Prevalence, Characteristics, and Predictors of Pulmonary Vein Narrowing After Isolation Using the Pulmonary Vein Ablation Catheter

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Background—The risk of pulmonary vein narrowing (PVN) after pulmonary vein isolation, using a novel multi-electrode ablation catheter, is unknown.

Methods and Results—Left atrial volume and PV diameters were compared by computed tomography (CT) before and 3 months after pulmonary vein isolation using duty-cycled phased radio frequency energy (2:1 or 4:1 bipolar/unipolar ratio) in 50 patients. Pulmonary vein diameter was measured in a coronal and axial view at 3 levels (A, ostium; B, 1 cm more distal; C, 2 cm more distal). Moderate PVN was defined as a pulmonary vein diameter reduction of 25 to 50%, and severe PVN as >50%. Left atrial volume decreased by 12±12% (P<0.01). Axial pulmonary vein diameter shortened by a median of 16% (interquartile range [IQR] 28 to 5%), 13% (IQR 25 to 5%), and 9% (IQR 21 to −3%) at level A, B, and C, respectively (P<0.01 for all); coronal pulmonary vein diameter decreased by a median of 16% (IQR 24 to 7%), 11% (IQR 21 to 4%), and 8% (IQR 18 to −2%; P<0.01 for all). Moderate PVN occurred in 30% of the PVs, in 78% of the patients; severe PVN occurred in 4% of the PVs, in 15% of the patients. PV diameter reduction was not related to changes in left atrial volume.

Conclusions—Isolation of the pulmonary veins using a multielectrode ablation catheter and duty cycled phased radiofrequency energy delivery results in a consistent moderate reduction of the PV diameters predominantly at the ostium. Severe PVN in 15% of patients raises concerns about the risk for clinical PV stenosis.  

Key Words: atrial fibrillation ■ pulmonary vein isolation ■ PV diameter reduction ■ PVAC

Electric isolation of the pulmonary veins is an essential element in the ablation strategy in patients with atrial fibrillation (AF).1 Recently, the pulmonary vein ablation catheter (PVAC, Medtronic, Inc, MN), an over-the-wire multielectrode catheter using duty-cycled bipolar and unipolar radiofrequency (RF) energy in variable degrees, has been introduced to facilitate pulmonary vein isolation (PVI). This method of energy delivery has the potential advantage to create more contiguous ablation lines (bipolar ablation) with sufficient depth (unipolar ablation). This can be explained by the fact that unipolar RF current flows from the electrodes to the reference patch on the skin (causing a deep lesion), while bipolar RF current flows between 2 adjacent electrodes positioned on the muscle (causing a more superficial lesion).2 However, deeper lesions might increase the risk of damage to neighboring structures, while shallower lesions might prove to be less stable over time. Initial studies on efficiency, efficacy, and safety of this device are encouraging, with medium-term and long-term success rates ranging from 61 to 86% in patients with paroxysmal AF.3−8 The aim of this prospective study was to assess changes in left atrial (LA) volume and pulmonary vein diameters (PVD) after PVAC ablation. Furthermore, we analyzed anatomic and RF characteristics related to the observed changes.

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Methods

Patient Population

Pulmonary vein diameters were studied in 50 patients before and 3 months after PVAC-guided pulmonary vein isolation using CT. Informed consent was obtained for each patient before enrollment.

Duty-Cycled Phased RF Via the PVAC

PVAC ablation technology (Medtronic, Inc, MN) and the generator (GENius, Medtronic, Inc, MN) have been described elsewhere.2,3 In summary, the PVAC catheter is a 9 F, over-the-wire,
decapolar mapping and ablation catheter with a distal 25-mm spiral array. Each platinum electrode has a thermocouple under the surface on the anterior side. Catheter placement and stability around the pulmonary veins (PVs) are facilitated by use of a 0.032-inch guide wire, selectively positioned into different side-branches to modify the tissue-electrode interface around the PV circumference. The GENius multichannel, duty-cycled RF generator is capable of delivering energy to each electrode independently. RF energy can be delivered in either unipolar or bipolar current by a phase difference between the channels. The generator has 5 preset energy settings: bipolar, unipolar, and 3 ratios of bipolar/unipolar energy: 4:1 (80% bipolar, 20% unipolar), 2:1 (66% bipolar, 34% unipolar), and 1:1 (50% bipolar, 50% unipolar). During RF application, energy delivery to individual electrodes is temperature controlled by a software algorithm that modulates power to reach the user-defined target temperature (60°C), but limits power to a maximum of 8 W per electrode when using the PVAC in a 4:1 power setting, or 10 W in all other settings.

**PVAC Ablation**

The ablation procedure (operator YDG or DS) was performed under general anesthesia. After obtaining vascular access, 3 sheaths were positioned in the right femoral vein. A 6F decapolar catheter was positioned in the coronary sinus for pacing purposes. Immediately before transseptal puncture, an intravenous loading dose of 10 000 U heparin was given. A double transseptal puncture using a modified Brockenbrough technique was performed under fluoroscopy, transoesophageal echocardiography, and pressure guidance using a 9F deflectable sheath (Channel sheath, Bard Electrophysiology, Lowell, MA) and a 8F nondeflectable sheath (SL0, St Jude Medical, St. Paul, MN). A continuous infusion of heparin was started to maintain an activated clotting time above 350 seconds throughout the procedure. Luminal oesophageal temperature was measured using a multi-electrode temperature probe (Esotherm Plus, Fiaf, Florence, Italy). In case of a rise of the esophageal temperature above 38.5°C, RF delivery was stopped. To anatomically delineate the PV ostia and side-branches, a selective PV angiography via the Channel sheath (manual injection of 15 to 20cc intravenous contrast) was performed for the left superior PV ([LSPV], anteroposterior [AP], and left anterior oblique [LAO]), left inferior PV ([LIPV], AP, and right anterior oblique [RAO]), right superior PV ([RSPV], AP, and LAO), and right inferior PV ([RIPV], AP, and RAO). Subsequently, the PVAC catheter was inserted over-the-wire into the steerable sheath in the LA. Before ablation, the PVAC was placed within the PV to register baseline PV recordings (5 bipolar recordings, amplification *16, filter settings 100 to 500Hz) during sinus rhythm, coronary sinus pacing, and dedicated pacing maneuvers using a quadripolar catheter advanced through the second transseptal sheath. Then the PVAC catheter was withdrawn to target the ostia of the PVs. Appropriate positioning was ensured by free rotation of the catheter, local electrogram interpretation, and by comparing the position of the PVAC catheter to the angiographically defined LA-PV ostium (Figure 1). RF delivery always was started with circular applications. Selective applications were used if residual potentials were no longer recorded on the complete circumference of the catheter. The selection of 2:1 versus 4:1 energy delivery was guided by (1) theatomic location of the catheter, and (2) the response to previous applications. If the catheter was in contact with the posterior wall (for example, when creating overlapping circles) or when the catheter was in clear proximity to the esophagus based on the position of the temperature probe, 2:1 energy was avoided whenever possible. In contrast, in case of clear residual potentials at the region of the carina or at the ridge between left atrial appendage and left veins, energy was mainly delivered in a 2:1 fashion. In between applications, remapping with the PVAC catheter within the PV was repeatedly performed. PVAC applications were continued until LA-PV entrance block was demonstrated on the distal PVAC recordings during sinus rhythm, CS pacing, and dedicated pacing using baseline recordings as a reference. After isolation of all PVs, the previously isolated veins were reassessed and, in case of reconnection, a PVAC-guided isolation was performed. At the end of the procedure, the total number of applications, number of circular and noncircular PVAC applications, number of 2:1 and 4:1 applications, procedure, and fluoroscopy times were collected.

**Postprocedural Management**

After the procedure, subcutaneous low-molecular weight heparin was administered to all patients together with the (re)-institution of oral anticoagulation therapy with a target international normalized ratio between 2.0 and 3.0. Oral anticoagulation was discontinued 1 month after the procedure if the patient had a CHADS2 score ≤1. Previously ineffective antiarrhythmic drugs were restarted after the ablation procedure and discontinued after 1 month. Patients were followed at 1, 3, and 6 months. Follow-up (YDG) consisted of a symptom-based evaluation focused on arrhythmia recurrences and symptoms compatible with PV stenosis and a 12-lead ECG recording. At 6 months an additional 7-day Holter recording was performed. AF was defined as any sustained atrial arrhythmia lasting >30 seconds. Success was defined as freedom of symptomatic or asymptomatic AF without antiarrhythmic drug therapy during 6 months follow-up with a blanking period of 1 month.

**Computed Tomography Scan of the Left Atrium and Pulmonary Veins**

A multi-detector CT (MDCT, 40-slice Philips, Brilliance, Eindhoven, the Netherlands) was performed 1 day before and 3 months after the procedure. Iodinated intravenous contrast material (100 mL of iobitridol, Xenetics 350, Guerbet, Gorinchem, the Netherlands) was administered through an antecubital vein with a power injection rate of 5 mL/s. Scanning was initiated on average 17 seconds after the onset of contrast injection using a triggered mode (enhanced density detection at the region of interest defined in the left ventricle). A collimation of 0.625 mm with a 0.2 pitch mode was
used for all veins. The CT images were reconstructed as 4 mm slices (coronal and axial) measurement of each PV (Figure 2). PVD was measured at 3 levels: level A, ostial; level B, 1 cm more distal; and level C, 2 cm more distal. At each level, PVD was measured with a manual caliper as the distance between 2 points perpendicular to the PV axis. In case of early branching, the PVD of the main branch was taken as level C both before and after ablation. All measurements were performed by one investigator (SR) blinded to pre versus post ablation. Concentric reduction was defined as a similar variation in reduction in the coronal and axial plane (<5% difference). Mild PV narrowing (PVN) was defined as a reduction at any level in PVD in the axial or coronal plane between 10 and 24%, moderate PV narrowing as a reduction between 25 and 50%, and severe PVN as a reduction of >50%.

Left atrial volume was measured according to the technique of Ho et al based on 3 orthogonal measures of the left atrial chamber (longitudinal, antero-posterior, and transverse). The transverse diameter (TD) was defined as the distance between the midpoint of the right and left sides of the PVs using an oblique axial image. The antero-posterior (AP) and longitudinal (superior-inferior [SI]) diameters were measured at the midpoint of the transverse diameter using oblique axial and sagittal images. The LA volume was calculated according to an ovoid cylinder: Volume = π. TD. AP/2. SI/2.

Statistical Analysis
For statistical analysis, GraphPad Prism version 5.0c and SPSS 15 were used. Data are given as mean±SD or as median with interquartile range according to their distribution. Paired data were compared using Wilcoxon matched-pairs signed rank test. Unpaired data were compared using a Mann-Whitney U test. A Kruskal-Wallis test with Dunn post test were used to compare multiple unpaired groups. Categorical variables were compared using Fisher exact test. Spearman correlation coefficient was used to determine correlation between changes in LA volume and changes in PV diameter. As the 4 PVs were treated in each patient during the same session, and PV data within 1 person might theoretically be correlated with one another (clustered data), the associations between PV diameter changes and left atrial volume changes were further analyzed by mixed effects models using SPSS 15. Additionally, we addressed the question whether diameter reduction at 1 PV drives diameter changes at the other PVs, proportional to the induced LA volume changes. Furthermore, intraclass correlations (ICC) were calculated by the single measures Shrout and Fleiss intraclass reliability procedure and expressed as ICC values with confidence intervals and corresponding probability values. ICC values were calculated between diameter changes of the 4 pulmonary veins measured at each level of the axial and coronal plane views of the multidetector computed tomography. A probability value <0.05 was considered as statistically significant.

Results
Patient Population
Fifty patients (mean age 61±10 years, 78% men) with symptomatic recurrent AF (37 paroxysmal, 13 persistent), resistant to at least 1 antiarrhythmic drug, were studied. The median duration of AF history was 36 months (IQR 14–72 months). Coronary artery disease was present in 10 patients, mild valvular heart disease in 7 patients, and arterial hypertension in 15 patients. The mean left atrial diameter (PS-LAX, Vivid 7, GE Healthcare, Buckinghamshire, UK) was 42±7 mm.

PVAC-Guided Ablation
Ablation data are given in Table 1. Electric PV isolation was obtained in all 200 targeted PVs. Mean procedural and fluoroscopy time were respectively 145±53 minutes and 39±16 minutes After 6 months of follow-up, 36 of the 50 patients (72%, 95% CI: 60 to 84%) remained free of any evidence of AF without antiarrhythmic drugs.

Table 1. Ablation Data

<table>
<thead>
<tr>
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<th>N or Median With IQR</th>
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<tbody>
<tr>
<td>No. of patients</td>
<td>50</td>
</tr>
<tr>
<td>No. of PVs</td>
<td>200</td>
</tr>
<tr>
<td>PVAC applications/patient</td>
<td>22 (18–28)</td>
</tr>
<tr>
<td>2:1 ratio</td>
<td>12 (7–19)</td>
</tr>
<tr>
<td>4:1 ratio</td>
<td>8 (5–12)</td>
</tr>
<tr>
<td>PVAC applications/vein</td>
<td>5 (4–8)</td>
</tr>
<tr>
<td>2:1 ratio</td>
<td>3 (2–5)</td>
</tr>
<tr>
<td>4:1 ratio</td>
<td>2 (1–4)</td>
</tr>
<tr>
<td>Circular applications</td>
<td>4 (3–6)</td>
</tr>
<tr>
<td>Selective applications</td>
<td>2 (1–3)</td>
</tr>
<tr>
<td>PVAC applications left superior PV</td>
<td>6 (5–7)</td>
</tr>
<tr>
<td>2:1 ratio</td>
<td>3 (2–5)</td>
</tr>
<tr>
<td>4:1 ratio</td>
<td>2 (1–4)</td>
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<tr>
<td>PVAC applications left inferior PV</td>
<td>5 (4–7)</td>
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<td>2:1 ratio</td>
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<tr>
<td>4:1 ratio</td>
<td>2 (1–3)</td>
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</table>

PV indicates pulmonary vein; IQR, interquartile range; PVAC, pulmonary vein ablation catheter.
LA Volume After PVAC Ablation
Mean LA volume decreased from 110±34 mL before to 100±36 mL after ablation (−12±12%,  P<0.001). The mean degree of LA reduction was more significant in patients with a successful outcome after ablation compared with patients with recurrence of AF (−14±11% versus −5±12%,  P<0.05).

Pulmonary Vein Diameters After PVAC Ablation
In 16 veins in 4 patients, image quality was insufficient to measure reliable PV diameters. Figure 3 shows the percentages of narrowed PVs as a function of the degree of PV narrowing, with an increment of 10%. PVD remained unchanged in 57 of 184 veins (31%, 95% CI: 24 to 38%). Mild concentric PVN occurred in 64 PVs (35%, 95% CI: 28 to 42%), moderate PVN in 55 PVs (30%, 95% CI: 23 to 36%), and severe PVN in 8 PVs (4%, 95% CI: 1 to 7%). No cases of eccentric PVN were observed. A representative example of mild ostial PV narrowing in all pulmonary veins is given in Figure 4. A representative example of moderate concentric ostial LSPV narrowing is given in Figure 5. Mild PVN was observed in the other PVs.

Every patient (100%) had at least 1 mildly narrowed PV, mild PV narrowing differed among the PVs and that PVNs did not narrow meaningfully between the PVs. Patient 1 had at least 1 mildly narrowed PV, and 7 of 46 (15%, 95% CI: 5 to 26%) had at least 1 severely narrowed PV. One patient with a severe concentric ostial PVN developed hemoptysis.10

Mean PV diameters before and 3 months after PVAC ablation are given in Table 2. Overall, axial PVD shortened by a median of 16% (IQR −28 to −5%), 13% (IQR −25 to −5%), and 9% (IQR −21 to 3%) at level A, B, and C, respectively (P<0.01 for all). Coronal PVD decreased by a median of 16% (IQR −24 to −7%), 11% (IQR −21 to −4%), and 8% (IQR −18 to 2%) at level A, B, and C, respectively (P<0.01 for all). With respect to the different levels, the percentage of PV narrowing decreased progressively from level A toward level C. For the overall group of PVs, level C was significantly less narrowed after ablation compared with level A and B (P<0.001). For individual PVs, PV narrowing was less pronounced at level C for the LSPV and RIPV when compared with the ostial level of the corresponding PV (P<0.05). Within each level, the degree of PVD reduction at the LSPV tended to be more pronounced than in the other veins. At level A and B, the LSPV diameter reduction was significantly more pronounced than in the LIPV and the RIPV (P<0.05). At level C, the LSPV was significantly more reduced than the RIPV (P<0.05).

Predictors of PV Narrowing
Mixed effect models indicated that the magnitude of narrowing differed among the PVs and that PVNs did not narrow meaningfully between the PVs. Patient 1 had at least 1 mildly narrowed PV, mild PV narrowing differed among the PVs and that PVNs did not narrow meaningfully between the PVs. Patient 1 had at least 1 mildly narrowed PV, and 7 of 46 (15%, 95% CI: 5 to 26%) had at least 1 severely narrowed PV. One patient with a severe concentric ostial PVN developed hemoptysis.10

Figure 3. Percentages of narrowed pulmonary veins as a function of the degree of pulmonary vein narrowing.
proportionally to the induced LA volume changes. This result was consistent at each of the 3 levels (most significant at level A) and for both axial and coronal views (most significant at axial views). Although the magnitude of diameter change of 1 pulmonary vein did not predict diameter changes at the other pulmonary veins, diameter changes of the pulmonary veins were not statistically unrelated. For instance, at the level A of both the axial and coronal MDCT views, intraclass reliability was relatively poor, albeit statistically significant: ICC (level A of axial view) = 0.152 [0.021 to 0.322], P = 0.01, and ICC (level A at coronal view) = 0.175 [0.038 to 0.348], P = 0.005.

There was a weak but statistically not significant correlation (R = 0.17) between average PVD reduction and LA reduction. In the total group, using multivariable regression analysis, no relation was found between the reduction in PV diameters for any PV at any level in any axis and the reduction in left atrial volume. The same was observed when only the group of patients with a mild PV stenosis were analyzed. There was no relation between the degree of PV narrowing and age, gender, LA size, or clinical outcome.

Procedural and anatomic characteristics of PVs of patients with no or mild PV narrowing (group 1, N = 121), moderate PVN (group 2, N = 55), and severe PVN (group 3, N = 8) are given in Table 3. The total number of applications, number of circular, and number of noncircular applications were not different between the groups. In contrast, the number of 2:1 applications was higher in group 2 (median 3, IQR 2–6) and group 3 (median 5, IQR 4–7), compared with group 1 (median 2, IQR 1–4; P < 0.001). Finally, a statistically significant (P < 0.05) greater representation of the LSPV was observed in group 2 (36%) and 3 (75%), compared with group 1 (17%). The other PVs were distributed equally between the groups.

Figure 4. Three-dimensional computed tomography reconstruction of the left atrium and pulmonary veins (PV) before and 3 months after pulmonary vein ablation catheter ablation. Coronal PV diameters measured at levels A (ostial level), B (1 cm distal from the ostium), and C (2 cm distal from the ostium) for each PV are displayed in the lower panel before and after ablation. The ablation-induced percentage in pulmonary vein diameter reduction at each level is given between brackets. Mild PV narrowing of all 4 pulmonary veins is observed after pulmonary vein ablation catheter ablation. The degree of PV narrowing is most pronounced for the left superior PV. The proximal-to-distal reduction in pulmonary vein diameter remained present after ablation. LIPV indicates left inferior PV; LSPV, left superior PV; RIPV, right inferior PV; RSPV, right superior PV.

Figure 5. Three-dimensional computed tomography reconstruction of the left atrium and pulmonary veins (PV) before and 3 months after pulmonary vein ablation catheter ablation. Coronal PV diameters measured at levels A (ostial level), B (1 cm distal from the ostium), and C (2 cm distal from the ostium) for each PV are displayed in the lower panel before and after ablation. The ablation-induced percentage in pulmonary vein diameter reduction at each level is given between brackets. The left superior PV demonstrates an ostial moderate PV narrowing of ~38%. Although to a lesser degree, pulmonary vein narrowing also is present at level B and C. Only mild pulmonary vein narrowing was observed in the other PVs. No focal pattern was observed, and the proximal to distal reduction in pulmonary vein diameter remained present after ablation. LIPV indicates left inferior PV; LSPV, left superior PV; RIPV, right inferior PV; RSPV, right superior PV.
In Figure 6, the number of 4:1 applications in relation to the 2:1 applications for each vein is plotted. The degree of PVN at 3 months is represented by different symbols. A hypothetical horizontal and vertical line drawn at 4 PVAC ablations divides the figure in 4 quadrants. Severe PVN (black stars) occurred only in case of 4 or more 2:1 applications (right lower quadrant). Furthermore, the likelihood of moderate PV narrowing (gray stars) is high (39%) with 4 or more 2:1 applications. However, the relation between the number of 2:1 applications and the degree of PVN narrowing is not absolute; a high number of 2:1 applications (up to 14) does not always result in PVN (right quadrants, white circles, 46 normal or mildly narrowed PVs out of 89 treated PVs with at least 4 2:1 applications), and moderate PVN can still occur in case of less than 4 2:1 applications (left quadrants, gray stars, 20 moderately narrowed PVs in 106 PVs treated with less than 4 2:1 applications). More than 4 4:1 applications were never associated with severe PVN (left upper quadrant). Out of the 25 veins treated exclusively with 4:1 applications (up until 9), only 3 PVs (13%) demonstrated moderate PVN.

Discussion
Prevalence of PV Narrowing After PVAC Ablation
PVAC-guided pulmonary vein isolation resulted in a consistent, concentric, and moderate reduction of the pulmonary vein diameters, especially at the ostium. Mild (10 to 24%), moderate (25 to 50%), and severe (>50%) PV narrowing occurred in respectively 35%, 30%, and 4% of PVs. These data are different from other reports. Boersma et al3 observed no PV stenosis (defined as >50% of PVD reduction) after PVAC guided PVI. However, a postprocedural magnetic

Table 3. Procedural and Anatomic Predictors of PV Narrowing

<table>
<thead>
<tr>
<th></th>
<th>No or Mild (&lt;25%) PV Narrowing (n=121, 66%)</th>
<th>Moderate (25%–50%) PV Narrowing (n=55, 30%)</th>
<th>Severe (&gt;50%) PV Narrowing (n=8, 4%)</th>
<th>P-Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total no. of applications</td>
<td>5 (4–7)</td>
<td>6 (5–8)</td>
<td>6 (5–7)</td>
<td>0.36</td>
</tr>
<tr>
<td>No. of circular burns</td>
<td>4 (2–6)</td>
<td>4 (4–6)</td>
<td>5 (4–6)</td>
<td>0.25</td>
</tr>
<tr>
<td>No. of selective burns</td>
<td>2 (1–3)</td>
<td>2 (1–3)</td>
<td>2 (2–1)</td>
<td>0.41</td>
</tr>
<tr>
<td>No. of 2:1 applications</td>
<td>2 (1–4)</td>
<td>3 (2–6)*</td>
<td>5 (4–7)*</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Ostial diameter at baseline (mm)</td>
<td>14 ±4</td>
<td>16 ±4</td>
<td>14 ±2</td>
<td>0.06</td>
</tr>
<tr>
<td>LSPV</td>
<td>23 (17%)</td>
<td>20 (36%)*</td>
<td>6 (75%)*</td>
<td>&lt;0.05</td>
</tr>
</tbody>
</table>

LSPV indicates left superior pulmonary vein.
resonance imaging (MRI) or angiography was only performed in 11 of 98 patients. Wieczorek et al. observed no PV stenosis (defined as PV diameter reduction of 30% or more) after PVAC guided PVI, but again only 18 of the 88 patients underwent MRI follow-up at 6 months. Fredersdorf et al. observed no change in PV diameter and no hemodynamically relevant PV stenosis (diameter reduction of 30% or more) in any vein in 21 patients studied before and after ablation. The methodology and the site of PV diameter measurement were not described in detail.

Other RF energy based ablation strategies can result also in PV narrowing. AF trigger elimination with ablation deep in the pulmonary veins led to focal stenosis in up to 42% of targeted veins. As a result, ostial segmental PVI or wide circumferential PVI, often guided by 3D anatomic mapping systems or intracardiac ultrasound, became the procedure of choice. Kato et al. performed a quantitative analysis of PV size and shape before and after segmental PV isolation in 28 patients using MRI. A decrease in PV diameter, defined as a reduction of ≥3 mm, occurred in 24% of PVs. PV narrowing <50%, 50 to 70%, and >70% PV still occurred in 21%, 14%, and 1.4%, respectively. Scharf et al. studied 58 patients with serial computed tomography scans and observed an 8% change in ostial PV diameter after segmental PV isolation. A focal PV narrowing of 28 to 61% occurred in 3% of the veins. Using serial MRI in 51 patients, Jayam et al. found a decrease of 11% in ostial PV diameter and a PV narrowing between 50 to 70% in 2 of 192 veins (1%). After an anatomic pulmonary vein ablation approach guided by an electro-anatomic mapping system in 41 patients, PV narrowing, defined as a decrease in PVD of ≥3 mm, occurs in 38% of PVs with <50%, 50 to 70%, and >70% occurring in respectively 34%, 3.2%, and 0.6% of ablated PVs. Although no direct comparison is available, these data suggest that the prevalence of PV narrowing after PVAC-guided ablation is slightly higher than after a point-by-point ablation strategy. Reduction in PV diameter in our patient population was most pronounced at the ostial level, suggesting that PVAC applications were delivered at the LA-PV junction. The left superior PV carried the highest risk for moderate and severe PV narrowing after PVAC ablation. Such preferential occurrence of the LSPV was not encountered after segmental or circumferential PV isolation, and seems therefore specific for PVAC ablation. The most likely explanation is that despite PV angiography and local electrogram interpretation, a proper delineation of the LA-LSPV junction remains subjective and prone to mistakes.

Mechanism of PV Narrowing After PVAC Ablation

Theoretically, the observed pulmonary vein narrowing could be related to a lower pulmonary vein pressure after cure of atrial fibrillation. In our population this mechanism is unlikely because the degree of pulmonary vein narrowing was not related to the clinical outcome after ablation. Part of the observed PV narrowing might be due to the reduction in left atrial volume and subsequent shrinkage of the pulmonary veins. This phenomenon also has been described after conventional point-by-point RF ablation. However, (1) the weak correlation between LA volume reduction and PV narrowing, and (2) the results of multivariate analysis, strongly suggest a direct effect of the PVAC ablation on PV diameters. Because PVs are regions of high blood flow, catheter-tip temperature on the endovascular surface of the PVAC electrodes may underestimate deeper tissue temperatures, exceeding the limit of 60°C. As a result, a potential irreversible heat-induced PV contraction can occur. Furthermore, circumferential cicatrization is related to the lesion depth, which has been shown to be deeper in a 2:1 compared to a 4:1 mode. In this respect it is worthwhile to note that, in contrast to our approach, Fredersdorf et al. only rarely used 2:1 applications and always in a segmental configuration and observed no PV narrowing. Published data on PV narrowing after PVI using the cryoballoon technique show that the risk of PV narrowing is very low.16-19 This indirectly indicates that the risk of PV narrowing after PVAC ablation is not related to the circular nature of lesion formation during the application, but more to the RF energy delivery as such.

Reduction in Left Atrial Volume in Patients With Sinus Rhythm at Follow-Up

In the present study, the reduction in LA volume was more pronounced in patients with a successful outcome (15±11% versus 5±12%). Beukema et al. also observed that after circumferential pulmonary vein ablation for paroxysmal AF, LA dimension decreased significantly from 40.5±4.4 mm to 37.5±3.5 mm after a successful procedure; no changes were observed in the patients with AF recurrences. Also, after PVAC ablation in combination with defragmentation in long-standing persistent atrial fibrillation, a beneficial clinical outcome is associated with a significant decrease in left atrial diameter.8 However, it remains unclear whether the reduction in left atrial volume is due to maintenance of sinus rhythm (reversed atrial remodeling) or to a direct-ablation induced scarring and constriction of the LA.
Clinical Implications of the Present Study

Although only 1 patient developed clinical signs of PV stenosis, the finding of moderate PVN (25 to 50%) in 78% and severe PVN (>50%) in 15% of patients is a reason for concern. The proximal-to-distal reduction in PVD remains present after ablation. As a result, PVN can be missed if no baseline measurements are available. Furthermore, late progression of PV narrowing has been described. Undiagnosed PV narrowing might account for unexplained dyspnoea, cough, chest pain, hemoptysis, or an x-ray image consistent with bronchitis or pneumonia, leading to unnecessary potentially dangerous invasive diagnostic procedures. Furthermore, in the presence of an asymptomatic PV stenosis, cessation of anticoagulation after an apparently successful PVI can result in an acute thrombotic occlusion, with adverse effect on pulmonary perfusion. Finally, some clinicians feel that an early intervention in the presence of severe asymptomatic pulmonary vein stenosis leads to a clinical benefit in the long term.21 Based on these elements, some investigators suggest to screen actively for pulmonary vein stenosis in every patient, using CT, MRI, or transoesophageal echocardiography.22

In order to avoid PVAC-induced PV narrowing, our data suggest (1) to use preferentially 4:1 bipolar/unipolar applications, and (2) to aim for more antral ablation, especially when ablatting in the LSPV. The latter may require additional imaging techniques, such as enhanced fluoroscopy with 3D rotational angiography of the left atrium or intracardiac echocardiography. Furthermore, a wider spiral array is a desirable change in catheter technology.

Study Limitations

Although the PVI ablations were performed in the same center by 2 operators using a similar ablation strategy, no strict protocol was followed regarding (1) the choice between 2:1 or 4:1 applications, and (2) circular application versus segmental applications. We analyzed the total number of applications per vein, but we are unable to differentiate between lesions delivered in the same general area and lesions delivered at various locations in the same vein in an attempt to create overlapping circles. In theory, ablations delivered in the same area for the same vein could result in more dramatic lesions, with a more significant impact on PV diameter reduction. Detailed information on the RF profile for each application is not available, and therefore no further in-depth analysis of the relation between RF profile and the risk of PV narrowing can be made. No intracardiac echocardiography, enhanced fluoroscopy, or electroanatomical mapping were used to assess objectively the PVAC position in relation to the pulmonary vein during ablation. The evaluation of the clinical severity of pulmonary vein stenosis was based only on a detailed dedicated history obtained at each follow-up visit. Finally, this is an observational study; we made no direct comparison between the degree of PV narrowing using the PVAC catheter and other ablation strategies (a segmental PV isolation only using a circular mapping catheter, a point-by-point ablation strategy using an electroanatomical mapping system, or PVI using cryoballoon technology).

Conclusions

A rigorous assessment of PV diameters after PVI ablation demonstrates a consistent moderate reduction of the PV diameters predominantly at the ostium. A radiological incidence of severe PVN in 15% of patients raises concerns about the risk for subsequent clinical PV stenosis.

Disclosures

None.

References


**CLINICAL PERSPECTIVE**

The pulmonary vein ablation catheter is an over-the-wire multi-electrode catheter using duty-cycled bipolar and unipolar radiofrequency energy in variable degrees, which recently has been introduced to facilitate pulmonary vein (PV) isolation. Initial studies are encouraging, with medium-term and long-term success rates of up to 86% in patients with paroxysmal atrial fibrillation. We analyzed the incidence of PV stenosis following pulmonary vein ablation catheter-guided PV isolation, using sequential computed tomography in 50 patients. Moderate PV narrowing (25 to 50%) occurred in 30% of the PVs, in 78% of the patients; severe PV narrowing occurred in 4% of the PVs, in 15% of the patients. Severe PV narrowing occurred more frequently in the left superior PV and was related to unipolar energy delivery. This relatively high incidence of PV narrowing, together with the recently reported higher incidence of silent emboli after pulmonary vein ablation catheter-guided pulmonary vein isolation, are important issues in the overall assessment of this ablation technology. Ostial positioning of the pulmonary vein ablation catheter, probably guided by enhanced imaging techniques, is essential, and unipolar radio frequency delivery should be used cautiously.
Prevalence, Characteristics, and Predictors of Pulmonary Vein Narrowing After Isolation Using the Pulmonary Vein Ablation Catheter

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