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Analysis During Sinus Rhythm of Critical Sites in Reentry Circuits of Postinfarction Ventricular Tachycardia

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Abstract. ***Background:*** **Critical sites within reentry circuits of postinfarction ventricular tachycardia (VT) were identified during sinus rhythm (SR) and VT to determine whether electrogram characteristics during SR may be helpful in identifying successful ablation sites.**

Methods: **In 33 patients (mean age 67 ± 11 yrs) with prior infarction, mapping and radiofrequency (RF) catheter ablation of 57 hemodynamically-tolerated VT's (cycle length 478 ± 96) were performed. The morphologies of electrograms (EGM) at sites of concealed entrainment (CE) were compared during SR and VT. RF energy was delivered at 94 sites (51 successful and 43 unsuccessful ablation sites).**

Results: **During SR, isolated potentials (IP), but not late potentials (LP) recorded via the mapping catheter, were associated with successful ablation. At 29/39 sites with an IP during sinus rhythm, an isolated diastolic potential (IDP) also was present during VT, whereas at 4 sites IP's were present only during SR ($p < 0.001$). At 11/29 sites where isolated potentials were present during SR and VT, the morphology of the isolated potential during VT and SR was similar; and all but one of these sites were successful ablation sites ($p = 0.01$). The EGM amplitude during VT correlated with the amplitude during SR ($R = 0.9$, $p < 0.001$). An identical pacemap was present during SR at 33/94 sites; this was not associated with successful ablation.**

Conclusion: **SR mapping may be helpful in identifying critical sites of reentry in postinfarction VT. At sites within the reentry circuit, characteristics of sinus rhythm EGM's that are associated with successful ablation include the presence of IP's, but not the presence of LP's.**

Key Words. **radiofrequency ablation, ventricular tachycardia, mapping**

Late potentials, fractionated electrograms and double potentials have been recorded during sinus rhythm in patients with prior myocardial infarction [1,2], and may represent activation of areas of slow conduction [3]. However, no prior studies have focused on the morphologic characteristics of sinus rhythm electrograms in areas of slow conduction that are critical for maintenance of ventricular tachycardia. The purpose of this study was to systematically analyze electrograms recorded during sinus rhythm and ventricular tachycardia, to determine whether there are electrogram characteristics during sinus rhythm that help to differentiate effective from ineffective ablation sites.

Methods

Characteristics of Patients

Radiofrequency catheter ablation of ventricular tachycardia was performed in 33 patients (29 men, 4 women) with a mean age of 67 ± 11 years. All had a history of prior myocardial infarction (anterior in 9, inferior in 13, and both inferior and anterior in 11). Their mean left ventricular ejection fraction was 0.27 ± 0.10. At the time of the electrophysiologic study, the underlying rhythm was sinus rhythm in 25 patients, atrial fibrillation in 1 patient, and sustained ventricular tachycardia in 7 patients. Two patients had an implanted dual chamber pacemaker and both of them were 100% paced. The mean QRS width during sinus rhythm was 150 ± 33 msec. Twenty patients had a left bundle branch block, 3 had a right bundle branch block, and the remaining 10 patients had a normal QRS duration.

The indication for radiofrequency catheter ablation was incessant ventricular tachycardia in 7 patients, frequent ICD discharges in 15 patients, and palpitations in 11 patients. Twenty-one of 33 patients were being treated with amiodarone

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at the time of the procedure. Twenty-two of the 33 patients also were included in a prior study [4].

Characteristics of Ventricular Tachycardia

Fifty-seven hemodynamically-tolerated ventricular tachycardias that had a mean cycle length of 478 ± 96 msec were targeted for radiofrequency catheter ablation. Twenty-three had a left bundle brunch block morphology and 34 had a right bundle branch block morphology. Ninety-four sites were analyzed during the baseline rhythm, which was sinus rhythm in 87 patients and atrial fibrillation in 5 patients, and also during ventricular tachycardia.

Electrophysiologic Testing

After informed consent was obtained, a quadripolar 7 French mapping catheter with 2-5-2 mm interelectrode spacing (EP Technologies Mountain View, CA or Mansfield,Watertown, MA) was positioned in the left ventricle using a retrograde aortic approach. A bolus of 5000 units of heparin was given at the beginning of the study, followed by 1000 units of heparin every hour. A quadripolar catheter in the right ventricle was used for programmed stimulation with four extrastimuli [5].

The electrocardiographic leads and intracardiac electrograms were displayed on an oscilloscope and recorded on a Mingograph 7 recorder (Siemens) at a paper speed of 100 mm/s. The left ventricular electrograms were recorded from electrodes 1/2, 2/4, 1/3 and 3/4 at gain settings of 20 and 80 mm/mV and at filter settings of 50 to 500 Hz and also were stored on optical disk (Quinton, Bothell, WA, or Bard 2.72).

Pacing during ventricular tachycardia was performed at endocardial sites that had any 1 of the following characterisitcs: an endocardial activation time of at least -70 msec relative to the onset of the QRS complex; an isolated potential; an electrogram amplitude ≤ 0.5 mV and duration >133 msec [6].

Bipolar pacing was performed with electrodes 1 and 3 of the mapping cather, and electrodes 1/2, 2/4, 1/3 and 3/4 were used for bipolar recordings.

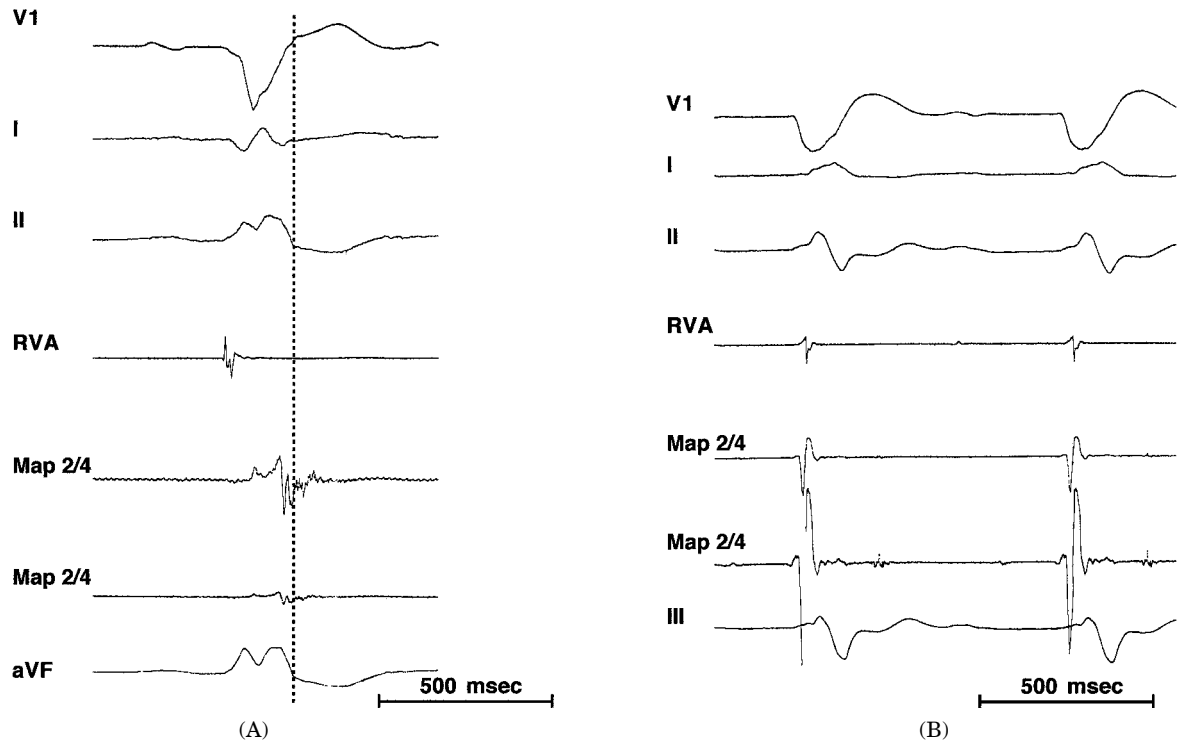

Fig. 1. *Examples of a late potential and isolated potential. (A) Recordings from a left ventricular mapping site during sinus rhythm. Shown are leads V1, I, II, and aVF, and intracardiac recordings from the right ventricular apex (RVA) and from the mapping catheter (Map 2/4) at gain settings of 80 and 20 mm/mV. The electrogram of the mapping catheter shows a late potential that extends beyond the end of the QRS complex by 90 msec. (B) Recordings from a left ventricular mapping site during sinus rhythm. Shown are leads V1, I, II, III, and intracardiac recordings from the right ventricular apex (RVA) and from the mapping catheter (Map 2/4) at gain settings of 40 and 80 mm/mV. The recording from the mapping catheter show for an isolated potential which is separated from the ventricular electrogram by an isoelectric line that has a duration of 80 msec.*

Pacing was performed at twice the diastolic threshold with a pulse width of 2 msec. If no capture was obtained, the output was increased to 10 mA and the pulse duration was increased to 9 msec as necessary to obtain capture.

Study Protocol and Data Analysis

Mapping was performed during ventricular tachycardia. The data were prospectively collected and analyzed in a post-hoc fashion. At sites displaying concealed entrainment [7,8], the local electrograms also were recorded during baseline rhythm. This objective was achieved at 94/133 sites with concealed entrainment. At the remaining sites, which were not included in the analysis, there was either incessant ventricular tachycardia (8 sites), or the ventricular tachycardia was resistant to antitachycardia pacing (31 sites).

Pacing was performed during baseline rhythm at the cycle length of the ventricular tachycardia and the QRS morphology was compared to that of the ventricular tachycardia. At 21/94 sites, pacing during baseline rhythm was not feasible because of catheter displacement (3 sites) or incessant ventricular tachycardia (18 sites). Only sites that were recorded during baseline rhythm and at which there was concealed entrainment during ventricular tachycardia were analyzed.

The width and amplitude of the local electrograms during baseline rhythm and during ventricular tachycardia were measured. The degree of fractionation was expressed as a fractionation index: [number of peaks/width of local electrogram] $\times 100$. The local electrogram was categorized according to whether it was or was not separated from the main portion of the electrogram by an isoelectric line (Fig. 1). The former was defined as an isolated potential and the latter was defined as a late potential. The morphology of these potentials was analyzed by 2 independent observers and compared to the morphology of diastolic potentials recorded during ventricular tachycardia (Figs. 2 and 3).

Noncontact Mapping

In 3 patients, a noncontact mapping catheter (Endocardial Solutions) was used during 5 hemodynamically-tolerated ventricular tachycardias. The activation sequence was assessed during baseline rhythm and VT, as described in prior reports [9,10]. Dynamic isopotential maps during baseline rhythm and during VT were compared at sites with concealed entrainment (Fig. 4).

Radiofrequency Ablation

Radiofrequency energy was applied only at sites of concealed entrainment. The target temperature

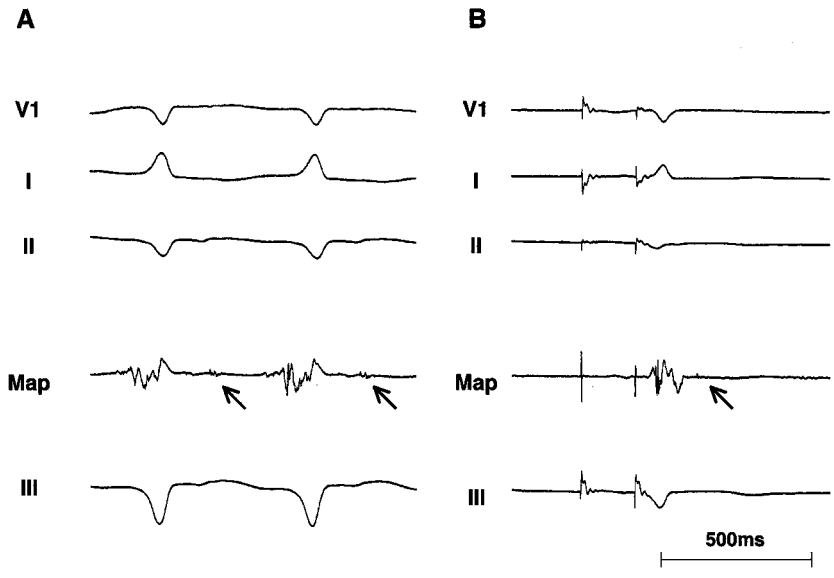

Fig. 2. *Example of an isolated diastolic potential recorded during ventricular tachycardia and an isolated potential during AV sequentially paced rhythm. (A) An ablation site recorded in the left ventricle during ventricular tachycardia. Shown are leads V1, I, II and III, electrograms recorded with the ablation catheter (Map) at a gain setting of 40 mm/mV. An isolated diastolic potential that could be dissociated from the ventricular tachycardia is present (arrows). Radiofrequency energy delivery at this site was ineffective. (B) Recordings during paced rhythm at the same site as in Figure 2A, before delivery of radiofrequency energy. The patient has a dual chamber pacemaker and is AV sequentially paced. Note that isolated potentials are also present during sinus rhythm (arrow). The morphology of the isolated potential during sinus rhythm differs from its morphology during ventricular tachycardia.*

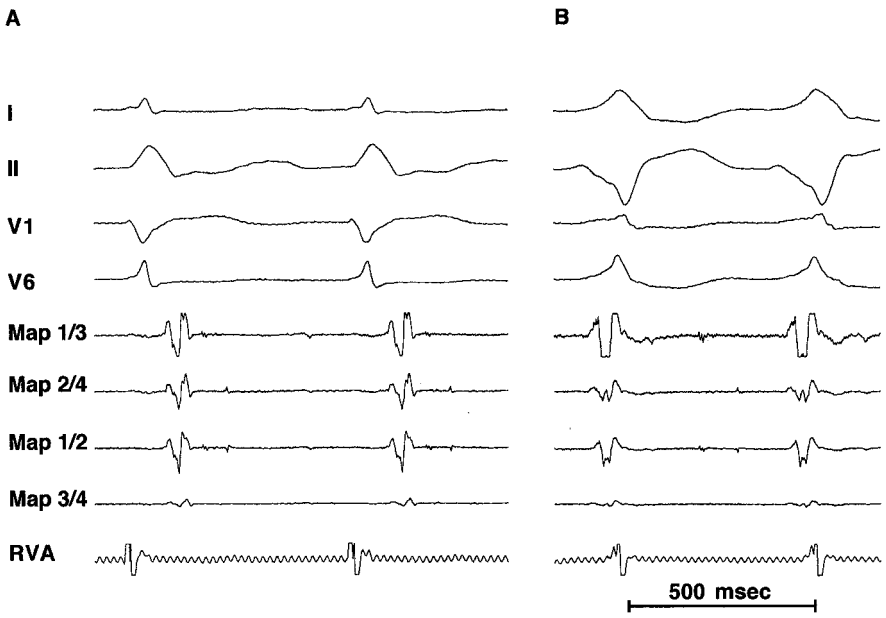

Fig. 3. *Another example of an isolated diastolic potential during ventricular tachycardia and an isolated potential during sinus rhythm. (A) A recording from the anterobasal left ventricle during sinus rhythm. Multicomponent isolated diastolic potentials are present during sinus rhythm. (B) A recording during ventricular tachycardia at the same site as in Figure 3A. The isolated potentials that were present during sinus rhythm are also present during ventricular tachycardia and show the same multicomponent morphology. Radiofrequency energy delivery at this site was effective in ablating the ventricular tachycardia.*

was 60°C. Once this temperature was reached, the radiofrequency energy was applied for at least 20 seconds. If the ventricular tachycardia terminated during the application, energy delivery was continued for 60 seconds. Radiofrequency energy was delivered at 94 sites. There were 51 successful and 43 ineffective sites.

Statistical Analysis

Continuous variables are expressed as the mean ± 1 standard deviation. Variables were compared using Student's t test, the Fisher exact test, or chi-square analysis, as apropriate. A p value <0.05 was considered significant.

Results

Electrograms During Baseline Rhythm and Ventricular Tachycardia

The characteristics of local electrograms recorded during baseline rhythm and during ventricular tachycardia are described in Table 1. There was

Fig. 4. *Noncontact mapping during ventricular tachycardia and sinus rhythm obtained at a site with isolated diastolic potentials during ventricular tachycardia and an isolated potential during sinus rhythm. (A) Shown on the left panel is a left ventricular reconstruction with an isopotential map during ventricular tachycardia generated by a noncontact mapping system; towards the top is the anterior basal left ventricle, towards the bottom is the apex, the septum is on the left and the right ventricular free wall is towards the right of the reconstruction. On the right panel are leads I, II, and V1, and bipolar electrograms recorded by the mapping catheter (Abl 1-2) at gain settings of 75 mm/mV from electrodes 1/2. The vertical line in the tracing coincides with the isolated diastolic potential recorded by the mapping catheter at the anterobasal wall and represents the point in time depicted by the isopotential map. Subsequent activation proceeded towards the apex and then towards the mid anterior left ventricular free wall where the exit site of the reentry circuit was located, corresponding with the onset of the surface QRS complex. The time interval between the diastolic potential and the onset of the next QRS complex is 230 msec. (B) An instantaneous isopotential map during the same ventricular tachycardia as in Figure 4A, corresponding in time to the onset of the surface QRS complex (vertical line). The format is the same as in Figure 4A. The endocardial activation proceeds from the site at which the isolated diastolic potential was recorded to exit at the mid anterior free wall. (C) An instantaneous isopotential map during sinus rhythm, in the same patient. The vertical line on the right coincides with an isolated potential in electrodes 1/2 of the mapping catheter. The isolated potential occurs 25 msec after the ventricular electrogram. The isopotential map demonstrates endocardial activation spreading from what was the exit site of the reentry circuit during ventricular tachycardia towards the site at which the isolated potential is recorded during both ventricular tachycardia and sinus rhythm. The time interval between the end of the QRS complex and the diastolic potential is 55 msec. Radiofrequency energy delivery at this site was effective in ablating the ventricular tachycardia.*

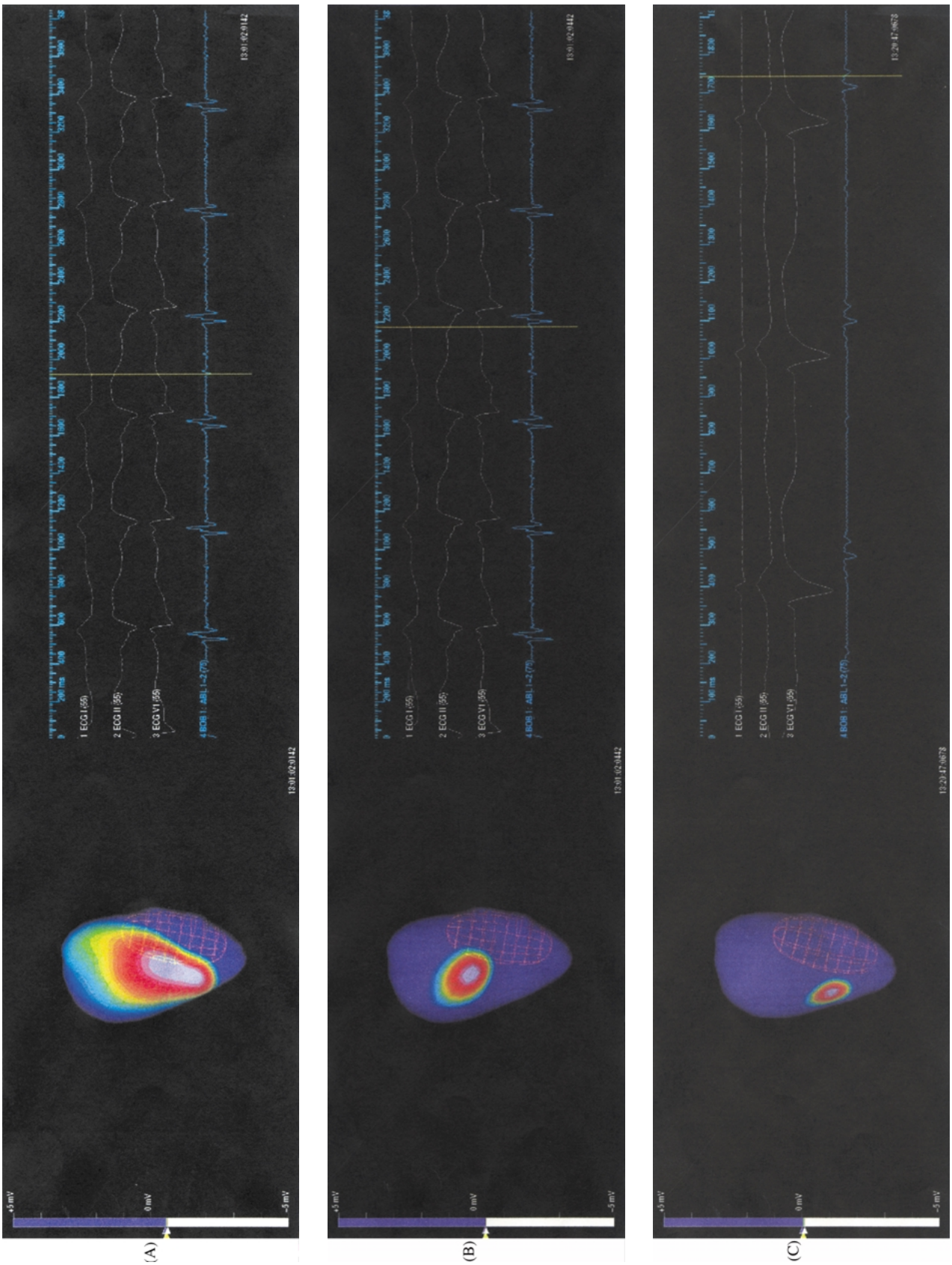
(A)
(B)
(C)

Table 1. Correlation between electrogram characteristics during the baseline rhythm (sinus rhythm or atrial fibrillation) and ventricular tachycardia

	VT	Baseline rhythm	*R* value	*P* value
Amplitude (mV)	0.36 ± 0.52	0.36 ± 0.51	0.9	<0.001
Width (msec)	289 ± 88	261 ± 103	0.5	<0.001
Peaks (n)	17 ± 7	14 ± 6	0.8	<0.001
Fractionation index	6.0 ± 2.3	5.9 ± 2.9	0.7	<0.001
S-QRS	220 ± 134	111 ± 49	0.1	0.6

Abbreviations: VT = ventricular tachycardia; S-QRS = stimulus-QRS interval.

a significant correlation between the amplitudes of the electrograms recorded during the baseline rhythm and ventricular tachycardia ($R = 0.9$, $p < 0.001$) at the same sites. Also, the width of the electrograms during the baseline rhythm correlated significantly with the widths of the electrograms during ventricular tachycardia ($R = 0.47$, $p < 0.001$). There was no correlation between the number of peaks in the electrograms during the baseline rhythm and during ventricular tachycardia ($R = 0.11$, $p = 0.3$).

Pace Mapping

Pace mapping was performed at 73 of the 94 sites. At 34/73 sites (47%), pacing during the baseline rhythm resulted in a QRS morphology identical to that of the targeted ventricular tachycardia. At the remaining sites, the QRS morphology during pacing differed from the QRS morphology during ventricular tachycardia.

Late Potentials and Isolated Potentials

Thirty-five of 94 sites displayed an isolated potential during the baseline rhythm (Table 2). An isoelectric segment of 182 ± 110 msec separated the isolated potential from the main portion of the ventricular electrogram. The isolated potentials consisted of single potentials with 1.3 ± 0.6 spikes at 8 sites and was composed of fractionated electrograms with multiple spikes at 27 sites. The electrogram was wider and had more peaks at sites with isolated potentials than at other sites. There were no differences in amplitude, stimulus-QRS interval or fractionation index between sites with isolated potentials and other sites. At all but 6 sites at which an isolated potential was present during the baseline rhythm, an isolated diastolic potential also was present during ventricular tachycardia. This association was significant ($p < 0.001$). The positive and negative predictive values of an isolated potential during baseline rhythm for an isolated diastolic potential during VT at sites of concealed entrainment were 87% and 73%, respectively. At 11/35 sites at which there was an isolated potential, the morphology of the isolated potential was similar to that of the diastolic potential recorded during ventricular tachycardia.

Table 2. Comparison of sites at which isolated potentials were present and absent during baseline rhythm

	IP present	IP absent	*P* value
No. of sites	35	59	
Successful sites	30/35 (86%)	14/59 (24%)	<0.001
IPs during VT	29/35 (83%)	10/59 (17%)	<0.001
EGM duration (msec)	332 ± 112	213 ± 61	<0.001
EGM amplitude (mV)	0.32 ± 0.25	0.39 ± 0.6	0.6
S-QRS	118 ± 58	100 ± 35	0.1
No. of peaks	16 ± 6	13 ± 5	<0.05
Fractionation index	5.7 ± 3.1	6.1 ± 2.8	0.5

Abbreviations: EGM = electrogram; IP = isolated potential; other abbreviations as in Table 1.

Twenty-five sites at which there was an isolated potential also displayed a late potential. Late potentials were present during baseline rhythm at 57 sites. At 27/57 sites at which there was a late potential, an isolated diastolic potential also was present during ventricular tachycardia. This association was not significant ($p = 0.3$). Late potentials extended 48 ± 30 msec beyond the end of the QRS complex. Isolated potentials during baseline rhythm occurred 200 ± 131 msec after the end of the QRS complex. Neither underlying bundle branch block nor the presence of either inferior or anterior myocardial infarction correlated with the presence of isolated potentials during the baseline rhythm.

Successful Catheter Ablation

Effective and ineffective ablation sites are compared in Table 3. Effective sites had a significantly higher incidence of isolated potentials during baseline rhythm compared to ineffective sites. Comparing the morphology of the isolated potentials during baseline rhythm to the morphology of isolated diastolic potentials during ventricular tachycardia, the morphology was similar in 11 instances; all but 1 of these sites were effective ablation sites ($p = 0.01$). Effective sites manifested wider electrograms during baseline rhythm and during ventricular tachycardia and displayed more peaks in the electrogram during both baseline rhythm and ventricular tachycardia compared to ineffective sites. Late potentials had a similar incidence at effective compared to ineffective sites. There were no significant differences in the electrogram amplitudes during baseline rhythm and ventricular tachycardia, or in the fractionation index during baseline rhythm and ventricular tachycardia, between

Table 3. *Comparison of successful and unsuccessful ablation sites*

	Successful sites	Unsuccessful sites	*P* value
No. of sites	51	43	
IP present in SR	30/51	5/43	<0.001
LP	31/51	26/43	0.9
Identical pace map	22/51	12/43	0.3
Similar IP in BR and VT	10/51	1/43	0.01
EGM duration (SR)	292 ± 110	230 ± 85	<0.01
EGM duration (VT)	314 ± 100	264 ± 67	<0.01
EGM amplitude (SR)	0.33 ± 0.23	0.39 ± 0.65	0.6
EGM amplitude (VT)	0.38 ± 0.39	0.34 ± 0.6	0.7
No. of EGM peaks (SR)	16 ± 6	12 ± 5	<0.01
No. of EGM peaks (VT)	19 ± 7	15 ± 7	<0.01
FI (SR)	6.3 ± 3.5	5.5 ± 2.2	0.2
FI (VT)	6.4 ± 2.7	5.6 ± 1.8	0.1

Abbreviations: FI = fractionation index; LP = late potential; BR = baseline rhythm; other abbreviations as in Tables 1 and 2.

effective and ineffective ablation sites. An identical pacemap was present equally often at effective and ineffective sites.

Noncontact Mapping

The endocardial activation was analyzed with the noncontact mapping system during 5 ventricular tachycardias. At five sites at which concealed entrainment was documented with the ablation catheter, the endocardial activation sequence was assessed with the noncontact mapping system during VT and during baseline rhythm. Four of the 5 sites displayed an isolated diastolic potential during ventricular tachycardia and an isolated potential during the baseline rhythm. An isolated potential and late potentials both were present during baseline rhythm at 3 of the 5 sites. At sites with an isolated potential during baseline rhythm, the isolated potential occurred 123 ± 6 msec after the QRS complex. Dynamic isopotential maps demonstrated activation proceeding from the catheter site towards the exit site of the ventricular tachycardia circuit during ventricular tachycardia (Fig. 4A and B).

The dynamic isopotential maps during baseline rhythm demonstrated that the activation proceeded from the exit site of the ventricular tachycardia reentry circuit towards the site where the catheter was located, thereby taking a reversed course compared to the ventricular tachycardia (Fig. 4C).

At sites where there was an isolated potential during both baseline rhythm and ventricular tachycardia, dynamic isopotential maps showed activation occurring at the same site during ventricular tachycardia and baseline rhythm (Fig. 4A and C).

Discussion

Main Findings

The results of this study demonstrate that the characteristics of bipolar electrograms recorded during sinus rhythm and ventricular tachycardia are similar at catheter locations that are within the reentry circuit of postinfarction ventricular tachycardia. At sites that are effective target sites for ablation of ventricular tachycardia, the presence of an isolated diastolic potential during ventricular tachycardia indicates a high likelihood that an isolated potential also will be present at the same site during sinus rhythm. With dynamic isopotential maps generated by a noncontact mapping system, the sites at which isolated potentials are recorded during sinus rhythm can be demonstrated to be bounded by anatomic boundaries. These findings suggest that certain characteristics of sinus rhythm electrograms may be helpful in identifying critical components of postinfarction ventricular tachycardia reentry circuits.

Isolated Potentials and Late Potentials During Sinus Rhythm

In a prior report, isolated diastolic potentials that could not be dissociated from ventricular tachycardia and that were recorded at sites of concealed entrainment were found to be generated in areas bounded by fixed anatomic boundaries [11]. This was confirmed in the present study with noncontact mapping, which demonstrated delayed activation during sinus rhythm at the same site at which an isolated diastolic potential was present during ventricular tachycardia. During ventricular tachycardia, activation was found to occur from the site of the isolated diastolic potential towards the exit site of the ventricular tachycardia circuit. However, during sinus rhythm, activation occurred in the opposite direction, from the exit site towards the site at which the isolated potential was recorded. Additional experience with noncontact mapping will be necessary to determine how often a critical isthmus in the ventricular tachycardia reentry circuit can be identified during sinus rhythm.

Although both late potentials and isolated potentials are generated in areas of slow conduction, late potentials recorded during sinus rhythm were not as helpful as isolated potentials in indicating a successful target site for ablation of ventricular tachycardia. The reason that isolated potentials recorded during sinus rhythm are more closely associated with successful ablation sites than are late potentials remains to be determined.

Comparison of Electrograms During Ventricular Tachycardia and Sinus Rhythm

Voltage mapping during sinus rhythm has been used to identify target sites for radiofrequency ablation of post-infarction ventricular tachycardia that are adjacent to an infarct scar [12]. In the present study, a strong correlation was found between the amplitude, duration, and degree of fractionation of local electrograms recorded during sinus rhythm and during ventricular tachycardia at sites at which there was concealed entrainment. Therefore, endocardial sites at which abnormal electrograms are recorded during sinus rhythm may serve as a useful marker of diseased tissue that may be related to a reentry circuit. However, these characteristics of endocardial bipolar electrograms are not as useful as the presence of an isolated potential during sinus rhythm for identifying successful ablation sites within the ventricular tachycardia reentry circuit.

Pace Mapping

The presence of an identical pace map identifies the exit site of a reentry circuit [13]. In patients with idiopathic right ventricular tachycardia, pace mapping has been a useful guide for identifying successful ablation sites [14]. However, in the present study, an identical pace map was not associated with effective ablation sites. This may be attributable to a broader, more funnel-shaped exit area in post-infarction ventricular tachycardia than in idiopathic ventricular tachycardia. Consistent with this possibility, a prior study demonstrated that cooled-tip radiofrequency ablation catheters that produce a larger lesion are more effective at exit sites compared to conventional radiofrequency ablation lesions [15]. Therefore, single, conventional radiofrequency lesions may be unlikely to eliminate ventricular tachycardia if pace mapping is used as the only mapping criterion.

Prior Studies

Harada et al. emphasized the importance of late potentials recorded during sinus rhythm when mapping post-infarction ventricular tachycardia [3]. This apparent discrepancy with the results of the present study may be explained by the analysis of different sites in the 2 studies. Whereas only sites at which there was concealed entrainment were analyzed in the present study, approximately one-third of sites analyzed in the prior study did not display concealed entrainment.

Limitations

The results of this study are applicable only to hemodynamically-tolerated ventricular tachycardias, and only to sites at which there is concealed entrainment. Because left ventricular mapping was not performed at all sites manifesting abnormal electrograms during sinus rhythm, no conclusions about positive and negative predictive values of abnormal electrograms at sites without concealed entrainment are possible. Additional prospective studies will be necessary to validate the value of sinus rhythm electrograms as a guide for identification of critical sites within the reentry circuit of post-infarction ventricular tachycardia.

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