Clinical Application of an Integrated 3-Phase Mapping Technique for Localization of the Site of Origin of Idiopathic Ventricular Tachycardia

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Background—Radiofrequency (RF) catheter ablation provides curative treatment for idiopathic ventricular tachycardia (VT).

Methods and Results—Nineteen consecutive patients with an idiopathic VT underwent RF catheter ablation. An integrated 3-phase mapping approach was used, consisting of the successive application of online 62-lead body surface QRS integral mapping, directed regional paced body surface QRS integral mapping, and local activation sequence mapping. Mapping phase 1 was localization of the segment of VT origin by comparing the VT QRS integral map with a database of mean paced QRS integral maps. Mapping phase 2 was body surface pace mapping during sinus rhythm in the segment localized in phase 1 until the site at which the paced QRS integral map matched the VT QRS integral map was identified (ie, VT exit site). Mapping phase 3 was local activation sequence mapping at the circumscribed area identified in phase 2 to identify the site with the earliest local endocardial activation (ie, site of VT origin). This site became the ablation target. Ten VTs were ablated in the right ventricular outflow tract, 2 at the basal LV septum, and 7 at the midapical posterior left ventricle. A high long-term ablation success (mean follow-up duration, 14±9 months) was achieved in 17 of the 19 patients (89%) with a low number of RF pulses (mean, 3.3±2.2 pulses per patient).

Conclusions—This prospective study shows that integrated 3-phase mapping for localization of the site of origin of idiopathic VT offers efficient and accurate localization of the target site for RF catheter ablation. (Circulation. 1999;99:1300-1311.)

Key Words: mapping n electrocardiography n tachycardia n cather ablation

Curative radiofrequency (RF) catheter ablation is becoming the primary mode of therapy for idiopathic ventricular tachycardia (VT). The 2 most common types of idiopathic VT originate from the right ventricular outflow tract (RVOT) or apical posterior left ventricle (LV). Several previous studies have described RF catheter ablation for idiopathic VT, and the success percentages varied from 69% to 94%.. Despite these promising results, mapping with a single catheter may still be cumbersome and time-consuming, because large areas need to be explored in a sequential fashion. Furthermore, a point-to-point activation mapping approach may not be possible when initiation of the VT is difficult or not feasible at all. Recently, a body surface mapping method for idiopathic VT localization was introduced, which enabled rapid identification of the target area.

This and other studies formed the basis for the development of a mapping technique that features the integration of 3 mapping methods. This mapping approach incorporates the successive use of global body surface mapping, regional paced body surface mapping, and local activation sequence mapping.

The primary objectives of this study were to prospectively test the feasibility and assess the acute and long-term efficacy of this integrated 3-phase mapping technique for localization and ablation of the site of origin of idiopathic VT. In addition, the potential advantages of the 3-phase mapping approach were determined compared with standard mapping techniques. Finally, the findings in the 3 successive mapping phases were spatially related to the anatomy of the VT substrate.
Methods

Patient Population

Nineteen consecutive patients (9 women and 10 men; mean age, 41 ± 14 years; range, 20 to 68 years) who underwent RF catheter ablation for symptomatic idiopathic VT were included. Informed consent was obtained from all patients. The patient group was previously unsuccessfully treated with a mean of 2.0 antiarrhythmic drugs. All antiarrhythmic drugs were discontinued at least 5 drug half-lives before the procedure. Clinical characteristics of the patients are summarized in Table 1. Structural heart disease was excluded in all patients by physical examination, laboratory testing, 12-lead ECG analysis, chest x-ray, and echocardiography. The documented monomorphic VT was sustained (>30 seconds) in 14 of the 19 patients and nonsustained (at least 3 consecutive complexes and <30 seconds) in 5 patients. In 11 patients, the VT QRS complex featured a left bundle-branch block (LBBB) morphology with inferior axis, whereas 8 patients demonstrated a right bundle-branch block (RBBB) configuration with a horizontal-to-superior axis. The mean rate of the clinically documented monomorphic VTs was 190 ± 30 bpm (range, 150 to 240 bpm).

Electrophysiological Study and RF Ablation

The electrophysiological study was performed in the postabsorptive nonfasted state. Three catheters were introduced into the right femoral vein and positioned in the high right atrium, RV apex, and His bundle region, respectively. VT induction was carried out by a programmed stimulation protocol consisting of pacing (at twice diastolic threshold with 2-ms pulse width) from the RV apex and RVOT at drive cycle lengths of 600 and 430 ms with up to 3 extrastimuli, including extrastimuli with a long-short sequence. Subsequently, incremental RV and right atrial pacing as well as burst pacing were performed. If VT could not be induced, isoproterenol (1 to 4 µg/min) was infused. The stimulation protocol was repeated if VT did not occur spontaneously under isoproterenol infusion. In case of persistent noninducibility, spontaneously occurring VT or ventricular ectopic complexes with the same QRS configuration as the clinical VT were targeted for mapping.

Pace mapping was performed with a steerable 7F quadripolar catheter (4-mm tip electrode; 2–5–2–mm interelectrode spacing). RF mapping was performed via the femoral vein, whereas a retrograde aortic approach was used for LV mapping. Stimulation was performed with the distal electrode pair at current outputs just above the local threshold starting from 1 to a maximum of 10 mA (cycle length, 500 ms; pulse width, 2 ms). Bipolar and unipolar endocardial electrograms were recorded simultaneously with this mapping catheter (filter settings, 50 to 1000 Hz and 0.1 to 1000 Hz; gain settings, 0.25 and 2 mV/cm, respectively). The endocardial electrograms were simultaneously displayed on a 16-channel ink-jet recorder. Biplane fluoroscopy with 45° right anterior oblique and 45° left anterior oblique projections was used. RF current was delivered at the appropriate target site by use of a custom-made device that generated a continuous unmodulated sine wave at 500 kHz. Energy was delivered between the tip electrode of the ablation catheter and a large surface electrode positioned at the lower back of the patient. The power output was started at 25 W and increased to 35 W for a total duration of 60 to 90 seconds.

Body Surface Mapping

Body surface mapping was performed online with a computerized mapping system and a radiotransparent carbon electrode set. Our methods of recording, processing, and analysis have been described previously. In summary, unipolar recordings from 62 torso sites (Figure 1) were acquired during episodes of monomorphic VT or ventricular ectopy and during pace mapping (sampling rate, 1 kHz) with a 486 microcomputer. Further data processing and analysis were performed with a second microcomputer (Amiga 1200; Commodore-Amiga, Ltd) that was linked to the parallel port of the acquisition computer. A mean of 2.0 ± 1.3 leads per map were rejected because of unsatisfactory signal quality and were replaced.
Three-Phase Mapping of Idiopathic VT

Body Surface Lead Sites

Figure 1. Diagram showing anatomical positions of 62 electrodes. A total of 14 straps cover thorax with 41 electrodes on front and 21 electrodes on back. Standard precordial leads V1 through V6 are included in array and are represented by open circles.

by a value computed from neighboring electrodes. The beginning and end of the QRS complex were set at the time instant at which one of the extreme amplitudes reached ±0.2 mV and at the J point, respectively. A QRS integral map was computed for each VT or ventricular ectopic complex and for every paced complex. Pattern matching of QRS integral maps was performed both visually and mathematically with correlation coefficients. Visual analysis involved comparison of the position and orientation of the extremes and the morphology of the zero line.

Integrated Three-Phase Mapping Protocol

Mapping Phase 1: Localization of Segment of VT Origin
First, a body surface QRS integral map of a single VT QRS complex was computed online. For the purpose of this study, the QRS integral map of either a VT complex or a single ventricular ectopic complex was called the VT QRS integral map. This VT QRS integral map was directly compared visually and correlated mathematically with a database of mean paced QRS integral maps for the structurally normal RV and LV previously developed by our group (Figure 2). In this database, each mean paced QRS integral map corresponds to a distinct endocardial segment of origin in the LV or RV. The mean area sizes of the 25 specific LV segments and 13 distinct RV segments are 3.3 and 6.7 cm², respectively. The ventricular segment of which the mean paced QRS integral map morphologically showed the best match with the VT QRS integral map was identified as the segment of VT origin and displayed on a schematic endocardial diagram of the RV or LV (Figure 2). When the VT QRS integral map showed characteristics of an intermediate pattern between 2 mean paced QRS integral maps from the database, the segment of origin was assumed to lie between the 2 corresponding segments.

Mapping Phase 2: Localization of VT Exit Site
Directed regional body surface pace mapping was performed during sinus rhythm in the segment identified in phase 1 to locate the VT exit site. At every stimulation site, a paced complex was converted online into a paced QRS integral map, which was instantaneously correlated visually and mathematically with the VT QRS integral map. The catheter was then navigated to the position at which maximal correlation was achieved.

Mapping Phase 3: Localization of VT Site of Origin
Detailed local activation sequence mapping was performed at and around the VT exit site selected in phase 2 to identify the site of VT origin. The VT was reinitiated when possible; otherwise, spontaneously occurring ventricular ectopic activity was analyzed. For the LBBB VTs, the site showing the earliest ventricular activation relative to the onset of the QRS complex on the surface ECG was identified and designated the site of VT origin. This site became the target site for ablation. For the RBBB VTs, we tried to identify the site at which the earliest Purkinje potential occurred with reference to the onset of the ectopic QRS complex. If no Purkinje potentials could be identified, the site with the earliest local ventricular activation was targeted for ablation. In those cases in which VT or ventricular ectopy did not appear in the third mapping phase, ablation was performed at the VT exit site identified in phase 2.

Spatial Localization of the VT Exit Site and Site of Origin
The distance between the VT exit site and the VT site of origin was determined in each patient to gain more insight into the extent of the arrhythmogenic substrate. The mutual distance between these 2 catheter positions was determined offline by use of a previously designed computerized localization technique with a resolution ≤5 mm.

Evaluation of Early Success
Ablation was defined to be initially successful at 30 minutes after the last RF application if VT or ventricular ectopic activity could not be reinitiated by use of the above-described protocol. For VTs that occurred spontaneously only before ablation, absence of spontaneous VT or ventricular ectopy during 30 minutes after the last RF energy delivery was considered to be a marker of success. In addition, all patients underwent telemetric ECG monitoring for 6 days to evaluate the short-term outcome of the ablative therapy. Also, on day 6, a treadmill exercise test was performed in those patients in whom VT had been exercise-related.

Long-Term Follow-Up
At 1 month, the patients visited the outpatient clinic to report whether they had been free of symptoms and to undergo physical examination and 12-lead ECG recording. Thereafter, patients were followed up on a regular basis every 2 to 6 months. When a patient reported symptoms suggestive of VT recurrence, 24-hour Holter monitoring was also performed. In addition, a treadmill exercise test was carried out if such a patient was known to have had previous exercise-related VT. Long-term success was considered to be present if the patient experienced no recurrence of symptoms related to his or her VT during the follow-up period.

Results

VT Characteristics
Details about the VTs identified during the electrophysiological study are summarized in Table 2. VT or ectopy could be induced at baseline in 9 patients. Eight of these 9 patients had an RBBB VT. Nine patients had spontaneous VT or ventricular ectopic complexes. Eight of these 9 patients had an LBBB VT.

Mapping Phase 1
VT QRS integral maps were computed from either a single VT complex or a ventricular ectopic complex in all of the 19 patients. There were 11 LBBB VTs and 8 RBBB VTs. By comparing these VT QRS integral maps with the database of mean paced QRS integral maps, we found that all but 1 LBBB VT originated from a segment in the RVOT. Five of the 11 QRS integral maps with LBBB configuration (45%) were localized to segment RV5, 2 (18%) to segment RV6, 2 (18%) between segments RV4 and RV7, and 1 (9%) to segment RV4 (Figure 2A). One LBBB VT (9%) appeared to arise from segment LV10, which corresponds to a basal anteroseptal site in the LV (Figure 2B). All 8 RBBB VTs were localized to the LV. The VT QRS integral maps of 5 of
Figure 2. Previously constructed database of 38 mean paced QRS integral maps obtained in normal LV and RV. A total of 13 RV (A) and 25 LV (B) mean paced QRS integral maps are depicted, each corresponding to a specific endocardial segment of activation onset. Endocardial segment of origin of a certain QRS integral map pattern is indicated by encircled number of that map in a schematic of appropriate ventricle. Additional numbers 1 through 18 represent 18 endocardial catheter mapping sites previously identified by Josephson et al. Reproduced with permission of the American Heart Association.
the 8 VTs (62%) were localized to or in the vicinity of segment LV15, to the apical posterior septum or apical posterior wall of the LV. The other 3 VT QRS integral maps (38%) correlated best with either segment LV13 or LV14, which were located basally at the posterior septum.

**Mapping Phase 2**

The VT exit site was localized by comparing paced QRS integral maps with the VT QRS integral map in each patient. In 10 of the 19 patients (53%), the site at which maximal correlation was achieved was located in the segment identified in phase 1. In the remaining 9 patients (47%), the exit site was found in a segment directly adjacent to the segment outlined in phase 1 (Table 3).

Figure 3 shows how comparison of body surface pace maps with the database provided information for catheter navigation. The level of pattern correspondence between the VT (A) and paced QRS integral maps (B through D) increased from the first to the third paced map as the pacing catheter was interactively steered to the site at which optimal QRS replication could be obtained.

**Mapping Phase 3**

In 5 patients (26%), ventricular ectopy could not be provoked, nor did it occur spontaneously during phase 3. Therefore, the site identified in phase 2 became the target site for ablation in these patients. In the other 14 patients, the site of VT origin could be identified in phase 3 by localized endocardial activation sequence mapping. This site of VT origin originated from the same segment as the site delineated in phase 2 in 9 of 14 patients (64%), an adjacent segment in 3 patients (22%), and a disparate segment in 2 patients (14%).

For the LBBB VTs, earliest ventricular activation during VT or an ectopic complex was found to occur between 15 and 35 ms (mean, 23±8 ms) before QRS onset on the surface ECG. Purkinje potentials could be identified during VT in 4 of the 7 patients with an RBBB VT who underwent activation mapping. These potentials preceded the QRS onset by 20 to 30 ms. In the remaining 3 patients, no Purkinje potentials could be identified, but the earliest local ventricular activation during VT was found to occur between 25 and 30 ms (mean, 27±3 ms) before the onset of the QRS complex. The results are summarized in Table 3. In all 14 patients in whom the VT site of origin could be identified during mapping phase 3, the successful RF application was given at the site with the earliest ventricular activation or earliest Purkinje potential. In 3 of the 5 patients (patients 1, 5, and 10) in whom the VT exit site was targeted for ablation, additional RF applications were delivered around the site showing the highest correlation of the paced QRS integral map with the VT QRS integral map. In 10 of the 11 LBBB VTs (91%), the target site for ablation was located in the segment identified in mapping phase 1, whereas this was the case in only 1 of the 8 RBBB VTs (13%).

Figures 4 and 5 show examples of the 3 consecutive mapping phases executed in patients 12 and 9, respectively.

**Distance Between VT Exit Site and Site of Origin**

In 5 patients, phase 3 could not be executed; thus, fluoroscopic projections of the VT site of origin could not be

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**TABLE 2. Results of Electrophysiological Study**

<table>
<thead>
<tr>
<th>Patient</th>
<th>Baseline EPS</th>
<th>Isoproterenol Infusion</th>
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<tr>
<td></td>
<td>Spont</td>
<td>PVE</td>
</tr>
<tr>
<td>1*</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>2</td>
<td>nsVT</td>
<td>VEC</td>
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<tr>
<td>3</td>
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<td>VEC</td>
</tr>
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<td>5</td>
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</tr>
<tr>
<td>19</td>
<td>–</td>
<td>nsVT</td>
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EPS indicates electrophysiological study; Spont, spontaneous; PVE, premature ventricular extrastimuli; RVP, rapid ventricular pacing; RAP, rapid atrial pacing; and =, same as at baseline. Other abbreviations as in Table 1.

*In this patient, episodes of nonsustained VT were provoked by intravenous administration of phenylephrine.
obtained. In 3 other patients, the fluoroscopic images were excluded from the analysis because of their inferior quality. Thus, fluoroscopic projections of the catheter sites could be examined in 11 of the 19 patients. In these 11 patients, the distance between the identified exit site and the site of VT origin for LBBB VTs ranged from 0 to 12 mm (mean, 6 ± 5 mm) and for RBBB VTs, from 0 to 32 mm (mean, 13 ± 14 mm) (Table 3).

Acute Ablation Outcome
RF catheter ablation appeared to be initially successful in 17 of 19 patients (89%), with a mean of 3.3 ± 2.2 (range, 1 to 7) RF applications and a mean fluoroscopy time of 30 ± 18 minutes (range, 12 to 70 minutes). VT remained inducible at the end of the ablation procedure in 1 patient (patient 13), and VT was observed in another patient (patient 2) 5 days after ablation. It should be realized that the acute ablation success remained uncertain in the 5 patients in whom ablation had been directed by phase 2 criteria. The distribution of sites at which ablation was successfully performed is indicated in a schematic diagram of the RV and LV (Figure 6).

Long-Term Follow-Up and Complications
During a mean drug-free follow-up of 14 ± 9 months (range, 2 to 34 months), recurrence of symptoms suggestive of VT occurred in 2 patients. Three months after the procedure, patients 7 and 10 started to experience the same symptoms as before ablation, and the same nonsustained VT was recorded on a 12-lead ECG. Patient 10 received metoprolol and has remained free of symptoms. Patients 2 and 7 underwent a second 3-phase mapping guided ablation procedure. The site of VT origin was localized in the same ventricular segment as during the first procedure in both patients. Both patients remained free of symptoms during 22 and 7 months after the second ablation procedure, respectively. Thus, if we include these 2 second attempts, ablation was successful without additional drug treatment after long-term follow-up in 17 of 19 patients (89%).

Except for a small arteriovenous fistula at the catheter insertion site in 1 patient, no complications occurred during or after the ablation procedure.

Discussion
Integrated Three-Phase Mapping Technique
This prospective study presents an integrated 3-phase mapping technique that is based on the successive use of online body surface mapping, directed regional body surface pace mapping, and subsequent local activation sequence mapping for localization of the site of origin of idiopathic VT before ablation therapy. The long-term success rate of 89% obtained in the present study is comparable to the results of other studies. Although similar success percentages have been demonstrated in the literature, we do believe that the integrated 3-phase mapping technique presented here offers several advantages over standard localization methods.

### TABLE 3. Three-Phase Mapping Results

<table>
<thead>
<tr>
<th>Patient</th>
<th>Localization in Mapping Phase, segments*</th>
<th>EAT, ms</th>
<th>VT Exit-Origin, mm</th>
<th>RF Pulses, n</th>
<th>Early Success</th>
<th>Follow-Up Duration, mo</th>
<th>Long-term Success</th>
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<tr>
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<td>RV5</td>
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<td>NA</td>
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<td>+</td>
</tr>
<tr>
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<td>25</td>
<td>5</td>
<td>7 (7)</td>
<td>31 (22)</td>
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</tr>
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<td>RV4–7</td>
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<td>2</td>
<td>+</td>
<td>23</td>
<td>+</td>
</tr>
<tr>
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<td>8</td>
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<td>23</td>
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<td>+</td>
<td>2</td>
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</table>

EAT indicates earliest endocardial activation time during VT relative to the onset of the QRS complex on the surface ECG; NP, not performed; NA, not available; and (P), earliest Purkinje potential.

*Endocardial segment contained in the database of 38 mean paced QRS integral maps.†These 2 patients needed 2 sessions for successful ablation. The number of RF applications, follow-up duration, and long-term success of the second attempt are shown in parentheses.
Three-phase mapping allowed RF target site identification in patients with noninducible VT, infrequently occurring spontaneous VT, or ventricular ectopic activity who would otherwise not have been considered eligible for catheter ablation. Successful ablation could be performed in this study with relatively low fluoroscopic exposure. The mean fluoroscopy time was 30.6 ± 18 minutes, compared with 46 ± 18 and 40 ± 15 minutes reported by Wen et al. and Zardini et al., respectively. The mean number of RF pulses in this study was 3.3 ± 2.2, which is lower than the mean number of RF applications in most other large studies (varying between 5.5 ± 7.7 and 8.1 ± 11). Mapping Phase 1

By comparing the VT QRS integral maps with the databases, the correct or an adjacent segment of VT origin could be identified in 14 of the 19 patients (74%). Thus, in most patients, body surface QRS integral mapping allowed for rapid initial localization of the region of interest. Especially for the 11 LBBB VTs, the prediction of the segment of VT origin was very accurate. Ten of these 11 VTs (91%) were localized to the segment in which ablation turned out to be successful. Furthermore, the results in patient 7 show that body surface mapping may become a valuable method to preselect patients with an idiopathic LBBB VT in whom the arrhythmia focus has to be ablated from the LV outflow tract. Mapping can then be instantaneously initiated at the basal LV septum so that no time will be lost by RV mapping. Krebs et al. recently described 12-lead ECG criteria for VTs with an LBBB configuration and an inferior axis suggestive of an origin outside the RV outflow tract. These included an early transition zone (first precordial lead with R>5), more rightward QRS axis, and a small R wave in lead V1. The 12-lead ECG of the VT obtained in patient 7 (Figure 7A) did indeed comply with these criteria. However, in 2 other patients (patients 2 and 5), the 12-lead ECG showed the same features (Figure 7B), but they were both successfully ablated at the anteroseptal section of the RV outflow tract.

Mapping Phase 2

An advantage of the 3-phase approach was that pace mapping during phase 2 was confined to a limited area in the RV or LV. Moreover, body surface pace mapping allowed quick and accurate analysis of pace maps because of the spatial format of the ECG data presentation. In contrast, 12-lead ECG pace mapping requires a complex and time-consuming lead-by-lead analysis.
lead scalar ECG waveform comparison. In addition to the visual analysis, quantitative map comparison using correlation coefficients provided instantaneous information on VT and pace map similarities.

Another important advantage of body surface pace mapping is that it could be applied as a dynamic mapping tool. Comparing the paced QRS integral maps with the maps of the database provided spatial information about the direction in which the catheter had to be navigated to obtain a better correlation with the VT QRS integral map (Figure 5). Such a directional mapping approach cannot be performed by 12-lead ECG analysis.

To date, only 1 preliminary study reported on the application of body surface pace mapping to localize the VT site of origin before catheter ablation.21 Paced body surface QRS integral mapping was prospectively performed in 3 patients to assist in identifying the site of VT origin, which was then successfully ablated. An important practical limitation of that study was that the described mapping system required 5 minutes of processing time for each QRS integral map, which makes it less attractive for online clinical purposes. In contrast, our portable body surface mapping system allows for rapid processing and analysis of QRS integral maps within a 30-second time frame.

Mapping Phase 3
Activation mapping could be restricted to a circumscribed area in all patients. This was especially advantageous in patients with noninducible VT who presented with only sporadic spontaneous episodes of ventricular ectopic activity. Activation mapping in a more extensive area would have been very time-consuming or even impossible in this particular group of patients.

Mapping Findings in Relation to the VT Substrate
In 5 patients, the site identified by pace mapping became the ablation target because ventricular ectopic activity could no longer be provoked or was no longer spontaneously present. Four of these 5 patients had an RV tachycardia, and ablation was successful in 3 of them. These findings suggest that the sole application of mapping phases 1 and 2 is often accurate enough to identify the successful ablation site for idiopathic
Figure 5. A, Mapping phase 1: VT QRS integral map of patient 9 is depicted together with best-matching paced QRS integral map from database (Figure 2A). Segment RV5 was identified as segment of origin of this VT. B, Mapping phase 2: best-matching paced QRS integral map was obtained at a site in adjacent segment RV6. C, Mapping phase 3: local activation mapping could be easily performed because patient’s spontaneous rhythm was a bigeminy of sinus complexes and ectopic ventricular complexes identical to documented VT. Earliest ventricular activation during ectopic complex was seen at segment RV6 and preceded QRS complex by 20 ms. D, An RF pulse was delivered at this site. In first 3 seconds after onset of RF energy delivery, a nonsustained VT of 3 complexes and 1 ectopic complex with QRS morphologies identical to ectopic activity during preceding bigeminy rhythm occurred. Thereafter, ectopic ventricular activity or VT was no longer observed. V1 tracing disappears after onset of RF energy because of baseline drifting. RV 1, 2 indicates bipolar electrogram of distal 2 electrodes of RV mapping catheter; RV 1 and RV 2, unipolar electrograms of corresponding tip and second electrode of mapping catheter; and EAT, earliest activation time. Other abbreviations as in Figure 6.
RV tachycardia, whereas additional activation mapping appears to be required for idiopathic LV tachycardia target site localization. This is in agreement with previous studies, in which pace mapping was often the primary mapping technique for RV tachycardia, whereas activation mapping was necessary for localization of LV tachycardia. Wen et al recently demonstrated that successful ablation of idiopathic LV tachycardia can sometimes be achieved at an area that is remarkably distant from the exit site (28 to 40 mm in their patient group). In our study, 10 of the 11 LBBB VTs (91%) were localized to the correct segment of origin during mapping phase 1, and the mean distance between the VT site of origin and the VT exit site was 6 ± 5 mm (range, 0 to 12 mm). In contrast, only 1 of the 8 RBBB VTs (13%) was localized to the correct segment of origin during mapping phase 1, and the mean distance between the origin and exit of these VTs was 13 ± 14 mm (range, 0 to 32 mm). This observation also suggests that the arrhythmogenic substrate of LBBB VTs is confined to a small area, whereas the VT exit site and VT site of origin of RBBB VTs are often located at distant sites. Involvement of the Purkinje network of the left posterior fascicle has been described in patients with idiopathic LV VT. As a result, ventricular activation may be rapidly conducted through the specialized conduction system and therefore exit at a remote site.

Study Limitations
A limitation of this study was that the 3-phase mapping approach was not compared in a randomized study with conventional pace and activation mapping techniques. However, such a study would not have been feasible within a reasonable time frame because of the generally low incidence of idiopathic VT.

Regional body surface pace mapping was performed during phase 2 until a site with a paced QRS integral map that was highly comparable to the VT QRS integral map was identified. We cannot exclude the possibility that better-matching paced QRS integral maps could have been obtained at other sites at which pacing was not performed.

Local activation mapping during phase 3 was carried out in a limited area. It is possible that endocardial sites outside this region with earlier activation times have not been identified. However, the mean earliest activation time of the local ventricular signal or Purkinje potential in this study was 25 ± 6 ms before the onset of the QRS complex on the surface ECG, which is in agreement with the findings reported in other studies.

Conclusions
This study shows that integrated 3-phase mapping for localization of the site of origin of idiopathic VT is safe, has several advantages over standard localization techniques, and offers immediate pinpointing of the region of interest. In 19 patients with idiopathic VT originating from either the RV or LV, a high long-term success rate of 89% was achieved with a minimal number of RF applications.

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References


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**Figure 7.** The 12-lead ECG and body surface QRS integral maps of spontaneous VTs obtained in patients 7 (A) and 5 (B). Note that both ECGs show a rightward QRS axis and a small R wave in V1. Transition zones are between V2 and V3 in A and between V2 and V3 in B. VT QRS integral map patterns of both patients were clearly distinct. VT QRS integral maps of patients 7 and 5 were localized to segment LV10 and segment RV5 of database of mean paced QRS integral maps (Figure 2A and 2B), respectively. VT of patient 7 was successfully ablated at basal LV septum, whereas VT of patient 5 was ablated from anterior septal aspect of RV outflow tract.


Clinical Application of an Integrated 3-Phase Mapping Technique for Localization of the Site of Origin of Idiopathic Ventricular Tachycardia
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