Comparison between single- and multi-sensor oesophageal temperature probes during atrial fibrillation ablation: thermodynamic characteristics

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Aims
Oesophageal temperature monitoring with single-sensor probe (SSP) has a variable ability to predict oesophageal ulceration as a consequence of pulmonary vein isolation (PVI). Multi-sensor self-expandable probes (MSPs) may offer improved thermal monitoring. The objective of this study was to compare the thermodynamic characteristics of both probes during PVI.

Methods and results
This prospective study enrolled 20 patients undergoing index PVI. Ten patients (group A) underwent dual monitoring with SSP and MSP and 10 control patients (group B) were monitored with SSP alone. Time to initial rise (>0.2°C), time to 1.0°C rise, peak temperature, and decay were recorded with each posterior wall lesion (20 W, 198 applications). The operator was blinded to the MSP temperature data and ablation was only interrupted when SSP temperature increased by ≥2°C. All patients underwent endoscopy within 24 h. Initial temperature increase was detected earlier with MSP (13.4 ± 7.5 vs. 30.5 ± 15.4 s; P < 0.001); led to shorter time to 1.0°C rise (18.5 ± 10.1 vs. 32.1 ± 12.0 s; P < 0.001); and higher change in peak temperature (1.6 ± 2.0 vs. 0.60 ± 0.53°C; P < 0.001). Decay time was similar between the probes (146.1 ± 35.3 vs. 150.4 ± 48.4 s; P = 0.89). The incidence of oesophageal ulceration was similar between the Groups A and B (5 and 4, respectively). Multi-sensor self-expandable probe provided greater sensitivity (100 vs. 60%) and similar specificity (60%) for detection of oesophageal ulceration. Five swine underwent oesophageal mapping before and after MSP placement without alteration in size or position.

Conclusion
Multi-sensor probes provide a superior thermodynamic profile. Its clinical value in reducing oesophageal injury requires further evaluation.

Keywords
Atrial fibrillation • Pulmonary vein isolation • Oesophageal temperature monitoring • Oesophageal injury • Single-sensor probe • Multi-sensor probe

Introduction
Radiofrequency (RF) catheter ablation of atrial fibrillation (AF) has become a common ablation procedure performed worldwide. The cornerstone of this procedure is pulmonary vein isolation (PVI). Energy delivery may extend beyond the atrial myocardium and result in damage to adjacent structures, including the oesophagus.¹–³ Atrio-oesophageal fistula (AEF) is a rare, but well-recognized complication of percutaneous AF ablation with an estimated incidence of 0.015–0.04%.²,³ Although the pathophysiology is not entirely understood, it is clear that thermal injury to the oesophagus during ablation of the posterior left atrial wall plays a crucial role in triggering a cascade of events that eventually results in the development of AEF.⁴–⁹
Common clinical strategies to prevent oesophageal injury include delivery of lower ablation energy along the posterior left atrium as well as the use of a luminal oesophageal temperature (LET) probe aimed to alert and guide energy delivery.\(^8\)\(^9\) Nonetheless, oesophageal injury is still common and AEF continues to be reported despite adherence to these guidelines.\(^10\)

A major limitation of LET monitoring stems from its variable proximity to the ablation site, as probes are difficult to position against the anterior wall of the oesophagus to face the ablation site during posterior wall left atrial ablation applications. This limitation may explain the limited relationship between oesophageal temperature and subsequent oesophageal ulceration.\(^6\)\(^\endnote{6} Multi-sensor expandable probes positioned into contact with the anterior oesophageal wall have been found to have a linear relationship between temperature and oesophageal ulceration in animal models.\(^6\)\(^11\)

The aim of this study was to compare the thermal characteristics of a standard linear single-sensor probe (SSP) with a multi-sensor self-expandable probe (MSP). We hypothesized that the MSP has a greater sensitivity to detect temperature gradients occurring within smaller oesophageal areas.

**Methods**

**Patient population**

This prospective, non-randomized study included 20 patients with symptomatic AF undergoing index PVI between October 2012 and December 2013. In 10 patients (group A), monitoring of oesophageal temperature was performed using a dual-probe approach with a standard linear SSP and a self-expandable MSP. In 10 additional patients (group B), oesophageal temperature was monitored only with the standard SSP in order to control for the possible interaction between the two probes, and specifically for the theoretical possibility that the expandable MSP will affect the SSP contact with the oesophagus. All patients underwent oesophagogastroduodenoscopy (EGD) the day after the ablation procedure. Table 1 summarizes the clinical characteristics of the study population. The research protocol was approved by the Institutional Review Board of the Beth Israel Deaconess Medical Center, and all patients provided written informed consent.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Group A (n = 10)</th>
<th>Group B (n = 10)</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (years), M ± SD</td>
<td>64.1 ± 6.5</td>
<td>58.9 ± 7.9</td>
<td>0.13</td>
</tr>
<tr>
<td>Male gender (%)</td>
<td>5 (50)</td>
<td>7 (70)</td>
<td>0.39</td>
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<tr>
<td>Hypertension, n (%)</td>
<td>5 (50)</td>
<td>5 (50)</td>
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<tr>
<td>Diabetes, n (%)</td>
<td>0 (0)</td>
<td>1 (10)</td>
<td>0.34</td>
</tr>
<tr>
<td>CAD, n (%)</td>
<td>0 (0)</td>
<td>2 (20)</td>
<td>0.17</td>
</tr>
<tr>
<td>OSA (%)</td>
<td>3 (30)</td>
<td>5 (50)</td>
<td>0.39</td>
</tr>
<tr>
<td>PAF (%)</td>
<td>5 (50)</td>
<td>4 (40)</td>
<td>0.67</td>
</tr>
<tr>
<td>LAD (mm), M ± SD</td>
<td>56.3 ± 5.0</td>
<td>58.0 ± 5.2</td>
<td>0.32</td>
</tr>
<tr>
<td>LVEF (%), M ± SD</td>
<td>55.6 ± 3.0</td>
<td>49.5 ± 10.7</td>
<td>0.11</td>
</tr>
<tr>
<td>BMI (kg/m²)</td>
<td>29.6 ± 4.5</td>
<td>30.9 ± 4.6</td>
<td>0.54</td>
</tr>
</tbody>
</table>

AF, atrial fibrillation; BMI, body mass index; CAD, coronary artery disease; LAD, left atrial diameter; LVEF, left ventricular ejection fraction; MSP, multi-sensor probe; OSA, obstructive sleep apnea; PAF, paroxysmal atrial fibrillation; RF, radiofrequency; SSP, single-sensor probe.

**Oesophageal temperature monitoring**

In group A, oesophageal temperature monitoring was performed using both a standard linear and non-deflectable SSP (Acoustoscope, Smiths Medical ASD, Inc.) and a self-expandable CIRCA S-Cath\(^{TM}\) MSP (CIRCA Scientific, LLC, Englewood, CO, USA). The 9F SSP was inserted orally and advanced into the oesophagus under fluoroscopic guidance to a position directly posterior to the left atrium. The probe was connected to a monitor and displayed temperature at a rate of 1 time per second. The 10F CIRCA S-Cath-S MSP has 12 temperature sensors spread over its double ‘S’ shaft configuration (Figure 1A). The probe is made of a soft and elastic material capable of expanding to a width of 18 mm in order to conform to the width of an adult oesophagus. Before insertion of the CIRCA S-Cath probe, a straight stylet is passed into the lumen of the probe to straighten the probe. The stylet is then inserted orally in a similar fashion to the standard SSP under fluoroscopic guidance to a position opposing the mid-posterior left atrial wall. The stylet is then removed and the probe conforms into the double ‘S’ configuration. The CIRCA S-Cath probe is connected to a separate monitor that displays the individual temperature of each sensor at a rate of 20 times per second. The position of the MSP was not changed throughout the ablation procedure, while the position of the SSP was continuously re-adjusted in both cranio-caudal and anterior–posterior fashions in an attempt to ensure that the thermistor was positioned as close as possible to the RF ablation catheter tip and anterior to the MSP to improve contact with the anterior oesophageal wall (Figure 1B).

**Oesophageal temperature data collection**

Oesophageal temperature monitoring was performed during each posterior wall RF ablation application. Two research team members continuously recorded temperature data from each separate oesophageal probe. Data acquired during each ablation application included baseline...
temperature, time to initial rise (defined as $\geq 0.2^\circ C$ rise), time to 1.0 $^\circ C$ rise, time to peak temperature, peak temperature, and temperature decay to baseline. Importantly, ablation re-application was initiated only after oesophageal temperature had returned to baseline (defined as $\pm 0.1^\circ C$ from the initial temperature) in both probes to ensure data accuracy. Operators were blinded to MSP temperature result and used only data from the standard SSP for temperature monitoring and ablation delivery guidance. Ablation was interrupted if SSP temperature increased by $\geq 2^\circ C$. Oesophageal temperature data collection was similar in group B patients, although limited to SSP. Temperature data analysis was performed offline.

Endoscopic evaluation

All patients underwent EGD 1 day after the ablation procedure. A single experienced gastroenterologist who was blinded to patient’s study group and temperature result interpretation of all studies. Injury was attributed to ablation if it was located on the anterior wall of the mid-oesophagus ($\sim 20$ to $30$ cm from the incisors). The EGD findings were classified into four injury grades: (i) absent; (ii) superficial; (iii) superficial with ulceration; and (iv) superficial with haemorrhage, as previously described. In cases of thermal injury, the mucosal injury diameter was measured and reported as either smaller or larger than 5 mm. Injury patterns with ulceration or haemorrhage were considered to be a definitive marker of thermal injury.

Swine experiment

Anatomic mapping of the left atrium and oesophagus was performed with Carto 3 (Biosense Webster, Inc.) to determine whether placement of the self-expandable CIRCA S-Cath probe affects the oesophagus width, volume, position, and/or relationship to the left atrium. In five anaesthetized Yorkshire pigs weighing 35–50 kg, mapping of the oesophagus and left atrium was performed using a 3.5 mm mapping catheter with contact force capabilities (Thermocool Smart Touch, Biosense Webster). Mapping of the structures was limited to a contact force range between 5 and 10 g to ensure adequate contact without distortion of wall borders. This swine size was selected to closely resemble the human adult oesophageal dimensions. Fluoroscopy was used to validate the cranial and caudal ends of the oesophagus in relationship to the superior and inferior aspects of the cardiac silhouette. Mapping was performed before and after insertion of the CIRCA S-Cath probe. Data were reviewed and analysed offline. In order to examine for change in oesophageal size, 30 equidistant width measurements were compared between the maps utilizing Carto measurement tools. In order to examine for potential displacement of the oesophagus, maps were superimposed on one another to determine the degree and vector of motion. The procedures were performed in the Beth Israel Deaconess Medical Center experimental electrophysiology laboratory and conformed to the Position of the American Heart Association on Research Animal Use as well as the Declaration of Helsinki. The protocol was approved by the institutional animal care and use committee.

Statistical analysis

Statistical analyses were performed with Stata/MP version 13 (Stata-Corp). Continuous variables were reported as mean $\pm$ SD, and distribution of discrete variables was reported as percentage for each group. Continuous variables were compared utilizing the Mann–Whitney–Wilcoxon test and categorical variables were analysed with the Fisher’s exact test. Temperature rise and decay slopes were calculated between designated data points ($x =$ time, $y =$ temperature increase) to determine the rate of temperature increase and the subsequent decay for each applicable lesion. Univariate Cox regression analysis was performed to assess correlation of clinical and temperature variables to thermal injury. Correlation coefficients of the oesophageal dimensions were calculated using linear regression analysis. $P$-values $<$ 0.05 was considered statistically significant. The correlation coefficients of the oesophageal dimensions were calculated using linear regression analysis.

Results

Patient characteristics

The baseline clinical characteristics of the cohort (20 patients) are summarized in Table 1. The mean age was $61.5 \pm 7.5$ years with $60\%$ men, and $45\%$ with paroxysmal AF. The mean ejection fraction and left atrial diameter were $52 \pm 8\%$ and $58 \pm 0.5$ mm, respectively. The mean body mass index (BMI) was $30 \pm 4.5$ kg/m$^2$. There were no statistically significant differences between the characteristics of the two groups.

Thermal characteristics

The differences in thermal characteristics between the probes were examined in study group A. The sensitivity to detect oesophageal temperature rise was higher with MSP compared with SSP (Figure 2). Of the 198 posterior wall ablation applications, temperature rise $\geq 0.3^\circ C$ was detected in 148 (74.7%) applications with the MSPs compared with only 57 (28.7%) applications with the SSP ($P = 0.001$). The MSP detected 93.8% of all temperature rises that were detected with SSP. Furthermore, the increased sensitivity of the MSP was more significant at temperature increase of $\geq 1.0^\circ C$ (41.4 vs. 8%; $P = 0.0001$) compared with temperature increases between 0.3$^\circ C$ and 1.0$^\circ C$ (33.3 vs. 20%; $P = 0.10$), presumably due to its improved tissue contact at smaller oesophageal areas. In a minority of cases (6.2%), the SSP detected temperature increase that was greater than the MSP recording. In these instances, the maximum temperature recorded was similar (SSP $37.8 \pm 0.4^\circ C$ and $37.7 \pm 0.3^\circ C$) between probes, but the SSP detected maximum temperature rise of $1.3 \pm 0.1$ vs. $0.7 \pm 0.3^\circ C$ with the MSP.

The thermal characteristics of the two probes showed a highly different dynamic profile. Initial temperature increase was detected

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**Figure 1** (A) Photograph of the multi-sensor 12-sensor, sinusoidal temperature probe without luminal stylet. The 12 sensors (arrow) are equally spaced and positioned to maximize contact with the oesophageal wall when deployed. (B) Fluoroscopy image in the right anterior oblique view of a patient in group A with the MSP and SSP (circle) within the oesophagus during a RF ablation application. The SSP was consistently positioned anterior to the MSP.
earlier with MSP (13.4 ± 7.5 vs. 30.5 ± 15.4 s; P < 0.001) and resulted in a shorter rise time to 1.0°C (18.5 ± 10.1 vs. 32.1 ± 12.0 s; P = 0.008). The rate of temperature rise was steeper with MSP compared with SSP (0.16 ± 0.18° vs. 0.08 ± 0.04° per second; P = 0.038). The overall mean peak temperature rise was also higher (1.6 ± 2.0 vs. 0.60 ± 0.53°C; P < 0.001). The temperature decay time was similar between the probes (146.1 ± 48.4 s; P = 0.89) as was the temperature decay slope (−0.014 ± 0.02 vs. −0.014 ± 0.01° per second; P = 0.22). The differences in the thermal dynamic profile between the probes were preserved over the spectrum of temperature rise (Figure 3) and were uniform among all patients (Figure 4). In addition, the thermal characteristics of the SSP were similar between Groups A and B for all the above measured parameters, suggesting its thermal profile is inherent rather than affected by the presence of MSP.

Posterior wall ablation application time was similar between both groups (group A 470.0 ± 107.6 s vs. group B 434.3 ± 96.41 s; P = 0.49).

As the MSP conforms into contact with the oesophageal wall, it may serve as a heat sink contributing to additional oesophageal heating. In order to examine this possibility, we compared the mean peak temperatures and the rate of decay recorded by the SSP in both study groups. The mean peak temperatures were similar (1.50 ± 0.43 vs. 1.65 ± 0.6°C; P = 0.31) as was the rate of temperature decay (0.015 ± 0.007 vs. 0.02 ± 0.009° per second; P = 0.08), suggesting that the presence of MSP in study group A did not act as a conductor or a heat sink.

### Oesophageal thermal injury

Overall, nine patients (45%) in the cohort had oesophageal ulceration identified on EGD. The two study groups shared similar frequency and severity of oesophageal lesions. In group A, five (50%) thermal injuries were identified while in group B, four (40%) thermal injuries were identified (P = ns). In group A, four injuries were classified as ulcerative and one haemorrhagic with three injuries <5 mm in

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**Figure 2** Bar graph detailing peak temperature increases with each probe for every RF application. The SSP detected significantly less temperature increases compared with MSP and the sensitivity of MSP to detect temperature rise was higher at temperature peaks ≥1.0°C.

**Figure 3** The thermal characteristics of SSP and MSP during RF energy application at four categorical ranges of temperature rises: 0.2–1.0, 1.0–2.0, 2.0–3.0, and >3.0°C. At all temperature increase ranges, a similar pattern in differences between the probes was observed: As compared to SSP, the initial temperature increase was detected earlier with MSP, it had a steeper rising slope, and led to increased peak temperature. The time to baseline was similar between the probes.

**Figure 4** The thermal characteristics of SSP and MSP during RF energy applications in each group A patients (patients 1–10). The data represent the correlating mean temperature changes between the probes for each patient. Multi-sensor probe showed improved dynamic profile with earlier detection of temperature rise, steeper rising slope, and peak temperature. The decay time was overall similar between the probes.
diameter and two injuries ≥ 5 mm in diameter. In group B, all four injuries were ulcerative with three injuries measuring ≥ 5 mm in diameter.

Clinical as well as thermal variables of each probe were examined in a univariate analysis to determine its effect on oesophageal ulceration (Table 2). No single variable independently correlated with oesophageal injury. We have also examined the combination of significant temperature increase, defined as the highest 20th percentile per patient, occurring in ≥ 3 consecutive ablation applications on occurrence of thermal oesophageal injury. For MSP, all patients with thermal injury had a combination of ≥ 1.3 °C rise in at least four consecutive ablation applications. There were two patients who also met this criteria, but without thermal injury (sensitivity 100% CI: 0.48–1; specificity 60% CI: 0.15–0.94). Using similar criteria, SSP detected only three patients with oesophageal injury (sensitivity 60% CI: 0.18–0.86; specificity 60% CI: 0.15–0.94).

### Swine experiment

The effect of MSP on the oesophagus size and position was examined in five swine that underwent anatomical mapping of the oesophagus before and after placement of the oesophagus and LET monitoring.8,15 – 19 Luminal oesophageal imaging with integration to the 3D map, oesophageal layers. Although the incidence of AE fistula is low, it remains a catastrophic complication of AF ablation and lower grade oesophageal trauma. Insertion of the standard SSP was successful in all 20 patients, however, in few cases, the probe curled in the oropharynx and several attempts were required to advance the probe into the oesophagus.

### Discussion

In this study, we prospectively compared the thermal characteristics and safety profile of single and multiple sensors oesophageal temperature probes. The major findings of this study are: (i) MSP detects oesophageal temperature increase earlier than SSP; (ii) MSP has a steeper rate of temperature increase with earlier detection of peak temperature; (iii) MSP detects higher peak temperature; (iv) temperature decay time is similar between the probes; and (v) MSP has an excellent safety profile. Specifically, it does not displace the oesophagus or its relationship to the left atrium and does not act as conductor or heat sink.

The mechanism of oesophageal injury during RF ablation is not clear but hypothesized to result from thermal injury related to conductive heating.4,5 Thermal injury then initiates a cascade of pathophysiological events affecting the microvasculature of the oesophageal tissue leading to ischaemic necrosis of the mucosal layers. Although the incidence of AE fistula is low, it remains a catastrophic complication of AF ablation and lower grade oesophageal injuries are common.10,14

Efforts to prevent oesophageal injury have focused on pre-ablation oesophageal imaging with integration to the 3D map, oesophageal mucosal protection with proton pump inhibitors, mechanical displacement of the oesophagus and LET monitoring.8,15 – 19 Luminal oesophageal temperature monitoring remains the most clinically
practiced method to prevent oesophageal injury. Singh et al.8 were the first to demonstrate the association between oesophageal tem-
perature monitoring and reduction in oesophageal injury during AF
ablation. They performed a retrospective comparison of oeso-
phageal injury in patients undergoing PVI with and without LET mon-
toring. The group subjected to temperature monitoring with ablation
limited or interrupted when the temperature reached 38.5°C had a
significantly lower incidence of oesophageal injury compared with
the unmonitored group (6 vs. 36%). However, in the group of patients
with LET monitoring, no safety temperature cut-off value or number
of RF application producing an increase ≥38.5°C distinguished
patients with from patients without oesophageal injury. The lack of
relationship between LET and occurrence of oesophageal injury
has been related to the inability of single non-deflectable-sensor
probes to locate and measure the highest oesophageal tempera-
ture during ablation.6 Nakagawa et al.6,11 examined the relationship
between oesophageal temperature and injury in a canine model of
RF-induced thermal injury. An air-filled balloon was positioned in
the oesophagus to move the oesophagus close to the posterior
left atrium and temperature was measured by seven sensors
facing the left atrium. Oesophageal ulceration occurred consistent-
ly at LET ≥49.6°C while lower LET did not result in oesophageal
injury. Importantly, in these canine studies, the highest LETs and
their associated steep gradient were restricted to very small
areas that are likely to be missed with single-sensor temperature
probes.

Several studies examined the possible effect of MSPs on oesopha-
geal thermal injury following human AF ablation procedures. In an
observational study, Sause et al. used a three-thermocouple probe for
oesophageal temperature monitoring in 184 patients undergoing
left atrial ablation with an open-irrigation RF catheter. They limited
RF energy delivery when the luminal temperature reached 40°C
and performed EGD in all patients 1 day after the procedure. They
demonstrated an exceedingly low incidence of oesophageal injury
of only 1.6%.9 Another observational study examined the incidence
of oesophageal injury following PVI in a group of patients monitored
by MSP compared with historical data of patients monitored with
SSP.20 Similar to our results, they found that MSP recorded higher
peak oesophageal temperatures compared with SSP. An oeso-
phageal temperature ≥39°C was recorded in 75% of patients moni-
tored with MSP compared with only 39% of patients monitored
with SSP. Although thermal injury was more frequently detected
in the group monitored with MSP (45.5 vs. 28.8%), EGD was only
performed in patients who had peak oesophageal temperatures
≥39°C, thus subjecting a significantly higher percentage of patients
monitored with MSP to EGD. In our study, all patients underwent
EGD the day after the ablation procedure. We did not detect a
difference in the incidence of oesophageal thermal injury between
the two groups. In particular, the incidence of oesophageal injury
in group B monitored by SSP alone was 40% consistent with
established data.21,22

There has been concern regarding oesophageal displacement
more towards the left atrium with the use of expandable probes
due to the dynamic nature of the oesophagus. Should this occur,
the resultant anatomical shift may potentially increase the risk of
injury during ablation. We have therefore examined the effect of
the MSP on oesophageal volume and displacement in a swine
model with oesophagus dimensions similar to humans. We showed
that the oesophagus volume and width were not affected by the use
of CIRCA S-Cath MSP. In addition, we found that the 3D ana-
tomical position and relationship to the left atrium was unchanged.
These data suggest that the difference in thermal behaviour
between the MSP and SSP (i.e. rates of temperature rise and
decay) is largely inherent to probe design and not to anatomical dis-
placement. The animal data are also consistent with our human data
showing highly different thermal behaviours at fluoroscopically
proximate locations.

Although multiple sensors in contact with the oesophageal muscu-
lar wall can potentially act as heat sinks resulting in further heating of
the oesophagus, our data showed that both catheters had similar
decay time to baseline, suggesting that heat sink does not play a sig-
ificant role in the different thermal profiles of the probes.

This study did not identify a single variable that corresponded to
oesophageal ulceration. We examined multiple individual variables
that included initial temperature increase, rate of increase, maximal
temperature, rate of decay, and number of consecutive ablation
lesions resulting in temperature increase. However, the combination
of significant temperature increase (defined as the highest 20th
percentile per patient) occurring in consecutive ablation applica-
tions showed 100% sensitivity with 60% specificity using MSP but
only 60% sensitivity with 60% specificity using SSP. The only mildly
improved detection rate with MSP might have been related to the
small study size designed to compare the thermal characteristics
of SSP and MSP rather than the differences in detection rate. In addi-
tion, although this study demonstrated that MSP offers a superior
thermal dynamic profile, its significance in reducing the incidence
of oesophageal injury remains to be examined in a larger prospect-
ive study. It is also possible that the small differences in detect-
ion rate are still due to insufficient-sensor density in contact
with the anterior oesophagus, or alternatively due to patient ana-
tomical variations in the thickness of the posterior left atrium and
oesophagus.

Study limitations
The study cohort was small and while it allowed characterization of
the thermal profiles of the two probes, it was underpowered to
examine their comparative role in detection and prevention of oeso-
phageal injury. Although the SSP was continuously adjusted using
fluoroscopy and positioned as close as possible to the ablation site,
the presence of the MSP may have limited its contact with the anter-
or oesophageal wall. To account for this, we compared the thermal
characteristics (initial increase, peak temperature, rate of increase,
and decay to baseline) between the two study groups and found
them to be statistically similar, thus excluding a significant effect of
MSP on the SSP thermal profile. Although we found that placement
of MSP does not affect the oesophagus size or location in a swine
model, differences between swine and human must always be
considered.

Conclusions
Luminal oesophageal temperature monitoring is a commonly used
technique during AF ablation procedures aimed to decrease the
risk of oesophageal injury. In this study, we compared the thermal
Comparison of single- and multi-sensor temperature probes

Characteristics of single- and multi-sensor oesophageal probes and found that MSPs provide a superior dynamic profile allowing more frequent recognition of temperature increase with an earlier detection time, steeper rising slope, and higher peak temperature. The clinical utility of multi-sensor in further reduction of oesophageal injury requires a larger randomized and prospective study.

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References