Cavotricuspid Isthmus Mapping to Assess Bidirectional Block During Common Atrial Flutter Radiofrequency Ablation

Jian Chen, MD; Christian de Chillou, MD; Tarek Basiouny, MD; Nicolas Sadoul, MD; Jorge Da Silva Filho, MD; Isabelle Magnin-Poull, MD; Marc Messier, PhD; Etienne Aliot, MD

Background—We sought to compare published methods to an alternative approach ascertaining cavotricuspid isthmus (CTI) block during atrial flutter ablation.

Methods and Results—In 39 consecutive patients who underwent an atrial flutter ablation procedure, a 24-pole mapping catheter was positioned so that 2 adjacent dipoles were bracketing the targeted CTI line of block (LOB), with proximal dipoles lateral to the LOB and distal dipoles in the coronary sinus. Two pacing sites were lateral (positions A and B) and 2 were septal (positions C and D) to the LOB, with locations A and D closest to the LOB. A resulting CTI block was accepted when 3 criteria were fulfilled: (1) complete reversal of the right atrial depolarization on the 24-pole catheter when pacing in the coronary sinus, (2) conduction delays from A to D greater than from B to D, and (3) conduction delays from D to A greater than from C to A. A successful CTI block was obtained in all patients. Before CTI block was obtained, a progressive CTI conduction delay was observed in 11 patients (28.2%). During the procedure, the 3 criteria defined above were either all present or all absent.

Conclusions—This study establishes that reversal of the atrial depolarization sequence up to the LOB is a definitive and mandatory criteria of successful atrial flutter ablation. (Circulation. 1999;100:2507-2513.)

Key Words: atrial flutter ■ catheter ablation ■ arrhythmia

Radiofrequency (RF) ablation is widely used1-7 to cure symptomatic patients with common atrial flutter (AF). Some authors even propose that RF ablation could be used as a first line treatment in this clinical setting.7

The cavotricuspid isthmus (CTI), lying between the inferior vena cava (IVC) and the tricuspid annulus, is the common target of AF ablation.6-16 Recent studies have shown that a resulting bidirectional conduction block in the CTI should be the end point of the ablation procedure.8-13

The method most widely used to assess this complete CTI block is based on the depolarization sequence observed in the right atrial lateral wall as well as the activation times measured on His bundle recordings and in the coronary sinus (CS) region. These are assessed using different pacing sites.8-10 Another technique13 relies on double potentials mapping within the CTI.

The aim of this study was to evaluate the accuracy of bracketing the targeted line of block (LOB) using a single 24-pole catheter to assess bidirectional CTI conduction block during RF ablation of AF.

Methods

Study Population

The study population consists of 39 consecutive symptomatic patients (34 men, mean age 60±11 years) admitted between December 1997 and June 1998 for RF catheter ablation of a common drug resistant AF (negative sawtooth flutter waves in leads II, III, and VF with an isoelectric positive pattern in V1). Nineteen patients (48.7%) also presented nonpredominant episodes of paroxysmal atrial fibrillation. Thirteen patients (33.3%) had a structural heart disease, including coronary heart disease (n=4), operated valvular heart disease (n=3), hypertensive cardiomyopathy (n=4), and congenital atrial septal defect (n=2). Before the ablation procedure, 3 additional patients were equipped with a pacemaker either for sick sinus syndrome (n=1) or for an atrioventricular block (n=2). A patient informed consent was obtained from all patients before the ablation procedure.

Catheter Positioning

A 24-pole mapping catheter (Orbiter™, Bard Inc, 2-7-2 mm electrode spacing) was positioned via the femoral vein in the CS, 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 and 30° right anterior oblique projection (Figure 1). Usually 4 to 5 pair of electrodes were inside the CS, 4 to 5 pair on the CTI and 2 to 4 pair on the lateral atrial wall. With the Orbiter catheter in this position, there were always 2 adjacent pair of electrodes bracketing the RF ablation line created within the CTI. During the procedure, the position of this catheter was repeatedly checked under fluoroscopic control. The tendency to shifting from the lateral right atrial wall toward a more posterior position (ie, closer to the crista terminalis) was corrected with a straightforward twist and repositioned.

A deflectable 7F quadripolar catheter (Cordis Webster, Johnson & Johnson Inc, 2-mm electrode spacing, 4-mm tip electrode) or a...
deflectable 8F quadripolar catheter (EP technologies, Boston Scientific Inc, 2.5-mm electrode spacing, 8- or 10-mm tip electrode) were used for the CTI mapping and ablation. In addition, a quadripolar catheter (Daig, St Jude Medical Inc, 10-mm electrode spacing) was used to record and pace in the His bundle region.

Electrophysiological Study and Ablation Procedure
Endocardial bipolar electrograms were filtered between 30 to 500Hz and recorded on a Midas 8200 system (Marquette Medical Systems Inc) and analyzed at a chart speed of 100 mm/s. Electrical stimulation was delivered through an external stimulator (Biotronik UHS 20, Biotronik Inc) with a 2-ms pulse width 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°C to 70°C target.

The ablation generated a line of RF lesions in the CTI using a technique described by other authors and resumed here. The ablation catheter was positioned on the ventricular side of the CTI and progressively dragged (3- to 4-mm steps) to the IVC under fluoroscopic control. Ablation was performed with a 60°C to 70°C target. An unsuccessful bidirectional block would sponsor a renewed attempt along the same line, with the difference that RF current be delivered only at sites were no atrial double potentials could be recorded.

Ablation was performed with patients either in AF or in sinus rhythm. When in sinus rhythm, the ablation was performed with pacing at 600 ms in the CS and continuous atrial activation recording along the Orbiter catheter. Patients in AF obtained a straight ablation line 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 became 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 defines the end point of the ablation procedure. Thirty minutes after the bidirectional block was obtained, all patients underwent a postablation control. A recurring conduction reinitiated the ablation procedure until a complete bidirectional block was obtained again and reconfirmed after another 30-minute wait.

The CTI conduction was evaluated in sinus rhythm postablation and in sinus rhythm either preablation or when patients in AF were converted to sinus rhythm periablation. This was performed sequentially with a 4-pacing-site protocol (Figure 2); bipolar pacing at sites A or B or D then at site C (His bundle). Sites A and B are defined on the lateral side of the LOB and sites C and D on its septal side. Site A is 1 of the 2 dipoles immediately adjacent and lateral to the targeted LOB; site B is 1 of the 2 dipoles immediately adjacent and lateral to site A; site D is 1 of the 2 dipoles immediately adjacent and septal to the targeted LOB.

Definition of Complete Bidirectional CTI Conduction Block
A complete bidirectional CTI block fulfilled the following criteria: (1) a descending wave front on the lateral atrial wall during CS pacing representative of a reversed atrial depolarization sequence, (2) a greater activation delay at site D when pacing at site A was compared with pacing at site B (AD delay>BD delay), and (3) a greater activation delay at site A when pacing at site D was compared with pacing at site C (DA delay>CA delay).

Figure 1. Fluoroscopic views of atrial flutter ablation. Left, 30° right anterior oblique projection; right, 45° left anterior oblique projection. Orb indicates Orbiter catheter; RF, radiofrequency ablation catheter; HIS, catheter recording the His bundle electrogram; and CS OS, coronary sinus ostium.

Figure 2. Schema of the right atrium, as seen from the 45° LAO projection, showing the 4 stimulation sites in relation with the anatomical structures.
Definition of Undirectional Conduction Block Within the CTI
A clockwise (mediolateral\(^{17}\)) conduction block fulfilled the following criteria: 1) AD delay<BD delay, and 2) DA delay>CA delay.
A counterclockwise (lateromedial\(^{17}\)) conduction block fulfilled the following criteria: 1) AD delay>BD delay, and 2) DA delay<CA delay.

Follow-Up
Patients were monitored for 48 hours postablation, then discharged. No antiarrhythmic drug therapy was prescribed except for some patients with history of atrial fibrillation. The patients were followed on an outpatient basis with clinical evaluations and 24-hour Holter recordings performed at 2, 4, 6, 9, and 12 months after hospital discharge.

Long-term clinical validation of the ablation procedure follows absence of recurring AF. Documented recurrences of AF promoted a second electrophysiological study of the CTI conduction and led to a repeated ablation procedure. Undocumented events, however, first required proof of AF inducibility before a renewed ablation could be attempted.

Statistical Analysis
Continuous variables are expressed as mean±SD and compared using the unpaired Student’s \( t \) test. \( P<0.05 \) was considered statistically significant.

Results
Catheter Positioning
The Orbiter catheter was positioned as described earlier in 36 of 39 patients (92.3%). During the procedure, the catheter shifted in 2 of these 36 patients (5.6%), this required a straightforward repositioning. The ideal catheter position was unreachable in 3 patients due to our 1) inability to catheterize the CS in 2 patients (both with an atrial septal defect), and 2) very unstable position of the catheter in 1 patient. In these 3 patients, the Orbiter catheter was positioned so that the distal dipole was applied just outside the CS ostium. This position was unstable, requiring several catheter repositioning during the procedure.

Ablation Procedure
At procedure onset, 24 patients (61.5%, group A) were in sinus rhythm whereas the remaining 15 patients (38.5%, group B) presented with AF. In group B patients, a restored sinus rhythm during RF energy applications was associated with a complete CTI block in only 1 patient, the remaining 14 patients requiring further RF applications to obtain a CTI block. In group B patients, the dipole just lateral to the targeted LOB was the last one to depolarize on interruption of AF (Figure 3). Sinus rhythm resumed after a mean number of 9±7 RF applications (ranging from 1 to 28). From a topological perspective, sinus rhythm was obtained on the first pass approximately midway between the ventricular starting point and the IVC in 5 patients (33.3%), whereas 4 patients (26.7%) were resolved near the last quarter, closer to the IVC. Six patients (40%) required numerous attempts at various locations.

Episodes of AF reoccurred spontaneously in 5 group B patients before CTI block was obtained. Transient AF were observed during the procedure in another 4 (group A) patients before CTI block achievement.

Complete CTI block was successfully achieved in 1 session in all patients. Mean number of RF application was 17±11 (ranging from 4 to 48). Mean total procedure duration (from femoral puncture to catheter withdrawal) was 168±71 minutes (ranging from 60 to 300), and mean fluoroscopic time was 46±22 minutes (ranging from 11 to 76).

The ablation procedure required continued CS pacing in all except 1 patient (in whom complete bidirectional CTI block was observed when sinus rhythm was restored). The first block evidenced was mediolateral because the CS was paced. This was always associated with a lateromedial conduction block; a unidirectional conduction block in the CTI was never observed here. Because mediolateral conduction within the CTI was continuously monitored during energy delivery, the block was always demonstrably abrupt, with the change in the activation sequence on the Orbiter catheter appearing from one beat to the next (Figure 4).

During the 30-minute postablation period, CTI conduction resumed once in 10 patients (25.6%) and twice in 3 patients (7.7%). The conduction recurrence delay ranged from 5 seconds to 25 minutes. A final CTI block could be successfully created in all cases after 1 to 6 additional RF energy applications.

Electrophysiological Data
During CS atrial pacing, a progression in conduction delays within the CTI evolved until a complete block occurred, the collision of the clockwise and counterclockwise wave fronts thus shifting to various positions in the isthmus (Figure 5).
The distance separating the target LOB and the evolving atrial collision zones could be measured with the help of the Orbiter catheter. In 28 patients (71.8%), the site of collision of the 2 wave fronts was always >44 mm away from the target LOB. The maximum shift, however, was found at a distance of 11 mm (2 electrode pairs) away from the target LOB in 4 patients, 22 mm away (3 electrode pairs) in 5 patients, and at 33 mm (4 electrode pairs) in 2 patients. For these 11 patients, proximity of the shifted collisions zones with the target LOB could suggest (erroneously) a CTI block had the distal pole of the mapping catheter been positioned 11, 22, or 33 mm lateral to the target LOB. This would have wrongly stopped the procedure if the reversal depolarization criteria alone had been used with a catheter mapping the infero-lateral right atrial wall only, missing 4 (10.2%), 9 (23.1%), and 11 (28.2%) patients, respectively, with the distal dipole positioned 11, 22, and 33 mm lateral to the LOB.

The Table shows the changes in the different activation delays measured before the ablation procedure and after a complete conduction block was obtained. In group B patients, the activation delays were first measured when sinus rhythm resumed and were significantly longer than preablation delays measured in group A. No significant differences in activation delays were observed between group A and group B patients when the CTI conduction block was obtained. In group A patients, the mean increase in the activation delays were 147.3±26.4 ms (ranging from 118 to 202 ms) for AD, 105.6±25.4 ms (ranging from 75 to 180 ms) for BD, 152.6±25.5 ms (ranging from 119 to 203 ms) for DA, and 107.1±23.9 ms (ranging from 78 to 160 ms) for CA. Figure 6 shows these different activation delays after CTI conduction block is obtained.

During CS pacing, a complete reversal of the atrial depolarization was always associated with the AD delay longer than the BD delay (178.0±30.7 versus 153.8±27.7 ms, P<0.001) and with the DA delay longer than the CA delay (181.1±27.1 versus 156.1±25.5 ms, P<0.001). When only a partial reversal of the atrial depolarization was observed, the AD delay was constantly shorter than the BD delay (106.6±23.3 versus 133.8±20.9 ms, P<0.001) [values for

Figure 4. Abrupt change with complete reversal of depolarization sequence on the Orbiter catheter (2nd to 3rd beat) during RF energy application.

Figure 5. Shift in the collision of the clockwise and counterclockwise wave fronts during coronary sinus pacing during the ablation procedure. A, collision at dipole 17-18 (lateral right atrium) at baseline. B, collision at dipole 11-12 after 9 RF pulses. C, collision at dipole 9-10 after 11 RF pulses. D, complete reversal of depolarization sequence on the Orbiter catheter after 15 RF pulses.
maximal shift in collision wave fronts]) and the DA delay was always shorter than the CA delay (109.7 ± 21.2 versus 139.3 ± 20.9 ms, \( P < 0.001 \) [values for maximal shift in collision wave fronts]).

**Follow-Up**

No significant complications occurred during the ablation procedure and none occurred during the hospital stay. Thirty-one patients received no antiarrhythmic therapy during the hospital stay and during the follow-up period. Eight patients with a previous history of paroxysmal atrial fibrillation were discharged with an antiarrhythmic drug treatment; 5 patients on flecaïne (200 mg daily), and 3 patients on cibenzoline (260 mg daily). An additional 6 patients were discharged with \( \beta \)-blocker therapy for coronary artery disease (3 patients) or hypertension (3 patients).

At a mean follow-up of 10.4 ± 2.0 months (range 7.5 to 14.5), 2 of 39 patients (5.1%) experienced at least 1 symptomatic episode of AF, starting 3 and 8 weeks after hospital discharge. In these 2 patients (one being treated with flecaïne and the other receiving no antiarrhythmic drug), a control electrophysiological study showed a return to CTI conduction associated with the recurrence of the arrhythmia. Using the same protocol as described above, a second ablation procedure was successfully performed in these 2 patients.

In addition, 7 other patients underwent a control electrophysiological study 4 to 8 months after the ablation procedure. This was performed in the setting of an atrial fibrillation ablation procedure in 2 patients or because of undocumented recurrent palpitations in 5 patients. In all 7 patients the control electrophysiological study showed a persistent CTI conduc-

<table>
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<tr>
<th>Activation Delays Recorded Before the Ablation Procedure (Group A Patients) or at Sinus Rhythm Resumption (Group B Patients), and After Complete CTI Conduction Block was Obtained</th>
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<tbody>
<tr>
<td>Activation Delays</td>
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<tr>
<td>Group A patients (( n = 24 ))</td>
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<td>Before ablation</td>
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<td>Group B patients (( n = 15 ))</td>
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<td>At sinus rhythm resumption*</td>
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<td>After successful ablation</td>
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<td>Range</td>
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A, B, C, and D sites are defined in Methods and presented in Figure 2.

*Data from 14 of 15 patients (no data available for patient with CTI block at sinus rhythm resumption). All numbers are expressed in ms. †\( P < 0.01 \), and ‡\( P < 0.05 \) compared to the preablation data from group A patients. §No statistical difference compared to the postablation data from group A patients.

Figure 6. Endocavitary activation sequences on the Orbiter catheter when pacing at site A, B, C, and D after a complete cavotricuspid isthmus conduction block was obtained (AD > BD and DA > CA). Note that AD and DA delays are similar.
tion block and noninducibility of AF either with a programmed atrial stimulation (from 1 to 3 atrial extrastimuli during sinus rhythm, and with atrial pacing at 600 and 400 ms cycle length) nor using atrial burst pacing (from 400 to 200 ms in 10-ms decrements).

Discussion
This study investigates the accuracy of a technique based on bracketing the targeted LOB to assess a bidirectional conduction block within the CTI during RF catheter ablation of AF. Four conclusions can be drawn from this work: 1) this technique is feasible in the majority of patients (92.3%), with a need to reposition the catheter during the procedure in only 5.6% of the patients; 2) to achieve a complete mediolateral cavotricuspid block, reversal of the atrial depolarization sequence during CS pacing has to be complete, with the wave front descending from the lateral atrial wall to the dipole immediately adjacent (within a few millimeters) to the targeted LOB; 3) complete reversal of the atrial depolarization sequence obtained on the Orbiter catheter during CS pacing is an essential and sufficient condition to conclude bidirectional CTI block, because multiple-site pacing (A, B, C, and D) and measured activation delays always coincide with this condition, given that unidirectional block was never observed; 4) multiple-site atrial pacing with activation delay measurements may be used as an alternative end point to assess complete cavotricuspid conduction blocks: this is useful as multiple-site atrial pacing can be performed without need of a multipolar catheter.

This technique allows a permanent monitoring of the CTI conduction, enabling real-time evaluation of mediolateral CTI conduction. Our procedure includes a 30-minute observation period that is often not mentioned in literature reports but seems of significance, as up to 33.3% of our population exhibited periprocedural cavotricuspid conduction recurrence, some up to 25 minutes after an apparently successful ablation.

The proof of a bidirectional conduction block within the CTI remains a critical issue in the confirmation of an ablated AF. While pacing in the CS, reversal of the atrial depolarization sequence on the Orbiter catheter had to be documented up to the targeted LOB to eliminate residual mediolateral conduction. Despite which, a very slow mediolateral conduction may still persist within the CTI, which explains the additional criteria defining a complete cavotricuspid conduction block. When there is no mediolateral block, pacing at site D will lead to an earlier depolarization of site A compared with pacing at site C. Similarly, if there is no lateromedial block, pacing at site A will lead to an earlier depolarization of site D compared with pacing at site B. The rationale for these assertions is based on anatomy and conduction delay, the stimulus to local activation time being shorter when the paced area is closest. There is still, however, one limitation with the AF model using conduction delay criteria. In case of a slow lateromedial conduction when pacing at site A, if the time interval necessary to reach point D through the CTI route precisely equals or exceeds the time interval necessary to reach point D by the opposite clockwise route parallel to the tricuspid annulus, then the AD delay will be longer than the BD delay despite the persistence of a mediolateral cavotricuspid conduction. A similar situation is also conceivable with mediolateral conduction. The following observations, however, marshal against this limitation: 1) the complete reversal in activation sequence on the Orbiter catheter was always abrupt, this being more consistent with the appearance of a conduction block rather than a slow conduction; 2) complete reversal of the depolarization sequence was always associated with the other 2 criteria used to define complete cavotricuspid conduction block and; 3) when CTI conduction resumed, all phenomena defining a complete cavotricuspid conduction block disappeared simultaneously. This regular, simultaneous, all or none situation of all 3 criteria supports a different atrial depolarization process on the lateral side of the targeted LOB when a complete reversed depolarization is observed. This is further supported by the observation that the control electrophysiological study of the 2 patients who experienced AF during the follow-up fulfilled none of the criteria defining a complete cavotricuspid conduction block.

The literature reports unidirectional and/or rate-dependent conduction blocks within the CTI in up to 31% of patients after CTI ablation. This has not been evidenced in our series nor in Poty’s report. There is no clear explanation regarding these discrepancies. Because unidirectional block is the basis of reentry phenomenon, one would expect that the last atrial paced beat in any atrial burst induces at least one reentrant atrial beat. Hence, in case of a lateromedial cavotricuspid block, the last atrial paced beat when pacing at site A would depolarize successively sites B, C, D, then site A and B because of slow or normal mediolateral cavotricuspid conduction. To our knowledge, such a phenomenon has never been described. This supports the hypothesis that activation patterns that have been described as unidirectional block more probably correspond to a slow, bidirectional conduction within the CTI.

Limitations
The ability to induce AF was not evaluated during the ablation procedure because recent studies have shown that complete bidirectional conduction block in the CTI is, by far, the best marker for long-term success after RF ablation of AF. No systematic electrophysiological control was warranted, thus information on the persistence of the cavotricuspid block is unavailable in the entire study population. The 600 ms CS pacing cycle length is about 3 times longer than AF cycle lengths. This does not impair, in fine, the evaluation of CTI conduction. Indeed, considering a hypothetical rate-dependent isthmus-conduction velocity, a CTI block will be preferentially observed with fast pacing, yet a slower AF remains possible. Inducibility of AF will be less likely, however, with CTI blocks occurring during slow pacing.

The duration of the follow-up period, with an average of 10.4 months, precludes evaluation of AF recurrence. When complete bidirectional CTI block is achieved at the end of the ablation procedure, Schumacher et al recently showed that the recurrence rate curve is flat after a 4-month follow-up period, which is consistent with the delay of recurrence
observed in our study population. In our study, all patients were followed for at least 7.5 months, so that the risk of recurrence is expected to be minimal.

Conclusion
Our study suggests that 1) reversal of the atrial depolarization sequence in the right lateral atrium only using CS pacing is not a sufficient marker for successful AF ablation, 2) complete reversal of the atrial depolarization sequence up to the targeted LOB using CS pacing is a definitive indicator of successful AF ablation, and 3) timing criteria (AD > BD and DA > CA) are always present when complete reversal of the depolarization sequence is observed.

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References
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