Analysis of Junctional Ectopy During Radiofrequency Ablation of the Slow Pathway in Patients With Atrioventricular Nodal Reentrant Tachycardia

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Background: Junctional ectopy may occur during radiofrequency (RF) catheter ablation of the slow pathway in patients with atrioventricular nodal reentrant tachycardia (AVNRT). The purpose of the present study was to characterize this junctional ectopy quantitatively.

Methods and Results: The subjects of this study were 52 consecutive patients with AVNRT who underwent slow pathway ablation and 5 additional patients included retrospectively because they had developed high-degree atrioventricular (AV) block during the procedure. A combined anatomic and electrogram mapping approach was used for slow pathway ablation, and AVNRT was successfully eliminated in all patients. In the group of 52 consecutive patients, the incidence of junctional ectopy was significantly higher during 52 effective applications of RF energy than during 36 ineffective applications (100% versus 65%, P<.001). Compared with ineffective RF energy applications, successful RF energy applications had a significantly longer duration of individual bursts of junctional ectopy (7.1±7.1 versus 5.0±7.0 seconds [±SD], P<.05), a greater total number of junctional beats during the applications (24±16 versus 15±8, P<.01), and a greater total span of time during which junctional ectopy occurred (19±15 versus 11±12 seconds, P<.01). Four of the 52 patients plus an additional 5 patients developed transient AV block lasting 34±37 seconds. In 1 of the 9 patients who had transient AV block, third-degree AV nodal block requiring a permanent pacemaker occurred 2 weeks later. In each of the 9 patients who developed AV block, there was ventriculoatrial (VA) block in association with junctional ectopy during the RF energy application immediately preceding the AV block. Among 48 patients who did not develop AV block, 17 patients had at least one episode of VA block during junctional ectopy. The positive predictive value of VA block during junctional ectopy for the development of AV block was 19% in the consecutive series of 52 patients. Among 31 patients who always had 1:1 VA conduction in association with junctional ectopy, 12 had poor VA conduction in the baseline state, with a VA block cycle length of at least 500 milliseconds during ventricular pacing.

Conclusions: In patients with AVNRT undergoing slow pathway ablation, junctional ectopy during the application of RF energy is a sensitive but nonspecific marker of successful ablation. The bursts of junctional ectopy are significantly longer at effective target sites than at ineffective sites. VA conduction should be expected during the junctional ectopy that accompanies slow pathway ablation, even when there is poor VA conduction during baseline ventricular pacing. VA block during junctional ectopy is a harbinger of AV block in patients undergoing RF ablation of the slow pathway. If energy applications are discontinued as soon as VA block occurs, the risk of AV block may be markedly reduced.

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coronary artery disease, and the remainder had no evidence of structural heart disease.

**Electrophysiological Testing**

Informed consent was obtained from all patients. Electrophysiology tests were performed with the patient in the fasting, sedated state after all antiarrhythmic medications had been discontinued for at least five half-lives. Three 7F quadrupolar electrode catheters were inserted into a femoral vein and positioned in the right atrium, across the tricuspid valve, to record the His-bundle electrogram, and in the right ventricle. The catheter across the tricuspid valve had a 4-mm distal electrode and a deflectable tip (Mansfield) and was also used for ablation. Leads V1, I, II, and III and the intracardiac electrograms were displayed on an oscilloscope and recorded on a Mingograf 7 recorder (Siemens-Elema). Pacing was performed with a programmable stimulator (Bloom Associates).

Incremental pacing and programmed stimulation were performed in the right atrium and right ventricle to define anterograde and retrograde AV nodal conduction and refractoriness and to confirm that AVNRT was inducible. In 24 patients, the induction of AVNRT required the infusion of 1 to 4 μg/min of isoproterenol. In these patients, applications of RF energy were delivered at least 10 minutes after discontinuation of the isoproterenol infusion. AVNRT was diagnosed using previously established criteria.\(^7\) The AVNRT was typical (slow-fast) in 52 patients and atypical (fast-slow) in 5 patients. The mean cycle length of AVNRT was 337±65 milliseconds. The baseline mean AV block cycle length was 380±94 milliseconds. There was VA dissociation in 3 patients in the baseline state, and the mean VA block cycle length in the remaining patients was 374±127 milliseconds. Dual AV nodal physiology was present in 42 patients. The mean effective refractory periods of the fast and slow pathways were 329±77 and 267±67 milliseconds, respectively.

**Catheter Ablation**

RF energy was delivered by a generator (EP Technologies, Inc) that supplied a continuous, unmodulated sine wave output at a frequency of 500 kHz. Suitable target sites for slow pathway ablation were identified during sinus rhythm. Mapping was performed along the tricuspid annulus in the inferior, posterior right atrium, in the region of the coronary sinus ostium. Target sites were identified based on an AV electrogram ratio of <0.5 and the presence of a double or multicomponent atrial electrogram.\(^8\) After a target site was identified, RF energy was applied at 30 to 35 W for 40 to 60 seconds. Applications of energy were terminated prematurely if there was coagulum formation or if VA block was observed during junctional ectopy. The inducibility of AVNRT and/or the presence of dual AV node physiology was assessed after each application of RF energy. In patients who required isoproterenol for tachycardia induction, elimination of dual AV node physiology was used as a preliminary end point, and isoproterenol was administered if dual AV node physiology was eliminated. Twenty to 30 minutes after the final application of RF energy, atrial and ventricular pacing were repeated before and during an infusion of isoproterenol to confirm that AVNRT could no longer be induced. The inducibility of AVNRT was successfully eliminated in each of the 57 patients in this study. Residual slow pathway function and a single AV nodal echo were present during isoproterenol infusion in 20 patients. In the remaining 37 patients, there was no evidence of residual slow pathway function.

**Junctional Ectopy**

The incidence and characteristics of junctional ectopy were analyzed in the group of 52 consecutive patients who underwent slow pathway ablation. Junctional ectopy was identified based on a QRS configuration and duration identical to that of sinus beats and the absence of AV conduction from a preced-

| TABLE 1. Incidence and Characteristics of Junctional Ectopy During Applications of Radiofrequency Energy in 52 Consecutive Patients Undergoing Slow Pathway Ablation |
|-----------------|-----------------|-----------------|-----------------|
| n               | Effective Applications | Ineffective Applications | P     |
| No. associated with JE (%) | 52 (100) | 239 (85) | <.001 |
| Onset of JE, s | 6±7 | 6±6 | NS  |
| Total no. of junctional beats | 15±15 | 11±15 | NS  |
| Total duration of junctional beats | 24±16 | 15±18 | <.01 |
| Cycle length of JE, ms | 452±118 | 415±183 | NS  |

Values are expressed as mean±SD. JE indicates junctional ectopy.

ing P wave. All episodes of junctional ectopy during applications of RF energy that were 20 seconds or longer were analyzed for the time of onset of junctional ectopy during energy delivery, the duration of the longest burst of junctional ectopy, the total span of time during which junctional ectopic beats occurred, the number of junctional ectopic beats during the longest burst, the total number of junctional ectopic beats, and the mean cycle length of the junctional ectopy.

The high right atrial electrogram was monitored during all applications of RF energy to assess VA conduction in association with junctional ectopy. For all episodes of VA block associated with junctional ectopy, the preceding RR interval and the duration of time that RF energy delivery was continued after the occurrence of VA block were measured.

**Results**

**Incidence of Junctional Ectopy**

Of 418 applications of RF energy that were analyzed in 52 consecutive patients who underwent slow pathway ablation, 239 were associated with junctional ectopy and 127 were not. In each of the 52 patients, junctional ectopy occurred during the application of RF energy that eliminated the inducibility of AVNRT. Junctional ectopy also occurred during 239 of 366 ineffective applications of RF energy. The incidence of junctional ectopy was significantly higher during effective applications of RF energy than during ineffective applications (100% versus 65%, \(P<.001\)).

**Characteristics of Junctional Ectopy (Table 1)**

Compared with ineffective RF energy applications, successful RF energy applications had a significantly longer duration of individual bursts of junctional ectopy (7.1±7.1 versus 5.0±7.0 seconds, \(P<.05\)), a greater total number of junctional beats during the applications (24±16 versus 15±8, \(P<.01\)), and a greater total span of time during which junctional ectopy occurred (19±15 versus 11±12 seconds, \(P<.01\)). The time of onset of junctional ectopy during the application of RF energy ranged from 0.5 to 19 seconds, with no significant difference between the effective and ineffective applica-
tions. There also were no significant differences between the effective and ineffective applications of RF energy in the number of consecutive junctional beats in the longest burst of junctional ectopy or in the mean cycle length of the junctional ectopy.

**AV and VA Block**

A total of 9 patients with transient second- or third-degrees AV block were analyzed. Four patients were part of the series of 52 consecutive patients undergoing slow pathway ablation, and they were combined with an additional 5 patients analyzed retrospectively. In each of the 9 patients, AV block was manifest on cessation of the application of RF energy and resolved after a mean of 34±37 seconds (range, 3 to 120 seconds). A His-bundle electrogram recording during AV block was available in 4 patients, and in each of these patients, the AV block was proximal to the recorded His-bundle depolarization. The applications of energy that resulted in AV block were delivered at the level of the coronary sinus ostium in 2 patients and within 1 cm anterior and superior to the ostium in 7 patients. The location of the ablation catheter was monitored continuously with fluoroscopy during applications of RF energy to confirm a stable catheter position. A His-bundle depolarization was not present at any of these target sites. In 1 of the 9 patients who had transient AV block, three-degree AV nodal block occurred 2 weeks later, and a permanent pacemaker was implanted.

In each of the 9 patients who developed AV block, there was persistent VA block in association with junctional ectopy during the RF energy application immediately preceding the AV block (Fig 1). Among 48 patients who did not develop AV block, 31 patients always had 1:1 VA conduction in association with junctional ectopy during energy applications, and 17 patients had one or more episodes of VA block during junctional ectopy (Fig 2). In 13 of these 17 patients, the episode of VA block was followed by junctional ectopy associated with 1:1 VA conduction. Among these 17 patients, there were no significant changes in the mean AH interval or VA block cycle length after the energy applications that resulted in VA block.

The incidence of VA block during junctional ectopy was significantly higher in patients who developed AV block than in those who did not (100% versus 35%, P<.001). The positive predictive value of VA block during junctional ectopy for the development of AV block was 19% in the consecutive series of 52 patients who underwent slow pathway ablation.

The mean cycle length of the episodes of junctional ectopy associated with VA block (426±222 milliseconds) was not significantly different from the mean cycle length of the episodes of junctional ectopy always associated with 1:1 VA conduction (421±154 milliseconds). The mean VA block cycle length during ventricular pacing in the baseline state did not differ significantly between the patients in whom VA block occurred.
(380±135 milliseconds) and those in whom it did not (370±125 milliseconds). Among 31 patients who always had 1:1 VA conduction in association with junctional ectopy, 12 had poor VA conduction in the baseline state, with a VA block cycle length of at least 500 milliseconds during ventricular pacing.

The characteristics of the junctional ectopy associated with VA block were compared in the 9 patients who developed AV block and the 17 patients who had VA block that was not followed by AV block (Table 2). The junctional ectopy in these two groups of patients did not differ significantly with regard to the time of onset of junctional ectopy during RF energy delivery, the total number of junctional beats, the mean cycle length of the junctional ectopy, the RR interval immediately preceding the VA block, or the duration of RF energy delivery after the occurrence of VA block.

**Discussion**

**Main Findings**

In this series of patients undergoing slow pathway ablation to eliminate AVNRT, a combined anatomic and electrogram mapping approach was used, and a successful outcome was achieved in all patients. Junctional ectopy during the application of RF energy was found to be a sensitive but nonspecific marker of successful ablation, occurring at the effective target site in all patients but also at 65% of the ineffective target sites. There was no difference in the mean cycle length of the junctional ectopy occurring during effective and ineffective applications of RF energy, and although the bursts of junctional ectopy were significantly longer at effective target sites than at ineffective sites, the difference was relatively small in absolute terms. Therefore, the quantitative characteristics of the junctional ectopy were not different between the two groups of patients.

**Table 2. Characteristics of Junctional Ectopy in Patients With VA Block During Applications of Radiofrequency Energy**

<table>
<thead>
<tr>
<th>Patients Without AV Block</th>
<th>Patients With AV Block</th>
</tr>
</thead>
<tbody>
<tr>
<td>No. of patients</td>
<td>17</td>
</tr>
<tr>
<td>Total no. of RF applications</td>
<td>54</td>
</tr>
<tr>
<td>Onset of JE, s</td>
<td>4.0±4.8</td>
</tr>
<tr>
<td>Total no. of junctional beats</td>
<td>20±22</td>
</tr>
<tr>
<td>Cycle length of JE, ms</td>
<td>439±108</td>
</tr>
<tr>
<td>RR preceding VA block, ms</td>
<td>414±129</td>
</tr>
<tr>
<td>Duration of RF application after onset of VA block, s</td>
<td>5.4±9.2</td>
</tr>
</tbody>
</table>

Values are expressed as mean±SD. * No significant difference compared with patients without AV block. AV indicates atrioventricular; JE, junctional ectopy; RF, radiofrequency energy; RR, RR cycle length; and VA, ventriculoatrial.
that occurs during delivery of RF energy are unlikely to be clinically useful in predicting whether a particular application was effective in eliminating the inducibility of AVNRT.

The results of this study also demonstrate that VA block during junctional ectopy uniformly precedes the inadvertent occurrence of second- or third-degree AV block in patients undergoing RF ablation of the slow pathway. Although the occurrence of VA block was not always followed by AV block, its consistent presence during RF energy applications that resulted in AV block indicate that VA block should be considered a harbinger of AV block and an indication to immediately discontinue the delivery of energy.

Incidence of Junctional Ectopy

As has been observed in prior studies, junctional ectopy was found to be a sensitive marker of successful slow pathway ablation. However, although the incidence of junctional ectopy during effective applications of RF energy was reported to be 75% to 92% in prior studies,1-3 in the present study the occurrence of junctional ectopy during effective energy applications was universal. The explanation for the lower incidence of junctional ectopy at effective target sites in prior studies is unclear, but this discrepancy may be attributable to differences in ablation technique, including differences in the locations of target sites, in the method of mapping, or in the power at which RF energy was delivered.

The occurrence of junctional ectopy during 65% of ineffective applications of RF energy in the patients in this study indicates that junctional ectopy is not a phenomenon that is specific to effective target sites for slow pathway ablation. Junctional ectopy during slow pathway ablation is presumably caused by stimulation of the AV junction by RF energy delivery to the posterior atrionodal inputs to the AV node. It may be that applications of RF energy that result in adequate heating of any portion of these atrionodal inputs will result in junctional ectopy but that a specific portion of these fibers must be ablated to eliminate AVNRT.

Duration and Cycle Length of Junctional Ectopy

No prior studies have compared the characteristics of junctional ectopy occurring during effective and ineffective applications of RF energy in patients undergoing slow pathway ablation. Applications of RF energy that were successful in eliminating AVNRT were associated with runs of junctional ectopy that were longer in duration but did not differ in cycle length compared with the junctional ectopy that occurred during ineffective applications of energy. However, there was considerable overlap in the number of junctional ectopic beats occurring during effective and ineffective energy applications, and therefore quantification of the junctional ectopy during an application of energy is unlikely to be clinically useful in predicting whether slow pathway ablation has been achieved.

AV and VA Block

Although not as frequently as during fast pathway ablation,9 slow pathway ablation may be complicated by inadvertent second- or third-degree AV block.10-14 The results of this study demonstrate that the onset of second- or third-degree AV block is consistently heralded by VA block during junctional ectopy. After it became apparent that VA block during junctional ectopy was a harbinger of AV block, it became the policy of the operators who participated in this study to discontinue the delivery of RF energy as soon as VA block was observed. This may be a factor explaining why the positive predictive value of VA block during junctional ectopy for the occurrence of AV block in the patients in this study was only approximately 20%. Had the applications of energy usually not been quickly discontinued after the onset of VA block, it is possible that the positive predictive value would have been higher than 20%. Indeed, in 2 patients in this study who developed AV block, the occurrence of VA block during junctional ectopy was not immediately recognized and RF energy was delivered for an additional 7 to 9 seconds, perhaps accounting for the occurrence of AV block.

It is noteworthy that in 8 of 9 patients in this study who developed AV block, the AV block was transient and never recurred. It is possible that longer applications of RF energy after the occurrence of VA block may have resulted in AV block that was more often permanent instead of transient.

Physiological Versus Pathological VA Block

Another possible explanation for why the positive predictive value of VA block for the occurrence of AV block was only approximately 20% is that in some patients the VA block may have been physiological rather than a reflection of injury to the AV conduction system. Physiological VA block may be distinguishable from pathological VA block if the RR interval immediately preceding the VA block is relatively short and/or if there is a return of 1:1 VA conduction during junctional ectopy despite the continued delivery of RF energy. Accordingly, AV block in the patients in this study was always preceded by VA block that persisted for as long as the energy application was continued.

To minimize the risk of AV block, it would seem prudent to immediately discontinue the delivery of RF energy whenever VA block is observed rather than continuing the application and monitoring VA conduction during junctional ectopy in an attempt to discern whether the VA block was an isolated instance of physiological block or a sign of injury to the conduction system.

Cycle Length of Junctional Ectopy Associated With VA Block

In a recent study by Thakur et al,6 junctional tachycardia leading to second- or third-degree AV block was found to have a more rapid rate than junctional tachycardias followed by normal AV conduction. In contrast, in the present study, the mean junctional ectopy cycle length was similar regardless of whether the junctional ectopy was associated with VA block or was followed by AV block. Therefore, the results of this study suggest that the occurrence of VA block is a more accurate predictor of impending AV block than is the rate of the junctional ectopy during which the VA block occurs.

Baseline VA Conduction and VA Block During Junctional Ectopy

Twelve patients who always had 1:1 VA conduction during junctional ectopy had poor VA conduction dur-
ing ventricular pacing, with a VA block cycle length of more than 500 milliseconds during ventricular pacing in the baseline state. Because the mean junctional ectopy cycle length during energy applications in these patients was less than 500 milliseconds, VA block might have been expected to occur during runs of junctional ectopy. The presence of 1:1 VA conduction in these patients suggests that the junctional ectopy arose at a point in the AV junction proximal to the site of VA block during ventricular pacing. Therefore, even in patients who have poor VA conduction during ventricular pacing in the baseline state, 1:1 VA conduction is expected during junctional ectopy, and the occurrence of VA block should be considered a possible sign of impending VA block.

**Location of Target Sites Resulting in AV Block**

In this study, most of the target sites at which AV block occurred were located anterior and superior to the ostium of the coronary sinus, apparently in close enough proximity to the compact AV node to impair conduction. However, in 2 patients who developed AV block, the ablation catheter was positioned at the level of the coronary sinus ostium, where injury to the compact AV node would not be expected. Because in a minority of patients the fast pathway is located posteriorly, near the coronary sinus orifice, it is possible that AV block occasionally results from simultaneous ablation of the slow and fast pathways.

**Study Limitations**

A limitation of this study is that the anatomic location of each ineffective application of RF energy was not recorded. Therefore, whether the occurrence of junctional ectopy during ineffective applications of RF energy was a site-dependent phenomenon cannot be determined. Because all applications of RF energy were in the region of the coronary sinus ostium, it is unlikely that any difference in the anatomic locations of the target sites could have been discerned fluoroscopically. A second limitation of this study is that the results may not be applicable in patients in whom RF energy is delivered during an infusion of isoproterenol. In this study, even when isoproterenol was required to induce AVNRT, energy applications were delayed until the effects of isoproterenol had dissipated. Isoproterenol might be expected to affect the cycle length and/or number of junctional ectopic beats. In addition, the sinus tachycardia caused by isoproterenol might override the junctional ectopy. Furthermore, isoproterenol might mask the VA block found in this study to be a marker of AV block.

**Clinical Implications**

When a combined anatomic and electrogram approach to slow pathway ablation is used, an application of RF energy that is not accompanied by junctional ectopy is highly unlikely to have been successful in eliminating the inducibility of AVNRT. The efficiency of the procedure can be improved by discontinuing or increasing the power of an application of RF energy if junctional ectopy has not occurred by approximately 20 seconds and by assessing efficacy by attempting to induce AVNRT only after energy applications that are accompanied by junctional ectopy.

Because fast pathway ablation markedly attenuates or eliminates VA conduction, VA block is an expected phenomenon during the junctional ectopy that accompanies energy applications aimed at ablating the fast pathway in patients with AVNRT and therefore cannot be used as a harbinger of AV block. However, 1:1 VA conduction should be expected during the junctional ectopy that accompanies slow pathway ablation, even when there is poor VA conduction or VA dissociation during ventricular pacing in the baseline state. The availability of VA block as a marker of impending AV block affords an advantage to the slow pathway approach over the fast pathway approach in patients undergoing catheter ablation of AVNRT.

Some investigators have recommended atrial overdrive pacing or administration of divided doses of energy when junctional rhythm occurs during slow pathway ablation, to check for AV block. However, this practice may predispose to instability or movement of the ablation catheter, resulting in prolongation of the procedure duration. The results of this study demonstrate that AV block is highly improbable as long as 1:1 VA conduction is maintained during junctional ectopy. Therefore, the status of VA conduction should be carefully monitored during slow pathway ablation. It is likely that the risk of AV block can be markedly reduced or eliminated if energy applications are discontinued as soon as VA block occurs.

**References**


Analysis of junctional ectopy during radiofrequency ablation of the slow pathway in patients with atrioventricular nodal reentrant tachycardia.

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