Teaching Points With 3-Dimensional Mapping of Cardiac Arrhythmias
Taking Points: Activation Mapping

Freddy Del Carpio Munoz, MD; Traci Buescher, RN; Samuel J. Asirvatham, MD

The map obtained of a tachycardia is greatly influenced by how meticulously individual activation points are annotated to indicate the timing of activation. The annotation window is typically set to display surface leads and intracardiac electrograms. These include the electrogram or ECG window is typically set to display surface leads and intracardiac electrograms. These include the electrogram or ECG lead used as the timing reference as well as the bipolar and unipolar signals from the mapping catheter. Assuming that the point of reference electrograms remains stable and the point of interest and tachycardia cycle length are unchanged, the consistency of annotating the timing of mapping catheter–derived electrograms is the defining factor for the accuracy of the map. The operator must have a consistent plan as to how to annotate the electrogram timing as well as a method of handling double potentials and fragmented signals.

Electrogram Annotation
Several potential options as to how to annotate the electrogram timing exist, including whether to use unipolar or bipolar signals, taking the maximum amplitude of the electrogram, earliest portion of the electrogram, and so forth.

Earliest Part of the Electrogram
This method is the least desirable approach. The earliest signal may represent far-field activation, and in some instances, especially on the septum or where there are neighboring electrically active structures or in the vicinity of scar/slow conduction, a marked discrepancy between the earliest recorded far-field signal and the timing of actual activation at the site can exist (Figure 1). Although such discrepancy is magnified with unipolar recordings, the problem also exists with standard spaced bipolar recordings.

Peak Amplitude of the Electrogram
This method also has the potential to yield erroneous results (Figure 2). In healthy myocardium, there is little difference between the earliest near-field electrogram and the peak amplitude timing. However, in diseased tissue or where there are scars, including those from prior surgery or ablation, there can be a variable delay between the onset of the local electrogram and the time to the peak amplitude. Because this interval is not constant across various sites, an early activation site may be recorded later if the peak electrogram occurs late, and another relatively later site of activation may be recorded early if the maximum peak is relatively earlier.

First Peak of the Near-Field Bipolar Electrogram
Appreciating that far-field signal representing activation at sites distant from the mapping site is an important source of error in activation maps, attempting to identify the earliest near-field electrogram is a common technique for annotating electrograms for activation mapping. In general, the near-field, local potential will have a sharper appearance than far-field potentials (Figures 1 to 3). The first sharp peak of the bipolar electrogram is usually selected. At times, however, it is difficult to distinguish between near and far-field components on the bipolar electrogram. Assessing the timing of activation at surrounding sites can also be helpful. Pacing at the site to assess which component of the electrogram is captured can also be helpful but may terminate the arrhythmia. Further confounding may occur when the two electrodes from the bipolar recording are in contact with the myocardium. Electrograms derived from tissue beneath the proximal electrode cannot be distinguished from those caused by depolarization of tissue below the distal electrode where ablation will be performed. These differences probably are minimal in normal tissue but can be significant when conduction delay exists between the distal and proximal electrode. Avoiding parallel orientation of the electrodes may help to minimize this potential for error.

Annotation of the Rapid Downstroke of the Unipolar Signal
The unipolar electrograms record electric activity between the distal tip electrode of the mapping catheter (cathode) and an indifferent electrode, which can be either the central terminal of Wilson or a catheter placed in the inferior vena cava to act as the anode. Although the earliest unipolar signal represents far-field activation, when activation passes beneath the distal electrode, a steeply negative deflection (s-wave) is recorded. The earliest rapid downstroke of the unipolar signal (fastest dV/dt) approximates the timing of activation of the myocardium in contact...
with the electrode. During endocardial recordings, however, the 3-dimensional nature of the tissue and potential for midmyocar-dial and epicardial activation as well as sites of conduction delay may cause difficulty in determining the exact timing of the fastest portion of the unipolar electrogram downstroke.

**Unipolar Versus Bipolar Signals**

For focal endocardial tachycardias, a sharp QS signal is seen on the unipolar electrogram at the site of earliest activation, as excitation wave fronts propagate away from the site. With reentrant tachycardias, a vector of activation toward the unipolar recording from the distal mapping catheter electrode always exists, but, using the earliest negative deflection as noted above, and correlating the timing of this electrogram with the earliest near-field deflection on the bipolar electrogram is a reasonable means to denote the timing of activation at the site in contact with the distal electrode.

**Annotating Double Potentials**

Two distinct electrograms separated by an isoelectric interval (double potentials) can be recorded from a catheter on either a line of conduction block or conduction delay and represents electric activation on both sides of such a line. Depending on the direction of the activation wave front and the exact location of the tip of the mapping catheter (favoring one side of the line or the other), the earliest signal may be either far field or near field in nature. The operator must have a consistent plan in dealing with double potentials.

It is generally unacceptable to simply take the earliest signal when double potentials are present because the far-field signal may appear as early, depending on selection of the mapping window and catheter position. (Figure 3).

Generally acceptable is attempting to identify the earliest near-field signal. Thus, on one side of the line of block/delay, the near-field signal may be the second potential, whereas this potential may be the far-field signal when recording from the opposite side of the line of block. When annotated consistently and in consideration of the surrounding activation times, the activation wave front can be reliably recorded.6–8

At times, however, both signals may appear near field (exactly on the line), or when prior ablation or markedly diseased tissue is present, neither component appears particularly near field. In such a situation, it is likely best to simply tag such sites as double potentials for location only and not use the signal for the purpose of activation mapping.

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**Figure 1.** Probably the least accurate method of taking activation points involves simply taking the earliest or start of the bipolar signal. The schematic shows possible findings for assessing activation times on adjacent sides of the septum, with early activation at the right side of the septum. Although this approach may correctly identify the ablation target in some instances, the earliest signal is likely a far-field signal (in this instance, activation on the other side of the intraventricular septum). The activation map will incorrectly show 2 fairly disparate sites to have similar activation times, making it impossible to identify the true pattern of activation.

**Figure 2.** Taking the maximum peak of the bipolar electrogram can sometimes be misleading, especially with diseased myocardium and the complexities of endocavitary myocardial structures near the mapping electrode. In this schematic, the maximal bipolar peak in the recordings from the septum indicates the true activation time at that site. At the lateral wall, the maximal peak occurs after the true time of activation, which is much earlier (arrow). Because of diseased myocardium, the early signal is smaller; however, the large late signal likely results from an overlapping papillary muscle or neighboring normal tissue.
Careful annotation of double potentials along a line that is incomplete is a very useful method to find a gap in such lines. The interval between the two components of the double potential is wide at sites remote from the gap and progressively shorter closer to the gap, and eventually, either a single electrogram or a fractionated electrogram at the gap at the site that can be targeted for ablation to complete the desired linear ablation (Figure 4).

**Fragmented Signals**

Fragmented signals are multicomponent signals without isoelectric intervals between components. These are often areas of slow conduction.

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**Figure 3.** Illustration of the difficulties posed when annotating double potentials caused by a line of block or slow conduction. In the schematic, the rounded potential is the far-field signal, and the sharp potential is the local potential that indicates activation at the site. If the earliest of the two electrograms is consistently taken on both sides of a line of block or slow conduction (in this figure, the crista terminalis), then an erroneous activation pattern results. Essentially, a large area of apparent early conduction (red) on either side of the line will be obtained. If on the other hand, the near-field, local potential is used for annotation, then the pattern of activation around a line of block (inset at right) or true region of slow conduction can be identified.

**Figure 4.** Electroanatomic activation map in left anterior oblique (LAO) and right anterior oblique (RAO) views of focal tachycardia originating in the suprapulmonic valve area. Activation time is color-coded from earliest (red) to progressively later (yellow, green, blue, and purple). Earliest activation is denoted by pink dot. Right lower panel, Annotation window of a point in the right ventricular outflow tract (RVOT); the bipolar electrogram shows far-field (red arrow) and near-field signals (white arrow). Upper right panel, Annotation window of the earliest activation point (pink dot), showing a sinus beat followed by an ectopic beat. On the ectopic beat, a small sharp local signal is followed by a lower-amplitude, more rounded-appearing far-field signal. Also notice that the unipolar signal shows an rS configuration on the sinus beat and a qS configuration on the ectopic beat.
conduction, and individual components may reflect local or far-field activation. A consistent approach similar to that for double potentials is required. These sites may represent the slow zone of conduction for the given tachycardia or bystander areas of slow conduction that may require iterative ablation anyway for complete substrate modification.

Sites of fragmented signals may be initially tagged as location-only points with no assigned activation time because it is not usually possible to determine the near-field component indicating local activation.

It should be remembered, however, for reentry tachycardias, the complete cycle length of the tachycardia will not be seen in an otherwise appropriate map in the correct chamber of origin when the fractionated “location-only” points are in the reentry circuit.

After complete mapping of the chamber, the electrophysiologist should look back at tagged fragmented signal sites to determine which of these is likely to represent the slow zone for the given circuit. This can usually be determined by reviewing the wave front of activation at adjacent regions. Inclusion of the appropriate region in the map then may account for the remaining portion of the tachycardia cycle length.

**Summary**

Annotation of the local electrograms is important for accurate definition of the arrhythmia circuit for reentrant tachycardias and for identifying origins of focal arrhythmias. Approaches to accurate annotation require an understanding of the genesis of electrograms and their limitations that facilitates recognition of far-field electrograms and informs approaches to identify likely local activation time. Review of annotated electrograms is important when mapping produces a confusing activation sequence.

**Disclosures**

None.

**References**


**Key Words:** ablation ■ mapping ■ arrhythmia ■ radiofrequency ■ carto ■ electroanatomic mapping
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Circ Arrhythm Electrophysiol. 2011;4:e22-e25
doi: 10.1161/CIRCEP.110.960351
Circulation: Arrhythmia and Electrophysiology is published by the American Heart Association, 7272 Greenville Avenue, Dallas, TX 75231
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Print ISSN: 1941-3149. Online ISSN: 1941-3084

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