Successful Radiofrequency Ablation of Idiopathic Left Ventricular Tachycardia at a Site Away From the Tachycardia Exit

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Objectives. This study sought to assess the possibility of ablating verapamil-responsive idiopathic left ventricular tachycardia at a site distant from the tachycardia exit and thus to define the tachycardia circuit.

Background. The nature of the reentry circuit in idiopathic left ventricular tachycardia is unclear. If the circuit is of considerable size, then it should be possible to ablate the tachycardia at a site distant from the exit site.

Methods. Electrophysiologic studies and radiofrequency ablation were performed in 27 consecutive patients with verapamil-responsive idiopathic left ventricular tachycardia. In all 27 patients, the tachycardia exit site was defined as the site where the earliest Purkinje potential was recorded ≥25 ms before the onset of the QRS complex during the tachycardia and where the pace map QRS complex resembled that during the tachycardia. A potential ablation site other than the exit site was then sought around the midseptum, proximal to the exit site. At such sites the tachycardia could be terminated transiently by pressure applied to the catheter tip, without induction of ventricular ectopic beats.

Results. The potential ablation site, other than the tachycardia exit site, was identified in seven male patients (mean ± SD age 31 ± 12 years, range 13 to 52). Application of the radiofrequency current at this site resulted in termination of the tachycardia within 1 to 5 s (mean 2.9 ± 1.6), and successful ablation of the tachycardia was achieved in all seven patients (success rate 100%, 95% exact confidence interval 0.5898 to 1). The mean distance between the ablation site and the tachycardia exit site was 3.1 ± 0.7 cm (range 2.0 to 4.0). A presystolic Purkinje spike was recorded 14 ± 5 ms (range 8 to 20) before the onset of the QRS complex during the tachycardia. During the follow-up period of 24 ± 11 months (range 12 to 39), there was no recurrence of tachycardia in these seven patients.

Conclusions. Successful ablation of idiopathic left ventricular tachycardia can be achieved at sites away from the tachycardia exit site in some patients. This finding suggests that the reentry circuit is likely to be of considerable size, encompassing the middle, inferior and lower aspects of the left interventricular septum.

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Idiopathic left ventricular tachycardia with a QRS configuration of right bundle branch block and superior axis was first designated as a specific entity by Lin et al. (1) in 1983. This tachycardia occurs in young male patients, is responsive to calcium channel blocking agents but not adenosine (1–5) and can be induced and terminated by programmed stimulation. A high frequency Purkinje potential is frequently registered on the local electrogram of the middle and lower portion of the left interventricular septum during the tachycardia (4,6). Reentry is believed to be the operative mechanism of the tachycardia. However, the nature of the reentry circuit has not been defined. Whether it is a microreentry or a macroreentry circuit has remained unanswered.

Radiofrequency ablation through the application of a current to the mid or inferior apical left interventricular septum at the tachycardia exit site, where the pace map 12-lead electrocardiogram (ECG) displays a QRS configuration matching that during the tachycardia, and where a sharp Purkinje potential is registered before the onset of the QRS complex, is highly effective (7,8). In the present study, successful ablation was achieved at a site distant from the tachycardia exit site. Detail mapping and resetting studies provided new insights into the understanding of this arrhythmia.

Methods

Patients. Between September 1993 and October 1996, a total of 27 consecutive patients (24 men, 3 women; mean ± SD age 28 ± 12 years, range 12 to 55) with verapamil-responsive idiopathic left ventricular tachycardia underwent radiofrequency ablation therapy at Chang Gung Memorial Hospital. The procedure was approved by the institutional review board and was in accordance with local ethical stan-
Radiofrequency ablation. After identification of the putative tachycardia exit site, a potential remote target site for ablation was searched for at the midseptal area proximal to and at least 2 cm away from the exit site. This potential ablation site was at a site where the ventricular tachycardia could be terminated transiently by application of mechanical pressure to the catheter tip without the induction of ventricular ectopic beats. When this potential site was identified, resetting and entrainment studies were conducted. Test current with an initial power of 25 to 35 W was then applied during an episode of tachycardia under continuous digital monitoring of power strength and impedance. If the tachycardia was terminated within 10 s, additional current was applied for another 60 to 120 s. The output current of a radiofrequency generator (Radionics RFG-3C) was delivered to the distal electrode of the large-tipped ablation catheter and a posteriorly positioned cutaneous patch. Programmed stimulation was performed after ablation. If the tachycardia was no longer inducible, programmed stimulation was repeated after an isoproterenol infusion designed to increase the sinus rate by 20%. Successful ablation was defined as the inability to induce ventricular tachycardia by programmed stimulation with or without isoproterenol infusion. The distance between the tachycardia exit site and the successful ablation site was assessed by cineradiography recorded in the right and left anterior oblique and lateral projections using the interelectrode distance of the ablation catheter for reference. The maximal distance measured among the three radiographic projections was taken as the distance between the exit and the target sites.

An initial bolus of 3,000 U of heparin was administered immediately before application of the radiofrequency current. Additional heparin (1,000 U) was given every hour until completion of the procedure.

Statistical analysis. Results are reported as mean value ± SD, unless otherwise indicated. A p value < 0.05 was considered significant.

Results

Successful ablation at a site distant from the tachycardia exit. Successful radiofrequency ablation of idiopathic left ventricular tachycardia at a distant site was achieved in 7 of 27 patients. Their clinical and electrophysiologic characteristics are summarized in Table 1. There was no difference in age, gender, tachycardia cycle length, QRS axis or tachycardia exit site between these 7 patients and the remaining 20. All seven were male aged between 13 and 52 years old (mean [± SD] age 31 ± 12). The putative tachycardia exit site was found at the mid and inferior apical septum in these seven patients. A potential remote target site for radiofrequency ablation was found at the superior midseptal area proximal to the tachycardia exit in all seven patients (Fig. 1 and 2). Delivery of the radiofrequency current to this site resulted in termination of ventricular tachycardia within 1 to 5 s (mean 2.9 ± 1.6), and successful ablation of the tachycardia was achieved in all seven patients (success rate 100%, 95% exact confidence interval
The pace map 12-lead ECG at this site exhibited a different QRS configuration (11 of 12 leads in five patients, 10 of 12 leads in one and 8 of 12 leads in one) from that seen during ventricular tachycardia. Recording during sinus rhythm revealed a high frequency Purkinje spike that preceded the QRS complex at both the target and exit sites. The spike–V interval (spike to QRS onset) was 29 ± 7 ms (range 20 to 40) at the target site and 9 ± 3 ms (range 7 to 15) at the exit site. The spike–V interval was much longer at the target site than at the exit site, consistent with a proximal location of the target site (p = 0.0022, 95% CI 22 to 12, Mann-Whitney test). Although a presystolic high frequency Purkinje spike was recorded at this site in all seven patients, it preceded the QRS onset (P–QRS interval) by only 14 ± 5 ms (range 8 to 20) during ventricular tachycardia. The stimulus–QRS interval was 33 ± 6 ms (range 25 to 40), which is longer than the P–QRS interval at this site (p = 0.0022, 95% CI 27 to –10, Mann-Whitney test). In contrast, the Purkinje spike registered at the exit site preceded the QRS onset (P–QRS interval) during the tachycardia by 31 ± 4 ms (range 25 to 38), the earliest among all mapped sites, and was identical to the stimulus–QRS interval of 31 ± 5 ms (range 25 to 38) (p = 0.898, 95% CI –5 to 5, Mann-Whitney test). The differences in the Purkinje spike–QRS interval at ablation site and tachycardia exit sites was statistically significant (p = 0.0022, 95% CI –22 to –10, Mann-Whitney test). The distance between the successful ablation site and the tachycardia exit site ranged from 2.0 to 4.0 cm (mean 3.1 ± 0.7) (Fig. 3).

**Entrainment and resetting during tachycardia.** Entrainment of the tachycardia could be demonstrated by overdrive

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**Figure 1.** Schematic representation of the left interventricular septum as viewed radiographically in the right anterior oblique projection, showing the exit site (light arabic numerals) and the distant ablation site (bold arabic numerals). Arabic numerals = patient numbers.

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**Table 1.** Clinical and Electrophysiologic Characteristics of Seven Male Patients

<table>
<thead>
<tr>
<th>Pt No./Age (yr)</th>
<th>VT Frequency (per yr)</th>
<th>VT-CL (ms)</th>
<th>Spike–QRS Interval</th>
<th>Stimulus–QRS Interval</th>
<th>Spike–V Interval (sinus)</th>
<th>Exit Site–Ablation Site (cm)</th>
<th>Follow-Up (mo)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1/13 24</td>
<td>12–15</td>
<td>30</td>
<td>28</td>
<td>7</td>
<td>20</td>
<td>30</td>
<td>2.0</td>
</tr>
<tr>
<td>2/23 12–15</td>
<td>360</td>
<td>30</td>
<td>35</td>
<td>10</td>
<td>20</td>
<td>30</td>
<td>26</td>
</tr>
<tr>
<td>3/30 4–6</td>
<td>405</td>
<td>25</td>
<td>25</td>
<td>8</td>
<td>10</td>
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<td>355</td>
<td>35</td>
<td>35</td>
<td>15</td>
<td>16</td>
<td>30</td>
<td>35</td>
</tr>
<tr>
<td>5/34 1–2</td>
<td>280</td>
<td>30</td>
<td>28</td>
<td>10</td>
<td>8</td>
<td>25</td>
<td>40</td>
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<td>40</td>
</tr>
<tr>
<td>7/52 4–6</td>
<td>300</td>
<td>30</td>
<td>30</td>
<td>8</td>
<td>10</td>
<td>35</td>
<td>35</td>
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</table>

Pt = patient; VT = ventricular tachycardia; VT-CL = cycle length of ventricular tachycardia.
pacing from the right ventricular outflow tract in all seven patients and from the right ventricular apex in two patients but from the left ventricle in none (overdrive pacing was limited to the tachycardia exit and ablation sites). Resetting studies were performed in all seven patients, but the data were analyzable only in five. The data were not analyzable in the other two patients (interference by ventricular ectopic beats in one; alternation of tachycardia cycle length in the other). Resetting with delivery of the ventricular extrastimulus to the exit site was followed by a poststimulus return interval (measured from the stimulus artifact to the Purkinje spike of the return beat) similar to, or slightly longer than (<20 ms), the tachycardia cycle length, when the stimulus was delivered during the late diastole. However, when the stimulus was delivered during the early diastole, a progressive lengthening of the post-stimulus return interval was observed (Fig. 4). Resetting with delivery of the ventricular extrastimulus to the remote successful ablation site was accompanied by a post-stimulus return interval slightly shorter than, similar to or slightly longer than (<20 ms) the tachycardia cycle length, when the stimulus was delivered during the late diastole. Likewise, a progressive lengthening of the poststimulus return interval was also noted when the stimulus was delivered during early diastole (Fig. 4). Resetting with delivery of the ventricular extrastimulus to the right ventricular apex or to the right ventricular outflow tract was followed by a post-stimulus return interval much longer than (>40 ms) the tachycardia cycle length. Figure 5 shows the recordings from Patient 3. The tachycardia cycle length was 405 ms in panels A, B and C and was 400 ms in panel D. Panel A shows an extrastimulus delivered to the target site (the successful ablation site) at a coupling interval of 360 ms. The stimulus captured both the left and the right ventricles with a similar QRS configuration but slightly different intracardiac electrograms from that seen during the tachycardia. The post-stimulus return interval was identical to the tachycardia cycle length. Panel C shows an extrastimulus delivered to the septal aspect of the right ventricular outflow tract at a coupling interval of 300 ms. The stimulus captured the whole right ventricle but only a portion of the left ventricle. Note that at the tachycardia exit site, the spike–spike interval was undisturbed, whereas the intracardiac electrogram was slightly different from that seen during the tachycardia. The post-stimulus return interval measured near the pacing site (from the His bundle catheter) was 455 ms but only 355 ms at the tachycardia exit site. Panel D shows an extrastimulus delivered to the right ventricular apex at a coupling interval of 330 ms. This stimulus captured the right but not the left ventricle. Note that at the tachycardia exit site, the spike–spike interval as well as the local electrogram was undisturbed. The post-stimulus return interval measured at the right ventricular apex was 460 ms but only 390 ms at the tachycardia exit site.

**Follow-up.** The mean follow-up period was 24 ± 11 months (range 12 to 39). All seven patients were symptom free, without medications. All seven patients underwent 24-h ambulatory ECG monitoring and treadmill exercise on two or more occasions and showed no recurrence of ventricular tachycardia. Two of the seven patients (Patients 1 and 7) agreed to a follow-up electrophysiologic study, during which ventricular tachycardia could not be induced, 75 days and 280 days after ablation.

**Discussion**

**Radiofrequency ablation.** Previous studies (7–11) have demonstrated that successful ablation of idiopathic left ventricular tachycardia could be achieved through the application of a radiofrequency current to a wide area over the inferior apical and mid-left ventricular septum, when the pace map
12-lead ECG was similar to that of the tachycardia or where the earliest Purkinje spike was registered before the local electrogram. The successful ablation site in these patients was assumed to be the tachycardia exit site. The present study demonstrates that successful ablation of the tachycardia can also be achieved at a site over the superior mid-left ventricular septum, away from the putative tachycardia exit site, where the pace map QRS configuration is different from that seen during the tachycardia and where the Purkinje spike was registered later than that of the putative tachycardia exit site. In the present study, pressure mapping was applied only to an area at least 2 cm away from and proximal to the exit site. The study design may explain why in only 7 of the 27 patients was a remote target site found. However, it is also possible that the reentry circuit in the other 20 patients was deep-seated and thus not affected by the mechanical pressure of the catheter.

**Entrainment and resetting.** Entrainment of the idiopathic left ventricular tachycardia is usually demonstrable with overdrive pacing from the right ventricular outflow tract, although it can also be demonstrated by overdrive pacing from other sites, including the outflow tract of the left ventricle (4,8,12). Aizawa et al. (13) compared the postspacing interval, measured from the last stimulus artifact to the first Purkinje spike at the exit site, during overdrive entrainment and showed that the postspacing interval was shorter at the right ventricular outflow tract than at the right ventricular apex. They suggested that the right ventricular outflow tract is closer to the entrance of the slow conduction zone, whereas the right ventricular apex is closer to the exit of the circuit. Resetting of the tachycardia by the introduction of a ventricular extrastimulus from different sites during the tachycardia has been shown (14,15) to be useful in characterizing the reentry circuit in patients with ventricular tachycardia secondary to a previous infarction. Stevenson et al. (15) demonstrated that the post-stimulus interval reflects the conduction time from the pacing site to and through the reentry circuit and back to the pacing site. Thus the post-stimulus interval is always greater than the tachycardia cycle length when the stimulus is delivered to sites outside the circuit, as in a bystander pathway or a nondominant bystander loop or along the path from the circuit exit to the QRS onset site. When the extrastimulus is delivered to sites in the circuit, the poststimulus interval is equal to the tachycardia cycle length, unless the stimulus causes a conduction delay in the circuit. Physiologically, entrainment and resetting reflect two aspects of the same reentry phenomenon: entrainment as repetitive resetting and resetting...
as the entrainment of a single beat. The resetting studies in the present report concur with the findings of Stevenson et al. (15). When the extrastimulus is delivered to the right ventricular outflow tract or the right ventricular apex, it resets the tachycardia with a longer post-stimulus interval at the tachycardia exit site. The local electrogram at the exit site shows varying degrees of fusion, but the Purkinje spike remains undisturbed. When the extrastimulus is delivered to the tachycardia exit site, it captures the ventricles with a QRS configuration resembling that recorded during episodes of tachycardia. The poststimulus interval is equal to or slightly longer than the tachycardia cycle length when the stimulus was delivered during the late diastole. However, when the stimulus was delivered earlier, a progressive lengthening of the post-stimulus interval was noted due to conduction delay of the circuit. When the extrastimulus is delivered to a remote successful ablation site (the target site), capture of the ventricles leads to a different QRS configuration. The post-stimulus interval is slightly shorter than, equal to or slightly longer than the tachycardia cycle length when the stimulus was delivered during the late diastole. Shortening of the post-stimulus interval during resetting studies of ventricular tachycardia has not been reported previously. This phenomenon is explained in the schematic diagram of Figure 6. In the left panel, during the tachycardia, the impulse emerges from the exit site, activates the Purkinje fibers and the myocardium and then spreads to the target site through the Purkinje network, resulting in registration of a late Purkinje spike and local electrogram at the target site. In the middle panel, with introduction of an extrastimulus to the target site during late diastole of the tachycardia, the extrastimulus captures the ventricles, producing a different QRS configuration. It also activates the slow conduction zone of the circuit at a site proximal to the tachycardia exit site. The impulse collides antidromically with the oncoming reentry impulse and conducts othodromically through the slow conduction zone. In the right panel, the impulse emerges from the exit site and spreads back to the target site through the Purkinje network. Because the post-stimulus interval reflects the conduction time from the target site to the exit site through the slow conduction zone of the circuit and the conduction time from the exit site back to the target site through the Purkinje tissue, it can be shorter than, equal to or longer than the tachycardia cycle length. It should be noted that inability to demonstrate entrainment from the target site in this study is most likely due to the use of only a single catheter for left ventricular stimulation, and no local electrogram was recorded from the exit site when the stimulus was delivered to the target site.

Clinical implications. The exact nature of the reentry circuit in idiopathic left ventricular tachycardia is unclear. Ward et al. (6) and Kottkamp et al. (16) have suggested that it is a microreentry circuit in the territory of the left posterior fascicle. Nakagawa et al. (7) suggested that the circuit is confined to the Purkinje system, which is insulated from the underlying ventricular myocardium. Suwa et al. (17) and Thakur et al. (18) have implied that the left ventricular fibromuscular band may be the anatomic substrate of this tachycardia. Previous studies from this laboratory (8,19) have shown that neither the Purkinje system nor the left
Ventricular fibromuscular band is the specific arrhythmogenic substrate of this tachycardia. The present study further demonstrates that the slow conduction zone of the reentry circuit is of considerable size, extending from the midseptum (the successful ablation site) to the inferior apical septum (the exit site) of the left ventricle in some patients with idiopathic left ventricular tachycardia. The findings of the present study also concur with previous suggestions that the entrance site of the circuit is closer to the base, whereas the exit site is closer to the apex of the heart (13) and that the slow conduction zone appears to be insulated from the nearby ventricular myocardium (7).

Limitations of the study. The present study has some limitations: 1) The putative tachycardia exit site might not be the true exit site because successful radiofrequency ablation was not achieved at this site. However, this was the site where the earliest Purkinje potential was recorded; the stimulus–QRS interval was identical to the Purkinje–QRS interval during the tachycardia; and the pace map 12-lead ECG matched the recording taken during the tachycardia. It was also the site where radiofrequency ablation achieved a high success rate. 2) It could be argued that only two of the seven patients had a follow-up study; thus, permanent success of radiofrequency ablation could not be ensured in this study. However, the frequency of attacks in these patients before ablation and the follow-up duration after ablation with no symptoms suggestive of tachycardia recurrence strongly implied that the tachycardia had indeed been permanently eradicated. 3) The resetting studies were performed in only five patients. Therefore, the full range of resetting responses in patients with idiopathic left ventricular tachycardia cannot be inferred from this study and will require further investigation in a large number of patients. 4) Successful ablation at a site away from the tachycardia exit was limited to the seven patients in whom a potential distant target site was identified by the pressure mapping technique; therefore, our conclusions may not be applicable to all patients with idiopathic left ventricular tachycardia.

Conclusions. Successful ablation of idiopathic left ventricular tachycardia can be achieved at sites away from the tachycardia exit site in some patients. This finding suggests that the reentry circuit is likely to be of considerable size, encompassing the middle, inferior and lower aspects of the left interventricular septum.

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