Evaluation of Pulmonary Vein Stenosis Following Pulmonary Vein Isolation Using a Novel Circular Mapping and Ablation Catheter (PVAC)

Running title: von Bary et al.; Pulmonary Vein Stenosis Following PVAC Procedures

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Abstract:

Background - Pulmonary-vein-stenosis (PVST) is a well-known complication of pulmonary-vein-isolation (PVI). Specific anatomically designed ablation catheters for antral PVI have not been evaluated regarding the incidence of PVST. We investigated the incidence, severity and characteristics of PVST following PVI with the Pulmonary-Vein-Ablation-Catheter (PVAC) and phased radiofrequency (RF) technology.

Methods and Results - A total of 100 patients (55 males, 45 females) underwent PVI for atrial fibrillation using the PVAC. PVI was guided by selective angiography of each PV in 70 (70%) patients and by reconstructed three-dimensional angiography (3D-ATG) in 30 (30%) patients. Gadolinium-enhanced magnetic resonance imaging (MRI) or multidetector-computed tomography (MDCT) was performed in all patients prior to treatment and 93±78 days after PVI. PVST was classified as follows: insignificant (<25%), mild (25-50%), moderate (50-75%) or severe (>75%).

A total of 410 PVs were analyzed. Cardiac imaging demonstrated a detectable narrowing of the PV diameter in 23 (23%) patients and in 28 (7%) PVs. In detail, insignificant PVST was observed in 12 (2.9%), mild PVST in 15 (3.7%) and moderate PVST in one (0.2%) PV. No instances of severe PVST were observed. The use of 3D-ATG was associated with a lower incidence of PVST (0.8 (95%-CI 0.0-2.2)% versus 5.4 (2.7-8.1)%; p=0.027).

Conclusions - This is the first study to report the incidence of PVST using the PVAC. In this regard the PVAC seems to be safe if used in an experienced center. In addition, the use of 3D-ATG may decrease the risk of PVST.

Key words: atrial fibrillation; catheter ablation; pulmonary vein isolation; pulmonary vein stenosis; cardiac imaging
Background

Atrial fibrillation (AF) is the most common arrhythmia encountered in clinical practice, accounting for approximately one-third of all hospitalizations for cardiac rhythm disturbances. During the last decade, pulmonary vein isolation (PVI) has emerged as a cornerstone therapy for paroxysmal and persistent AF, as the pulmonary veins (PV) are the most important source of ectopic activity for initiation and maintenance of AF. Today, different ablation techniques have been established using a segmental and anatomical approach for PVI and all of these strategies may be complicated by the risk of causing pulmonary-vein-stenosis (PVST), which can be life threatening and challenging to treat.

In the attempt to reduce the incidence of PVST and to improve the efficacy of AF-ablation, new technologies able to create continuous linear lesions for antral PVI, so-called “single-shot-devices”, have been developed. A recently introduced ablation device is the Pulmonary-Vein-Ablation-Catheter (PVACTM, Medtronic, Minneapolis, USA). This novel 10 pole, circular catheter is used in combination with a multichannel, duty-cycled radiofrequency (RF) generator (GENius, Medtronic, Minneapolis, USA). Mapping and ablation are performed through a single catheter at the antral portion of the PVs, delivering duty-cycled bipolar and unipolar RF energy at relatively low power. Electrode cooling is achieved without active irrigation during “off-periods” of duty-cycled RF-current delivery and due to passive circulatory cooling from blood flow. The feasibility and efficacy of the PVAC has been demonstrated in multiple clinical studies. However, there are no prior studies that have systematically evaluated the incidence of PVST following ablation using this alternative energy source.
Thus, the aim of our study was to ascertain the incidence, type and risk factors of PVST following phased RF ablation with the PVAC. Occurrence of PVST was assessed using pre- and postinterventional CT or MRI, currently regarded as gold standard in the diagnosis.

Methods

Study Design

The current study was an observational study of 140 consecutive patients who underwent PVAC ablation at our institution between September 2007 and December 2010. We routinely carry out pre-procedural imaging with MRI or CT to define the PV-anatomy and post-procedural imaging is standard to exclude potential PVST. Retrospective chart review was performed for all 140 patients and availability of pre- or post-procedural cardiac imaging was assessed. All patients with both adequate pre- and post-procedural cardiac imaging data were included in the analysis.

Subject Characteristics

All patients reviewed showed highly symptomatic and drug refractory paroxysmal or persistent AF and presented for PVI. LA-size and fractional shortening was assessed in the long parasternal view by echocardiography. Written informed consent was obtained in all patients before the ablation procedure. Ethics approval was waived by the institutional ethics commission.

Catheter Characteristics and Generator

The PVACTM catheter and the GENius™ multichannel, phased-RF generator have been described previously. In brief, the PVAC catheter is a non-adjustable 9-F, over-the-wire, circular, decapolar mapping and ablation catheter, which is designed to be positioned at the
antral portion of the PVs. In fact, the circular portion can be manipulated by turning the catheter to increase or decrease the diameter from 20 mm to max. 25 mm. Each platinum electrode (3mm long, 1.5mm outer diameter, 3mm spacing) has a thermocouple under the surface, which directly contacts the endocardium.

The GENius™ multichannel-phased RF generator has five preset energy settings: bipolar, unipolar, and three ratios of bipolar/unipolar energy: 4:1, 2:1, and 1:1. During unipolar ablation current flows from the catheter electrodes to the dispersive electrodes on the patient’s back resulting in larger lesion depth than during pure bipolar energy application. During bipolar ablation current flows between adjacent pairs of electrodes. Each electrode is temperature-controlled and power-limited and a software algorithm modulates the power to reach the predefined target temperature. In addition, electrode cooling is achieved without active irrigation and by passive circulatory cooling from the blood flow. Together these features should prevent electrodes from overheating and temperature overshoot. Power is limited to a maximum of 8W per electrode when using the 4:1 power setting or 10W in all other settings.

**Electrophysiological Study**

Electrophysiological studies and PVI were performed with patients under general anesthesia, which we offer all patients presenting for PVI for reasons of comfort. After single transseptal puncture, systemic anticoagulation was achieved with intravenous heparin to maintain an activated clotting time of ≥300 seconds.

Antral ablation of the PVs was performed using the PVAC. Initially, the PVAC was placed inside the vein to record PV potentials. When the diameter of the PV fitted approximately to the size of the PVAC this was achieved by simply rotating the catheter into the ostium. In cases of smaller PV diameter the catheter was first extended to decrease the
diameter and then rotated inside the vein (Figure 1C). Retracting the PVAC inside the vein usually restored the circular shape with a reduced diameter. Subsequently, the PVAC was positioned in the antral region for ablation. When the diameter of the PV fitted to the diameter of the PVAC, the catheter was pushed against the PV-antrum. In cases of a large PV-ostium or a common ostium, the PVAC was sequentially repositioned around the ostium of the PV or at the antral site of the common ostium to achieve PVI. When no isolation of the common ostium could be achieved by this technique, ablation of remaining PV-potentials was performed moving closer to the common trunk of the LSPV and LIPV. RF-energy was usually delivered for 60s per application with a target temperature of 60°C. Ablation was always initiated with an energy setting of 4:1. Only after several applications, when no PVI could be achieved, the energy ratio was changed to 2:1 to increase lesion depth. PVAC ablation was continued until all recorded PV-signals were abolished. To confirm entrance block, differential pacing was performed with the PVAC inside the vein: depending on the timing of PV-potentials during general pacing from the coronary sinus, pacing from the left-atrial-appendage, the posterior left atrial wall or the superior-caval-vein was done, using a deflectable octapolar catheter (Bard,EPXT™). To confirm exit block, consecutive pacing was performed over all PVAC electrodes inside the vein with an amplitude of 10V and a width of 0.5ms.

Only PVI was performed during the procedure. In the presence of right atrial flutter before or during the procedure, ablation of the cavitricuspid isthmus was performed using a non-irrigated 8-mm-tip.

**PV Imaging for Guiding PVI during the Procedure**

Once the LA was accessed, selective PV-angiography with two-dimensional visualization of each PV was performed to delineate the PV-ostia and later to facilitate the
placement of the PVAC (Figure 1A/B). Since the installation of a rotational angiography system at our institution (February 2010), a three-dimensional-atriography (3D-ATG) for guiding PVI was performed in all subsequent patients instead of selective PV-angiography. For this purpose, a rotational angiography was carried out during adenosine-induced asystole. The LA and PVs were reconstructed with specialized 3D-ATG software (EP navigator, Philips Medical Systems). In the latter group, 3D-ATG was employed as a single-navigation tool for guiding PVI (Figure 1C/D).

Cardiovascular Imaging before and after PVI

MR-imaging was performed with a 1.5-T-MR-system (Magnetom Avanto, Siemens Healthcare, Erlangen, Germany) using a 32-channel cardiac coil. During contrast-enhanced MR-angiography we applied a three-dimensional fast spoiled gradient echo sequence in the coronal plane. 0.1mmol/kg Gadobutrol (Gadovist, Bayer Schering AG) was injected at a flow rate of 2ml/s for the ce-MRA. The following parameters were used for the MRA-sequence which was repeated 2 times without interruption during a single breath hold: echo time 1.18ms, repetition time 3.12ms, flip angle 25°, field-of-view 350mm, image matrix 269x384, slice thickness 1.2mm (voxel size:1.3mmx0.9mmx1.2mm), acquisition time 12s. Images of the LA and the PVs were reconstructed employing maximum intensity projection and multiplanar reformations.

For CT imaging a 16-slice multidetector-CT-scanner was used (Somatom Sensation 16, Siemens Healthcare, Erlangen, Germany) and acquisition parameters were as follows: collimation 16x0.75mm, rotation time 0.5s, pitch 1.25, tube voltage 120kV, tube current dose modulated 50-200mAs. The injection protocol consisted of 100ml of non-ionic iodinated contrast-agent (Iohexol, Accupaque 300, Amersham Health, Vienna, Austria) administered at
a flow rate of 3ml/s. CT images were reconstructed at contiguous section widths of 2mm in axial and coronal planes using a soft tissue reconstruction kernel.

PV anatomy including potential variants was examined in consensus by an experienced radiologist and by a clinical electrophysiologist. Quality of the obtained images was visually assessed applying the following score: inappropriate for analysis, minor quality, good quality and excellent quality. To detect a potential PV-narrowing, the diameter of each PV was measured at the maximum distance between two ostial points before and after the ablation procedure. The PV ostium was defined as the point of inflection between the LA-wall and the PV-wall (Figure 2). Whenever PVST was evident by visual aspect, the PV-diameter was assessed ostial and at the narrowest point of the stenosis if this point was away from the ostium. Depending on the shape of the PV either an axial plane (anterior-posterior dimension) or a coronal plane (superior-inferior dimension) was chosen for optimal evaluation of the PVST. PVST was categorized as insignificant (<25%), mild (25-50%), moderate (50-75%) and severe (>75%). The pattern of PVST was determined as concentric or eccentric.

**Follow-Up**

Patients were evaluated clinically at 3, 6 and 12 months following the ablation procedure. Symptomatic arrhythmia occurrence was determined and a 3-day Holter was performed to reveal asymptomatic recurrences of AF at each follow-up. AF-recurrence was defined as a documented AF-episode lasting longer than 30 seconds. In all patients with a documented PVST >25%, a third MRI or CT scan was performed to determine a potential progression of PVST. All patients with PVST were evaluated for clinical symptoms like cough, dyspnea or hemoptysis.

**Statistical Analysis**
Only PVST >25% were included in the statistical analysis. The data is presented as mean±standard deviation, counts or percentages, as appropriate. Comparison between groups was performed by multivariate regression analysis using a random-effects multi-level regression model with subject-specific intercepts to allow for clustering on the individual level. Additional parameters entered into the model were age and gender of the subjects, number of subject as a continuous variable (to adjust for the experience with the procedure, assuming a linear learning curve) and the pre-ablation PV-diameter of each PV. Associations are given as odds ratios for the incidence of PVST following PVAC ablation with 95%-confidence intervals (95%CI) and the exact two-sided p-value.

Results

Study Group

Pre- and post-ablation cardiac imaging was performed in 100 (55 males, 45 females) out of the 140 patients. Reasons for exclusion were missing imaging data in 13 patients before ablation and in 27 patients after ablation, respectively. AF was paroxysmal in 77 (77%) and persistent in 23 (23%) patients. The mean age of the study group was 60±10 years. All patients were treated unsuccessfully with at least 1.3±0.66 antiarrhythmic drugs. Mean left atrial size was 43±6mm. Mean fractional shortening measured by transthoracic echocardiography was 39±7%. Coronary artery disease was present in 16 patients, arterial hypertension in 52 patients and left ventricular hypertrophy in 19 patients.

Ablation Procedure

Total procedure time including general anesthesia was 163±36 minutes. Mean fluoroscopy time was 30±11 minutes. The mean RF-application time for successful isolation of all PVs was 30±11 minutes. The mean number of PVAC applications for complete PVI of
all veins was 23±9 for 4:1-energy ratio and 7±8 for 2:1-ratio. Complete isolation could be achieved in all of the PVs. Additional ablation of the cavo-tricuspid isthmus was performed in 5 (5%) patients.

**Cardiovascular Imaging and PV Anatomy**

PVI was guided by selective angiography in 70 (70%) patients and by 3D-ATG in 30 (30%) patients during the procedure. Pre-ablation cardiac imaging of the pulmonary veins was performed in a total of 410 PVs using CT in n=43 (43%) patients and MRI in 57 (57%) patients and in 32 (32%) and 68 (68%) patients after ablation, respectively. Pre-ablation imaging was performed the day before the procedure, post-ablation imaging was performed after a median (interquartile range) of 89 (15-165) days following the procedure. Both CT and MRI emerged as excellent diagnostic tools to estimate possible PVST with a high level of image quality during routine imaging (Table 1). The mean diameter in the left superior pulmonary veins (LSPV) before ablation was 17±3.6mm, left inferior pulmonary veins (LIPV) 15±3.6mm, right superior pulmonary veins (RSPV) 17±3.4mm and right inferior pulmonary veins (RIPV) 16±3.1mm. Cardiac imaging revealed an additional right middle pulmonary vein (RMPV) in 10 patients and a left-sided common ostium in 17 patients. Although PVI must be performed at the antrum of a common ostium, ablation was necessary close to the common trunk of the LSPV and LIPV to isolate the PVs in the majority of the patients. Thus, there was also a risk of PVST for both PV branches in patients with common ostiums, and all PVs terminating into a common ostium were counted independently.

**Incidence, Characteristics and Risk Factors of PVST**

Pre- and postprocedural imaging identified a reduction in PV diameter in 23 (23%) patients. As illustrated in Table 2, five (5%) patients had more than one PVST. Correspondingly a
detectable PV-narrowing was evident in 28 out of 410 (7%) PVs. In summary, of the pulmonary veins examined, insignificant PVST (<25%) was observed in 12 (2.9%), mild PVST (25-50%) in 15 (3.7%) and moderate PVST (50-75%) in 1 (0.2%). Specifically as noted in Table 3, the LSPV was affected in 12 (12%), the RSPV in 10 (10%), the LIPV in 5 (5%) and the RIPV in 1 (1%). No severe PVST (>75%) was detected. The majority of the PVST showed a concentric pattern, only one mild and one moderate PVST were eccentric (Figures 2 and 3). The location and severity of documented PVST are also summarized in Table 3.

The use of 3D-ATG was associated with a significantly reduced occurrence of PVST, with an incidence of 0.8 (95%-CI 0.0-2.2)% in the group of 30 subjects in which 3D-ATG was used, compared to an incidence of 5.4 (2.7-8.1)% during two-dimensional catheter guidance in the other 70 subjects. This corresponds to an OR of 0.048 (95%-CI 0.003-0.70; p=0.027). None of the other factors was associated with an increased occurrence of PVST.

**Clinical Outcome and Follow-Up**

At the three-month follow-up 92 out of 100 patients (92%) were free of AF, at six months 81 out of 92 patients (88%) were free of AF and at twelve months 49 out of 67 patients (73%) were free of AF, all without the use of antiarrhythmic drugs based on symptoms and 3-day Holter monitoring. 14 (14%) patients with recurrent AF post-ablation had persistent AF before PVI. There were two major complications. One patient had a stroke. After three months the patient recovered completely. Another patient developed a severe femoral hematoma requiring transfusion.

All of the patients with documented PVST were free of symptoms. Additional cardiac imaging was performed after a mean of 706±251 days in all patients with a PVST >25% (n=13), also including patients with duality of PVST. No progress of the PVST in any of the cases could be demonstrated.
Discussion

Here we present the first data demonstrating the incidence of PVST following phased-RF ablation of paroxysmal and persistent AF using the PVAC. We can demonstrate a detectable narrowing of PV diameter in 7% of the PVs corresponding to 23% of the patients. The majority of the PVST was insignificant or mild. Only one moderate PVST was found. No patient developed severe PVST. All affected patients were free of symptoms and the documented PVST did not worsen over time. In addition – despite not being the primary aim of the study and thus observed in a subgroup only – our results show that the use of 3D-imaging (3D-ATG) during the ablation procedure reduced the risk for occurrence of PVST significantly. Apart from that, PVST was not associated with other factors like operator’s experience or the age, gender and pre-ablation PV diameter of the subjects.

PVST is a well known complication after conventional RF ablation of AF using a point-by-point procedure with an irrigated single-tip catheter. An incidence of PVST requiring intervention in 0.29% of cases has been reported for this approach. New technologies such as the cryoballoon or the duty-cycled, phased-RF ablation with PVAC, which is specifically designed for circular antral PVI, have raised hopes of simplifying the procedure and minimizing the risk of this intrinsic complication. Concerning the cryoballoon, no cases of PVST have been observed so far. Despite several clinical studies demonstrating the feasibility and efficacy of the PVAC there have been no systemic evaluations of PVST by means of pre- and post-procedural CT or MRI, the gold standard to diagnose this complication. This is of importance, as electrode cooling during energy application is achieved without active irrigation and the impact of this new technology on the occurrence of PVST remains unclear. In contrast, the presence of PVST after conventional PVI applying irrigated-tip ablation has been evaluated more extensively. Dong et al...
reported PV-narrowing in 38% of PVs after conventional circumferential PVI. The vast majority of PV-stenoses were mild and asymptomatic and none required intervention. The incidence of such asymptomatic PV-narrowing was much lower (7%) in our study group, which may be due to the principal use of the 4:1-ablation mode, which might be less traumatic than irrigated-tip ablation and attributable to the circular shape of the PVAC, which is explicitly designed for optimal antral positioning. On the other hand, one may attribute the high incidence of asymptomatic, mild PVST in both studies to PV-reverse-remodeling after successful ablation rather than fixed PVST, because all mild stenoses were concentric rather than eccentric and PV narrowing was accompanied by a decrease in LA volume in the study group of Dong et al^25. This raises the question of whether a concentric narrowing of the PV-diameter <50% following successful ablation is indeed pathological or clinically irrelevant. Dong and co-workers^25 also found that a larger pre-ablation PV-size is a predictor for PVST.

Theoretically, a larger PV-diameter could provoke a shift of the circular PVAC deeper into the PV-ostium during ablation and therefore, is predisposed for PVST. Interestingly, PVST was not associated with the pre-ablation PV-diameter in our study group, although the mean PV-diameter in our cohort was slightly smaller compared to the data of Dong and co-workers^25. Taken together, our data demonstrate that PVST is a possible but rare complication following PVAC procedures. Moreover, PVST did not worsen over time.

However, a recent case report by de Greef et al^32 showed a severe PVST after phased-RF ablation. This finding may be surprising, as the primary goal of PVI by using the PVAC should be the circumferential antral ablation without energy application inside the vein. De Greef et al^32 found the most likely explanation to be inaccuracy of ostial delineation using selective PV-angiography and excessive use of the 2:1 ablation mode, which results in increased lesion depth resulting in higher risk for PVST. In our study group ablation was always performed by the use of the 4:1 ablation mode and the energy ratio was changed to
the 2:1 ablation mode only when no PVI could be achieved. In addition, it has been shown that the application of an optimized 3D-visualization during the ablation procedure improves safety in terms of the occurrence of PVST\textsuperscript{33-35}. When using the PVAC however, no electroanatomical mapping is necessary and selective PV-angiography is only performed before the procedure, which ultimately results in shorter procedure times. Nevertheless, this approach provides only a crude two-dimensional representation of true PV-anatomy and can misrepresent the exact positioning of the PVAC relative to the PV and this may be a risk factor giving rise to PVST. In our study, PVST was predominantly observed in the group with catheter-guidance via selective PV-angiography during the procedure. Thus, implementing 3D-imaging during the ablation procedure seems to reduce the occurrence of PVST because a displacement of the catheter into the vein becomes more recognizable (Figure 1 D).

**Limitations**

This study has several limitations. First, this was an observational study with retrospective chart review without a control group. Although the question of whether the incidence of PVST is lower with the PVAC than with standard irrigated RF-ablation could not be addressed, regarding the overall occurrence of PVST and the use of 3D-ATG our results are not affected by the study design. In particular, by taking into account the experience of the operator with the multivariate statistical approach we were able to distinguish the possible effects of operator experience from real associations. In addition, the number of patients in whom 3D-ATG was implemented is small. However, the finding of a decreased risk for PVST in these patients was highly significant and needs to be reported so that future studies can be designed accordingly.
Second, PVST is a complication with decreasing incidence but severe PVST may occur, as shown in the case report by De Greef et al., although no cases were found in our patient cohort. Our study focused solely on PVST after phased-RF ablation. However there was one incidence of stroke in our study group. Thus, larger randomized multicenter trials are now needed to compare phased-RF ablation with conventional ablation strategies for PVI in terms of safety.

Follow-up imaging was performed after 93±78 days, even though it was shown that PVST may progress over time. So it is unclear whether undetected PVST developed at a later stage in our study group. However, all patients with documented PVST >25% were followed up by MRI over a period of 706±251 days without any evidence of progression and also no evidence of any regression.

Finally, sensitivity of PVST might differ between MRI and CT scanning. Nevertheless, MRI and CT imaging of the PVs appear to provide similar anatomic and quantitative information.

**Conclusion**

This is the first study to report the incidence, characteristics and risk factors of PVST using phased-RF technology and the PVAC. Our data indicate that - with regard to the occurrence of PVST - the PVAC seems to be safe if used in an experienced center. As ablation inside the PVs should be avoided, detailed imaging of the PV anatomy seems to be important. Despite not being the primary aim of the study, the greatly decreased occurrence of PVST linked to the use of 3D-ATG is a remarkable result, as this clearly indicates further possibilities to lower the risk of PVST and needs to be examined in future. Randomized studies are now warranted to compare conventional PVI with PVAC procedures and the incidence of PVST in procedures with and without 3D-ATG.
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Conflict of Interest Disclosures: This study was not supported by industry. The author Christian von Bary receives consulting fees <5000 €/year from Medtronic.

References:


### Table 1: Quality of PV imaging

<table>
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<tr>
<th></th>
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<th>Minor</th>
<th>Good</th>
<th>Excellent</th>
<th>Total</th>
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<tr>
<td>MRI before PVI</td>
<td>0</td>
<td>5</td>
<td>24</td>
<td>28</td>
<td>57</td>
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<tr>
<td>MDCT before PVI</td>
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<td>0</td>
<td>4</td>
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<tr>
<td>MRI after PVI</td>
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<td>8</td>
<td>22</td>
<td>38</td>
<td>68</td>
</tr>
<tr>
<td>MDCT after PVI</td>
<td>0</td>
<td>0</td>
<td>2</td>
<td>30</td>
<td>32</td>
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</table>

Quality of PV imaging with MDCT or MRI before and after PVI. Values are given as n.
Table 2: Duality of PVST

<table>
<thead>
<tr>
<th>Patients with a duality of PVST</th>
<th>Affected PVs</th>
<th>Type of stenosis</th>
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<tbody>
<tr>
<td>1 (1%)</td>
<td>LSPV/LIPV</td>
<td>Mild/Moderate</td>
</tr>
<tr>
<td>1 (1%)</td>
<td>LSPV/LIPV</td>
<td>Insignificant/ Insignificant</td>
</tr>
<tr>
<td>1 (1%)</td>
<td>RSPV/LSPV</td>
<td>Insignificant/Mild</td>
</tr>
<tr>
<td>2 (2%)</td>
<td>LIPV/RSPV</td>
<td>Mild/Mild</td>
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</tbody>
</table>

A combination of more than one PVST was documented for five patients. Values are given as n (%).

Table 3: Characteristics of PVST

<table>
<thead>
<tr>
<th></th>
<th>Insignificant stenosis</th>
<th>Mild stenosis</th>
<th>Moderate stenosis</th>
<th>Severe stenosis</th>
<th>Total (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>&lt;25%</td>
<td>25-50%</td>
<td>50-75%</td>
<td>&gt;75%</td>
<td></td>
</tr>
<tr>
<td>RSPV (n=100)</td>
<td>2</td>
<td>8</td>
<td>0</td>
<td>0</td>
<td>10 (10%)</td>
</tr>
<tr>
<td>RIPV (n=100)</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1 (1%)</td>
</tr>
<tr>
<td>RMPV (n=10)</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0 (0%)</td>
</tr>
<tr>
<td>LSPV (n=100)</td>
<td>7</td>
<td>5</td>
<td>0</td>
<td>0</td>
<td>12 (12%)</td>
</tr>
<tr>
<td>LIPV (n=100)</td>
<td>2</td>
<td>2</td>
<td>1</td>
<td>0</td>
<td>5 (5%)</td>
</tr>
<tr>
<td>Total (n=410)</td>
<td>12 (2.9%)</td>
<td>15 (3.7%)</td>
<td>1 (0.2%)</td>
<td>0 (0%)</td>
<td>28 (7%)</td>
</tr>
</tbody>
</table>

RSPV=right superior pulmonary vein; RIPV=right inferior pulmonary vein; RMPV=right middle pulmonary vein; LSPV=left superior pulmonary vein; LIPV=left inferior pulmonary vein
Figure Legends:

Figure 1: Different imaging techniques for guiding PVI during the procedure were used. Selective PV-angiography with two-dimensional visualization of a left-sided common ostium and PVAC in mapping position is shown in panel A. Delineation of the PV-ostia and placement of the PVAC inside the common ostium relative to the PVs without 3D-imaging is challenging (B). 3D-ATG allows exact navigation of the PVAC with better visualization of catheter displacement inside the anterior part of the RSPV (D). Panel C shows the PVAC extended into the RSPV. Co=common ostium; RSPV=right superior pulmonary vein; LSPV=left superior pulmonary vein; LIPV=left inferior pulmonary vein; RIPV=right inferior pulmonary vein; LA=left atrium.

Figure 2: Figure 2 shows a mild concentric PVST of the RSPV (A-D) and a moderate eccentric PVST of the LIPV (E/F). The RSPV is shown before (A/C) and after (B/D) PVI in the axial (A/B) and coronal (C/D) plane. A reduction of 25-50% of the PV diameter was measured at the PV ostium. An eccentric moderate stenosis inside the LIPV is shown in the axial plane pre- (E) and post-ablation (F). The asterisks mark the PV-ostium determined by the inflection point between the LA-wall and the PV-wall (B/C/E).

Figure 3: 3D-reconstruction of the PVs and the LA identifies an eccentric PVST of the LIPV close to the ostium (black arrow).
Evaluation of Pulmonary Vein Stenosis Following Pulmonary Vein Isolation Using a Novel Circular Mapping and Ablation Catheter (PVAC)
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