Special Report

The Electrocardiogram at a Crossroads

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The ECG is at a crossroads as to its future integration into modern medical practice. Those most interested in electrocardiography remain the old guard, whose careers evolved with this technology. They remain as enamored by the experiential mythology as by the experimental science of the ECG. Electrophysiologists, who rightly should be carrying on the torch of further ECG development, are too busy with their therapeutic invasive procedures and devices to invest much time in diagnostic decision support. Young physicians in training are too busy learning the plethora of new diagnostic modalities and treatment procedures to even become competent in ECG interpretation. Many of them only have goals to recognize an ST elevation myocardial infarction and atrial fibrillation, and to pass their board examinations. Their understanding of ST elevation myocardial infarction criteria could be easily exposed by asking them to name the contiguous pairs of standard ECG leads. A disappointing number would refer to pairs of leads that are contiguous on the ECG display such as II and III or V1 and V6, rather than the leads separated by 30° going around the surface of the heart as specified in the guidelines. Reimbursement provides a further counterincentive: to paraphrase George Bernard Shaw (The Doctor’s Dilemma, 1926), “the doctor orders the test that pays the most” and that is no longer the ECG, but a panoply of imaging procedures.

Examples of the experiential mythology that continue to haunt electrocardiography include the requirement for contiguous or adjacent leads instead of a single lead for fulfilling diagnostic criteria. The contiguous or adjacent lead constraint is a residual from the thick, noisy tracings from the early days of electrocardiography before high-impedance amplifiers, DC coupling, and digital processing produced the high-resolution tracings of today (Figure 1). Applying the criteria to a single digitally processed ECG lead would avoid the confusion previously discussed without affecting the diagnostic characteristics of the ECG.

Another example of the mythology is consideration of the T-P segment as the baseline for amplitude measurement rather than the PR segment. The T-P baseline remains from vectorcardiography, whereas the PR segment has many reasons to be set as the baseline, as explained in the Common Standards for Quantitative Electrocardiography statement. Another persistent belief is that R- and S-wave amplitudes estimate left ventricular mass and that all of the voltage criteria for left ventricular hypertrophy have clinical value. How important is it really for physicians to memorize all the voltage criteria for left ventricular hypertrophy?

The crossroad is being intersected by the channelopathies, which have made cellular physiologists and geneticists so important in electrocardiography. The channelopathies are providing clinicians with knowledge of new syndromes that can explain sudden cardiac death in individuals with morphologically normal hearts. Association between surface ECG characteristics with these syndromes and sudden cardiac death is complicated by new patterns with dynamic manifestations often requiring drug challenge, maneuvers, or continuous monitoring.

Further complicating the future are the influences of automated ECG interpretation, new ECG guidelines, and the confusion caused by the J-wave pattern (early repolarization). The ECG was one of the first medical tests to be computerized. Programs that originated in academia were quickly commercialized (for example, Telemed, IBM, HP, and Marquette). Today, nearly all commercial ECG devices use microprocessors that perform algorithms for signal averaging, noise reduction, waveform amplitude, and duration measurements and that generate diagnostic statements. Although automated programs require Food and Drug Administration approval for equivalence in analysis, they are not standardized and vary among manufacturers. Excellent gold standards for diagnosis and standardized databases actually do exist, but they have not been adequately influential. Although expert groups have provided standards for ECG measurement and interpretation, their recommendations have not been mandated by the Food and Drug Administration for manufacturers to adopt in their programs. The excellent “Third universal definition of myocardial infarction,” for instance, has proposed radically different criteria for previous myocardial infarction and abnormal ST elevation (see the Table, adapted from this statement). To date, these criteria have not been implemented in any commercial automated system and, indeed, are not even known by most students or faculty. Perhaps that is for the best, because they have not been validated, but we should not be surprised if they soon become a part of the board examinations.

J-wave patterns (early repolarization) are an example of a collision at the crossroads. An important new ECG waveform variation, best identified as the Haïssaguerre pattern, has caused confusion, because it is hypothesized to be generated during the early repolarization phase of the myocyte action potential. Most of the commercially available automated...
ECG programs base a diagnostic statement of early repolarization on ST-segment elevation in an otherwise normal ECG (Figure 2). This pattern, which occurs in the leads with the positive poles in the lateral and inferior directions, is common in young, black male athletes. The Haïssaguerre pattern does not consider the ST amplitude but is based on J-wave patterns, specifically J waves and slurs.

Such J waves and slurs often accompany the ST elevation of the classic early repolarization pattern. Although the Common Standards for Quantitative Electrocardiography ECG Measurement Standard illustrates QRS end/ST beginning to occur after J waves or slurs (see Figure 3), cellular physiologists and some electrophysiologists consider QRS end to occur at the beginning of the J wave or slur. Most rest and exercise ECG guidelines have considered that the J point is located at the beginning of the ST segment, which serves as reference for identifying ST elevation myocardial infarction criteria. However, many of those studying the new early repolarization patterns consider the J point to be the top of the J wave or slur. To the clinical electrocardiographer, clearly the J wave or slur on the routine, stable ECG are part of ventricular depolarization. This is in contrast to the dynamic ECG patterns of the Haïssaguerre syndrome preceding episodes of ventricular tachycardia/ventricular fibrillation where clearly the J waves, slurs, and ST elevation occur during early repolarization.

The actual point where depolarization ends and repolarization begins differs throughout the ventricular myocardium. Despite advances to solve the inverse problem of bioelectricity, this point cannot be determined on the standard surface ECG. Yet, clinicians must make consistent measurements of QRS duration and ST level for clinical decision making. Furthermore, population and clinical studies evaluating the association of the Haïssaguerre pattern with clinical outcomes can only obtain reproducible results if they rely on the same measurements. The available prognostic studies cannot be combined for the purpose of clinical decision making because of the confusion with regard to the terms used and measurements made between the disparate studies.

The question now is where should we turn at this crossroads to salvage what we can of the still merit-worthy ECG, while engaging a new generation of busy clinicians who are

### Table. The Universal MI Definition Statement Criteria for Ischemia and Previous MI

<table>
<thead>
<tr>
<th>ECG manifestations of acute myocardial ischemia (in the absence of LVH and LBBB)</th>
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<tr>
<td><strong>ST elevation</strong></td>
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<tr>
<td>New ST elevation at the J point in 2 contiguous leads with the cut points: ≥0.1 mV in all leads other than leads V₂ through V₆ where the following cut points apply: ≥0.2 mV in men ≥40 y; ≥0.25 mV in men &lt;40 y; or ≥0.15 mV in women.</td>
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<tr>
<td><strong>ST depression</strong></td>
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<tr>
<td>New horizontal or downsloping ST depression ≥0.05 mV in 2 contiguous leads or T inversion ≥0.1 mV in 2 contiguous leads with prominent R wave or R/S ratio &gt;1.</td>
</tr>
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</table>

**ECG changes associated with previous MI**

- Any Q wave in leads V₁ through V₆ ≥0.02 s or QS complex in leads V₂ and V₆.
- Q wave ≥0.03 s and ≥0.1 mV deep or QS complex in leads I, II, aVL, aVF, or V₂ through V₆ in any 2 leads of a contiguous lead grouping (I, aVL; V₁ through V₆; II, III, aVF).
- R wave ≥0.04 s in V₆ through V₆ and R/S ≥1 with a concordant positive T wave in the absence of conduction defect.

LBBB indicates left bundle branch block; LVH, left ventricular hypertrophy; and MI, myocardial infarction.
bombarded with excessive data for each new patient they meet? Our efforts must start at the beginning, with education and mentorship from the first day of medical school. Instilling in our newest recruits to the field about the immense usefulness of the ECG and passing on the joy of adding diagnostic information with such an elegant technology is the start. And once we have their enthusiasm, we must follow it up with continued education. Boring lectures from yesteryear can now be replaced by YouTube videos, ecgpedia (http://en.ecgpedia.org/wiki/Main_Page), and interactive learning Websites, such as the University of Utah ECG Website (http://ecg.utah.edu/) and http://learning.bmj.com/ECGathlete. Democratizing the process of reading an ECG to the primary care physician, not just the cardiologist, or worse, just the electrophysiologist, is essential to its continued beneficial impact on patient care. A step in that direction has been the Seattle Criteria and the British Medical Journal Learning module designed to teach Sports Medicine physicians how to interpret the ECGs of athletes. We can simplify the automated ECG statements so that more physician interaction is required to lend clinical relevance to computer readout. We can influence the ECG manufacturers by having the International Society for Computerized Electrocardiography set high standards for automated ECG interpretation, diagnostic algorithm updates, and guideline driven improvements.

Finally, in the current age of skyrocketing healthcare costs, we need to use evidence-based data to create guidelines about when the clinician should rely on the ECG in favor of a more expensive diagnostic tool. ECGs have the power to help us cost-effectively manage our patients, and when that will suffice without further imaging, we need to seize every last one of those opportunities to save our costly healthcare system. With a deliberate and thoughtful approach, the era of the ECG need not end, but we must choose wisely at this transformational crossroads. Simplification and reliance on science rather than experiential mythology is critical to leaving the proper legacy of the ECG to those who follow.

Disclosures
Dr Froelicher is co-owner of Cardea Associates Inc. The other authors report no conflicts.

References

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