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

Running title: Peng et al.; Prevalence and morphologic characteristics of LAD

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Abstract:

**Background** - The anatomical 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 morphologic characteristics of LAD in patients referred for radiofrequency transcatheter ablation of AF with dual-source computed tomography (DSCT).

**Methods and Results** - DSCT 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 morphologic characteristics of LAD, and their relationship with adjacent pulmonary veins and left atrial appendage (LAA). In AF patients 77 (36.0%) (95%CI, 29.6%-42.4%) had 90 LAD, while in control subjects 70 (32.7%) (95%CI, 26.4%-39.0%) had 81 LAD ($P = 0.551$). In patients with AF, LAD locations were right anterosuperior (47.8%), left anteropsrior (8.9%), left lateral (32.2%), interatrial septum (4.4%), right inferior (5.6%) and posteroserior (1.1%) walls, respectively. The mean size of the LAD was $5.3 \pm 2.9 \times 5.6 \pm 3.3$ mm. The wall of 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 to 13.1 mm.

**Conclusions** - Left atrial diverticula are common with a prevalence of 36.0% in patients with AF, that 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.

**Key words:** Left atrial diverticulum; Atrial fibrillation; Catheter ablation; Arrhythmias; Dual-source computed tomography
Introduction

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 in 1.0% to 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]. As 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 anatomical 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 morphologic characteristics of LAD with dual-source computed tomography (DSCT) in patients referred for radiofrequency catheter ablation of AF.

Methods

Patient population

From July 17th 2009 to April 9th in 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 less than 1 year. (3) catheter radiofrequency ablation of AF was performed. DSCT image quality was graded on a 3-point scale as follows: 1
point, non-diagnostic image quality with severe artifacts on the left atrial wall; 2 points, adequate image quality with mild artifacts on left atrial wall in a few slices; 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; range, 24-79 years, male 124, female 94) 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, Germany). 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 ≥ 85kg, 120kV for each tube; weight < 85kg, 100kV for each tube); Body mass index (BMI) dependent tube current (BMI ≥ 25, 330mAs per rotation; BMI < 25, 220mAs 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 prior to scanning.

All patients received 60-80ml nonionic contrast agent (iopamidol, 370mg/ml; Bracco Sine Pharmaceutical Corp. Ltd, Shanghai, China) via an antecubital vein by a power injector (Stellant, Medrad, Inianola, USA) 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 post-processing**
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 three dimensional (3D) cardiac post-processing software (Syngo 3D, Siemens Medical Solutions). Multiplanar reformation (MPR) and volume rendered technique (VRT) 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 [7]. As 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 project from the heart cavity to 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, right and 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 looked like 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 PV 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 left atrial appendage (LAA) is an under-recognized trigger site of AF [8].

**Statistical analysis**

Continuous data were expressed as mean ± SD. Categorical variables were presented as percentages. Descriptive statistics were calculated. 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's chi-square 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's chi-square 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. Kappa test was used to test the inter-observer variability for detecting LAD in 40 patients with repeat AF ablation. A two-tailed \( P \) value of less than 0.05 indicated statistically significant. Statistical analysis was performed.
using commercially available software (SSPS for Windows, 11.5).

Results

Two hundred and 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 were 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 vs. 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 vs. 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% vs. 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 of left atrium) in patients with and without AF (\( r = -0.13, P = 0.853 \) and \( r = -0.32, P = 0.645 \), respectively).

Imaging features of LAD in patients with AF

In patients with AF, 56.7% (51/90) LAD locations were located in the anterosuperior wall (right anterosuperior, 47.8%; left anterosuperior, 8.9%), 32.2% (29/90) were in the left lateral wall,
10% (9/90) were in the right lateral wall (interatrial septum, 4.4%; right inferior wall, 5.6%), and 1.1% (1/90) were in the posterosuperior wall (Figure 2). In the control group, 79% (64/81) LAD were located in anterosuperior wall (right anterosuperior 75.3%; left anteropsuperior 3.7%), 9.9% (8/81) were in the left lateral wall, 8.6% (7/81) were in the right lateral wall (interatrial septum 1.2%; right inferior 7.4%), and 2.5% (2/81) were in the posteroinferior wall. The locations of LAD in patients with AF were statistically different from those in patients without AF \((P = 0.001)\).

In patients with AF, LAD could be single (74%, 67/90) or multiple (26%, 23/90) (Figure 2). LAD may appear as cystiform (53.2%), cone-shaped (36.3%), tubiform (4.8%) or irregular (4.8%) (Figure 3). Cystiform LAD were most common.

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

**The 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 to 31.8 mm with a mean distance from 8.7 to 13.1 mm.

**Interobserver variability for detecting LAD**
Interobserver variability for detecting of LAD by two different readers was assessed in 40 cases. The first reader diagnosed 10 patients with LAD, while the second reader missed one patient with LAD. There was excellent agreement ($\kappa = 0.931$, $P < 0.001$).

**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 ($0.89 \pm 0.46$ mm vs. $2.39 \pm 0.83$ 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 to 13.1 mm.

**Presences, 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 [6, 7]; 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 [6, 7].

LAD in the right inferior wall or IAS tended to be tubiform or irregular. Tubiform LAD usually had a long and tortuous body. These findings have never been reported previously [6, 7]. 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 stuck in a LAD in our series.

Wall of LAD and relationship of LAD with ablation sites

Our results showed that the wall of 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 LAD and common ablation sites including the ostia of adjacent pulmonary veins and LAA might increase the chance of encountering an LAD with the ablation catheter. In our series, 2/214 patients (0.9%) who had a LAD experienced cardiac tamponade due to 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 are 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 recognized several limitations in our study. Firstly, 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]. Secondly, 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 left atrial appendages, 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.

**Conflict of Interest Disclosures:** None.

**References:**


Table 1. Characteristics of Patients with and without Atrial Fibrillation.

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total No. of patients</td>
<td>214</td>
</tr>
<tr>
<td>Age (yrs) (mean ± SD, range)</td>
<td>59.5 ± 11.8 (24-79)</td>
</tr>
<tr>
<td>Men</td>
<td>142 (66.4%)</td>
</tr>
<tr>
<td>Atrial fibrillation</td>
<td>214 (100%)</td>
</tr>
<tr>
<td>Patients underwent catheter ablation</td>
<td>214 (100%)</td>
</tr>
<tr>
<td>Antero-posterior diameter of LA (mm)</td>
<td>40.9 ± 7.9 (19.1-59.9)</td>
</tr>
<tr>
<td>Coronary artery diseases</td>
<td>51 (23.8%)</td>
</tr>
<tr>
<td>Structural heart diseases</td>
<td>51 (23.8%)</td>
</tr>
<tr>
<td>Atrial septal defect</td>
<td>2 (0.9%)</td>
</tr>
<tr>
<td>Patent foramen ovale</td>
<td>6 (2.8%)</td>
</tr>
<tr>
<td>Pulmonary valve stenosis</td>
<td>1 (0.5%)</td>
</tr>
<tr>
<td>Valvular diseases</td>
<td>37 (17.3%)</td>
</tr>
</tbody>
</table>

* DSCT = dual-source computed tomography; AF = atrial fibrillation; LA = left atrium

Table 2. Size of LAD in Different Locations in Patients with Atrial Fibrillation.

<table>
<thead>
<tr>
<th>Variables (n = 90)</th>
<th>Orifice width (mm)</th>
<th>Body length (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Size of right anterosuperior LAD (n = 43)</td>
<td>5.4 ± 3.6 (1.8-18.8)</td>
<td>6.1 ± 2.8 (2.3-14.4)</td>
</tr>
<tr>
<td>Size of left anterosuperior LAD (n = 8)</td>
<td>4.9 ± 2.5 (1.7-12.6)</td>
<td>4.8 ± 2.1 (1.7-12.6)</td>
</tr>
<tr>
<td>Size of left lateral LAD (n = 29)</td>
<td>4.9 ± 2.7 (1.7-12.5)</td>
<td>5.0 ± 2.7 (1.7-16.7)</td>
</tr>
<tr>
<td>Size of LAD in IAS (n = 4)</td>
<td>5.0 ± 1.1 (2.1-4.5)</td>
<td>14.7 ± 5.6 (5.9-21.2)</td>
</tr>
<tr>
<td>Size of right inferior LAD (n = 5)</td>
<td>4.4 ± 3.4 (2.1-10.4)</td>
<td>21.1 ± 10.9 (7.1-37.6)</td>
</tr>
<tr>
<td>Size of posterosuperior LAD (n = 1)</td>
<td>2.3</td>
<td>2.1</td>
</tr>
<tr>
<td>Size of right anterosuperior LAD (n = 43)</td>
<td>5.4 ± 3.6 (1.8-18.8)</td>
<td>6.1 ± 2.8 (2.3-14.4)</td>
</tr>
</tbody>
</table>

* LAD = Left atrial diverticula/diverticulum, IAS = interatrial sepsum, “n” denotes the number of LAD.

Table 3. The Distance from the Orifice of LAD to the Ostia of Adjacent PVs and LAA.

<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 to 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 to 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 to 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 to 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>

* LAD = Left atrial diverticula/diverticulum; LAA = left atrial appendage; PV = pulmonary vein
† “n” denotes the number of LAD.
‡ The distance from the orifice of IAS to LAD is not measured, because IAS LAD locates far away from ostia of pulmonary veins.
Figure Legends:

**Figure 1:** Ablation lines for radiofrequency ablation of atrial fibrillation. Red dotted lines show ablation sites required to complete the pulmonary vein and left atrial appendage isolation on 3-dimensional CT reconstruction.

(RSPV: right superior pulmonary vein, RIPV: right inferior pulmonary vein, LSPV: left superior pulmonary vein, LIPV: left inferior pulmonary vein, LAA: left atrial appendage, LA: left atrium)

**Figure 2:** Different locations of left atrial diverticula (LAD) in left atrial wall. A: A cystiform LAD in right anterosuperior wall (short arrow) close to the ostia of right superior pulmonary vein. Note a tubiform LAD right inferior wall of left atrium (long arrow). B: A cone-shaped LAD in right anterosuperior wall (long arrow) close to the ostia of right superior pulmonary vein, and a cystiform LAD near the ostia of LAA (short arrow). C: A cystiform LAD in left lateral wall (arrow). D: A cystiform LAD in left inferior wall (arrow) seats closely to mitral isthmus (dotted line). Note: a sinoatrial nodal artery transverses mitral isthmus; this artery is susceptible to injury during ablation of mitral isthmus. E: A cone-shaped LAD in right inferior wall (arrow) of left atrium.

(Abbreviations as in figure 1).

**Figure 3:** left atrial diverticula (LAD) in different shapes. A: A cystiform LAD in right anterosuperior wall (arrow) close to the ostia of right superior pulmonary vein. B: A cone-shaped LAD in right anterosuperior wall (arrow) close to the ostia of right superior pulmonary vein. C: A tubiform LAD in interatrial septum (white arrow).
finding: left atrium to coronary sinus fistula (asterisk). D and E: A big and irregular LAD in right inferior wall (arrow) of left atrium in different patients. F: A tubiform LAD in right inferior wall (arrow) of left atrium close to left inferior pulmonary vein.

(CS: coronary sinus, RA: right atrium; other abbreviations as in figure 1).

**Figure 4:** The wall of left atrial diverticula (LAD) is much thinner than that of left atrium.

A and B: The wall of a right anterosuperior LAD (short arrow) is much thinner than that of adjacent left atrium (long arrow).

(Abbreviations as in figure 1).

**Figure 5:** The relationships of left atrial diverticula (LAD) with ablation sites of left pulmonary veins and left atrial appendage. A-C: 3-dimensional CT reconstruction shows that ablation sties (red dotted lines) might fall in LAD (arrows). D: Virtual endoscopy demonstrates ablation sties (red dotted lines) do not fall in an LAD (arrow).

(RMPV: right middle pulmonary vein; other abbreviations as in figure 1).
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