

# Esophageal Injury and Temperature Monitoring During Atrial Fibrillation Ablation

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**Background**—It is common practice to empirically limit the radiofrequency (RF) power when ablating the posterior left atrium during atrial fibrillation ablation to avoid thermal injury to the esophagus. The objective of this study was to determine whether RF energy delivery limited by luminal esophageal temperature (LET) monitoring is associated with a reduction in esophageal injury compared with a strategy of RF power limitation alone.

**Methods and Results**—Eighty-one consecutive patients who underwent atrial fibrillation ablation followed by esophageal endoscopy were included in this observational study. All patients underwent extraostial electric pulmonary vein isolation by using an electroanatomic mapping system and irrigated RF ablation. All RF applications on the posterior left atrium were limited to 35 W. A commercially available, single-thermocouple esophageal probe was used to monitor LET in a subset of patients (n=67). In these cases, applications were promptly interrupted when LET was  $\geq 38.5^{\circ}\text{C}$ ; further applications were performed at reduced power to obtain a LET  $< 38.5^{\circ}\text{C}$ . Esophageal endoscopy was performed 1 to 3 days after the procedure. Ablation-related esophageal ulcerations were identified in 9 of 81 (11%) patients. All patients were asymptomatic. Of these 81 patients, LET monitoring during ablation occurred in 67 (83%) of patients. Esophageal injury was observed more frequently (36% versus 6%,  $P < 0.006$ ) in the group without LET monitoring.

**Conclusions**—These data suggest that LET monitoring may be associated with a reduction in esophageal injury compared with power limitation alone. (*Circ Arrhythmia Electrophysiol.* 2008;1:162-168.)

**Key Words:** catheter ablation ■ fibrillation, atrial ■ complications

Radiofrequency (RF) catheter ablation of atrial fibrillation (AF) has become a common ablation procedure performed worldwide.<sup>1</sup> The cornerstone of this procedure is the placement of ablation lesions around the pulmonary vein (PV) ostia to isolate AF triggers. RF lesions extending beyond the atrial myocardium may result in collateral damage to adjacent structures, including the esophagus.<sup>2-7</sup>

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Left atrial-esophageal (LA-Eso) fistula formation is now a well-recognized complication of percutaneous AF ablation, with an estimated incidence of approximately 0.1%. Although less prevalent than reported in the surgical literature,<sup>8</sup> this complication remains devastating, with significant morbidity and mortality.<sup>1,4-7</sup> Although the pathophysiology is not fully understood, it is clear that thermal injury to the esophagus during ablation of the LA posterior wall plays a crucial role in triggering the cascade of events that eventually result in the development of LA-Eso fistula.<sup>8-10</sup>

Currently, the most commonly used clinical strategy to minimize esophageal thermal injury during AF ablation involves limiting the magnitude of power (25 to 35 W), as well as the duration ( $< 30$  s), of RF applications placed along the posterior wall of the LA.<sup>11-13</sup> A major limitation of this approach is that it fails to account for the variability in the thickness of the posterior LA wall and the presence of periesophageal connective tissue—important determinants of esophageal heating.<sup>7,14,15</sup> Thus, empirically limiting the power and duration of RF applications may be insufficient to prevent esophageal thermal injury in all patients. The aim of this study was to determine whether RF power delivery during AF ablation guided by luminal esophageal temperature (LET) monitoring is associated with less frequent esophageal injury compared with a strategy of power limitation alone.

## Methods

### Patients

Eighty-one consecutive patients with symptomatic, drug-refractory AF who underwent AF ablation followed by a postprocedural,

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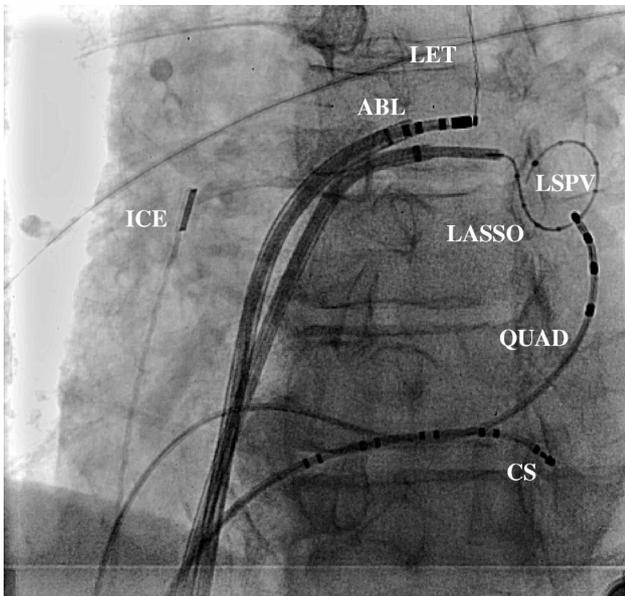
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**Figure 1.** Location of LET probe in relation to ablation catheter. ICE indicates intracardiac echocardiography catheter; LET, luminal esophageal temperature probe; CS, coronary sinus catheter; QUAD, reference quadrapolar catheter placed in the coronary sinus for NavX (St. Jude Medical); ABL, ablation catheter; LASSO, 20-mm Lasso catheter (St. Jude Medical); LSPV, left superior pulmonary vein.

non-symptom-driven esophageal endoscopy (EGD) within 3 days of the ablation procedure were included in this observational study. Patients were identified between October 2006 and November 2007 at the Massachusetts General Hospital, Boston, MA, and the Saint John's Health Center, Santa Monica, CA. All patients provided verbal and written consent for both procedures according to institutional guidelines. The study was approved by the research ethics board of each institution.

Patient demographics (age, sex, body mass index), disease characteristics (paroxysmal AF, normal heart, ejection fraction, LA size, previous AF ablation), and medication use (current use of antiarrhythmic drugs, aspirin, and proton pump inhibitor or histamine-2 receptor antagonist) were obtained.

### Monitoring Esophageal Temperature

In patients who underwent LET monitoring, a 9F single-thermocouple esophageal temperature probe (Vital Temp, Vital Signs Colorado Inc.) was inserted nasally and advanced into the esophagus under fluoroscopic guidance to a position directly posterior to the LA. The position of the tip of the temperature probe was continuously verified by fluoroscopy throughout the procedure and was adjusted in a craniocaudal fashion to the level of the ablation catheter before the application of each ablation lesion to ensure that the thermometer tip was positioned as close as possible to the RF ablation catheter tip (Figure 1). Continuous real-time esophageal temperature monitoring was performed and recorded throughout each case.

### PV Isolation

Conscious sedation or general anesthesia was available for each case and was used according to the patient's preference and physician's discretion. Ablation procedures were performed by operators with experience in AF ablation (AD, SD, TM and VR). All patients underwent a preprocedural computed tomography or magnetic resonance imaging scan of the LA. A transesophageal echocardiogram was performed on the day of the procedure when clinically indicated. Double transseptal punctures were made in all patients. Intravenous unfractionated heparin was administered in boluses immediately

prior and subsequent to the transseptal punctures, followed by an infusion to maintain an activated clotting time of 250 to 350 s. Intracardiac echocardiography (AcuNav, Siemens) was frequently used to guide transseptal puncture. An electroanatomic map of the LA and PVs was created with the CARTO (Biosense Webster) or NavX/ESI (St. Jude Medical) navigation systems. Of note, in no case was the image of the esophagus obtained on a preprocedural computed tomography or magnetic resonance imaging segmented or displayed.

RF pulses were delivered circumferentially around each vein pair approximately 1 cm from each PV ostium; additional linear lesions were placed, and ablation of fractionated potentials was performed at the operator's discretion. RF energy was delivered at the lesions by using a 3.5-mm externally (Thermocool, Biosense Webster) or 4-mm internally (Chili, Boston Scientific) irrigated catheter. The RF generator (Stockert, Biosense Webster) was set to deliver RF energy of up to 35 W and 40°C.

RF applications were terminated when the LET exceeded 38.5°C in patients with LET monitoring. Subsequent lesions in the adjacent areas were ablated with reduced power to avoid further temperature elevation. The maximal LET for each patient was documented with the average power and duration of ablation for the corresponding RF lesion.

### Esophageal Evaluation/Follow-Up

All patients underwent a non-symptom-driven EGD between 1 and 3 days after procedure. Ulceration was attributed to AF ablation if it was located on the anterior wall of the midesophagus (approximately 20 to 30 cm from the incisors) and was adjacent to the pulsating heart. These findings were confirmed by the gastroenterologist who performed the EGD (who were blinded to the use of LET monitoring). All patients with ulcerations were treated with high-dose proton-pump inhibitor therapy for at least 1 week, and all underwent repeat endoscopy after 1 week to ensure ulcer healing. Any additional follow-up was scheduled at the discretion of the gastroenterologist.

Typically, the day after the procedure, patients were discharged on anticoagulation with warfarin (target international normalized ratio of 2.0 to 3.0) for at least 3 months after ablation. Preablation antiarrhythmic drugs were generally maintained for 4 weeks after the procedure. Patients were seen in the outpatient clinic for follow-up at 6 weeks and 3 months after procedure. AF recurrences were documented with electrocardiograms, Holter, or transtelephonic monitoring. The presence of esophageal ulceration, postprocedure pericarditis, or pericardial effusion, and AF recurrence at 3 months was ascertained for each patient.

### Statistical Analysis

Patients were divided into two groups: those with and without LET monitoring. The primary end point of the study was the presence of esophageal ulceration on EGD. Continuous variables were reported as mean  $\pm$  SD, and distribution of discrete variables were reported as percentages for each group. Means of continuous variables were compared with the Student *t* test. Two-by-two contingency tables were created for discrete variables, and frequencies were compared using Fisher's exact test when any cell within the table contained a value  $\leq 5$ ; the  $\chi^2$  test was used in all other cases. The strength and direction of the association between LET and RF power applied were quantified using Pearson's correlation coefficient. Probability values  $<0.05$  were considered significant. All statistical analyses were performed with SAS version 9 (SAS institute, Cary, NC). The authors had full access to the data and take responsibility for its integrity. All authors have read and agree to the manuscript as written.

## Results

### Patient Characteristics

The mean age of the cohort (81 patients) was  $58 \pm 11$  years, 74% were male, and 44% had paroxysmal AF with an

**Table. Univariate Analysis Comparing Patients With and Without Luminal Esophageal Temperature Monitoring (LET)**

	LET Monitoring (n=67)	No LET Monitoring (n=14)	P
Demographic information			
Age, mean±SD	57±11	61±11	0.2
Male, %	70	86	0.2
Body mass index	31±6	28±3	0.05
History of gastroesophageal reflux disease, %	9	14	0.62
Disease characteristics			
Paroxysmal AF, %	42	50	0.6
Duration of AF, y, mean±SD	5±4	4±4	0.5
Structurally normal heart, %	66	64	0.7
Ejection fraction, %, mean±SD	60±9	61±7	0.8
LA size, mm, mean±SD	44±9	42±5	0.3
Redo AF ablation, %	21	14	0.8
Medication use			
Current No. of AAD	1.6±0.8	2.1±0.8	0.02
ASA, %	33	36	0.8
PPI or H2-antagonist, %	21	14	0.8
Procedural characteristics			
General anesthesia, %	13	43	0.01
Preprocedural transesophageal echocardiography, %	15	14	1.0
Intracardiac echocardiography, %	93	93	0.9
Preprocedure CT or MRI, %	97	100	0.7
Duration of RF ablation, s, mean±SD	3530±1420	4030±2240	0.3
Postprocedure complications			
Esophageal ulcer, %	6% (4/67)	36% (5/14)	0.007
Pericarditis/pericardial effusion, %	9	0	1.0
AF recurrence at 3 months, %	31	43	0.5

AF indicates atrial fibrillation; LA, left atrium; AAD, antiarrhythmic drugs; ASA, aspirin; PPI, proton pump inhibitor; H2, histamine 2 receptor; CT, computed tomography; MRI, magnetic resonance imaging; RF, radiofrequency.

average duration of AF of 5±4 years. The mean ejection fraction and LA size were 60±8% and 43±9 mm, respectively. The CARTO and NavX/ESI mapping systems were used in 78% and 22% of patients, respectively.

Sixty-seven patients (83%) underwent AF ablation with LET monitoring. Fourteen (17%) did not undergo LET monitoring: five (36%) because of difficulties in placing the LET probe within the esophagus and nine (64%) because of the operator's preference. LET monitoring was used with equal frequency throughout the study period and among all operators.

The Table displays the characteristics of the two groups. There were no significant differences between each group, with the exception that individuals without LET monitoring had a lower body mass index, used more antiarrhythmic drugs, and underwent ablation more frequently with general anesthesia.

### Esophageal Ulceration

Overall, nine patients (11%) in the cohort had esophageal ulceration on EGD (Figures 2 and 3). Esophageal ulceration

was more prevalent in the group without LET monitoring (36% versus 6%,  $P<0.006$ ). Ulcer formation was not clustered at any time during the study period or with a specific operator. Qualitatively, ulcerations in patients without LET monitoring appeared longer and linear (vertical) compared with ulcerations observed in patients with LET monitoring, which was discrete with a diameter between 3 and 10 mm. All patients with ulceration were asymptomatic, treated with high-dose proton pump inhibitor, and demonstrated ulcer healing on follow-up EGD at 1 week. No patient developed a LA-Eso fistula.

### Esophageal Temperature

Esophageal temperature recordings for 67% (45/67) of patients with LET monitoring were recorded and reviewed. Despite stopping RF energy when the LET was 38.5°C, the LET continued to rise to ≥39°C at least once in more than half of the study cohort (53% [24/45]; maximum recorded LET=41.9°C). There was no clear relationship between the maximal esophageal temperature recorded (Figure 4) or number of elevated LET recording (Figure 5) in the patients with and without esophageal ulceration. A trend toward more esophageal ulceration was noted in patients with maximal LET ≥39°C (75% versus 54%,  $P=0.4$ ).

### RF Power and LET

No correlation was observed between LET and the average RF power applied to the corresponding lesion ( $r=0.1$ ,  $P=0.2$ ; Figure 6). In patients requiring reductions in RF power, elevated LET often continued to be present with subsequent RF applications. Of all applications resulting in an LET ≥38.5°C (n=101), 34% occurred at a power of ≤20 W, including 8% at a power ≤10 W.

### Other Adverse Events

A statistically significant difference was not observed between the two groups in the incidence of postprocedure pericarditis or pericardial effusion and AF recurrence at 3 months. No complications associated with LET probe placement were observed in the cohort of patients who underwent LET monitoring.

### Discussion

This study suggests that temperature monitoring during AF ablation may be associated with a reduction in esophageal injury.

### Esophageal Injury Associated With AF Ablation

The mechanism of esophageal injury during RF ablation is not clear but hypothesized to be secondary to thermal injury related to conductive heating.<sup>11–13</sup> It has been suggested that the muscular layer of the esophagus absorbs most of the heat and is most susceptible to injury.<sup>8,12</sup> Injury to this area may result in reduced esophageal elasticity producing symptoms of dysphagia.<sup>4</sup>

Aupperle et al<sup>12</sup> systematically evaluated esophageal injury in sheep undergoing AF ablation. Twenty-four (62%) sheep demonstrated histological evidence of post-AF ablation esophageal injury, which occurred predominantly in the periesophageal and outer esophageal muscular layers. Only one animal had visible evidence of esophageal injury.

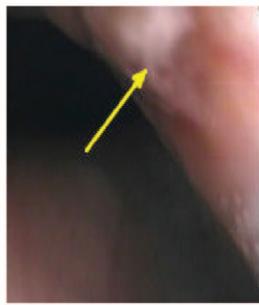
Patient	A:	B:	C:	D:
				
Max. Temperature	36.5°C	39.2°C	39.6°C	40.6°C
# of T > 38.5°C	0	1	2	4
Location of ulcer	26cm from incisors	29cm from incisors	25-30cm from incisor	30-35cm from incisors
Lesion description	3 mm in diameter	3 mm in diameter with red spot on wall opposite to the ulcer	small ulceration	Patchy mucosal ulceration and erythema

Figure 2. Esophageal ulceration in patients with luminal esophageal temperature monitoring.

To our knowledge, three human studies have attempted to evaluate the presence of esophageal injury associated with AF ablation. Cummings et al<sup>13</sup> performed an EGD on 16 patients who underwent AF ablation with an 8-mm nonirrigated catheter, with power titration guided by microbubbles formation on intracardiac echocardiography. No patient demonstrated esophageal injury on EGD within 24 hours after ablation. Marrouche et al<sup>16</sup> examined 28 patients with EGD post-AF ablation (14 underwent AF ablation with an irrigated tip catheter and 14 with an 8-mm nonirrigated catheter). Overall, 13 patients (48%) demonstrated EGD evidence of esophageal injury—5 (18%) developed ulceration and 8 (29%) erythema. Nakagawa et al<sup>17</sup> reported EGD findings on 16 patients who underwent AF ablation under general anesthesia with power limitation of 20 to 25 W in areas near the esophagus; nine patients (56%) developed esophageal ulcer-

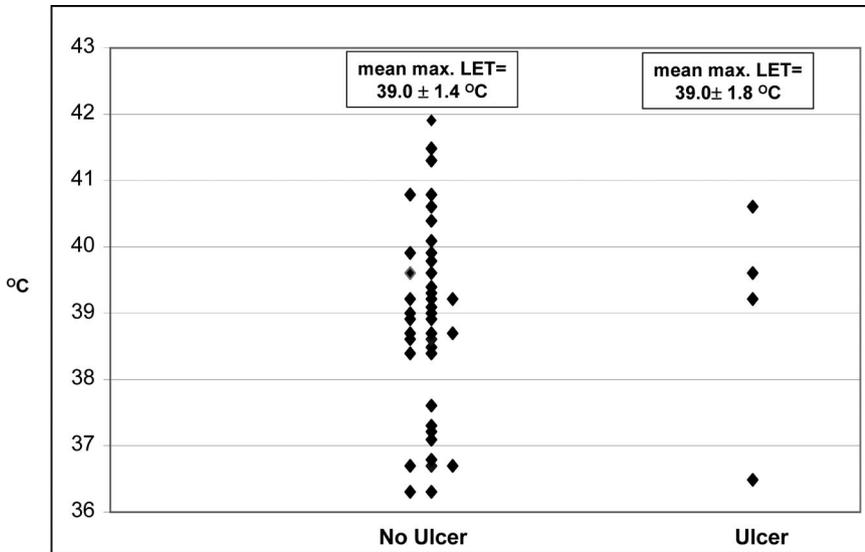
ation. Thus, the rate of AF-related esophageal ulceration during AF ablation is variable.

### Use of Esophageal Temperature Monitoring During AF Ablation

Continuous evaluation of the intraluminal esophageal temperature during the ablation procedure may prevent thermal injury. However, this approach has several limitations: (1) accurate intraluminal temperature monitoring depends on optimal contact between the probe and esophageal wall, which is difficult to ensure during the procedure; and (2) intraluminal esophageal temperature underestimates intramural thermal damage to the muscular layers of the esophagus. In addition, the complex anatomy of the esophagus (including the presence of transverse folds) and the malalignment of the LET probe at the region of ablation may result in a slow rise

Patient	A:	B:	C:	D:
				
Location of ulcer	30cm from incisors	17-23cm from incisors	35cm from incisors	30cm from incisors
Lesion description	Linear superficial ulcer with white exudates	Linear ulcer	Linear ulcer	Linear ulcer

Figure 3. Esophageal ulceration in four of five patients without luminal esophageal temperature monitoring. Note: images available for four of five patients. The fifth patient's ulcer was located at 30 cm from the incisors and 5 to 6 mm in diameter.



**Figure 4.** Maximum luminal esophageal temperature (LET) recording (n=45 patients with documented LETs).

in temperature, with ensuing esophageal injury occurring at otherwise acceptable LETs.

Because of the inherent limitations of LET monitoring, LET was not used to titrate power up in our study. Rather, LET was used simply to ensure that the power settings thought to be safe would not result in undesired high esophageal temperatures. Thus, intraluminal esophageal temperatures were used to interrupt RF applications prematurely if high esophageal temperatures ( $\geq 38.5^{\circ}\text{C}$ ) were detected at a given power and subsequently titrate power down with additional RF applications. In this regard, this study is important, as it suggests that LET monitoring may confer additional protection from esophageal thermal injury as compared with a strategy of power limitation alone. This is of particular importance because 34 of 101 RF applications with resulting  $\text{LET} \geq 38.5^{\circ}\text{C}$  occurred despite a reduction in power to  $\leq 20$  W (Figure 6). High LETs were also noted despite power applications of  $< 10$  W, suggesting that in certain patients, thermal injury may occur despite significant reductions in RF power. These findings suggest value for LET monitoring during AF ablation.

In patients who underwent LET monitoring, a clear relationship between the maximum LET and number of LET

$\geq 38.5^{\circ}\text{C}$  was not observed in those with and without ulceration. Despite this finding, we suspect that the protective benefit of LET monitoring still lies in its ability to detect elevated LET. We hypothesize that empirical ablation of the posterior LA at a constant RF power of 35 W may result in frequent undetected elevations of LET with ensuing esophageal thermal injury, whereas prompt identification of elevated LET during RF ablation in the posterior LA with subsequent down-titration of power to avoid continuous elevated LET may minimize this injury. Although difficult to prove, the presence of longer linear ulcerations in patients without LET monitoring, compared with the discrete ulcerations in patients with LET monitoring, supports this hypothesis.

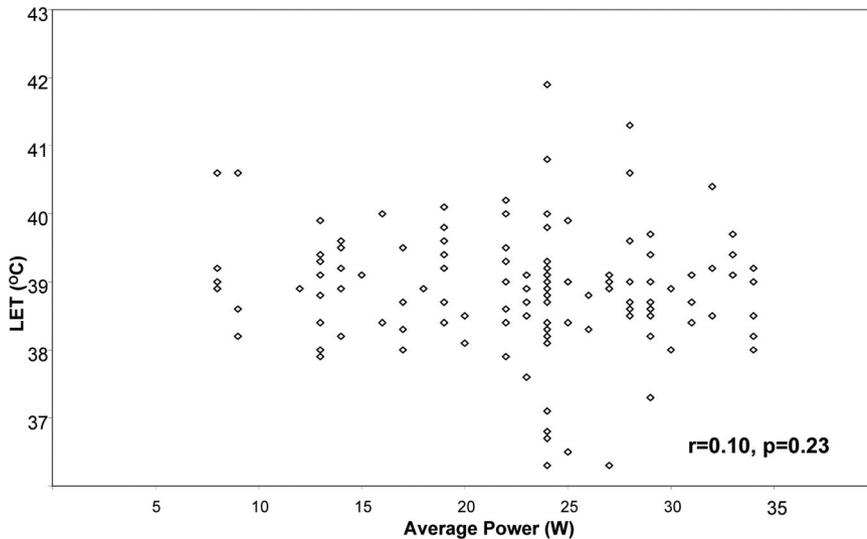
**Advantages and Limitations of LET**

Compared with alternative approaches to minimize esophageal injury, LET monitoring is straightforward, inexpensive, well tolerated, and may provide information on the risk of esophageal thermal injury independent of the RF application settings used during ablation.

The optimal LET threshold to avoid injury has not been defined, and must account for limitations in proper LET probe positioning, thermal latency, and the underestimation



**Figure 5.** Number of elevated luminal esophageal temperature (LET) recordings  $\geq 38.5^{\circ}\text{C}$  in 45 patients with documented LETs. (Note: Thirteen patients did not have a maximum  $\text{LET} \geq 38.5^{\circ}\text{C}$  and thus have 0  $\text{LET} \geq 38.5^{\circ}\text{C}$ .)



**Figure 6.** Correlation between average power applied and luminal esophageal temperature (LET) for maximum esophageal temperature and each esophageal temperature  $>38^{\circ}\text{C}$  (136 temperature points in 45 patients).

of mural temperatures with luminal recordings.<sup>18</sup> A LET cutoff of  $38.5^{\circ}\text{C}$  was empirically selected in this study based on our prior experience with LET monitoring during AF ablation. Although patients with a  $\text{LET} \geq 39^{\circ}\text{C}$  had a trend toward ulceration, we are unable to suggest a specific LET cutoff to end ablation lesions, as the maximal LET recorded is frequently higher than the LET at which ablation is terminated. Similar to the conclusions obtained by other investigators,<sup>11,13</sup> no relationship between RF power and LET was present.

Theoretically, the use of an LET probe is associated with its own risks, including traumatic insertion (with hematoma formation or perforation), aspiration, and patient intolerance. Although no complications of LET monitoring were noted in this study, probe placement was not possible in five patients. However, with increasing experience, it is possible to properly place the LET probe in most patients.

Titration of power and limiting ablation duration to rises in LET may result in the administration of short, low power RF lesions, which may theoretically reduce the efficacy of AF ablation. This was not supported in this study, as no difference in the rate of AF recurrence was noted at 3 months in both groups. Thus, a strategy of power titration guided by esophageal temperature monitoring does not compromise on efficacy for safety.

### Alternative Esophageal Protective Strategies

Alternative strategies described to avoid esophageal injury during AF ablation have included visualization of the esophagus with an enteral feeding tube, barium paste, or electroanatomic mapping,<sup>19,20</sup> cooling of the esophagus to counter RF ablation-associated increases in esophageal temperature,<sup>21</sup> and using cryoablation rather than RF energy.<sup>22</sup> However, the effectiveness of these approaches on minimizing esophageal injury has not been thoroughly studied.

### Study Limitations

Our study has several limitations. First, this was an observational, nonrandomized study, and hence, unmeasured confounding factors may be present and not accounted for. Second, the sample size was small and unbalanced between the two groups, thereby reducing the statistical power to

ascertain the role of additional clinical and procedural factors (such as the use of general anesthesia) in the development of esophageal injury. However, this is the largest series of its kind assessing the use of LET during AF ablation as well as systematically evaluating for esophageal injury after ablation. Moreover, despite the small sample size, our results are statistically significant. Third, the end point of visible esophageal mucosal injury may result in an underestimation of true incidence of esophageal injury, which may be microscopic<sup>12</sup> or limited to the muscular layer.<sup>8,12</sup> Estimating the periesophageal and muscular injury to the esophagus can only be adequately performed at autopsy, which is not feasible for a human study of this nature. In addition, we believe that the outcome of interest (ie, visible endoscopic esophageal injury) is clinically relevant. Fourth, the distance between the left atria and the esophagus was not accounted for in this analysis. Although the total tissue thickness between the esophagus and LA is an important factor determining esophageal injury,<sup>15</sup> computed tomography analyses have suggested a close relationship of the posterior LA and esophagus in virtually all patients.<sup>23</sup> Moreover, adjusting for patient's body mass index did not result in any additional protection from esophageal ulceration.

The strengths of this study include its size (which is the largest study of its kind to date), complete follow-up, the simple intervention examined, and the clinically relevant end point reported.

### Clinical Implications

Although limiting RF power titration and ablation duration in response to esophageal temperature  $\geq 38.5^{\circ}\text{C}$  does not eliminate AF ablation-associated esophageal injury, these data suggest that it may be associated with reduced esophageal injury. As the frequency of LA-eso fistula is approximately 0.1%, it would be extremely difficult to prove that this strategy reduces this complication; however, the reduction of collateral damage to the esophagus remains significant.

### Conclusions

These data demonstrate an association between esophageal temperature monitoring and a reduction in esophageal injury during AF ablation and is suggestive of a potential role for

LET monitoring during AF ablation. Further studies are needed to confirm these findings, as this intervention may be beneficial during AF ablation.

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### Disclosures

None.

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### CLINICAL PERSPECTIVE

The close proximity of the esophagus to the posterior left atrium creates the potential for thermal injury during radiofrequency ablation of atrial fibrillation. Although rare, cases of atrial-esophageal fistulas have been reported and are often fatal. Limiting radiofrequency power and duration during ablation at the posterior left atrium is one strategy that has been suggested to reduce the risk of esophageal injury. However, this strategy may not account for variability in the thickness of the left atrial wall and periesophageal tissue, which affect the extent of esophageal heating. To assess the utility of esophageal temperature monitoring to minimize esophageal thermal injury, routine endoscopy was performed after catheter ablation. In this nonrandomized study, esophageal injury was more common in those patients without intraprocedural temperature monitoring. These results are suggestive of a reduction in esophageal injury with the use of esophageal temperature monitoring.

# Correction

In the article, “Esophageal injury and temperature monitoring during atrial fibrillation ablation,” by Singh et al, which appeared in the August 2008 issue of the journal (*Circ Arrhythm Electrophysiol.* 2008;1:162–168), the wrong DOI was displayed.

The correct DOI for this article should be 10.1161/CIRCEP.108.789552.

The publisher regrets this error.

The online version of the article has been corrected.

## Esophageal Injury and Temperature Monitoring During Atrial Fibrillation Ablation

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