Left Atrial Diverticula in Patients Referred for Radiofrequency Ablation of Atrial Fibrillation
Assessment of Prevalence and Morphologic Characteristics by Dual-Source Computed Tomography

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Background—The anatomic features of left atrial diverticula (LAD) are still unclear in patients with atrial fibrillation (AF). The purpose of this study was to evaluate the prevalence and morphological characteristics of LAD in patients referred for radiofrequency transcatheter ablation of AF with dual-source computed tomography.

Methods and Results—Dual-source computed tomography images were obtained in 214 patients referred for AF catheter ablation and 214 sex- and age-matched control subjects. Images were analyzed to determine the prevalence and morphological characteristics of LAD and their relationship with adjacent pulmonary veins and left atrial appendage. In AF patients 77 (36.0%) (95% confidence interval, 29.6–42.4%) had 90 LAD, whereas in control subjects 70 (32.7%) (95% confidence interval, 26.4–39.0%) had 81 LAD ($P_{H11005} = 0.551$). In patients with AF, LAD locations were right anterosuperior (47.8%), left anterosuperior (8.9%), left lateral (32.2%), interatrial septum (4.4%), right inferior (5.6%), and posterosuperior (1.1%) walls, respectively. The mean size of LAD was 5.3 ± 2.9 mm. The wall of the LAD was much thinner than that of adjacent left atrium (0.89 ± 0.46 versus 2.39 ± 0.83 mm). Most LAD were located close to a pulmonary vein or atrial appendage ostium, with a mean distance of 8.7–13.1 mm.

Conclusions—LAD are common, with a prevalence of 36.0% in patients with AF, which is not statistically greater than that in patients without AF. Thin-walled LAD are more commonly located on the superior anterior wall of left atrium and close to common ablation sites. (Circ Arrhythm Electrophysiol. 2012;5:345-350.)

Key Words: left atrial diverticulum • atrial fibrillation • catheter ablation • arrhythmias • dual-source computed tomography

Atrial fibrillation (AF) is the most common clinically significant cardiac arrhythmia and is increasing in frequency as the population ages.1 Left atrial radiofrequency transcatheter ablation of AF is currently considered a reasonable alternative to pharmacological therapy to prevent recurrent AF in symptomatic patients, and the procedures are performed increasingly.1–5 Catheter-related major complications including pulmonary vein stenosis, atrioesophageal fistula, stroke, and cardiac tamponade have been reported in about 1.0–2.4% of procedures.5 Recent studies have shown that left atrial diverticula (LAD) are a common anatomic variant in patients referred for computed tomography (CT) coronary angiography.6,7 Because LAD are possible sites for catheter entrapment, they theoretically could contribute to complications, such as perforation and thrombus formation in AF catheter ablation. However, the anatomic features of LAD are largely unknown in patients referred for catheter ablation for AF. Thus, the purpose of this study was to evaluate the prevalence and morphological characteristics of LAD with dual-source computed tomography (DSCT) in patients referred for radiofrequency catheter ablation of AF.

Clinical Perspective on p 350

Methods

Patient Population
From July 17, 2009, to April 9, 2011, 245 patients underwent DSCT pulmonary venography. The study was approved by the institutional review committee of our hospital, and all the subjects gave informed consent. Inclusion criteria were as follows: (1) adequate image quality (graded ≥2), (2) paroxysmal AF or persistent AF <1 year, (3) catheter radiofrequency ablation of AF was performed. DSCT image quality was graded on a 3-point scale as follows: 1 point,
nondiagnostic image quality with severe artifacts on the left atrial wall; 2 points, adequate image quality with mild artifacts on the left atrial wall in a few slices; and 3 points, good image quality free of artifacts. Fourteen patients without ablation and 17 patients with poor image quality were excluded, leaving 214 patients (mean age, 59.5±11.8 years; range, 24–79 years; male, n=124; female, n=90) who were included. A group of 214 sex- and age-matched control subjects without AF, who underwent DSCT coronary angiography, served as a control group. Patient characteristics of our study population are listed in Table 1.

### DSCT Protocol

All studies were performed using a DSCT scanner (Somatom Definition, Siemens Medical Solutions, Chengdu, Sichuan, China). Scanning was performed in cranio-caudal direction with retrospective ECG-gated mode. The ECG-pulsing window was set on auto to lower the radiation dose. The scanning parameters were as follows: tube potential (weight ≥85 kg, 120 kV for each tube; weight <85 kg, 100 kV for each tube); body mass index (BMI)-dependent tube current (BMI ≥25, 330 mAs per rotation; BMI <25, 220 mAs per rotation); collimation, 64×0.6 mm; gantry rotation time, 330 ms; pitch (heart rate-dependent: 0.2–0.5). No β-blocker was administered before scanning.

All patients received 60–80 mL nonionic contrast agent (iopamidol, 370 mg/mL; Bracco Sine Pharmaceutical Corp Ltd, Shanghai, China) through an antecubital vein by a power injector (Stellant, Medrad, Inianola, Chengdu, Sichuan, China) at a flow rate of 5.0 mL/s. The injection of contrast agent was followed by a saline flush of 20 mL at the same flow rate. Bolus tracking was used with the region of interest on the left atrium, and the threshold was 100 Hounsfield units. The image acquisition was automatically triggered with a delay of 5 seconds.

### DSCT Data Postprocessing

Images were reconstructed at 5% step of the R-R interval within the range of full tube current with a slice thickness of 0.75 mm and an increment of 0.5 mm by using a B26f medium soft-tissue kernel (Siemens Medical Solutions). The phase with the best image quality in diastole was used for further analysis. The data sets were all transferred to an off-line work station (Leonardo, Siemens Medical Solutions) and loaded to a 3D cardiac postprocessing software (Syngo 3D, Siemens Medical Solutions). Multiplanar reformation and the volume-rendered technique were used for image analysis.

With these dedicated software, the left atrium could be appreciated on any plane and in volume-rendered images.

### Image Analysis

In general, LAD have been considered cyst-like structures projecting from the atrial cavity. Because there is not an established definition, and some LAD are not like a cyst according to our experience and previous studies,6,7 we used an adapted definition of LAD from a previous study.7 We defined LAD as projecting from the heart cavity outside the plane of the left atrial wall, irrespective of its etiology.

The location was characterized on the basis of the atrial wall as superior, inferior, left lateral, anterior, and posterior, and septal. There is no established method for describing the shape of LAD. We evaluated the shape of LAD according to a method adapted from a previous study.7 If the LAD had a broad orifice and domelike fundus with (body length/orifice width ratio ≤3), it was cystiform; if the LAD appeared as a cone with a broad orifice, it was cone-shaped; if it had a long but relatively small cavity (length/orifice width >3), it was tubiform; if the LAD cavity was irregular, it was irregular. The major diameter of the orifice and the length of the LAD body were measured. The thickness of the wall of the LAD was measured at the bottom of the LAD. The thickness of left atrial wall adjacent to the LAD was also measured.

In our study, all 214 AF patients underwent circumferential pulmonary vein isolation. Ablation lines were placed around the ostia of pulmonary veins (Figure 1). Additional linear ablation including a left atrial roof line plus a line connecting the left inferior pulmonary vein to the mitral annulus was performed in 11 patients. Additional focal ablation was performed in 10 patients.

To describe the relationship of LAD with common ablation sites, we measured the distance from orifice of LAD to the ostia of the adjacent pulmonary vein and left atrial appendage (LAA) (Figure 1). The LAA was included, based on a recent study showing that the LAA is an underrecognized trigger site of AF.

### Statistical Analysis

Continuous data are expressed as mean±SD. Categorical variables are presented as percentages. Descriptive statistics were calculated. The 95% confidence interval (CI) was provided when estimating the prevalence of LAD. Comparisons between prevalence of LAD in
patients with and without AF were performed by McNemar χ² test. Comparisons between location of LAD in patients with and without AF and comparison of prevalence of LAD in men and women were performed by Pearson χ² test. Spearman rank correlation test was performed between the number of LAD and absolute left atrial diameter to test the correlation of prevalence of LAD and left atrial size. To test the reproducibility of diagnosing LAD on CT images, the first reviewer read the CT images to evaluate the LAD, and a second blinded reviewer read the same CT images again to assess the LAD. χ² Test was used to test the interobserver variability for detecting LAD in 40 patients with repeat AF ablation. A 2-tailed probability value of <0.05 indicated statistically significant. Statistical analysis was performed using commercially available software (SSPS for Windows, 11.5).

Results

Two hundred fourteen patients who underwent circumferential pulmonary vein ablation for AF and 214 sex- and age-matched patients who underwent DSCT coronary angiography were included. Detailed patient characteristics of our study population are listed in Table 1.

Prevalence of LAD

In patients with AF, a total of 90 LAD were found in 77 of 214 (36.0%) (95% CI, 29.7–42.3%) patients. Of the 77 patients with LAD, 57 men had 60 LAD and 20 women had 30 LAD. The prevalence of LAD in men was greater than that in women (40.1%, 57/142 versus 27.8%, 20/72; P = 0.030).

In the control group without AF, a total of 81 LAD were found in 70 of 214 (32.7%) (95% CI, 26.4–39.0%) patients. Of the 70 patients with LAD, 49 men had 55 LAD and 21 women had 26 LAD. No statistical difference was found between prevalence of LAD in men and that in women (34.5%, 49/142 versus 29.2%, 21/72; P = 0.431).

The prevalence of LAD in patients with AF was not statistically significantly different from that in control group without AF (36.0% versus 32.7%; P = 0.551). Spearman rank correlation showed that there were no correlations between the prevalence of LAD (expressed as number of LAD) and left atrial size (expressed as absolute anteroposterior diameter).
Table 2. Size of LAD in Different Locations in Patients With Atrial Fibrillation

<table>
<thead>
<tr>
<th>Variables (n=90)</th>
<th>Size</th>
</tr>
</thead>
<tbody>
<tr>
<td>Size of right anterosuperior LAD, n=43</td>
<td>Orifice Width, mm</td>
</tr>
<tr>
<td>Size of left anterosuperior LAD, n=8</td>
<td>5.4±3.6 (1.8–18.8)</td>
</tr>
<tr>
<td>Size of left lateral LAD, n=29</td>
<td>4.9±2.5 (1.7–12.6)</td>
</tr>
<tr>
<td>Size of IAS LAD, n=4</td>
<td>3.0±1.1 (2.1–4.5)</td>
</tr>
<tr>
<td>Size of right posterior LAD, n=5</td>
<td>4.4±3.4 (2.1–10.4)</td>
</tr>
<tr>
<td>Size of right anterosuperior LAD, n=43</td>
<td>5.4±3.6 (1.8–18.8)</td>
</tr>
</tbody>
</table>

LAD indicates left atrial diverticula/diverticulum; IAS, interatrial septum; n denotes the number of LADs.

Size and Wall of LAD
In patients with AF, the overall mean orifice width and body length of the LAD were 5.3±2.9 mm and 5.6±3.3 mm, respectively. Table 2 summarizes the detailed information on size of LAD in different locations.

The mean wall thickness of LAD was 0.89±0.46 mm (range, 0.3–2.7 mm). The thickness of the adjacent wall of the left atrium was 2.39±0.83 mm (range, 1.1–5.5 mm). The wall of the LAD was much thinner than that of the adjacent left atrium (Figure 4).

Relationship of LAD With Pulmonary Veins or LAA
Most LAD were often located close to the ostia of a pulmonary vein or LAA (Figure 5). The distance from the LAD orifice to the ostia of adjacent pulmonary vein and LAA is summarized in Table 3. The distance from the LAD orifice to the ostia of adjacent pulmonary veins varied greatly, ranging from 0–31.8 mm, with a mean distance from 8.7–13.1 mm.

Interobserver Variability for Detecting LAD
Interobserver variability for detecting of LAD by 2 different readers was assessed in 40 cases. The first reader diagnosed 10 patients with LAD; the second reader missed 1 patient with LAD. There was excellent agreement (κ=0.931, P<0.001).

Discussion
DSCT with fast scanning speed and high temporal resolution enables imaging of the cardiac structural details free of or with much less motion artifacts.9 Our study showed that DSCT was feasible for assessing the presence and features of LAD.

Main Findings
The main findings of this study were that (1) LAD were common entities, with a prevalence of 36.0% (95% CI, 29.7–42.3%) in patients referred for catheter ablation for AF in the present study; and the prevalence of LAD in patients with AF was not higher than that in patients without AF (32.7%) (95% CI, 26.4–39.0%) (P=0.551); (2) there were no correlations between the prevalence of LAD and left atrial size in patients with and without AF (r=−0.13, P=0.853,
and $r=-0.32$, $P=0.645$, respectively; (3) LAD locations vary, and right anterosuperior and left lateral wall LAD are more common in patients with AF; (4) LAD can be single or multiple, and a single LAD is much more common than multiple LAD; LAD can have different shapes, with cystiform being most common; (5) the LAD wall is much thinner than that of adjacent left atrium in the majority of patients (0.89±0.46 mm versus 2.39±0.83 mm); (6) the majority of LAD are located close to ostia of adjacent pulmonary veins or the LAA, with a mean distance of 8.7–13.1 mm.

**Presence, Locations, and Morphology of LAD**

The prevalence of right anterosuperior location of LAD in our study in patients with and without AF was similar to previous studies; however, the prevalence of left lateral wall location of LAD in patients with AF in our series was much higher than that reported in our series and previous studies in patients without AF.

LAD in the right inferior wall or interatrial septum tended to be tubiform or irregular. Tubiform LAD usually had a long and tortuous body. These findings have never been reported previously. If a catheter is placed inside one of these diverticula, it seems likely that low flow could potentially facilitate excessive heating with low power and a risk of steam pop or coagulum formation. Additionally, if the LAD has a long body, the catheter tip could theoretically become trapped. No patient had a catheter lodged in an LAD in our series.

**Wall of the LAD and Relationship of LAD With Ablation Sites**

Our results showed that the wall of the LAD was much thinner than that of adjacent left atrium, resulting in a potentially vulnerable area of left atrium for perforation during radiofrequency ablation. The close vicinity between the orifice of the LAD and common ablation sites including the ostia of adjacent pulmonary veins and the LAA might increase the chance of encountering the LAD with the ablation catheter. In our series, 2 of 214 patients (0.9%) who

<table>
<thead>
<tr>
<th>Variables (n=90)</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Distance from the orifice of right anterosuperior LAD to that of right upper PV, n=43</td>
<td>9.0±4.1 mm (range, 0–18.2 mm)</td>
</tr>
<tr>
<td>Distance from the orifice of left anterosuperior LAD to that of left upper PV or LAA, n=8</td>
<td>9.0±5.0 mm (range, 0–19.3 mm)</td>
</tr>
<tr>
<td>Distance from the orifice of left lateral LAD to that of left upper PV, left lower PV or LAA, n=29</td>
<td>13.1±7.3 mm (range, 0–31.8 mm)</td>
</tr>
<tr>
<td>Distance from the orifice of right inferior lateral LAD to that of right lower PV, n=4</td>
<td>8.7±4.6 mm (range, 2.8–13.4 mm)</td>
</tr>
<tr>
<td>Distance from the orifice of posterosuperior LAD to that of left superior PV, n=1</td>
<td>17.5 mm</td>
</tr>
</tbody>
</table>
had an LAD had cardiac tamponade caused by acute hemopericardium during ablation procedure. Both patients had LAD, but this occurrence might be explained by chance. Thus, further prospective studies are needed to clarify whether the presence of LAD is associated with catheter-related complications.

Interobserver Variability for Detecting LAD
Our data showed excellent agreement concerning evaluating the LAD in repeated CT images. One patient with LAD was missed by the second reviewer. The divergence might be explained by the fact that the missed LAD was very small, and the CT images used for evaluation were not in the same cardiac phase.

Study Limitations
We recognize several limitations in our study. First, the CT scan has radiation exposure to patients; however, CT has been the optimal method for evaluating pulmonary vein anatomy and left atrial structure in clinical practice.10,11 Second, owing to the observational, retrospective design of our study, whether LAD are associated with increased catheter ablation-related complications remains uncertain. Further prospective studies are needed in this aspect in the future. Last, a few accessory LAAs, which are similar to LAD in shape, were noted in the present study. However, these were not included in the present study.

Conclusions
LAD are common, with a prevalence of 36.0% in patients with AF. The prevalence of LAD in patients with AF was not higher than that in patients without AF. Thin-walled LAD are more commonly located on the superior anterior wall of left atrium and are close to common ablation sites.

Disclosures
None.

References
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