Typical atrial flutter ablation outcome: correlation with isthmus anatomy using intracardiac echo 3D reconstruction

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Abstract

Aims To verify if sites of conduction gaps on the isthmus correlate with anatomical peculiarities using the intracardiac echo (ICE) and a new 3D device to reconstruct the isthmus in patients undergoing cavotricuspid isthmus ablation.

Methods and results Twenty patients underwent isthmus ablation using an 8 mm tip ablation catheter. Two-dimensional and 3D ICE reconstruction of the isthmus was made before, during and after ablation. At the end of the lesion line isthmus block was validated by electrophysiological criteria. In case of its absence we closed the remaining conduction gaps verifying the position of the sites with ICE. Fourteen patients required a median of 8 RF pulses to obtain complete isthmus block (Group A). In the remaining 6 patients isthmus block was obtained with a median of 25 RF pulses due to conduction gaps 'resistant' to ablation (Group B). Conduction gap positions assessed by ICE were located in the central portion of the isthmus below the coronary sinus os in 71% of cases in Group A and along a prominent Eustachian ridge in Group B patients, respectively. 3D reconstruction showed a smooth isthmus in Group A with a 'peak and valleys' isthmus in Group B. In these latter patients isthmus block was obtained only after the complete ablation of the prominent Eustachian ridge.

Conclusion The isthmus presents anatomical variants particularly due to Eustachian ridge peculiarities which may represent a site of conduction gaps "resistant" to ablation.

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KEYWORDS atrial flutter; radiofrequency ablation; intracardiac echocardiography; isthmus anatomy
Introduction

Radiofrequency (RF) ablation of typical atrial flutter (AFL) uses as target the inferior vena cava-tricuspid annulus (IVC-TA) isthmus which represents the critical area of the reentry circuit [1–14].

The end point of the ablation procedure is the production of an IVC-TA isthmus block [15–19]. The inability to produce such a block or the recurrence of AFL has been correlated with the presence of conduction gaps along the RF lesion line [20]. A cooled tip catheter, producing deeper lesions, has been used effectively [21,22] to overcome this problem. These clinical results may imply that anatomical peculiarities exist between patients affecting the ablation outcome.

To our knowledge no data are available about the correlation of anatomy and morphology of the IVC-TA isthmus and AFL resistant to ablation.

The aim of this study was to perform a two-dimensional and 3D intracardiac echo reconstruction of the IVC-TA isthmus in order to verify if the isthmus anatomy correlated with the isthmus ablation outcome. In particular, we tried to locate the sites of conduction gaps and to verify if sites of conduction gaps resistant to ablation correlated with specific anatomical peculiarities.

Methods

Study population

This study included 20 patients, 14 males and 6 females (age 60±10 years) who had episodes of typical counterclockwise AFL. Four patients had cardiomyopathy (2 dilated cardiomyopathy, 1 ischaemic cardiomyopathy and 1 mitral regurgitation), 16 patients presented AFL not associated with cardiac disease. All patients gave written informed consent.

Intracardiac echocardiography

At the beginning of the procedure we first performed intracardiac echocardiography (ICE) using a 9-MHz ultrasound transducer mounted at the tip of a 9F catheter (model 9900 Ultra ICE, Boston Scientific EP Technologies, Orchard Parkway, San Jose, CA, USA). The catheter was positioned in the right atrium through a long sheath with an angle of 120° at its distal portion (9F Soft Tip Sheath 60 cm length, 120° III, Boston Scientific EP Technologies, Orchard Parkway, San Jose, CA, USA) inserted via the femoral venous approach. Two-dimensional images were acquired with a Clear View Ultra System (Boston Scientific). The system provided a maximal radial imaging depth up to 10 cm and an optimum axial resolution of 0.2–0.3 mm. Images were recorded on S-VHS videotapes for review. The ICE catheter was positioned across the tricuspid (T) valve and then withdrawn from the ventricular aspect of the T ring toward the IVC. The imaging plane obtained with this scanning allowed visualization of specific landmarks in the low right atrium such as the T valve, the coronary sinus (CS) os, the fossa ovalis and the Eustachian ridge.

The ICE was performed before, during and after ablation analyzing the position of each RF ablation site. During the mapping and ablation procedure the distal ablation electrode was identified with ICE by means of the characteristic and specific fan-shaped acoustic shadow and its relative position was established as previously described [23,24].

In addition to this manual scanning the ICE catheter was used in combination with a 3D ultrasound system (TomTec, Munich).

The 3D ultrasound system consists of a device that automatically pulls back the catheter stepwise (0.5 mm for each step), gated by the R–R and respiration signal of the patient. Transthoracic electrodes are used to acquire the gating signals. In each position of the transducer a clip of a full cardiac cycle is acquired. Postprocessing algorithms transform the two-dimensional image slices into a dynamic volumetric dataset representing the anatomical structures. The spatial resolution along the catheter axis is determined by the size of the individual steps which has been 0.5 mm. Image transfer was performed via video channel (PAL) which leads to a temporal resolution of the dynamic sequences of 25 frames/s.

The pullback length from the right ventricular entry to the IVC was between 50 and 70 mm.

For later reviewing of the volumetric dataset the 3D ultrasound system allows retrieval of an infinite number of cardiac cross-sections even imaging planes that cannot be assessed originally by the catheter. For the present study mostly oblique planes were used to render 3D projections that view the isthmus from a stand-point above the IVC looking towards the T valve, with fossa ovalis, CS and T valve itself as reference structures.

In order to verify the reproducibility of the 3D reconstruction we performed each acquisition scan twice for the first six patients.

Electrophysiological study

Antiarrhythmic drugs had been discontinued for at least five half lives and no patient had received...
amiodarone in the preceding 6 months. The electrophysiological study was performed using a standard decapolar Halo catheter (Cordis-Webster Inc., Baldwin Park, CA, USA) positioned in the right atrium. The Halo catheter was placed adjacent to the tricuspid annulus with the distal bipole in the low lateral right atrium and the proximal bipole positioned on the interatrial septum above the His bundle. An octapolar steerable catheter with 2 mm interelectrode distance (Cordis-Webster Inc., Baldwin Park, CA, USA) was positioned in the CS and was used to pace and to map the region of the coronary sinus os and its proximal portion. Both catheters were inserted via a femoral venous approach. Bipolar digitized atrial electrograms up to 28 simultaneous endocardial sites and 12 lead surface ECG were simultaneously recorded (1 kHz sampling frequency, 30–500 Hz band pass filters), displayed on a multichannel recorder and stored on magneto-optical disks (Cardiolab, Prucka GE Marquette, Milwaukee, Wisconsin, USA).

In patients in AFl, endocavitary mapping was performed before the ablation and concealed entrainment was used to confirm that the IVC-TA isthmus was part of the reentry circuit.

In patients in sinus rhythm (SR) we used the pacing protocol to validate the isthmus conduction at 600 and 400 ms cycle length as previously described [15,17].

Ablation procedure

Radiofrequency ablation was performed with a generator EPT-1000 XP (EP Technologies, Mountain View, CA, USA) that delivered continuous unmodulated current at 500 kHz in monopolar fashion and had a maximum power output of 150 W.

RF lesions were performed using a 8 mm tip electrode catheter (Blazer XP large curve, EP Technologies, Mountain View, CA, USA) in a temperature guided mode (preset temperature of 60–70 °C).

The ablation catheter was introduced into the right atrium by a right femoral venous approach. Initial position of the ablation catheter within the isthmus near the T annulus was such that a large ventricular potential and a small atrial electrogram were recorded (A/V ratio 0.1). The preset duration of the pulse was 60 s.

The isthmus ablation was performed using the point by point technique withdrawing the ablation catheter, under fluoroscopic guidance, from the T ring up to the junction between the right atrium and the IVC in the posteroseptal area. The end point of the procedure was the achievement of a complete bidirectional block on the IVC-TA isthmus as previously described [15–19].

In patients in SR the ablation procedure was performed during pacing from CS (output twice threshold) at a drive cycle length of 600 ms. After completion of the line or after the AFI interruption, we validated the presence or absence of conduction block on the IVC-TA isthmus by pacing from the low right atrium and the proximal CS. In case of the absence of a complete bidirectional block we mapped the lesion line looking for conduction gaps defined as sites with single, fragmented or double but very close atrial electrograms between two sites with split electrograms and a well defined isoelectric interval (Fig. 1). The site of conduction gap defined by the above mentioned electrophysiological criteria was correlated with the anatomical position by ICE because it was possible to detect the tip of the ablation catheter by means of the specific fan-shaped acoustic shadow.

RF was delivered at each site of conduction gap until a clear separation between the two atrial components was obtained and consequently the isthmus block was achieved.

Finally, AFI inducibility was tested using atrial bursts up to 200 ms.

Results

At the time of the procedure 10 patients were in SR and 10 patients presented typical AFI with mean cycle length of 268.8 ± 30.6 ms (range 240–320 ms).

Ablation results

The ablation procedure was performed successfully in all 20 patients. In the ten patients presenting AFI at the time of the procedure, interruption of the arrhythmia during RF delivery was obtained. The median number of RF pulses was 10 (range 1–38). No immediate or late complications were seen.

After a retrospective analysis, it resulted that 14 patients required a median of 8 RF pulses to obtain a complete isthmus block (Group A) while in the remaining six patients a median of 25 RF pulses was necessary to achieve the same ablation endpoint (Group B). In the Group B patients, sites of conduction gaps resistant to more than 2 RF pulses (delivered on the same site) were present.

In Group A eight patients were in SR and six patients were in AFI at the time of the procedure. Three patients of these 14 (two in SR and the other
in AFL) presented at the completion of the lesion line (1, 5 and 7 RF pulses) complete block without any residual conduction gaps. In the remaining 11 patients it was necessary to deliver more RF pulses (from one to three) to close some conduction gaps, after having completed the lesion line extending from the TA to the edge of the IVC.

In Group B four patients were in SR and two patients were in AFL at the time of the procedure. At the end of the completion of the lesion line the isthmus conduction was still evident in all these six patients because of the presence of a residual single conduction gap. Closing these conduction gaps to obtain complete isthmus block, required

Figure 1  Top: Anatomical representation of the right atrium as shown in RAO view. IVC, inferior vena cava; FO, fossa ovalis; CS, coronary sinus os; T, septal leaflet of the tricuspid valve. The black bar with white numbers represents a schematic lesion line along the isthmus and numbers correlate with the mapping position. A, anterior portion of the isthmus; C, central portion of the isthmus; I, inferior portion of the isthmus. Bottom: endocardial recordings during mapping along the lesion line while pacing from proximal CS. CS, coronary sinus os; ABL, distal bipole of the ablation catheter; I, V1, ECG surface leads; A, atrial electrogram. Panel 3 shows a fragmented atrial potential with separate components but still very close to each other surrounded by sites with split atrial electrograms (A) and a well defined isoelectric interval (recordings from panels 1, 2, 4). Panel 3 is a typical recording from a conduction gap site (black star).
a much higher number of additional RF deliveries compared with the fewer number of RF pulses used in the Group A patients (Table 1).

**Conduction gap’s location assessed by ICE**

Isthmus as viewed in the RAO projection was arbitrarily divided in an anterior (close to TA) central and inferior (close to the IVC orifice) portion (Fig. 1).

**Group A**: in 11 of the 14 patients a total of 14 gaps were found. Ten (71%) gaps were in the central portion of the isthmus, just in front of the CS os, one (7%) was in an anterior portion close to the TA and three (21%) were in an inferior portion near the edge of the IVC orifice. No specific anatomical structures were identified as being correlated with these sites.

**Group B**: in the six patients with a total of six gaps (one gap in each patient) all these gaps were located at the same site: the border between the central and inferior portion of the isthmus at the level of a prominent Eustachian ridge.

This site correlated with an atrial electrogram which was only slightly affected by initial RF deliveries.

In these patients complete block was obtained only after the complete abolition of electrical conduction along this structure by means of RF applications.

It was also possible to visualize the effects of RF deliveries with two-dimensional ICE. One hundred and ninety-two RF pulses were delivered in all 20 patients and in 107 (56%) after the RF delivery, we were able to detect the appearance on the isthmus surface of a depression that in 46 of 107 (43%) was surrounded by a more echogenic border probably expression of local oedema (Fig. 2).

**Intracardiac echocardiography 3D reconstruction**

The intracardiac echo procedure and 3D reconstruction was feasible and reproducible.

By means of ICE reconstruction two different types of isthmus anatomy were evident on a mere morphological basis.

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**Table 1**

<table>
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**Group B**

| 15      | 7                      | 1                     | 10                    | 17                   | E       |
| 16      | 8                      | 1                     | 16                    | 24                   | E       |
| 17      | 10                     | 1                     | 28                    | 38                   | E       |
| 18      | 10                     | 1                     | 8                     | 18                   | E       |
| 19      | 9                      | 1                     | 16                    | 25                   | E       |
| 20      | 11                     | 1                     | 16                    | 27                   | E       |

Ablation data in the study population: No. of RF pulses (line), number of radiofrequency pulses to complete the initial line; No. of conduction gaps, number of conduction gaps in the lesion line; No. of RF pulses (gap), number of subsequent radiofrequency applications to eliminate conduction gaps; No. of RF pulses (total), total numbers of radiofrequency pulses to obtain complete isthmus block; Gap site, conduction gap site on the isthmus; A, anterior portion; C, central portion; I, inferior portion; E, prominent Eustachian ridge.
No quantitative data (height and thickness) were measured but the differentiation was made only on the basis of the morphological aspects of the isthmus.

(1) All Group A patients showed a smooth isthmus with slight irregularities parallel to the TA, probably due to the pectinate muscles coming from the end of the crista terminalis in the low lateral right atrium. In this type of isthmus the Eustachian ridge was small and had a prevalent vertical direction on the septum between the IVC and CS os. This structure was not involved in the IVC-TA isthmus (Fig. 3).

(2) All Group B patients presented a different isthmus anatomy due to a prominent Eustachian ridge having a different course. The Eustachian ridge looked like a membrane outlining the anterior part of the IVC orifice toward the T ring, coming from the low lateral atrium and directed toward the CS os where it became smoother. Therefore, in contrast to the

Figure 2  (A) Two-dimensional intracardiac echocardiographic (ICE) image of the anterior portion of the isthmus (arrow) before the RF delivery in patient 2 (see Table 1). (B) Two-dimensional ICE image of the same anterior portion of the isthmus shown in (A) after the RF delivery. The two-dimensional ICE plane makes a perpendicular cut of the anterior portion of the isthmus, the interatrial septum and the lateral wall of the right atrium. In (B) it is possible to appreciate that a portion of the isthmus has become more echogenic and thicker (arrow), which is most likely to be an expression of local oedema due to RF delivery. FO, fossa ovalis; RA, right atrium.

Figure 3  Two different projections of 3D reconstruction of the inferior vena cava-tricuspid isthmus (patient 6 in Table 1). This picture shows an example of a smooth isthmus with slight irregularities. In this case the Eustachian ridge is vertical, behind the coronary sinus os. *, coronary sinus os; IVC, inferior vena cava orifice; T, septal leaflet of the tricuspid valve; E, Eustachian ridge.
previous group the isthmus in these patients was a 'peak and valleys' shaped structure (Fig. 4). In all cases of 'resistant' AFl ablation the site of conduction gap correlated with a prominent Eustachian ridge crossing the isthmus (Fig. 5).

In two patients of Group A, the above-mentioned two-dimensional ICE visualization of the effects of RF deliveries was documented for all the ablation sites. In these patients the complete 3D reconstruction of the whole lesion line appeared as an image of a rail along the isthmus (Fig. 6).

Follow up

After a mean follow-up of 13.1 ± 2.01 months (range 9–17) no recurrence of typical AFl was noted.

Discussion

The present study has shown that the IVC-TA isthmus is not uniform and different anatomical variants can be demonstrated. These in vivo observations correlate well with what has been already described in anatomical reports. Waki et al. [25] examined 50 hearts obtained at autopsy demonstrating a non-uniform muscular trabecular pattern in the lower part of the right atrium, the zone known as the 'flutter isthmus'. In particular the non-uniformity was conspicuous in the area immediately inferior to the coronary sinus os. Two different anatomical patterns were evident, one with a uniform trabecular pattern and the other with a non-uniform trabecular pattern. Muscular defects between trabeculae were differently distributed in the two groups. In both groups the majority of the hearts presented the Eustachian valve containing muscular extensions from the terminal crest to the CS os.

Similar findings were also made in our study. In fact, the 3D reconstruction allowed differentiation of the isthmus zone into two types. One group (A) presented a smooth isthmus while the second (B) a 'peak and valleys' shaped structure. The major anatomical difference between the two groups was represented by a different extension and location of the Eustachian ridge. In Group A patients the Eustachian ridge was small and had a prevalent vertical direction on the septum between the IVC and CS os. This structure was not involved in the
IVC-TA isthmus. In Group B patients the Eustachian ridge (E) originates in the low lateral right atrium (L) from the terminal portion of the crista terminalis. The middle panel shows the ablation catheter (white arrow) positioned on the Eustachian ridge on the corresponding site of an electrophysiologically determined conduction gap. Right panel shows a 3D reconstruction of the isthmus in the same patient (patient 20, Table 1). S, interatrial septum; E, Eustachian ridge; L, low lateral wall of the right atrium; white arrow indicates the tip of the ablation catheter on the Eustachian ridge; *, coronary sinus os; T, septal leaflet of the tricuspid valve; IVC, inferior vena cava; black star, site of conduction gap resistant to ablation. Bottom: endocardial traces during pacing from the coronary sinus os in (A) before and in (B) after RF delivery to a conduction gap site. Endocardial recordings. H 1-2 up to H 19-20: Halo catheter positioned around the tricuspid valve with electrode 1-2 in the low lateral right atrium; CS, coronary sinus os; ABL d, distal bipole of the ablation catheter; ABL p, proximal bipole of the ablation catheter; II, V1, ECG surface leads; A, atrial electrogram; V, ventricular electrogram. (A) shows the endocardial recordings from the conduction gap site shown on the above two-dimensional image. Note the presence of a second small atrial component following a high amplitude signal on the distal ablation catheter recording associated with a pattern compatible with an incomplete clockwise isthmus block on the Halo recordings before the RF delivery. In (B), after the RF delivery, it is possible to appreciate the splitting of the atrial potential (double arrow) on the ablation catheter recording correlating with the appearance of complete isthmus block pattern on the Halo recordings (arrow). Black star with arrow matches the conduction gap electrogram to the anatomical site on the Eustachian ridge both on the two-dimensional echo image (top, middle) and on the 3D reconstruction (top, right).
a complete bidirectional isthmus block [21]. The exact reason for this resistance to conventional RF ablation has not been clear. It has been speculated that it might be due to thicker than usual isthmus myocardium or to a particular topography of the isthmus or even to the oedema associated with RF lesions. In fact previous work has already shown that the oedema can make it difficult to complete the necrosis in deeper layers [26,27]. Also in our study the oedema following RF deliveries was demonstrated in some cases using ICE (Fig. 2). In no case was it associated with resistance to ablation.

Different authors reported that this resistance to conventional RF ablation may be overcome by using irrigated ablation catheters allowing production of larger and deeper lesions [21,22,28–30]. From the results of our study it can be inferred that, not unexpectedly, anatomical variants correlate with the ablation outcome. In a retrospective analysis all the patients with an atrial flutter ‘resistant’ to ablation belonged to Group B. In these patients the Eustachian ridge was prominent and able to conduct the electrical impulse and represented the site of conduction gaps which were difficult to ablate. Only the complete abolition of the Eustachian ridge conduction determined the occurrence of complete bidirectional isthmus block. This finding can be explained nicely by the anatomical demonstration that the Eustachian ridge may contain, in the majority of cases, muscular fibres [25]. The complex morphology and the extension of the Eustachian ridge together with the fact that muscular fibres are deep inside fibrous tissue may explain the difficulty in obtaining a transmural lesion and consequently complete block. Our observations are similar to those described by Heidbüchel et al. [31] who used angiography to evaluate the isthmus. In that study the presence of a Eustachian valve or concave isthmus was associated with statistically more RF applications.

In such cases these anatomical findings support the use of more powerful ablation catheters. However, the complex topography of this region implies very careful mapping in order to verify the entire Eustachian ridge extension that has to be ablated.

It should be also noted that conduction gaps were present in the ‘non-resistant’ atrial flutter as well. These gaps were eliminated by few RF deliveries and were located in the central portion of the isthmus below the CS os in 71% of cases. However, in these cases the lack of specific ridges makes it easier to achieve a transmural lesion with few additional RF pulses resulting in complete block.

In conclusion, what clearly emerges from our study is that ICE is very useful in identifying endocardial details and anatomical structures not visible on fluoroscopy and confirming what has been described by Morton et al. [32]. In that study ICE was clearly able to characterize the complex anatomical structures of the cavo-tricuspid isthmus visualizing complex endocardial features such as pouches, recesses and trabeculations. In addition ICE permits demonstration of a direct correlation of electrical behaviour with the underlying anatomy because the relative position and stability of the ablation catheter can be well established with ICE [5,10,14,23,24,26,27,32,33]. Therefore, in our study we were able to correlate sites of resistant conduction gaps with peculiar anatomical structures.

Up to now, due to the cost of the device, it may be not reasonable to suggest routine use of ICE in the ablation of the atrial flutter. However, in the very few cases of resistant atrial flutter the use of ‘irrigated’ ablation electrodes in conjunction with ICE may play a role in achieving a successful outcome.

Limitations

The small number of patients represents an important limitation of the study. Moreover, we have not
performed any measurements of length and depth of the isthmus because the plane visualized by ICE very often is an oblique line and consequently the measurements do not correspond with anatomical perpendicular cross-sections.

Conclusions

The IVC-TA isthmus presents anatomical variants preferentially due to Eustachian ridge peculiarities. During AFL ablation conduction gap sites are located in the central/inferior zone of the isthmus in most cases. In the event of conduction gaps ‘resistant’ to ablation, a redundant Eustachian ridge represents the most likely site of conduction gap. ICE clearly unveiled this anatomical peculiarity.

References


M. Scaglione et al.


