Significance of Late Diastolic Potential Preceding Purkinje Potential in Verapamil-Sensitive Idiopathic Left Ventricular Tachycardia

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Background—Verapamil-sensitive idiopathic left ventricular tachycardia (VT) is due to reentry with an excitable gap. A late diastolic potential (LDP) is recorded during endocardial mapping of this VT, but its relation to the reentry circuit and significance in radiofrequency (RF) ablation remain to be elucidated.

Methods and Results—Sixteen consecutive patients with this specific VT were studied (12 men and 4 women; mean age, 32 years). In all patients, sustained VT was induced and during left ventricular endocardial mapping, LDP preceding Purkinje potential (PP) was recorded at the basal (11 patients), middle (3 patients), or apical septum (2 patients). The area with LDP recording was confined to a small region (0.5 to 1.0 cm²) in each patient and was included in the area where PP was recorded (2 to 3 cm²). The relative activation times of LDP, PP, and local ventricular potential (V) at the LDP recording site to the onset of QRS complex were 250.4±18.9, 215.2±9.6, and 3.0±13.3 ms, respectively. The earliest ventricular activation site during VT was identified at the posteroapical septum and was more apical in the septum than the region with LDP in every patient. In 9 patients, VT entrainment was done by pacing from the right ventricular outflow tract while recording LDP. During entrainment, LDP was orthodromically captured, and as the pacing rate was increased, the LDP-to-PP interval was prolonged, whereas stimulus-to-LDP and PP-to-V interval were constant. In 3 patients, the pressure applied to the catheter tip at the LDP region resulted in conduction block between LDP and PP and in VT termination. RF energy application at the LDP recording site successfully eliminated VT.

Conclusions—LDP was suggested to represent the excitation at the entrance to the specialized area with a conduction delay in response to the increase in the rate within the critical slow conduction zone participating in the reentry circuit of this VT. LDP can be a useful marker for successful RF ablation for this VT.

Key Words: tachycardia ■ potentials ■ catheter ablation

Idiopathic left ventricular tachycardia (VT) with a right bundle-branch block configuration and superior or left axis is an uncommon but well-described clinical arrhythmia.1–8 This VT was shown to be due to reentry with an excitable gap and an area of slow conduction with a conduction delay in response to the increase in the rate is present within the reentry circuit.3–6 Purkinje potential (PP) recorded during VT is used to identify the successful ablation site.7 Wen et al6 demonstrated that a successful ablation site for this VT is away from the VT exit site in the mid and inferior apical septum and is located at the superior midseptal area. Kottkamp et al8 demonstrated continuous or mid-diastolic electrical activity preceding PP at these sites in patients with this VT and suggested these activities as markers for successful ablation. These findings suggest that the reentry circuit of this VT is localized in the left ventricular septum and that electrical marker(s) presumably related to the circuit can be used for identifying the successful ablation site for this VT.

During endocardial catheter mapping of this VT, we recorded a discrete late diastolic potential (LDP) preceding PP at sites similar to those reported as the successful ablation site by Wen et al.6 This potential may represent the same electrical activity as that reported by Kottkamp et al,8 but either its relation to the reentry circuit or the significance in identifying the target site for successful ablation has not been fully understood. In this study, we characterized this LDP and prospectively examined whether this LDP is related to the reentrant circuit by using entrainment technique4,5,9–11 and thus can be a marker for radiofrequency (RF) catheter ablation for this VT.
Methods

Patients
Sixteen consecutive patients (12 men and 4 women, with a mean age of 32 years, ranging from 15 to 61) with recurrent sustained VT and without any underlying heart disease were studied. The ECG recorded during VT exhibited a right bundle-branch block configuration and superior or left axis in all patients. Intravenous verapamil (5 to 10 mg) had been found to be effective in terminating VT in all patients. In the first 7 patients (patients 1 to 7) LDP was retrospectively characterized, and in the remaining 9 patients (patient 8 to 16) its relation to the reentry circuit and the significance as a marker for successful ablation as well as the characteristics were prospectively examined.

Electrophysiological Study
Written informed consent was obtained from all patients before the electrophysiological study and ablation procedure. All antiarrhythmic drugs were discontinued for >5 half-lives of each drug before the study. With the use of standard techniques, 2 or 3 quadripolar electrode catheters (6F, Josephson, Bard Electrophysiology) were placed at the right ventricular apex, right ventricular outflow tract, and/or His bundle region and were used for recording bipolar electrograms and pacing. A 7F, deflectable quadripolar electrode catheter with a 2-mm interelectrode interval (Cordis Webster) was retrogradely inserted into the left ventricle to perform endocardial catheter mapping during VT by recording an electrogram from the distal electrode pair and also to perform pacing. All bipolar electrograms were filtered between a bandpass of 50 and 600 Hz and recorded simultaneously with 3 or 4 electrocardiographic leads (I, II, [III], and V.) with the use of a polygraph (RMC-2000, Nihon Kohden or Cardiolab System, Prucka Engineering). Ventricular pacing was performed at a stimulus strength of twice diastolic threshold and with a pulse width of 2 ms by use of a programmable stimulator (SEC-3102, Nihon Kohden). After VT was induced by ventricular programmed stimulation or burst pacing, endocardial mapping in the left ventricle was performed during VT, and the early ventricular programmed stimulation or burst pacing, endocardial mapping during VT by recording an electrogram from the right ventricular outflow tract while recording LDP. In 7 of these patients, entrainment was also attempted from the right ventricular outflow tract and earliest ventricular activation site 4,5,9–11 In 9 patients (patients 8 to 16), entrainment was also attempted from the right ventricular outflow tract while recording LDP. In 7 of these patients, entrainment was attempted by pacing from the LDP recording site. When VT was still present after termination of the pacing, rapid pacing was again performed with an increase in the pacing rate by 5 to 10 bpm. This procedure was repeated until VT was interrupted.

Radiofrequency Catheter Ablation
RF energy was delivered by a generator (CABLI IT, Central Inc) that supplied a continuous, unmodulated sine wave output at a frequency of 500 kHz. The catheter used to deliver RF energy was a 7F, deflectable quadripolar electrode catheter with (Radi-T, Cardiac Pathways) (8 patients) or without a thermistor (Cordis Webster) (8 patients). RF energy at 20 to 30 W was applied during VT for 30 seconds.

Of the first 7 patients who were retrospectively studied for LDP, the initial target site of RF ablation was the earliest ventricular activation site8,12 in 5 and the earliest PP site9 in the other 2. In the remaining 9 patients who were prospectively studied, initial target site was the LDP recording site. When VT was terminated during RF ablation, the inducibility of VT was assessed with programmed and burst pacing protocol. Thirty minutes after the final RF energy application, the inducibility of VT was again assessed before and after isoproterenol infusion (1 μg/min).

Data Analysis
Continuous variables are expressed as mean±1 SD. Statistical analysis was done with an unpaired t test for comparison of 2 variables and with 1-way ANOVA followed by Scheffé’s test for comparison of ≥3 variables. P<0.05 was considered statistically significant.

Results
Sustained VT with a mean cycle length of 350.1±56.1 ms (rate 175.2±25.4 bpm) and with the same QRS morphology as that of the spontaneous VT was repeatedly induced in all patients.

Endocardial Mapping During VT and Characteristics of LDP
Left ventricular endocardial mapping during VT identified the earliest ventricular activation site, with an activation time of −22.8±1.9 ms relative to the onset of QRS complex at the posteroapical left ventricular septum in all patients (Table). LDP preceding PP could be recorded in all patients (Figure 1). The LDP recording site was located at the basal septum in 11 patients, middle septum in 3, and apical septum in the other 2 and was more basal in the septum than the earliest ventricular activation site. The region with LDP recording was confined to a small area (0.5 to 1.0 cm²) in each patient and was included in the area where PP was recorded (2 to 3 cm²). The local activation order at the LDP recording site was always LDP-PP-local ventricular potential (V), and the relative activation times of each potential to the onset of the QRS complex was −50.4±18.9, −15.2±9.6, and 3.0±13.3 ms, respectively.

The absolute value of the relative timing of LDP to the QRS complex was significantly greater than those of PP and V at the LDP recording site and than that of the ventricular potential at the earliest ventricular activation site (all P<0.0001). In some patients, PP at the LDP recording site preceded the ventricular potential at the earliest activation site, whereas in the others the former appeared after the latter, and there was no statistical difference between the relative activation times of the former and the latter.

In 1 patient, a similar LDP was recorded during sinus rhythm at the same site. In contrast, PP was recorded during sinus rhythm as well as during VT in all patients. The relative timing of PP to the onset of QRS complex during sinus rhythm was −22.1±6.7 ms, which was not statistically different from that during VT.

Entrainment of VT
In all patients, entrainment phenomena including constant fusion and progressive fusion were demonstrated by rapid pacing from the right ventricular outflow tract, and a long conduction interval between the pacing site and the earliest ventricular activation site, indicating a slow conduction zone, was demonstrated during entrainment.5,5 Figure 2 shows an example of entrainment from the right ventricular outflow tract while recording LDP. The cycle length of VT was 355 ms and the intervals between LDP and PP (LDP-PP) and PP and ventricular potential (PP-V) during VT were 52 and 12 ms, respectively. As clearly demonstrated during pacing at 185 and 190 bpm (Figure 2, center and right panels), the
morphology of LDP (indicated by arrows) remained unchanged during entrainment, indicating an orthodromic capture of the potential, whereas that of the ventricular potential at the site with LDP recording was different from that during VT, indicating an antidromic capture of the potential. PP was not observed during pacing because it was masked by the local ventricular potential captured antidromically. The intervals between the stimulus artifact and LDP (stimulus-LDP) and LDP-PP interval, which could be measured in the last entrained beat, during pacing at 175 bpm were 340 and 100 ms, respectively (Figure 2, left panel). When the pacing rate was increased to 185 and 190 bpm, stimulus-LDP interval during entrainment remained unchanged, whereas LDP-PP interval was increased to 135 and 180 ms, respectively. The same findings were observed in the other 8 patients in whom entrainment study was performed while recording LDP. The changes in stimulus-LDP and LDP-PP intervals in response to the increase in the pacing rate during entrainment are shown in Figure 3 for 9 patients. LDP-PP interval was gradually increased as the pacing rate was increased in every patient, whereas stimulus-LDP interval was constant.

In 7 of the study patients, entrainment of VT was attempted by rapid pacing at the LDP recording site. However, the pacing at a rate(s) at which VT was entrained from the right ventricular outflow tract immediately terminated VT in all patients and thus could not elucidate the entrainment phenomenon. The configuration of QRS complex during pacing at the LDP recording site performed during sinus rhythm was different from that during VT in these patients.

### Effect of Pressure Application to Tip of Ablation Catheter at LDP Site

In 3 patients, the pressure was applied to the tip of the ablation catheter at the LDP recording site, which resulted in the termination of VT. In 1 patient, before the termination of VT, the pressure resulted in a variation in both VT cycle length and LDP-PP interval in a beat-to-beat fashion, whereas the intervals from PP to V (PP-V) and from V to LDP (V-LDP) were almost constant (Figure 4A). Moreover, VT cycle length changed in parallel with the change in LDP-PP interval. Figure 4B shows the correlation of VT cycle length

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<th>PP-Q, ms</th>
<th>EAS, ms</th>
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| LDP Width, ms | LDP-PP, ms | PP-Q, ms | CL indicates cycle length of ventricular tachycardia; EAS, relative timing of ventricular potential to onset of QRS at earliest ventricular activation site; EAS-PP, earliest activation site of Purkinje potential (PP); EAS-V, earliest activation site of ventricular potential; LDP-PP, relative timing of LDP to onset of PP; PP-Q, relative timing of PP to onset of QRS complex; SR, sinus rhythm; and VT, ventricular tachycardia.

Figure 1. Example of LDP preceding PP recorded at the middle of the left ventricular septum during VT. Tracings are ECG leads I, II, and V1, and intracardiac electrograms recorded from the mapping catheter located at the middle of the left ventricular septum (MAP), the right ventricular apex (RVA), and the right ventricular outflow tract (RVOT). V indicates ventricular potential.
with each of LDP-PP, PP-V, and V-LDP intervals shown in Figure 4A. The VT cycle length was highly correlated with LDP-PP interval ($R^2 = 0.9$), whereas it was not with PP-V interval or V-LDP interval. In this and the other 2 patients, VT was terminated by pressure application, being associated with the local conduction block occurring between LDP and PP.

**RF Catheter Ablation**

In all patients, VT was successfully terminated and became uninducible by RF energy application. The number and total energy of RF energy applied for all patients were $3.8 \pm 3.1$ times and $3025.6 \pm 2064.0$ J, respectively (Table). When the number and total energy of RF energy applied were compared between the patient group in which RF energy was initially applied to the earliest ventricular activation site (patients 1 to 5) and the earliest PP site (patients 6 and 7) and the group in which RF energy was applied to the LDP site (patients 8 to 16), both parameters were significantly smaller in the latter group than the former group (number, $6.7 \pm 2.4$ vs $1.6 \pm 1.0$ times, $P = 0.0001$; energy, $4933.4 \pm 1473.5$ vs $1541.8 \pm 835.4$ J, $P = 0.0001$). In 6 of the 9 patients in whom RF energy was initially applied to the LDP recording site, VT was successfully terminated by a single energy application. Figure 5 shows the RF energy application sites and the earliest ventricular activation sites in the 6 patients in whom VT was eliminated by a single energy application. It was noted that the ablation sites were more basal to the earliest activation sites.

In 2 patients, RF ablation guided by LDP resulted in the termination of VT and transient left bundle-branch block during subsequent sinus rhythm for 10 minutes. VT was still not inducible after left bundle-branch block disappeared.

An example of ablation at the LDP recording site is shown in Figure 6. After the initiation of RF energy application (indicated by RFCA in the figure), LDP-PP interval was gradually prolonged during the first 3 beats, whereas PP-V interval was constant. It is noted that VT cycle length was prolonged in parallel with the increase in LDP-PP interval and VT was suddenly terminated, being associated with local conduction block between LDP and PP recordings. In this particular patient, transient left bundle-branch block occurred after ablation (asterisks), and a mid-diastolic potential (indicated by an arrow) with a similar morphology to LDP during VT was recorded during sinus rhythm in addition to PP. In all patients, PP persisted even after successful ablation. During a mean follow-up period of $17.6 \pm 10.5$ months, no patient had VT recurrence.

**Discussion**

We found that LDP was recorded in a small area at the basal and middle septal regions during tachycardia in all patients with this idiopathic, verapamil-sensitive VT and that RF energy applied to the LDP recording site eliminated VT. This LDP recording site appears to be identical to the proximal target site for RF ablation reported by Wen et al., although these authors did not describe any specific potential at this site, as shown in the present study. LDP can therefore be a

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**Figure 2.** Example of entrainment by pacing from the right ventricular outflow tract (RVOT) at rates of 175, 185, and 190 bpm while recording LDP. Tracings are ECG leads I, II, III, and V₁ and intracardiac electrograms recorded at His bundle region (HB), a site where LDP (indicated by arrows) was recorded with distal and proximal pair of mapping catheters (MAP-d and MAP-p, respectively), the RVOT, and the right ventricular apex (RVA). All values are in ms. Numbers in italic print indicate conduction interval between LDP to PP; those inside circles indicate conduction intervals from stimulus artifact to LDP and electrogram at RVA. See text for discussion.

**Figure 3.** Graphs showing relations between pacing rate and intervals from pacing stimulus artifact to LDP (stimulus-LDP interval) (left) and from LDP to PP (LDP-PP interval) (right) measured during entrainment of VT. See text for discussion.
useful marker for successful ablation of the present VT. Its origin and relation to the reentry circuit, however, remains unclear.

During entrainment of this VT, a long conduction interval indicative of a slow conduction zone was present between the right ventricular outflow tract and the earliest ventricular activation site, and a property of conduction delay in response to the increase in the rate was demonstrated within this slow conduction zone. The similar findings were obtained in sustained VT associated with healed myocardial infarction and right ventricular dysplasia. In the present study, we further analyzed the conduction interval during entrainment with regard to LDP and found that LDP-PP interval was prolonged as the pacing rate was increased, whereas stimulus-LDP interval was constant (Figure 3). Thus it is suggested that the entire slow conduction zone can be divided into 2 components by LDP: One is a component in the distal part to the LDP recording site, which is characterized by a property of conduction delay in response to the increase in the rate, and the other between the right ventricular outflow tract and the LDP recording site showing no conduction delay property. We have suggested that a tissue with calcium channel-dependent conduction is involved in the conduction delay demonstrated during entrainment. Thus LDP is likely to represent the excitation at the entrance to the specialized slow conduction area with a conduction delay property associated with calcium channel-dependent conduction. Because the relative activation time of PP at the LDP site to the QRS complex was not different from that of the ventricular potential at the earliest activation site, PP appears not to represent activation of a part of the reentry circuit but that of a bystander.

When VT was entrained by pacing from the right ventricular outflow tract, the ventricular potential at the LDP recording site was always captured antidromically, whereas LDP was captured orthodromically. As shown in the left panel of Figure 2, antidromic capture of the ventricular potential was observed even during pacing at a rate only 5 bpm faster than the VT rate. We reported that the earliest ventricular activation site during VT, which is likely to be the exit site from the slow conduction zone and is located more apically to the LDP recording site, is captured orthodromically at relatively lower pacing rates, whereas it is captured antidromically at higher rates. Thus a ventricular tissue with LDP recording is indicated to be electrically insulated either anatomically or functionally from the surrounding ventricular myocardium. Although we could not clarify the origin of LDP in this study, it might be speculated that LDP originates from the specialized conduction system because the potential is sharp and narrow. It could be an example of functional longitudinal dissociation of the proximal left bundle-branch.

Wen et al recently reported cases in which pressure applied to the tip of the catheter placed at the sites similar to the present LDP recording site transiently terminated VT and RF ablation was successfully accomplished at these sites. In the present 3 patients, the pressure applied to the tip of the catheter placed at the LDP site resulted in variation of VT cycle length and termination of VT, being closely associated with variable degrees of local conduction block between LDP and PP recording sites. This finding is consistent with that reported previously. Together with the findings obtained during entrainment and the results of RF ablation, it is
strongly suggested that LDP represents the excitation of the critical area participating in the reentrant circuit of this VT and is unlikely to represent the excitation at the bystander pathway in the slow conduction zone. LDP was recorded at the basal or middle septal region apparently away from the VT exit site in the apical region. VT could be eliminated by a single RF energy application in 6 of the 9 patients in whom RF energy was applied to the LDP recording site. Thus the reentry circuit or a slow conduction zone is indicated to be located in the relatively wide area from the basal to the apical septum.

Recently Nakagawa et al\(^8\) reported that the earliest PP was useful in guiding successful RF ablation. Wen et al\(^12\) reported that such discrete sharp spikes as PP were likely to represent the fascicular potentials rather than a specific marker for the reentry circuit of this VT. In contrast to PP, the present report suggests that LDP reflects the excitation within the critical slow conduction area participating in the reentry circuit and that VT could be eliminated by a single RF energy application guided by LDP. Thus LDP appears to be a very useful marker in guiding the successful ablation site for this VT.

It should be emphasized that in 2 of the present patients, RF energy application resulted in not only immediate termination of VT but transient complete left bundle-branch block. VT remained noninducible even after left bundle-branch block disappeared. It is suggested that the reentry circuit, especially the LDP recording site, is suggested to be located close to the main trunk of the left bundle branch. Further studies on the relation between the reentry circuit of this VT and left bundle branch itself are required.

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**References**


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