Anatomic Relationship of the Esophagus and Left Atrium*

Implication for Catheter Ablation of Atrial Fibrillation

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Study objectives: **Atrioesophageal fistulas have been reported to be a lethal complication following catheter ablation of atrial fibrillation (AF). The purpose of this study was to investigate the relationship between the esophagus and posterior left atrium (LA) and provide the anatomic information necessary to minimize the risk of esophageal injury during AF ablation.**

Methods and results: **Forty-eight patients (43 men; mean ± SD age, 59 ± 12 years) with drug-refractory paroxysmal AF and 32 control subjects (26 men; mean age, 60 ± 9 years) were included. All underwent a CT scan for delineation of the relationship between the esophagus and posterior LA. In the paroxysmal AF group, two major types of esophageal routes were demonstrated. Type 1 routes were found in 42 patients with the lower portion of esophagus close to the ostium of the left inferior pulmonary vein (LIPV), including three subtypes of courses according to the proximity to the left superior pulmonary vein (PV) and LIPV. Type 2 routes were found in six patients with the lower portion of esophagus close to the ostium of the right inferior pulmonary vein (RIPV), including three subtypes of courses according to the proximity to the right superior PV and RIPVs. The mean shortest distance of the esophagus to the four individual PVs significantly differed between type 1 and type 2: 28.4 ± 6.1 mm vs 10.5 ± 5.7 mm (to the right superior), 19.6 ± 7.0 mm vs 3.7 ± 3.4 mm (to the right inferior), 10.1 ± 3.4 mm vs 22.8 ± 4.2 mm (to the left superior), and 2.8 ± 2.5 mm vs 18.7 ± 5.2 mm (to the left inferior), respectively ($p < 0.001$ for all). Contact of the esophagus and middle part of posterior LA was observed in each patient. However, direct contact of the aorta with the posterior LA wall was more frequent in type 2 than in type 1 ($p = 0.001$). The clinical characteristics, type of esophageal routes, distance from the esophagus to the four PVs, and diameter of the thoracic cage, LA, and aorta in the control group were similar to those in the AF group ($p > 0.05$ for all).**

Conclusion: **Although the anatomic relationship between the esophagus and LA posterior wall varied widely, two major patterns of esophageal routes could be depicted. This information is important for deciding the location of the ablation lesions around the PV ostia and LA and for avoiding the potential risk of esophageal injury.** ***(CHEST 2005; 128:2581–2587)***

Key words: ablation; esophagus; left atrium

Abbreviations: AF = atrial fibrillation; LA = left atrial/atrium; LIPV = left inferior pulmonary vein; LSPV = left superior pulmonary vein; PV = pulmonary vein; RIPV = right inferior pulmonary vein; RSPV = right superior pulmonary vein

Catheter ablation of the pulmonary veins (PVs) is effective for curing a subset of atrial fibrillation (AF).[1,2] Left atrial (LA) ablation techniques, including wide circumferential lesions encircling the PVs and linear lesions on the posterior LA, mitral isthmus, and LA roof, have been reported to increase

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the long-term success rate.[3,4] However, following the popular applications of the AF ablation techniques, various complications have been reported. Atrioesophageal fistulas may be the most deleterious and life-threatening condition among all the complications.[5,6]

Atrioesophageal fistulas have been noted during intraoperative radiofrequency ablation of AF using the endocardial approach, percutaneous PV isolation, and LA ablation.[5–8] An atrioesophageal fistula can cause an air embolism with a stroke, mediastinitis, or GI bleeding, and is associated with a high mortality rate. Doll et al[8] suggested that the distance between the esophagus and LA has contributed to the occurrence of this complication. Understanding the anatomic relationship between the esophagus and PV/LA may provide useful information for avoiding esophageal injury during the catheter ablation procedure. The purpose of this study was to demonstrate the relationship between the esophagus and LA/PV in patients with paroxysmal AF using a CT scan.

Materials and Methods

Patient Selection

This study population included the following: (1) 48 patients referred for an electrophysiologic study and considered for the possibility of catheter ablation because of frequent episodes of AF (more than one episode per week) and being refractory to more than one antiarrhythmic drug; and (2) 33 control subjects without any history of AF. The study population underwent a CT scan 1 to 14 days before the ablation procedure, and informed consent was obtained.

CT

The LA, PVs, aorta, and esophagus were evaluated with a contrast-enhanced CT scan (Highspeed LX/I; GE Healthcare; Milwaukee, WI). A nonionic contrast medium (Omnipaque [iohexol injection]; Amersham Health; Amersham, UK; 350 mg of iodine per milliliter) was administered in a test dose to determine the moment of the peak LA filling; subsequently, 98 mL of contrast medium was administered through the antecubital vein with the use of a power injector at a rate of 2 mL/s, after which the scanning was initiated. Data acquisition was performed from the base of the lungs to the apices during a single breath-hold. We used a pitch of 1.5. The scan parameters were used as follows: 5-mm collimation; gantry rotation time, 1 s per rotation; tube voltage, 120 kilovolts; tube current, 160 mA. The protocols used to obtain the images and measurements were designed by our cardiac radiologist. The measurements of the images were independently determined by two cardiologists using the axial planes, and they were blinded to the patient diagnosis. The cardiac radiologist checked the final results. The following measurements were performed: (1) the shortest distance from the adventitial border of the esophagus to the posterior aspect of the ostia of the four PVs; (2) the maximal width of the esophagus at the inferior PV level; (3) the maximal distance from the sternum to the vertebral body (thoracic cage diameter) at the inferior PV level; (4) the maximal anteroposterior diameter of the LA; and (5) the maximal diameter of the descending aorta at the inferior PV level. The PV ostium was defined as the point of inflection between the PV wall and posterior LA wall.

Definition

Esophageal route type 1 was defined as having a distance between the esophagus and left inferior PV (LIPV) less than the distance between the esophagus and right inferior PV (RIPV); type 2 was defined as having a distance between the esophagus and RIPV less than the distance between the esophagus and LIPV.

Type 1 was further categorized into three subtypes—1a, 1b, and 1c—according to the proximity to left superior PV (LSPV) and LIPV. Type 1a was defined as having distances between the esophagus and LSPV and LIPV both of < 10 mm; type 1b was defined as having a distance between the esophagus and LSPV of > 10 mm and distance between the esophagus and LIPV of < 10 mm; and type 1c was defined as having a distance between the esophagus and LSPV and LIPV both > 10 mm (Fig 1).

Type 2 was further categorized into three subtypes—2a, 2b, and 2c—according to the proximity to the right superior PV (RSPV) and RIPV. Type 2a was defined as having distances between the esophagus and RSPV and RIPV both of < 10 mm; type 2b was defined as having a distance between the esophagus and RSPV of > 10 mm and the distance between the esophagus and RIPV of < 10 mm; and type 2c was defined as having distances between the esophagus and RSPV and RIPV both of > 10 mm (Fig 1).

Electrophysiologic Study and Catheter Ablation

Each patient underwent an electrophysiologic study and catheter ablation in the fasting, nonsedative state after written informed consent was obtained. In brief, we tried to find spontaneous onset of atrial ectopic beats or repetitive episodes of short-run or sustained AF before or after infusion of isoproterenol, or following a designed algorithm for facilitating initiation of paroxysmal AF. If a consistent ectopic focus and atrial activation pattern was demonstrated to induce paroxysmal AF, the site with the earliest and most consistent atrial activation was considered to be the initiating focus of paroxysmal AF. The methods used to provoke paroxysmal AF were tried at least twice to ensure reproducibility. After creation of PV/LA geometry by the NavX system (Endocardiol Solutions; St. Paul, MN), isolation of the four PVs was performed from the atrial side of PV antrum using the electrogram-guided approach (entrance block), and disappearance of all PV potentials in the PV antrum was confirmed by the circular catheter recording. After successful four-PV isolation, high current (up to 20 mA) stimulation from the proximal and distal coronary sinus was performed for > 20 times (10-ms decrement from 250 to 150 ms, and duration of each pacing cycle length was 10 s). If induced AF was sustained for > 1 min, linear ablation on the mitral isthmus was guided by the NavX system with creation of splitting potentials or electrogram voltage reduction $> 50\%$ after each application of radiofrequency energy. If sustained AF was induced after mitral isthmus ablation, then the linear ablation on the anterior roof was performed. A temperature control model with maximal temperature setting of 50 to 55°C, maximal power < 45 W, and duration of 20 to 40 s was used. The end point of ablation was disconnection between the PV and the LA, and AF was noninducible (< 1 min).

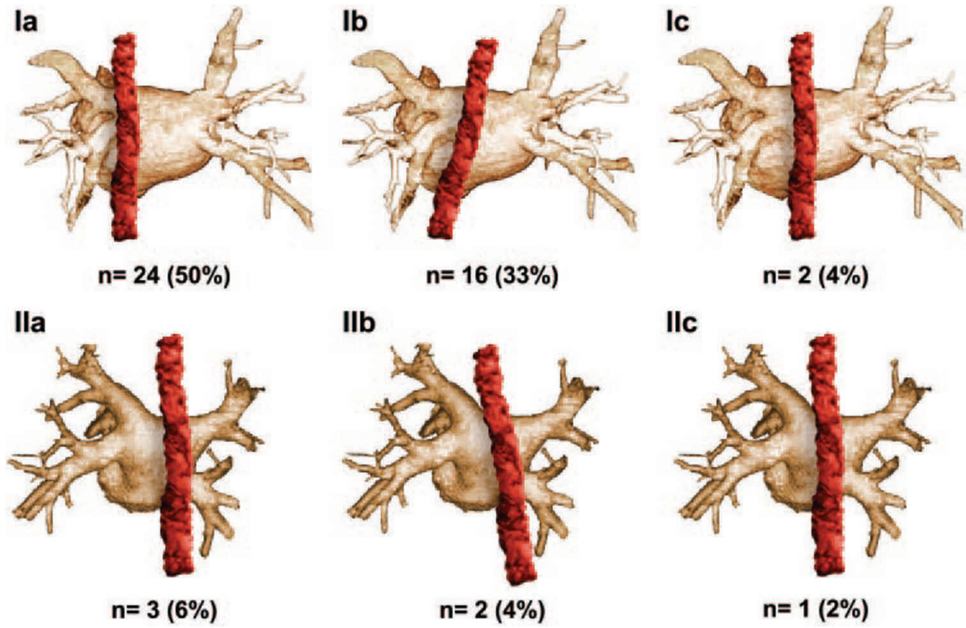

FIGURE 1. The major types and subtypes of esophageal route on the posterior wall of LA with the computer-modified images.

Statistical Analysis

All quantitative data were expressed as the mean ± SD. A χ^2 test with Yates' correction or Fisher Exact Test was used for categorical data; the Mann-Whitney rank-sum test was used for continuous data. A value of $p < 0.05$ was considered to be statistically significant.

Results

Patient Characteristics

The clinical characteristics of the control group and patient group, including age, gender, and structural heart disease, are presented in Table 1. The control and patient groups were classified into two subgroups according to the relative spatial position of the esophagus and PVs (types 1 and 2). The clinical parameters were similar between the two groups (Table 1).

CT Findings of the Gross Relationship of the Esophagus, Posterior LA, and Aorta

The courses of the esophagus could be demonstrated in all patients. The esophagus directly came in contact with the posterior wall of the LA between

Table 1—*Patient Characteristics and Anatomic Parameters**

Characteristics	AF Group			Control Group		
	Type 1 (n = 42)	Type 2 (n = 6)	p Value	Type 1 (n = 26)	Type 2 (n = 6)	p Value
Age, yr	60 ± 12	59 ± 9	0.78	62 ± 8	60 ± 9	0.63
Male gender, %	90	83	0.50	81	83	> 0.99
Structural heart disease, %	10	17	0.50	8	17	0.48
Distance of the esophagus to the PVs, mm						
RSPV	28.4 ± 6.1	10.5 ± 5.7	< 0.001	28.2 ± 7.6	13.5 ± 3.3	< 0.001
RIPV	19.6 ± 7.0	3.7 ± 3.4	< 0.001	16.9 ± 6.0	3.3 ± 4.1	< 0.001
LSPV	10.1 ± 3.4	22.8 ± 4.2	< 0.001	11.2 ± 4.4	17.7 ± 9.6	0.08
LIPV	2.8 ± 2.5	18.7 ± 5.2	< 0.001	2.0 ± 2.0	13.0 ± 5.0	< 0.001
Width of the esophagus, mm	18.4 ± 5.2	21.8 ± 8.2	0.38	19.2 ± 4.3	20.0 ± 4.8	0.47
Contact of the descending aorta and LA, %	10	83	< 0.001	12	100	< 0.001
AP diameter, mm						
LA	33.0 ± 4.0	34 ± 2.4	0.44	33.2 ± 6.9	34.3 ± 6.0	0.68
Thoracic cage	100 ± 14.6	99.0 ± 14.8	0.66	105.3 ± 18.0	113.8 ± 12.8	0.23
Descending aorta	25.0 ± 3.6	24.1 ± 2.9	0.61	24.4 ± 3.7	24.3 ± 3.2	0.92

*Data are presented as mean ± SD unless otherwise indicated. The p values for the comparisons of all the clinical and anatomic parameters between the AF and control groups for both type 1 and type 2 are not significant ($p > 0.05$).

the midportion of posterior LA and lower border of the inferior PVs. A thin and discontinuous layer of fat pad could be observed in between the adventitia of the esophagus and epicardium of the posterior LA, with the thinnest fat pad at the inferior PV level. Twenty-two patients (46%) did not have a fat pad between the esophagus and RIPV or LIPVs. The esophagus gradually moved away from the LA below the inferior PVs. (Fig 2)

Although the relationship between the esophagus and LA posterior wall varied between individuals, the esophageal routes could be categorized into two types according to the spatial proximity of the esophagus and inferior PVs. Each type was further classified into three subtypes, according to the proximity to the superior and inferior PVs (Fig 1). Type 1 included 42 patients who had an esophagus coursing between the spine and descending aorta, close to the LSPV and LIPV, and most of those were near the ostium of the LIPV. The aorta was located at the posterior aspect of the proximal LIPV (Fig 3). The shortest distance between the border of the esophagus and four individual PVs was 28.4 ± 6.1 mm (± SD) [to the RSPV], 19.6 ± 7.0 mm (to the RIPV), 10.1 ± 3.4 mm (to the LSPV), and 2.8 ± 2.5 mm (to the LIPV) in type 1 patients. They were further categorized into three subtypes—1a, 1b, and 1c—according to the distance to the LSPV and LIPV (Fig 1, Table 2). Type 1a included 24 patients with a straight esophageal route that was close (< 10 mm) to both the LSPV and LIPV. Type 1b included 16 patients with an oblique esophageal route that was > 10 mm from the LSPV and < 10 mm from the LIPV. Type 1c included two patients with a straight esophageal route that was > 10 mm apart from both the left PVs.

Type 2 included six patients who had an esophagus coursing between the posterior LA and right PVs,

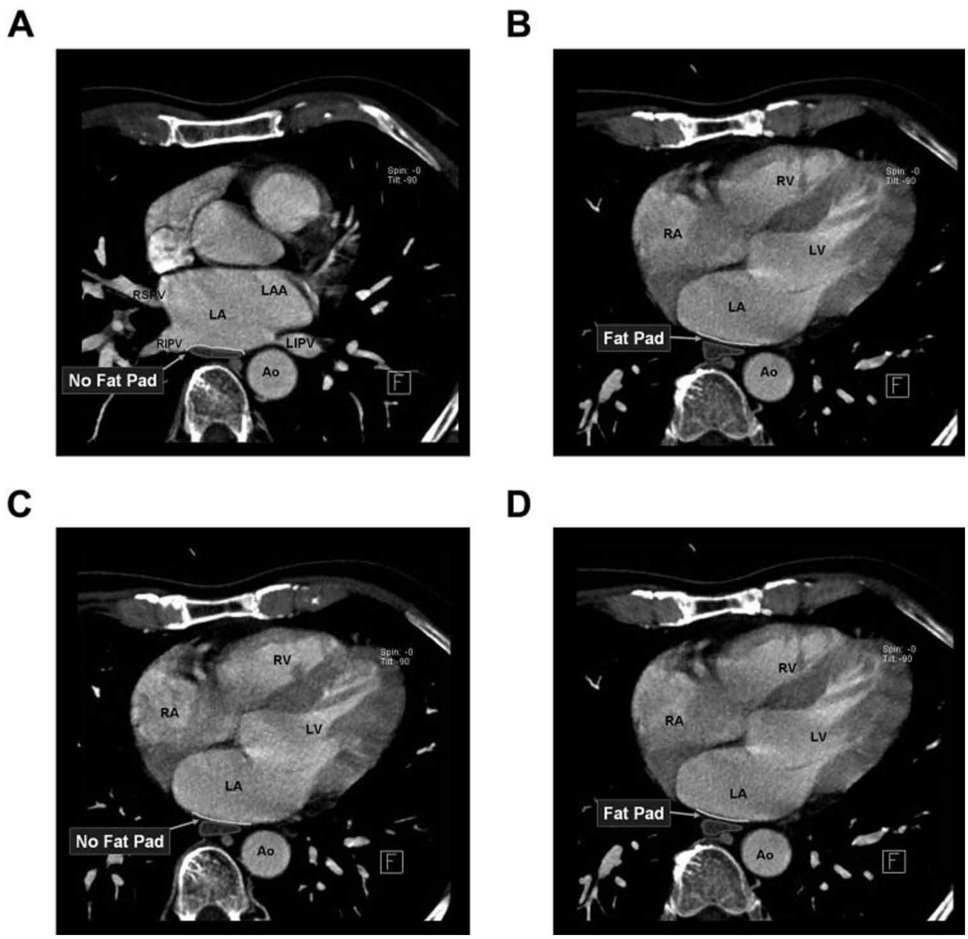

FIGURE 2. Discontinuous distribution of the fat pad between the LA posterior wall and esophagus. *Top left*, *A*: The fat pad was not seen between the esophagus and central posterior wall of LA. *Top right*, *B*: The fat pad was seen between the esophagus and posterior wall of LA below the level of inferior PVs. However, the fat pad was not seen again below the level shown in top right, B (*bottom left*, *C*). *Bottom right*, *D*: The fat pad appeared again below the level shown in *bottom left*, *C*. Ao = aorta; LAA = LA appendage; LV = left ventricle; RA = right atrium; RV = right ventricle.

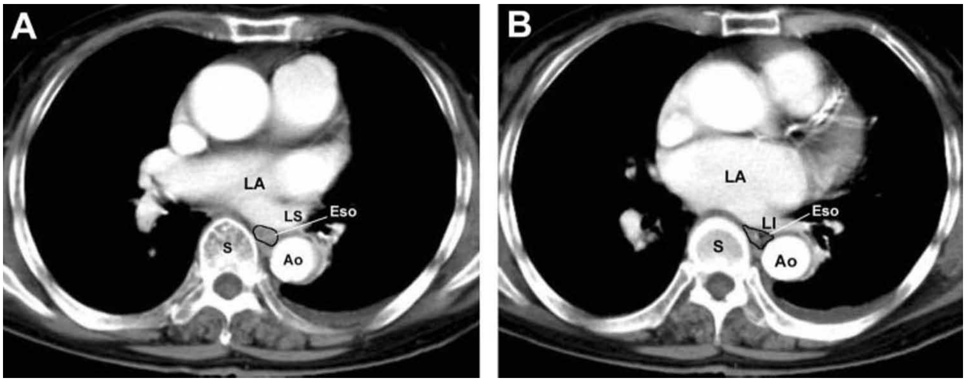

FIGURE 3. Axial CT images of a patient with a type 1 esophageal route (the distance to the LIPV is shorter than that to the RIPV). *Left*, *A*: At the LSPV level, the location of the esophagus (enhanced border) is behind the LA and LSPV, between the thoracic spine (S) and descending aorta. *Right*, *B*: At the LIPV level, the esophagus is crowded into a space surrounded by the LIPV, spine, and descending aorta. Thus, it becomes triangular. Eso = esophagus; LS = left superior; LI = left inferior; see Figure 2 for expansion of abbreviation.

and closer to the ostium of the RIPV. In those patients, the aorta deviated rightward and was located in the posterior LA near the LIPV ostium (Fig 4). The shortest distance between the border of the esophagus and four individual PVs was 10.5 ± 5.7 mm (to the RSPV), 3.7 ± 3.4 mm (to the RIPV), 22.8 ± 4.2 mm (to the LSPV), and 18.7 ± 5.2 mm (to the LIPV) in the type 2 patients. They were categorized into three subtypes—2a, 2b, and 2c—according to the proximity to the RSPV and RIPV (Fig 1, Table 2). Type 2a included three patients with a straight esophagus close (< 10 mm) to both the RSPV and RIPV. Type 2b included two patients with an oblique esophagus close (< 10 mm) to the RIPV, *ie*, the upper esophagus was located at the central part of the posterior LA and the lower esophagus deviated toward the RIPV. Type 2c included one patient with a straight esophagus that was centrally located and > 10 mm apart from both of the right PVs.

A comparison between type 1 and type 2 showed that the distance between the border of the esophagus and four individual PVs significantly differed ($p < 0.001$ for the RSPV, RIPV, LSPV, and LIPV, respectively) [Table 1]. In addition, the descending aorta was in contact with the posterior LA wall in 4 of 42 patients with type 1 and 5 of 6 patients with type 2 ($p < 0.001$). However, there was no significant difference in the average width of the esophagus between the two types (18.4 ± 5.2 mm vs 21.8 ± 8.2 mm, respectively; $p = 0.38$).

The other anatomic parameters including the anteroposterior diameter of the LA (33.0 ± 4.0 mm vs 34.0 ± 2.4 mm, $p = 0.44$), thoracic cage diameter (100.0 ± 14.6 mm vs 99.0 ± 14.8 mm, $p = 0.66$), and diameter of the aorta (25 ± 3.6 vs 24.1 ± 2.9 mm, $p = 0.61$) were similar between type 1 and type 2. Furthermore, the age, gender, and incidence of structural heart disease were similar between the two types (Table 1).

Comparisons Between the Control and Patient Groups

Patient age (59 ± 12 years vs 62 ± 10 years), gender (male, 90%; female, 81%), and incidence of

Table 2—*Mean Distances Between Esophagus and PVs**

Variables	Type 1			Type 2		
	Subtype 1a	Subtype 1b	Subtype 1c	Subtype 2a	Subtype 2b	Subtype 2c
Patients, No.	24	16	2	3	2	1
Esophageal width, mm	20.4 ± 4.7	18.5 ± 3.3	18.2 ± 5.6	20.1 ± 9.9	24.4 ± 6.9	22.4
Distance from esophagus, mm						
LSPV	7.8 ± 1.5	12.6 ± 2.6	13.7 ± 4.0	24.5 ± 3.0	23.1 ± 5.2	17.8
LIPV	2.6 ± 1.8	2.4 ± 2.6	10.9 ± 0.1	18.6 ± 1.6	15.9 ± 8.9	21.8
RSPV	28.8 ± 6.2	27.3 ± 6.2	20.7 ± 2.4	5.7 ± 1.1	17.2 ± 2.2	11.7
RIPV	19.3 ± 8.3	20.5 ± 5.0	16.4 ± 0.3	3.0 ± 2.6	2.1 ± 3.0	10.4

*Data are presented as mean ± SD unless otherwise indicated.

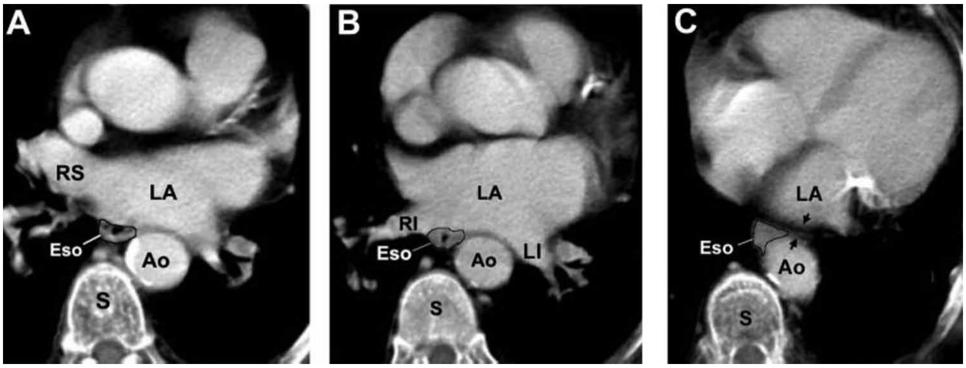

FIGURE 4. Axial CT images of a patient with a type 2 esophageal route (the distance to the RIPV is shorter than that to the LIPV). *Left*, *A*: At the RSPV level, the location of the esophagus (enhanced border) is behind the LA and RSPV, in front of the thoracic spine, and medial to the descending aorta. *Center*, *B*: At the RIPV level, the esophagus is very close to the RIPV ostium. Thus, the potential risk for the development of an atrioesophageal fistula is higher during ablation around the RIPV ostium than around the LIPV ostium. *Right*, *C*: At a level below the RIPV, in contrast to the tight contact between the esophagus and LA (in *left*, *A*, and *center*, *B*), a fat pad (between the two arrows) between the posterior LA and esophagus is observed. See Figures 2, 3 for expansion of abbreviations.

structural heart disease (10% vs 9%) were similar between the control and patient groups, respectively. The types of esophageal routes were also similar between the two groups (type 1/ type 2: 42/6 (control subjects) vs 26/6 (patients); $p = 0.53$). The other parameters, including the distance from esophagus to the four PVs, width of the esophagus, diameter of the thoracic cage, diameter of the LA, and diameter of the aorta, exhibited similar values between the control group and patient group with a type 1 esophageal route. Furthermore, these parameters also had similar values between the control group and patient group with a type 2 esophageal route (Table 1).

Discussion

Major Finding

First, we demonstrated two major patterns of esophageal routes. Second, in the majority (90%) of the subjects (type 1 patients), the esophagus coursed down beside the ostia of the left PVs with a mean distance of 10.1 mm to the LSPV and 2.8 mm to the LIPV. Third, in the type 1a and type 1b patients with an esophagus very close to the LIPV, and in the type 2a and 2b patients with an esophagus very close to the RIPV, even PV isolation had the potential risk of causing esophageal injury if the posterior aspect of the inferior PV ostia were ablated. Fourth, the descending aorta was located around the posterior aspect of the LIPV in type 1 patients, but it was in direct contact with the left posterior wall of the LA when the esophagus shifted rightwards in type 2 patients.

Clinical Implications for Catheter Ablation of AF

PV isolation and linear ablation of the posterior LA using radiofrequency energy are effective in treating paroxysmal and persistent AF. Oral et al[3] reported that LA ablation by encircling the left and right PVs, plus additional ablation lines to the mitral isthmus and posterior LA, could cure 88% of paroxysmal AF patients at a mean follow-up of 6 months, and was superior to segmental ostial ablation. Due to the encouraging results, ablation lesions encircling the PVs 1 to 2 cm outside the ostia and linear lesions on the posterior LA wall and LA inferior isthmus have been performed in an increasing number of patients. However, a fatal complication (atrioesophageal fistula) was reported recently with percutaneous LA ablation and circumferential PV ablation procedures.[5,6] It raises a great concern about the prevention of esophageal injury during AF ablation.

Because we have demonstrated that the shortest distance between the esophagus and inferior PVs was < 4 mm and thinnest fat plane was between the esophagus and inferior PVs, radiofrequency energy applied a few millimeters outside the ostia of the inferior PVs will carry a high risk of burning the esophagus. In addition, the posterior ablation line connecting the right and left PVs cannot avoid crossing the esophagus, because the esophagus extends along the full height of the posterior LA.[9] Thus, we should be very careful when applying radiofrequency energy over the posterior wall of the LA, and use a decreased power and temperature setting. Although the esophagus is a moving structure, information about how far the esophagus can migrate is very limited. We had used barium swallows to visualize the real-time motion of esophagus during the whole course of AF ablation recently. According to our experience, the majority of patients (approximately 90%) showed an esophageal course consistent with that demonstrated by CT scan, and > 90% of the esophagus did not swing markedly during the procedure. Therefore, from a clinical point of view, CT scan is still an applicable method to investigate the anatomic relationship of esophagus and posterior LA. The static anatomic relationship between the PV/LA and esophagus, demonstrated by the CT scan before the ablation procedure, would be helpful to avoid creating an LA-esophageal fistula by guiding the titration of the radiofrequency energy. Furthermore, if linear lesions were definitely necessary to modify the atrial substrate, a linear lesion along the anterior roof of the LA would not affect the esophagus.

The LA inferior isthmus (mitral isthmus) was the most frequently performed lesion site to modify the LA substrate, and this ablation line could decrease the possibility of LA flutter occurring. Because the esophagus was in close contact with the LA at the inferior PV ostial region, and then gradually coursed far from the LA when it was below the level of the inferior PVs, the distance between the esophagus and lower level of the mitral isthmus would be longer. However, the distance between esophagus and the higher level of mitral isthmus might be very short. It would be necessary to decrease the radiofrequency energy at a higher level of the mitral isthmus to avoid esophageal injury.

Although to our knowledge there have been no reported cases of injury to the descending aorta, the aorta may be another potential structure that can be damaged when more powerful energy sources are introduced to make a deep lesion. It is likely that the cooling effect of the rapid blood flow may protect the descending aorta from heat injury. However, we should pay attention in order to prevent injury to the descending aorta in addition to the esophageal injury, because the descending aorta contacted directly with the left posterior wall of the LA or proximal LIPV in most of the cases.

Limitations

First, because the spatial resolution of the spiral CT scan was approximately 3 mm, that inherent limitation may have influenced the measurements. Second, the peristalsis and dynamic movement of the esophagus was suspected to influence the results. However, the anatomic parameters about the relation among esophagus, PV, and LA posterior wall are useful for us to understand the possible risk of esophageal injury during catheter ablation of AF.

Conclusion

The esophagus came in close contact with the posterior LA wall, and two major patterns of the course of the esophagus were demonstrated. That information is crucial for deciding on the location of the ablation lesions in the LA and around the PVs, and preventing potential complications such as an atrioesophageal fistula after the catheter ablation.

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