Heart, Lung and Circulation (2019) **28,** 1050–1058
1443-9506/04/$36.00
https://doi.org/10.1016/j.hlc.2018.05.197

ORIGINAL ARTICLE

The Durability of Atrial Fibrillation Ablation Using an Oesophageal Temperature Cut-Off of 38 °C

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Received 16 September 2016; received in revised form 3 March 2018; accepted 27 May 2018; online published-ahead-of-print 14 June 2018

Background A lower cut-off of the oesophageal temperature (ET) during catheter ablation of atrial fibrillation (AF) should be safer, but its durability may become in question. We evaluated an ET cut-off of 38 °C with an output of 25 W on the posterior wall.

Methods In 636 consecutive patients (age: 60 ± 10 years, male: 542, paroxysmal AF: 405, $CHADS_2$ score: 0.7 ± 0.9), an ET probe was utilised in 303 patients (259 pulmonary vein isolations [PVIs] and 44 simultaneous isolations of the posterior wall and all PVs box isolations [BOXIs]). When the ET increased to >38 °C, the radiofrequency delivery was switched off and the ablation point was tagged as an ''EsoTag'' by the CARTO™ system (Biosense Webster, Irvine, CA, USA). We analysed the characteristics of the ablation lesions at the EsoTags with respect to the dormant conduction, gaps in the redo-session, and ablation outcome.

Results EsoTags were identified in 94.6% of the left PVIs and all BOXIs, and dormant conduction at the EsoTags was identified in 12.0% and 6.8%, respectively. In 10,796 ablation points, the ablation at the EsoTags that were associated with dormant conduction had a significantly shorter duration, smaller force-time integral, and smaller Δimpedance. The duration of an ET of >38 °C was significantly and positively correlated with the body mass index and negatively with the left atrial appendage flow velocity. During the redo-sessions in a 10.5 ± 6.0 months of follow-up (PVI: 14.7%, BOXI: 11.4%), reconnections at the EsoTags with dormant conduction were observed only in two patients after the PVI. The AF survival rate did not significantly differ in the presence of dormant conduction at the EsoTags (83.1% vs. 75.0%, p = 0.696). There were no patients hospitalised for gastroparesis.

Conclusions Atrial fibrillation ablation utilising an oesophageal temperature cut-off of 38 °C might be safe and durable.

Keywords Ooesophageal temperature • Gastroparesis • Catheter ablation • Atrial fibrillation • Dormant conduction • Follow-up study

Abbreviations: AF, atrial fibrillation; BOXI, box isolation; ECG, electrocardiogram; EsoTag, ablation site that was associated with the oesophageal temperature increase above 38 °C; ET, oesophageal temperature; PVI, pulmonary vein isolation; RF, radiofrequency; TTE, transthoracic echocardiography; TEE, transoesophageal echocardiography

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Introduction

Radiofrequency (RF) catheter ablation always faces a trade-off between a durable lesion formation and the risk of damage to an adjacent organs. During catheter ablation of atrial fibrillation (AF), thermal injury to the oesophagus can happen because of its close proximity to the posterior wall of the left atrium, especially to the antral region of the left inferior pulmonary vein (PV), for the cost of creating a durable PV isolation. A consequent oesophageal mural haemorrhage, ulcer formation, or atrio-oesophageal fistula, which is mostly lethal although its incidence is quite rare at 0.05% [1], have been reported. Besides those, gastroparesis can be a serious complication as well, which occurs in 0.38% of the patients in Japan [2]. There is no doubt that oesophageal temperature (ET) monitoring plays an important role in reducing these risks [3,4]. However, its usage varies among the facilities and there is no consensus for its cut-off value: ulcerations were identified in 11% with the ET cut-off of 38.5 °C under the RF output of 35 W [5], 10% ulceration with an ET cut-off of 39 °C under an output of 25 W [6], and no ulcerations with an ET cut-off of 41 °C [7]. On the contrary, even a 1 °C-ET increase was reported to induce an oesophageal fistula [8]. A lower cut-off should be safer for the oesophagus, but the durability of the ablation may be affected. Therefore, we aimed to reveal the durability of the isolation under safer conditions for the oesophagus.

Since the proximity between the left atrium (LA) and oesophagus is a significant risk factor for increasing the ET [9], the ET probe was located as close as possible to the ablation site during the ablation. Given that there was no thermal injury with a 2 °C increase of the ET under an RF output of 25 W [10], we decided to perform our procedure with an ET cut-off of 38 °C under an RF output of 25 W for the posterior wall while the ET data was collected every second. With concern for a negative effect toward the ablation outcome under a rigorous ET cut-off, we visualised the ablation site where the ET increased above 38 °C in the three-dimensional mapping system as an ''EsoTag''. Then, we analysed the characteristics of the ablation applications at the EsoTags with respect to the dormant conduction revealed by a rapid injection of adenosine triphosphate (ATP), gaps in the redo-session, ablation outcome, and ablation parameters including the catheter temperature, impedance changes, and contact force.

Materials and Methods

This study was a retrospective observational study approved by our institutional review board based on the ethical guidelines of the Declaration of Helsinki. All patients were provided with the written informed consent for catheter ablation.

Study Population

A consecutive series of 636 patients (age: 60 ± 10 years, male: 542, paroxysmal AF: 405, $CHADS_2$ score: 0.7 ± 0.9) who underwent an initial catheter ablation of AF in our facility were included. Out of them, 303 consecutive patients underwent catheter ablation using ET monitoring (SensiTherm™, St. Jude Medical, St. Paul, MN, USA) from October 2012. The former 333 consecutive patients underwent ablation without monitoring the ET. The indication for catheter ablation was decided according to the Japanese guidelines [11]. Transthoracic echocardiography (TTE) and multi-detector computed tomography (CT) were performed to reveal the anatomy of the PVs and left atrium (LA) unless contraindicated. Therapeutic oral anticoagulation therapy was maintained for more than one month regardless of the $CHADS_2$ score using either warfarin or direct oral anticoagulants (DOACs). Transoesophageal echocardiography (TEE) or intracardiac echocardiography was performed to rule out any preexisting thrombi.

Ablation Procedure

The patients were sedated with a continuous intravenous infusion of propofol to keep the BIS-monitor value (Aspect Medical Systems, Newton, MA, USA) within a range of 40 to 60. An oesophageal temperature probe was introduced from the nasal cavity. An eight-pole electrode catheter for the right ventricle (Inquiry™ L1/XL1, St. Jude Medical; Suprime™, Nihon Kohden Corporation, Tokyo, Japan) and a 14-pole electrode catheter for the coronary sinus (Inquiry™ SC1, St. Jude Medical) were introduced. Following the right atriography and administration of 100 U/kg of intravenous heparin, a double or triple transseptal puncture was performed. Two long sheaths (Swartz™, SL0, SL1, St. Jude Medical) for a circumferential pulmonary vein isolation (PVI) or three sheaths (Swartz™, SL0, SL1, Agilis™, St. Jude Medical) for a simultaneous isolation of all PVs and the posterior wall (BOX isolation: BOXI) were introduced into the LA from the right femoral vein. The activated clotting time was measured every 30 minutes and maintained above 300 seconds throughout the procedure. After simultaneous superior and inferior pulmonary venography, a single circular mapping catheter (Lasso™, Biosense Webster, Irvine, CA, USA, or Inquiry™ Afocus™, St. Jude Medical, or Libero, Japan Lifeline Co. Ltd, Tokyo, Japan) for the PVI, double circular mapping catheter for the BOXI, and a 3.5 mm saline-irrigated mapping catheter (EZ Steer Thermocool™, or Thermocool™ SmartTouch, or Thermocool™ SF, Biosense Webster) were introduced. The procedure was performed under the guidance of a CARTO™ system (CARTO™, or CARTO™ 3, Biosense Webster). We created continuous linear lesions surrounding the antrum of the PVs and posterior wall (Figure 1).The alarm of the SensiTherm™ system was set to sound at 38 °C, which was a sign to terminate the RF delivery. We tagged the ablation site where the ET increased above 38 °C as an ''EsoTag''. The position of the ET probe was controlled to locate it as close as possible to the ablation site. The ET was recorded every second during the isolation. The output was set to 25 W and the duration was limited to less than 15–30 seconds in the posterior wall with a catheter temperature cut-off of 43 °C. The saline irrigation speed was set to 8 mL/min for the Thermocool™ SF catheter and 17 mL/min for the others. Bidirectional conduction block was confirmed by the elimination of the dormant conduction with a rapid infusion of 20 mg of ATP and exit block with 25mA-output pacing from the PVs. The dormant conduction

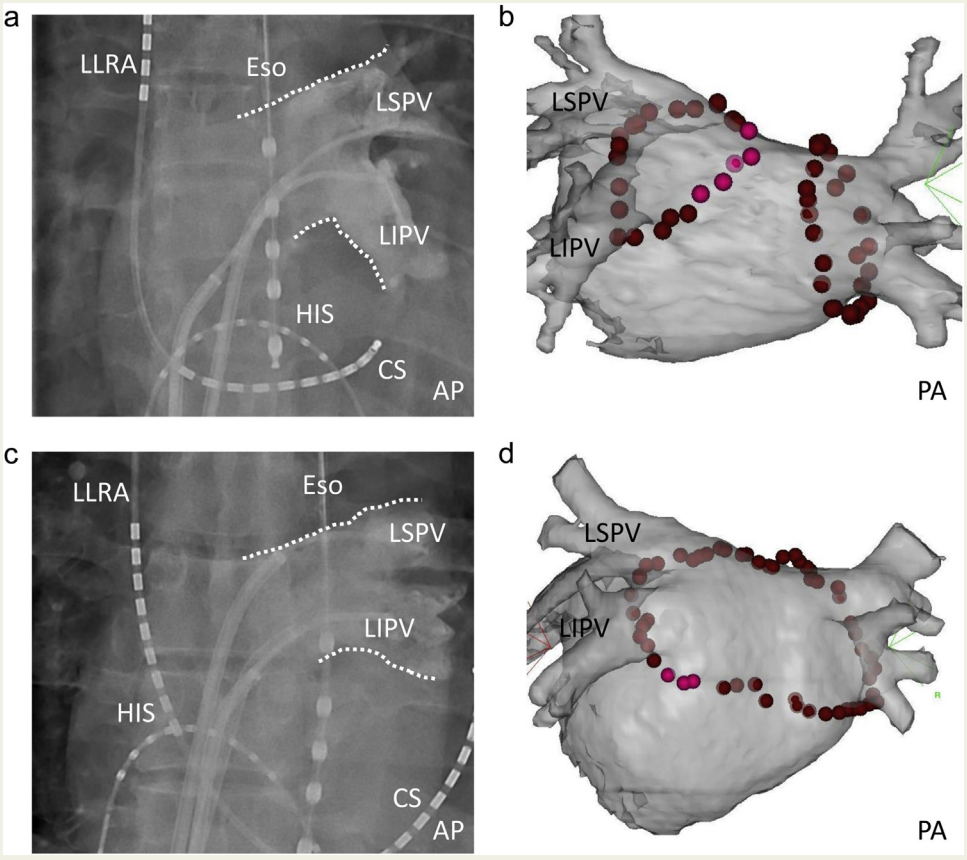

Figure 1 Visualisation of the ablation sites with EsoTags.
Typical examples of pulmonary venography and a positional relationship of an oesophageal temperature (ET) probe (Eso) are shown (a, c, antero-posterior view). The outline of the angiography is highlighted by the white dotted line. The ET probe was placed so it was located at the closest possible position to the ablation site during the ablation. The ablation sites where the ET increased above 38 °C are tagged as EsoTags (pink tag, postero-anterior view), during the left pulmonary vein isolation (b) and box isolation (d).

was reconfirmed 30 minutes after the initial bidirectional isolation. We defined ''dormant'' in this paper as an ATP-induced reconnection observed 30 minutes after the initial isolation. After burst stimulation and an isoproterenol infusion, the endpoints of the ablation procedure were determined depending on the types of AF, triggers, arrhythmia induction, and physicians.

Follow-up

The patients were followed-up with a 10-second electrocardiogram (ECG) on every clinic visit, 24-hour Holter ECG, and 30-second telemonitoring ECG (Cardiophone™, NihonKoden,Tokyo, Japan) twice daily and upon any symptoms. The necessity for a redo-session was decided by the physicians based on an arrhythmia documented in any ECG. The AF-free survival period was defined as the time from the initial catheter ablation to the redo-session or the last clinic visit. An AF relapse was defined by a redo-session or AF documented in the last clinic visit. The diagnosis of gastroparesis was based on the abdominal x-rays upon symptoms, such as a loss of appetite, sense of distension, nausea, and vomiting.

Data Analysis

Patients with an EsoTag whose location was identical to the dormant site (the Dormant = EsoTag group) were compared to the rest (the Dormant ≠ EsoTag group). The reconnections of the isolation and gaps during the redo-session were also evaluated by referring to the initial session. The detailed characteristics of the RF application collected from the CARTO™ system, such as the RF output, duration, impedance, and temperature, were analysed. The contact force and force-time integral (FTI) were calculated when the Thermocool™ SmartTouch catheter was utilised. The ET data recorded every second during the ablation was analysed to measure the maximum ET and the duration of the ET above 38 °C. The number of patients requiring hospitalisation for gastroparesis was counted. The incidence of gastroparesis and the patient background were compared between ablation with and without ET monitoring.

Statistical Methods

The data obtained are presented as the mean ± standard deviation, percentage, or number of the population. The

significant differences between the two groups were analysed using the Mann-Whitney's U test. A p value of less than 0.05 was considered significant. The odds ratio (OR) and the 95% confidence interval (95% CI) were calculated. The AF-free survival curve between the Dormant = EsoTag group and the Dormant ≠ EsoTag group was constructed using the Kaplan-Meier method and was compared using the log-rank test. A receiver operating characteristic (ROC) curve was calculated to evaluate the sensitivity and specificity of predicting dormant conduction. The area under the ROC curve (AUC) was also calculated. The sample size for analysing the incidence of gastroparesis between ablation applications with and without ET monitoring was calculated as 235 in each group, when the ET monitoring decreased the incidence of gastroparesis by 10% with an alpha error of 0.05 and beta error of 0.2. All statistical analyses were performed using SPSS statistical software (version 21.0, SPSS Inc., Armonk, NY, USA).

Results

In 303 initial sessions using ET monitoring, PVI was performed in 259 patients (paroxysmal: 183) and a BOXI was performed in 44 patients (paroxysmal: 5). Ablation applications with an ET above 38 °C, which were marked as EsoTags, were identified in 245 patients (94.6%) during left PVIs, 10 patients (3.9%) during right PVIs, and in all patients during the BOXI, respectively (Figure 2). In the PVI, most of the EsoTags in the left PVs were located on the posterior wall but six patients (2.4%) had EsoTags on the roof and three (1.2%) had them on the ridge. Four patients had EsoTags in both the left and right PVs. In the BOXI, most EsoTags were located on the bottom line and two patients (4.6%) had EsoTags on the roof line as well.

A total of 10,796 RF energy applications were also analysed. There were 1402 ablation points that were associated with the EsoTags (EsoTag points) with a mean output of 24.5 ± 1.9 W for a mean duration of 11.0 ± 5.6 sec. The comparison of the ablation applications between the EsoTag points and the non-EsoTag points is shown in Table 1. The output in the EsoTag point group was significantly lower and the duration was significantly shorter. The average impedance did not differ, however, the impedance drop during the ablation (Δ impedance) was significantly smaller in the EsoTag point group. The mean catheter temperature was significantly higher and the temperature increase during the ablation was significantly smaller in the EsoTag point group. The contact-force sensing catheter was utilised in a total of 1759 RF energy applications during 63 ablation sessions. The FTI was significantly smaller in the EsoTag point group, though the contact force was significantly higher.

Dormant Conduction vs. EsoTags

The EsoTag = Dormant group, who had dormant conduction at the EsoTags, consisted of two patients (0.8%) in the right PVI, 31 (12.0%) in the left PVI, and three (6.8%) in the BOXI. The comparison between the EsoTag = Dormant group and EsoTag ≠ Dormant group is shown in Table 2. There were no significant differences between the groups regarding the patient background including the type of AF, number of patients who underwent a BOXI, and the TTE/TEE data. The patients in the Dormant = EsoTag group had a significantly larger number of EsoTags during the left PVI (EsoTag

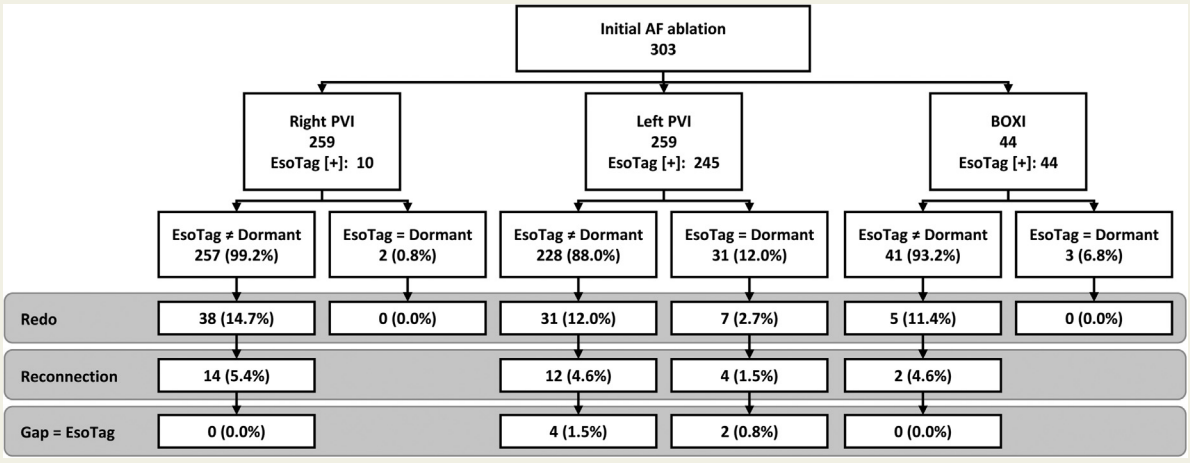

Figure 2 The ablation outcome according to the dormant conduction at the EsoTags.
The ablation outcome of the patients with an ablation site where the oesophageal temperature (ET) increased above 38 °C (EsoTag) and which was responsible for adenosine triphosphate-induced dormant conduction (Dormant; EsoTag = Dormant) are compared with the rest of the patients (EsoTag ≠ Dormant). The number of patients with EsoTags during the isolation (EsoTag [+]), redo-sessions (Redo), reconnections identified during the redo-session (Reconnection), and reconnected sites that increased the ET above 38 °C during the redo-session (Gap = EsoTag) are shown.
Abbreviations: AF, atrial fibrillation; BOXI, box isolation.
The numbers indicate the number of patients and the percentage.

Table 1 **The comparison of the ablation points with an oesophageal temperature increase.**

		Non-EsoTag point	EsoTag point	p
Output (W)		28.3 ± 3.7 (9394)	24.5 ± 1.9 (1402)	<0.001
Duration (sec)		32.5 ± 22.3 (9394)	11.0 ± 5.6 (1402)	<0.001
Impedance (ohm)	Max	118.3 ± 14.5 (9394)	114.0 ± 11.2 (1402)	<0.001
	Min	98.3 ± 10.2 (9394)	100.2 ± 9.5 (1402)	<0.001
	Average	105.3 ± 11.4 (9394)	105.2 ± 9.9 (1402)	0.980
	Delta	-17.6 ± 7.6 (9394)	-13.1 ± 5.2 (1402)	<0.001
Temperature (°C)	Max	36.5 ± 2.4 (9394)	36.3 ± 2.0 (1402)	0.439
	Min	33.1 ± 1.7 (9394)	33.4 ± 1.6 (1402)	<0.001
	Average	34.4 ± 2.5 (9394)	34.7 ± 2.1 (1402)	<0.001
	Delta	1.7 ± 2.2 (9394)	1.2 ± 1.7 (1402)	<0.001
Force (g)		15.5 ± 11.0 (1557)	16.7 ± 10.7 (202)	<0.001
FTI (gs)		442.7 ± 390.3 (1557)	182.0 ± 162.1 (202)	<0.001

The numbers are shown as the mean ± standard deviation (n).
Abbreviation: FTI, force-time integral.

≠ Dormant vs. EsoTag = Dormant; 4.3 ± 2.5 vs. 5.9 ± 3.6 points; p = 0.011), markedly shorter time for the isolation, and smaller number of RF energy applications. The maximum ET and duration of the ET above 38 °C did not differ between the groups. There were no significant differences in the type of irrigated catheters (EZ Steer Thermocool™ vs. Thermocool™ SmartTouch vs. Thermocool™ SF; 5 [16.7%] vs. 6 [9.5%] vs. 25 [9.5%], p = 0.609) or physicians who performed the ablation procedures (p = 0.585).

The correlation between the patient background, number of EsoTags during the isolation, and recorded ET were analysed. The number of EsoTags had a mildly significant correlation with the number of RF energy applications required for the initial isolation completion (r = 0.190, p = 0.008) and the maximum ET (r = 0.183, p = 0.034), but not with the other patient background data including the age, body mass index (BMI), LA size, left atrial appendage (LAA) flow velocity, and grade of spontaneous echo contrast. The maximum ET had a mildly significant correlation with the left ventricular ejection fraction measured using TTE (r = −0.251, p = 0.005), but not with the BMI (p = 0.126). The duration of the ET above 38 °C was significantly correlated with the body weight (r = 0.316, p < 0.001), BMI (r = 0.334, p < 0.001), serum HbA1c level (r = 0.217, p = 0.013), and LAA flow velocity (r = −0.183, p = 0.039).

Follow-up Data

During 10.5 ± 6.0 months of a follow-up, 1.1 ± 0.4 redo sessions were performed 8.4 ± 3.4 months after the initial session in 38 patients (14.7%) after the PVI and in five patients (11.4%) after the BOXI, respectively (Figure 2). Reconnections of the isolation were observed in 14/259 (5.4%) patients in the right PVI, 16/259 (6.2%) in the left PVI, and 2/44 (4.6%) in the BOXI, respectively. The number of patients with a redo-session did not differ between the groups (EsoTag ≠ Dormant vs. EsoTag = Dormant; 36 [13.5%] vs. 7 [19.4%]; p = 0.336). There were no redo-sessions in the patients in the EsoTag = Dormant group regarding the right PVI and BOXI. In the left PVI, the number of patients with a redo-session did not differ between the groups (EsoTag ≠ Dormant vs. EsoTag = Dormant; 31 [13.6%] vs. 7 [22.6%]; p = 0.183). Among four patients that had reconnections at the left PV, three had a gap whose location was identical to the dormant site during the initial session and two gaps were tagged as EsoTags in the redo-session. The number of patients with reconnections (EsoTag ≠ Dormant vs. EsoTag = Dormant; 12 [5.3%] vs. 4 [12.9%]; p = 0.097) and gaps corresponding to EsoTags (EsoTag ≠ Dormant vs. EsoTag = Dormant; 4 [1.8%] vs. 2 [6.5%]; p = 0.103) did not differ between the groups. None of the gaps in the BOXI were related to either the dormant site during the initial session or the EsoTag during the redo-session.

The follow-up data were compared between the Dormant ≠ EsoTag group and Dormant = EsoTag group (Figure 3). The AF-free survival rate, proportion of patients with normal sinus rhythm during the last visit without any redo-sessions, did not significantly differ between the groups (EsoTag ≠ Dormant vs. EsoTag = Dormant; 222 [83.1%] vs. 27 [75.0%], p = 0.696). The use of antiarrhythmic drugs at the time of the last visit did not differ (EsoTag ≠ Dormant vs. EsoTag = Dormant; 42 [15.7%] vs. 6 [16.7%], p = 0.885).

The Characteristics of the RF Energy Applications at the EsoTags

Among 1349 ablation applications at the EsoTag points, 173 points (12.8%) were associated with dormant conduction (EsoTag points with dormant). The comparison of the EsoTag points with and without dormant conduction (EsoTag points without dormant) is shown in Table 3. The average power, catheter temperature, and contact force did not differ

Table 2 Patient background according to dormant conduction at the EsoTags.

			Dormant ≠ EsoTag n = 267	Dormant = EsoTag n = 36	p
Patient background	Paroxysmal AF		63.7% (170)	58.3% (21)	0.533
	Female		7.9% (21)	16.7% (6)	0.082
	Redo		13.5% (36)	19.4% (7)	0.336
	BOXI		15.4% (41)	8.3% (3)	0.262
	Body mass index		24.6 ± 3.1 (267)	24.1 ± 2.9 (36)	0.507
	Age		60 ± 10 (267)	59 ± 12 (36)	0.786
	CHADS2		0.6 ± 0.8 (267)	0.5 ± 0.9 (36)	0.577
	CHA2DS2-VASc		1.0 ± 1.0 (267)	1.1 ± 1.3 (36)	0.717
	Cr (mg/dL)		1.0 ± 0.7 (267)	0.9 ± 0.3 (36)	0.228
	HbA1c (%)		5.4 ± 0.5 (267)	5.3 ± 0.4 (36)	0.460
	LDL (mg/dL)		108.5 ± 29.0 (267)	102.8 ± 22.5 (36)	0.235
	BNP (pg/mL)		86.5 ± 98.9 (267)	69.0 ± 57.5 (36)	0.398
	Duration of AF (M)		33.1 ± 36.7 (81)	28.3 ± 22.0 (12)	0.796
	No. of AADs		0.5 ± 0.6 (267)	0.6 ± 0.9 (36)	0.908
	Follow-up period (M)		10.3 ± 6.0 (267)	12.3 ± 6.4 (36)	0.100
TTE	LVEF (%)		57.6 ± 8.6 (249)	56.8 ± 7.0 (31)	0.452
	LA (cm)		4.0 ± 0.6 (249)	3.9 ± 0.7 (31)	0.629
	Deceleration time (msec)		192.7 ± 55.3 (226)	192.4 ± 57.4 (30)	0.991
TEE	Grade of SEC		0.5 ± 0.6 (250)	0.4 ± 0.7 (35)	0.227
	LAA flow velocity (cm/sec)		54.7 ± 18.9 (252)	58.6 ± 21.1 (35)	0.186
Ablation	No. of EsoTag				
		during BOXI	4.7 ± 3.9 (41)	7.7 ± 4.5 (3)	0.221
		during PVI	4.3 ± 2.5 (226)	5.9 ± 3.6 (33)	0.011
	No. of RF application				
		during BOXI	58.8 ± 17.5 (41)	51.7 ± 9.1 (3)	0.534
		during PVI	36.0 ± 14.2 (226)	38.8 ± 14.9 (33)	0.252
	Time for isolation (sec)				
		during BOXI	65.0 ± 35.2 (41)	46.0 ± 1.0 (3)	0.299
		during PVI	42.2 ± 24.8 (226)	40.4 ± 27.6 (33)	0.167
	Max ET (°C)		39.0 ± 0.7 (121)	39.0 ± 0.5 (13)	0.943
	Duration of ET > 38 °C (sec)		30.0 ± 12.2 (121)	24.8 ± 7.9 (13)	0.146

Abbreviations: AADs, antiarrhythmic drugs; AF, atrial fibrillation; BOXI, box isolation; BNP, brain natriuretic peptide; Cr, creatinine; ET, oesophageal temperature; LAA, left atrial appendage; LDL, low-density lipoprotein; LVEF, left ventricular ejection fraction; PVI, pulmonary vein isolation; TEE, transoesophageal echocardiography; TTE, transthoracic echocardiography; RF, radiofrequency.

between the groups. The EsoTag points with dormant group had a significantly shorter duration, smaller FTI, and smaller Δimpedance. The maximum ET and duration of the ET above 38 °C did not differ between the groups.

The AUC for predicting the dormant conduction at the EsoTags was tolerant for the Δimpedance (0.663), but was not for the ablation duration (0.352) and FTI (0.363). When the cut-off of the Δimpedance for predicting dormant conduction at the EsoTags was set at 10.5 ohms, the sensitivity and specificity were 66.7% and 40.1%, respectively. A multivariate analysis adjusted for the duration of the RF energy applications revealed that the Δimpedance was the independent predictive factor for dormant conduction (standardised beta = 0.037, p = 0.047, 95% CI = 1.000–1.076).

The Usefulness of EsoTags for Reducing the Incidence of Gastroparesis

A consecutive series of 303 patients who underwent catheter ablation with tagging EsoTags (ablation with EsoTags) was compared to the former 333 ablation procedures without using ET monitoring (ablation without EsoTags). The incidence of gastroparesis requiring hospitalisation was zero in the ablation with EsoTags group, which was lower than that in the ablation without EsoTags group (0 [0.0%] vs. 3 [0.9%]; p = 0.098, Supplementary Table 1). Although the ablation protocol and $CHADS_2$ score significantly differed between the groups, the cofactors affecting the ET elevation as described above, such as the left ventricular ejection fraction, BMI, and LAA flow

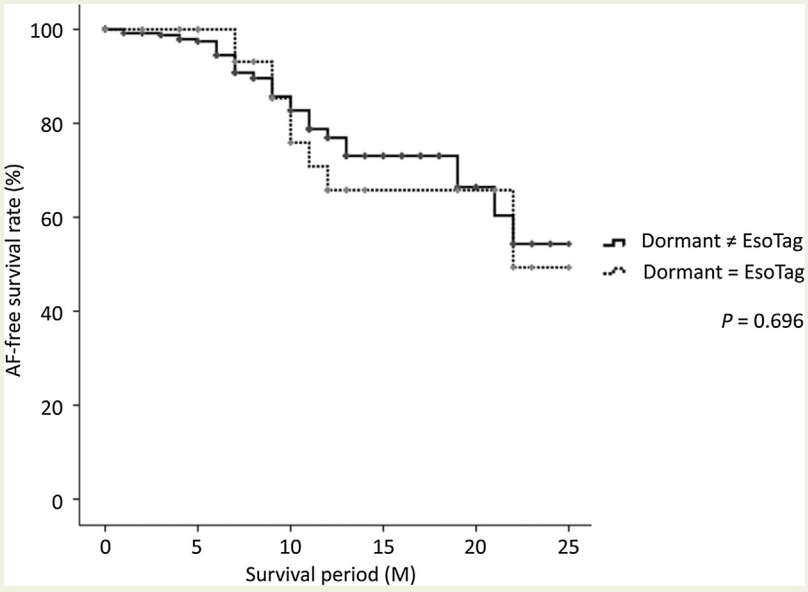

Figure 3 AF-free survival curve compared according to dormant conduction at the EsoTags.
The AF-survival curve did not significantly differ between the patients with dormant conduction where the ablation increased the oesophageal temperature to above 38 °C (Dormant = EsoTag) and the rest of the patients (EsoTag ≠ Dormant).
Abbreviation: AF, atrial fibrillation.

velocity, did not differ. Three patients with gastroparesis recovered spontaneously. There were no patients with an atrio-oesophageal fistula throughout the study.

Discussion

Major Findings

We visualised the ablation site that was associated with an ET increase above 38 °C with an output of 25 W at the EsoTags. Out of 303 AF ablation procedures, EsoTags were identified in all of the BOXI and 94.6% of the left PVI procedures. Dormant conduction at the EsoTag sites was observed in 6.8% of the BOXI and 12.0% of the left PVI procedures. After 10.5 ± 6.0 months of follow-up, the AF-free survival rate did not significantly differ between those with and without EsoTags that were associated with dormant conduction. There were no patients with gastroparesis, but there were three in the former 333 patients in which EsoTags were not utilised.

Table 3 **The comparison of the ablation points with dormant conduction.**

		EsoTag point without dormant	EsoTag point with dormant	p
Duration (sec)		11.0 ± 5.7 (1176)	9.9 ± 4.6 (173)	0.017
Ave. Power (W)		24.6 ± 1.8 (1176)	24.0 ± 2.2 (173)	0.595
Impedance (ohm)	Max	114 ± 11.3 (1176)	115.7 ± 10.2 (173)	0.077
	Min	100.1 ± 9.3 (1176)	102.7 ± 9.9 (173)	0.005
	Average	105.2 ± 9.9 (1176)	107.5 ± 10.0 (173)	0.014
	Delta	−13.2 ± 5.3 (1176)	−12.1 ± 4.5 (173)	0.013
Temperature (°C)	Max	36.3 ± 2.0 (1176)	36.2 ± 1.8 (173)	0.954
	Min	33.4 ± 1.6 (1176)	33.3 ± 1.5 (173)	0.627
	Average	34.7 ± 2.1 (1176)	34.7 ± 1.9 (173)	0.604
	Delta	1.2 ± 1.7 (1176)	1.2 ± 1.9 (173)	0.557
Force (g)		16.9 ± 10.9 (173)	14.8 ± 9.7 (24)	0.452
FTI		191 ± 170.7 (173)	115.1 ± 65.6 (24)	0.030
Max ET (°C)		39.1 ± 0.9 (384)	39.3 ± 1.0 (34)	0.301
Duration of ET >38 °C (sec)		29.4 ± 13.5 (384)	25.9 ± 13.2 (34)	0.103

The numbers are shown as the mean ± standard deviation (n).
Abbreviation: FTI, force-time integral; ET, oesophageal temperature.

A Trade-Off Between Safety and Durability

The elimination of lethal complications is the goal of catheter ablation together with a better outcome. In order to minimise redundant oesophageal thermal injury, it is important to know the position of the oesophagus. The mean width and length of the contact between the LA and oesophagus are 24.0 ± 5.8 mm and 41.9 ± 11.6 mm, respectively [3]. The CT image performed prior to ablation reveals the anatomical relation between the PVs and oesophagus [12]. However, it is fundamental to monitor the ET in real time during the ablation, because the oesophageal location during catheter ablation correlates with the CT image in only 59% [13], and the oesophagus can be displaced in 83% of the patients at a range of 2.1–2.4 cm [14]. A previous report showed that a real-time ET increase of more than 0.5 °C is observed in 55% of left PVs and 10% of right PVs [15]. Our data showed that the incidence of an ET above 38 °C was higher. This was because the factors affecting the ET were not only the position of the oesophagus, but also the various anatomical parameters. Previously, a computer simulation demonstrated that the degree of the oesophageal lesion is strongly influenced by the thickness of the connective tissue [16]. We should be aware that fat pads are less frequently present in the inferior PV compared with the superior PV, especially in AF patients [12]. The BMI was also reported as an independent factor for predicting gastroparesis [17]. Our data showed that the duration of an ET above 38 °C was significantly and positively correlated with the BMI, but the maximum ET was not significantly correlated with the BMI, suggesting that the patients with a lower BMI might receive rapid thermal changes. The ET cut-off of 42 °C might sound feasible when considering the cut-off value of heat denaturation. However, the temperature measured by the ET probe might underestimate the maximum temperature increase [18], given that the multi-sensor probe detects more ET increases than the single-sensor probe [19]. Interestingly, the incidence of oesophageal damage and a maximal ET are significantly higher in patients undergoing general anaesthesia compared to patients with conscious sedation [20]. We performed ablation under deep sedation to minimise the patient's discomfort and invasiveness. The involuntary movement associated with the ET elevation might be useful as a qualitative cut-off, since only 0.8% of RF applications that are associated with an ET increase are reported to be pain free [21].

Regarding the durability, there was a report showing that the overall success rate at 6 months after the BOXI was 78% in patients with a cut-off of the ET above 40 °C [22]. With a cut-off of the ET above 39 °C, the sites of ablation lesions prematurely terminated did not correlate with the PV reconnections [23]. Our data showed that the ET cut-off of 38 °C did not meaninglessly reduce the outcome. Although the durability of the isolation was not assessed in all patients, most of the gaps were not located around the oesophagus, even if the dormant conduction was inevitable because of the lower ET cut-off. Therefore, the cut-off of the ET above 38 °C was feasible not only from the standpoint of the safety, but also its durability.

In addition, the importance of Δimpedance monitoring during ablation was also re-acknowledged in order to avoid dormant conduction, especially when it disrupts an ablation application near the oesophagus with a smaller duration and FTI. The initial Δimpedance-based ablation was reported to be efficient for a better prognosis, however, oesophageal injury was observed in 12% of patients in the previous study [24]. Our data showed that the Δimpedance was an independent risk factor for dormant conduction near the oesophagus, but the sensitivity and specificity were not adequate enough to rely on.

As operators strive to create a concrete lesion, a countermeasure must be taken to preserve its safety. Since the prophylactic use of proton pump inhibitors [25] or cooling of the oesophagus [26,27] may not supply a satisfactory option, our data suggested that coping with a lower ET elevation might result in a safer and sufficient ablation.

Limitations

The number of redo sessions was too small to elucidate the durability of the isolation. The data on each RF energy application was obtained when the tag was acquired by the CARTO™ system. The timing of the tagging was aimed to be consistent, but it might have affected the parameters. The incidence of reconnections might have been underestimated, since we did not perform a redo-session in all patients. Gastroscopy was not routinely performed to rule out the oesophageal anatomy and minor complications, such as a diverticulum or oesophageal haematoma [28]. The trigger for making a diagnosis of gastroparesis mainly depended on the patient's symptoms and x-rays at the clinic visits. A quantitative measure for the thermal oesophageal injury would be helpful. We used a straight three-electrode temperature monitor to measure the ET, which obviously did not cover the width of the oesophagus, and if the CIRCA S-CATH™ system (CIRCA Scientific, Englewood, CO, USA) which has a two-plane sinusoidal shape to cover a wider area of the esophagus can be used, the results could change.

Conclusions

Atrial fibrillation ablation utilising an oesophageal temperature cut-off of 38 °C might be safe and durable.

Conflict of Interest

None declared.

Funding Sources

None.

Acknowledgements

None.

Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at https://doi.org/10.1016/j.hlc.2018.05.197.

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