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Luminal esophageal temperature monitoring to reduce esophageal thermal injury during catheter ablation for atrial fibrillation: A review

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ABSTRACT

Over the past decade, catheter ablation for atrial fibrillation has emerged as an important rhythm control strategy. One of the most dreaded complications of this procedure is atrio-esophageal (AE) fistula formation, which is relatively rare but usually fatal. Esophageal tissue injury during ablation appears to be a precursor to the formation of AE fistulae. Luminal esophageal temperature (LET) monitoring is one of the most commonly utilized strategies to mitigate this risk, despite little evidence that it reduces esophageal injury. The incidence of AE fistulae appears to be on the rise, despite the widespread use of LET monitoring. This may be due to the advent of improved large lesion technology including force-sensing catheters and the use of high power, although AE fistulae have also been observed with the use of low power along the left atrial posterior wall. Currently available discrete sensors probes, whether single or multiple, do not appear to significantly reduce injury rates. The purpose of this manuscript is to systematically review the incidence of esophageal thermal injury with and without LET monitoring and review the factors that may be associated with increased risk of injury.

Introduction

Catheter ablation has become a common treatment for drug refractory atrial fibrillation (AF) and a rapidly increasing number of ablation procedures is being performed as indications expand [1]. Circumferential ablation with antral pulmonary vein isolation remains the cornerstone of most ablation strategies [1]. Lesions may also be created at additional sites in the atria believed to be critical in the initiation or maintenance of atrial fibrillation. Regardless of approach, ablation along the left atrial posterior wall remains a central component of current AF ablation strategies [1]. The esophagus is located in close proximity to the posterior left atrium, and thus ablation in that vicinity may cause collateral damage to the esophagus resulting in complications such as peri–esophageal nerve injury, esophageal ulceration or atrio-esophageal (AE) fistulae [2,3]. Atrio-esophageal fistula is believed to be a relatively rare complication, with an estimated incidence of 0.03–0.11% [4–6], however the true "real-world" incidence is unknown and likely exceeds these estimates. This complication carries significant clinical impact because AE fistulae are often fatal with mortality rates > 80% [5]. Recent clinical studies [7] provide direct evidence that esophageal injuries in patients can evolve to lethal fistula, thus confirming the mechanism initially proposed in preclinical studies [8].

A reduction in the frequency of esophageal thermal injury would be expected to lead to a decrease in the incidence of AE fistulae. Thus, it follows that a strategy of luminal esophageal temperature (LET) monitoring during ablation should enable detection of esophageal temperature rises and early termination of energy delivery before thermal injury occurs. As such, LET monitoring is expected to reduce the incidence of esophageal ulcerations and fistulae, and is commonly employed during AF ablation. Approximately 65% of the AF Ablation Consensus Statement committee members utilize some form of measurement of LET despite scant and conflicting evidence that this approach actually results in decreased risk of esophageal injury [1].

The purpose of this manuscript is to present a state-of-the-art clinical review of LET monitoring and its effect on prevention of esophageal thermal injury.

Assessment of efficacy for prevention of atrioesophageal fistulae

Assessment for esophageal fistulae is not a practical endpoint for efficacy due to its relative rarity and late presentation. Esophageal thermal injury, however, is quite common occurring in up to 47% of patients following pulmonary vein iso-

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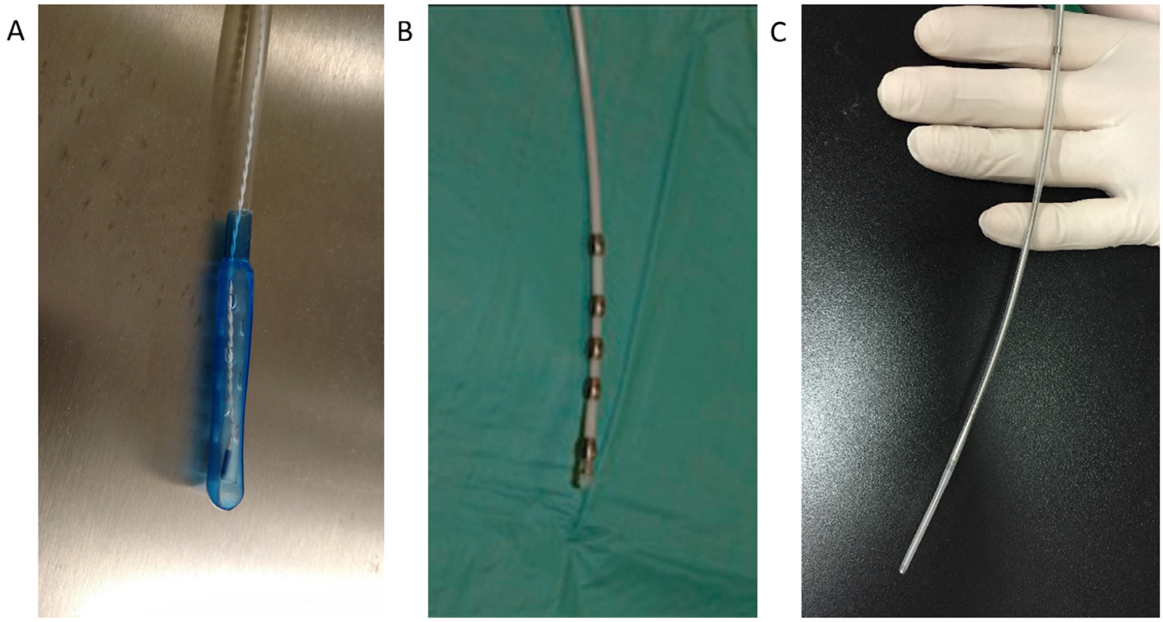

Fig. 1. Different types of luminal esophageal temperature probes in clinical use.
Examples of discrete single sensor (Smiths Medical, Dublin, OH, USA) and multi-sensor (Sensitherm™, FIAB, Italy) probes are shown in panels A and B respectively. An infrared thermography probe (Securus, Cleveland, OH, USA) with similar 9F diameter is shown in panel C.
Photo from panel B modified from Muller et al. Heart Rhythm. 2015;12(7):1464–9.

lation [9,10]. While ulcerations due to ablation often have a characteristic appearance on endoscopy, erythematous thermal lesions must be differentiated from other etiologies such as trauma from pre-procedure transesophageal echo and other incidental pathologies [11].

In an animal model of esophageal thermal injury, ulceration was a prerequisite for fistula formation [12]. Similarly in a large clinical series of AF ablation patients undergoing endoscopy, esophageal perforation occurred only in patients with thermally-induced ulcers noted on post-procedure endoscopy [7]. Thus, acute esophageal tissue damage after ablation appears to be a reasonable surrogate marker for the potential development of long-term AE fistulae because an AE fistula is not likely to develop in the absence of visible tissue injury.

LET monitoring catheters in clinical use

There is wide variability of the types of catheters in clinical use. Most clinically used esophageal temperature probes utilize thermistors; however, thermocouples are also used as sensors. Thermistors generally contain a metal oxide sensor, the resistance of which decreases with increasing temperature. Thermocouples work from the principle that the junction of two different metals creates a measurable voltage that increases with temperature. In both types of sensors, the mass of the sensor must be heated or cooled by intervening tissue or air contacting its surface before temperature change can be detected. Currently used probes consist of either a single sensor that can be moved as necessary during the procedure, or as a fixed array containing multiple sensors (see Fig. 1). More recently, a probe utilizing infrared thermography has been introduced, which provides instantaneous high-resolution temperature monitoring while scanning the esophageal surface without having to manually move the probe.

Impact of LET monitoring on rates of esophageal injury

A PUBMED database search revealed 16 series where EGD or video capsule endoscopy was performed and reported rates of esophageal thermal injury in patients following catheter ablation for atrial fibrillation using a single ablation and esophageal protection strategy (Table 1). Eleven studies were performed either without any esophageal temperature monitoring at all, or without incorporating the LET into the ablation strategy in any way. A wide range of esophageal injury rates (0–40%) was observed in these studies not guided by LET monitoring. In total, five other series reported on injury rates incorporating a strategy of limiting energy delivery based on LET monitoring. Generally, these studies stopped energy delivery when temperature rose by more than 2 °C or exceeded 39–40 °C using RF, or went below 5 °C using cryoablation. Despite the use of these cutoffs to limit ablation, esophageal thermal injury was still commonly observed (0–26%). These 16 series represent a very heterogenous group of studies with wide variation in both ablation and LET monitoring strategy. However, it appears that the guidance of ablation by temperatures obtained from discrete sensors in the esophagus does not appear to eliminate thermal injury during ablation, and may have comparable injury rates to that obtained without temperature monitoring.

Direct comparisons of ablation with and without LET monitoring

Seven additional studies reported on patients who underwent ablation both with and without LET-monitoring to limit ablation, with mixed results (Table 2). Six of the seven studies used probes with multiple sensors. All were nonrandomized.

Singh et al. compared AF ablation with and without LET monitoring among 81 consecutive patients. Exclusion from LET monitoring was due to operator preference or inability to pass the temperature probe. Radiofrequency applications on the posterior left atrium were delivered at 35 W. In the group with LET monitoring, energy delivery was terminated and power was reduced when temperature exceeded 38.5 °C. A reduction in esophageal ulceration was seen with LET monitoring using a single sensor probe (4/67, 6%) compared with no LET monitoring (5/14, 36%). Patients without LET monitoring, however, had lower BMI and were more likely to have their procedures performed under general anesthesia, factors that may be associated with increased risk of esophageal injury [13].

Table 1
Incidence of esophageal lesions during RF and cryoballoon ablation of AF.

	Author	*Year*	*N*	*Energy Source*	*Esophageal T Probe*	*LET strategy*	*Power Settings*	*Incidence of EI (%)*
Ablation cessation based on LET changes	Leite et al. [51]	2011	45	RF, OI	SSP	Stop if rise > 2 °C	25 W, 30 s	0
	DiBiase et al. [36]	2009	50	RF, OI	SSP	Stop if T ≥ 39 °C	35 W, 20 s	26
	DiBiase et al. [52]	2010	88	RF, OI	SSP	Stop if T ≥ 39 °C	35 W, 20 s	17
	Sause et al. [53]	2010	184	RF, OI	MSP	Stop if T ≥ 40 °C	30 W	2
Ablation procedure did not alter based on LET changes	Halm et al. [54]	2010	185	RF, OI	MSP	Did not alter based on LET	30 W, 30 s	15
	Knopp et al. [55]	2014	425	RF	MSP	Did not alter based on LET (EGD for T > 41 °C)	30 W	11
	Konstantinidou et al. [56]	2011	50	RF, OI	MSP	Did not alter based on LET	30 W	40
	Contreras-Valdez et al. [37]	2011	219	RF	SSP	Did not alter based on LET (EGD for T ≥ 39 °C)	25 W, 30 S	27
	Martinek et al. [57]	2010	267	RF, OI	None	Did not alter based on LET (43 °C max catheter T)	25 W, 30 s	2
	Yamasaki et al. [35]	2011	104	RF, OI/NI	None	Did not alter based on LET (43 °C and 52 °C max catheter T)	15–20 W, 30 s	4
	Zellerhoff et al. [10]	2010	29	RF, OI	None	Did not alter based on LET (48 °C max catheter T, stopped in response to pain)	20 W	0
	Daly et al. [31]	2018	16	RF	IT	Did not alter based on LET	20 W	13
Cryoballoon Ablation	Ahmed et al. [58]	2009	35	CB	SSP	Did not alter based on LET	1st gen; 23 and 28mm	17
	Furnkranz et al. [59]	2010	38	CB	MSP	Did not alter based on LET	1st gen; 28 mm	0
	Furnkranz et al. [61]	2013	32	CB	MSP	Stop if ≤ 5 °C	2nd gen	19
	Metzner et al. [60]	2013	50	CB	MSP	Did not alter based on LET	2nd gen; 28 mm	12

RF: radiofrequency, OI: open irrigation; SSP: single-sensor probe; MSP: multi-sensor probe; LET: luminal-esophageal temperature; EGD: esophogastroduodenoscopy; IT: infrared thermography; CB: cryoballoon; EI: esophageal injury.

Table 2
Incidence of esophageal lesions during AF ablation comparing LET monitoring to no monitoring.

Author	Year	N	Energy Source	Esophageal T Probe	LET strategy	Power Settings	Incidence of EI (%)
Deneke et al. [18]	2011	69	RF, PVAC	MSP	Stop if T ≥ 40 °C	PVAC (10 W)	LET 19% No LET 0%
Halbfass et al. [17]	2017	80	RF, OI	MSP	Stop if T ≥ 39 °C	25 W, 20 s	LET 7.5% No LET 10%
Kiuchi et al. [15]	2016	160	RF, OI	MSP	Stop if T ≥ 39 °C	20 W, 20 s	0% LET 7.5% no LET
Muller et al. [19]	2015	80	RF, OI	MSP	Stop if T ≥ 39.5 °C	25 W	LET 30% No LET 3%
Rillig et al. [16]	2010	42	RF, OI, RNS	MSP	Stop if T ≥ 39 °C	25 W	LET 14% No LET 14%
Singh et al. [13]	2008	81	RF, OI/CI	SSP	Stop if T ≥ 38.5 °C	35 W	6% LET 36% no LET
Tilz et al. [14]	2010	39	RF, OI, RNS	MSP	Stop if T > 41/43 °C	30 W or 20 W	10% LET 100% no LET

RF: radiofrequency, OI: open irrigation; SSP: single-sensor probe; MSP: multi-sensor probe; LET: luminal-esophageal temperature; PVAC: pulmonary vein ablation catheter; CB: cryoballoon; RNS: robotic navigation system.

Another small study using a multisensor probe showed high rates of esophageal injury when ablating with a robotic navigation system when using higher power on the posterior wall. In the first four patients, operators were blinded to LET while using 30 W on the posterior wall. All four developed esophageal ulcerations, including one perforation, which prompted reduction in power to 20 W and un-blinding to LET, with discontinuation of ablation for temperature > 41 °C. Using this new strategy of reduced power and LET monitoring in 10 subsequent patients, only 1 further ulceration was seen (10%) [14].

Similarly, Kiuchi et al. studied 160 patients with AF undergoing ablation with the aim of comparing the incidence of esophageal injury with and without esophageal temperature monitoring. Half of the patients underwent AF ablation with esophageal temperature monitoring, with ablation cessation occurring at temperatures > 39 °C. Endoscopy performed within 5 days of the procedure on all patients revealed a significantly lower incidence of injury in patients with temperature monitoring (0%) than without (7.5%) [15].

On the other hand, Rillig et al. reported on 42 patients who underwent endoscopy after AF ablation using a robotic navigation system, 7 of which could not have their multisensor probe passed for technical reasons. Power used was 25 W on the posterior wall and ablation was discontinued for temperature > 39 °C in the LET group. In this study, the rate of esophageal ulceration was identical in the group with LET monitoring (5/35, 14%) and without (1/7, 14%) [16]. A similar incidence of esophageal lesions was seen by Halbfass et al. where 80 patients underwent ablation using a force sensing catheter. A multisensory temperature probe was used in 40 patients and all patients underwent EGD within 1–4 days of ablation. The incidence of lesions was comparable, 7.5% and 10% in the groups with and without LET monitoring respectively [17].

Two other studies, both of which used similar multi-sensor probes, actually showed a marked increase in esophageal injury with LET compared with no LET monitoring [18,19]. In the first, rates of esophageal thermal injury were compared between 48 consecutive patients using LET monitoring, compared with 42 consecutive subsequent patients without an esophageal probe who served as control. In the LET group, ablation was discontinued for T > 40 °C and patients only underwent endoscopy if T exceeded 39 °C. In the LET group, esophageal injury was seen in 5/27 patients (19%), whereas none of the patients in the control group had thermal injury [18]. The authors inferred that the LET probe may be contributing to the thermal effect, possibly due to a changed flow of thermal energy secondary to the metal of the thermal probe. The metallic probes may alter the electric field creating focal areas of increased current density. In the second study, Muller et al compared 40 consecutive patients with and without LET monitoring. This time, ablation ceased for LET rises > 39.5 °C and all patients in the LET group underwent endoscopy, regardless of maximal LET. Again there was a marked increase in esophageal injury among patients who had LET monitoring; 12/40 patients (30%) in the LET group had injury vs only 1/40 (3%) in the control. The authors could not exclude any esophageal damage caused by insertion and/or manipulation of the temperature probe or trans-esophageal echo probe [19].

In these seven series directly comparing LET monitoring to no LET monitoring, variable results were seen but no clear reduction in esophageal injury was noted. This deduction is supported by a meta-analysis by Koranne et al. on 4 of the above studies that evaluated the role of esophageal temperature monitoring in preventing thermal esophageal injury. A total of 411 patients were included in the analysis with 8.9% of patients with thermal esophageal injury in the LET monitoring group and 6.8% with thermal injury in the no LET monitoring group. No statistical difference was seen between the two groups [20].

Comparison of single sensor versus multi-sensor probes

Single sensor probes are unlikely to sample the maximal esophageal temperature due to the distance between the sensor and the hottest point with relatively steep temperature gradients in esophageal tissue. This underestimation of the extent of esophageal heating may be one of the main reasons single sensor probes have shown lack of efficacy. Probes with multiple sensors might be expected to perform better in this regard. The efficacy of single sensor versus multi-sensor probes was compared head-to-head in two studies, one randomized and one nonrandomized and thermodynamic profiles compared in a third study. (Table 3).

Kuwahara et al. randomized 100 patients to ablation at 25–30 W with LET monitoring using a cutoff of 42 °C using a single sensor deflectable probe versus a multi-sensor (Sensitherm, St Jude Medical, Minneapolis, MN, USA) probe. They found no significant difference in esophageal injury rates between the groups (30 vs 20%, $p = 0.25$) [21]. Carroll et al. compared rates of esophageal lesions between single (Acoustascope, Smiths Medical ASD, Inc, Keene, NH, USA) and multi-sensor (Circa S-Cath, Circa Scientific, Park City, UT, USA) probes among 543 consecutive patients (455 with single and 88 with multi-sensor probe). Power of 25 W was delivered in the posterior wall and ablation was terminated if LET exceeded 38 °C. Only patients with maximal LET exceeding 39 °C underwent endoscopy. A significantly higher rate of esophageal ulceration was found with the multi- than single sensor probe (46 vs 29%, $p = 0.02$). They concluded that despite detecting more frequent temperature rises, multi-sensor probes may not be superior to single-sensor probes in preventing esophageal injury [22].

In a small study of 20 patients, Tschabrunn et al compared the thermodynamic profiles of a single-sensor probe (Smiths Medical, Minneapolis, MN) in 10 patients versus a multi-sensor probe (CIRCA Scientific, Englewood, CO) in 10 patients. Operators were blinded to data from the multi-sensor probe, but lesions were interrupted for a single-sensor probe LET increase of ≥ 2 °C. Compared with the single-sensor probes, multi-sensor probes detected initial LET rise (>0.2 °C) faster, had shorter time to 1 °C rise, and showed higher change in peak LET. Using a cutoff of LET rise of > 1.3 °C on four consecutive applications, they found multi-sensor probes to have greater sensitivity (100%) than single-sensor probes (60%) to predict esophageal injury, with the same specificity (60%) [23]. However, the two study groups shared a similar incidence of esophageal lesions (50% using single-sensor probes, 40% using multi-sensor probes).

These three studies indicate that despite greater sensitivity for detecting temperature rises with multi-sensor probes, a lower incidence of esophageal injury has not been achieved. In addition to the likely continued underestimation of maximal esophageal temperature, it has been hypothesized that some of the multi-sensor catheters may actually induce thermal injury. Catheters with stiff curves may cause esophageal distension towards the left atrium or fix the position of the esophagus preventing its movement away from the energy source [22]. Other catheters with large metal electrodes may serve as an antenna inducing more current flow to the esophagus [18].

Temperatures associated with esophageal thermal injury

The pathophysiology of esophageal thermal injury seen with atrial ablation is complex. In addition to the direct effects of full thickness thermal injury, ischemic injury to the esophageal microvasculature may result in an inflammatory reaction culminating with cell necrosis and apoptosis. Furthermore, thermal injury to peri–esophageal branches of the vagus nerve, which lie on the external surface of the esophagus, may result in complications of gastric hypomotility, acute pyloric spasm or gastroesophageal reflux [24], and potentially could occur without development of critical temperature rises within the lumen of the esophagus.

There is significant variability in the sensitivity of different tissues to thermal injury [25] and the temperature-time relationship needed to create esophageal thermal injury is unclear. Irreversible myocardial injury is generally believed to occur at temperatures above ∼50 °C [26–28]. The esophagus, however, is lined with protective stratified squamous epithelium, which may be somewhat resistant to thermal injury, and might be able to briefly withstand similar temperatures without irreversible injury. Routine consump-

Table 3
Incidence of esophageal lesions during RF of AF using sinle-sensor probes (SSP) vs multi-sensor probes (MSP).

Author	Year	N	Energy Source	Esophageal T Probe	LET strategy	Power Settings	Incidence of EI (%)
Carroll et al. [22]	2013	543	RF, OI	SSP/MSP	EGD if ≥ 39 °C	25 W, 30 s	29% SSP 46% MSP
Kuwahara et al. [21]	2014	100	RF, OI	SSP/MSP	Stop if T ≥ 42 °C	25–30 W	30% SSP 20% MSP
Tschabrunn et al. [23]	2015	20	RF, OI	SSP/MSP	Stop if SSP T increased by ≥ 2 °C	20 W	40% SSP 50% MSP

RF: radiofrequency, OI: open irrigation; SSP: single-sensor probe; MSP: multi-sensor probe; LET: luminal-esophageal temperature.

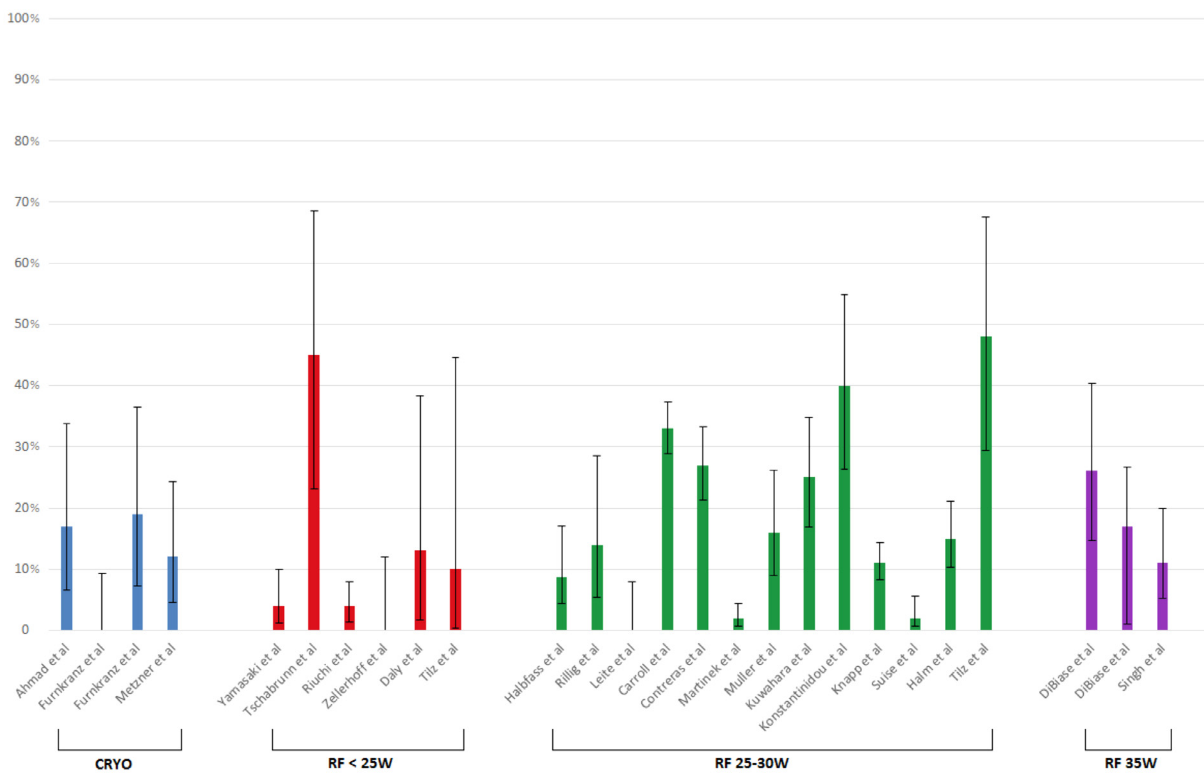

Fig. 2. Incidence of esophageal injury by energy source and magnitude.
The incidence of esophageal thermal injury using various energy sources and magnitudes across 26 studies is shown. Error bars represent Clopper–Pearson 95% confidence intervals for each study. Despite use of cryoballoon or reduction in power to under 25 W, significant thermal injury rates are still observed.
Cryo: Cryoballoon; RF: Radiofrequency.

tion of hot beverages such as tea and coffee commonly results in exposure of the esophageal epithelial layer to temperatures well above 40 and even transiently above 50 °C without any apparent acute injury [29]. Preclinical studies of isolated esophageal tissue demonstrate that irreversible esophageal injury occurs only for sustained (>30 s) temperatures above 50 °C [30].

While the lethal isotherm for esophageal tissue is unknown, the LET that is commonly believed to be associated with injury and the LET thresholds that are clinically used as cutoffs to terminate ablation are implausibly low. These artefactual LET thresholds are more related to limitations in the current temperature probe technology than to pathophysiology of esophageal lesion formation. When esophageal temperatures were likely more accurately measured via infrared thermography during ablation, temperatures greater than 50 °C were required before visible injury was seen [31]. As previously discussed, multiple single-center studies have demonstrated variable results when monitoring esophageal temperatures associated with visible thermal injury on EGD (Fig. 2). This heterogeneity demonstrates the poor sensitivity and specificity of the currently available and studied probes, along with the temperature thresholds used, at preventing esophageal thermal lesions.

Considerations when monitoring luminal temperature in the esophagus

There are multiple reasons why LET monitoring with a finite number of discrete sensors may fail to prevent esophageal thermal injury. Temperature gradients in the esophagus during cardiac ablation are quite steep. Using a balloon catheter with 7 thermocouples with 2 mm separation in a canine model of esophageal thermal injury, Yokoyama et al demonstrated temperature differences of > 20 °C between adjacent thermocouples [8]. The preclinical observation of high esophageal temperature gradients was also recently clinically validated using infrared thermography [31]. Thus, measurement of temperature at any single point or limited number of points is likely to grossly underestimate maximal esophageal temperatures, as the thermistor is likely to be at some distance from the point of maximal temperature. Clinicians have no way of knowing whether or not the sensor is in direct contact with the esophageal surface or residing in the free space of the esophageal lumen and therefore providing lower temperature readings and a false sense of security. In fact, if the probe is in contact with the posterior rather than anterior esophageal wall, fluoroscopy would appear identical, but no temperature rise at all may be detected despite active thermal injury. Thus, the absence of an elevation in esophageal temperature may not necessarily represent an area at a safe distance from the esophagus appropriate for high energy ablation. Importantly, frank esophageal fistulae have been reported to develop in cases where LET monitoring was employed and no significant temperature rises were observed [32].

All currently utilized probes have lengthy time constants (the time taken to realize 63% of temperature change), thereby resulting in a significant delay for the sensor to record a temperature rise. There is large variability between probes, and a recent study showed significant delay in the time constant of two commercially available insulated probes (8.3 and 33.5 s) compared to a standard non-clinical exposed thermistor (1.5 s) [33]. Factors such as insulation surrounding the sensor and the amount of time needed to heat the volume of the sensor itself may contribute to this delay in temperature rise. Heat energy conduction and dissipation into the surrounding and intervening tissues also precludes real-time temperature readings with currently used thermistors. Spatial averaging of the temperature occurs over a relatively large temperature sensor and thus, exact temperature measurements may be altered. Thus, even if the minimum temperature that results in injury is known and the maximal esophageal temperature is adequately recorded, it still would be difficult to expeditiously discontinue ablation and avoid injury due to these constraints.

Infrared thermography

Although clinical data are lacking, a new esophageal temperature probe is available which utilizes infrared technology to provide a high resolution map of esophageal surface temperatures in real time. 7680 points are obtained every second covering a 6 cm cylinder of the esophagus contiguous with the left atrium [31]. This potentially eliminates the under-sampling problem with traditional probes. In addition, as temperature changes are detected instantaneously and refreshed every second, ablation can be terminated without delay to avoid injury [34]. Preliminary results suggest that esophageal temperature rises in the range of currently used cutoffs (eg 38–41 °C) are common during ablation, but visible esophageal injury is only seen with temperature excursions above 50 °C. Thus, in addition to preventing injury, it may allow more efficient procedures without frequent discontinuations for low grade temperature rises. However, it is unclear that monitoring luminal temperature, even with high degree of accuracy, will help prevent injury to esophageal arteries and branches of the periesophageal vagus nerve which course on the external surface of the esophagus. In addition, larger clinical studies are still warranted to further establish this novel thermography system as an effective means of preventing and reducing esophageal injury during ablation.

Risk factors for thermal injury

One of the major determinants of esophageal heating is the distance of the ablation electrode to the esophagus. Low body mass index, which may be associated with reduced pericardial fat and closer anatomical relationship between the heart and esophagus, has been associated with increased risk of esophageal injury in several studies [35]. General anesthesia, which may reduce swallowing, peristalsis, and esophageal mobility, may lead to less cooling and prolonged exposure of the same area to thermal energy and has been associated with increased risk of injury [36,37]. Ablation parameters influencing the potential for injury include the energy source and magnitude, catheter tip size, contact force pressure and catheter orientation [38].

Atrio-esophageal fistulae have been reported with a wide range of energy sources including cryoballoon [39], radiofrequency [40], and ultrasound [41], and with various operative techniques including robotic catheter guidance [14] and surgical mini-maze [42]. Cryoablation has been purported to potentially carry lower risk of esophageal thermal injury, however the development of atrio-esophageal fistula has been reported with this technology [43] and it is not clear whether the apparent lower incidence is related to actual reduction or underreporting. When using radiofrequency energy, reduced power will result in less conducted heat to the esophagus. Delivering higher energy on the posterior wall of the left atrium, up to 50 W, has been associated with a higher rate of esophageal lesions [44]. However, there is poor correlation between power delivered and maximal LET. AE fistula has been reported when using no more than 20 W on the posterior wall [[14],[23],[35]], and LET rises to >40 °C have been seen despite power <10 W [13]. In Fig. 2, the incidence of esophageal thermal injury across all studies is displayed grouped by energy source and magnitude. It is apparent that significant rates of injury are still observed despite reducing radiofrequency power to <25 W or using cryoablation.

In an effort to create durable transmural lesions and improve procedural efficacy, force sensing catheters have gained widespread use. While ensuring sufficient catheter-tissue contact and promoting deeper ablation lesions, these catheters may also increase the extent of collateral damage to the esophagus. Black-Maier et al. studied 2689 adverse events reports involving ablation catheters, 78 of which were AE fistula cases. 65 of those cases (84%) involved contact force sensing catheters. The proportion of AE fistula formation was much higher with the use of contact force sensing catheters as compared to non-contact force sensing catheters [45]. These data are consistent with a recently published large, multicenter registry study from Brazil where ten cases (0.113%) of AEF were reported from 8863 ablation procedures and the rate of AEF was higher (0.23%) following the release of newer force sensing technologies [4].

Alternative strategies to prevent injury

With the evidence currently at hand, it is apparent that LET monitoring, at least with discrete sensors, has not eliminated esophageal thermal injury. Several other strategies have been employed in attempts to reduce the incidence of AE fistulae and are summarized in Table 4. When performing pulmonary vein isolation, it is generally not possible to completely avoid areas contiguous to the esophagus without mechanically altering the relationship of the left atrium and esophagus. However, real-time imaging and localization of the esophagus such as with intracardiac echo may allow some tailoring of the ablation lesion set to minimize the amount of ablation in these areas. Greater depth of tissue heating or cooling increases the risk of esophageal thermal injury and thus limiting energy delivery when ablating on the left atrial posterior wall is recommended. It is clear that reduction in power alone or use of cryoablation does not eliminate the risk of thermal injury (see Fig. 2). However, limiting energy delivery through a combination of decreased power, application time, and contact force is likely to limit the depth of heating and reduce risk of injury. The use of high power (eg 50 W or more) for very short durations (eg < 5–10 s) has been proposed to create more superficial lesions when ablating on the relatively thin posterior wall. A recent animal study showed favorable results with the use of high power (90 W), short-duration (4 s) ablation [46]. However, there are little data to support this approach at present.

Other strategies to mitigate esophageal damage include the use of a closed-loop water-irrigated intra-esophageal balloon

Table 4
Strategies to prevent esophageal injury.

Luminal esophageal temperature monitoring
o Single or multiple discrete sensors
o Infrared thermography
Limiting energy delivered to the posterior wall
o Reduction in RF power
o Decreasing RF application time (eg, ≤20 s)
o Decreasing contact force (eg, ≤10 gs)
Alternate energy source? (eg cryo)
Avoidance of ablation immediately adjacent to the esophagus
o Esophageal imaging and localization
o Mechanical deflection of esophagus
o Thermal insulation of esophagus (eg, balloon in pericardium)
Pharmacologic gastric acid suppression
Active cooling of the esophagus

[[47],[48]]. However, the device is somewhat complex to set up, and runs the risk of increasing exposure to esophageal injury due to the balloon expansion of the esophagus towards the left atrium. Pre-cooling the esophagus with ice water prior to ablation was also shown to be ineffective at reducing the rate of esophageal thermal injury when compared against the standard of care [49]. Another setback is possible ineffective ablation secondary to atrial cooling [48]. Other studies examined esophageal displacement for prevention of complications associated with thermal heating during ablations [50]. A clinical trial is currently underway with the objective of determining the outcome and effect of implementation of an esophageal stylet to move the esophagus away from the site of ablation. Limited data remain available to fully determine the safety and feasibility of this technique before implementation into clinical practice. It may also require the use of a temperature probe and general anesthesia. The risk of mechanical trauma to the esophagus remains a concern, and it is unclear if this technique may result in stretching and thinning of the esophageal wall in patients with a relatively immobile esophagus.

Limitations of review

Ablation techniques to isolate the pulmonary veins are changing relatively rapidly. The bulk of the literature reviewed herein for instance pertains largely to radiofrequency ablation catheters without force-sensing capabilities that are not commonly in use today. Multiple additional balloon ablation technologies are currently in development that could create different esophageal thermodynamic profiles. In addition, ablation using irrigated radiofrequency catheters are currently being trialed at high power for very short durations on the posterior wall with unknown effects on esophageal injury. However, regardless of the ablation technology utilized, LET monitoring using discrete sensors is unlikely to provide meaningful feedback to prevent injury. Shorter duration of ablation will likely only magnify the limitations of these temperature probes, which have long response times.

Conclusion

LET monitoring is currently widely used and considered standard of care in most centers to prevent esophageal thermal injury during catheter ablation for AF. However, despite its widespread use, LET monitoring using discrete sensor probes does not appear to significantly reduce thermal injury to the esophagus. Multisensor probes appear to have higher sensitivity than single sensor probes to detect esophageal temperature rises; however, this has not translated into lower injury rates. Inaccurately low temperatures that are recorded using currently available discrete sensor probes give operators a false sense of security during ablation, whereas the use of implausibly low cutoff thresholds (38–41 °C) may unnecessarily halt otherwise safe ablation. The routine use of discrete sensor LET probes should thus be reevaluated. Operators should not rely on discrete temperature sensing probes alone, but should practice other safety measures such as avoidance of areas directly contiguous to the esophagus when possible, and reduction in delivered energy and catheter contact force in the posterior left atrium.

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