Differential Pacing for Distinguishing Block From Persistent Conduction Through an Ablation Line

Dipen Shah, MD; Michel Haïssaguerre, MD; Atsushi Takahashi, MD; Pierre Jaïs, MD; Mélèze Hocini, MD; Jacques Clémenty, MD

Background—Because complete linear conduction block is necessary to minimize the recurrence of reentrant tachycardias such as typical atrial flutter, we investigated a simple technique to recognize a persistent gap or complete linear block.

Methods and Results—We prospectively evaluated cavotricuspid isthmus conduction in 50 patients (age 63±8 years, 43 men) after radiofrequency ablation. The distal and proximal bipoles of a quadripolar catheter placed close to the ablation line were successively stimulated during recording from the ablation line. We hypothesized that because the initial and terminal components of local potentials reflected activation at the ipsilateral and contralateral borders of the ablation lesion, a change to a more proximal pacing site without moving the catheter would prolong the stimulus to the initial component timing, whereas the response of the terminal component would depend on the presence of block or persistent conduction. A shortening or no change in timing of the terminal component would indicate block, whereas lengthening would indicate persistent gap conduction. The results were compared with previously described criteria for isthmus block. Ninety-two sites were assessed: 17 before and 75 after the achievement of complete isthmus block. The timing of the initial component was delayed by 19±9 ms, and the terminal component was advanced by 13±8 ms after block and delayed by 12±9 ms in case of persisting conduction. The sensitivity, specificity, and positive and negative predictive values for linear block were 100%, 75%, 94%, and 100%, respectively.

Conclusions—An accurate assessment of isthmus block or persistent isthmus conduction is possible with this technique of differential pacing. (Circulation. 2000;102:1517-1522.)

Key Words: conduction ■ cavotricuspid isthmus ■ pacing maneuver

The successful achievement of complete block in the cavotricuspid isthmus provides an objective end point to a curative therapeutic procedure for typical atrial flutter and reduces recurrence rates.1–6 This is accomplished by creating a segment of linear block in the isthmus between the inferior vena cava and the tricuspid annulus. The achievement of complete block is verified through documentation of a change in activation of the septal or lateral right atrium during pacing from the opposite side of the lesion as evidence of an actual detour around the area of block, through sequential multipoint mapping along the ablation line to document double potentials, or both.4–12 However, confusing or inconclusive electrograms can be encountered along the ablation line.

We describe here a new technique to reliably and rapidly recognize complete block at the ablation line in the cavotricuspid isthmus that does not require roving multipoint mapping or multielectrode activation mapping.

Methods

Patients

Fifty patients who underwent radiofrequency (RF) catheter ablation in the cavotricuspid isthmus (n=48) for atrial flutter or evaluation after previous RF ablation for typical atrial flutter (n=2) were prospectively included in the study (mean age 63±8 years, 43 men). Ten had structural heart disease, including coronary artery disease (n=4) and valvular heart disease (n=6).

Electrophysiological Study and Ablation

Both the study and ablation were performed after informed consent was obtained and oral antiarrhythmic drugs were stopped 48 hours in advance. The procedure was performed with the patient under local anesthesia after a fasting period of ≥4 hours. Bipolar electrograms were filtered through a band pass of 30 to 500 Hz, whereas unipolar electrograms were filtered through a band pass of 1 to 500 Hz; both were recorded on a multichannel polygraph (Midas PPG) at a paper speed of 100 mm/s and at gains of 0.1 and 1 mV/cm, respectively. Bipolar stimulation was performed with a programmable stimulator (Elan Medical) at an output amplitude of 4 times diastolic threshold and a 2-ms pulse width. A single diagnostic catheter was placed in the right atrium via the femoral vein; this included (1) a quadripolar catheter in 30 patients (5-mm interelectrode spacing in 26; 2-, 5-, and 2-mm spacing in 3; and 2-mm spacing in 1), (2) a hexapolar catheter (2-mm interelectrode spacing) in 17 patients, (3) an octapolar catheter (2-, 5-, and 2-mm spacing) in 1, and (4) a decapolar catheter (2-, 5-, and 2-mm spacing) in 2 patients. The diagnostic catheter was curved and positioned in the right atrium with the tip pointing down so that the most distal electrode was close to the intended linear ablation line at the lateral border of the cavotricuspid isthmus and the...
Identification and Mapping of the Ablation Line

The lesion line was located by recording double potentials (Ai, At) with isoelectric intervals (defined as double-spike electrograms separated by an isoelectric interval of ≥30 ms) or triple/fractionated electrograms (defined as electrograms with 3 clearly defined deflections and fractionated potentials as those with >3) from the ablation catheter during pacing from the distal bipole of the low lateral right atrial catheter. A complete line of block was identified by a continuous corridor of double potentials separated by an isoelectric interval. Gaps in this line (ie, sites of persistent conduction) were localized by single or triple/fractionated potentials centered on or occupying the isoelectric interval of adjacent double potentials.8-12 No RF energy was delivered at sites that already exhibited double potentials. The gaps were ablated until complete isthmus block was achieved. As described in detail by Shah et al,2 in addition to the absence of any “gap” electrograms on the line, a completely descending septal activation sequence was required with the His-atrial electrogram time preceding the coronary sinus ostial activation time, which in turn preceded the second potential timing all along the line; moreover, descending activation of 2 adjacent low lateral right atrial sites (recorded from the quadrupolar diagnostic catheter used previously for lateral right atrial pacing) during pacing from the coronary sinus ostium with the ablation catheter was also required.7,9,10 In case of doubt, detailed mapping was performed on both the ablation line and the immediate surroundings on the side opposite to the pacing site to exclude a penetrating wavefront by verifying the later timing of the second potential on the ablation line compared with activation timing at the coronary sinus ostium (during lateral right atrial pacing) and at the low lateral right atrium (during pacing from the coronary sinus ostium).

Differential Pacing

A dynamic pacing maneuver was used to evaluate whether components of the local potentials recorded from the ablation line were produced by a penetrating wavefront of persisting isthmus conduction or by wavefronts colliding on either side of a complete line of block (Figure 2). The response to differential pacing was compared with the presence of isthmus block or conduction as described earlier without modifying or affecting ablation strategy.

Hypothesis

During unidirectional activation of the isthmus (lateral right atrial pacing), electrograms recorded along the ablation line reflect activation in its immediate vicinity: the initial component (Ai) reflects activation at the ipsilateral border, and the terminal component (At) reflects that at the contralateral border. We hypothesized that pacing from another site farther away from the ablation line would obviatingly delay the stimulus to initial component timing but that the response of the terminal component would depend on the presence or absence of conduction through the ablation line. The terminal component would be delayed like the initial component if it was activated by the same wavefront penetrating through the ablation line, indicating persistent conduction, but would be advanced if it was activated by the wavefront going around, indicating conduction block, instead of through the line because the length of the detour is shortened by withdrawal of the pacing site.

Maneuver

The pacing site was changed (without moving any of the catheters or changing the stimulation rate) from the distal to a proximal bipole (the most proximal bipole in case of quadrupolar and hexapolar catheters but the third bipole for octapolar and decapolar catheters to avoid both too little and too much change in pacing position) except in 4 cases, where the catheter was manually withdrawn and repositioned 1.5 cm proximally because stable capture was possible only from the distal bipole. The change in pacing position (which was directly responsible for the increment in stimulus to Ai timing) was calculated from the center of 1 pacing bipole to the other based on electrode ring width and interelectrode spacing.

Care was taken to ensure that the pacing catheter tip was close to the ablation lesion as indicated by short stimulus to Ai times of <50 ms and that both catheter positions remained stable during the maneuver. Furthermore, the morphology of the electrogram was...
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**Results**

**Ablation**

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**Differential Pacing**

Ninety-two assessments were performed in 50 patients at different sites: 17 in 12 patients before the achievement of complete isthmus block and 75 in 49 patients after complete block was achieved; 11 patients were assessed both before and after block. Electrograms at the site of assessment were double potentials in 72 instances, triple potentials in 13 instances and fractionated potentials in 2 instances. There were “single” potentials (ie, double potentials with 1 miniscule/barely discernible potential) in 5 instances. The different sites assessed and the electrogram characteristics are presented in Table 1.

The pacing position was changed by 15 ± 2 mm in the group as a whole and was similar in the patients assessed before and after block (14 ± 2 and 15 ± 2 mm, respectively; $P = \text{NS}$).

As a result, the stimulus to the initial potential timing was delayed by 19 ± 9 ms: by 20 ± 9 ms in assessment before block and by 18 ± 9 ms in the group assessed after block ($P = \text{NS}$).

The stimulus to the terminal potential timing was delayed by 12 ± 9 ms in the group before block, whereas it was advanced by 13 ± 8 ms in assessment after block ($P = \text{NS}$ for the comparison of the magnitude of change, not its direction) (Figures 3 and 4).

**Correlation With Isthmus Block**

Of 17 assessments performed with persisting isthmus conduction, the stimulus to the second or terminal potential timing was delayed in 14, advanced in 1, and unchanged in 2.

**Distribution of Assessment Sites and Their Electrogram Morphologies in the 50 Study Patients**

<table>
<thead>
<tr>
<th></th>
<th>After Block (n=49)</th>
<th>During Persisting Conduction (n=12)</th>
</tr>
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<tbody>
<tr>
<td>Sites</td>
<td>75</td>
<td>17</td>
</tr>
<tr>
<td>Double potentials</td>
<td>55</td>
<td>17</td>
</tr>
<tr>
<td>Triple potentials</td>
<td>13</td>
<td>...</td>
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<tr>
<td>Fractionated potentials</td>
<td>2</td>
<td>...</td>
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<tr>
<td>“Single” potentials</td>
<td>5</td>
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n=50 patients.
Of 75 assessments performed after isthmus block, the stimulus to second potential timing was shortened in 63 and unchanged in 12. The terminal potential was not delayed in any instance.

Triple potentials separated by isoelectric intervals were found after isthmus block: of 13 sites, only the third potential was advanced in 9, whereas the second and third were both advanced in 4. Similarly, in both instances with a fractionated potential, the terminal potential was advanced (Figure 4).

Analysis of Assessment at Multiple Sites
Multiple sites (n = 53) on the ablation line (including up to 5 different sites in the same patient) were assessed in 22 patients: in 4 before block (n = 9) and in 19 after block (n = 44), including 1 both before and after. Consistent results were obtained at all sites after block, whereas in 2 of 4 patients, the stimulus to At was unchanged or shortened in the presence of persisting conduction.

The sensitivity, specificity, and negative and positive predictive values of the response to differential pacing for complete isthmus block were 100%, 75%, 94%, and 100%, respectively.

Outcome
During a follow-up of 25 ± 2 months after discharge there were four recurrences.

Discussion
In the present study, we were able to use a simple new technique to reliably distinguish persisting conduction from complete isthmus block without catheter movement and in nearly all cases by assessment at a single site. Triple or fractionated local electrograms, that may be confounded with conducting gaps, were shown to also result from slow conduction on 1 flank or another of a complete line of block.

Criteria of Linear Block
Commonly used techniques of assessing isthmus conduction rely on the assessment of the change in activation of the lateral or septal right atrium with multielectrode catheters preshaped to fit the tricuspid annulus. During pacing from 1 side of an isthmus ablation line, antidromic or orthodromic activation of the opposite side of the ablation line indicates block or persisting conduction, respectively. The slower the penetrating orthodromic front through the region of ablation, the nearer to the line the collision with the detouring antidromic front is likely to occur, necessitating detailed mapping in this region to distinguish it from complete block. Therefore, mapping the ablation line or the adjacent region with a roving catheter is frequently necessary to demonstrate the achievement of a complete corridor of double potentials with isoelectric intervals.7–11 However, whereas triple and
fractionated potentials commonly indicate conducting gaps, they may also represent bystander zones of slow conduction in the presence of actual complete isthmus block, probably due to several passages or parallel ablation lines that result in a wide RF lesion.

The present technique is based on demonstration of the functional linking of local electrograms to a single wavefront passing through the isthmus in case of persisting conduction versus dissociation of the initial and terminal electrogram components in the case of block (Figure 2). Isthmus conduction is therefore assessed through sampling at a single point on the ablation line. Assessment at multiple sites provided consistent results in all except 2 instances but also demonstrated changes in timing of the terminal component, probably as a result of local inhomogeneities of conduction.

The high sensitivity and positive and negative predictive values underline the efficacy of this new technique. The terminal potential was never delayed in the presence of complete block and advanced only rarely in the presence of persistent conduction. The method was particularly useful in the evaluation of triple or fractionated potentials recorded in 22% of patients after complete block.

**Factors That Affect Differential Pacing**
The demonstration of functional linking through changing pacing sites depends on the relative conduction times to both flanks of the ablation line and therefore may be affected by the selection of the pacing position, relative conduction velocities, length of the activation detour, and intervening areas of slow conduction or block that affect only 1 of the 2 pacing positions. The pacing catheter was therefore positioned as close as possible to the lesion line and the magnitude of displacement of the pacing position was limited (15±2 mm) so that the stimulus to the initial potential time was 42±13 ms during distal pacing and 61±16 ms during proximal pacing. To detect very slow conduction through the isthmus, both pacing sites may have to be even closer to the ablation line (ie, with shorter stimulus to initial potential times). As an example, if we assume that after isthmus block the impulse travels around a tricuspid annulus of 14 cm in circumference with a uniform conduction velocity of 0.7 m/s and the proximal pacing site is 2.1 cm from the ablation line, corresponding to a stimulus to initial potential time of 30 ms, slow isthmus conduction with a velocity of 0.079 m/s over a lesion width of 7 mm would behave like block, which means that the distal side of the ablation line would be captured by activation around the ablation line, thus advancing the terminal potential. A close pacing site (favoring capture of the contralateral side of the ablation line by a penetrating wavefront of persistent conduction) is therefore important to avoid orthodromic capture of the opposite side of the ablation line during distal pacing and antidromic capture of the opposite side during proximal pacing, in the presence of persistent but slow conduction. Although not observed in the present study, it is logical to suspect this in case a major change in the morphology of the terminal electrogram component is produced by a change in the pacing site without catheter movement.

Similarly, although the same pacing maneuver could be applied to assessment of the functional linking of electrograms a certain distance away from the ablation line, this would limit the ability to detect slow penetrating conduction, which is maximized by assessment on the ablation line. The latter consideration means that the absence of any lengthening of activation time of the terminal component (At) is strong support for the presence of block. This was borne out in the present study not only by comparison with accepted criteria for block but also by repeat assessment at another site on the ablation line, which demonstrated clear shortening of the timing of the second potential. These variations in timing of the terminal component are due to local activation inhomogeneities, probably secondary to ablation. Areas of slow conduction or block may impair accuracy if they selectively affect only 1 of the 2 pacing positions. These limitations, however, also apply to other means of conduction assessment and are in fact common to all.

**Study Limitations**
Although the study was prospectively performed, an assessment of the response to differential pacing could not be systematically performed in a blinded fashion. Fewer assessments were performed with persisting conduction because the presence of persisting conduction was generally evident. A systematic evaluation of the optimal magnitude of change in the pacing site position was not performed. Although only unidirectional isthmus conduction was assessed with differential pacing, this was correlated with bidirectional isthmus conduction assessment based on local electrogram criteria described earlier, the fidelity of which was confirmed by the low recurrence rate; however, no direct comparison with multielectrode catheter techniques was performed. Very slow conduction through the isthmus could not be absolutely ruled out, and although we did not find any instances of false-positive diagnoses of persisting conduction, this is theoretically possible in the presence of a conduction delay that affects only activation from the second pacing position.

**Clinical Implications**
This single-site assessment technique is a complement to local electrogram assessment and provides an on-site evaluation of each double or triple fractionated potential, without having to move the recording ablation catheter from the recording site or to perform supplemental mapping. This is an obvious additional advantage when a gap electrogram is validated to represent persistent conduction through the ablation lesion instead of bystander slow conduction and permits prompt ablation, whereas the recognition of conduction block despite triple or fractionated potentials prevents unnecessary ablation.

Moreover, this technique can also be applied without modification to other locations in the atria where detailed mapping is more difficult, such as in the left atrium to evaluate lines that join the mitral annulus. In such a situation, a multipolar catheter in the coronary sinus and another recording catheter on the ablation line allows effective evaluation of conduction without moving any of the 2 catheters (unpublished data, 1999).

**Conclusions**
This technique of single-site assessment of conduction is simple and highly sensitive in distinguishing block from slow conduction. It
also allows the distinction of triple or fractionated potentials that result from bystander slow conduction contiguous or adjacent to the ablation line from true markers of conducting gaps.

References
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