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ORIGINAL ARTICLE

Intra-procedural evaluation of the cavo-tricuspid isthmus anatomy with different techniques: comparison of angiography and intracardiac echocardiography

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Abstract

Cavo-tricuspid isthmus (CTI) anatomies are highly variable, and specific anatomies lead to a difficult CTI ablation. This study aimed to compare the clinical utility of angiography and intracardiac echocardiography (ICE) in evaluating CTI anatomies, and to investigate the impact of the CTI anatomy on the procedure when the ablation tactic was adjusted to the anatomy. This study included 92 consecutive patients who underwent a CTI ablation. The CTI morphology was assessed with both right atrial angiography and ICE before the ablation, and the ablation tactic was adjusted to the anatomy. The mean CTI length was 34 ± 9 mm. On ICE imaging, 21 (23%) patients had a flat CTI, while 41 (45%) had a concave CTI with a mean depth of 5.6 ± 2.7 mm. The remaining 30 (32%) had a distinct pouch with a mean depth of 6.4 ± 2.3 mm, located at the posterior, middle, and anterior isthmus in 15, 14, and 1 patients, respectively. The Eustachian ridge (ER) was visualized in 46 (50%) patients. On angiography, a pouch and ER were detected in 22 and 15 patients, but not in the remaining 8 and 31, respectively. A complete CTI block line was created in all patients without any complications. The CTI anatomy did not significantly impact any procedural parameters. ICE was superior to angiography in evaluating the detailed CTI anatomy, especially pouches and the ER. An adjustment of the ablation tactic to the anatomy could overcome the procedural difficulties of the CTI ablation in cases with specific anatomies.

Keywords Cavo-tricuspid isthmus · Intracardiac echocardiography · Catheter ablation

Introduction

The electrophysiologic substrate underlying atrial flutter has been shown to have a slow conduction velocity in the cavo-tricuspid isthmus (CTI) between the tricuspid annulus (TA) and inferior vena cava (IVC), and the ablation of the CTI has been an established treatment strategy [1]. The CTI is anatomically bound by the IVC and Eustachian ridge (ER) posteriorly and by the TA anteriorly, however, the anatomy in individual patients is highly variable and unpredictable prior to the procedure [2], which has an influence on the procedural difficulty. Indeed, a specific anatomy such as a sub-Eustachian pouch in the CTI leads to a more complex procedure [3, 4]. The detailed anatomy of the CTI has been assessed by intra-procedural angiography [3, 4] and intracardiac echocardiography (ICE) [5.6]; however, few studies have compared the utility of the two modalities. The aims of this study were (1) to compare the clinical utility of angiography and ICE in the evaluation of the detailed CTI anatomy, and (2) to investigate the impact of the CTI morphology on the procedural parameters and outcomes of the CTI ablation when the ablation tactic was adjusted to the morphology.

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Methods

Study population

This study consisted of 92 consecutive patients who underwent a CTI ablation following pulmonary vein isolation of atrial fibrillation between May 2013 and April 2015 in our institute. The anatomy of the CTI was evaluated with both right atrial (RA) angiography and ICE prior to the CTI ablation. All the patients gave their written informed consent. The study protocol was approved by the hospital's institutional review board. The study complied with the Declaration of Helsinki.

Angiographic evaluation

Biplane RA angiography was performed by positioning a 5 F pigtail catheter at the level of the superior vena cava and RA junction. Contrast was injected with a speed of 15 ml/s and the total injection volume was 35 ml. The angiograms were digitally acquired in the right anterior oblique and left anterior oblique views (Fig. 1a, b). This visualized the inferior isthmus between the Eustachian valve and hinge of the septal leaflet of the tricuspid valve. A detailed measurement was performed after the study period.

Intracardiac echocardiography

An ICE probe with a CARTO navigation sensor imbedded close to the phased array (SoundStar, Biosense Webster, Diamond Bar, CA, USA) was positioned into the low RA. The representative images were stored, and all detailed measurements (mentioned below) were performed after the study period. The anatomical parameters were measured during the latest atrial diastolic phase. The perpendicular distance between the line connecting the tricuspid valve and IVC and deepest point of the isthmus were quantified (Fig. 1c). According to the previous work, the patient groups were classified by the CTI length (short, ≤ 35 mm, or long, > 35 mm) and CTI morphology (straight, concave, and presence of a pouch) (Fig. 2a–b) [4]. The maximal perpendicular distance between the line of the IVC–tricuspid ring and isthmus was < 2 mm (straight) or > 2 mm (concave) [3]. A pouch was defined when the isthmus could be divided by a flat vestibular part against the TA and a pouch-like recess [4]. We also assessed whether the ER was clearly visualized (Fig. 2d).

Catheter ablation procedure

Patients were taken off antiarrhythmic drugs for at least 5 half-lives with the exception of amiodarone. Procedures were performed under dexmedetomidine and thiopental. The surface electrocardiogram and bipolar intracardiac

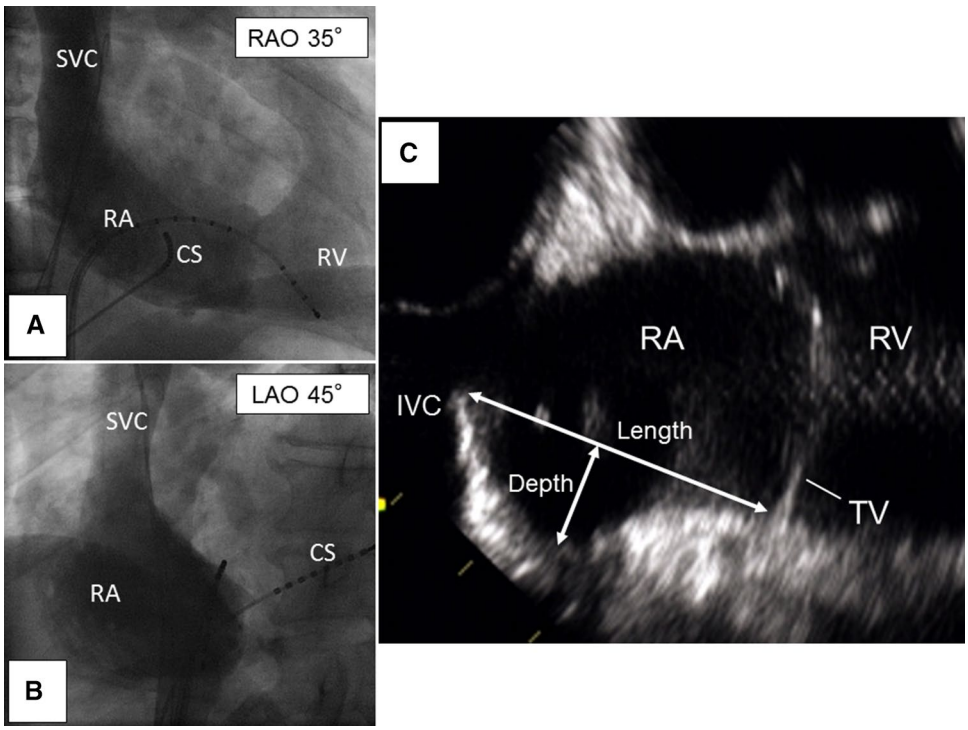

Fig. 1 Visualization of the CTI anatomy by angiography (**a** RAO view, **b** LAO view) and ICE (**c**). The length and depth of the CTI were measured on ICE. *CS* coronary sinus, *CTI* cavo-tricuspid isthmus, *ICE* intracardiac echocardiography, *IVC* inferior vena cava, *LAO* left oblique view, *RA* right atrium, *RAO* right oblique view, *RV* right ventricle, *TV* tricuspid valve

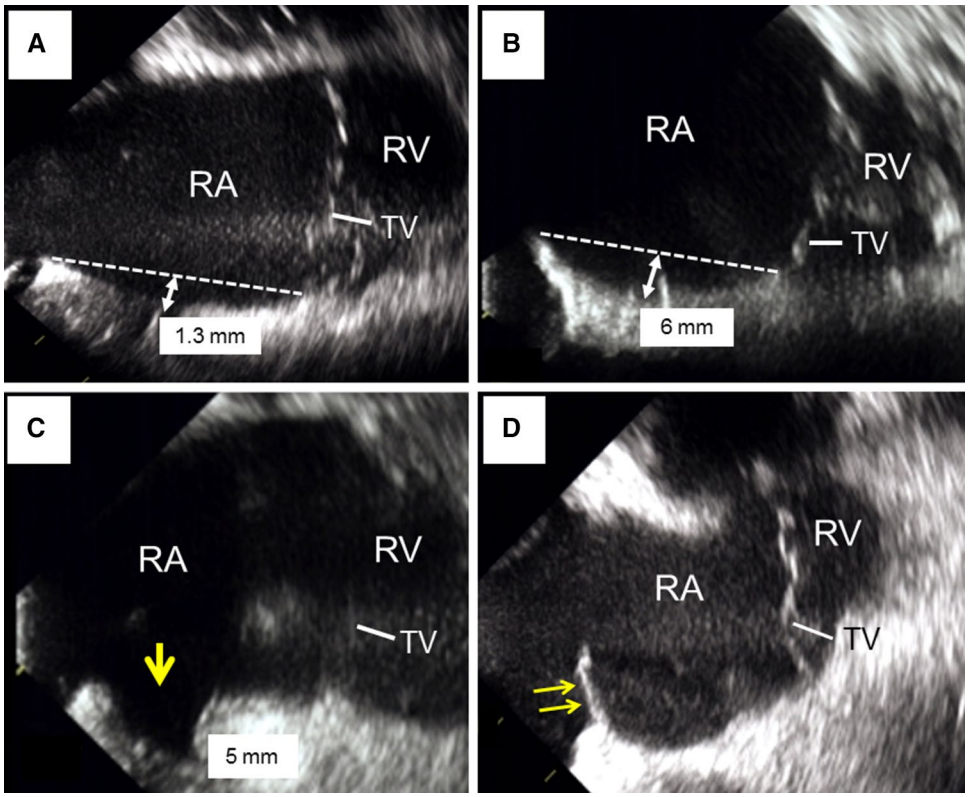

Fig. 2 Variations in the CTI anatomy. **a** Straight type, **b** concave type, **c** presence of a pouch (yellow arrow), **d** presence of a Eustachian ridge (ER) (yellow arrows). *RA* right atrium, *RV* right ventricle, *TV* tricuspid valve

electrograms were continuously monitored and stored on a computer-based digital recording system (EP-WorkMate, St. Jude Medical, Minneapolis, MN, USA). In all the patients, following an anatomical evaluation with RA angiography and ICE, the CTI ablation was performed with an irrigation tip catheter (Thermocool, SmartTouch, or Surround Flow, Biosense Webster, Diamond Bar, CA, USA) with support by a long sheath (SL-0, St. Jude Medical, Minneapolis, MN, USA) under fluoroscopic and 3-D mapping system (CARTO3, Biosense Webster) guidance. RF current was delivered with a power of up to 35 W and CF of > 10 g (if contact force was available) in a point-by-point fashion, and the footprint was tagged on the 3D mapping system (Fig. 3a). In the cases with a pouch or ER and not achieving

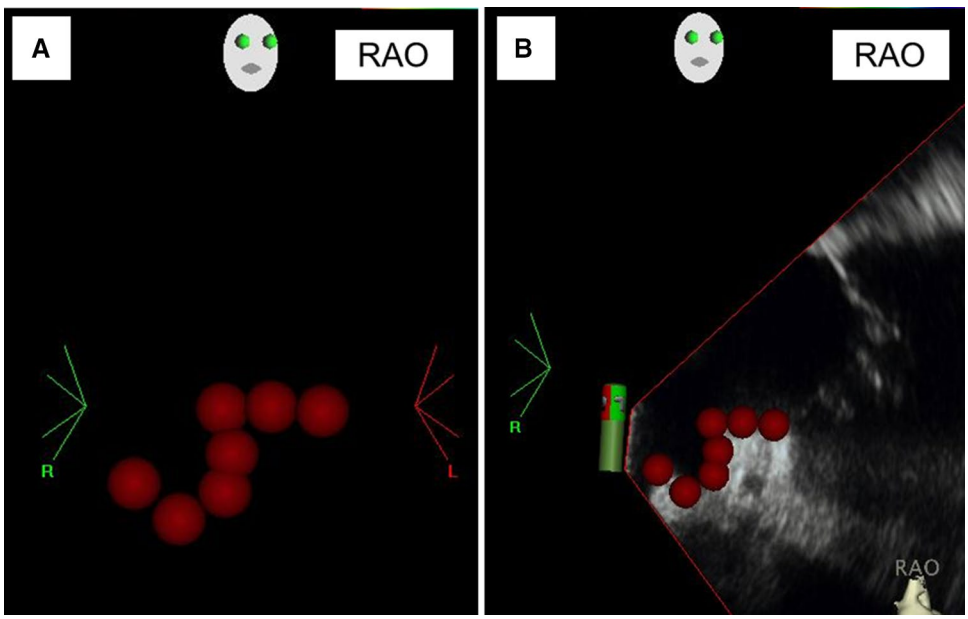

Fig. 3 **a** Radiofrequency applications were applied to the CTI in a point-by-point fashion, and the red tags indicate each RF application site. **b** The ablation points are shown along the CTI anatomy as evaluated by ICE

complete block, a catheter with very short curve, like the shape of a sigma, was used for an effective touch. We created the linear lesion at 6 o'clock in the left oblique view, and did not change the ablation line medially or laterally based on the observation of the anatomy. The procedure endpoint was defined as a complete bidirectional conduction block along the CTI line validated with a differential pacing technique and double potentials along the entire ablation line, as described elsewhere [5]. The cumulative time and energy of the RF delivery were recorded.

Statistical analysis

Continuous variables are given as the mean ± SD and were compared using a Student's *t* test or ANOVA. A probability value of $p < 0.05$ was accepted as statistically significant.

Results

Among a total of 92 patients, 68 (74%) were men, and the mean age was 64 ± 10 years. Four patients (4%) had structural heart disease including ischemic heart disease in three and hypertrophic cardiomyopathy in one.

On the ICE imaging, the mean CTI length was 34 ± 9 mm (range 18–59 mm). The CTI morphology is summarized in Table 1. 21 (23%) patients had a flat CTI, and 41 (45%) had a concave CTI with a mean depth of 5.6 ± 2.7 mm (range 2.4–13.2 mm). The remaining 30 (32%) had a distinct pouch with a mean depth of 6.4 ± 2.3 mm (range 3.4–11.7 mm). The length of a straight CTI was significantly longer than that of a concave CTI and a CTI with a pouch (Table 1). The pouches were located on the IVC side (posteriorly), middle isthmus, and TA side (anteriorly) in 15, 14, and 1 patients, respectively. The ER was visualized in 46 (50%) patients.

On the angiographic evaluation, a pouch was detected in 22 patients, but was not identified in the remaining eight patients among the 30 patients in whom a pouch was identified on ICE imaging (Figs 3b, 4, 5). An ER could be visualized in 15 patients, but not identified in the remaining 31 patients among the 46 in whom an ER was identified on ICE imaging.

A complete block line of the CTI was achieved in all patients without any complications. No audible pops were observed in any patients. In patients with a pouch and/or ER, a complete CTI block line could be created by careful manipulation of the catheter at those portions. Complete block was achieved at the portion of the ER in 50% of the patients with ER (Fig. 6). Neither the CTI length nor CTI morphology significantly impacted the procedure time, total RF duration, and total RF energy in the CTI ablation (Table 2).

At a mean of 17 months after the procedure, nine patients underwent a second ablation procedure for recurrent atrial fibrillation. Among them, conduction resumption of the CTI line was found in seven patients (straight, concave, and a pouch in 0, 6, and 1 patients, respectively), and four patients had an ER. All conduction gaps were successfully closed during the second procedure in all the patients.

Discussion

The present study showed the superiority of ICE over RA angiography as a technique to evaluate the detailed anatomical structures of the CTI. Ablation adjusted to the patient-specific isthmus anatomy lead to a successful CTI ablation without any complications or any differences in the procedural parameters.

Anatomical evaluation of the CTI

Revealing the anatomic isthmus could be accomplished by several modalities, yet RA angiography has been a widely

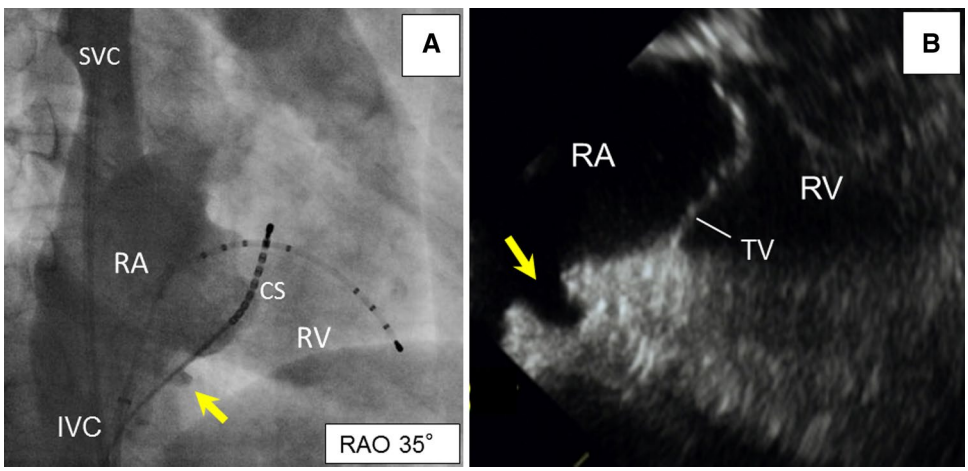

Fig. 4 A representative case in whom a pouch was identified by both angiography (**a** yellow arrow) and ICE (**b** yellow arrow). *CS* coronary sinus, *ICE* intracardiac echocardiography, *IVC* inferior vena cava, *RA* right atrium, *RAO* right oblique view, *RV* right ventricle, *SVC* superior vena cava, *TV* tricuspid valve

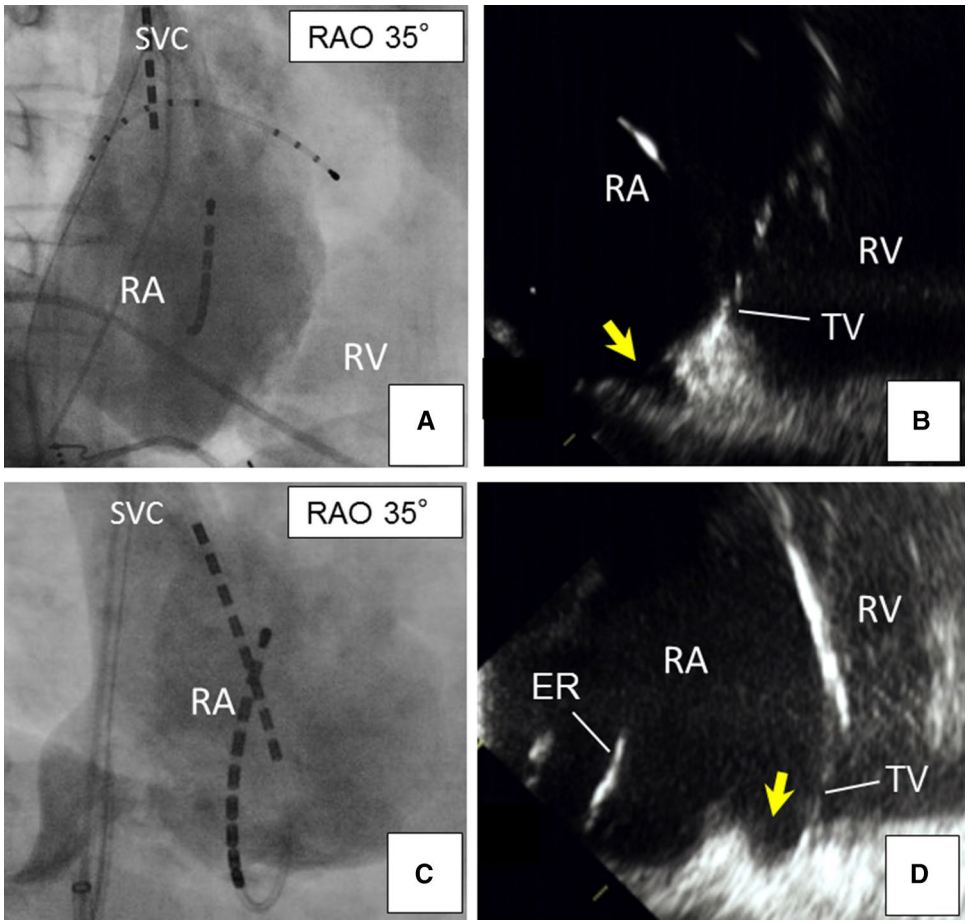

Fig. 5 Two representative cases (upper and lower panels) in whom a pouch was identified by ICE (**b**, **d**) but not by angiography (**a**, **c**). *ER* Eustachian ridge, *ICE* intracardiac echocardiography, *RA* right atrium, *RAO* right oblique view, *RV* right ventricle, *SVC* superior vena cava, *TV* tricuspid valve

Table 1 CTI anatomy evaluated with ICE

	Straight	Concave	Pouch	*p* value
Number of patients, *n* (%)	21 (23)	41 (45)	30 (32)	
CTI length, mm				
> 35mm/≦35mm	17/4	13 / 28	10/20	< 0.01
ER				
ER (+)/ER (−)	8/13	22 / 19	16/14	0.46

CTI cavo-tricuspid isthmus, *ER* Eustachian ridge, *ICE* intracardiac echocardiography

available and inexpensive technique. The usefulness of RA angiography in the evaluation of the isthmus anatomy has already been established [3, 4]. Moreover, an excellent correlation between the isthmic measurements made on angiography and on postmortem examination has established the validity of the technique [6]. A detailed angiographic evaluation revealed that the width of the isthmus was 31.3 ± 7.9 mm, an ER was visualized in 24%, and that a deep sub-Eustachian recess was revealed in 47%, with a mean depth of 4.3 ± 2.1 mm, however, there was a high variability in the anatomy [3].

ICE was more recently introduced as a unique, real-time imaging technique to assist catheter ablation. Morton et al. [7] elegantly reported the detailed anatomical topography of the CTI in 15 patients. They reported that the isthmus length was 30–35 mm, and that a pouch or recess was seen in the majority of the patients. Another study showed that an ICE-guided CTI ablation significantly shortened the procedure and fluoroscopy times than a conventional ablation (without the evaluation of the isthmus anatomy) [8]. However, to the best of our knowledge, there has been no direct comparison between the RA angiography and ICE with respect to the intra-procedural evaluation of the isthmus anatomy. In the present study, we clarified that ICE was more sensitive than angiography in identifying the important structures for the CTI ablation, such as a pouch and ER, using both techniques in the same patients. The other advantages of ICE are real-time visualization without radiation exposure and the use of contrast, and capability of multi-plane evaluation. Our observation of the CTI morphology was in accordance with the published data on pathology study and clinical studies [2–4, 7, 9].

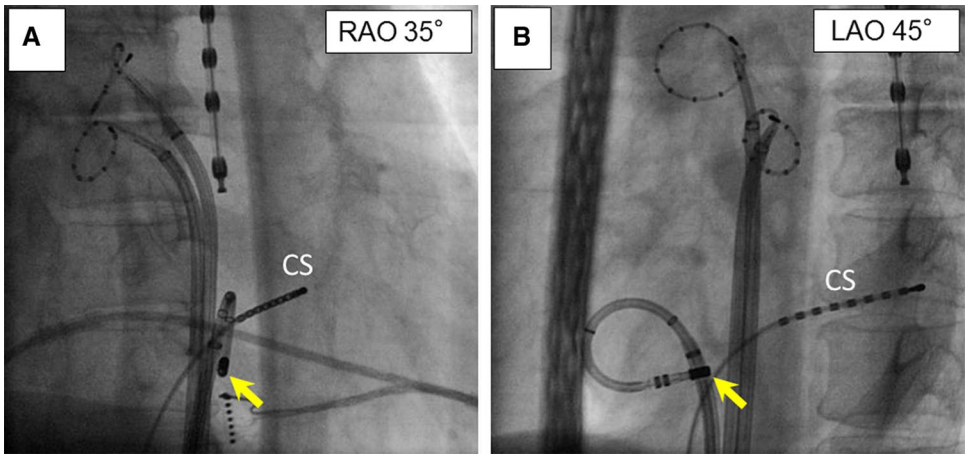

Fig. 6 The representative image of the sigma curve technique in the CTI ablation. The ablation catheter was placed like the shape of a sigma to reach the isthmus immediately behind the ER (yellow arrows) (**a** RAO view, **b** LAO view). *CS* coronary sinus, *LAO* left oblique view, *RAO* right oblique view

Table 2 Association between the CTI anatomy and procedural parameters

	Number of patients, *n* (%)	Procedure time, min	Total RF time, s	Total RF energy, J
(A) CTI morphology				
Morphology				
Straight	21 (23)	13.0 ± 5.5	471.3 ± 156.2	15,645.8 ± 5132.6
Concave	41 (45)	13.0 ± 7.9	455.9 ± 221.5	18,105.7 ± 19,632.4
Pouch	30 (32)	12.7 ± 7.6	417.7 ± 203.6	13,281.6 ± 6082.2
p value		0.98	0.61	0.35
(B) CTI length				
Length				
> 35mm	40 (43)	11.9 ± 4.9	438.2 ± 211.3	17,581 ± 19,884.6
≦35mm	52 (57)	13.7 ± 8.6	453.8 ± 195.3	14,732 ± 5972.2
p value		0.20	0.72	0.39
(C) Eustachian ridge				
Ridge				
Ridge (+)	46 (50)	13.2 ± 9.1	441.1 ± 205.9	17,684 ± 18,463.7
Ridge (−)	46 (50)	12.6 ± 4.9	452.9 ± 199.0	14,258 ± 6345.6
p value		0.68	0.78	0.24

CTI cavo-tricuspid isthmus, *RF* radiofrequency

Impact of the isthmus anatomy on the CTI ablation

Ablation difficulties are typically caused by the anatomical width, pouches, muscular bridges or trabeculae, and the presence of an ER. The presence of sub-Eustachian recesses, evaluated by angiography, significantly prolongs the ablation time and is associated with a higher risk of complications and a lower rate of success [3]. A study revealed that ER peculiarities might represent a site of conduction gaps ''resistant'' to ablation [8]. A prospective study revealed that unsuccessful cases with a conventional approach were more likely to have peculiar isthmus anatomies including a concave isthmus with the presence of a pouch [10]. The majority of these anatomical obstacles are unfortunately detected only at the time of the CTI ablation, which significantly prolongs the procedure time and reduces the success rate. The CTI ablation is generally performed with RF ablation from the TA to the edge of the IVC while confirming the continuity of the ablation lesion under fluoroscopy or 3-D mapping system guidance without a detailed evaluation of the anatomy. On the contrary, in the present study, the operators evaluated the detailed CTI anatomy prior to the RF applications. Then, the CTI ablation was performed in a point-by-point fashion while considering the CTI anatomy (Fig. 3a). Although the images were not merged during the ablation, the footprints well correlated with the CTI anatomies obtained from ICE (Fig. 3b). Our findings, together with the published literature, showed that a universal ablation approach might not be optimal, and that individualization of the ablation approach depending on the CTI morphology might be rational. This

was especially true if there was a deep sub-Eustachian pouch, a concave deformation of the isthmus, or the presence of an ER. The results of the present study highlighted the importance to adjust the ablation tactic to the isthmus morphology of individual patients and the utility of ICE in identifying the detailed anatomical structure.

Study Limitations

First, this was a single-center observational study. Second, ICE requires an additional cost and its use is not affordable solely for the CTI ablation due to the lack of reimbursement in many countries.

Conclusions

ICE was superior to angiography in identifying the detailed CTI anatomy, especially pouches and the ER. Adjustment of the ablation tactic to the anatomy could overcome the procedural difficulties of the CTI ablation in cases with a specific anatomy.

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Compliance with ethical standards

Conflict of interest The authors declare that they have no competing interests.

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