# Accuracy of the Unipolar Electrogram for Identification of the Site of Origin of Ventricular Activation

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**Unipolar Electrogram.** ***Introduction:*** **The purpose of this study was to determine the accuracy of the unipolar electrogram for identifying the earliest site of ventricular activation. The earliest site of ventricular activation may be identified with the unipolar electrogram by the absence of an R wave. However, the accuracy of this technique is unknown.**

***Methods and Results:*** **A single ventricular premature complex was induced mechanically at the tip of an electrode catheter to simulate a ventricular premature depolarization site of origin. Unipolar electrograms were recorded from the right ventricular septum at the tip electrode and at 2, 5, 8, and 11 mm from the electrode tip in 20 patients. No R waves were detected at the ventricular premature depolarization site of origin. R waves were detected in 4 of 20 patients (20%) at 2 mm from the tip electrode and 7 of 20 patients (35%) at 5, 8, and 11 mm from the tip electrode. An R wave was not observed at distances ≤ 11 mm from the site of tachycardia origin in 13 of 20 patients (65%).**

***Conclusions:*** **While an R wave in the unipolar electrogram can be seen as close as 2 mm from the site of impulse origin, the absence of an R wave as an indicator of the site of impulse origin in the right ventricle is highly inaccurate. Therefore, the absence of an R wave in the unipolar electrogram is unlikely to be an adequate guide for identification of an effective target site for ablation of right ventricular tachycardia.** *(J Cardiovasc Electrophysiol, Vol. 8, pp. 974-979, September 1997)*

*catheter ablation, unipolar electrogram, activation mapping, spatial resolution, ventricular tachycardia*

## Introduction

Unipolar electrograms have been used as a guide for catheter ablation of accessory pathways and atrial tachycardias.[1-7] The earliest site of atrial or ventricular activation may be identified by a unipolar electrogram that lacks an initial positive deflection, or "R wave," indicating that the vector of depolarization is entirely away from the recording electrode.[8-10] This technique might be useful as a guide for ablation of idiopathic right ventricular tachycardia, which often is caused by triggered activity or abnormal automaticity, and in which activation mapping generally has been less helpful than pace mapping for identification of the site of origin.[11,12] However, no studies to date have determined the precision with which the unipolar electrogram identifies the earliest site of ventricular activation. Therefore, the aim of this study was to determine the accuracy of the unipolar ventricular electrogram in identifying the site of origin of a ventricular depolarization.

## Methods

### *Study Population*

The study consisted of 20 patients who underwent a clinically indicated electrophysiologic procedure. There were 9 men and 11 women (mean age 46 ± 19 years [± SD]). Three patients had coronary artery disease, 2 patients had valvular

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heart disease, and the other 15 had no structural heart disease.

### *Study Protocol*

Electrophysiologic tests were performed after discontinuation of all antiarrhythmic agents for at least five half-lives. The study protocol was performed after completion of the clinically indicated portion of the electrophysiologic procedure. Using a femoral vein approach, a unipolar pentaelectrode catheter (Cordis-Webster, Baldwin Park, CA, USA) was positioned at the septum of the right ventricle, with the electrodes lying against the septum. The interelectrode spacing of the pentaelectrode catheter was 2 mm, with an electrode width of 1 mm. The indifferent electrode, located in the inferior vena cava, was 25 cm from the tip electrode. Adequate tissue contact of each electrode was confirmed by a unipolar stimulation threshold $< 1.0$ mA at a pulse width of 2.0 msec at the proximal and distal poles of the catheter. The mean unipolar pacing thresholds did not differ significantly between the proximal and distal poles ($0.47 \pm 0.10$ and $0.42 \pm 0.11$ mA, respectively; $P = 0.25$).

In a pilot study, pacing stimuli were used to induce ventricular premature depolarizations.[13] However, because of the stimulus artifact, an accurate analysis of the unipolar electrogram was not possible. Therefore, to avoid distortion of the initial portion of the unipolar electrogram by a stimulus artifact, mechanically induced ventricular premature depolarizations were used in the present study. After confirmation of adequate myocardial tissue contact, a single ventricular depolarization was mechanically induced under fluoroscopic visualization by gently pressing the distal electrode tip against the right ventricular septum. The ventricular premature depolarizations were excluded from analysis if: (1) there was any visual evidence of catheter displacement associated with the impulse formation; or (2) the ventricular depolarizations did not demonstrate a progressive increase in the ventricular electrogram onset as the recording electrode distance from the tip electrode increased (Fig. 1). Relative to the distal electrode, the recording sites were at distances of 0, 2, 5, 8, and 11 mm. The unipolar electrograms were recorded at a paper speed of 100 mm/sec and at a gain setting of 5 mm/mV using a Mingograph-7 recorder (Siemens-Elema, Solna, Sweden). The filter settings for the unipolar electrogram were between 0.5 and 500 Hz.

### *Analysis of Unipolar Electrograms*

In each patient, unipolar electrograms of a single ventricular premature depolarization were recorded at each electrode and examined visually for the presence or absence of an R wave. If an R wave was present, its amplitude was measured from the baseline to the peak of the R wave, to the nearest mV (0.5 mm).

### *Intraobserver Variability*

All intracardiac electrograms were analyzed independently by two of the authors and assessed for intraobserver variability. A total of 100 intracardiac electrograms (5 unipolar electrograms per ventricular premature depolarization $\times$ 20 patients) were analyzed. There was agreement on the presence or absence of an R wave in 100% of the electrograms, and 85% agreement in the measurement of the R wave amplitude to the nearest millivolt. Differences were resolved by consensus.

### *Data Analysis*

Data are expressed as mean $\pm$ SD. Amplitude comparisons were performed by ANOVA with repeated measures. Pacing threshold comparisons were analyzed by unpaired *t*-test. $P < 0.05$ was considered significant.

## Results

### *Presence of an R Wave in the Unipolar Electrogram (Table 1, Fig. 2)*

The number of patients that demonstrated the presence of R waves increased as the distance from the tip electrode increased from 2 to 5 mm and remained constant from 5 to 11 mm. No R waves were detected at the ventricular premature depolarization site of origin. R waves were detected in 4 of 20 patients (20%) at 2 mm from the tip electrode and 7 of 20 patients (35%) at 5, 8, and 11 mm from the tip electrode.

In two patients in whom R waves were detected at 2 mm (patients 14 and 18), a loss of R waves were noted at 8 and 11 mm from the tip electrode.

An R wave was not observed at distances $\leq$ 11 mm from the site of tachycardia origin in 13 of 20 patients (65%).

### *R Wave Amplitudes (Table 1)*

The mean R wave amplitudes were $0.20 \pm 0.00$, $0.36 \pm 0.22$, $0.53 \pm 0.32$, and $0.40 \pm 0.29$ mV at

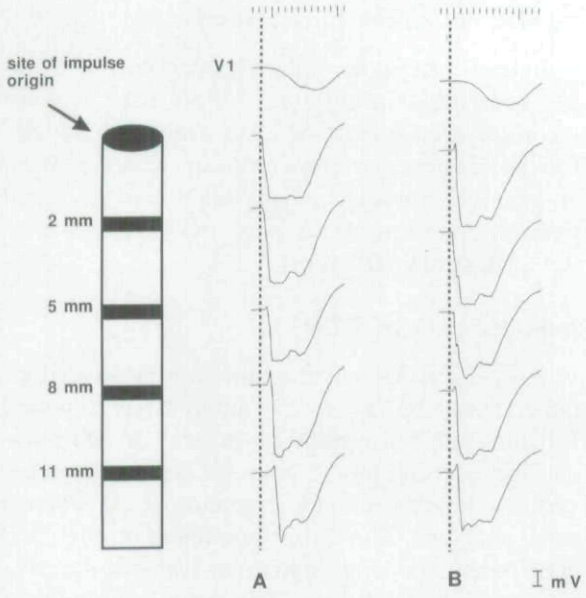


**Figure 1.** *Unipolar electrograms recorded during mechanically induced ventricular depolarizations. (A) Progressive delay in the onset of the electrogram as the distance from the tip electrode increases, consistent with the site of impulse origin at the tip electrode. (B) Earliest electrograms at 2 and 5 mm from the tip electrode (electrodes 2 and 3) indicating that the site of impulse formation was not at the tip electrode. These types of ventricular depolarizations were excluded from analysis.*

2, 5, 8, and 11 mm from the ventricular premature depolarization site of origin distances, respectively. The R wave amplitudes were significantly smaller at 2 mm when compared to 8 mm from the impulse origin ($P < 0.05$). The R wave amplitudes were not significantly smaller at 8 and 11 mm from the distal electrode ($P = 0.22$).

## Discussion

### *Main Findings*

In theory, the absence of an initial positive deflection in the unipolar electrogram indicates that the recording site is at or very close to the site of origin of a depolarization. However, the results of this study demonstrate that, in practice, this may not always be the case. Although an R wave in the unipolar electrogram at times may be seen as close as 2 mm from the site of impulse origin, R waves are absent more often than not at distances up to 11 mm from the site of impulse formation. Therefore, the absence of an R wave in the unipolar electrogram is not likely to be an accurate indicator of the site of origin of ventricular tachycardia, at least in the right ventricle.

### *Prior Studies*

Spach et al.[10] demonstrated, in a canine in vitro preparation, that a QS morphology was observed only within 100 to 200 $\mu$m from the site of origin of a depolarization along the longitudinal axis of fibers. In the present study, the relatively poor resolution of the unipolar electrogram in identifying the site of impulse origin may be attributable to a lesser degree of precision of unipolar electrograms as recorded conventionally in the clinical electrophysiology laboratory. It is possible that inadequate amplification and the use of a low-frequency 0.5-Hz filter may have contributed to the poor resolution of the unipolar electrogram in this study. In addition, in the study by Spach et al.,[10] the unipolar electrograms were recorded along the longitudinal axis of impulse conduction. It is possible that the poor resolution of the unipolar electrogram in the present study was at times attributable to an orientation of the electrode catheter along the transverse axis of impulse spread.

Prior studies have demonstrated the usefulness of the unipolar electrogram as a guide for catheter ablation of accessory pathways. A unipolar ventricular electrogram that has a QS configuration has been a reliable indicator of a successful target site for ablation of the ventricular insertion of the accessory pathway, whereas an rS configuration has predicted an unsuccessful outcome.[1,4] The apparent disparity between the clinical utility of the unipolar ventricular electrogram as a guide for accessory pathway ablation and the lack of precision of the unipolar ventricular electrogram in identifying the site of origin of a ventricular depolarization in the present study may be explained by differences in anisotropic conduction at the mitral or tricuspid annulus compared to within the ventricle. Additionally, in these studies, the unipolar electrograms were recorded only at ablation sites that were identified using other mapping criteria. The possibility that the QS configuration may occur at sites other than ablation sites was not evaluated.

Another prior study demonstrated that a QS configuration or an initial R wave of $\leq 0.1$ mV was predictive of a high success rate during radiofrequency ablation of accessory pathways.[6] In contrast, in the present study, when an R wave was present in the unipolar electrogram recorded 2 mm from the site of impulse origin, its mean amplitude was $> 0.1$ mV. This disparity also may be attributable to differences in conduction at the annulus compared to the ventricle.

A QS pattern in the unipolar electrogram also has been reported to be useful in the identification

**TABLE 1**
Amplitude of R Waves in the Unipolar Electrogram

| Pt. No. | Distance from Site of Origin of Ventricular Depolarization (mm) | | | | |
|---|---|---|---|---|---|
| | 0 | 2 | 5 | 8 | 11 |
| 1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 2 | 0.0 | 0.2 | 0.4 | 0.7 | 0.9 |
| 3 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 4 | 0.0 | 0.0 | 0.7 | 0.8 | 0.7 |
| 5 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 6 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 7 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 8 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 9 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 10 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 11 | 0.0 | 0.0 | 0.0 | 0.2 | 0.2 |
| 12 | 0.0 | 0.0 | 0.6 | 0.5 | 0.2 |
| 13 | 0.0 | 0.2 | 0.2 | 0.2 | 0.1 |
| 14 | 0.0 | 0.2 | 0.1 | 0.0 | 0.0 |
| 15 | 0.0 | 0.0 | 0.0 | 0.0 | 0.2 |
| 16 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 17 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 18 | 0.0 | 0.2 | 0.3 | 0.3 | 0.0 |
| 19 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 20 | 0.0 | 0.0 | 0.2 | 1.0 | 0.4 |

Values are expressed in millivolts.

of target sites for ablation of atrial tachycardias.[2,3] However, in these studies, pace mapping and activation mapping also were used, and the utility of the unipolar electrogram as a guide for ablation was not evaluated separately.

### *dV/dt of Ventricular Depolarizations*

A recent study demonstrated that while an R wave may be absent at some distance from the earliest site of activation, analysis of the initial dV/dt of the unipolar ventricular electrogram may enhance the specificity of this mapping parameter.[7] The slope, dV/dt, can be used quantitatively to assess the distance from ventricular activation.[7,14,15] However, the application of dV/dt may not be clinically useful for determining ventricular activation in the ventricle in patients with structural disease. For example, the patient shown in Figure 1A demonstrates a slope (dV/dt) that is suggestive of a ventricular activation site that is far away from the recording electrode, even though the recording sites were at the origin of impulse formation and 2, 5, 8, and 11 mm away. This apparent discrepancy may reflect localized areas of conduction delay or block secondary to the presence of structural disease.

### *Unipolar R Wave Regression*

In two patients, there was a loss of R wave at 8 and 11 mm from the impulse origin. The trend toward smaller R waves and the disappearance of R waves as the distance from the impulse origin increases suggest that the amplitude of the R waves and, more specifically, the presence of "embryonic R waves" are not useful in determining proximity to the site of impulse origin. Small R waves may be recorded at distant sites as a result of the impulse being recorded along the transverse axis.[10] Additionally, it is possible that R wave regression and its disappearance are due to the formation of ventricular depolarizations at sites other than the electrode tip. For instance, the disappearance of R waves in patients 14 and 18 may be due to ventricular depolarizations arising from 8 and 11 mm from the tip electrode, respectively. However, this possibility was excluded because only electrograms with progressive delay in onset of the ventricular electrogram as the distance from the tip electrode increased, consistent with impulse formation arising from the tip electrode, were included for analysis.

### *Comparison with Pace Mapping*

Previous studies have compared differences in QRS configuration during unipolar pacing to determine the spatial resolution of ventricular pace mapping.[16,17] When analysis was based on major configurational changes in the QRS complex, the resolution was at 15 mm. When minor changes in configuration and amplitude were included, the resolution was at 5 mm. In the present study, an R wave in the unipolar electrogram was observed only 35% of the time at 5 mm from the site of origin. Therefore, the accuracy of ventricular pace mapping appears to be superior to the unipolar electrogram for localizing the site of impulse origin in the right ventricle.

### *Limitations*

A limitation of this study is that the analysis was limited to the right ventricle. It is possible that different results might be obtained in the left ventricle or in the atrium. The right ventricle was used in this study to determine if the unipolar electrogram might be useful in the mapping of idiopathic ventricular tachycardia arising from the right ventricle, and to lessen the potential impact that structural heart disease, such as coronary artery disease, may have on the accuracy of the unipolar electrogram.

A second limitation of this study is that the analysis of R waves was limited to within 11 mm from the impulse origin. As a consequence, the distance from the impulse origin in which R waves are consistently present is unknown.

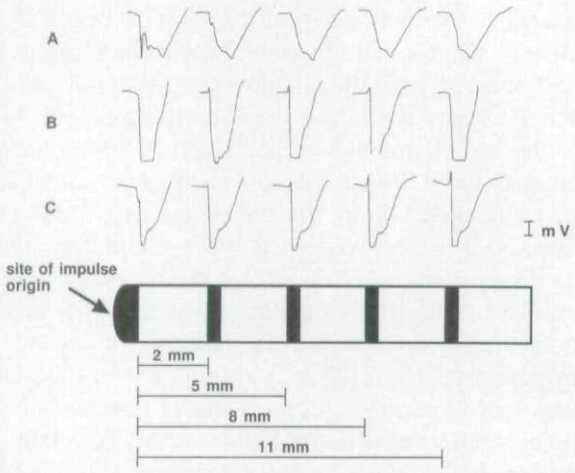


**Figure 2.** *Comparison of unipolar electrograms recorded at known distances from a ventricular premature depolarization induced at the tip electrode. (A) Patient 1 demonstrates no R waves in the unipolar electrogram at distances ≤ 11 mm from the impulse origin. (B) Patient 18 demonstrates no R waves in the unipolar electrogram at the site of impulse origin, R wave amplitudes of 0.2, 0.3, and 0.3 mV at distances of 2, 5, and 8 mm from the tip electrode, and the disappearance of R waves at 11 mm from the tip electrode. (C) Patient 2 demonstrates increasing R wave amplitudes of 0.2, 0.4, 0.7, and 0.9 mV as the distance increases from the tip electrode to 2, 5, 8, and 11 mm, respectively.*

A third limitation of this study is the 5 mm/mV gain setting used to record the unipolar electrograms. It is possible that greater amplification would enhance the detection of R waves. A gain of 5 mm/mV was used for the unipolar recordings to allow for all five unipolar electrograms to be recorded simultaneously, without excessive overlap. The 5 mm/mV gain was amplified to 20 mm/mV in a simultaneous digital recording without any changes in the results.

### *Clinical Implications*

The results of this study suggest that the unipolar electrogram may not be an adequate guide for identification of an effective target site for ablation of idiopathic right ventricular tachycardia. An R wave is often absent at distances as great as 11 mm from the site of origin of a right ventricular depolarization. Because the width of a radiofrequency lesion is approximately 6 mm with a 4-mm distal electrode,[18] the lesions created by radiofrequency energy at sites where the unipolar electrogram does not demonstrate an initial positive deflection often may not encompass the site of origin of a ventricular depolarization.

## References

1. Haissaguerre M, Dartigues JF, Warin JF, et al: Electrogram patterns predictive of successful catheter ablation of accessory pathways. Circulation 1991;84: 188-202.
2. Poty H, Saoudi N, Haissaguerre M, et al: Radiofrequency catheter ablation of atrial tachycardias. Am Heart J 1996;131:481-489.
3. Salarro JA, Stori C, DeParrti R, et al: Role of the unipolar signal in identification of the target for radiofrequency catheter ablation of permanent ectopic atrial tachycardia. (Abstract) PACE 1996;19:413.
4. Grimm W, Miller J, Josephson ME: Successful and unsuccessful sites of radiofrequency catheter ablation of accessory atrioventricular connections. Am Heart J 1994;128:77-87.
5. Magnin-Poull I, deChillou C, Sadoul N, et al: Valeur del'enregistrement unipolaire et bipolarire dansl'ablation par radiofrequnce des faisceaux accessoires auriculo-ventricularires. Arch Mal Coeur Vaiss 1996;89: 1177-1183.
6. Simmers TA, Hauer R, Wever E, et al: Unipolar electrogram models for prediction of outcome in radiofrequency ablation of accessory pathways. PACE 1994; 17:186-199.
7. Simmers TA, Peeters HA, Wittkampf FH, et al: Effect of electrode-target distance on dv/dt of initially negative unipolar electrograms: Implications for RF ablation. (Abstract) PACE 1996;19:23.
8. deBakker JMT, Hauer RNW, Simmers TA: Activation mapping: Unipolar versus bipolar recording. In Zipes DP, Jaliffe J eds: *Cardiac Electrophysiology: From Cell to Bedside*. WB Saunders Co., Philadelphia, 1995, pp. 1068-1078.
9. Spach MS, Barr RC, Serwer GA: Extracellular potentials related to intracellular action potentials in the dog Purkinje system. Circ Res 1972;30:505.
10. Spach MS, Miller WT, Miller-Jones E, et al: Extracellular potentials related to intracellular action potentials during impulse conduction in anisotropic canine cardiac muscle. Circ Res 1979;45:188-204.
11. Calkins H, Kalbfleisch SJ, El-Atassi R, et al: Relation between efficacy of radiofrequency catheter ablation and site of origin of idiopathic ventricular tachycardia. Am J Cardiol 1993;71:827-833.
12. Coggins DL, Lee RJ, Sweeney J, et al: Radiofrequency catheter ablation as a cure for idiopathic tachycardia of both left and right ventricular origin. J Am Coll Cardiol 1994;23:1333-1341.
13. Man KC, Chan K, Daoud E, et al: Spatial resolution of unipolar mapping of the earliest site of ventricular activation. (Abstract) PACE 1995;18:289.
14. Taccardi B, Arisi G, Macchi E, et al. A new intracavitary probe for detecting the site of origin of ectopic

ventricular beats during one cardiac cycle. Circulation 1987;75:272-281.

15. Khoury D, Taccardi B, Lux R, et al: Reconstruction of endocardial potentials and activation sequences from intracavitary probe measurements: Localization of pacing sites and effects of myocardial structure. Circulation 1995;91:845-863.
16. Kadish AH, Childs K, Schmaltz S, et al: Differences in QRS configuration during unipolar pacing from adjacent sites: Implications for the spatial resolution of pace-mapping. J Am Coll Cardiol 1991;17:143-151.
17. Kadish AH, Schmaltz S, Morady F: A comparison of QRS complexes resulting from unipolar and bipolar pacing: Implications for pace-mapping. PACE 1991;14:823-832.
18. Langberg JJ, Gallagher M, Strickberger SA, et al: Temperature-guided radiofrequency catheter ablation with very large distal electrodes. Circulation 1993;88: 245-249.