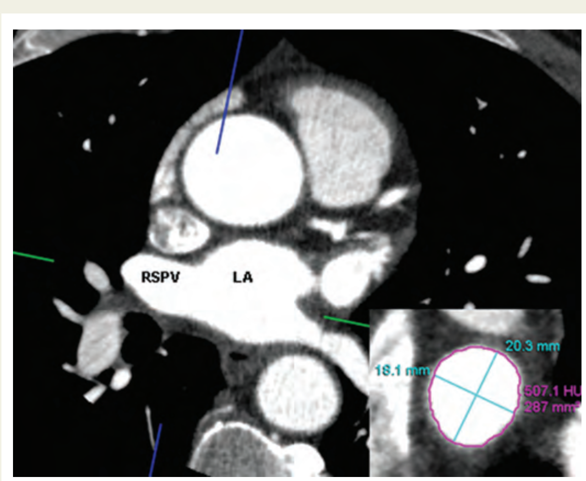

Figure 1 Main figure depicts a reconstructed transverse MSCT image through the left atrium and RSPV. The inset illustrates an orthogonal view of the cross-section of the RSPV ostium from which the PV diameters and area were measured. RSPV, right superior pulmonary vein; LA, left atrium.

Results

This study included 73 consecutive patients [46 men (64%), mean age 60 ± 7.3 years]. During a mean follow-up period of 12 months, 11 (15%) patients did not receive the follow-up MSCT-scan. These patients either refused the second MSCT scan, had their follow-up performed in another hospital or were lost-to-follow-up. In 4 patients, the MSCT scan was performed after 9–10 months follow-up due to a scheduled second ablation procedure. A total of 248 PVs in 62 patients were included at follow-up. A left or right common ostium was present in 17 patients and 12 individual PVs could not be judged due to an inadequate scan range, which excluded the PVs from the MSCT image. After exclusion, 219 PVs were available for analysis.

One year after ablation, 50 (68%) patients were in SR, without usage of anti-arrhythmic drugs. At least one episode of AF-recurrence was observed in 23 (32%) patients. Baseline characteristics of patients with an MSCT scan before and after the procedure were found to be comparable between patients with SR maintenance and patients with AF recurrence (*Table 1*).

Pulmonary vein narrowing

Pulmonary vein dimensions showed a significant uniform decrease 12 months after ablation (*Figures 3* and *4*). Pulmonary vein ostial area decreased from 236 ± 7.0 to 173 ± 7.4 mm^2 (mean reduction 27%, *Figure 3*, $P < 0.01$), minimal diameter decreased from 14.7 ± 0.29 to 12.3 ± 0.26 mm (mean reduction 16%, $P < 0.01$), and maximal diameter from 18.9 ± 0.33 to 16.9 ± 0.34 mm (mean reduction 11%, $P < 0.01$), independent of ablation outcome ($P = 0.447$). Pulmonary vein narrowing based on ostial area reduction was insignificant in 52% of the PVs (< 25%), mild in 37% (25–50%), moderate in 9% (50–70%), and severe in 3% (>70%, *Table 2*). Moderate and severe stenosis was found most often in the left superior PV.

The LA volume in patients with SR 12 months after ablation decreased from 106 ± 22 to 91 ± 20 cm^3 (14%, $P < 0.01$). The mean decrease in ostial area of the PVs in these patients was 31%. The LA volume in the AF-recurrence group decreased from 102 ± 24 to 97 ± 24 cm^3 (5%, $P = 0.015$). The mean decrease in PV ostial area in the corresponding patients was 22%. Left atrial volume reduction was significantly higher in the SR group compared with the AF recurrence group ($P < 0.01$). A weak, but significant, relation was observed between LA volume reduction and PV ostial area reduction ($R = 0.237$, $P < 0.01$). In spite of this weak relation, we corrected PV ostial area reduction for LA volume reduction by calculating the ratio of ostial area/LA volume (mm^2/cm^3) before and after ablation. Pulmonary vein ostial area/LA volume ratio still showed a significant decrease in both groups from 2.42 ± 0.67 before ablation to 1.97 ± 0.68 1 year after PVAC (*Figure 4*, $P < 0.01$), also independent of ablation outcome ($P = 0.610$).

Local pulmonary vein notching

Based on the follow-up MSCT scan, 11 cases of local notching of one of the PVs were diagnosed in 11 patients. One case was classified as severe (>70%), one case as moderate (50–70%), and the remaining cases as mild (25–50%). No complaints of dyspnoea,

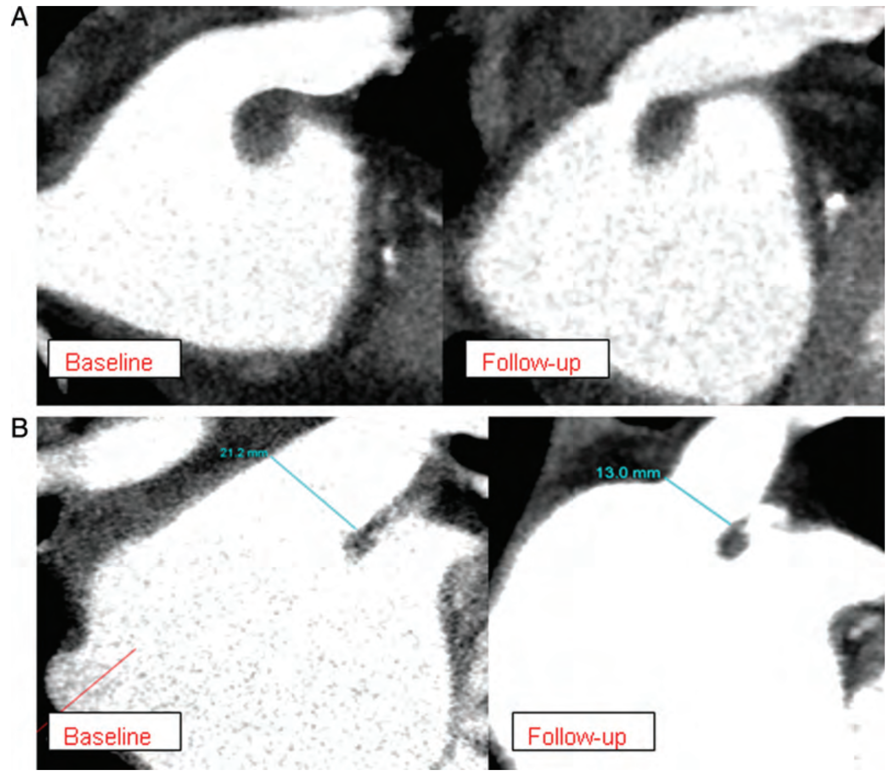

Figure 2 (*A*) Left superior PV before and after PVAC with narrowing of the lumen and notch formation. (*B*) Left superior PV before and after PVAC with narrowing of the lumen, but without notch formation.

Table 1 Baseline characteristics

Baseline parameter	Sinus rhythm group (n = 41)	AF recurrence group (n = 21)	*P* value
Male gender, n (%)	27 (66)	17 (81)	0.22
Age (±SD)	60.9 ± 6.9	58.5 ± 7.0	0.19
AF type: paroxysmal, n (%)	39 (95)	20 (95)	0.98
AF duration (years, ±SD)	4.4 ± 3.6	5.7 ± 5.0	0.23
LA diameter on echo (mm, ±SD)	40.5 ± 4.2	40.0 ± 6.2	0.73

haemoptysis, or shortness of breath were registered. The ventilation/perfusion scans were performed in all patients with diagnosed PV notching >50% and showed no abnormalities.

The incidence of local notching was compared between ablation with RF energy delivery at 4 : 1 and at 2 : 1 (unipolar : bipolar). In 46 patients, 4 : 1 energy delivery was applied, while in 27 patients 2 : 1 energy delivery was used. The incidence of mild notching tended to be higher after ablation with 4 : 1 RF energy, including 8 out of 11 cases. This difference was however not significant (P = 0.1). No further differences were observed between both groups.

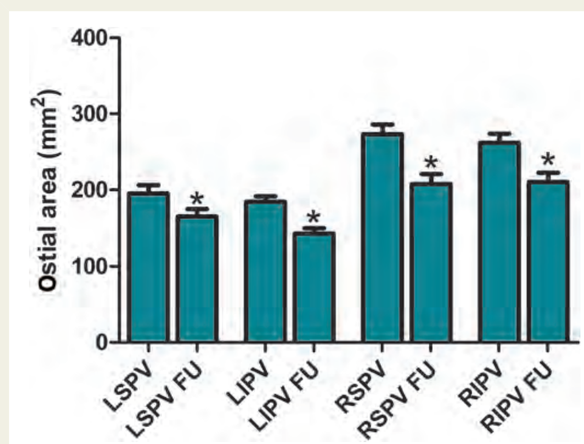

Figure 3 Ostial area of PVs before (234 mm^2) and 12 months after ablation (171 mm^2, follow-up, FU) in all patients (*significant decrease compared with baseline, $P < 0.01$). LSPV, left superior pulmonary vein; LIPV, left inferior pulmonary vein; RSPV, right superior pulmonary vein; RIPV, right inferior pulmonary vein.

Discussion

Key findings of this study are (i) ablation with a duty-cycled circular ablation device (PVAC) leads to narrowing of all PVs at long-term follow-up, even when corrected for LA reverse remodelling. (ii) Ablation with PVAC leads to a local PV notching rate of 5%. To the best of our knowledge, this is the first study investigating PV narrowing due to PVAC ablation after long-term follow-up.

Procedural outcome

Several studies investigated the efficacy of the PVAC ablation technique. Bittner *et al.*[6] studied freedom of AF recurrence using either point-by-point ablation or PVAC. Both procedures showed an equal short- and middle-term success rate of 68 vs. 72%, respectively. Beukema *et al.*[7] found that 61% of patients were still in SR 12 months after ablation with PVAC without usage of anti-arrhythmic drugs. In agreement with this, a success rate of 68% without usage of anti-arrhythmic drugs was reported in this study 1 year after ablation.

Pulmonary vein narrowing

The definitions of PV stenosis or narrowing and local PV notching have been used interchangeably in previous literature.[17,18] There is no consensus on the usage of both terms. However, both conditions lead to decreased PV dimensions, potentially causing increased PV resistance and reduced blood flow (*Figure 2A* and *B*).

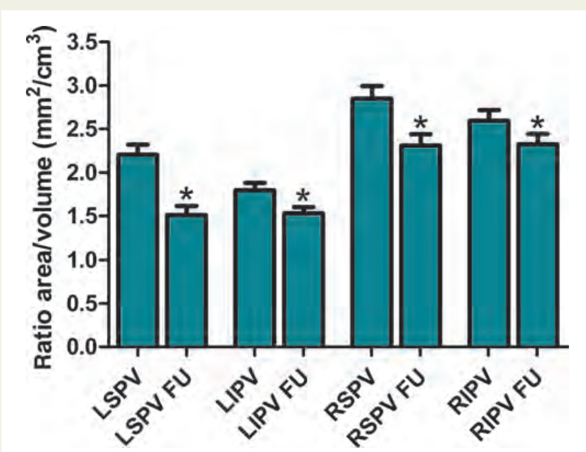

Figure 4 Ostial areas of PVs corrected for LA remodelling before and 1 year after PVAC in all patients (*significant decrease compared with baseline, $P < 0.01$). LSPV, left superior pulmonary vein; LIPV, left inferior pulmonary vein; RSPV, right superior pulmonary vein; RIPV, right inferior pulmonary vein; FU, follow-up.

Pulmonary vein dimensions were significantly reduced when compared with dimensions before ablation in all patients. Although a uniform reduction was found, the ostial area narrowing was insignificant or mild in 89% of PVs (<50%, *Table 2*). Moderate and severe PV narrowing was less frequent and found most often in the left superior PV. This study included both diameter and ostial area measurements, since the latter was found to be the most reliable tool to assess PV stenosis on magnetic resonance angiography.[19] Besides local scarring due to the ablation, physiological reverse remodelling of the LA may also cause decreased PV dimensions.[12] A weak, but significant correlation ($R = 0.237$, $P < 0.01$) was observed between LA volume reductions and PV dimension reductions, indicating that the two parameters are slightly inter-related. Therefore, PV measurements were corrected for LA reverse remodelling. The decrements in LA size found in this study were comparable with volume reductions as found previously in our department.[13] After correction for LA remodelling, PV dimensions were still significantly decreased. The reduction in PV ostial area can thus only partly be explained by reverse remodelling concomitant to LA reverse remodelling.

The results from this study were compared with results from previous studies on PV narrowing after ablation with PVAC (*Table 3*). These studies defined PV narrowing as diameter reduction instead of ostial area reduction. Although ostial area reduction seems more accurate, diameter reduction expressed in per cent of PVs and per cent of patients from this study were included in *Table 3* (Compier, 2012). Comparison of PV narrowing between this study and previous studies was thus performed with the PV diameter reduction data, as mentioned in the results section.

Moderate and severe PV narrowing found in this study were comparable with the results described by Mulder *et al.*[20] De Greef *et al.*[11] found higher incidences of mild and moderate PV narrowing, while these incidences were lower in the study of von Bary *et al.*[9] The difference with our results may be caused by three different factors. First, von Bary *et al.* mainly used 4 : 1 energy delivery to prevent PV stenosis, while we used both 2 : 1 and 4 : 1 energy delivery. De Greef *et al.* often used 2 : 1 energy delivery. However, we did not find a difference in PV notching between 2 : 1 and 4 : 1 energy. On the other hand, de Greef *et al.* did describe an increase in mild and moderate PV narrowing after multiple applications (>4) of 2 : 1 energy, which was not found for applications of 4 : 1 energy. Secondly, the MSCT in the study by von Bary *et al.* was performed relatively short after the ablation procedure (8–10 weeks), after which the development

Table 2 Incidence and severity of individual PV narrowing based on ostial area (mm^2)

PV narrowing, *n* (%)	LSPV (*n* = 51)	LIPV (*n* = 56)	RSPV (*n* = 56)	RIPV (*n* = 56)	Total (*n* = 219)
None/insignificant (<25%)	21 (41%)	28 (50%)	29 (52%)	35 (63%)	113 (52%)
Mild (25–50%)	18 (35%)	24 (43%)	20 (36%)	18 (32%)	80 (37%)
Moderate (50–70%)	7 (14%)	4 (7%)	6 (11%)	2 (4%)	19 (9%)
Severe (≥70%)	5 (10%)	0 (0%)	1 (2%)	1 (2%)	7 (3%)

LSPV, left superior PV; LIPV, left inferior PV; RSPV, right superior PV; RIPV, right inferior PV.

Table 3 Pulmonary vein narrowing after PVAC ablation as described in the literature and this study based on diameter measurements (mm)

	Ablation device	FU (months)	Imaging modality	Nr. PVs	Nr. Patients	Mild (25–50%) (%)		Moderate (50–69%) (%)		Severe (>70%) (%)	
						PV	Pt	PV	Pt	PV	Pt
Von Bary (2011)	PVAC	3	MRI/MSCT	410	100	3.7	14	0.2	1	0	0
De Greef (2012)	PVAC	3	MSCT	184	50	30	78	4	15	–	–
Mulder (2012)	PVAC	3–6	MRI/angio	635	153	?	?	1.6	5.2	0	0
Compier (2012)	PVAC	12	MSCT	219	62	16	48	1.4	4.8	0.5	1.6

FU, follow-up; PV, per cent of affected pulmonary veins; pt, per cent of affected patients.

of PV narrowing may not have been completed yet. De Greef *et al.* and our study indeed showed higher incidences of PV narrowing 3 and 12 months after ablation, respectively. Finally, incidence of PV narrowing may decrease when using imaging modalities during ablation to secure ostial location of the catheter, like intracardiac echocardiography, which was used in our study. A 10-fold decrease of severe PV narrowing was reported when using ICE guidance during PVAC ablation.[17] Von Bary *et al.* used either selective angiography or 3D atriography to guide PVAC placement. Guidance with 3D atriography also seemed to decrease the incidence of PV narrowing. De Greef *et al.* only used selective angiography, which may be less accurate in guiding placement of the catheter.

In spite of these differences, PV narrowing does not seem to progress when comparing our results at 1-year follow-up to the results of other studies after 3 months of follow-up.

Comparison of PV narrowing based on ostial area reduction (*Table 2*) and diameter reduction (*Table 3*) reveals a much higher percentage of narrowing when using ostial area measurements. This difference is probably due to the anatomy of the low-pressure venous system, including the PVs, which is not completely circular. In a previous study, measuring ostial area was found to be a more reliable tool to evaluate PV narrowing when compared with a linear parameter such as PV diameter.[19] Ostial area measurements may therefore be more accurate for the assessment of PV narrowing. In addition, ostial diameter measurements seem to underestimate PV narrowing compared to ostial area measurements.

Pulmonary vein narrowing after ablation with other devices

Using classical RF energy, incidence of PV narrowing decribed by Saad *et al.*[17] was relatively high with severe PV narrowing occurring in 3.4% of patients. Dong *et al.*[12] reported an incidence of moderate PV stenosis of 3.2% and severe PV stenosis of 0.6%. These studies were performed under guidance of electroanatomic mapping, while a much lower incidence of PV narrowing was found when replacing electroanatomic mapping with ICE guidance. Also, these studies were conducted when ablation of ectopic activity was performed at the individual PV ostium, which was later on found to induce PV stenosis. Segmental PV isolation has therefore been replaced by circumferential PV isolation at the antrum.

Ablation with a cryoballoon does not seem to induce PV narrowing.[21] Apparently, cryoenergy is a safer energy source than RF energy when considering PV stenosis. Ablation with the cryoballoon is also aimed at a more antral position, which may reduce incidence of PV narrowing.

Local pulmonary vein notching

Besides concentric PV narrowing, local eccentric PV notching has been described.[12] Local notching was observed in 5% of PVs in our study, 4% of which were categorized as mild. No clinical complaints were reported and no pulmonary perfusion deficits were detected. These findings were in line with results reported by von Bary *et al.*,[9] who found no symptoms in patients with mild and moderate PV stenosis.

Clinical implications

In the current study, long-term instead of short-term incidence and clinical effects of PV narrowing and local notching caused by PVAC ablation were investigated. Even though we described significant remodelling of all PVs and a 5% incidence of local PV notching one year after ablation with PVAC, this did not lead to any clinical complication during follow-up.

A first ablation procedure with the PVAC catheter thus leads to PV remodelling and occasionally local notching, but this appears to be mild and asymptomatic in the long term.

As ablation with PVAC leads to uniform narrowing of the PVs, it is worthwhile, however, to routinely perform a MSCT before ablation. If a patient subsequently develops symptoms after ablation or when a patient is scheduled for a second procedure, PV dimensions can be compared with dimensions before the first procedure. This may facilitate the diagnosis of moderate PV remodelling without descriptive notch formation and evoke the operator of the second procedure to employ extra care in placing additional ablation lesions outside the ostium of the vein. In addition, it may be worthwhile to increase the follow-up period of patients with moderate-to-severe PV remodelling to prevent future complications and assess further development of PV remodelling years after ablation.

Study limitations

Some limitations to this study have to be mentioned. Multi-slice CT scans were mainly acquired at the 75% phase of a heartbeat, which is the end of diastole of the atria. In case of arrhythmia, scanning protocol occasionally needed to be adjusted in order to get good scan quality. As a result, the MSCT scan had to be acquired at a different phase of the heartbeat in a small amount of patients. A different phase may have influenced PV ostial area and LA volume measurements in these patients. However, a subgroup analysis including only patients with both CT scans performed in the exact same phase did not alter the results.

Conclusion

Ablation with PVAC results in a significant decrease in PV dimensions on MSCT independent of LA reverse remodelling 1 year after the procedure. Patients did not develop any clinical symptoms during 1-year follow-up. A follow-up CT scan after PVAC ablation may be useful if a patient develops symptoms or when a patient is scheduled for a second procedure. It may facilitate the diagnosis of moderate PV narrowing and evoke the operator of the second procedure to place additional ablation lesions outside the PV ostium.

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References

1. Calkins H, Brugada J, Packer DL, Cappato R, Chen SA, Crijns HJ *et al.* HRS/EHRA/ECAS expert consensus statement on catheter and surgical ablation of atrial fibrillation: recommendations for personnel, policy, procedures and follow-up. *Europace* 2007;**9**:335–79.
2. Haissaguerre M, Jais P, Shah DC, Takahashi A, Hocini M, Quiniou G *et al.* Spontaneous initiation of atrial fibrillation by ectopic beats originating in the pulmonary veins. *N Engl J Med* 1998;**339**:659–66.
3. Macle L, Jais P, Weerasooriya R, Hocini M, Shah DC, Choi KJ *et al.* Irrigated-tip catheter ablation of pulmonary veins for treatment of atrial fibrillation. *J Cardiovasc Electrophysiol* 2002;**13**:1067–73.
4. Cappato R, Calkins H, Chen SA, Davies W, Iesaka Y, Kalman J *et al.* Worldwide survey on the methods, efficacy, and safety of catheter ablation for human atrial fibrillation. *Circulation* 2005;**111**:1100–5.
5. Boersma LV, Wijffels MC, Oral H, Wever EF, Morady F. Pulmonary vein isolation by duty-cycled bipolar and unipolar radiofrequency energy with a multielectrode ablation catheter. *Heart Rhythm* 2008;**5**:1635–42.
6. Bittner A, Monnig G, Zellerhoff S, Pott C, Kobe J, Dechering D *et al.* Randomized study comparing duty-cycled bipolar and unipolar radiofrequency with point-by-point ablation in pulmonary vein isolation. *Heart Rhythm* 2011;**8**:1383–90.
7. Beukema RP, Beukema WP, Smit JJ, Ramdat Misier AR, Delnoij PP, Wellens H *et al.* Efficacy of multi-electrode duty-cycled radiofrequency ablation for pulmonary vein disconnection in patients with paroxysmal and persistent atrial fibrillation. *Europace* 2010;**12**:502–7.
8. Roelke M, Smith AJ, Palacios IF. The technique and safety of transseptal left heart catheterization: the Massachusetts General Hospital experience with 1,279 procedures. *Cathet Cardiovasc Diagn* 1994;**32**:332–9.
9. von Bary C, Weber S, Dornia C, Eissnert C, Fellner C, Latzin P *et al.* Evaluation of pulmonary vein stenosis after pulmonary vein isolation using a novel circular mapping and ablation catheter (PVAC). *Circ Arrhythm Electrophysiol* 2011;**4**:630–6.
10. Deneke T, Bunz K, Bastian A, Pasler M, Anders H, Lehmann R *et al.* Utility of esophageal temperature monitoring during pulmonary vein isolation for atrial fibrillation using duty-cycled phased radiofrequency ablation. *J Cardiovasc Electrophysiol* 2011;**22**:255–61.
11. De Greef Y, Tavernier R, Raeymaeckers S, Schwagten B, Desurgeloose D, De Keulenaer G *et al.* Prevalence, characteristics, and predictors of pulmonary vein narrowing after isolation using the pulmonary vein ablation catheter. *Circ Arrhythm Electrophysiol* 2012;**5**:52–60.
12. Dong J, Vasamreddy CR, Jayam V, Dalal D, Dickfeld T, Eldadah Z *et al.* Incidence and predictors of pulmonary vein stenosis following catheter ablation of atrial fibrillation using the anatomic pulmonary vein ablation approach: results from paired magnetic resonance imaging. *J Cardiovasc Electrophysiol* 2005;**16**:845–52.
13. Tops LF, Bax JJ, Zeppenfeld K, Jongbloed MR, van der Wall EE, Schalij MJ. Effect of radiofrequency catheter ablation for atrial fibrillation on left atrial cavity size. *Am J Cardiol* 2006;**97**:1220–2.
14. Cappato R, Calkins H, Chen SA, Davies W, Iesaka Y, Kalman J *et al.* Updated worldwide survey on the methods, efficacy, and safety of catheter ablation for human atrial fibrillation. *Circ Arrhythm Electrophysiol* 2010;**3**:32–8.
15. Wijffels MC, Van Oosterhout M, Boersma LV, Werneth R, Kunis C, Hu B *et al.* Characterization of in vitro and in vivo lesions made by a novel multichannel ablation generator and a circumlinear decapolar ablation catheter. *J Cardiovasc Electrophysiol* 2009;**20**:1142–8.
16. Yamanaka K, Fujita M, Doi K, Tsuneyoshi H, Yamazato A, Ueno K *et al.* Multislice computed tomography accurately quantifies left atrial size and function after the MAZE procedure. *Circulation* 2006;**114**(1 Suppl.):I5–I9.
17. Saad EB, Rossillo A, Saad CP, Martin DO, Bhargava M, Erciyes D *et al.* Pulmonary vein stenosis after radiofrequency ablation of atrial fibrillation: functional characterization, evolution, and influence of the ablation strategy. *Circulation* 2003;**108**:3102–7.
18. Wieczorek M, Hoeltgen R, Brueck M, Bandorski D, Akin E, Salili AR. Pulmonary vein isolation by duty-cycled bipolar and unipolar antrum ablation using a novel multielectrode ablation catheter system: first clinical results. *J Interv Card Electrophysiol* 2010;**27**:23–31.
19. Tintera J, Porod V, Cihak R, Mlcochova H, Rolencova E, Fendrych P *et al.* Assessment of pulmonary venous stenosis after radiofrequency catheter ablation for atrial fibrillation by magnetic resonance angiography: a comparison of linear and cross-sectional area measurements. *Eur Radiol* 2006;**16**:2757–67.
20. Mulder AA, Balt JC, Wijffels MC, Wever EF, Boersma LV. Safety of pulmonary vein isolation and left atrial complex fractionated atrial electrograms ablation for atrial fibrillation with phased radiofrequency energy and multi-electrode catheters. *Europace* 2012;**14**:1433–40.
21. Neumann T, Vogt J, Schumacher B, Dorszewski A, Kuniss M, Neuser H *et al.* Circumferential pulmonary vein isolation with the cryoballoon technique results from a prospective 3-center study. *J Am Coll Cardiol* 2008;**52**:273–8.