Double Potentials Along the Ablation Line as a Guide to Radiofrequency Ablation of Typical Atrial Flutter

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OBJECTIVES
The purpose of this study was to determine the characteristics of double potentials (DPs) that are helpful in guiding ablation within the cavo-tricuspid isthmus.

BACKGROUND
Double potentials have been considered a reliable criterion of cavo-tricuspid isthmus block in patients undergoing radiofrequency ablation of typical atrial flutter (AFL). However, the minimal degree of separation of the two components of DPs needed to indicate complete block has not been well defined.

METHODS
Radiofrequency ablation was performed in 30 patients with isthmus-dependent AFL. Bipolar electrograms were recorded along the ablation line during proximal coronary sinus pacing at sites at which radiofrequency ablation resulted in incomplete or complete isthmus block.

RESULTS
Double potentials were observed at 42% of recording sites when there was incomplete isthmus block, compared with 100% of recording sites when the block was complete. The mean intervals separating the two components of DPs were 65 ± 21 ms and 135 ± 30 ms during incomplete and complete block, respectively (p < 0.001). An interval separating the two components of DPs (DP1-2 interval) < 90 ms was always associated with a local gap, whereas a DP1-2 interval ≥ 110 ms was always associated with local block. When the DP1-2 interval was between 90 and 110 ms, an isoelectric segment within the DP and a negative polarity in the second component of the DP were helpful in indicating local isthmus block. A DP1-2 interval ≥ 90 ms with a maximal variation of 15 ms along the entire ablation line was an indicator of complete block in the cavo-tricuspid isthmus.

CONCLUSIONS
Detailed analysis of DPs is helpful in identifying gaps in the ablation line and in distinguishing complete from incomplete isthmus block in patients undergoing radiofrequency ablation of typical AFL. (J Am Coll Cardiol 2001;38:750–5) © 2001 by the American College of Cardiology

A corridor of parallel double potentials (DPs) along the ablation line has been recognized to be an indicator of complete isthmus block in patients undergoing radiofrequency catheter ablation of typical atrial flutter (AFL) (1,2). However, DPs may also be present along the ablation line when isthmus block is incomplete (3,4). The minimal degree of separation needed to indicate complete isthmus block has not been well defined. In addition, it is possible that other characteristics of DPs, such as polarity or the presence of an isoelectric segment within the DPs, might also be helpful in distinguishing complete from incomplete isthmus block. The purpose of this prospective study was to determine the characteristics of DPs that are helpful in identifying gaps in the ablation line and in distinguishing complete from incomplete isthmus block during radiofrequency catheter ablation of typical AFL.

METHODS

Characteristics of subjects. Among 50 consecutive patients who underwent radiofrequency catheter ablation of isthmus-dependent AFL at the University of Michigan Medical Center, 30 had recordings obtained along the ablation line both during incomplete isthmus block and after complete isthmus block had been achieved. These 30 patients (23 men and 7 women, mean age 58 ± 13 years, ± SD) served as the subjects of this study. Of the patients, 4 had coronary artery disease, 3 had idiopathic dilated cardiomyopathy and 23 had no structural heart disease.

Electrophysiologic procedure. All patients provided written, informed consent before the electrophysiologic procedure. Three venous sheaths were inserted into a femoral vein for vascular access. A 7F duo-decapolar halo catheter (2-mm spacing between electrodes of each bipole; 20-2-2-2-25-25-25-25-mm spacing between pairs of electrodes, Daig Corp., Minnetonka, Minnesota) was positioned along the tricuspid annulus with the distal bipole of the halo catheter within the proximal portion of the coronary sinus (Fig. 1). A 7F quadripolar catheter (EP Technologies Inc.,
San Jose, California) was positioned within the proximal coronary sinus for pacing. A 7F quadripolar catheter with a deflectable tip, 4-mm distal electrode, 2-5-2-mm interelectrode spacing and a thermistor embedded in the distal electrode (EP Technologies Inc.) was used for mapping the isthmus and delivering radiofrequency energy.

Bipolar electrograms were always recorded with the distal electrode serving as the cathode, filtered at settings of 30 to 500 Hz and recorded digitally (EPMed Systems, Inc., Mount Arlington, New Jersey). Electrograms were analyzed off-line at a gain setting of 0.1 to 0.2 mV/cm and at a sweep speed of 100 to 200 mm/s. Pacing was performed with a stimulator (Model EP-3 Clinical Stimulator, EPMed Systems, Inc.) at twice the diastolic threshold and with a pulse width of 2 ms.

Radiofrequency ablation was performed during AFL in 16 patients who presented with AFL (mean cycle length 248 ± 26 ms) or during coronary sinus pacing at a cycle length of 500 to 600 ms in the 14 patients who were in sinus rhythm. Under fluoroscopic guidance, individual contiguous applications of radiofrequency energy were delivered to create a line of block in the cavo-tricuspid isthmus. The power was automatically adjusted to maintain a target temperature of 60°C at the electrode-tissue interface. Each application of energy was 45 to 60 s in duration.

The end point of the procedure was complete isthmus block in the clockwise and counterclockwise directions. This end point was attained in all patients in this study. The criteria used to identify complete block consisted of an atrial activation sequence around the tricuspid annulus consistent with complete block (5–11), negative initial polarity of the electrograms recorded just lateral to the ablation line during coronary sinus pacing (12) and the presence of DPs along the entire ablation line (Fig. 2) (1,2). These criteria had to be present before and during infusion of 2 μg/min of isoproterenol (13). In a previous study, complete isthmus block was associated with DPs separated by an interval ranging from 60 to 190 ms during pacing at the posterolateral right atrium (1). However, one of the goals of this study was to determine whether there is a critical degree of separation between the two components of a DP that distinguishes incomplete from complete isthmus block. Therefore, the degree of separation within DPs was not used as an end point in this study.

During a mean of 12 ± 4 months of follow-up, none of the patients in this study had a recurrence of AFL. Eleven of the patients continued treatment with a class I or III antiarrhythmic drug to prevent recurrences of atrial fibrillation.

Analysis of electrograms. In accordance with the criteria used to select the subjects in this study, complete isthmus block was preceded by incomplete block in all patients in

**Figure 1.** A 45° left anterior oblique fluoroscopic view of catheter positions during atrial flutter ablation (ABL) is shown. A duo-decapolar halo catheter is positioned around the tricuspid annulus and along the cavo-tricuspid isthmus. Electrode pairs of the halo catheter are labeled E1 to E9. Note that E1 and E2 are positioned just lateral to the intended ABL line. A quadripolar electrode catheter is positioned within the coronary sinus (CS) for pacing. The ABL catheter is positioned at the intended ABL line. The recordings displayed in Figures 2 through 5 were obtained with the catheters positioned as shown in this figure.
Incomplete block, also referred to as slowing of transisthmus conduction, was defined as a measurable delay in conduction across the cavo-tricuspid isthmus, in the absence of criteria for complete isthmus block. To ensure that the electrograms before and after a change in transisthmus conduction were being compared at exactly the same recording site, the analysis was limited to the sites at which an application of radiofrequency energy resulted in measurable slowing of conduction or complete block. The electrograms recorded along the ablation line during incomplete and complete isthmus block were analyzed post hoc by two observers. In the 14 patients who were in sinus rhythm at the onset of the procedure, the electrograms recorded along the ablation line were compared before and after the onset of incomplete isthmus block. In addition, in all 30 patients, the electrograms recorded along the ablation line were compared just before and after the transition from incomplete to complete isthmus block.

The interval separating the two components of a DP (DP\(_{1-2}\) interval) was measured with electronic calipers from the peak of the first component of the DP to the peak of the second component. In addition, the segment separating the two components of DPs was classified according to whether or not it was isoelectric (Fig. 2). The morphology of the second component was characterized by terminology used to describe QRS complexes. The smaller arrows indicate the first component of the DPs. St = stimulus channel.

**RESULTS**

**DP\(_{1-2}\) interval.** A DP was recorded along the ablation line at 25 (42%) of 58 sites at which an application of radiofrequency energy resulted in slowing of transisthmus conduction and at each of 30 sites (100%) at which an application of radiofrequency energy resulted in complete isthmus block (p < 0.001). The mean DP\(_{1-2}\) interval was 65 ± 21 ms (range 35 to 103 ms) when there was incomplete block, compared with 135 ± 30 ms (range 95 to 198 ms) when there was complete block (p < 0.001) (Fig. 4).

**Isoelectric segments within DPs.** At the 25 sites at which a DP was recorded when there was incomplete isthmus block, the segment separating the two components of the DP was isoelectric at 5 (20%). In contrast, at the 30 sites at which a DP was recorded on the transition to complete isthmus block, the segment separating the two components of the DP was isoelectric at 25 (83%, p < 0.001) (Fig. 2).

**Polarity.** The initial polarity of the second component of DPs was mainly negative (Qr, QS or rSr pattern) in 11 (44%) of 25 DPs recorded when there was incomplete block.
and in 27 (90%) of 30 DPs recorded on the transition to complete isthmus block \((p < 0.001)\) (Fig. 5).

**Sensitivity and specificity of DP criteria.** The sensitivity, specificity and predictive accuracy of DP criteria for complete cavo-tricuspid isthmus block are shown in Table 1. There were no significant differences among these criteria.

**DISCUSSION**

**Major findings.** The results of this study demonstrate that DPs recorded along the ablation line during coronary sinus pacing are helpful in identifying gaps in the ablation line, but only when the specific characteristics of the DPs are analyzed. Patients were selected for inclusion in this study if their block was incomplete after an initial series of applications of radiofrequency energy in the cavo-tricuspid isthmus. In these patients, a local DP1-2 interval $\geq 110$ ms was found to be a reliable indicator of local block, and a DP1-2 interval $< 90$ ms was found to be a reliable indicator of a local gap. When the DP1-2 interval was between 90 and 110 ms, the recording site was equally likely to be a site of local block or a gap, and other characteristics of the DP were found to be helpful in making this distinction. When the segment between the two components of the DP was not isoelectric,

<table>
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<tr>
<th>Criteria</th>
<th>Sensitivity (%)</th>
<th>Specificity (%)</th>
<th>PPV (%)</th>
<th>NPV (%)</th>
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<tr>
<td>(\text{DP}_{1-2} \geq 90) ms</td>
<td>100</td>
<td>80</td>
<td>86</td>
<td>100</td>
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<tr>
<td>(\text{DP}_{1-2} \geq 110) ms</td>
<td>83</td>
<td>100</td>
<td>100</td>
<td>83</td>
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<tr>
<td>(\text{DP}_{1-2} \geq 90) ms + isoelectric interval</td>
<td>83</td>
<td>96</td>
<td>96</td>
<td>83</td>
</tr>
<tr>
<td>(\text{DP}_{1-2} \geq 90) ms + negative (\text{DP}_2)</td>
<td>90</td>
<td>88</td>
<td>90</td>
<td>88</td>
</tr>
<tr>
<td>(\text{DP}_{1-2} \geq 90) ms + isoelectric interval + negative (\text{DP}_2)</td>
<td>77</td>
<td>100</td>
<td>100</td>
<td>78</td>
</tr>
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*There were no significant differences among these criteria.*

\(\text{DP}_{1-2}\) = interval separating the two components of double potentials; \(\text{DP}_2\) = second component of a double potential; NPV = negative predictive accuracy; PPV = positive predictive accuracy.
or when the polarity of the second component of the DP was positive, the recording site was likely to be at or very close to a gap in the ablation line.

The results of this study also demonstrate that the DP
\[1-2\] intervals recorded along the ablation line during coronary sinus pacing can serve as an end point for the ablation procedure. A DP
\[1-2\] interval $> 90$ ms at all points along the ablation line and maximal variation $\pm 15$ ms in the DP
\[1-2\] intervals recorded along the ablation line are reliable indicators that complete bidirectional block in the cavo-tricuspid isthmus has been achieved.

**Degree of splitting within DPs.** Using electroanatomic mapping in a group of eight patients, a recent study demonstrated that when there is a gap in the ablation line in the cavo-tricuspid isthmus, the DP
\[1-2\] interval varies according to the proximity of the recording site to the gap. When the recording site was adjacent to the gap, the width of the DP was $62 \pm 16$ ms, and at recording sites farther away from the gap, the DP width was $123 \pm 34$ ms (3).

In the present study, the analysis of DPs was limited to sites at which an application of radiofrequency energy resulted in either a measurable slowing of conduction across the cavo-tricuspid isthmus or complete isthmus block. Therefore, these sites were very likely to be within or in close proximity to a gap in the ablation line. When there was incomplete isthmus block, the mean DP
\[1-2\] interval was found to be $65 \pm 21$ ms, remarkably similar to the mean value of $62 \pm 16$ ms reported in a previous study (3).

However, the present study extends the findings of the previous study (3) by comparing the DP
\[1-2\] interval at the same recording site before and after complete isthmus block and demonstrating that a DP
\[1-2\] interval $< 90$ ms always indicates the persistence of a gap in the ablation line, whereas a DP
\[1-2\] interval $\geq 110$ ms always indicates the absence of a gap at that recording site. Because the DP
\[1-2\] interval lengthens as the distance of the recording site from a gap increases (3), a DP
\[1-2\] interval $\geq 110$ ms might be present along an ablation line, even when block is incomplete, if the recording site is not near a gap.

**Isoelectric interval within DPs.** In this study, the DP
\[1-2\] interval was found to be isoelectric in most instances of complete isthmus block, and usually it contained fractionated and low-amplitude electrical activity when the block was incomplete. Low-amplitude, fractionated activity recorded during ventricular tachycardia is thought to represent slow conduction through diseased tissue in a portion of the re-entry circuit (14). In a similar fashion, it is possible that the low-amplitude, fractionated activity recorded within DPs in the cavo-tricuspid isthmus is attributable to slow or discontinuous conduction, or both, through a gap in the ablation line.

**Polarity of DPs.** A previous study found that the initial polarity of the electrograms recorded lateral to the ablation line during coronary sinus pacing changes from positive to negative on the transition from incomplete to complete isthmus block (12). In this study, the initial polarity of the second component of the DPs recorded at the gap in the ablation line was also found to usually become negative on elimination of the gap. This change in polarity may be explained by a reversal in the direction of the activation wave front across the distal bipolar of the ablation catheter on transition from incomplete to complete isthmus block.

**Study limitations.** A limitation of this study is that the analysis of DPs was limited to sites at which an application of radiofrequency energy had a measurable effect on isthmus conduction. Mapping of the entire ablation line before and after an application of radiofrequency energy would have made it very difficult to compare electrograms at exactly the same recording site. Therefore, the results of this study cannot be applied to DPs that are recorded at sites along the ablation line that are distant from a gap.

A second limitation of this study is that the clinically available end points that are used to identify complete isthmus block, including the atrial activation sequence around the tricuspid annulus during pacing in the coronary sinus and at the posterolateral right atrium, may not accurately distinguish a line of complete block from a line with a small gap that allows very slow conduction across the isthmus. However, the absence of recurrent AFL during follow-up in all of the patients in this study suggests that even if cavo-tricuspid isthmus block was incomplete sometimes, the degree of persistent conduction across the isthmus was not clinically important.

A third limitation is that only the DPs recorded during pacing from the coronary sinus were analyzed in this study. Therefore, the specific criteria described in this study may not apply to DPs that are recorded along an ablation line during pacing from the posterolateral right atrium. However, the DP criteria described in this study were indicative of complete bidirectional isthmus block; therefore, pacing from the posterolateral right atrium to confirm block in the counterclockwise direction is not necessary when using these criteria.

**Conclusions.** During conventional radiofrequency ablation in the cavo-tricuspid isthmus, the first series of radiofrequency applications across the isthmus often do not result in complete block. In fact, this was the case in over half of the 50 patients with isthmus-dependent AFL who were screened for this study. Therefore, an awareness of the local electrogram characteristics that identify a gap in the ablation line should facilitate a successful outcome of the ablation procedure. Additional applications of radiofrequency energy are appropriate, not only at sites at which the electrogram is single instead of double, but also at sites where the DP
\[1-2\] interval is $< 90$ ms. When the DP
\[1-2\] interval is between 90 and 110 ms, an additional application of radiofrequency energy is appropriate if there is fractionated, low-amplitude activity in the segment between the two components of the DP, or if the second component of the DP is positive in polarity. If the local DP
\[1-2\] interval is $\geq 110$ ms, the recording site is very unlikely to be at a gap, and an
additional application of radiofrequency energy is not needed at that site.

When the DP_{1-2} interval is >90 ms at all points along the ablation line during coronary sinus pacing, and when the maximal variation in the DP_{1-2} interval along the ablation line is ≤15 ms, it is likely that complete bidirectional isthmus block has been achieved. Therefore, in addition to identifying target sites for ablation, analysis of DPs also provides a reliable end point for the ablation procedure. The use of DPs as an end point for ablation in the cavo-tricuspid isthmus has potential advantages over other techniques for identifying complete block: 1) the atrial activation sequence around the tricuspid annulus is sometimes ambiguous as an indicator of complete isthmus block (10,11) and, at times, may be inaccurate, such as when there is conduction posterior to the inferior vena cava (15); and 2) the ablation line is easily mapped with the ablation catheter, obviating the need for a halo catheter or more sophisticated and expensive mapping systems, such as electroanatomic mapping (3), or noncontact mapping.

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