

Computed Tomographic Analysis of the Anatomy of the Left Atrium and the Esophagus Implications for Left Atrial Catheter Ablation

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Background—During left atrial (LA) catheter ablation, an atrioesophageal fistula can develop as a result of thermal injury of the esophagus during ablation along the posterior LA. No in vivo studies have examined the relationship of the esophagus to the LA. The purpose of this study was to describe the topographic anatomy of the esophagus and the posterior LA by use of CT.

Methods and Results—A helical CT scan of the chest with 3D reconstruction was performed in 50 patients (mean age, 54 ± 11 years) with atrial fibrillation before an ablation procedure. Consecutive axial and sagittal sections of the CT scan were examined to determine the relationship, size, and thickness of the tissue layers between the LA and the esophagus. The mean length and width of the esophagus in contact with the posterior LA were 58 ± 14 and 13 ± 6 mm, respectively. The esophagus had a variable course along the posterior LA. The esophagus was close (10 ± 6 mm from the ostia) and parallel to the left-sided pulmonary veins (PVs) in 56% of patients and had an oblique course from the left superior PV to the right inferior PV in 36% of patients. The mean thicknesses of the posterior LA and anterior esophageal walls were 2.2 ± 0.9 and 3.6 ± 1.7 mm, respectively. In 98% of patients, there was a fat layer between the esophagus and the posterior LA. However, this layer was often discontinuous.

Conclusions—The esophagus and posterior LA wall are in close contact over a large area that may often lie within the atrial fibrillation ablation zone, and there is marked variation in the anatomic relationship of the esophagus and the posterior LA. Both the esophageal and atrial walls are quite thin. However, a layer of adipose tissue may serve to insulate the esophagus from thermal injury, explaining why atrioesophageal fistulas are rare. (*Circulation*. 2004;110:3655-3660.)

Key Words: fibrillation ■ atrium ■ esophagus ■ radiofrequency catheter ablation ■ computed tomography

An uncommon but devastating complication of intraoperative or percutaneous radiofrequency catheter ablation of atrial fibrillation (AF) is thermal injury to the esophagus, resulting in an atrioesophageal fistula.¹⁻⁵ This complication has resulted in death in 50% of reported cases.¹⁻⁵ The esophagus lies against the groove formed by the left- and right-sided pulmonary veins (PVs), and the posterior left atrium (LA) is often targeted during elimination of non-PV arrhythmogenic foci,⁶ extraostial PV isolation,⁷ PV antrum disconnection,⁸ circumferential PV ablation,^{9,10} or wide-area circumferential ablation. There have been no detailed in vivo studies of the anatomic relationship of the human LA to the esophagus. Therefore, the purpose of the present study was to describe the relationship of the posterior LA to the adjacent esophagus in patients with AF by use of detailed CT analysis.

Methods

Study Subjects

The subjects of this study were 50 patients with paroxysmal (n=45) or chronic (n=5) AF who were referred for radiofrequency catheter ablation of AF. There were 39 men and 11 women, and their mean age was 54 ± 11 years. AF was first diagnosed 8 ± 5 years before referral. Structural heart disease was present in 1 patient, who had ischemic heart disease. The mean left ventricular ejection fraction was 0.55 ± 0.03 , and the mean left atrial (LA) diameter by transthoracic echocardiography was 43 ± 4 mm. All patients provided written informed consent.

CT With 3D Reconstruction

An ECG-gated helical CT scan of the chest was performed 1 to 4 weeks before the ablation procedure. Images were acquired with a LightSpeed Pro 16, 16-row multidetector CT scanner (GE LightSpeed, GE Medical Imaging). An initial timing bolus (15 mL bolus

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The online-only Data Supplement, which contains a movie, can be found with this article at <http://www.circulationaha.org>.

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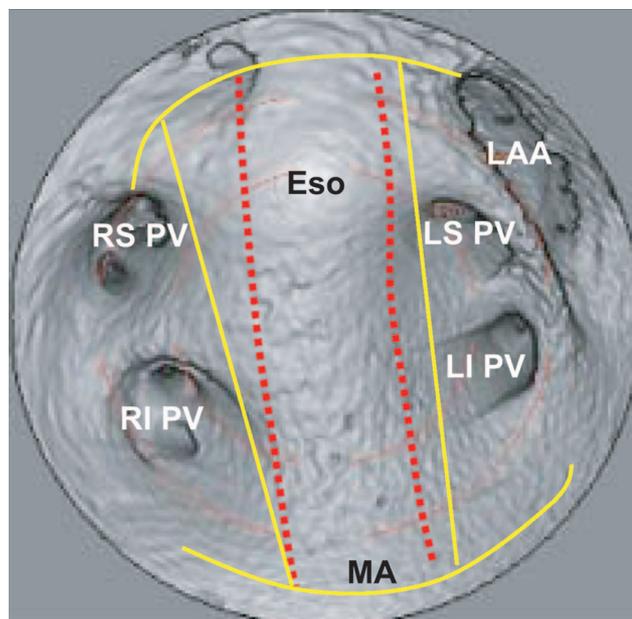


Figure 1. Endovascular view of posterior left atrium (anteroposterior projection) with 3D reconstruction. Posterior left atrium was defined by most superior points of roof of left atrium, a line tangential to most medial points of ostia of left-sided PVs, and another line tangential to most lateral points of ostia of right-sided PVs and posterior mitral annulus. Shown is a representative CT image to illustrate location of reference points (yellow lines), which were determined by examining both axial and coronal images. Location of borders of adjacent esophagus is shown (dashed red lines). LS indicates left superior; LI, left inferior; RS, right superior; RI, right inferior; LAA, LA appendage; PV, pulmonary vein; MA, mitral annulus; and Eso, esophagus.

of Omnipaque 300, Nycomed, Inc) was injected to determine the scan delay time for optimal imaging of the LA. The study then was performed with 120 mL of Omnipaque 300, and scanning was initiated at the time of the peak LA opacification with an additional 3 seconds at an injection rate of 4 mL/s. A collimation of 1.25 mm was used. Image acquisition was ECG-gated; therefore, table speed and pitch were heart rate dependent. The scan was performed from the lung bases to the apices during a single breath-hold. Each CT voxel was isometric at 1.25 mm. Using specific volume analysis software (GE Advantages Windows workstation, GE Medical Systems), the volumetric data were reconstructed to create 3D models as described previously.^{11,12}

Analysis of the Relationship of the Esophagus and the LA

To precisely describe the relationship between the esophagus and the posterior LA and to allow measurements in reference to landmarks that are easily identifiable during an ablation procedure, the posterior LA was outlined by (1) a superior line formed by the most superior points of the roof of the LA on axial CT images, (2) a medial line that was tangential to the most lateral points of the ostia of the right-sided PVs, (3) a lateral line that was tangential to the most medial points of the ostia of the left-sided PVs, and (4) an inferior line formed by the posterior mitral annulus (Figure 1). The PV ostium was defined by an abrupt angular change between the LA and pulmonary venous planes as described previously.^{11,12}

All short-axis or transverse axial CT images (75 ± 19 images per patient), starting from the superior border of the posterior LA to the level of the posterior mitral annulus, were examined. CT images in the sagittal and coronal planes also were analyzed to describe the course of the esophagus along the posterior LA wall. The following parameters were measured at multiple planes and were described in

reference to the borders of the posterior LA described above: the thickness of the posterior LA and esophageal walls, the presence and the dimensions of the fat pad between the esophagus and the LA, the width (transverse axis) and length (sagittal axis) of the portion of the esophagus in contact with the posterior LA wall, and the location of the shortest distance from the posterior LA to the lumen of the esophagus (Figure 2).

Measurements

All measurements were performed offline using digital calipers by the same investigator (K.L.). The intraobserver variability was $5 \pm 3\%$. The spatial resolution in all 3 dimensions was 0.58 mm. A fat pad between the LA and the esophagus was identified by an abrupt change in signal density. The thickness of the posterior LA wall was measured from the density of the intravenous contrast that filled the LA to the fat pad (Figure 2). The thickness of the esophageal wall was measured from the fat pad to the air density within the lumen of the esophagus. When there was no fat pad present, the measurements were made to/from the outline of the anterior esophageal wall, which was identified by a change in signal density. If the esophagus was collapsed, with no apparent luminal air density, the thickness of the anterior esophageal wall was calculated by dividing the anteroposterior diameter of the esophageal wall, from the fat pad to the pleura, by 2 (Figure 2).

Statistical Analysis

Continuous variables are expressed as mean \pm SD. Continuous variables were compared by use of Student's *t* test. A probability value of $P < 0.05$ indicated statistical significance.

Results

Esophagus and the Posterior LA

The mean length of the esophagus in the superoinferior axis in contact with the posterior LA was 58 ± 14 mm (range, 23 to 97 mm). The most superior site of esophageal contact with the posterior LA was at the level of the superior border of the posterior LA in 47 of the 50 patients (94%). In the remaining 3 patients (6%), the initial site of superior contact was 10 ± 4 mm (range, 4 to 9 mm) lower. The most inferior site of contact between the esophagus and posterior LA was at the level of the posterior mitral annulus in 24 of the 50 patients (48%) and was 11 ± 5 mm superior to the posterior mitral annulus in the remaining 26 patients (52%).

At the level of the superior PVs, the border of the esophagus in contact with the posterior LA was 10 ± 6 mm from the ostium of the left superior PV and 25 ± 8 mm from the ostium of the right superior PV (Figure 3, $P < 0.001$). At the level of the inferior PVs, the mean distances were 11 ± 7 mm from the ostium of the left inferior PV and 13 ± 6 mm from the ostium of the right inferior PV ($P = 0.1$).

In 28 of the 50 patients (56%), the esophagus was located to the left of the midline of the posterior LA wall and ran parallel to the ostia of the left superior and inferior PVs. In 18 patients (36%), the esophagus had an oblique course from the left superior PV to the right inferior PV. In 3 patients (6%), the esophagus was located to the right side of the midline of the posterior LA wall and ran parallel to the ostia of the right-sided PVs. In 1 patient (2%), the esophagus had an oblique course from the ostium of the right superior PV to the ostium of the left inferior PV (Figure 3).

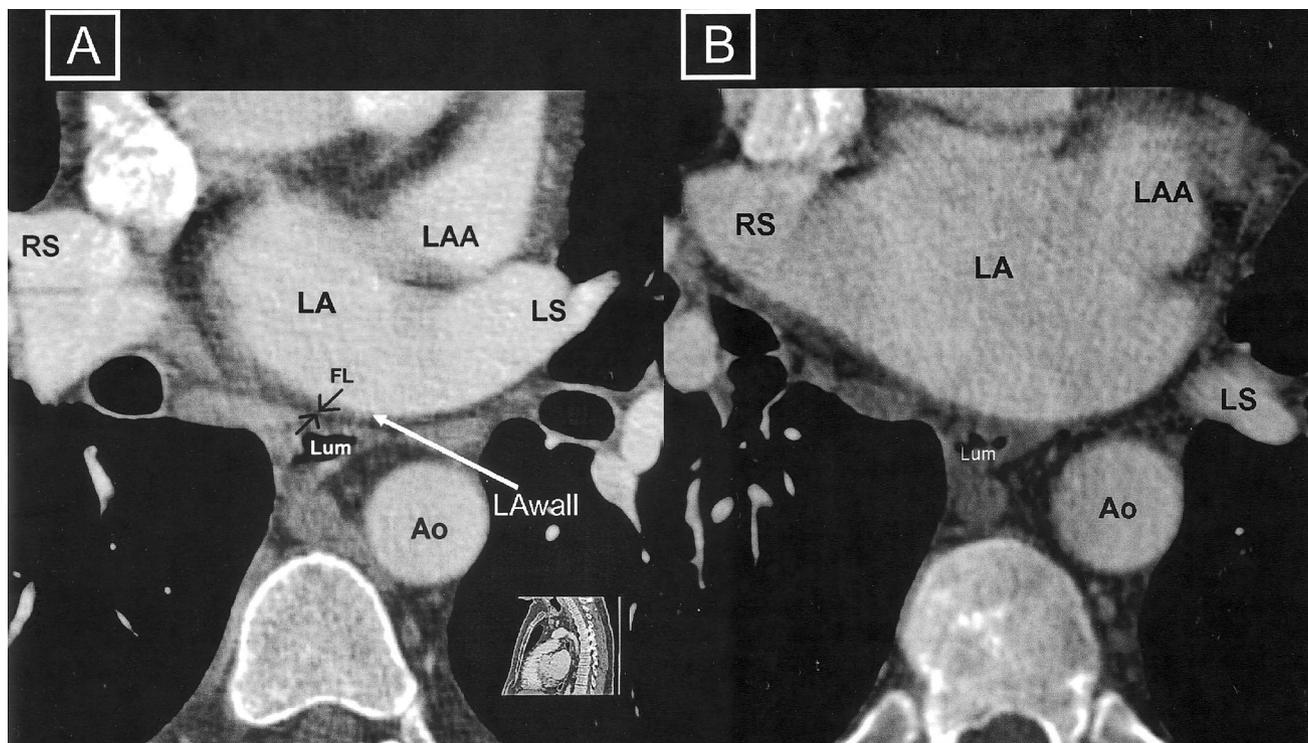


Figure 2. Axial image of esophagus and posterior LA at level of superior PVs. Between LA and esophageal lumen (A), 4 different layers are visible: radiocontrast agent within left atrium (most radiodense), a thin layer of posterior LA wall (less radiodense than LA), a thin layer of adipose tissue (radiolucent), and anterior esophageal wall (radiodense). B, There is no fat layer visible between left atrium and esophagus. Measurements were made using digital calipers. FL indicates fat layer; LA, left atrium; LAwall, posterior LA wall; Lum, lumen of esophagus; Ao, aorta; other abbreviations as in Figure 1.

Posterior Wall of the LA

The posterior LA was outlined by 4 PV ostia in 39 of the 50 patients (78%). In 5 patients (10%), there was a separate ostium for the right middle lobe PV, and in 6 patients (12%), there was a common ostium for the left-sided PVs.

The posterior LA was wider between the ostia of the superior PVs, 46 ± 8 mm, than between the ostia of the inferior PVs, 38 ± 7 mm ($P < 0.001$). The mean thickness of the posterior LA wall was 2.2 ± 0.9 mm (range, 0.9 to 7.4 mm), with no significant differences at the superior, middle, and inferior regions of the posterior LA wall ($P = 0.5$). There was no relationship between body weight, LA size, sex, duration of AF, whether AF was paroxysmal or chronic, and the posterior LA thickness.

Thickness of the Esophageal Wall Adjacent to the Posterior LA

The mean thickness of the anterior aspect of the esophageal wall adjacent to the posterior LA was 3.6 ± 1.7 mm (range, 1.3 to 6.2 mm). There were no significant differences in the thickness of the anterior esophageal wall at the superior, mid, and inferior aspects of the posterior LA ($P = 0.8$).

Fat Pad Between the LA and the Esophagus

There was a fat pad between the esophagus and the LA in 49 of the 50 patients (98%). The thickness of the fat pad was 0.9 ± 0.2 mm (range, 0.3 to 1.3 mm). In 1 patient (2%), the fat pad was a continuous layer between the posterior LA and the

esophagus along its superoinferior axis. In the remaining 48 patients (96%), the fat pad was discontinuous. A gap in the fat pad usually was located at the level of the mid posterior LA, between the superior and inferior PVs, and had a mean diameter of 18 ± 10 mm (range, 3 to 40 mm).

Among the clinical variables of age, sex, body weight, and LA size, there were no independent predictors of the presence or thickness of the fat pad between the esophagus and the posterior LA.

Contact Between the Esophageal Wall and Posterior LA

The mean width of the esophagus in contact with the posterior LA was 11 ± 5 mm at the level of the superior PVs and 15 ± 5 mm at the level of the inferior PVs ($P < 0.001$). There was no relationship between the LA size and the width of the esophagus.

The shortest distance from the posterior LA to the esophageal lumen was 3.5 ± 1.0 mm (range, 2.0 to 5.3 mm) and was located 27 ± 8 mm medial to the left-sided PVs, 21 ± 9 mm lateral to the right-sided PVs, and 16 ± 8 mm inferior to the superior border of the posterior LA (Figures 1 and 3).

In 13 of the 50 patients (26%), the shortest esophagus-to-LA distance was at the site at which the esophagus crossed from the left to the right of the midline over a vertebral body. At this site, the esophagus was compressed between the LA and the vertebral body.

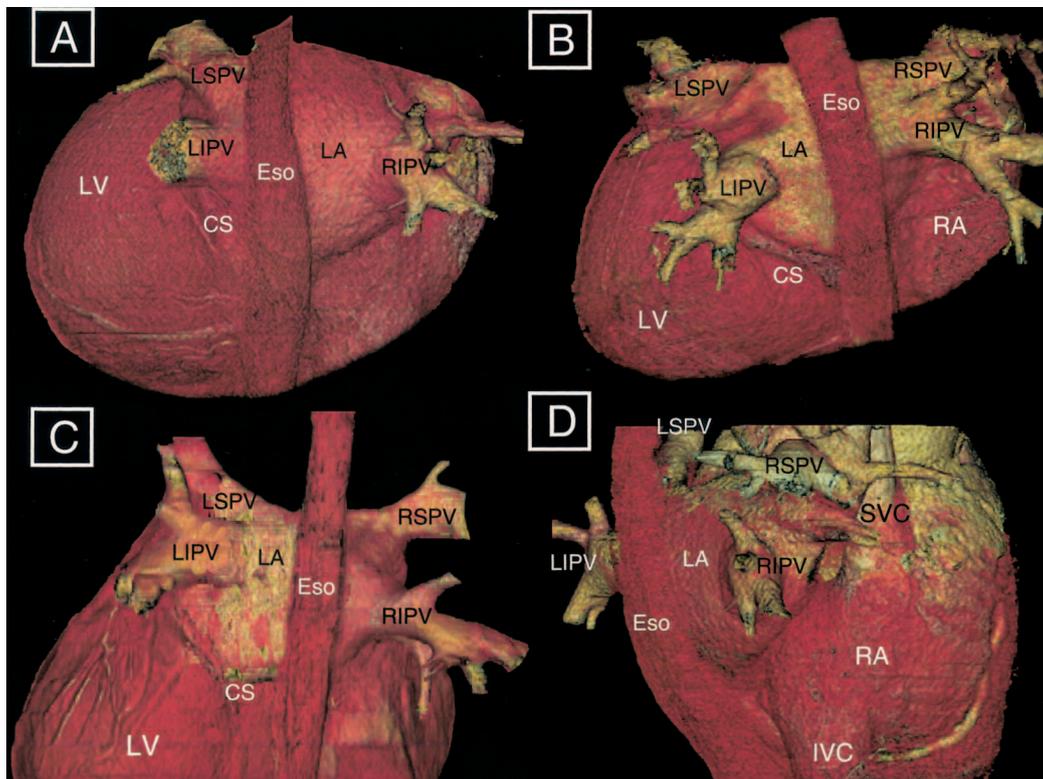


Figure 3. Relationship of esophagus to posterior LA wall: 3D CT images. Esophagus may be positioned very close to ostia of left-sided PVs (A, PA projection), may have an oblique course from left to right as it travels caudad (B, PA projection), or may be closer to right-sided PVs than left-sided PVs (C, PA projection). In sagittal projection, esophagus wraps around posterior left atrium along its entire length (D). LV indicates left ventricle; CS, coronary sinus; RA, right atrium; SVC, superior vena cava; IVC, inferior vena cava; other abbreviations as in previous figures.

Discussion

Main Findings

The main findings of this study are that (1) the course of the esophagus along the posterior LA is variable, but in >90% of patients, the esophagus either lies close and parallel to the ostia of the left-sided PVs or follows an oblique course from the left superior to the right inferior PV; (2) both the posterior LA and anterior esophageal walls are quite thin, often <5 mm; (3) the esophagus is in direct contact with the posterior LA for >5 cm along its long axis; (4) there is a thin layer of adipose tissue between the esophagus and the posterior LA, but this fat pad usually is not continuous, and there may be an area \approx 2 cm in diameter between the esophagus and mid-portion of the posterior LA without a fat pad; (5) the transverse extent of contact between the esophagus and the posterior LA is generally 10 to 15 mm; (6) in \approx 25% of the patients, the esophagus is compressed between the LA and a vertebral body as it travels from left to right; and (7) there are no demographic or clinical predictors of the size of the fat pad or minimum thickness of the esophageal and posterior LA walls.

On the basis of these findings, it is clear that target sites during catheter ablation of AF may often fall within the region of contact between the esophagus and the posterior LA. Despite this, atrioesophageal fistulas have apparently been uncommon, perhaps because of the usual presence of a fat pad that may insulate the esophagus from thermal injury.

Posterior LA and Esophagus

There was no correlation between the esophageal diameter and LA size. In a patient with a small LA, the esophagus may occupy a larger relative area of the posterior LA than in a patient with a dilated LA. Therefore, patients with a small LA may be at higher risk for fistula formation.⁴ Moreover, both the posterior LA and anterior esophageal walls are quite thin, often <5 mm, creating a risk of thermal injury from radiofrequency ablation regardless of whether a conventional 4-mm-tip catheter, 8-mm-tip catheter, or irrigated-tip catheter is used.

An important anatomic observation was that the esophagus often came in contact with the posterior LA wall at the level of the superior border of the posterior LA and remained in contact beyond the level of the inferior PVs, often to the posterior mitral annulus. Therefore, ablation along the atrial aspect of the posterior mitral annulus may not avoid the esophagus.

Fat Pad

There was a layer of fat between the left atrium and esophagus in 98% of patients, and although thin, this fat layer may serve to insulate the esophagus from thermal injury during radiofrequency ablation. In a patient who had a fatal atrioesophageal fistula, there was no layer of fat on the posterior LA, probably explaining why the fistula occurred in this patient.⁴ Unfortunately, there does not seem to be any

simple clinical or demographic identifier (such as body weight) of the occasional patient without a layer of adipose tissue between the left atrium and esophagus. A preablation CT scan may be useful to identify such patients.

Previous Studies

There are no previous studies that investigated the relationship between the esophagus and the posterior LA in vivo. In a postmortem study, Ho et al¹³ described the histology and anatomy of the LA. However, the relationship between the esophagus and the posterior LA was not described in that study.

Ho et al reported the thickness of the posterior LA wall to range from 2.5 to 5.3 mm (mean, 4.1 ± 0.7 mm), slightly thicker than reported in this study. However, those measurements were made in postmortem specimens, fixed in formalin, from a different patient population. In the present study, the measurements were made in vivo, in a supine position similar to that used during catheter ablation. Moreover, there was blood circulating that filled and probably stretched the LA cavity, particularly after intravenous injection of a contrast agent. Therefore, the findings of this study may be more representative of the actual thickness of the tissue layers during a catheter ablation procedure.

Implications for LA Catheter Ablation

Various approaches, either alone or in combination, may minimize the risk of esophageal injury, as follows.

Imaging of the Esophagus

One approach to reduce the risk of esophageal injury is to avoid delivery of radiofrequency energy at all posterior LA sites that are in proximity to the esophagus. However, this requires precise imaging of the esophagus in relation to the posterior LA, either by digital image fusion technology, which incorporates CT images acquired before ablation into the 3D map of a navigation system,^{14,15} or by real-time MRI.¹⁵ These new technologies are not readily available and may have their own limitations. Because the esophagus is a mobile structure (see video image in the online-only Data Supplement) and can readily move and migrate during the course of an ablation procedure,¹⁶ static images may be of limited value. Therefore, real-time dynamic imaging of the esophagus in relation to the left atrium appears to be necessary to avoid the esophagus if radiofrequency energy will be delivered along the posterior LA wall.¹⁶

Other approaches for imaging of the esophagus may be swallowing a radiocontrast agent or placing a small-caliber probe into the esophagus before the procedure. Posterior LA sites in contact with the esophagus may subsequently be tagged on a 3D map used for catheter navigation. However, the probe will show only the site of the esophageal lumen rather than the wall, and swallowing a radiocontrast agent shortly before the procedure may carry a small risk of aspiration during sedation or anesthesia.

Energy Source for Ablation

Fistula formation has been reported primarily with applications of radiofrequency energy in the posterior LA both intraoperatively and during catheter ablation procedures.¹⁻⁵

Cryoablation preserves the collagen structure of the tissue and may be less likely to disrupt the integrity of the atrial and esophageal walls. However, no studies to date have determined whether cryoablation can be used safely near the esophagus.

Monitoring Esophageal Temperature

By placing probes with temperature sensors in the esophagus adjacent to the LA, it may be possible to monitor temperature rises in the esophagus during radiofrequency energy application. However, the temperatures recorded within the lumen of the esophagus may not accurately represent intramural temperature. Because this complication is infrequent, it may not be possible to determine the temperature threshold for safety, and animal data may not be applicable to humans. More importantly, there appears to be a latency period of 3 to 7 days between ablation and fistula formation. It is possible that this complication results from vascular injury/ischemic necrosis rather than from thermal injury, similar to the post-polypectomy syndrome that occurs in other parts of the gastrointestinal tract.¹⁷ However, it was not feasible to visualize the vascular supply of the esophagus with the CT scans used in this study.

Ablation Strategy

On the basis of the close relationship of the esophagus to the posterior LA wall, the safest ablation strategy would be one that avoids the posterior left atrium. However, the ablation strategy that provides the best combination of efficacy and safety remains to be determined.

Acknowledgments

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Disclosure

Drs Morady and Oral have served as consultants to Biosense-Webster.

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