

From electrocardiographic patterns to prognostic insights: AI-assisted perspectives on revascularization decisions

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This editorial refers to ‘Deep learning electrocardiogram model for risk stratification of coronary revascularization need in the emergency department’, by A. Büscher *et al.*, <https://doi.org/10.1093/eurheartj/ehaf254>.

Graphical Abstract

Deep learning applied to ECG may redefine coronary revascularization in the ED

Current diagnostic challenges in ACS

Challenge in ECG criteria for total occlusion in STEMI

High false positive rates

23.0%

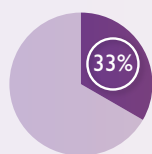
Agrawal *et al.*, PMID: 30694822

Low sensitivity

43.6%

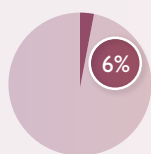
de Alencar Neto *et al.*, PMID: 38382857

Treatment gap in NSTEMI patients



33% NSTEMI patients with acute occluded coronary artery

McLaren *et al.*, PMID: 39435181



Only 6% of very high-risk NSTEMI patients receive angiography within 2 hours

Lupu *et al.*, PMID: 35266561

AI-ECG's capabilities

Current capabilities of AI models



Discriminates type 1 MI with high accuracy



Stratifies risk and revascularization needs



Shorten door to balloon time

Next steps



Prospective multicenter validation



Development of explainable AI models



Evaluation in randomized clinical trials

ACS, acute coronary syndrome; AI, artificial intelligence; ECG, electrocardiogram; ED, Emergency Department; MI, myocardial infarction; NSTEMI, non-ST-elevation myocardial infarction; STEMI, ST-elevation myocardial infarction

The opinions expressed in this article are not necessarily those of the Editors of the *European Heart Journal* or of the European Society of Cardiology.

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Coronary artery disease (CAD) remains the leading cause of morbidity and mortality worldwide, despite remarkable advancements in revascularization techniques and secondary prevention measures. In particular, the evolution of myocardial infarction (MI) diagnosis from the era of 'Q-wave MI' to 'ST-elevation MI' (STEMI) not only reflects improvements in percutaneous coronary intervention (PCI) and a deeper understanding of ischaemic pathophysiology, but also highlights the need for early identification of all obstructive lesions that could benefit from urgent intervention. Indeed, classifying MI into STEMI or non-ST-elevation MI (NSTEMI) alone can miss a substantial portion of patients who actually harbour a culprit lesion. Recent findings suggested that the Fourth Universal Definition of MI identifies STEMI with only 43.6% sensitivity for detecting acute coronary occlusion, potentially missing a substantial proportion of patients who require urgent revascularization.¹ Therefore, the occlusion MI (OMI) vs. non-occlusion MI (NOMI) paradigm may provide a more accurate and clinically relevant diagnostic framework.

A meta-analysis underscored this gap by revealing that NSTEMI patients with total occlusion shared similar Killip classifications with their non-occlusive counterparts, highlighting the inadequacy of symptoms alone for risk prediction.² Such underdiagnosis translates into a 40% and 30% increased short- and long-term risk of major adverse cardiovascular events, respectively, alongside a 67% rise in all-cause mortality in these patients.² Therefore, just as it is widely accepted that the door-to-balloon time for STEMI should be under 90 min,^{3,4} we may also need to manage NSTEMI patients with total occlusion more aggressively. However, current NSTEMI management is highly variable, requiring clinical judgement and effective communication with patients.⁵⁻⁷ The challenge in clinical practice is that NSTEMI patients with total occlusion are difficult to distinguish using current medical standards, potentially necessitating the use of emerging tools to aid in their management.

Against this backdrop, the pursuit of more objective, rapid, and accurate methods for identifying obstructive coronary lesions—especially those masquerading as NSTEMI or presenting with only subtle electrocardiogram (ECG) changes—has intensified.⁸ The integration of artificial intelligence (AI) into ECG analysis represents a pivotal advancement in diagnostic capability.⁹ Traditional computerized ECG algorithms, built on simple rule-based criteria, have long struggled with borderline ST-segment changes, conduction abnormalities, or a variety of confounders such as left bundle branch block. In contrast, deep learning-based models are inherently capable of recognizing high-dimensional ECG patterns across multiple leads, thus providing a richer, more holistic perspective on myocardial ischaemia. The deep learning model evaluated by Büscher and colleagues in their study published in this issue of the *European Heart Journal* showed robust performance in risk-stratifying patients who ultimately underwent coronary revascularization, even when applied to an external European cohort that differed in both patient demographics and clinical practice patterns.¹⁰

These AI-driven solutions have multifaceted clinical potentials, beginning with a fundamental challenge to the traditional STEMI–NSTEMI classification paradigm. By focusing on the underlying pathology, namely obstructive coronary lesions requiring revascularization, these models promise to narrow the diagnostic gap that currently leaves many high-risk patients unrecognized. Advanced AI techniques can parse these borderline patterns with a level of nuance that human eyes may miss, thereby prompting earlier and more aggressive management whenever indicated. Moreover, AI-ECG systems can complement established biomarkers such as high-sensitivity troponin. Although troponin assays are invaluable, they require serial testing and may delay critical therapeutic

decisions. In contrast, deep learning models provide an instantaneous probabilistic estimate of ischaemia by analysing subtle repolarization and conduction changes. Therefore, they hold the promise of bridging the critical gap between symptom onset and definitive revascularization—a goal equally critical for patients with clear STEMI and those with more subtle clinical presentations.

In this large retrospective study, the authors developed an AI-ECG model to predict revascularization events using a US cohort of 144 691 emergency department (ED) patients. The model achieved an area under the curve (AUC) of 0.91 for ECG interpretation in an internal test set, surpassing conventional ECG interpretation (AUC 0.65), and an AUC of 0.71 for cardiac troponin T. In an external validation cohort of 35 995 European ED patients, it achieved an AUC of 0.81, outperforming conventional ECG interpretation (AUC 0.70) but trailing for high-sensitivity troponin T (AUC 0.85). Key findings include the model's robust discrimination of patients at high risk for restenosis and its strong correlation with established myocardial ischaemia indices. However, several limitations and unanswered questions remain.

Integrating AI into the ED presents several challenges. One major concern is the variability in clinical practice across different healthcare settings. NSTEMI management often varies considerably, necessitating nuanced clinical decision-making, and clear and effective patient communication.⁵⁻⁷ This discrepancy may explain the two-fold difference in PCI rates between the USA and Europe in the study of Büscher and colleagues.¹⁰ The fragmented US healthcare system and lack of on-site surgical backup at many hospitals limit PCI access.^{11,12} Geographic and socioeconomic disparities further complicate availability in certain communities.¹² Additionally, clinical practice patterns differ, with the USA typically adopting a more conservative approach, while Europe favours early intervention strategies, contributing to lower PCI rates in NSTEMI patients in the USA compared with Europe.^{3,4,13} In such contexts, the adoption of an AI-based clinical decision support system (CDSS) could serve as a harmonizing force, standardizing the interpretation of complex ECG data and enabling more uniform patient triage. Another challenge lies in the variability of interpretation standards across AI-ECG models developed by different teams. The AI model developed by Büscher and colleagues, utilizing the fully public MIMIC database, is likely to resolve this issue by offering a consistent standard for ECG interpretation when implemented on a large scale in clinical diagnostics.

An additional practical concern involves the opaque, 'black box' nature of deep learning models.¹⁴ Despite impressive performance metrics, the lack of transparency regarding which features the model uses to predict occlusion can limit clinician trust. Efforts to improve explainability, such as mapping feature importance to specific ECG segments, are crucial for transitioning from academic validation to routine clinical implementation. This transparency is particularly critical for MI patients, as cardiac catheterization carries a significant risk of fatal complications, with mortality rates approaching 1% in certain high-risk populations.¹⁵ Encouragingly, preliminary investigations have shown that these models tend to emphasize physiologically relevant features, such as abnormalities in the ST segment or T wave, which align well with established markers of myocardial ischaemia.

Nevertheless, additional research is needed to validate and refine these AI-based tools. Prospective, multicentre trials with longer follow-up periods will be essential in determining whether the observed time savings in the ED translate into tangible improvements in morbidity and mortality. A landmark study, the ARISE trial, demonstrates the feasibility of integrating AI-based ECG analysis into clinical workflows.¹⁶ In the ARISE trial, for instance, real-time AI-ECG analysis significantly reduced

both door-to-balloon and ECG-to-balloon times, providing a clear benefit in the urgent diagnosis of STEMI. However, there are still no clinical trials for NSTEMI patients with total occlusion. Moreover, cost-effectiveness analyses are necessary to evaluate the broader impact on healthcare systems, particularly in resource-limited settings where the burden of cardiovascular disease remains high. Despite these challenges, the convergence of deep learning with ECG technology represents one of the most promising avenues for advancing the early detection and management of acute coronary syndrome.

In conclusion, the integration of AI into ECG interpretation marks a paradigm shift in the way we approach acute myocardial ischaemia. By transcending the limitations of traditional STEMI/NSTEMI classifications, deep learning models offer the potential to identify high-risk patients based on subtle, yet significant, ECG patterns. This could lead to more timely coronary interventions and, ultimately, improved clinical outcomes. Realizing the full potential of this technology may ultimately pave the way for a more personalized, pathology-driven framework in the management of acute coronary syndrome.

Declarations

Disclosure of Interest

All authors declare no disclosure of interest for this contribution.

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