Pulmonary Vein Ostium Geometry
Analysis by Magnetic Resonance Angiography
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Background—During a catheter ablation procedure for selective electrical isolation of pulmonary vein (PV) ostia, the size of these ostia is usually estimated using fluoroscopic angiography. This measurement may be misleading, however, because only the projected supero/inferior ostium diameters can be measured. In this study, we analyzed 3-dimensional magnetic resonance angiographic (MRA) images to measure the minimal and maximal cross-sectional diameter of PV ostia in relation to the diameter that would have been projected on fluoroscopic angiograms during a catheter ablation procedure.

Methods and Results—In 42 patients with idiopathic atrial fibrillation who were scheduled for selective electrical isolation of PV ostia, the minimal and maximal diameters of these ostia were measured from 3-dimensional MRA images. Thereafter, these images were oriented in a 45° right or left anterior oblique direction and the projected diameter of the PV ostia were measured again. The average ratio between maximal and minimal diameter was 1.5 ± 0.4 for the left and 1.2 ± 0.1 for the right pulmonary vein ostia. Because of the orientation and oval shape of especially the left pulmonary vein ostia, their minimal diameters were significantly smaller than the projected diameters.

Conclusion—Pulmonary vein ostia, especially those at the left, are oval with the short axis oriented approximately in the antero/posterior direction. Consequently, PV ostia may sometimes be very narrow despite a rather normal appearance on angiographic images obtained during a catheter ablation procedure. (Circulation. 2003;107:21-23.)

Key Words: fibrillation ■ atrium ■ veins ■ magnetic resonance imaging ■ catheter ablation

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leaves of atrial myocardium extending 1 to 2 cm into the pulmonary vein (PV) ostia can be part of the arrhythmogenic substrate responsible for initiation and/or perpetuation of idiopathic atrial fibrillation.1–3 Therefore, electrical isolation of these ostia by catheter ablation is presently used as a treatment modality for patients with this problem. This isolation can be achieved by discrete lesions at the rim of the ostium, guided by perimetric mapping with a multipolar loop catheter like the Lasso (Biosense Webster, Inc) or by lesions in the left atrium encircling multiple PV ostia.1,4

The size of PV ostia is an important factor in selecting the optimal Lasso diameter, and larger PV ostia may more often be arrhythmogenic.5 Additionally, isolation of smaller ostia may have to be performed more carefully.6 Therefore, PV angiography is usually performed at the beginning of the procedure to determine the position and size of the PV ostia. Estimation of the PV ostium size may be inaccurate, however, not only because of the lack of sufficiently accurate calipers in standard angiographic images, but also because only the projected diameter can be measured.

The aim of this study was to analyze by 3-dimensional magnetic resonance angiography (MRA) the cross-sectional dimensions of PV ostia in patients with idiopathic atrial fibrillation who were scheduled for catheter ablation and to compare these data with the diameters that would have been projected on anterior angiographic images.

Methods
In 42 consecutive patients with idiopathic paroxysmal atrial fibrillation who were scheduled for catheter ablation, gadolinium enhanced MRA of the left atrium was performed. At first, all structures that hindered a clear view of the PV ostia, including arteries, PV branches, and anterior part of left atrium, were erased from the 3-dimensional image using advanced image processing techniques (Vitrea, Vital Images Inc). The minimal and maximal diameters of each ostium were then measured semi-automatically by recognition of the outer borders of the image along a line drawn by the operator through the center and at the level of the ostium. Thereafter, the same MRA image was also used to simulate angiographic projections during a catheter ablation procedure. The image was rotated to a 45° right anterior oblique (RAO) or left anterior oblique (LAO) view angle, and the projection that gave the best view on the ostium was used to measure its diameter at the same level where the minimal and maximal diameters had been measured. These data thus allowed for comparison between minimal and maximal PV ostium diameters and...
Figure 1. Magnetic resonance angiographic and fluoroscopic images of the left atrium of one of the patients of this study. Left, Posterior view on the left atrium showing both left pulmonary veins. The diameter of the left inferior ostium appears to be normal. Middle, Caudal view of the same left inferior ostium, which clearly demonstrates a very narrow antero/posterior diameter. Right, Fluoroscopic angiography (45° LAO) of the same left inferior ostium showing an apparently normal ostium diameter. The narrow antero/posterior diameter remains invisible.

Results

In 42 patients, a total of 38 left superior, 38 left inferior, 42 right superior, and 42 right inferior ostia were analyzed. Four patients had a common left ostium, whereas 4 others had a right middle PV.

Figure 1 shows left atrial images of one of the patients. The posterior MRA projection shows apparently normal diameters for both left PV ostia. The caudal MRA projection, however, clearly demonstrates that the left inferior PV ostium is remarkably narrow in the antero/posterior direction. The LAO angiogram, obtained at the beginning of the ablation procedure, again suggests a normal left inferior ostium.

Data of all PVs are summarized in the Table. The ratio between maximal and minimal diameter, a measure of the ovality of the ostia, was 1.4±0.4 for the left superior, 1.5±0.4 for the left inferior, 1.2±0.1 for the right superior, and 1.2±0.2 for the right inferior PV (Table). The overall F test showed that these values differed significantly among the 4 PV groups (P<0.005). The Scheffé analysis resulted in a highly significant difference between right and left PVs (P<0.005); differences between ipsilateral PVs were not significant.

With an oval ostium, the minimal cross-sectional diameter can only be equal to or smaller than the projected diameter. For the fairly circular right PV ostia, the average difference between projected and minimal ostium diameter was only 1.6±1.6 mm for the superior and 1.8±2.3 mm for the inferior ostium (Figure 2). For the less circular left PV ostia, the average difference between minimal and projected ostium diameters was 3.6±3.4 mm for the superior and 3.7±2.8 mm for the inferior ostia (Figure 2). Again the differences among the 4 PV groups were only caused by differences between right and left PV ostia (P<0.005). For only 2 right superior and 5 right inferior PV ostia, the minimal diameter was more than 5 mm smaller than the projected diameter. This was also the case for 11 left superior and 8 left inferior ostia. For 3 of these left ostia, this difference was more than 10 mm. Four left superior, 11 left inferior, and 2 right inferior PVs had a minimal ostium diameter <10 mm.

Discussion

In the absence of clear markers indicating specific PVs as targets, large PV ostia are often considered to be main targets. With selective isolation of PV ostia, the dimensions of the ostia are also important for choosing the optimal Lasso size. Last but not least, ostium size may relate to the risk of PV stenosis caused by catheter ablation. Isolation of small ostia

### Average Pulmonary Vein Ostium Diameters

<table>
<thead>
<tr>
<th></th>
<th>n</th>
<th>Minimum, mm</th>
<th>Maximum, mm</th>
<th>Ratio</th>
<th>Range, mm</th>
<th>Projected, mm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Left superior</td>
<td>38</td>
<td>18.7±2.9</td>
<td>13.9±3.7</td>
<td>1.4±0.4</td>
<td>1.0–3.0</td>
<td>17.5±2.9</td>
</tr>
<tr>
<td>Left inferior</td>
<td>38</td>
<td>15.9±3.1</td>
<td>11.2±3.1</td>
<td>1.5±0.4</td>
<td>1.0–2.3</td>
<td>15.0±2.7</td>
</tr>
<tr>
<td>Both left</td>
<td>76</td>
<td>1.5±0.4*</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Right superior</td>
<td>42</td>
<td>18.8±2.7</td>
<td>16.0±2.0</td>
<td>1.2±0.1</td>
<td>1.0–1.5</td>
<td>17.5±2.1</td>
</tr>
<tr>
<td>Right inferior</td>
<td>42</td>
<td>17.9±2.9</td>
<td>15.1±3.0</td>
<td>1.2±0.2</td>
<td>1.0–1.7</td>
<td>16.9±3.1</td>
</tr>
<tr>
<td>Both right</td>
<td>84</td>
<td>1.2±0.1*</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Left common</td>
<td>4</td>
<td>27.3±6.2</td>
<td>18.7±6.7</td>
<td>1.6±0.5</td>
<td>1.0–2.2</td>
<td>26.5±4.8</td>
</tr>
<tr>
<td>Right middle</td>
<td>4</td>
<td>7.6±3.1</td>
<td>5.6±2.1</td>
<td>1.4±0.4</td>
<td>1.0–2.0</td>
<td>7.0±1.9</td>
</tr>
</tbody>
</table>

Dimensions of PV ostia measured with MRA. For each PV, the maximal and minimal ostium diameters were measured together with the projected diameter by using a 45° RAO or LAO view angle for the MRA images. The ratio between maximal and minimal ostium diameters is a measure of the ovality of the PV ostia.

* Differences in ovality were only significant between right and left PV ostia (P<0.005).
may have to be performed outside the rim of the ostium to avoid PV stenosis.4

The present study demonstrates that contrast angiography can be misleading; anterior projections only show the supero/inferior PV ostium diameter. Most PV ostia, and especially those at the left, are oval, with an average long/short axis ratio of 1.5 ± 0.4. Their short axis is oriented approximately in the antero/posterior direction and is not visualized with angiography. Because of their more circular shape, estimation of the right-sided PV ostium diameters from anterior projections is less accurate. When catheter ablation has caused edema or stenosis in anterior or posterior sections of the ostia, however, this may also remain undetectable with anterior projections. An oval shaped ostium may also affect the position and stability of a circular Lasso type catheter because it may tend to orient itself in a canted position and cause a misleading activation sequence.

Other investigators have also studied the size and anatomy of PV ostia, but they ignore the possibility of an oval shape by reporting only single values for ostium diameters, ranging from approximately 14 mm for both superior ostia to approximately 8 mm for both inferior ostia.3,5 When measured with transesophageal echocardiography at a depth of 1.5 to 2 cm from the ostium, the diameters of the right and left superior PVs were only approximately 1.1 cm.6 The dimensions measured in our study are substantially larger, and we cannot explain this discrepancy. Our most frequently used Lasso size was 20 mm, which confirmed the MRA data.

Limitations
The true and projected ostium dimensions were only measured from MRA images. Angiographic measurements would have introduced extra inaccuracies, and it would have been almost impossible to measure at exactly the same location as where the MRA measurements had been performed. In this study, we compared MRA data with 45° RAO and LAO projections. Other angulations like 0, 30, or 60 degrees could have resulted in slightly different projected diameters, but the minimal diameter, approximately oriented in the antero/posterior direction, would still remain invisible.

This study describes the geometry of PV ostia and the limitation of fluoroscopic angiography. All MRA images were available during the mapping-guided ablation procedure and facilitated PV angiography, selection of the optimal Lasso catheter size, and recognition of proximal PV branches that might complicate electrical isolation. Radiofrequency applications in very narrow ostia (minimal diameter <10 mm) were avoided to limit the risk of PV stenosis. The benefits of MRA before the ablation procedure should, however, be analyzed in a prospective randomized study.

Conclusions
Left PV ostia are oval, with a mean ratio between maximal and minimal diameter of 1.5 ± 0.4 and a short axis oriented approximately in the antero/posterior direction. Right-sided PV ostia are more circular, with a mean ratio value of 1.2 ± 0.1. Consequently, PV ostia may sometimes be very narrow despite a rather normal appearance on venograms obtained during a catheter ablation procedure. True ostium dimensions can only be measured with 3-dimensional imaging techniques like MRA or computer tomography.

References
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Circulation. 2003;107:21-23; originally published online December 9, 2002;
doi: 10.1161/01.CIR.0000047065.49852.8F
Circulation is published by the American Heart Association, 7272 Greenville Avenue, Dallas, TX 75231
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Print ISSN: 0009-7322. Online ISSN: 1524-4539

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