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Assessment of Temperature, Proximity, and Course of the Esophagus During Radiofrequency Ablation Within the Left Atrium

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***Background*—**Left atrioesophageal fistula is a devastating complication of atrial fibrillation ablation. There is no standard approach for avoiding this complication, which is caused by thermal injury during ablation. The objectives of this study were to evaluate the course of the esophagus and the temperature within the esophagus during pulmonary vein antrum isolation (PVAI) and correlate these data with esophagus tissue damage.

***Methods and Results*—**Eight-one patients presenting for PVAI underwent esophagus evaluation that included temperature probe placement. Esophagus course was obtained with computed tomography, 3D imaging (NAVX), or intracardiac echocardiography. For each lesion, the power, catheter and esophagus temperature, location, and presence of microbubbles were recorded. Lesion location and esophagus course were defined with 6 predetermined left atrial anatomic segments. Endoscopy evaluated tissue changes during and after PVAI. Of 81 patients, the esophagus coursed near the right pulmonary veins in 23 (28.4%), left pulmonary veins in 31 (38.3%), and mid-posterior wall in 27 (33%). Esophagus temperature was significantly higher during left atrial lesions along its course than with lesions elsewhere (38.9±1.4°C, 36.8±0.5°C, $P<0.01$). Lesions that generated microbubbles had higher esophagus temperatures than those without (39.3±1.5°C, 38.5±0.9°C, $P<0.01$). Power was not predictive of esophagus temperatures. Distance between the esophagus and left atrium was 4.4±1.2 mm.

***Conclusions*—**Lesions near the course of the esophagus that generated microbubbles significantly increased esophagus temperature compared with lesions that did not. Power did not correlate with esophagus temperatures. Esophagus variability makes the avoidance of lesions along its course difficult. Rather than avoiding posterior lesions, emphasis could be placed on better esophagus monitoring for creation of safer lesions. **(*Circulation*. 2005;112:459-464.)**

Key Words: ablation ■ catheter ablation ■ complications ■ fistula, atrioesophageal ■ pulmonary veins

Catheter ablation is rapidly becoming the treatment of choice for symptomatic drug-refractory atrial fibrillation (AF). Although this procedure carries with it a relatively low incidence of complications, there have been recent case reports of postprocedural left atrioesophageal fistula formation.[1,2] Although rare, this complication is associated with a very high mortality and morbidity, including air embolism, sepsis, endocarditis, and gastrointestinal exsanguination. Originally documented after radiofrequency (RF) ablation of the left atrium (LA) during open heart surgery, esophagus damage has been attributed to thermal injury during ablation application.[3–5] To prevent this damage during both intraoperative and catheter-based procedures, various modifications, including reduction of the RF generator power settings and moving posterior wall lesion locations, have been suggested.[2,6] However, these modifications often presume not only a predictable esophagus course but also that lower power or temperature settings during ablation are safer while continuing to be effective. Because of the variability in energy delivery and tissue damage/destruction despite constant generator settings, as well as anatomic variation of the esophagus, it is unknown whether these modifications can effectively prevent inflammation and damage to the esophagus. The objective of the present study was to systematically evaluate the anatomy and temperature change of the esophagus during RF within the LA during standard pulmonary vein antrum isolation (PVAI). Additionally, previous studies have suggested that the presence of microbubbles on intracardiac echocardiography (ICE) may indicate endocardial overheating.[7] Therefore, we specifically hypothesized that RF

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lesions placed near the esophagus that generated microbubbles would be associated with higher esophagus temperatures than those lesions without microbubble formation.

Methods

PVAI Protocol

Eighty-one patients presented for standard PVAI as treatment for symptomatic drug-refractory AF. Verbal and written informed consent was obtained from each patient. Data were collected and entered into an electrophysiology database approved by the institutional review board. PVAI was performed according to a standard protocol. Briefly, double transseptal puncture was performed under ICE guidance. A circular mapping catheter (Lasso, Biosense Webster) was advanced to the antrum of each pulmonary vein (PV). A quadripolar 8-mm Celsius catheter (Biosense Webster) was used to place RF lesions around the antrum of each PV where there was electrical evidence of muscle sleeve extension as documented by the Lasso catheter. A 70-W Stockart generator (Biosense Webster) was set to deliver RF lesions up to 70 W and 55°C. Catheter temperature, power, and location and presence of microbubbles were recorded with each RF application. Lesions were delivered either by limiting the power to 50 W alone or by titrating the power according to the presence or absence of microbubbles. When lesions were delivered by limiting power, all lesions were placed with a starting power of 25 W, a maximum power limited to 50 W, and a maximum temperature set at 55°C. With this approach, lesions were delivered at each site for 30 seconds. Only 1 patient received PVAI by this method. The remainder of the patients had the power of their lesions titrated on the basis of microbubble detection. When power is titrated according to the presence of microbubbles, RF energy is applied initially at 25 W and 55°C. ICE is used to monitor the ablation catheter–endocardium interface for the presence of microbubbles. If no microbubbles appear, the power is titrated up in 5-W increments every 5 seconds to a maximum of 70 W. If microbubbles appear at any point during lesion placement, the power is titrated down in 5-W decrements until microbubbles disappear or power is ≤5 W, at which time the generator is shut off and the catheter repositioned. If a shower of microbubbles occurs at any power level, the generator is immediately shut off and the catheter repositioned before repeat RF application. Pulse duration of each lesion is 30 seconds, after achievement of a stable power level. If microbubbles appeared at any point during a lesion, that lesion was documented as having microbubbles, even if microbubbles resolved after adjustment of the power.

Esophageal Monitoring/Evaluation

Measurement of esophagus temperature involved placement of a monotherm esophageal temperature probe (Mallinckrodt Medical), which was advanced under fluoroscopic guidance to the lower third of the esophagus directly posterior to the LA. Anatomic course, as visualized fluoroscopically, and baseline temperature within the esophagus lumen were then recorded. The temperature probe was adjusted to equal the “height” of the lesion. During each lesion, simultaneous esophagus temperature, RF catheter temperature, power, and lesion location were recorded. Position of the temperature probe was adjusted to the height of the ablation lesion. In all patients who agreed, evaluation of immediate tissue damage was performed by direct visualization with esophagogastroduodenoscopy during and after the procedure. A pediatric neonate scope was used for patient comfort by a gastroenterologist using standard precautions for airway protection with the patient under conscious sedation.

Esophageal course was first evaluated by visualization of the temperature probe under direct fluoroscopy and by fast cardiac computed tomography (CT) performed before the procedure. Sagittal, axial, and coronal slices were reviewed by 2 independent physicians who evaluated the esophagus course. The area of closest contact between the LA endocardium and esophagus lumen was measured with a digital measuring tool. The area of the esophagus that was directly posterior to the LA was referred to as the left atrioesophageal interface.

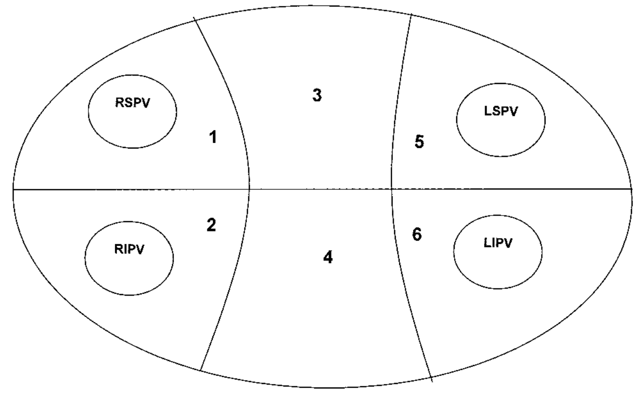

Figure 1. Schematic of LA demonstrating 6 anatomic segments used to define lesion location and esophageal course. LSPV indicates left superior PV; LIPV, left inferior PV; RSPV, right superior PV; and RIPV, right inferior PV.

Anatomic course and location of the esophagus were then documented with 6 predefined areas of the LA. These areas were (1) right superior pulmonary vein antrum, (2) right inferior PV antrum, (3) superior-posterior LA wall, (4) inferior-posterior LA wall, (5) left superior PV antrum, and (6) left inferior PV antrum (Figure 1). Lesions delivered within the LA were localized and categorized with the same LA divisions (Figure 1). Lesions placed in the same assigned area as the esophagus were considered in proximity to the esophagus. Lesions placed in different areas were considered remote from the esophagus.

Additionally, esophagus contact and course were imaged with ICE. After the ICE catheter (AcuNav, Siemens) was advanced to the right atrium, the esophagus was identified posterior to the LA. Its position and course were documented with ingestion of no more than 2 mL of a carbonated beverage, which generated echo-brilliant bubbles within the esophagus. In patients who had 3D mapping (NAVX, ESI) during their procedure, additional documentation of the esophagus course was performed with this system. A standard esophagus electrode was advanced under fluoroscopy to the lower third of the esophagus. 3D mapping points were taken from this electrode during pullback of the esophagus electrode. Because NAVX software cannot measure distance, only esophageal course was evaluated and documented with this system.

The course of the esophagus on the CT scan, the 3D mapping system, and ICE were recorded independently and the results compared. All patients had their PVAI performed only under conscious sedation. All patients were awake and alert during esophageal probe placement and evaluation.

Follow-Up

All patients were monitored in the hospital overnight. On discharge, patients were given an arrhythmia transmitter for documentation of any arrhythmias. All patients underwent screening CT scans before ablation and 3 months after the procedure. Additional CT scans were obtained at 6 and 12 months if PV narrowing was detected. Patients were also followed up in the outpatient clinic at 6 months and 1 year and as needed. In all patients who consented, evaluation of immediate tissue damage was performed by direct visualization with esophagogastroduodenoscopy during and the day after the procedure to evaluate tissue changes within the esophagus.

Statistical Analysis

Continuous variables are expressed as mean±SD. Differences among groups of continuous variables were determined by ANOVA. The Student *t* test and standard least-squares analysis were used to compare data with continuous variables. In addition, to account for multiple observations made in individual patients, a generalized

TABLE 1. Patient Characteristics

Male/Female	63/18
Age, y	55.8±8.8
Ejection fraction	0.52±0.07
LA size, cm	4.31±0.9
Duration of AF, y	7.4±6.7
Baseline temperature, °C	36.2±0.488
Distance between esophageal lumen and left atrium, mm	4.4±1.2

estimating equations (GEE) model was fit to the esophageal temperature data with the exchangeable correlation to account for within-patient correlation. Results with values of $P<0.01$ were considered statistically significant.

Results

Patient Characteristics

As displayed in Table 1, of the 81 patients in the present study, 63 were men. The mean age was 55.8±8.8 years, with a mean ejection fraction of 0.52±0.07. The mean duration of AF was 7.4±6.7 years, with 65% (53/81) of patients having paroxysmal AF and 36% (28/81) having persistent AF. Mean LA size was 4.3±0.9 cm, as recorded by preprocedural echocardiogram. At the time of the procedure, all patients had previously failed medical treatment. A multivariate analysis was performed to predict esophageal location. The independent variables used were gender, age, type of atrial fibrillation, and ejection fraction. These variables were poor predictors of esophageal location ($R^2=0.0003$, $P=0.55$).

Esophageal Anatomy

The anatomic course of the esophagus was documented during advancement of the esophagus probe with fluoroscopy in all patients. In 28.4% (23/81) of patients, the esophagus coursed along the right superior and inferior PV antra. In 38.3% (31/81), the esophagus coursed along the left superior and inferior PV antra. In the remaining 27 patients (33.3%), the esophagus appeared to course directly behind the mid-posterior wall of the LA (Figure 2). There was 100% correlation between CT scan, fluoroscopic assessment, and NAVX mapping of the esophageal course with the 6 defined anatomic segments. No patient characteristic was predictive of esophageal location. The average distance between the endocardial surface of the LA and midesophagus lumen on the CT scans was 4.4±1.2 mm at the area of closest contact. This was consistent with the distance between endocardium and endothelium as measured by ICE (4.2±2.1 mm). Additionally, the thickness of the LA posterior wall, as measured by ICE, was only 2.8±0.9 mm (ranging from 1.9 to 4.0 mm).

In the only patient who underwent ablation with the power limited to 50 W and temperature limited to 55°C, microbubbles were seen with powers ranging from 25 to 43 W. During energy delivery along the esophageal course (close to the left PVs), the esophageal temperature increased to 42.6°C to 44.2°C. With these temperatures, dense microbubble formation was seen at the area of the lesions. In this patient, the 24-hour esophagogastroduodenoscopy showed a linear endothelial blanching consistent with tissue damage in the area of the esophagus directly behind the LA. No fistula development was seen. In view of these findings, no additional patients underwent ablation with only power and temperature limitation. All remaining patients had lesions delivered with titra-

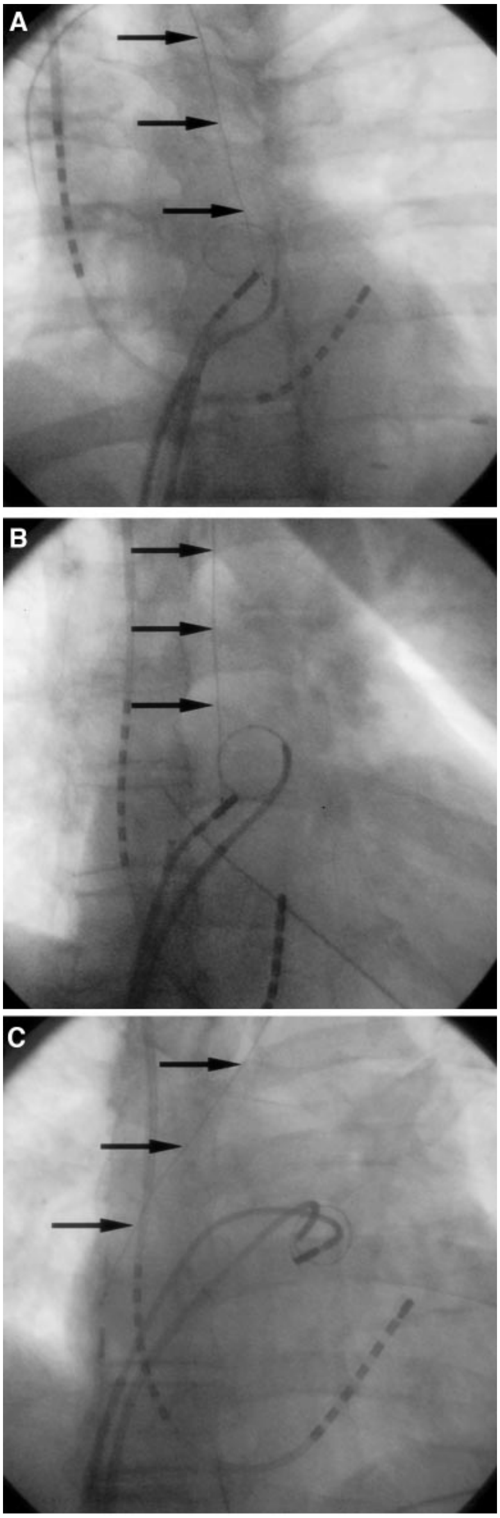

Figure 2. Representative fluoroscopic images of esophageal temperature probe (arrows) within esophagus of 3 different patients. These images demonstrate variability of esophageal course: posterior to left PVs (A), mid-posterior wall (B), and right PVs (C).

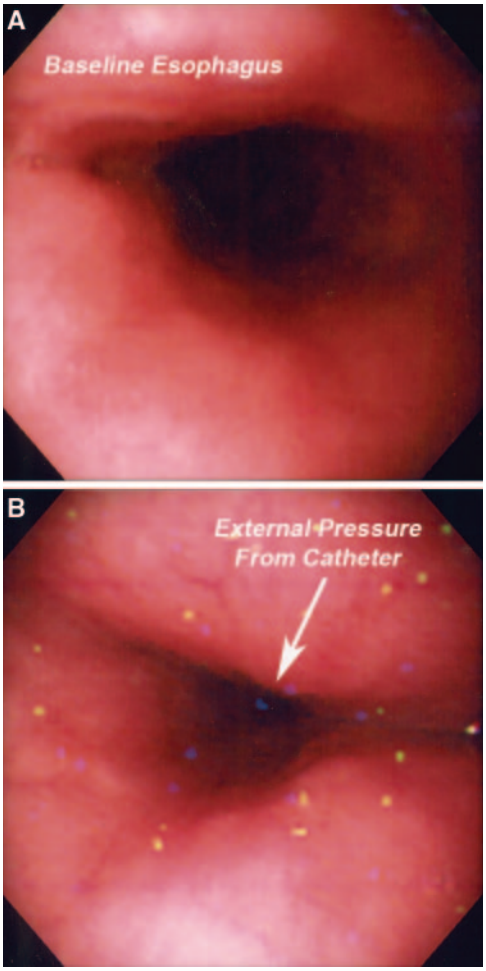

Figure 3. Representative example of esophageal images at baseline (top) and during RF ablation within LA (bottom). External pressure from ablation catheter creates depression within esophagus. Artifact from RF energy is seen in right panel.

tion of power according to the presence or absence of bubbles.

In patients who underwent direct esophagus visualization during (n=8) and 24 hours after (n=16) the procedure with microbubble-guided RF delivery, no evidence of esophagus endothelial damage was recorded. Although direct compression of the esophagus was seen during ablation, there was no acute (periprocedural) or delayed (24 hours) esophageal endothelium damage seen (Figure 3).

In all patients, the esophagus was identified with the ICE catheter. Real-time documentation and evaluation of the esophagus course posterior to the LA clearly demonstrated a close association of the 2 structures along the entire length of the left atrioesophageal interface. Ingestion of carbonated beverages proved to be an effective means of verifying echocardiographic identification of the esophagus in all patients (Figure 4). Additionally, no movement or change in esophagus course, defined as a change in LA anatomic division, was seen during the course of the procedure as documented by fluoroscopic assessment. No patient demonstrated any evidence of atrial esophageal connection on the 3-month follow-up CT scan.

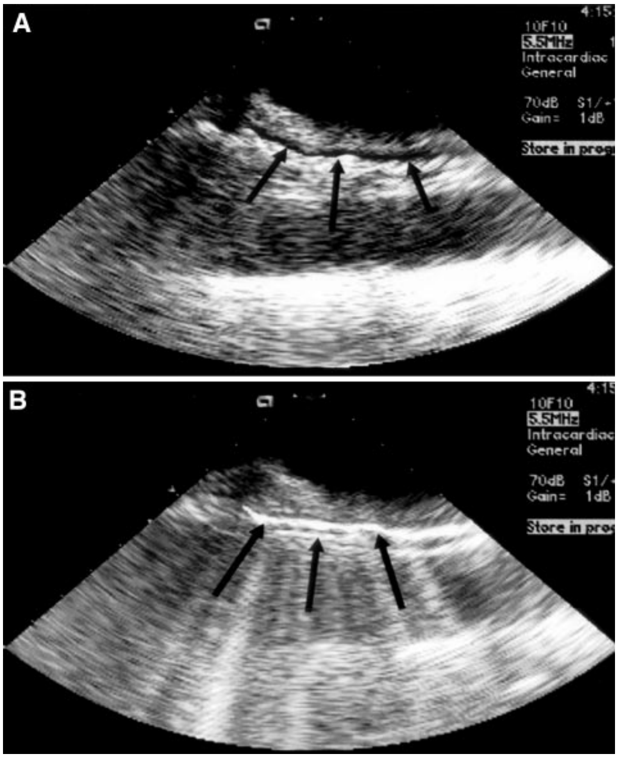

Figure 4. Representative ICE images before and during administration of carbonated beverage. These images demonstrate close proximity of esophagus (black arrows) to entire length of LA.

Esophageal Temperature

There were a total of 3118 RF lesions recorded from all 81 patients. Lesions placed in the same area (Figure 1) as the esophagus were considered in proximity to the esophagus. Lesions placed in all other areas were considered remote from the esophagus. Of the 3118 RF lesions, 367 were in proximity to the esophagus, and 2751 were remote from the esophagus. The median number of lesions in proximity to the esophagus per patient was 5 (range 2 to 12). The median number of lesions remote from the esophagus per patient was 30 (range 15 to 90). The mean power of lesions near the esophagus (n=367) was 45.3±13.6 W (range 2 to 70 W). The mean power of lesions remote from the esophagus was 43.0±13.5 W (range 10 to 70 W).

When RF energy was applied within the LA in proximity to the esophagus (n=367 lesions), the temperature within the esophagus was significantly higher than when LA lesions were placed in areas remote to the esophagus (n=2751; 38.9±1.4°C versus 36.9±0.5°C, $P<0.01$). When the 367 lesions placed in proximity to the esophagus were analyzed further, the esophagus temperature was significantly higher during lesions that generated microbubbles (n=199) than those that did not (n=168; 39.3±1.5°C versus 38.5±0.9°C, $P<0.01$; Figure 5).

To account for anatomic variability between patients, further analysis was limited to only those lesions near the esophagus. For these lesions (n=367), the relationship between esophagus temperature and power was evaluated by regression analysis. Although higher temperatures were as-

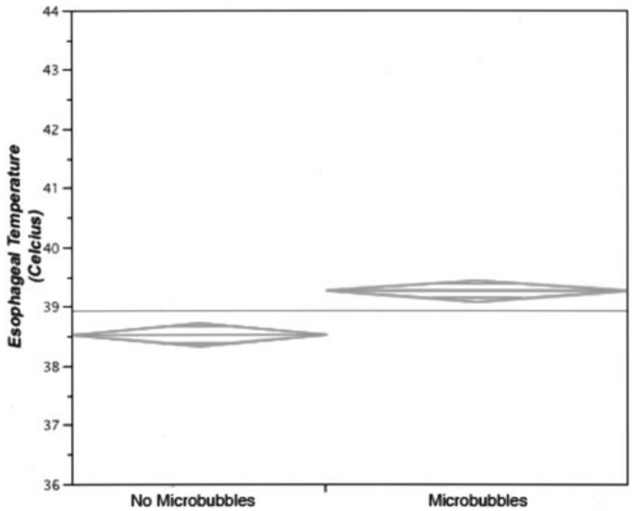

Figure 5. Mean and SD of esophageal temperature (°C) of lesions along esophageal course with microbubbles (n=199) compared with those without (n=168; 39.3±1.5°C versus 38.5±0.9°C, $P<0.01$).

sociated with higher esophageal temperatures, the regression demonstrated a poor fit ($R^2=0.08$, $P<0.01$; Figure 6). Additionally, to account for multiple observations made in individual patients, a GEE model was fit to the esophageal temperature data with the exchangeable correlation to account for within-patient correlation. The results are shown in Table 2. In summary, this confirmed that proximity to the esophagus and presence of microbubbles were significant predictors of esophageal temperature ($P<0.01$).

Discussion

This study is the first to systematically evaluate not only the variable anatomy of the esophagus in relation to the LA but also esophagus temperature changes during LA ablation. Esophagus damage, perforation, and left atrioesophageal fistulas were first described after LA RF ablation placement at the time of open heart surgery.[3,5,8] These procedures used lesion settings of 50 to 100 W and 60°C to 80°C applied under direct visualization to the LA endocardium. Evidence of atrioesophageal communication presented 5 to 7 days after surgery. Presenting symptoms included neurological deficits from air emboli, massive gastrointestinal bleeding, and septic shock. Of the 4 total cases reported by Gillinov et al[3] and Mohr et al,[5] 2 patients died, and the remaining 2 patients had residual neurological deficits from air emboli despite undergoing surgical repair.

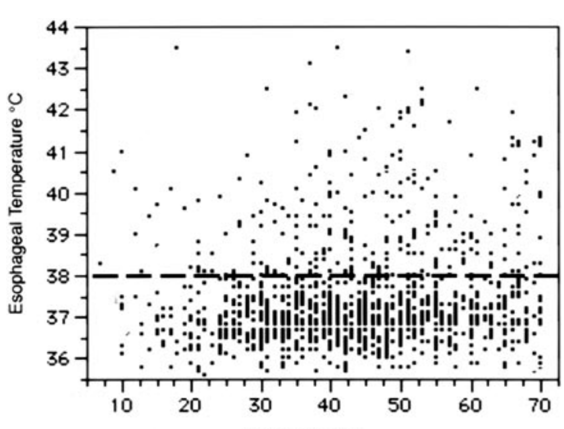

Figure 6. Scatterplot demonstrating wide range of esophageal temperature (°C) achieved regardless of power (Watts) of each lesion placed in proximity to esophagus (n=367). Esophageal temperatures greater than 38°C (dashed line) were achieved even at power settings <10 W.

TABLE 2. Multivariate Analysis Based on the GEE Model With Identity Link and Exchangeable Within-Patient Correlation

Variable	Parameter Estimate	98% CI	*P*
Proximity vs remote	2.00	1.77–2.22	<0.0001*
Power	0.004	0.0007–0.0074	0.02
Presence of microbubbles	0.09	0.03–0.15	0.002*

To account for multiple observations made in individual patients, a GEE model was fit to the esophageal temperature data with the exchangeable correlation to account for within-patient correlation. Results with $P<0.01$ were considered statistically significant. Proximity to the esophagus and presence of microbubbles were significant predictors of esophageal temperature.

*$P<0.01$.

Later, Doll and colleagues[8] reported 4 cases in their series of 129 patients receiving intraoperative RF ablation. All 4 patients developed neurological sequela of air emboli, and 1 of those 4 died secondary to massive air embolism.[8] Although many editorials and commentaries have implicated catheter type, area of lesions, and presence of a transesophageal echocardiogram probe, no series has been able to elucidate a predictor of patients more likely to develop this complication.[4,9] There have been several advancements and modifications in the tools used to perform ablation, as well as modifications in surgical approach, but the presence of this complication persists.[6]

Over the past several years, catheter ablation of AF has become the treatment of choice for symptomatic drug-resistant AF in many patient populations. Although access is achieved endovascularly, RF lesions are applied to the LA endocardium in a manner similar to intraoperative ablation. Thus, despite being significantly less invasive, catheter ablation within the LA has also recently been associated with esophagus damage and left atrioesophageal fistula formation. Recent case reports have described at least 2 occurrences of left atrioesophageal fistula formation and estimate an incidence of <0.01%.[2]

Although this incidence of left atrioesophageal fistula appears to be low, the consequences remain devastating and often fatal. Even those patients who undergo successful repair often develop permanent neurological deficits from air emboli or profound sepsis from endocarditis. More importantly, no studies have consistently screened patients for evidence of esophagus damage or injury after LA ablation. Therefore, it is difficult to truly estimate the number of patients with non–life-threatening esophageal damage or injury, and this estimate of <0.01% may not represent the true prevalence of this phenomenon.

Recommendations have been made to move lesions from the mid posterior wall closer to the roof, where the LA wall tends to be thicker.[2] However, these recommendations have not yet demonstrated equal effectiveness in treatment of AF. Additionally, as this study demonstrates, there is significant variability in the anatomic course of the esophagus, and a generalized change in lesion location may not ensure safety or avoidance of areas near the esophagus. In fact, when imaged with carbonated liquids and ICE, the esophagus appears to lie along the entire vertical length of the LA (Figure 4).

An alternative strategy to prevent esophageal damage could be to consider a target temperature of 40°C to 45°C with the 8-mm-tip catheter. On the other hand, it is possible that a more conservative temperature setting may result in less effective lesions and higher recurrence rate. Suggestions, originally from surgical literature, recommend the reduction of power for lesions along the posterior wall of the LA.[2,8,10] However, the present data suggest that power alone is a weaker predictor of esophagus temperature than presence of microbubbles. This is consistent with the fact that more than 60 and 164 lesions with powers less than 35 and 50 W, respectively, generated esophagus luminal temperatures of >38°C (Figure 6). In fact, of the data reviewed, the presence of microbubbles during ablation near the esophagus was strongly predictive of increased esophagus temperatures even when accounting for multiple observations made within individual patients (Table 2; Figure 5). If power was limited and restricted with the appearance of microbubbles, no esophageal damage was seen. With this method, multiple lesions were delivered safely at the highest power (70 W). In contrast, esophageal lesions were documented only in the patient who underwent ablation by limiting power to 50 W and with a set temperature of 55°C without microbubble titration. In this case, the esophageal temperature exceeded 40°C (temperature range 40.0° to 44.2°C). In this respect, the present data could also suggest that esophageal temperatures higher than 40°C are required to generate esophageal wall damage. Monitoring of esophageal temperature would be an alternative approach to safe RF delivery in the posterior wall of the LA.

Study Limitations

Microbubble-guided RF delivery depends on constant adjustment of the echocardiographic window. In addition, temperature increase is seen even in the absence of microbubbles. However, the mean esophageal temperature was still significantly lower in lesions without microbubbles than in those with microbubbles.

Conclusions

These data demonstrate that lesions placed within the LA near the esophageal course significantly increase the luminal temperature of the esophagus from baseline. This is consistent with data that suggest that LA ablation can cause thermal injury of the esophagus. This thermal injury may subsequently lead to inflammation and potential fistula formation. With the anatomic variation of the esophagus course, the creation of a general lesion pattern or modification to avoid areas within the LA that are close to the esophagus may be difficult and perhaps may decrease the effectiveness of the procedure. The decreased ability to correlate power alone with increased temperatures within the esophagus raises concerns about how to prevent thermal injury of the esophagus. Continuous monitoring of the esophagus temperature and/or limiting RF power delivery on the basis of the effervescence of microbubbles may provide an option for making necessary posterior wall lesions safe.

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