Quantitative Analysis of Surface P-Wave Morphology in Isthmus Ablation for Type 1 Atrial Flutter — Differentiation Between Complete Isthmus Block and Slow Isthmus Conduction —

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Changes in P-wave morphology in inferior leads during atrial pacing at the margins of the carvo-tricuspid isthmus have been reported to be useful for predicting the creation of isthmus block in radiofrequency (RF) ablation of type 1 atrial flutter (AFL). However, it is not known whether these changes in P-wave morphology allow the clinician to differentiate between complete isthmus block and slow isthmus conduction. P-wave morphology during low lateral right atrial (LLRA) pacing, as well as during coronary sinus ostium (PCS) pacing, was evaluated prior to ablation, during slow isthmus conduction, and after complete isthmus block in 30 patients with AFL. Changes in P-wave morphology during LLRA pacing were not sufficient to differentiate between complete isthmus block and slow isthmus conduction. While changes in P-wave morphology in lead II from inverted to biphasic during PCS pacing were observed in both slow isthmus conduction and complete isthmus block, the ratio of the positive component to the total P-wave amplitude (P-wave ratio) was significantly different between slow isthmus conduction ($20 \pm 11\%$) and complete isthmus block ($40 \pm 11\%$) ($P < 0.0001$). When the P-wave ratio in lead II during PCS pacing was more than 75% of the F-wave ratio in lead II during AFL, bilateral complete isthmus block was predicted with a sensitivity of 88%, a specificity of 71%, a positive predictive value of 75%, and a negative predictive value of 85%. These results indicate that a P-wave ratio greater than 20% or a P-wave ratio during PCS pacing greater than 75% of the F-wave ratio during AFL may predict a bidirectional complete isthmus block. (*Jpn Circ J* 1999; 63: 244–248)

Key Words: Atrial flutter; electrocardiogram; P-wave; radiofrequency catheter ablation

Type 1 atrial flutter (AFL) is due to reentry in the right atrium (RA), with an area of slow conduction located in the lower part of the RA^{1–3}. Recently, linear radiofrequency (RF) ablation of the carvo-tricuspid isthmus has been shown to be effective in the treatment of AFL^{2,3}. The creation of a line of block at the carvo-tricuspid isthmus by RF energy has been shown to predict successful ablation of AFL. Changes in P-wave morphology in the inferior leads during atrial pacing at the margins of the isthmus have been reported to be useful for predicting the creation of isthmus block^{4,5}. However, it is not known whether these changes in P-wave morphology can differentiate complete isthmus block from slow isthmus conduction (incomplete isthmus block). The aim of this study was to clarify the usefulness of P-wave morphology during pacing near the isthmus to verify the creation of a bidirectionally complete block line.

Methods

Subjects

The study population comprised 30 consecutive patients

with Type 1 AFL who were referred to the Gunma Prefectural Cardiovascular Center for RF catheter ablation between October 1996 and December 1997. There were 28 men and 2 women. The mean $\pm$ SD patient age was 60 ± 12 years (range 40 to 86 years). All patients had a documented history of AFL, with F-waves inverted in a typical “saw-tooth” pattern in ECG leads II, III, and aVF, biphasic in I and V₆, and upright in V₁. Nine patients (30%) presented with persistent AFL. Of the 30 patients, 13 (43%) had had previously documented episodes of atrial fibrillation, but the majority of recorded arrhythmias were AFL. Ten patients had associated structural heart disease, including old myocardial infarction in 3 patients, aortic valvular heart disease in 3, angina pectoris in 2, dilated cardiomyopathy in 1, and hypertrophic obstructive cardiomyopathy in 1. Antiarrhythmic drugs had been discontinued in 15 patients (50%) before the ablation procedure for at least 5 half-lives. The remaining 15 patients were receiving antiarrhythmic drugs to prevent the recurrence of atrial fibrillation, ie, cibenzoline succinate in 5 patients, pirlenol hydrochloride in 5, disopyramide in 2, quinidine sulfate in 1, pilsicainide hydrochloride in 1, and cibenzoline succinate and amiodarone in 1.

Electrophysiological Studies

RF ablation was performed in all patients after informed consent had been obtained. Patients were sedated with 5 mg of diazepam, 1 h before the procedure. Electrograms from the coronary sinus (CS) were recorded by either a decapo-

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lar or a hexapolar catheter introduced by a right subclavian puncture. A duodecapolar catheter "Halo" (Cordis-Webster Inc, Baldwin Park, CA, USA) with 10 bipoles (2-mm paired spacing) separated by a 1-cm distance was used in all patients to record the activation sequence around the tricuspid annulus. A distal pair of Halo catheters (H1-2) was carefully placed in the immediate vicinity of the opposite side of the ablation site. An additional multipolar catheter was introduced to obtain electrograms from the region of the bundle of His. Electrograms were filtered between 30 and 400 Hz and recorded on a computerized multichannel system (EPAmP™/EPLab™, Quinton, Seattle, WA, USA), allowing up to 32 simultaneous recordings and analysis at a paper speed from 100 to 400 mm/s. Electrical stimulation was delivered through a programmable stimulator (SEC-3102, Nihon Kohden Co, Tokyo, Japan); care was taken to pace no higher than twice the diastolic threshold with a 2-ms pulse duration to prevent initial activation of remote areas that might affect the results.

Ablation Procedure

RF ablation was performed with a generator CAT-500 (Central Industry, Tokyo, Japan) that delivered continuous, unmodulated current at 500 kHz. RF current was delivered in a monopolar fashion in the power mode (preset power output of 20 W) via a 4-mm-tip electrode catheter (Cordis-Webster). Ablation was guided anatomically and directed to the carvo-tricuspid isthmus. The ablation catheter was introduced into the RA by a right femoral approach in all patients. The initial position of the ablation catheter within the isthmus near the tricuspid annulus was such that a large ventricular potential and a small atrial electrogram were recorded. The preset duration of the pulse was 120 s. The ablation catheter was withdrawn progressively under fluoroscopic guidance during RF delivery, with sequential stops, in order to reach the junction between the RA and the inferior vena cava (IVC). The RF application was repeated until AFL termination and a bidirectional isthmus block were achieved. Subsequent pulses were delivered either on the same line (when application was prematurely stopped because of catheter instability and/or impedance rise) or immediately laterally or septally.

RF energy was delivered during either ongoing AFL or sinus rhythm. Low lateral RA (LLRA) and proximal CS (PCS) pacing were performed to assess the bidirectional characteristics of the block before, during, and after ablation with multiple cycle lengths (300, 400, and 600 ms), in order to clearly visualize the paced P-wave morphology unobscured by QRS complexes or T-waves. In all patients, after the creation of a line of block between the IVC and tricuspid valve, we attempted to reintroduce AFL by pacing from different RA sites (including the PCS and the lateral RA). These pacing maneuvers consisted of rapid incremental pacing (from 350 to 180 ms) or programmed atrial stimulation. Ablation was considered successful when AFL was no longer inducible and there was evidence of bidirectional complete block at the carvo-tricuspid isthmus.

Definitions of the Different Types of Isthmus Block and the Ratio of Positive Component to Total P-Wave Amplitude

Complete/incomplete clockwise isthmus block and complete/incomplete counterclockwise isthmus block have been defined by Poty et al.² Complete clockwise

Fig 1. Schematic drawing from a patient illustrating the calculation of the P-wave ratio. F-waves in the inferior leads during type 1 atrial flutter (AFL) comprise 3 components: the first component (1) is a short initial plateau phase, the second (2) is a widening of the negative component, and the third (3) is a positive component following the second component. The first component is absent in paced P-waves from the LLRA or PCS during sinus rhythm. The P (F)-wave ratio is obtained from the amplitude of the positive component (a) divided by the sum of the amplitude of the positive components (a) and negative component (b), expressed as a percentage.

isthmus block is defined by a pure descending wave front at the lateral wall to the carvo-tricuspid isthmus when paced from the PCS, ie, the septal side of the ablation site. This block is associated with marked prolongation of the PCS-H1-2 interval duration. Incomplete clockwise isthmus block is present when a descending wave at the lateral wall still allows the lateral part of the isthmus to be activated from the PCS, resulting in displacement of the collision at the lower part of lateral RA. The distal bipole of the Halo catheter (H1-2) at the lateral part of the isthmus is activated slightly before or at the same time as bipole H3-4, situated more laterally. A complete counterclockwise isthmus block is defined by a single ascending wave front at the lateral wall followed by a descending wave front at the septum to the CS ostium. Compared with baseline, a counterclockwise isthmus block is associated with an inversion of the direction of septal activation from ascending to descending. The PCS electrogram, close to the low lateral pacing site, is activated after the high RA and the His bundle region. An incomplete counterclockwise isthmus block is present when an ascending wave at the lateral wall still allows the septal part of the isthmus to be activated from the LLRA, resulting in displacement of the collision at the lower part of the septal RA. The distal bipole of the Halo catheter (H1-2) at the septal part of the isthmus is activated slightly before or at the same time as the bipole at the PCS, situated more medially.

F-waves in the inferior leads during AFL comprise 3 components (Fig 1): the first component is a short initial plateau phase, the second is a widening of the negative component, and the third is a positive component following the second component. The first component is absent in paced P-waves from the LLRA or PCS during sinus rhythm. The P (F)-wave ratio is defined as the ratio of the positive component to the total P (F)-wave component, which is obtained from the amplitude of the positive component divided by the sum of the amplitude of the positive and negative components, and is expressed as a percentage (Fig 1). The height or depth of the P (F)-wave is measured from the peak or nadir to the line connecting the

Fig 2. Three different activation patterns of the right atrium are observed progressively in a patient during pacing from the coronary sinus ostium (PCS). A. Before ablation. A collision of one ascending wave front (from H1-2 to H9-10) with a descending wave front (H19-20 to H9-10) occurs at the lateral wall of the right atrium. The stimulus-H3-4 interval duration, representing isthmus conduction, is short (85 ms). B. Incomplete isthmus block. After RF applications, the stimulus-H3-4 interval lengthened to 118 ms, suggesting altered conduction through the isthmus. Collision at the lateral right atrium is displaced to the lower right atrium (H8-9). Bipole H3-4 is still activated directly by the PCS catheter. C. Complete isthmus block. The ablation is pursued to obtain a pure descending wave front at the low right atrium. Bipole H3-4 is now activated from H4-5. A marked prolongation of the stimulus-H3-4 interval duration (147 ms) is finally observed, related to a complete clockwise isthmus block.

Fig 3. Representative changes in P-wave morphologies and the P-wave ratio during pacing from the coronary sinus ostium (PCS) in sinus rhythm and the F-wave ratio during type 1 atrial flutter (AFL). The P-wave configuration during PCS pacing changed from negative to biphasic following creation of the isthmus block. The P-wave ratio during PCS pacing also increased following creation of the isthmus block. The P-wave morphologies in complete isthmus block were similar to the F-wave morphologies, and the P-wave ratio was greatest in complete isthmus block. Pre, before ablation; IC, incomplete isthmus block; C, complete isthmus block.

end of the plateau phase with the end of the subsequent one. Five P (F)-waves were measured and averaged for each measurement. Representative changes in intracardiac electrograms, P (F)-wave morphology, and P (F)-wave ratio are shown in Fig 2 and 3.

Statistical Analysis

Quantitative values are expressed as a mean $\pm$ SD, and compared using the paired t test. The relationship between the F-wave ratio during AFL and the P-wave ratio during

Fig 4. The P-wave ratios in all inferior leads during pacing from the low lateral right atrium (LLRA) or PCS and the F-wave ratios in all inferior leads in the initial 10 patients. A. The P-wave ratio in all inferior leads during LLRA pacing tended to increase from inverted in incomplete isthmus block to biphasic in complete isthmus block. However, it varied widely between patients. B. During PCS pacing, the P-wave ratio in all inferior leads increased following the creation of the isthmus block. While changes in the P-wave morphology from inverted to biphasic during PCS pacing were also observed in both complete and incomplete isthmus blocks, the P-wave ratio during PCS pacing was different between complete and incomplete isthmus blocks. Among the inferior leads, the difference between the P-wave ratio in complete and incomplete isthmus blocks was greatest in lead II and the difference between the P-wave ratio in complete isthmus block and the F-wave ratio was smallest in lead II. Abbreviations are the same as in Fig 3.

Fig 5. A. Changes of the P-wave ratio in lead II during PCS pacing in all patients. The P-wave ratio during PCS pacing was significantly higher in complete than in incomplete isthmus block ($P<0.0001$), and but it was slightly lower than the F-wave ratio in lead II. There was no case where the P-wave ratio in lead II during PCS pacing was higher in incomplete isthmus block than in complete isthmus block. B. Changes of the P-wave duration in lead II during PCS pacing in all patients. The P-wave duration in lead II also increased with progression of the isthmus block, but the difference between complete and incomplete blocks was not as prominent as the changes in the P-wave ratio. * $P<0.0001$, ** $P<0.01$, \$ $P<0.05$.

PCS pacing in complete isthmus block, or in slow isthmus conduction, was assessed by linear regression analysis. A $P<0.05$ was considered to be statistically significant.

Results

Sequence of the Creation of Isthmus Block

In 6 patients (20%), a bidirectional complete isthmus block had already been created at the first confirmation

Fig 6. The relationship between the F-wave ratio in lead II during AFL and the P-wave ratio in lead II during PCS pacing in complete or incomplete isthmus block. The P-wave ratio in complete isthmus block correlated significantly with the F-wave ratio ($r=0.795$, $P<0.0001$). The P-wave ratio in complete isthmus block is higher than that in incomplete isthmus block in all cases.

with pacing from the LLRA or PCS. Of the remaining 24 patients, a complete isthmus block had been created in both directions at the same time in 7 patients (23%); a complete isthmus block in a counterclockwise direction had been created before it was created in a clockwise direction in 17 patients (57%). There was no case in which a complete isthmus block in a clockwise direction was created before an isthmus block was created in a counterclockwise direction. Evaluation of the P-wave morphology at baseline, with an incomplete isthmus block, or a complete isthmus block, was performed in these 24 patients.

Result of P (F)-Wave Analysis in Inferior Leads in the Initial 10 Patients With AFL

Changes in P-wave morphology in all inferior leads during LLRA or PCS pacing with a complete or incomplete isthmus block were evaluated in the initial 10 patients. The P-wave ratio in all inferior leads during LLRA pacing tended to increase as the P-wave morphology changed from inverted in incomplete isthmus block to biphasic in complete isthmus block (Fig 4A). However, it varied widely between patients. However, during PCS pacing, the P-wave ratio in all inferior leads increased following the creation of the isthmus block in all patients (Fig 4B). While these changes of P-wave morphology were also seen in both complete and incomplete isthmus blocks, the P-wave ratio during PCS pacing was markedly different between complete and incomplete isthmus blocks, and the P-wave morphology and the P-wave ratio in complete isthmus block were close to the F-wave morphology and the F-wave ratio, respectively. Among the inferior leads, the difference between the P-wave ratio in complete and incomplete isthmus blocks was greatest in lead II, and the difference between the P-wave ratio in complete isthmus block and the F-wave ratio was smallest in lead II. Thus, the changes in the P-wave morphology and the P-wave ratio in lead II were considered to be useful in differentiating complete isthmus block from incomplete isthmus block.

The P-Wave Ratio and Width in Lead II During PCS Pacing in all Patients

Changes in the P-wave ratio in lead II during PCS pacing in all 24 patients were similar to those in the initial 10 patients (Fig 5A): the P-wave ratio during PCS pacing

was significantly higher in complete isthmus block than in incomplete isthmus block ($P<0.0001$), but it was slightly lower than the F-wave ratio. There was no case where the P-wave ratio in lead II during PCS pacing was higher in incomplete isthmus block than in complete isthmus block. The P width in lead II also increased with the progression of the isthmus block, but the difference between complete block and incomplete block was not as prominent as for the changes in the P-wave ratio (Fig 5B). The P-wave ratio in lead II during PCS pacing in complete isthmus block was more than 20% in all patients, and it correlated significantly with the F-wave ratio in lead II ($r=0.795$) (Fig 6). If the P-wave ratio during PCS pacing is more than 75% of the F-wave ratio, bidirectional complete isthmus block is predicted with a sensitivity of 88%, a specificity of 71%, a positive predictive value of 75%, and a negative predictive value of 85%.

Discussion

In the present study, we found that: 1) changes in the P-wave morphology with LLRA or PCS pacing could not, in and of itself, differentiate between complete isthmus block and incomplete isthmus block, 2) the P-wave morphology during PCS pacing in complete isthmus block resembled the F-wave morphology during AFL, and the P-wave ratio, which was obtained from changes in the P-wave morphology in lead II during PCS pacing, was useful for discriminating bidirectional complete isthmus block from incomplete isthmus block, and 3) when the P-wave ratio in lead II during PCS is greater than 20%, or this P-wave ratio is greater than 75% of the F-wave ratio in lead II during AFL, a bidirectional complete isthmus block is likely.

Sequence of the Creation of Isthmus Block

A bidirectional complete isthmus block is the end point of AFL ablation. However, there have been no studies to investigate whether a clockwise complete isthmus block preceded a counterclockwise block, or vice versa, or whether a bidirectional complete isthmus block was created all at once. A recent study⁶ of RF ablation for AFL has shown that an initial alteration of counterclockwise conduction is present before an alteration of clockwise conduction in 13 of 41 patients (32%) and clockwise conduction was primarily affected in 5 (12%) patients. A counterclockwise complete isthmus block was finally created in 33 patients (80%), and a clockwise complete isthmus block was created in 24 patients (53%). In this study, either a complete isthmus block was created bidirectionally all at once, or it was created earlier in a counterclockwise direction. There was no case in which a complete isthmus block in a clockwise direction was created before a block in a counterclockwise direction. These results indicate that a clockwise complete isthmus block may be more difficult to create than a counterclockwise complete isthmus block, although we cannot account for this difference. The creation of a clockwise complete isthmus block may indicate that a bidirectional complete isthmus block has actually been created. Therefore, PCS pacing is more important than LLRA pacing to confirm a bidirectional complete isthmus block in AFL ablation.

Changes in P-Wave Morphology and the P-Wave Ratio

Two recent studies^{4,5} have reported that changes of the

P-wave morphology in lead II during LLRA pacing were useful in verifying the creation of isthmus block. However, it is not known whether these changes in P-wave morphology can differentiate between complete isthmus block and slow isthmus conduction (incomplete isthmus block). Recently, Man et al⁷ have reported that changes in P-wave morphology from inverted to biphasic, characteristic of complete isthmus block, were observed even in incomplete isthmus blocks in 8 (80%) of 10 patients. In this study, the P-wave ratio in all inferior leads during LLRA pacing changed from inverted in incomplete isthmus block to biphasic in complete isthmus block. However, morphology varied widely between patients. Furthermore, as described above, there were no cases in which a complete isthmus block in a clockwise direction was created earlier than an isthmus block in a counterclockwise direction. Therefore, changes in P-wave morphology during LLRA pacing are not specific to the counterclockwise complete isthmus block, and LLRA pacing was not sufficient to verify bidirectional complete isthmus block. These changes in P-wave morphologies also were observed in both complete and incomplete isthmus blocks during PCS pacing, but the P-wave ratio during PCS pacing was significantly different in incomplete isthmus block and in complete isthmus block. Furthermore, bidirectional complete isthmus block could be confirmed using the P-wave ratio during PCS pacing and the F-wave ratio during AFL in lead II. Therefore, we believe that PCS pacing is more useful than LLRA pacing in AFL ablation. Because the atrial activation sequence during PCS pacing after the creation of clockwise complete isthmus block is the same as that during AFL, P-wave morphologies during PCS pacing in complete isthmus block were similar to F-wave morphologies during AFL. Therefore, if P-wave morphologies during PCS pacing are similar to F-wave morphologies, and the P-wave ratio in lead II is more than 75% of the F-wave ratio in lead II, bidirectional isthmus block is considered to be complete. Tai et al¹⁰ recently have reported that class I antiarrhythmic drugs decreased conduction velocity of the right atrial free wall during PCS pacing. In this study, 15 (50%) patients with AFL were treated with class I antiarrhythmic drugs to prevent the recurrence of atrial fibrillation. It is thought that decreased conduction velocity in the right atrial free wall might cause decreased amplitude of the positive component following a widening of the negative component in a paced P-wave. Therefore, the P-wave ratio in lead II during PCS pacing in complete isthmus block might be slightly less than the F-wave ratio in lead II in most patients. It is easy to compare the P-wave morphologies in PCS pacing with the F-wave morphologies in AFL, and this simple examination of the surface P-wave in lead II during PCS pacing might be useful to confirm bidirectional isthmus block.

Study Limitations

First, in this study, pacing from PCS or LLRA was performed at multiple cycle lengths to clearly visualize the paced P-wave morphology. Therefore, it is possible that the atrial activation sequence during pacing was different from

that during AFL. However, recent studies^{8,9} have reported that atrial activation sequences during pacing at multiple cycle lengths were the same as in AFL, and atrial activation times were not significantly different between pacing cycle lengths. We consider that differences in pacing cycle lengths may not influence either the atrial activation sequence during PCS or LLRA pacing or P-wave morphology.

Second, because the amplitude of the P (F)-waves is relatively small, quantitative analysis of them may be difficult in some cases. In this study, P-wave morphology during PCS pacing in complete isthmus block was similar to F-wave morphology during AFL. Therefore, in such cases, it may be important to continue catheter ablation until P-wave morphology during PCS pacing resembles F-wave morphology, indicating the creation of bidirectional complete isthmus block.

Third, our sensitivity and specificity data are based on retrospective data. However, since the present study shows that analysis of paced P-wave morphology provides good predictive power for identifying bidirectional complete isthmus block, it might be possible to use our P-wave ratio criteria in a prospective fashion.

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