Spatial relationship between left atrial roof or superior pulmonary veins and bronchi or pulmonary arteries by dual-source computed tomography: implication for preventing injury of bronchi and pulmonary arteries during atrial fibrillation ablation

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Aims
Bronchi or pulmonary arteries (PAs) could be injured during atrial fibrillation (AF) ablation. Therefore, the aim of the present study was to evaluate the spatial relationship between left atrial roof or superior pulmonary veins (PVs) and neighbouring structures of AF patients and provide anatomic guidance for AF ablation to avoid injuring bronchi or PAs.

Methods and results
A dual-source computed tomography (DSCT) scan was used to depict the left atrium (LA), PVs, and nearby structures including bronchi and PAs in 58 patients with drug-refractory AF (mean age, 64 ± 9 years). The distance between LA roof or superior PVs (SPVs) and bronchi or PAs was measured. The average minimal distances from the left, middle, and right points of the LA roof to the principal bronchi were 17.0 ± 6.4, 23.7 ± 5.1, and 23.2 ± 7.7 mm, respectively. The LA roof was closer to the right PA (RPA) than the left PA (LPA) for more than 90% of patients. The average minimal distances from the left, middle, and right points of the LA roof to the PAs were 8.3 ± 5.0, 5.9 ± 3.1, and 6.0 ± 2.8 mm, respectively. The average minimal distances between the left superior pulmonary vein and bronchi or LPA were 0.32 ± 0.79 or 0.4 ± 1.0 mm, respectively. The average minimal distances between the right superior pulmonary vein and bronchi or RPA were 0.27 ± 0.94 and 0.0 ± 0.1 mm, respectively.

Both of the root parts of SPVs of most patients were in direct contact with branches of trachea and PAs.

Conclusion
Dual-source computed tomography provides important imaging information for determining the relationship between LA, PVs, and neighbouring structures. Use of pre-procedural cardiac CT scans may help avoid ablation-induced injury of bronchi and PAs.

Keywords
Atrial fibrillation • Dual-source computed tomography • Left atrial roof • Pulmonary vein • Ablation

Introduction
Percutaneous catheter ablation with circumferential pulmonary vein (PV) isolation using radiofrequency energy is increasingly used for treating atrial fibrillation (AF). Ablation strategies include circumferential PV ablation, linear ablation, complex fractionated electrogram ablation, etc. However, segmental ablation is still used in practice in some laboratories, which may

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result in PV stenosis or other complications. For many AF patients, especially persistent AF patients, left atrium (LA) roofline ablation is necessary for maintaining sinus rhythm after the procedure. As the LA roof and superior PVs (SPVs) are in very close vicinity to bronchi and pulmonary arteries (PAs) that branch out around them, radiofrequency energy application during ablation of roofline and superior PVs may injure the nearby bronchi and PAs, which is very rare but fatal.7–9

With the recent introduction of dual-source computed tomography (DSCT), which significantly improved temporal resolution of ECG-gated multidetector-row CT,10–12 cardiac visualization of AF patients with irregular or high heart rate is much more accurate and reliable. The aim of the present study was to evaluate the anatomic relationship between the LA roof or SPVs and bronchi or PAs using DSCT.

Methods

Patient selection

The study population consisted of 58 AF patients who underwent electrophysiological examination and catheter ablation procedure in Shanghai Xinhua Hospital from March to October in 2008. All patients had frequent AF episodes or serious symptoms while antiarrhythmics were not effective enough or the patients could not tolerate the side effects. All patients underwent cardiac DSCT scan in order to determine the anatomic relationship between LA/SPV and bronchi/PAs. Those who had a medical history of rheumatic heart disease, valvular heart disease, congenital heart disease, dilated cardiomyopathy, hypertrophic cardiomyopathy, heart surgery, or organic diseases of the bronchus, lung, or oesophagus were not included. Those whose cardiac images were not clear enough, especially LA and PV, were also excluded.

Image acquisition and reconstruction

The patients underwent cardiac imaging using a 64-slice DSCT system (Somatom Definition, Siemens Medical Systems, Forchheim, Germany). Eighty millilitres non-ionic contrast medium iohexol (Omnipaque, Amersham Health, Amersham, UK) were injected through the antecubital vein and chased with 40 mL of saline by using a power injector at a rate of 5 mL/s, after which the scanning was initiated at the time that the CT value of aortic root increased to 100Hu. Image acquisition was performed from the base of the lungs to the apices during a single breath-hold. Image acquisition was ECG-gated. A collimation of 0.6 mm was used. Scan data were transferred to the Syngo workstation (Leonardo, Siemens, Forchheim, Germany) for reconstruction, measurement, and analysis. Cardiac image reconstruction was undertaken using the series of ‘0.75 mm slice thickness and best diastole’.

Measurement

Syngo workstation provides sagittal, coronal, and transverse sections for investigation and measurement. The distance from the LA roof to the bronchus or PA was measured from the coronal section while sometimes sectional adjustment was necessary. In order to avoid measurement difference between different researchers, all data were taken by one person.

Parameters measured included LA dimension (LA1, LA2, and LA3), shortest distance between the LA roof and bronchi or PAs, and shortest distance between the SPVs and bronchi or PAs. LA1 and LA3 were defined as the maximal transverse diameter and superior–inferior diameter of LA from coronal section, and LA2 defined as the maximal antero-posterior diameter of LA from the sagittal section (Figure 1). Left atrium roof was defined as the area between two SPVs. When measuring the distance between two structures, it referred to the distance between their inner surfaces that were identified by a change in signal density. Distance between the LA roof and bronchi or PAs was measured at three locations of the LA roof, that is the left point [the intersection point of the left superior pulmonary vein (LSPV) and LA], the right point [the intersection point of the right superior pulmonary vein (RSPV) and LA], and the middle point (the midpoint of the above two points) (figure 4). The distance from the PV ostia to the position where SPV was closest to bronchus or PA was also measured, which is defined as dA or dB, respectively (figures 3 and 4). Pulmonary arteries ostium was composed by points where the change in curvature of the LA surface was most dramatic. When an antrum existed, PV ostium indicated the interface of LA and antrum.

Figure 1  Coronal section and sagittal section of left atrium obtained by Syngo workstation. (A) Sagittal section showing measurement of LA2. (B) Coronal section showing measurement of LA1 and LA3.
Statistical analysis
Statistical analyses were performed using SPSS11.5 (SPSS 11.5 for Windows, LEAD Technologies Inc., Chicago, IL, USA). Values are expressed as mean ± standard deviation for continuous variables, constituent ratio for categorical variables. Comparisons between the two groups were made by a two-tailed Student’s t-test for continuous variables. The difference was considered statistically significant when P-value was <0.05.

Results
Patient population
The subjects of this study were 58 patients with average age of 64 ± 9 years. Twenty-five of all subjects were women while 33 were men. They were 41 paroxysmal AF patients (22 women and 19 men) and 17 persistent AF patients (3 women and 14 men).

Left atrium dimension
The mean LA1, LA2, and LA3 were 69.2 ± 7.8, 43.2 ± 8.1, and 57.1 ± 7.4 mm, respectively.

Difference in the LA dimension was examined between patients with different AF type (paroxysmal or persistent AF), gender, and age (Table 1). Persistent AF patients had significant greater LA dimensions in all directions than paroxysmal AF patients. Men had a significantly greater transverse diameter than women. No significant difference in the antero-posterior and superior–inferior diameter was found between men and women. Patients older or younger than 70 years did not have significant difference in LA dimension (Table 1).

The relationship between the left atrium roof and bronchi or pulmonary arteries
The anatomic relationship between the LA roof, the left and right principal bronchi, LPA, and RPA was depicted for each patient (Figure 2). The trachea was located in front of the oesophagus and was divided into the left and right principal bronchi above the LA roof. The LA roof was not in close proximity to both principal bronchi as the RPA ran transversely above the LA roof and the principal bronchi. The average minimal distance from the left, middle, and right point of the LA roof to two principal bronchi was 17.0 ± 6.4, 23.7 ± 5.1, and 23.2 ± 7.7 mm, respectively. The left point was nearest to the principal bronchus, which was significantly closer than the other two points (P < 0.001).

When comparing the distance with LPA and RPA, except that 10% of left points of LA roof were closer to the LPA, all the other points of the LA roof (including left, right, and middle points) were in closer proximity to the RPA. This is a result of anatomy that the RPA ran transversely above the LA roof for almost all patients while LPAs were located supero-left to the LA roof (Figures 2–4). The average minimal distance from left, middle, and right points of LA roof to PAs were 8.3 ± 5.0, 5.9 ± 3.1, and 6.0 ± 2.8 mm, respectively. The left point was farthest away from PAs, which was significant compared with the middle and right points, respectively (P < 0.001 and P = 0.001). The minimum among the distances between PAs and the three points was defined as the minimal distance between the LA roof and PAs, which was 4.7 ± 2.6 mm. Three patients had their LA roofs in direct contact with PAs.

All patients were divided into two groups according to the maximal superior–inferior diameter of LA (LA3): one group with LA3 ≤ 57 mm and the other one with LA3 > 57 mm. The distance between the LA roof and PA was measured for these two groups. The left point of LA roof was closer to PA for the group with LA3 > 57 mm (6.7 ± 3.5 vs. 9.6 ± 5.6 mm, P = 0.024). There was no significant difference in the distance from

### Table 1 Comparison of left atrium dimension between patients with different atrial fibrillation type, gender, and age

<table>
<thead>
<tr>
<th></th>
<th>n</th>
<th>LA1 (mm)</th>
<th>LA2 (mm)</th>
<th>LA3 (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Paroxysmal AF</td>
<td>41</td>
<td>66.1 ± 12.5</td>
<td>41.4 ± 7.5</td>
<td>55.4 ± 6.2</td>
</tr>
<tr>
<td>Persistent AF</td>
<td>17</td>
<td>73.6 ± 5.5</td>
<td>47.5 ± 8.1</td>
<td>61.0 ± 8.7</td>
</tr>
<tr>
<td>P value</td>
<td></td>
<td>0.021⁺</td>
<td>0.008⁺</td>
<td>0.008⁺</td>
</tr>
<tr>
<td>Male</td>
<td>33</td>
<td>71.1 ± 6.3</td>
<td>42.5 ± 7.7</td>
<td>58.4 ± 7.5</td>
</tr>
<tr>
<td>Female</td>
<td>25</td>
<td>66.7 ± 8.9</td>
<td>44.1 ± 8.7</td>
<td>55.3 ± 7.1</td>
</tr>
<tr>
<td>P value</td>
<td></td>
<td>0.031⁺</td>
<td>0.443</td>
<td>0.443</td>
</tr>
<tr>
<td>Age &lt;70 years</td>
<td>36</td>
<td>68.5 ± 8.1</td>
<td>42.5 ± 8.9</td>
<td>56.5 ± 7.3</td>
</tr>
<tr>
<td>Age ≥70 years</td>
<td>22</td>
<td>70.3 ± 7.3</td>
<td>44.4 ± 6.6</td>
<td>58.1 ± 7.7</td>
</tr>
<tr>
<td>P value</td>
<td></td>
<td>0.399</td>
<td>0.397</td>
<td>0.430</td>
</tr>
</tbody>
</table>

⁺Persistent atrial fibrillation compared with paroxysmal atrial fibrillation, P < 0.05; female compared with male, P < 0.05.
the middle or right points of the LA roof to PAs, or minimal distance between the LA roof and PAs ($P = 0.103, 0.403, \text{ and } 0.101$, respectively).

The relationship between superior pulmonary veins and bronchi or pulmonary arteries

Branches of SPVs, principal bronchi, and PAs were in very close proximity to each other in the neighbourhood of the LA roof and SPVs (Figures 3 and 4).

LSPVs of 49 patients (85%) and RSPVs of 52 patients (90%) were in direct contact with the bronchi. The average minimal distances from the SPV root to the bronchi were $0.32 \pm 0.79 \text{ mm}$ for LSPV and $0.27 \pm 0.94 \text{ mm}$ for RSPV, which were not significantly different ($P = 0.708$). $d_{BL}$ referred to $d_{L}$ for LSPV and $d_{BR}$ for RSPV. The mean value of $d_{BL}$ was $22.7 \pm 7.5 \text{ mm}$ with 95% confidence interval of $20.7–24.6 \text{ mm}$ while the mean value of $d_{BL}$ was $16.9 \pm 8.2 \text{ mm}$, significantly shorter than $d_{BL}$ ($P < 0.001$), with 95% confidence interval of $14.8–19.0 \text{ mm}$ (Figure 5).

LSPVs of 49 patients (85%) and RSPVs of 57 patients (98%) were in direct contact with PAs. The average minimal distances from the SPV root to the PAs were $0.4 \pm 1.0 \text{ mm}$ for LSPV and $0.0 \pm 0.1 \text{ mm}$ for RSPV, which was significantly different ($P = 0.007$). $d_{PL}$ referred to $d_{L}$ for LSPV and $d_{PR}$ for RSPV. The mean value of $d_{PL}$ was $28.9 \pm 9.5 \text{ mm}$ with 95% confidence interval of $26.4–31.4 \text{ mm}$ while the mean value of $d_{PR}$ was $19.9 \pm 9.4 \text{ mm}$, significantly shorter than $d_{PL}$ ($P < 0.001$), with 95% confidence interval of $17.4–22.3 \text{ mm}$ (Figure 5).

When the risk of injury to the bronchus or PA is considered altogether, 95% confidence interval of $d_{B}$ and $d_{P}$ of the same side should be combined. The shortest intervals were $20.7–31.4 \text{ mm}$ from the LSPV ostium, and $14.8–22.3 \text{ mm}$ from the RSPV ostium to either bronchi or PAs.

Discussion

Left atrium dimension

Our study showed a significant difference in LA dimension between persistent and paroxysmal AF patients, indicating that
LA gets dilated as AF develops. This result is consistent with the known fact that atrial dilatation and AF may be mutually dependent and constitute a vicious circle. Left atrium enlargement is an independent risk factor for the development of AF\textsuperscript{13–15} while AF itself can also cause atrial dilatation.\textsuperscript{16,17} The relationship between the left atrium roof and the bronchi or pulmonary arteries Trachea divides into left and right principal bronchi above PAs. For the vast majority of patients, there was no neighbouring relationship between the principal bronchi and the LA roof. The distance between LA roof and principal bronchi was long enough that LA roof ablation could hardly injure principal bronchi. Therefore, it can be concluded that most atrio-bronchial fistulae were possibly not caused by roofline ablation.

For all people, the RPA ran to the right since ramifying from the PA trunk, lying above the LA roof. This close anatomic relationship between the LA roof and the PAs was demonstrated in our study, especially the neighbouring relationship between the LA roof and the RPA, inferring that roofline ablation may cause injury to PAs, especially RPAs. Although there has not been any report about PA injury during AF ablation, it still deserves serious attention for the close anatomic relationship between the LA roof and the PA.

The dilation of LA dimension could affect the anatomic relationship between the LA and neighbouring structures and this impact is showed in this study that the roof of LA with greater superior–inferior diameter is closer to PA at the left point. On the other hand, the distance between the right or middle point of the LA roof and PA as well as the minimal distance between these two structures was not affected by LA dilation. The result also showed that the left point of the LA roof was the farthest one away from PAs (8.3 ± 5.0 mm) compared with the middle and right point. Therefore, although our study indicates that LA dilation may affect correlation between the LA roof, this impact is not enormous.

The relationship between superior pulmonary vein and bronchi or pulmonary arteries To avoid PV stenosis, circumferential PV ablation is often performed outside the ostia, that is, ablation to the atrial wall. Since three-dimensional electroanatomic system-guided circumferential PV ablation could hardly be accurate enough to distinguish the interface of the LA and PVs, ablation at the interior wall of PVs still occurs occasionally. Moreover, when complete circumferential PV isolation could not be achieved or it was difficult to identify gaps, segmental ablation at the interior wall of PVs is still exercised for complete electrical isolation in some labs. Therefore, knowledge about the relationship between the root part of SPVs and nearby structures is helpful for avoiding injury. The close anatomic relationship between the root of SPVs and PAs or bronchi was clearly shown in this study, which further support many experts’ opinion against segmental ablation because this ablation method is likely to cause PA or bronchus injury.

Although Wu et al.\textsuperscript{18} have made an investigation about the close relationship between the bronchi and PVs, they just gave an overall description of the anatomic connection between those two structures. This study went deeper that besides the minimal distance between the SPVs and bronchi, it focused more on the distance away from the PV ostia when the SPVs were closest to the bronchi or PAs, which is obviously more clinical significant, telling electrophysiology (EP) doctors where it is highly risky to ablate. When SPVs were closest to the bronchi or PAs, the closest position was some distance away from PV ostia (d\textsubscript{left} or d\textsubscript{right}) which showed significant difference between left and right sides. Both d\textsubscript{left} and d\textsubscript{right} were smaller for the right than those for the left. Moreover, the minimal
distance from RSPV to PA was significantly shorter than that from LSPV to PA. These results indicate that it takes more risk when performing ablation in the interior wall of root RSPV because it is more possible to injure the neighbouring bronchi or PAs.

Use of dual-source computed tomography for atrial fibrillation ablation

Dual-source computed tomography has a much wider scale of examination and better quality of visualization than traditional multislice CT. Based on the 64-slice CT, DSCT adds a second X-ray tube and a corresponding detector so that it realizes an ideal temporal resolution for cardiac visualization of 83 ms.19 With the adaptive ECG-gated technology, it is no longer a problem to give a cardiac scan for those who have very high heart rate or irregular heart rhythm, especially for AF patients.

In most centres, pre-procedure cardiac CT scans are used just for cardiac visualization and integration with the reconstructed cardiac image by three-dimensional electroanatomic mapping.20–22 However, in order to reduce the risk of injury to surrounding structures, the images should also be used for evaluation of the spatial relationship between LA, PVs, and surrounding structures like bronchi, PAs, and oesophagus.18,23 Moreover, information such as thickness of the posterior wall of the LA, thickness of the myocardium at the mitral isthmus region, and the spatial relationship between the LA and coronary sinus or left circumflex is also very helpful.24,25 This anatomic information could be very important for guidance of the ablation procedure. With knowledge of the relevant anatomic information of the specific patient, EP doctors could be more aware of the risky locations during energy application to avoid complications.

Conclusion

Roofline ablation may carry the risk of PA (especially RPA) injury while ablation in the interior wall of SPVs could be more possible to cause injury to bronchial or PA branches. Cardiac DSCT scan provides important imaging information for determining the relationship between LA, SPVs, and neighbouring structures. Pre-procedural analysis of cardiac CT scan images may help reduce risk of complications.

Conflict of interest: none declared.

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