

Anatomic Relations Between the Esophagus and Left Atrium and Relevance for Ablation of Atrial Fibrillation

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Background—Esophageal injury is a potential complication after intraoperative or percutaneous transcatheter ablation of the posterior aspect of the left atrium. Understanding the spatial relations between the esophagus and the left atrium is essential to reduce risks.

Methods and Results—We examined by gross dissection the course of the esophagus in 15 cadavers. We measured the minimal distance of the esophageal wall to the endocardium of the left atrium with histological studies in 12 specimens. To measure the transmural thickness of the atrial wall, we sectioned another 30 human heart specimens in the sagittal plane at 3 different regions of the left atrium. The esophagus follows a variable course along the posterior aspect of the left atrium; its wall was <5 mm from the endocardium in 40% of specimens. The posterior left atrial wall has a variable thickness, being thickest adjacent to the coronary sinus and thinnest more superiorly. Behind is a layer of fibrous pericardium and fibrofatty tissue of irregular thickness that contains esophageal arteries of 0.4 ± 0.2 -mm external diameters.

Conclusions—The nonuniform thickness of the posterior left atrial wall and the variable fibrofatty layer between the wall and the esophagus are risk factors that must be considered during ablation procedure. Esophageal arteries and vagus nerve plexus on the anterior surface of the esophagus may be affected by ablative procedures. (*Circulation*. 2005;112:1400-1405.)

Key Words: ablation ■ atrium ■ catheter ablation ■ esophagus ■ fistula

Catheter ablation techniques are being used increasingly to treat paroxysmal and persistent atrial fibrillation (AF). From the initial relatively limited methodologies approaching the pulmonary veins (PVs),^{1,2} techniques have evolved to more extensive procedures that include additional linear lesions on the posterior wall of the left atrium (LA).³⁻⁸ Recently, development of a fistula between the esophagus and the LA has been reported as an unusual complication of intraoperative and percutaneous radiofrequency (RF) ablation procedures for AF.⁹⁻¹³ Because this complication is not infrequently fatal, a better understanding of the anatomic relations between the posterior LA wall and the esophagus is needed to identify areas of potential high risk for the application of RF pulses. An anatomic study of these relations has been conducted with a 16-row multidetector CT scanner in patients with AF undergoing a percutaneous catheter ablation procedure.¹⁴ Such an approach is subjected to limitations of both spatial and temporal resolution inherent to the imaging technology used in the investigation. The present study was designed to examine by morphological dissection and histological sections the course of the esophagus and its relations with the thickness of the posterior wall of the LA.

Methods

We studied 45 specimens from patients who died of noncardiac causes (30 men; age, 54 ± 12 years). The mean heart weight was 360 ± 20 g (range, 330 to 470 g). The specimens were in 2 groups: 15 intact thoracic organs of cadavers (9 men) and 30 isolated heart-lung blocks.

The first group was without obvious signs of thoracic pathology or prior surgery, and none had a history of atrial arrhythmia. Ischemic heart disease was present in 2 patients, and 1 of them had a dilated LA. The cadavers were fixed in 10% formalin and preserved in 30% ethanol. The fibrous pericardium, heart, lungs, esophagus, and thoracic aorta were removed in 1 block (Figure 1). A 5-cm-wide, 30-cm-long blade was used to cut slices 10 cm thick in transverse (6 specimens) and sagittal (9 specimens) bodily planes (Figures 2 and 3). Using calipers, we measured the minimal distance between the endocardium of the posterior wall of the LA and the esophageal wall in the area where the closest "contact" between them was evident. We excised tissue blocks containing the full thicknesses of the thoracic aorta, esophagus, fibrous pericardium, and posterior LA wall or right or left VA junctions from 12 cadavers. From each cadaver, 3 blocks with a thickness of ≈ 5 mm were dehydrated in a graded series of ethanol, embedded in paraffin, and serially sectioned at $10\ \mu\text{m}$ in transverse or sagittal planes. Sister sections were stained with Masson's trichrome technique and with van Gieson stain. Measurements from the sections were made under the microscope

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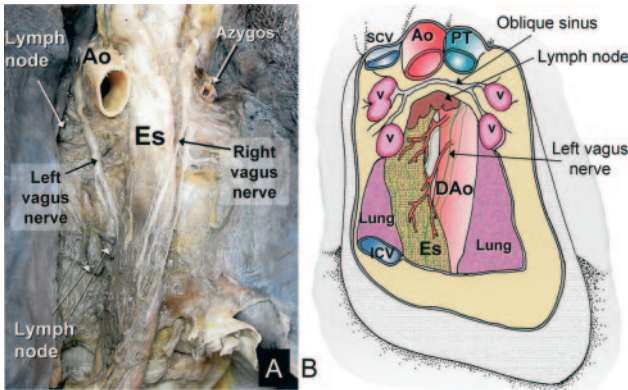


Figure 1. A, Thoracic organs viewed from the back after removal of the descending thoracic aorta to show the course of the esophagus (Es) in situ and its relationship to the vagus nerves and lymph nodes. B, The course of the esophagus as viewed from the front after removal of the heart and posterior pericardium. The LA wall between the PVs (v) is in front of the esophagus, which is covered by a plexus of branches from the vagus nerve (green) and esophageal arteries arising from the descending aorta (DAo). Ao indicates aorta; CS, coronary sinus; ICV, inferior caval vein; and PT, pulmonary trunk.

with the SigmaScan/Image program. For the architecture of the different layers between the left posterior wall and esophagus, we prepared and examined under the SEM (Jeol JSM 5600) the thickest histological sections.

Three hearts in the second group, previously fixed in 10% buffered formalin, had ischemic heart disease. The LAs were sectioned in a sagittal plane at 3 different regions: left VA junction, middle of the posterior atrial wall, and right VA junction. We measured with calipers the transmural thickness (endocardium to epicardium) and the muscular thickness of the posterior LA wall at these 3 regions and at 3 different levels: superior (at the superior border of the superior PV), middle (at the inferior border of the inferior PV), and inferior (adjacent to the coronary sinus) (Figure 2).

Statistical Analysis

Data are expressed as mean±SD. Quantitative data were compared by use of the F test for 2-way layouts. ANOVA and Tukey’s highest-significant-difference tests for multiple comparisons were

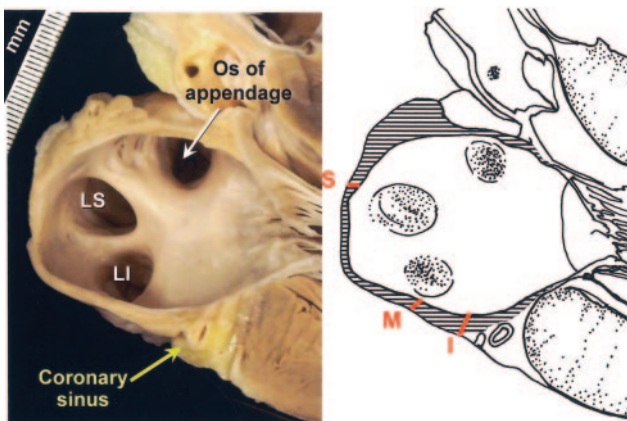


Figure 2. A sagittal section close to the left VA junction showing the nonuniform thickness of the atrial wall and 3 levels (red lines) at which measurements were made. S indicates superior; M, middle; I, inferior; LI, left inferior; and LS, left superior PV.

used when the results were significant (STATISTICA, version 6). Values of $P < 0.05$ were considered significant.

Results

The esophagus is a muscular tube 23 to 26 cm long that descends anteriorly to the vertebral column through the superior and posterior mediastinum. In its upper course, the esophagus is situated slightly to the left between the trachea and the vertebral column. It then passes behind and to the right of the aortic arch to descend to the posterior mediastinum along the right side of the descending thoracic aorta (Figure 1). Lower, it bends leftward as it crosses anteriorly to the aorta to enter the abdomen through the diaphragm at the level of the 10th thoracic vertebra.

Relations Between the Esophagus and Posterior Wall of the LA

The length of the esophagus in contact with the posterior LA was 42 ± 7 mm (range, 30 to 53 mm). Transversely, the width of the esophagus in contact with the posterior wall of the LA was 13.5 ± 5 mm (range, 9 to 15.5 mm). Relations between the esophagus and posterior wall of the LA are variable because of displacement of the esophagus by the aortic arch. In 6 specimens (40%), it passed along the middle posterior LA wall between the right and left pulmonary venous orifices (Figure 3C). In 3 specimens (20%), the esophagus descended close to the right VA junction (Figure 3D); in the remaining 6 cases (40%), it had a leftward course close to the left VA junction (Figure 3E). The minimal distance of the closest contact varied from 3.3 to 13.5 mm, and in 6 specimens (40%), the esophageal wall was < 5 mm from the LA endocardium (Table 1).

Histological examination of the transverse and sagittal sections detailed the spatial relations between the esophagus and the posterior wall of the LA or VA junction (Figures 4 and 5). The mean thickness of the esophageal wall (from mucosa to adventitia) adjacent to the LA was 2.5 ± 1 mm (range, 1.5 to 4.5 mm).

Variable Thickness of the Posterior LA Wall

Data relative to the thicknesses of the posterior LA wall are shown in Table 2. Sagittal and transverse sections through the LA enabled us to measure the thickness and myocardial content of the posterior wall of the LA across the 3 levels and regions. We found significant differences in the wall thickness across the 3 levels (superior, middle, inferior) of the sagittal sections ($P < 0.001$) and between the 3 transverse regions as a result of a thicker middle posterior LA wall ($P < 0.05$). There were no significant differences in wall thickness and myocardial content between the left and right VA junctions. The myocardial thickness was also significantly different from the superior to the inferior level of the posterior atrial wall ($P < 0.001$), whereas there were no significant differences along the 3 regions. The inferior level, immediately superior to the coronary sinus and between 6 and 15 mm from the mitral annulus, had the thickest posterior LA wall from epicardium to endocardium because of a thicker myocardial layer and more profuse fibrofatty tissue content than present at more superior levels of the posterior LA wall.

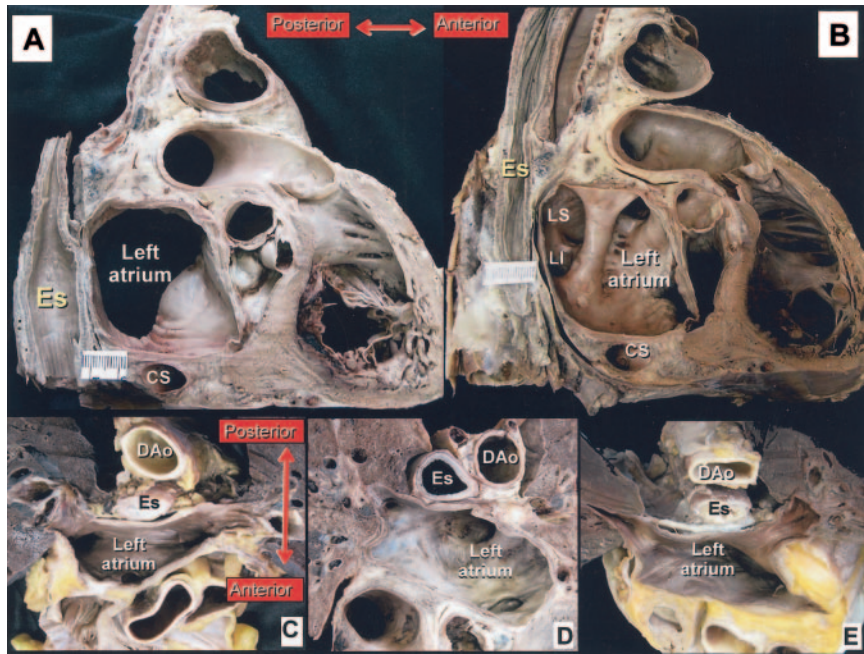


Figure 3. A, B, Sagittal sections through the heart and esophagus (Es) showing a middle section between the left and right PVs and a section close to the left PVs (LS and LI), respectively. Transverse sections through the LA and esophagus show the esophagus related to the middle of the posterior atrial wall (C), the esophagus passing close to the right inferior PV (D), and the esophagus close to the left inferior PV (E).

Conversely, the superior level, defined by the cranial border of the orifices of the superior PV, was the thinnest in terms of muscular and fatty tissue content across all regions (Figure 2). In addition, histological sections through the PV and posterior atrial wall showed that the myocardial layer had small areas of discontinuities that were filled with fibrous tissue. There were no relations between body weight, gender, LA size, and thickness of the posterior atrial wall.

Structure and Heterogeneous Content of the Space Between the Posterior LA Wall and Esophagus

The space between the esophagus and the posterior LA wall showed wide variations resulting from differences in thickness of the connective tissue of the parietal pericardium and of the fibrofatty tissues between the esophagus and LA (Figures 4 and 5). Within the fat pad, we found in 12 specimens (67%) lymph nodes and branches of the left vagus nerve that descend along the anterior aspect of the esophageal wall to form with branches of the right vagus nerve a plexus around the esophagus. In all specimens, there was a sheet of connective tissue of the oblique pericardial sinus between the esophagus and the LA (Figures 4 and 5). The mean histological thickness of this parietal pericardium was 0.3 ± 0.1 mm

(range, 0.1 to 0.9 mm). The fat pad immediately behind the parietal pericardium had a variable thickness that was independent of factors such as age, body weight, gender, and LA size. The fat pad was thinnest at the level between the orifices of the inferior PV (Figure 5), measuring 0.5 ± 0.2 mm (range, 0.2 to 1.2 mm). Conversely, the fat pad was thickest at the superior border of the posterior LA (at the level of the

TABLE 1. Mean Minimal Distances Between the Esophageal Wall and the Right-Sided VA Junction, Middle of Posterior Wall of the LA, and Left-Sided VA Junction

	Minimal Distance From Esophageal Wall, mm
R V-A (3 specimens)	6.3 ± 2.8 (3.4–11.5)
MPW (6 specimens)	6.2 ± 2.5 (3.6–13.5)
L V-A (6 specimens)	5.6 ± 2.2 (3.3–10.5)

R V-A indicates right-sided VA junction; MPW, middle of the posterior wall of the LA; and L V-A, left-sided VA junction. Values in parentheses are ranges.

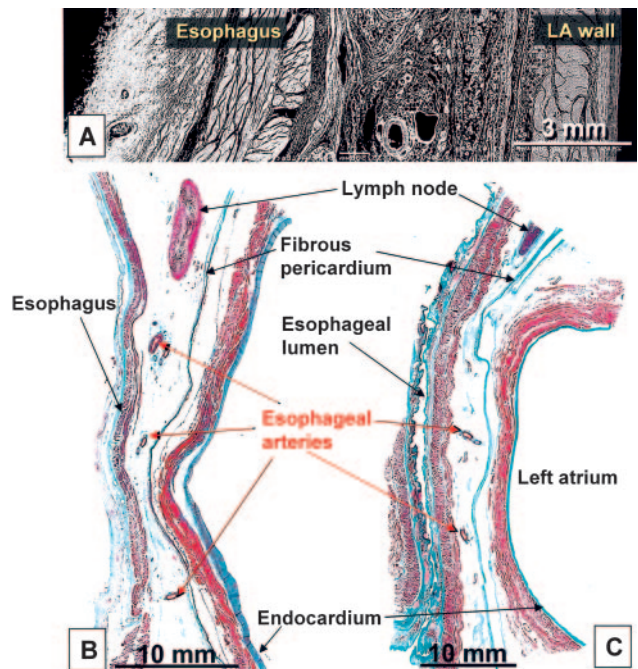


Figure 4. A, SEM of a sagittal section. B,C, Histological sections in similar orientation showing the fibrous pericardium between the LA wall and the esophageal wall and the fatty tissue plane containing lymph nodes and esophageal arteries immediately behind that (Masson's trichrome stain).

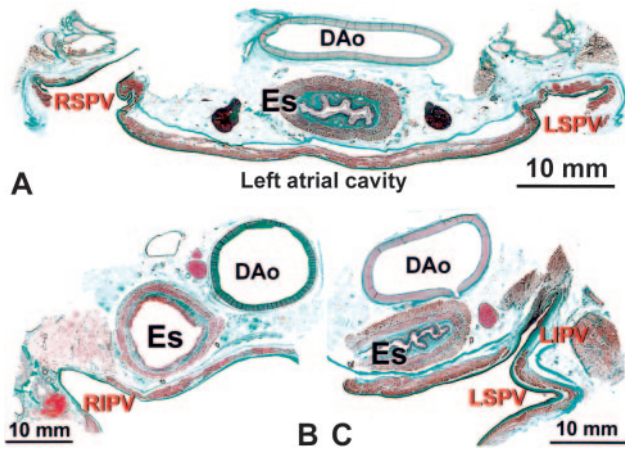


Figure 5. Transverse histological sections (Masson's trichrome stain) showing the proximity of the esophagus to middle of the posterior wall of the LA (A), the right inferior PV (B), and the left inferior PV (C). DAo indicates descending aorta; E, esophagus; LIPV, left inferior caval vein; LSPV, left superior PV; RIPV, right inferior PV.

superior PV). There were lymph nodes within the fat in the latter area, and the serous pericardium continued with the parietal layer of the pericardium (Figure 5). Accordingly, the mean distance from the esophagus to the posterior LA wall at this superior level was 2.3 ± 1.2 mm (range, 1 to 8.2 mm).

Within the fat pad and in contact with posterior LA wall through parietal pericardium, we found branches of the left vagus nerve with a mean thickness of 0.3 ± 0.1 mm (range, 0.1 to 1.1 mm) that descended along the anterior aspect of the esophageal wall (Figures 1 and 5) before forming a plexus around the esophagus. The fat pad also contained esophageal arteries with external diameters of 0.4 ± 0.2 mm (Figures 4 and 5) that arose anteriorly from the thoracic aorta to descend obliquely onto the esophagus, forming a vascular chain on it.

TABLE 2. Transmural Thickness (Endocardium-Epicardium) and Muscular Thickness of the Posterior Atrial Wall in 3 Different Regions: Right VA Junction, Middle of the Posterior Atrial Wall, and Left VA Junction at the Superior, Middle, and Inferior (Adjacent to the Coronary Sinus) Levels

	R V-A, mm	MPW, mm	L V-A, mm
Superior level			
Epi-Endo	2.3 ± 0.5 (1.1–4.8)	2.5 ± 0.5 (1.1–5.3)	2.2 ± 0.3 (1.2–4.5)
Myocardium	1.7 ± 0.3 (0.3–3.1)	1.9 ± 0.7 (0.6–3.2)	1.8 ± 0.6 (0.3–3.3)
Middle level			
Epi-Endo	2.8 ± 0.5 (1.5–5)	3.8 ± 0.6 (3.1–5)	3.5 ± 1.2 (1.7–5)
Myocardium	2.5 ± 0.5 (0.5–4)	2.9 ± 0.5 (0.6–4.2)	2.8 ± 0.5 (0.4–3.5)
Inferior level			
Epi-Endo	5.7 ± 2.5 (2.7–10)	6.5 ± 2.5 (2.8–12)	5.3 ± 2 (2.5–9)
Myocardium	4.2 ± 1 (1.1–5.3)	4.3 ± 0.8 (1.3–5.3)	4.1 ± 0.5 (1.1–5)

Abbreviations as in Table 1, plus Epi-Endo indicates epicardium-endocardium. Values are mean \pm SD (range).

Discussion

Main Findings

Our study has shown that the thickness of the posterior LA wall and of the fat pad between the LA and the esophagus is not uniform and that the differences in thickness follow a general pattern: The posterior LA wall is significantly thinner at the superior level of the LA than more caudally where the contact with the esophageal wall is closest, and the fat-pad layer between the esophagus and the parietal LA pericardium is thinner at the inferior level than more cranially. In addition, we have shown a variable structural content within the fat pad containing lymph nodes, branches of the left vagus nerve, and esophageal vessels. The present study provides a detailed anatomic background essential to interventionists and surgeons, thus facilitating an understanding of direct or indirect thermal injury of the esophageal wall and a guide to designing safer ablation lines targeting the posterior wall of the LA. From the anatomic perspective, we suggest that the atrial roof, or superior wall, which is not in direct contact with the esophagus, would be a safer place to put the posterior ablation to lessen the risk of damaging the esophagus, but the atrial myocardium is thinner at the level of the superior venous orifices.

Posterior Linear Lesions and LA Wall Thickness

The posterior wall of the LA is a target of currently used ablation procedures in patients with AF. Early surgical interventions aimed at reducing the critical mass of atrial tissues created long transmural linear lesions incorporating the posterior LA wall.^{15–17} Intraoperative RF ablation for AF can be associated with esophageal perforation with an incidence as high as 1% of patients.¹⁶ Although intraoperative ablation showed a high success rate,¹⁸ this devastating complication has led to concerns about performing this procedure in patients undergoing cardiac surgery until safer methods of ablation are developed.⁹ In recent years, the major percutaneous approaches for patients with paroxysmal and persistent AF have included the creation of linear lesions between the encircled pulmonary venous orifice areas involving the LA posterior wall.^{1,2,4,5,7,19} Recent reports from 3 institutions in which a large number of ablations were performed demonstrated that atrio-esophageal fistula may also result from percutaneous catheter ablation of the posterior LA.^{12,13} Although the risk of esophageal injury appears to be very low, this technique is becoming widely practiced, and there is an increasing number of personal communications of this serious complication. Overlapping lines in the posterior wall may have been responsible for esophageal injury^{11,12}; the investigators recommend avoiding excessively deep lesions by decreasing the power, temperature, and duration of RF energy application. The esophagus descends in virtual contact with the posterior LA from the superior level to the posteroinferior mitral annulus; in 40% of our specimens, the esophageal wall was <5 mm from the endocardium. A recent CT analysis showed the close contact over a large area between the esophagus and posterior LA wall, and in 36% of patients, the esophagus coursed obliquely from left superior to right inferior.¹⁴ However, the esophagus is mobile, and its location

relative to the posterior LA can change during the ablation procedure from being close to the left to close to the right side,^{14,20} necessitating real-time imaging.²¹ Furthermore, CT resolution does not allow measurements of wall thickness of <0.5 to 0.7 mm, which was encountered in our anatomic specimens (Table 2).

A significant finding is that the esophagus is not in direct contact with the roof of the LA. Thus, some investigators suggest that the posterior ablation line should be placed at the roof of the LA to prevent esophageal injury.^{11,20} Although safer for the esophagus, our study also reveals that if the roof line is placed along the upper borders of the superior pulmonary VA junctions, the operator should be mindful that this area of the myocardial wall is thin (Table 2).

In a previous study, we reported the overall thickness of the posterior LA wall.²² Our present study details nonuniform wall thickness from superior to inferior. The atrial wall was thickest immediately superior to the coronary sinus but was thinner at the inferior level of the inferior VA junctions. The approximate location of atrio-esophageal fistula reported in several patients was related to ablation lines of the left VA junctions.^{11–13} We have noted thin areas of myocardium and thinnest fat pads close to the left inferior junctions.

Structural Content Between the Posterior LA and Esophagus

Increasing numbers of ablation procedures using 8-mm and irrigated distal-tip catheter to create transmural lesion lines on the LA posterior wall have been performed worldwide. Despite the deployment of RF energy application in close proximity to the esophagus, the incidence of complications is relatively low. A recent study showed in patients a variable fat layer with a mean thickness of 0.9 ± 0.2 mm that may serve to insulate the esophagus from thermal injury during RF ablation.¹⁴ A thicker fat layer observed in most of the specimens at the level of superior border of the VA junction, the presence of esophageal lymph nodes, and the in-folding of the serous pericardium with the parietal layer of the serous pericardium may protect the esophagus wall from direct thermal injury.

Esophageal perforation appeared several days or weeks after RF ablation,^{9,10,13} suggesting an initial and subacute esophageal wall lesion that may later result in esophageal-LA fistula rather than an acute perforation directly from the LA to the esophagus. Doll and colleagues⁹ suggested that heat from the probe resulted in subacute inflammatory reaction of the esophageal wall. However, the presence of esophageal arteries may generate a cooling and protective effect on the posterior LA wall. Conversely, it is also possible that the heat applied to the endocardium can cause direct injury to the esophageal arteries, resulting in ischemic damage and necrosis of the esophageal wall.

Conclusions

Despite the limitations of using cadaveric materials fixed in formalin and from patients not known to have a history of AF, our anatomic study provides details demonstrating heterogeneous structures and relationships between the esophagus and the posterior LA wall relevant to clinical practice. We showed that, although the proximity of the esophageal wall to the

endocardial surface of the LA is variable, the distance was <5 mm in 40% of our specimens. It is conceivable that enlargement and thinning of the atrial wall in patients with AF will make this distance even shorter.

Numerous and diverse ablation lines are in use at different centers. From the anatomic viewpoint, it is not possible to say where precisely the lines are that will not put the esophagus at risk because the esophagus is mobile in the living patient. Although it is generally thought that the transverse lines connecting the lines encircling right and left pulmonary venous orifices are the culprits, our study shows that the atrial wall closest to the venous orifices is thinner than in the middle of the wall between orifices. In this regard, even the encircling lesions may cause damage if the esophagus runs close to the pulmonary venous orifices, as in 60% of our specimens. If the endocardial procedure is carried out during surgery, placing a gauze in the oblique sinus is a sensible precaution.¹¹ In surgery, RF in the bipolar mode or epicardial microwave may also be safer modalities.^{10,15,17} For the interventionist, imaging that can allow the esophagus to be seen in real time with adequate resolution of wall thickness will help considerably.^{23,24}

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