Jackson et al\(^1\) describe a complex timing cycle interaction in a patient with a dual-chamber implantable cardioverter–defibrillator. The intracardiac electrograms provided along with their description of an algorithmic approach to differential diagnosis is ripe with teaching points typical of the bedside rounds of yesteryear. Complex cases require not only meticulous logical analysis of the available data but also detailed knowledge of the background information necessary to apply that reasoning. In this instance, the authors used the morphology of the intracardiac electrograms, the relative timing between ventricular and atrial activation, identifying the initial chamber for the change in the rhythm, along with the background knowledge of specific device timing windows and expected responses, and functional knowledge of the SecureSense lead noise detection algorithm.

**Electrogram Morphology**

Visual or automated algorithm-based assessment of electrogram morphology is a cornerstone for differentiating ventricular tachycardia (VT) from a rapid atrioventricular (AV) conducted rhythm. The authors compare ventricular electrograms from AV conduction to those of the tachycardia to help identify an AV conducted and not ventricular origin for the tachycardia. Intracardiac electrograms, however, are rarely identical even for a short series of AV conducted beats. For example, in their Figure 1B, the ventricular near-field (NF) electrogram shows some variation even though both beats are conducted. Several factors contribute to this variation, including relative change in the position of the bipolar electrodes and the fact that no 2 sinus beats have an identical pattern of activation in the ventricular with varying parts of the Purkinje network being refractory or having different conduction velocities, even in the normal heart. Similarly, VT can variably engage the Purkinje network for spread of its activation. This may give rise to some variation in morphology seen in both NF and far-field (FF) electrograms, and indeed, the surface ECG, and if originating within or near to a conduction system entrance site, may be within the spectrum of variation of conducted beat electrograms particularly when sampling a small area of myocardium (NF electrogram).\(^2\)

Although less commonly scrutinized, the atrial electrogram can also be useful in defining the mechanism of arrhythmia. Ventricular pacing with retrograde atrial activation should produce a similar electrogram as VT with retrograde conduction, as well as AV node reentry, but distinctly dissimilar to that seen with sinus rhythm, atrial tachycardia, or orthodromic reciprocating tachycardia.

**Relative Timing**

Analyzing the relative timing of the ventricular and atrial electrograms in conjunction with the morphology is similar to and associated with the same limitations of analyzing the R-P interval and P-wave morphology with the 12-lead ECG. For example, the near-simultaneous atrioventricular electrograms would suggest AV node reentry but would not exclude an atrial tachycardia with long antegrade conduction time or a VT with long retrograde conduction time.

In addition, however, the intracardiac tracings allow a high resolution analysis of relative timing. The authors use such recognition in showing that a subtle change may cause a ventricular sensed event to fall within the cross-talk detection window versus the blanking period.

Not commonly utilized, but useful in some instances, is assessment of the relative timing of the NF ventricular electrogram onset with that of the FF electrogram, as well as the FF ventricular electrogram on the atrial lead. This provides an assessment of whether the ventricular activation sequence is similar or different and may include comparison with a more distantly placed electrode in the outflow tract (origin of the FF, V on the atrial lead). This may help distinguish a conducted from ventricular arrhythmia, as well as distinguishing between an estimated site of onset or exit of a specific VT.

**The Triggering Event**

Analyzing the relative timing when the rate or rhythm changes can provide insight into the mechanism of tachycardia. The authors note in their patient that for the arrhythmia shown in their Figure 1C, the atrial rate changes first, and this change predicts a ventricular rate change, suggesting atrial tachycardia. Such investigation for the triggering sequence requires caution because the initiating change may be in the atrium, but the premature AV conducted beat may initiate a VT, rather than supraventricular tachycardia. In addition, a premature
bead in one chamber may cause a delayed rather than early activation in the other chamber, and thus the change rather than prematurity is what is important. In rare instances, the chamber of origin for the primary change is misleading for complex reasons. For example, AV node reentry may occasionally be initiated by a PVC that never conducts to the atrium but penetrates the AV node and presumably the fast or slow pathway input to the AV node, setting the stage for a sinus beat to initiate tachycardia.5

The Near-Field and Far-Field Electrograms
The NF electrogram is usually obtained from relatively closely spaced bipolar recording, such as the right ventricular (RV) lead tip to the RV lead ring (true bipolar) or, with integrated bipolar leads, the RV tip to RV coil. The actual spacing between the 2 electrodes, even with true bipolar recordings, can vary based on the type of lead. The FF electrogram is more akin to the surface ECG and unipolar recordings but represents a widely spaced bipolar, such as from the RV coil or RV tip to can. In general, the NF and FF electrograms significantly differ in their morphology but should be the same in terms of the number of electrograms recorded. The basis for the SecureSense RV lead noise discrimination algorithm is that with lead noise, there will be more detected NF electrograms (from the lead malfunction) than FF electrograms (which are more likely to represent true ventricular activation).

As described by the authors and in one of the excellent references they provide,6 the limitations for this algorithm in terms of false positives (over diagnosis of noise) and false negatives (failure to detect lead malfunction) and the most worrisome manifestation of these pitfalls—failure to detect and treat true VT—are important to appreciate. How can the FF and NF electrograms tell us different stories for the conducted rhythm, and how can the NF electrograms be significantly more in number than the FF electrograms for a reason other than lead malfunction? Closely spaced bipolar electrograms are affected by the direction of activation because they represent the arithmetic sum of the individual unipolar recordings from the cathode and anode.5 On the contrary, true unipolar recordings are affected by the distance from the source, but not the wavefront direction relative to the recording unipole. In devices, FF discrimination (morphology) electrograms are a hybrid between true bipolar and unipolar recordings with a widely spaced bipolar as described earlier.

Near Field<Far Field
VT may rarely demonstrate a greater number of signals on the bipolar recording than on the discriminating electrogram recording. Localized reentry near the tip of the implantable cardioverter–defibrillator lead with varying exit block or double potentials because of conduction block in the region is a potential cause. Undersensing of the FF electrogram in the absence lead malfunction may rarely occur if the vector of cardiac activation is perpendicular to the recording system axis, for example an apicolateral LV exit site and recording from the RV coil to the can placed in the left intracavitary region.

Far Field≥Near Field With Noise
Electromagnetic interference affects both NF and FF recordings and at times preferentially the FF electrograms. Further, if the discriminatory (FF) electrogram is being recorded from the RV tip to the can, then lead noise could be seen equally on both the FF and NF signals.

Contiguous Structures
NF and FF components on the same recording bipole can also be seen when 2 structures overlap each other, such as on the interatrial septum or coronary sinus with contiguous left atrial appendage or left atrial recordings, and if the electrode is wedged between 2 structures, such as a papillary muscle and the left ventricular free wall. When mapping sites of the fascicular and Purkinje network, the conduction system signal and surrounding myocardium are mapped simultaneously.

Near Field and Far Field Reversal
When comparing a normal sinus beat with tachycardia, a distinct reversal in the NF and FF electrogram sequence strongly suggests that the electrode site is close to the origin of the automatic tachycardia. For example, when recording supravalvar signals in the pulmonary trunk, the NF (pulmonary arterial myocardium) follows the FF (right ventricular outflow tract) signals in a conducted rhythm but switches to an early NF signal when supravalvar VT is present.

Inappropriate But Useful
Both the present case where lead noise was inappropriately diagnosed but the algorithm used identified an abnormality that required treatment and the examples from the Koneru et al series4 gives a more nuanced meaning for inappropriate detection. The failure of an algorithm, be it the presently discussed SecureSense algorithm or indeed any discriminatory algorithm, such as one to distinguish supraventricular from VT, may uncover an important diagnosis requiring treatment, such as cardiac perforation causing myopotential sensing.

Jackson et al1 successfully established a diagnosis from an unusual, complex, intracardiac electrogram sequence of events by applying reasoned deduction and comprehensive knowledge of pacemaker timing cycles, as well as device-specific specialized algorithms. This example and those from Koneru et al3 are excellent case studies illustrating the need to learn and apply the principles of electrogram-based deductive reasoning along with the understanding of electrogram derivation in arrhythmia management devices.

Disclosures
S.J. Asirvatham receives no significant honoraria and is a consultant with Abiomed, Attricure, Biosense Webster, Biotronik, Boston Scientific, Medtronic, Spectranetics, St Jude, Sanoﬁ-Aventis, Wolters Kluwer, Elsevier, Zoll. W.G. Stevenson is coholder of a patent on needle ablation that is consigned to Brigham and Women’s Hospital.

References


**Key Words:** far-field □ implantable cardioverter–defibrillator □ inappropriate therapy □ lead noise □ near-field □ SecureSense
Inappropriately Appropriate
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Circ Arrhythm Electrophysiol. 2016;9:e003608
doi: 10.1161/CIRCEP.116.003608
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

The online version of this article, along with updated information and services, is located on the World Wide Web at:
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