Beyond diagnosis: ECG waveforms predict MI-E treatment response

Written by The Life Science Feed Editorial Team · Published 8 September 2026 · Edited by Mara Voss

Myocardial infarction with epicardial coronary artery disease (MI-E) remains a significant clinical challenge, demanding precise diagnostic and prognostic tools. The ability to predict treatment efficacy early could transform patient management, guiding clinicians toward more effective interventions and away from therapies unlikely to yield benefit. Electrocardiogram (ECG) waveforms, long a cornerstone of cardiac assessment, may offer a non-invasive route to this critical insight.

KEY TAKEAWAYS

- The Pivot: ECG waveform analysis moves beyond diagnosis to offer potential insights into treatment response for MI-E.
- The Data: Specific changes in T-wave morphology and QRS duration correlate with myocardial viability and reperfusion success.
- The Action: Clinicians should consider integrating advanced ECG interpretation into their assessment of MI-E patients to gauge early treatment effects.

Myocardial infarction with epicardial coronary artery disease (MI-E) represents a complex relationship of ischaemia, necrosis, and subsequent remodelling. The immediate goal of therapy is reperfusion, but the ultimate success hinges on salvaging viable myocardium and preventing adverse ventricular remodelling. Traditional markers, such as troponin levels and angiographic findings, confirm the event and guide initial intervention. But they offer limited real-time insight into the physiological response to treatment at the tissue level.

The standard 12-lead ECG, a ubiquitous and cost-effective tool, captures the electrical activity of the heart. Its waveforms reflect not only the initial injury but also the dynamic changes occurring during and after reperfusion. These changes, particularly in the ST segment, T wave, and QRS complex, provide a window into myocardial health and the efficacy of interventions. Understanding these subtle shifts allows for a more comprehensive assessment of treatment success, moving beyond simply confirming patency of the infarct-related artery.

The electrical signature of ischaemia and reperfusion

Acute myocardial ischaemia manifests on the ECG primarily through ST-segment elevation or depression, T-wave inversion, and sometimes Q-wave development. These changes reflect alterations in myocardial repolarisation and depolarisation duect to cellular injury and electrolyte shifts. With successful reperfusion, the ST segment typically normalises, indicating resolution of acute ischaemia. But the story does not end there. Persistent ST-segment elevation after reperfusion, for example, often indicates microvascular obstruction or no-reflow phenomenon, a critical predictor of adverse outcomes. This suggests that while the epicardial artery may be open, blood flow at the capillary level remains impaired, limiting myocardial salvage. For a deeper dive into the acute phase, consider our previous coverage on ruling out heart attacks faster.

The T wave, representing ventricular repolarisation, offers further insights. In the acute phase of MI-E, tall, peaked T waves (hyperacute T waves) can precede ST-segment elevation. Following reperfusion, T-wave inversion often develops, which can be a normal post-ischaemic phenomenon. But the depth and persistence of T-wave inversion, particularly in the precordial leads, can correlate with the extent of myocardial stunning and viability. Deep, symmetrical T-wave inversions, sometimes referred to as 'reperfusion T waves,' indicate successful reperfusion but also suggest significant myocardial injury that is recovering. The morphology of these T waves, including their symmetry and duration, can distinguish between transient ischaemia and more permanent damage, offering a non-invasive marker of myocardial recovery.

QRS complex and myocardial viability

The QRS complex reflects ventricular depolarisation. In the context of MI-E, the development of pathological Q waves signifies myocardial necrosis. These Q waves represent electrical silence from the infarcted tissue, with the electrical forces moving away from the necrotic area. The presence and extent of Q waves are well-established markers of infarct size and transmurality. But even in the absence of new Q waves, subtle changes in QRS duration and fragmentation can provide prognostic information. Fragmented QRS (fQRS), characterised by additional R waves, notching, or slurring in at least two contiguous leads, is thought to represent heterogeneous ventricular activation due to myocardial scarring or ischaemia. This fragmentation has been associated with increased risk of ventricular arrhythmias and adverse cardiovascular events, even after successful reperfusion. It offers a marker of myocardial substrate vulnerability that extends beyond simple infarct size.

QRS duration itself can also be a prognostic indicator. Prolongation of the QRS duration post-MI-E, even within the normal range, has been linked to larger infarct size and impaired left ventricular function. This is likely due to delayed conduction through injured or remodelled myocardium. The Braunwald's Heart Disease textbook provides extensive detail on these complex electrophysiological changes.

ST-segment resolution and its limitations

ST-segment resolution (STR) is a widely accepted ECG marker for assessing reperfusion success in ST-elevation myocardial infarction (STEMI). Complete STR, typically defined as a >70% reduction in ST-segment elevation from baseline, correlates strongly with myocardial salvage and improved clinical outcomes. This immediate post-reperfusion assessment provides a rapid, non-invasive way to gauge the effectiveness of primary percutaneous coronary intervention (PCI) or fibrinolysis. But STR has limitations. It is an early marker, primarily reflecting epicardial artery patency rather than microvascular integrity. Patients with complete STR can still experience microvascular obstruction, leading to suboptimal myocardial reperfusion and poorer prognosis. This highlights the need for additional ECG parameters that can offer a more comprehensive picture of myocardial health beyond just the epicardial vessel.

The dynamic nature of ST-segment changes over time also matters. Early and rapid STR is more favourable than delayed or incomplete resolution. Serial ECGs, therefore, are critical in monitoring the evolving electrical landscape (the market) of the heart post-MI-E. The rate of normalisation, rather than just the final state, provides valuable information about the extent of myocardial stunning and the potential for recovery. This is particularly relevant when considering primary prevention strategies in older adults, where the long-term effects of myocardial injury are amplified.

Beyond the basics: advanced ECG parameters

Beyond the standard measurements, advanced ECG parameters offer even deeper insights. T-wave alternans, for example, refers to beat-to-beat variations in T-wave morphology or amplitude. It is a marker of electrical instability and has been associated with an increased risk of ventricular arrhythmias and sudden cardiac death in post-MI patients. While not routinely used for acute reperfusion assessment, its presence in the subacute or chronic phase can identify patients at higher risk who might benefit from closer monitoring or implantable cardioverter-defibrillator (ICD) therapy.

QT dispersion, the difference between the maximum and minimum QT intervals across all 12 leads, is another parameter reflecting heterogeneity in ventricular repolarisation. Increased QT dispersion post-MI-E has been linked to a higher incidence of ventricular arrhythmias and mortality. This suggests that a more dispersed repolarisation pattern indicates a greater susceptibility to electrical instability, even in patients with seemingly successful reperfusion. These advanced metrics, while requiring more sophisticated analysis, push the boundaries of what a simple ECG can tell us about myocardial recovery and future risk.

The utility of ECG waveforms extends to predicting the efficacy of specific pharmacological interventions. For instance, certain antiarrhythmic drugs may alter repolarisation, and these changes can be monitored via QT interval and T-wave morphology. Similarly, drugs aimed at reducing myocardial oxygen demand or improving microvascular function may induce subtle but measurable changes in the ST-T segment. The challenge lies in standardising these measurements and integrating them into routine clinical practice. The Oxford Handbook of Cardiology offers a concise guide to these modern cardiological practices.

Where it falls short

While ECG waveforms provide invaluable information, they are not without limitations. The sensitivity and specificity of individual ECG markers can vary, and they are often influenced by confounding factors such as electrolyte imbalances, pre-existing conduction abnormalities, and concomitant medications. The interpretation of subtle changes requires expertise and can be subjective. The 12-lead ECG provides a two-dimensional projection of a three-dimensional electrical event, meaning some regional abnormalities may be missed or underestimated. It cannot directly visualise myocardial tissue or blood flow, relying instead on electrical surrogates. Imaging modalities like cardiac MRI or echocardiography offer direct assessment of infarct size, myocardial oedema, and ventricular function, providing complementary information that can refine the prognostic assessment. The ECG is a powerful screening and monitoring tool, but it is not a standalone diagnostic for all aspects of myocardial health.

> **CLINICAL IMPLICATIONS**
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> The enduring utility of the ECG in MI-E management is clear, but its potential to predict treatment efficacy is often underutilised. Clinicians should move beyond simply confirming ST-segment resolution and pay closer attention to the evolving morphology of T waves and QRS complexes. These subtle electrical signatures offer a low-cost, readily available window into myocardial viability and microvascular integrity, guiding decisions on further interventions or risk stratification.

> Integrating advanced ECG interpretation into routine post-MI-E assessment could refine patient pathways. Identifying patients with persistent microvascular obstruction or significant electrical instability via waveform analysis might prompt earlier consideration of adjunctive therapies or closer follow-up. This proactive approach could reduce readmissions and improve long-term outcomes, particularly in a population prone to adverse remodelling.
> The industry needs to support this by developing more sophisticated, automated ECG analysis tools that can reliably detect and quantify these subtle waveform changes. Current systems often focus on basic interval and segment measurements, overlooking the rich prognostic information embedded in T-wave symmetry or QRS fragmentation. Better tools would empower general practitioners and specialists alike to leverage the full diagnostic and prognostic power of the ECG, making it a truly predictive instrument rather than just a diagnostic one.

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