Simple and efficient identification of conduction gaps in post-ablation recurring atrial flutters

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Aims
Cavo-tricuspid isthmus (CTI) radiofrequency (RF) ablation is a curative therapy for common atrial flutter (AFl), but is associated with a recurrence rate of 5–26%. Although complete bidirectional conduction block is usually achieved, the recurrence of AF is due to recovered conducting isthmus tissue through which activation wavefronts pass. We evaluated a simple and efficient electrophysiological strategy, which pinpoints the ablation target.

Methods and results
Twenty-five patients (19 men), mean age 61 ± 6, with recurrent AFl required a repeat ablation, 250 ± 160 days after a successful RF CTI procedure. Transverse CTI conduction was monitored during AFl or coronary sinus (CS) pacing by a 24-pole mapping catheter positioned in the right atrium (RA), with the distal poles in the CS, proximal poles on the lateral RA, and intermediate poles on the CTI. A slow conduction area traversing the CTI (velocity, 37 ± 22 vs. 98 ± 26 cm/s on either side, P < 0.05) and a lower potential amplitude than at both sides (0.2 ± 0.15 vs. 0.5 ± 0.5 mV, P < 0.05), defined by a bayonet-shaped depolarization sequence, were considered to represent the incomplete line of block (InLOB). An ablation catheter was progressively dragged up to this InLOB, from the tricuspid annulus to the inferior vena cava, analysing the widely separated double potentials (DPs) until these coalesced. In nine patients (35%), the target conduction gap was a coalesced fractionated atrial potential within the InLOB (duration, 77 ± 12 ms), and in 16 patients (65%), a narrow DP toward the healthy margins of this InLOB (duration, 28 ± 15 ms). Adopting this strategy yields 100% successful re-ablation of recurring AFl leading to bidirectional block, with a mean 2.7 ± 1.4 RF applications.

Conclusion
Transverse CTI mapping precisely locates the InLOB and helps find conduction gaps along the CTI in re-ablation procedures for common AFl.

KEYWORDS
Recurrent atrial flutter; Conduction gaps; Catheter ablation; Arrhythmia

Introduction
Radiofrequency (RF) catheter ablation in the cavo-tricuspid isthmus (CTI) combined with confirmation of bidirectional conduction block during sinus rhythm results in high success rates for the cure of typical atrial flutter (AFI). This technique, initially described in 1993,1 is associated with recurrence ranging from 5 to 26% for recent series,2–8 presumably because of recovered conduction tissue. Post-ablation analysis of most recurrent flutters reveals a discrete gap in the incomplete line of block (InLOB), allowing conduction through the CTI.9 Published experience of repeat ablation is limited, but a new complete line of block is commonly performed, although the ‘gap’ can be identified by on-site electrograms.4,9–11 The aim of our study is to evaluate a new electrophysiological strategy useful in identifying and selectively ablating gaps within the InLOB. This practice was prospectively applied to 25 consecutive patients with recovering CTI conduction after an initial successful bidirectional block.

Methods
Patients
Between January 1999 and October 2003, 555 consecutive symptomatic patients underwent RF catheter ablation of an isthmus-dependent common AFI with negative saw-tooth flutter waves in leads II, III, and VF and an iso-electric positive pattern in V1. A successful CTI block was obtained in all patients after a single ablation procedure as previously described.2,6

First procedure
Catheter positioning
A 7F duo-decapolar mapping catheter (Orbiter TM, Bard Inc., 2–7–2 mm electrode spacing) was positioned in the...
coronary sinus (CS) (through a venous sheath in the femoral vein), then advanced and rotated so that the distal poles were in the CS and the proximal poles positioned around the tricuspid annulus, assessed by a 45° left anterior oblique (Figure 1) and 30° right anterior oblique projections. Usually, four to five pairs of electrodes were inside the CS, four to five pairs on the CTI, and two to four pairs against the lateral atrial wall. In this position, the duo-decapolar mapping catheter made it possible to access septo-lateral and latero-septal conduction through the CTI. During the procedure, the position of this catheter was repeatedly checked under fluoroscopic control. The tendency to shift from the lateral right atrial (RA) wall toward a more posterior position (i.e. closer to the crista terminalis) was corrected with a straightforward twist and repositioned. Either a deflectable 7F quadripolar catheter (Cordis Webster, Johnson & Johnson Inc., Waterloo, Belgium, 2 mm electrode spacing, 8 mm tip electrode) or a deflectable 8F quadripolar catheter (EP technologies, Boston Scientific Inc., Nanterre, France, 2.5 mm electrode spacing, 10 mm tip electrode) was used for the CTI mapping and ablation.

Electrophysiological study and ablation procedure
Endocardial bipolar electrograms were filtered between 30 and 500 Hz and analysed at a chart speed of 200 mm/s. Electrical stimulation was delivered from an external stimulator with a 2 ms pulse duration at twice the diastolic threshold. Ablation was performed with the Stockert-Cordis RF generator and energy was applied in a temperature-controlled mode with a 60–70°C target.

The ablation generated a line of RF lesions in the CTI using a technique previously described and followed here. The ablation catheter was positioned on the ventricular side of the CTI and progressively dragged under fluoroscopic control (3 to 4 mm steps) to the IVC. At each new position of the ablation catheter, RF energy was delivered for 1 min. In the case of an unsuccessful bidirectional block after reaching the IVC, a renewed attempt along the same line was made, with the difference that RF current was delivered only at sites where no atrial DPs were recorded.

Ablation was performed with patients either in AF or in sinus rhythm. When in sinus rhythm, the ablation was performed with pacing intervals at 600 ms in the CS and continuous atrial activation recording along the Orbiter catheter. For patients in AF, a straight ablation line was obtained by delivering the RF energy when the local atrial electrogram occurred within 5 ms of the middle of the plateau phase preceding the F-wave. For ablation procedures performed under CS pacing, the electrophysiological mark was a fixed interval (+5 ms) between the pacing spike and the local electrogram recorded on the ablation catheter.

The bidirectional conduction block within the CTI defined the endpoint of the ablation procedure. Thirty minutes after the bidirectional block was obtained, all patients underwent a post-ablation study. Recurring conduction re-initiated the ablation procedure until complete bidirectional block was obtained again and reconfirmed after another 30 min wait.

CTI conduction was evaluated in sinus rhythm post-ablation and in sinus rhythm either pre-ablation or when patients in AF were converted to sinus rhythm perablation.
Definition of complete bidirectional CTI conduction block
Using a technique described previously and followed here, complete bidirectional CTI block fulfilled the following criteria: (1) a complete reversal of the atrial depolarization sequence up to the targeted LOB during CS pacing and (2) timing criteria previously described by Shah et al. as differential pacing.

Second procedure
A repeat ablation was required for 25 patients, 250 ± 160 days after the first procedure, for recurrent common atrial flutter (AFI). In this study, only patients with documented recurrences of typical atrial flutter on ECG or during Holter monitoring were included. Of the 25 patients, mean age 61 ± 6 years, 19 were men, 17 had a structural heart disease, including coronary heart disease (n = 5) and valvular heart disease (n = 15). With the exception of amiodarone (five patients), all anti-arrhythmic drugs were stopped 3 or 4 days before each ablation procedure, equivalent to five half-lives.

Electrophysiological procedure
Informed consent was obtained from all patients before the procedure. The electrophysiological study was performed after 12 h of fasting. A 7F duo-decapolar mapping catheter was positioned in the CS, then advanced and rotated to obtain the same shape as the first procedure (four to five pairs of electrodes inside the CS, four to five pairs on the CTI, and two to four pairs against the lateral atrial wall). This was done under fluoroscopic control (including comparison with fluoroscopic pictures taken during the first ablation).

CTI mapping and ablation strategy
Electrograms were analysed continuously at a gain setting of 0.5 mV/cm and at a sweep speed of 100–200 mm/s. Bipolar electrograms were in a digital form and filtered with a band-pass of 30–500 Hz.

Either a 7F quadripolar catheter (Cordis Webster, Johnson & Johnson Inc., 2 mm electrode spacing, 8 mm tip electrode) or a deflectable 8F quadripolar catheter (EP technologies, Boston Scientific Inc., 2.5 mm electrode spacing, 10 mm tip electrode) was used for the CTI mapping and RF ablation. This catheter was positioned perpendicular to the duo-decapolar mapping catheter and mapped the antero-posterior conduction through the CTI. Ablation was initiated with patients in AFl (n = 16) or in sinus rhythm (n = 9). When in sinus rhythm, the electrophysiological study was performed with pacing intervals at 600 ms in the CS (twice the diastolic threshold and with a pulse duration of 2 ms) and continuous atrial activation recorded along the Orbiter catheter.

We hypothesized that the InLOB could be identified by a slow conduction area transverse to the CTI, composed of low amplitude atrial potentials. The Orbiter catheter was positioned along the tricuspid annulus always with two adjacent pairs of electrodes bracketing the supposed zone of the previously RF ablated line.

Transverse mapping from the right ventricular edge (ventricular aspect of the InLOB) to the inferior vena cava was then performed with the ablation catheter. On the basis of previous data, we considered gaps within the InLOB to be indicated by sites with a double atrial potential or a narrow fractionated potential. While recording from the distal bipole, the ablation catheter was progressively dragged through this low amplitude window, analysing the atrial potentials on both sides (widely separated DPs) until these coalesced. Sites with coalesced electrogram potentials (double or fractionated) within the InLOB defined the target conduction gap.

The ablation procedure was performed after sedation with midazolam 2.5–5 mg. A Stockert-Cordis RF generator was used to apply closed-loop temperature-controlled RF current in unipolar mode between the catheter tip electrode and an indifferent 525 cm² skin patch. The energy was applied for 60 s, in a temperature-controlled mode with a 60–70 °C target, according to a protocol found to be safe for this kind of procedure.

CTI conduction was evaluated when sinus rhythm appeared. Reversal of the atrial activation sequence and validation of complete bidirectional block with differential pacing marked the end of the gap search and the beginning of the 30 min waiting period.

Statistical analysis
Continuous variables are expressed as mean ± SD and compared using the unpaired Student’s t-test. P < 0.05 was considered to be statistically significant.

Results
Mapping and ablation results
Activation mapping in the CTI
All patients presented trans-isthmus ‘conduction slowing’ in the atrial depolarization sequence (Figures 2 and 3) on the 24-pole mapping catheter, showing the previously ablated RF line. This ‘bayonet-shaped’ depolarization window corresponded to a measurable delay in conduction across the CTI and accurately delineated the InLOB.

This ‘bayonet-shape’ was defined by (Table 1):

1. a fast conduction velocity found on either side of the InLOB (98 ± 26 cm/s),
2. a slow conduction across the InLOB (37 ± 22 cm/s),
3. a significant difference between the two areas (P < 0.05), and
4. a lower potential amplitude in the InLOB than at both sides (0.2 ± 0.15 vs. 0.5 ± 0.5 mV, P < 0.05).

The distal dipole of the ablation catheter, progressively dragged through this bayonet-shaped depolarization window, recorded, in all patients, a coalesced atrial potential (double or fractionated), between two adjacent pairs of electrodes of the Orbiter catheter within or toward the healthy margins of the InLOB. The approach detailed here allowed us to locate the conduction gap in each patient with the 8 mm tip ablation catheter.

Ablation results
The electrograms at the target site showed fractionated atrial potential (duration, 77 ± 12 ms) in nine patients and
Figure 2 Simultaneous recordings of the surface ECG (lead II) and intracardiac electrograms after sinus rhythm restoration (atrial stimulation on dipole: RA 1–2). The ‘bayonet-shape’ during sinus rhythm was defined by a fast conduction found on either side of the InLOB, a slow conduction across the InLOB, and a lower potential amplitude in the InLOB than at each side.

Figure 3 Simultaneous recordings of the surface ECG (lead II) and intracardiac electrograms during counter-clockwise atrial flutter. The ‘bayonet-shape’ during atrial flutter was defined by a fast conduction found on either side of the InLOB, a slow conduction across the InLOB, and a lower potential amplitude in the InLOB than at each side.
Table 1  Electrophysiological results: the ‘bayonet-shape’ was defined by a fast conduction velocity found on either side of the InLOB (98 ± 26 cm/s), a slow conduction across the InLOB (37 ± 22 cm/s), a significant difference between the two areas (P < 0.05), and a lower potential amplitude in the InLOB than at each side (0.2 ± 0.15 vs. 0.5 ± 0.3 mV, P < 0.05)

<table>
<thead>
<tr>
<th>Each side of the InLOB</th>
<th>Previously ablated RF line</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>Conduction velocity (cm/s ± SD)</td>
<td>98 ± 26</td>
<td>37 ± 22</td>
</tr>
<tr>
<td>Potential amplitude (mV ± SD)</td>
<td>0.5 ± 0.5</td>
<td>0.2 ± 0.15</td>
</tr>
</tbody>
</table>

Table 2  The electrograms at the target site showed fractionated atrial potentials in nine patients and narrow double potentials in 16 patients

| Duration (ms ± SD) | 77 ± 12 | 28 ± 15 | <0.05 |
| Time to CLOB (s ± SD) | 12 ± 13 | 15 ± 9 | NS |

Table 3  Double potentials were always composed of two atrial signals with different amplitudes

<table>
<thead>
<tr>
<th>Double potentials</th>
<th>First potential &gt; Second (8/16)</th>
<th>Second potential &gt; P</th>
</tr>
</thead>
<tbody>
<tr>
<td>Potential amplitude (mV ± SD)</td>
<td>0.7 ± 0.7 vs. 0.25 ± 0.25</td>
<td>0.3 ± 0.2 vs. 0.8 ± 0.7</td>
</tr>
<tr>
<td>Septal margin</td>
<td>5/5</td>
<td>2/0</td>
</tr>
<tr>
<td>AFl/SR</td>
<td>0/5</td>
<td>2/0</td>
</tr>
<tr>
<td>Lateral margin</td>
<td>3/6</td>
<td></td>
</tr>
<tr>
<td>AFl/SR</td>
<td>3/0</td>
<td>0/6</td>
</tr>
</tbody>
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a narrow DP (duration, 28 ± 15 ms) in 16 patients (Table 2). DPs were always composed of two atrial signals with different amplitudes (Table 3). The first gap component had a higher voltage amplitude than the second in eight patients: 0.7 ± 0.7 vs. 0.25 ± 0.25 mV, P < 0.05 (Figure 4). In the other eight patients, we observed the contrary (Figure 5): 0.3 ± 0.3 vs. 0.8 ± 0.7 mV, P < 0.05. The gaps were located in various parts of the CTI. A complete linear bidirectional isthmus block was obtained by the application of 2.7 ± 1.4 RF pulses (median of 3, ranging from one to eight). A complete isthmus block was obtained 12 ± 13 s after beginning the last RF point delivery. The procedure (including the 30 min waiting period for each patient) lasted 92 ± 30 min and fluoroscopic exposure was 14 ± 5 min. By adopting this strategy, the mean power delivered was (36 ± 20 W). No side effects were observed. After a follow-up of 22 ± 7 months, two patients presented typical atrial flutter recurrence.

Discussion

To our knowledge, this present study is the first to show that transverse CTI mapping with a 24-pole catheter positioned along the tricuspid annulus is useful in accurately localizing and delineating the InLOB and makes it possible to find the conduction gap quickly, during the re-ablation procedure of common AFI.

The main findings of this study are:

1. a ‘bayonet-shaped’ depolarization window across the CTI corresponded to the InLOB;
2. the conduction gap was found either within the InLOB or toward the healthy margins of this InLOB,
3. the conduction gap was revealed by a fractionated atrial potential in 35% (9/25) within the InLOB or a narrow DP in 65% (16/25) toward the healthy margins of this InLOB, and
4. in most patients, three punctate RF applications procured a successful re-ablation.

A bayonet-shaped depolarization window

During an RF ablation procedure, the loss of electrophysiological function of the conduction tissue of the CTI is caused by thermal tissue injury, which results in a focal region of coagulation necrosis. According to in vitro studies, hyperthermia was found to cause significant changes in the electrophysiological properties of myocardial cells including a loss of cellular excitability, a decrease in the amplitude and duration of action potential, a slower conduction velocity, or an irreversible conduction block. In our study, we identified the electrophysiological properties of InLOB as a slow conduction zone with low potential amplitude. To our knowledge, this bayonet-shaped depolarization window across the CTI has never been described during post-ablation recurring atrial flutter, even though it is often seen by electrophysiologists as a sign of impending block during a first ablation procedure. We noticed that this shape was particularly marked (very low potential amplitude and very slow conduction area across the InLOB), when patients required less than three RF applications to complete the line of block. These findings are in accordance with the fact that the smaller the gap, the slower the atrial conduction across the CTI.

The conduction gap within this InLOB

In common practice, several ablation techniques are able to create a complete CTI bidirectional block, using either a strictly anatomically guided approach or a combined electrophysiological and anatomically guided approach. In all of the patients included in this study, the first ablation procedure was performed with the same electrophysiological strategy using a combined approach, which has been previously described. This technique, guided by the Halo catheter, makes it possible to obtain a relatively straight RF line. It is well known that the mechanisms of atrial flutter recurrence are related to recovered conduction properties through the CTI, because of a single gap in most cases. However, we did not observe any specific reason for these recurrences with regard to the different
electrophysiological parameters recorded during the first procedure.

According to these data, the conduction gaps found in our patients were always located within an InLOB, corresponding accurately to the first RF line ablation. We were able to complete the conduction block with relative ease because of our previous effort to draw a relatively straight RF line.
In our study, the successful ablation targets recorded in the window of the 'bayonet shape' area were measured from $28 \pm 15$ to $77 \pm 12$ ms, compared with $48 \pm 6$ to $97 \pm 32$ ms, in another series. In a recent study of 30 patients with incomplete isthmus blocks, a DP interval $<90$ ms was found to be a reliable indicator of a local gap, with a mean DP interval $65 \pm 21$ ms in duration, similar to the mean value of $45 \pm 32$ ms measured in our study.

An experimental study in rabbit heart tissue has shown that a minimum intact atrial tissue gap of 3 mm between two RF lesions is required for a conduction breakthrough. A recent study performed with the Cordis-Biosense EP Navigation system (CARTO) and high-density activation mapping through incomplete isthmus ablation lines revealed 7.6 $\pm$ 3 mm gaps of recovered conduction. This suggests that only a short length of CTI needs to be re-ablated instead of making a completely new line of ablation. In our experience, the recurrence of AF, in most cases, was due to a single gap (20/25), requiring triple punctate RF applications in most patients. The last successful RF application was completed by another 60 s application in most patients (18/25). This extra RF point delivery was included in our data. On average, a complete bidirectional isthmus block was obtained by the application of 2.7 $\pm$ 1.4 RF pulses (median of 3, ranging from one to eight), 12 $\pm$ 13 s after the beginning of the last RF point delivery, similar to the mean value of $12 \pm 10$ s, reported in a previous study. These data confirm the accuracy of this method in locating the gap. The most important proof of the accurate location of the gap in the CTI was successful ablation of flutter with few RF applications in most patients.

We noticed that the parameters (mean power and mean temperature), obtained during RF applications on unsuccessful sites, were not sufficient to create a complete lesion (temperature $<50^\circ$C and/or power $<15$ W). When we analysed the seven procedures which required more than three applications, we noticed that during these procedures, it was difficult to maintain good contact with the tip of the catheter inside the InLOB. In addition, we observed several recurrences during two procedures probably influenced by CTI characteristics (Pouch-like recesses), as previously described by Da Costa et al. These two patients eventually presented typical atrial flutter recurrence during follow-up. These elements could explain the large range of RF applications in our study.

The morphological characteristics of the conduction gap

In our study, the successful ablation targets recorded in the window of the 'bayonet-shaped' area, presented different morphologies depending on the site of recording (astride the InLOB or toward the healthy margins of the InLOB) and the direction of wave propagation (recording during flutter or CS pacing). The conduction gaps were either fractionated atrial potentials (Figure 6) or narrow DPs within the InLOB. The significance of double vs. fractionated electrograms on the gap is unclear, but DPs with short-duration electrograms may indicate rapidly and homogeneously conducting tissue, whereas fractionation indicates a more tenuous, slowly conducting tissue gap, as previously described. We did not observe both fractionated and DPs in a single...
patient. For ablations initiated in patients in AFL (n = 16), termination of the flutter coincided with a bidirectional isthmus block in nine patients (56%). Whereas fractionated atrial potentials were recorded astride the InLOB and suggested a slowly conducting tissue gap, narrow DPs were found toward the healthy margins of the InLOB. We found no correlation between the presence of fractionated potentials in the InLOB and the amount of tissue damage during the first procedure (tip size of the catheter, number of RF applications, procedure duration) or the use of amiodarone.

The analysis of the direction of wave propagation (recorded during flutter or CS pacing) helped us to locate precisely the conduction gaps on the margins of the InLOB. We recorded DPs corresponding to short duration atrial activation, always composed of two signals of different amplitudes. We always recorded a first gap component with a lower voltage amplitude than the second, on the septal margin of the InLOB in the cases of AFL and on the lateral margin of the InLOB in the cases of SR. We observed a first gap component with a higher voltage amplitude than the second, on the lateral margin of the InLOB in the cases of AFL and on the septal margin of the InLOB in the cases of SR.

The significance of DPs with different amplitudes according to the location and direction of wave propagation is unclear, but the higher voltage amplitude potential may indicate the healthy side of the CTI upstream or downstream of wave propagation.

Relevance to the previous studies

Yamabe et al. reported that the recurrent conduction site in the CTI can be identified during low lateral RA pacing in sinus rhythm while recording bipolar electrograms from the septal portion of the CTI along the InLOB (previously ablated line). Electrogram polarity reversal (transitional electrogram with equal amplitudes in positive and negative components recorded between the sites showing mainly negative and positive electrograms) was observed at the conduction gap in each patient.

Shah et al. reported that the gap within the InLOB was represented by a single narrow electrogram or a fractionated potential spanning the isoelectric interval of adjacent DPs.

The major difference between these two studies and the present method is the mapping site. Mapping was always performed along the InLOB (Shah et al.) or on the septal margin of the initial ablated line (Yamabe et al.). In our study, the mapping strategy was always first realized within the InLOB and then toward the healthy septal or lateral margins of this InLOB. The ablation catheter was progressively dragged from the tricuspid annulus to the inferior vena cava, analysing the healthy margins, particularly when the analysis of low amplitude atrial potentials along the InLOB was not relevant or when it was difficult to maintain good contact with the tip of the catheter inside the InLOB. It is possible that the use of unipolar recordings could be helpful for some patients undergoing re-ablation of recurring AFL, but in this study, we only analysed bipolar electrograms.

With this method, most of the narrow DPs were found on the lateral margin of the InLOB.

Conclusion

This study confirms that in most cases, the recurrence of AFL is due to a single gap within the previously ablated RF line, which can be precisely located during transverse CTI mapping with a 24 pole mapping catheter.

In our study, the conduction gaps found were always located in this slow-conduction area. Whereas fractionated atrial potentials were recorded within the InLOB, narrow DPs were found toward the healthy margins of the InLOB.

References

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