Rate-Dependent Conduction Block of the Crista Terminalis in Patients With Typical Atrial Flutter

Influence on Evaluation of Cavotricuspid Isthmus Conduction Block

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Background—The crista terminalis (CT) has been identified as the posterior boundary of typical atrial flutter (AFL) in the lateral wall (LW) of the right atrium (RA). To study conduction properties across the CT, rapid pacing was performed at both sides of the CT after bidirectional conduction block was achieved in the cavotricuspid isthmus by radiofrequency catheter ablation.

Methods and Results—In 22 patients (aged 61 ± 7 years) with AFL (cycle length, 234 ± 23 ms), CT was identified during AFL by double electrograms recorded between the LW and posterior wall (PW). After the ablation procedure, decremental pacing trains were delivered from 600 ms to 2-to-1 local capture at the LW and PW or coronary sinus ostium (CSO). At least 5 bipolar electrograms were recorded during sinus rhythm in that area. No double electrograms were recorded during pacing from the PW or CSO (cycle length, 334 ± 136 ms), but it was fixed in only 4 patients. During pacing from the LW, complete block appeared at a shorter pacing cycle length (281 ± 125 ms; P<0.01) and was fixed in 2 patients. In 3 patients, complete block was not achieved.

Conclusions—These data suggest the presence of rate-dependent transversal conduction block at the crista terminalis in patients with typical AFL. Block is usually observed at longer pacing cycle lengths with PW pacing than with LW pacing. This difference may be a critical determinant of the counterclockwise rotation of typical AFL. (Circulation. 1999;99:2771-2778.)

Key Words: atrial flutter ■ atrium ■ electrophysiology ■ conduction

Typical atrial flutter (AFL) is a macroreentrant rhythm propagating between both venae cavae and the tricuspid annulus (TA).1–10 For such a circuit to exist, a posterior electrical barrier is needed to prevent a short-circuiting between the posterior wall (PW) and lateral wall (LW).11,12 In humans, this barrier is related to the crista terminalis (CT).13 The fibers of this structure run longitudinally between the LW and PW in a high-to-low pattern. This structure, which is the fastest pathway in the lateral free wall in the craniocaudal direction,14,15 creates a line of block in the transversal direction that determines the activation pattern of the LW during AFL. Although the CT is an electrical barrier during AFL,11–13 there are no data about the conduction properties of this structure after sinus rhythm has been restored, namely, if the conduction block is functional or fixed. The recording of double electrograms is a marker of areas of conduction block, but they are observed only during reentry or when the activation wave front is perpendicular to the line of block.11–13,16,17 Thus, to determine whether the CT is a fixed or functional line of block, pacing was performed on both sides of the CT at several rates.

The AFL circuit is critically dependent on conduction through the cavotricuspid isthmus (CTI), and this region is the target of transcatheter ablation procedures.18,19 Because detection of CTI conduction block is based on changes in the activation patterns of the LW and interatrial septum during low LW and coronary sinus ostium (CSO) pacing,20,21 an additional purpose of the present study was to determine the influence of CT conduction properties on activation patterns of the right atrium during pacing and therefore on CTI conduction-block evaluation.

Methods

Population

The study group consisted of 22 patients with typical AFL, defined by an inverted sawtooth pattern in the inferior ECG leads and a
regular atrial rate $>$ 240 bpm in the absence of antiarrhythmic drugs, referred for radiofrequency ablation of the CTI (Table 1). At the time of the study, patients 4 and 12 were taking amiodarone, and patient 21 was taking flecainide; the remaining patients were not taking any class I or III antiarrhythmic drugs.

Electrophysiological Testing: Electrical Stimulation and Recordings

Studies were performed with patients in a nonsedated and postabsorptive state; written consent was obtained from each patient. Intracardiac recordings, which were filtered between 30 and 500 Hz with a gain amplification between 0.5 and 0.1 mV/cm, were displayed simultaneously with $\geq$ 1 ECG lead (II or aVF) on a 12-channel recorder (Midas, Hellige Biomedical) at paper speeds of 100 and 200 mm/s. Atrial stimulation was performed with a programmable stimulator (UHS-20 BiotronIK) set to deliver rectangular pulses of 1-ms duration at twice the diastolic threshold.

Figure 1 shows the fluoroscopic appearance of the catheter arrangement. A "deflectable halo" catheter (2-mm interelectrode distance, 10-mm interbipole distance; Webster Laboratories) was placed around the TA to obtain the right atrium activation sequence during flutter and the catheter ablation procedure; the distal pair was located close to the ablation line at approximately the 6-o’clock position of the TA. A quadrupolar catheter was placed at the CSO to test conduction between the septal and lateral walls through the CTI. A third quadrupolar deflectable-tip catheter was used for radiofrequency application. This catheter was also used for CT identification by searching the double electrogram during flutter between the LW and PW. In 10 patients, a 20-pole deflectable catheter (Crista Catheter, Cordis), spacing 1–3–1 mm, was placed at or in the proximity of the CT, and the distal electrode was next to the inferior vena cava.

Radiofrequency Ablation

After mapping and entrainment techniques characterized the arrhythmia as AFL, if sinus rhythm could be restored, pacing at both sides of the CTI was performed. Incremental pacing trains (from 600 ms to 2-to-1 atrial capture) were delivered at the CSO and from the distal pair of the halo catheters to establish right atrium activation patterns before radiofrequency ablation. A quadrupolar deflectable-tip catheter was used for radiofrequency application. Radiofrequency ablation was performed with current generated by a conventional 500-kHz radiofrequency energy source (EPT-1000, EP Technologies or Atakr, Medtronic Cardiorhythm), delivered from the 8- or 4-mm tip of a steerable mapping catheter (Blazer T, EP Technologies and Marinr, Medtronic Cardiorhythm) to a left subscapular chest wall patch. Ablation was anatomically guided and performed during AFL or sinus

![Figure 1](https://example.com/figure1.png)
Linear lesions were produced in the CTI, and the ablation catheter was progressively withdrawn under fluoroscopic guidance during radiofrequency energy delivery from the TA to the inferior vena cava (pulse duration between 90 and 120 seconds). Linear lesions were produced in the CTI in an attempt to achieve bidirectional conduction block between the LW and interatrial septum. To test the appearance of CTI block, the previously mentioned pacing protocol at both sides of the CTI was repeated after each ablation line was completed. CTI block was presumed to be present when the activation pattern of the side opposite to the pacing site was completely craniocaudal in nature.

CT Location
CT location was defined by recording double electrograms during flutter in the union of the LW and PW. Frames of the right and left anterior oblique fluoroscopic projections obtained during mapping were used to determine the location of the CT after sinus rhythm was restored.

Evaluation of Conduction Across the CT
After the radiofrequency ablation procedure was finished, in cases in which the Crista catheter was not used to record CT electrograms, the halo catheter was rotated counterclockwise and then pulled back to achieve close contact of the distal electrode with the atrial wall at the proximity of the CT, so that 5 or 6 bipolar electrograms were recorded along the CT from the high to the low right atrium, which was done to maintain the distal electrode next to the inferior vena cava. After a stable position of the catheter was achieved, we proceeded to pace on both sides of the CT. To obtain activation wave fronts perpendicular to the CT, we selected sites from which the activation time differences among the bipolar electrograms recorded from the low to the high atrium were the shortest possible at the slowest rate. When it was difficult to locate a stable position at the PW, pacing was performed at the CSO. The second pacing site was at the low lateral right atrium. Multiple 10-second-duration synchronized trains of rapid atrial pacing at a constant rate were delivered at decremental cycle lengths from 600 ms until 2-to-1 atrial capture occurred.

Definitions
Double electrograms are defined as 2 discrete deflections separated by an isoelectric interval.

Focal transversal conduction block in the CT was recognized by the recording of double electrograms at 1 site during pacing at the LW and PW.

Complete transversal conduction block along the CT was detected by the appearance of double electrograms at all recording sites and a change in the activation sequence, with the development of a craniocaudal activation sequence at the opposite side of the pacing site. Recording of double electrograms at the highest portion of the CT was not necessary for the assumption of complete block, because this area was considered the turning point of the activation wave front.

Constant clockwise block of the CTI was defined by observation of a completely descending activation of the LW during pacing from the CSO at 600 ms.

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Mean±SD 234±23 384±132† 281±125* 498±122† 334±136* 568±102 530±136

CTIB indicates CTI block; FCL, flutter cycle length; PB, partial block; CB, complete block; CCWB, counterclockwise block; CWB, clockwise block; ND, not determined.

*P<0.01; †P<0.03.
Rate-dependent clockwise block of the CTI was defined by the observation of 2 activation wave fronts, one ascending and the other descending, in the LW during pacing from the CSO at 600 ms, but only a single descending activation of the LW during pacing at shorter cycle lengths.

Constant counterclockwise block of the CTI was presumed to occur when the CSO electrogram was activated after the high interatrial septum and His bundle area during pacing at 600 ms from the low lateral right atrium.

Rate-dependent counterclockwise block of the CTI was presumed to occur when the CSO electrogram was activated simultaneous with or before the high interatrial septum and His bundle area during pacing at 600 ms, but later at a shorter cycle length.

Conduction interval was defined as the interval between the CSO and the low LW (poles 1 and 2 of the halo catheter) during pacing from both sites at the shortest cycle length before CT block and at the pacing cycle length that provoked complete CT block.

Statistical Analysis
Values are expressed as mean ± SD. Statistical comparisons for 2 groups were performed with the Student’s t test or the signed rank test. A value of P < 0.05 (2-tailed) was considered significant.

Results
Recordings obtained along the right atrium during flutter showed activation propagating in a counterclockwise direction in all patients. The flutter cycle length of this group was 234 ± 23 ms. After radiofrequency ablation, constant bidirectional CTI block was observed in 17 patients, whereas 3 patients showed clockwise rate-dependent block and 2 showed both counterclockwise and clockwise rate-dependent block. During sinus rhythm, neither double nor fragmented electrograms were recorded in the CT area. (See Table 2.)

Conduction Across the CT
Although complete transversal conduction block was observed in all patients from ≥1 pacing site, it was observed at the longest possible pacing cycle length in only a minority, suggesting the presence of fixed conduction block (patients 2, 11, 12, and 20 during pacing from the PW/CSO and patients 12 and 20 during pacing from the LW; Figure 2). In the remaining patients, the block was rate dependent (Figure 3). As shown in Table 2, both partial and complete block were achieved at longer pacing cycle lengths from the PW/CSO.
than from the LW. In 3 patients (patients 1, 6, and 13), complete block was not achieved with the shortest pacing cycle length from the LW (Figure 4), which suggests pacing site–dependent conduction block.

**CT Conduction and CTI Block Assessment**

Constant clockwise CTI block was observed in 4 and 13 patients with fixed and rate-dependent CT conduction block, respectively. In 4 of the 5 cases in which CTI block was rate dependent (patients 15, 16, 18, and 19), the block appeared at the same cycle length as at the CT (Figure 5). In the remaining case (patient 14), CTI block appeared at a longer cycle length than for CT block (Figure 6). Constant counterclockwise CTI block was present in all but 2 patients, who had CT rate-dependent block.

In 11 patients with rate-dependent CT conduction block, we could measure the conduction interval between the CSO and the low LW before and after the appearance of complete block at the CT (Table 3). It was during clockwise CTI block testing that the conduction interval increment was signifi-
cantly greater (67±39 versus 4±4 ms; P < 0.02) in patients with rate-dependent block (Figure 5) than in patients with constant CTI block (Figure 7).

Discussion

The presence of a line of block along the CT is presumed to be essential for AFL to occur. A match between wavelength and circuit size is achieved if this line of block prevents the short circuit between the PW and LW, circumscribing the macroreentry around the tricuspid ring. We have shown that CT transversal conduction block in patients with typical AFL is rate and pacing-site dependent, with the exception that in some patients, complete block did not appear during pacing from the LW. We have also shown that conduction properties are not uniform along the CT; in most patients, partial block occurs at very different pacing cycle lengths than complete block. Complete bidirectional block at the CT was usually observed only at short cycle lengths. This observation may be the reason for the narrow limits of the flutter cycle length. Reentry would remain stable if conduction time along the macroreentrant circuit was shorter than the cycle length at which CT block developed.

Differences Between PW and LW Rate-Dependent Transversal Conduction Block

We observed that conduction block in the CT was achieved at slower pacing rates from the PW than from the LW, where only partial block was observed in some cases. Differences in cell arrangement between the smooth and trabeculated atrial walls may produce a different electrical input in the CT and consequently a different rate-dependent block. This characteristic could explain the greater incidence of counterclockwise rotation in spontaneous AFL. According to CT conduction characteristics, AFL should be more easily induced by atrial arrhythmias arising in the PW or the left atrium than by those arising from the high and lateral right atrium, which would require a shorter cycle length to cause complete conduction block. Because the direction of rotation of atrial

### TABLE 3. Electrophysiological Results

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CCW indicates counterclockwise; CTIB, CTI block; CTCB, complete block; Δ CI, conduction interval difference during pacing before and after CT block; and CW, clockwise.
fibrillation (AF) may be dependent on the site of induction (pacing from the PW induces counterclockwise flutter, and pacing from the lateral right atrium induces clockwise flutter\textsuperscript{22,23}), counterclockwise flutter should occur more frequently. In the same sense, atrial arrhythmias with coupling intervals or cycle lengths that provoke conduction block only from the PW to the LW will induce stable flutter if propagation is counterclockwise. If conduction block is only present from the PW to the LW and conduction is possible in the opposite direction, the only way for the CT to act as a line of bidirectional conduction block is if the postactivation refractoriness of the CT, just before the line of block, exceeds the time required to surround the line of block. This will depend on the conduction time of the activation wave front around the CT. Therefore, when activation is counterclockwise, propagation between both sides of the CT through the high right atrium will have a short delay, and the CT will function as a barrier in both directions. If activation of the opposite side of the CT is delayed (ie, clockwise propagation through the previously mentioned slow-conducting area located in the low atrium), the barrier of refractoriness could end, because there is enough time to recover and conduction to the other side of the CT is possible at some level of the CT, thus creating smaller and more unstable circuits. This hypothesis could explain why counterclockwise right atrium circus movement is more commonly observed than clockwise movement in type 1 AFL. Nevertheless, some other determinants are presumably involved, because AFL in transplanted hearts is usually counterclockwise despite the lack of any role for the CT in the flutter mechanism\textsuperscript{24}.

Influence of CT Rate-Dependent Conduction Block on the Evaluation of CTI Block

The CTI is commonly used as the target of radiofrequency ablation.\textsuperscript{18,19} Achievement of constant block at this isthmus is the best marker of success.\textsuperscript{20,21} Nevertheless, rate-dependent block does not imply recurrence during follow-up.\textsuperscript{21,25} A complete craniocaudal activation pattern of the opposite wall to the pacing site (CSO and low LW) is consistent with CTI block. Theoretically, to observe this activation pattern, a posterior electrical barrier should be present to prevent short-circuiting between the PW and LW. Because this line of block is usually functional, a change would be expected in the activation pattern and conduction interval when functional block appears at the CT. This hypothesis is consistent with the observation of rate-dependent CTI block, as was seen in the cases in which CT and CTI blocks appeared simultaneously. In these patients, a short-circuiting of the low LW at lower rates could mimic conduction along the CTI, thus precluding recognition of CTI block.

Permanent CTI block was observed, as expected, in all patients in whom we could demonstrate fixed block at the CT, but it was also seen in the majority of cases of rate-dependent block. This surprising observation suggests that activation of the LW, at least close to the TA, is in some cases independent of the conduction state of the CT. In these patients, the conduction interval from the CSO to the low LW is not modified by the appearance of block at the CT, probably because the conduction velocity is faster along the longitudi-

![Image of ECG surface lead and 12 intracardiac electrograms recorded during CSO pacing. AbC is ablation catheter. A. During pacing at 400 ms, no double or fragmented electrograms are recorded except at CT1. LW activation pattern is craniocaudal, and conduction interval to LWS is 120 ms. B. During pacing at 300 ms, appearance of double electrograms at all CT recordings and activation pattern suggest CT complete block. Nevertheless, activation sequence at LW remains unchanged, and conduction interval is only 10 ms longer. Activation sequence of LW and conduction interval to low LW are independent whether conduction across CT is still present or not.](http://circ.ahajournals.org/DownloadedFrom)
nal fibers surrounding the TA than across the CT. In these cases, the block along the CT may be essential for the initiation of AFL but not for its perpetuation.

Study Limitations
There are several limitations to this study. The CT was identified by the recording of double electrograms during flutter; we did not use intravascular echocardiography. Nevertheless, in all cases, we were able to record double electrograms at a particular location between the LW and PW that were stable throughout the entire pacing protocol; therefore, we can assume there is constant location for this line of block, and the electrophysiological implications are identical whether the line of block is at or close to the CT. Another limitation is that we obtained data from only 1 selected pacing site on each side of the CT, and this paced activation wave front might be different from that observed during flutter. Therefore, rate dependency may be different during flutter and pacing.

Clinical Implications
The production of bidirectional block between the lateral and septal walls in the CTI is currently being used as the end point of radiofrequency catheter ablation of AFL. Nevertheless, in patients in whom the CT does not act as a barrier between the LW and PW at the flutter cycle length, a clockwise rotating circuit may not be stable because of its absence. Thus, in these patients, it is conceivable that bidirectional block is unnecessary and that unidirectional block between the lateral and septal walls may suffice to treat AF by catheter ablation. In cases with rate-dependent CTI block, it is important to determine the relationship with the CT rate-dependent block to avoid the possibility that conduction across the CT could mimic permeability across the CTI.

References
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