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Accuracy of cath lab activation decisions for STEMI-equivalent and mimic ECGs: Physicians vs. AI (Queen of Hearts by PMcardio)

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ABSTRACT

Introduction: Accurate ECG interpretation is crucial to identify occlusive myocardial infarction (OMI) to determine the need for immediate catheterization laboratory activation (CLA). STEMI-equivalent and STEMI-mimic ECG patterns deviate from conventional STEMI criteria, risking misclassification of OMI cases. The diagnostic accuracy for these complex ECGs is unknown.
Objectives: This study aimed to measure physician accuracy for interpreting STEMI-equivalent and STEMI-mimic ECGs for catheterization laboratory activation (CLA) and compare their performance to a machine learning-based artificial intelligence algorithm, Queen of Hearts AI (QoH AI).
Methods: Fifty-three EPs and 42 cardiologists interpreted 18 ECGs (eight STEMI-equivalents, eight STEMI-mimics, with one STEMI, and a normal ECG as controls) to determine the presence of OMI requiring immediate CLA. The same ECGs were analyzed by QoH AI. Interpretations were compared against a reference standard based on angiography, troponin, echocardiography, and clinical follow-up.
Results: Interpretation accuracies were similar between EPs and cardiologists (65.6 %, 95 % CI [51, 78]; 65.5 %, 95 % CI [51, 77], respectively; $p = 0.969$), and significantly lower than QoH AI (88.9 %, 95 % CI [82, 93]) vs. physicians overall, 65.6 %, 95 % CI [52, 77]; $p < 0.001$). Physicians most frequently misclassified de Winter, Transient STEMI, Hyperacute T-wave OMI, and bundle branch block ECGs. QoH AI only misclassified left bundle branch block with OMI and left ventricular aneurysm without OMI.
Conclusion: Physicians frequently misinterpret STEMI-equivalent and STEMI-mimic ECGs, potentially impacting CLA decisions. QoH AI demonstrated superior accuracy, suggesting a potential to reduce missed OMIs and unnecessary catheterization laboratory activations. Prospective studies are needed to validate these findings in clinical practice.

1. Introduction

1.1. Background

Accurate diagnosis of occlusive myocardial infarction (OMI) in the emergency department is essential for timely reperfusion and improved outcomes. This is occasionally accomplished with fibrinolytics, but more commonly, immediate angiography identifies the occlusion, and percutaneous coronary artery intervention (PCI) restores perfusion. The ECG remains the primary diagnostic tool for catheterization laboratory activation (CLA) decisions, often supplemented by clinical assessment, troponins, and prior, repeat, or EMS ECGs.

For decades, the ST-elevation myocardial infarction (STEMI) criteria have served as the cornerstone for identifying patients who require immediate reperfusion, supported by landmark studies from the mid-1980s [1,2]. However, in 1996, expert consensus recognized the first of many STEMI criteria exceptions, hyperacute T-wave occlusive myocardial infarction (HATW OMI) and posterior wall myocardial infarction (PW OMI) [3]. Subsequent guidelines recommended accepting up to

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2.5 mm of ST-segment elevation in leads V2–V3 as normal, depending upon age and sex [4]. Since that time, a steady stream of exceptions to the classical STEMI criteria have emerged, creating two broad categories: "STEMI-equivalents" (OMI without ST-elevation) and "STEMI-mimics" (ST-elevation without OMI) (Supplemental Table S1a, S1b). As new exceptions continue to occur [5], these categories increase ECG diagnostic complexity and likely reduce interpretation accuracy.

A pivotal study by McCabe et al. in 2013, using angiography as a reference standard, reported that physician accuracy was only 70 % among patients suspected of OMI who proceeded to angiography [6]. Given this modest accuracy, performance on ambiguous ECGs is likely even lower.

Machine learning artificial intelligence (AI) models offer a potential solution to this challenge. The Queen of Hearts AI (QoH AI) is a deep neural network AI model developed by Powerful Medical [7] and is currently undergoing Food and Drug Administration (FDA) approval as of March 24, 2025. It has been trained to recognize OMI from ECGs and is 91 % accurate [7]. However, whether it can outperform physicians for STEMI-equivalent and mimic ECG types remains unknown.

1.2. Objective

Our primary objective was to determine the ECG interpretation accuracy for OMI (and thus CLA decision) among emergency physicians and cardiologists, compared to that of QoH AI for STEMI-equivalent and STEMI-mimic ECG types, using a reference standard based on angiography, troponin, echocardiography, and follow-up. A secondary objective was to identify which ECG patterns are most prone to misinterpretation.

1.3. Importance

The results from this investigation could impact clinical decision-making for CLA, potentially improving patient safety, morbidity, and overutilization of cardiology resources.

2. Methods

2.1. Study design and setting

We conducted a cross-sectional online survey of experienced emergency physicians (EPs) and cardiologists to interpret 18 STEMI-equivalent and mimic ECGs from September 19, 2024, to April 3, 2025, following an initial pilot survey of 17 emergency medicine residents. Our hospital system comprises two community hospitals and four stand-alone emergency departments (EDs), managing over 108,000 adult ED visits, 239 cath lab activations, and 295 coronary bypass surgeries annually, and operates as 24-h STEMI-receiving centers. All EPs were residency-trained, and both EPs and cardiologists routinely interpret ECGs for CLA decisions. The hospital's institutional review board deemed the study exempt from human participant research and waived consent requirements. We adhered to the STARD guidelines [8].

2.2. Study population and data Collection

ECG selection began with a scoping review to identify ECG types representing STEMI-equivalents and STEMI-mimics (Fig. 1). We included four STEMI-equivalent ECG types, as described in recent cardiology guidelines [9], as non-STEMI cases that require "immediate reperfusion therapy." We added Wellens and aVR STEMI ECG types, as these have been described as STEMI equivalents elsewhere, and immediate angiography is our clinical practice for these conditions. Two additional ECGs were added, having similar recommendations, Transient STEMI and RBBB with LAFB OMI (right bundle branch block with left anterior fascicular block and OMI) [10,11]. We also included eight ECGs representing STEMI-mimics that frequently provoke false-positive CLAs [12]. Full definitions and supporting references are detailed in Supplementary Tables S1a and S1b. We excluded ECGs observed in pericarditis, Takotsubo cardiomyopathy, and Prinzmetal angina since there are limited published criteria differentiating them from OMI. De-identified ECGs matching these definitions were sourced from the authors' clinical practice and Stephen Smith's ECG database (https://hqmeded-ecg.blogspot.com/) with permission. Seven pilot ECGs were replaced with ones not used to train the QoH AI. The final 16 ECGs (plus one STEMI and one normal ECG serving as controls) used in the survey are displayed in Supplemental Table S2. OMI status was determined by angiography or serial troponins.

Fifty-three EPs and 56 cardiologists were emailed a link to access the 18 ECG survey via Survey Monkey and were asked to interpret each displayed ECG for a yes/no decision whether they would activate the cath lab for immediate reperfusion, based solely on the ECG's appearance, given there was clinical concern for acute coronary occlusion. Department directors encouraged broad voluntary participation to minimize self-selection bias, resulting in responses from 53/53 EPs and 49/56 cardiologists. Incomplete responses (7/49 cardiologists) were excluded.

Physicians were blinded to OMI prevalence and patient outcomes and had no recent ECG interpretation training prior to the study. Respondents received no clinical context other than concern for coronary artery occlusion, except in case #8 (Transient STEMI), where minimal EMS history was provided only to physicians—not AI: "We have ST elevation, estimated time to ED arrival—five minutes." The EMS ECG obtained 6 min before case #8's ECG can be viewed in Supplemental Table S2, but was not shown to the respondents or the QoH AI. Survey responses were double-entered by two authors (KS, SRS), with discrepancies resolved by consensus.

Queen of Hearts is a deep-learning artificial intelligence (QoH AI) algorithm designed to predict OMI from ECG changes, developed by Powerful Medical and described by Herman et al. [7]. All eighteen ECGs were submitted to the QoH AI by the authors using screenshots captured via iPhone and submitted through PMcardio's iPhone application, OMI AI ECG model version 1.10, 2025. We did not submit photographs of computer-screen-displayed ECGs in order to avoid any potential image distortion that could occur between user photographs. QoH AI returned one of three interpretation results through the PMcardio application: 1. STEMI/STEMI-equivalent, 2. reperfused OMI, or 3. No signs of OMI. We classified "STEMI and STEMI-equivalent" ECGs as indicating CLA [13]. We classified "reperfused OMI"—as seen in Wellens and Transient STEMIs—also as indicating CLA since immediate or emergent angiography is our clinical practice and supported by others [14] (Supplemental Table S1a). We classified "No signs of OMI" as no indication for CLA.

2.3. Definitions

We defined ECG interpretation accuracy as the correct binary classification of OMI compared to the following reference standard criteria: *OMI present*, 1) angiographic culprit lesion with ≤ TIMI II flow and elevated troponin, or 2) angiographic culprit lesion with TIMI III flow and significantly elevated troponin vs. *OMI not present*, 1) no culprit lesion ≥50 % stenosis on angiography; or 2) when angiography was not performed, negative serial troponins, no new echocardiographic wall motion abnormalities, and negative clinical follow-up. Additional standardized definitions include: true positive for OMI and thus CLA (ECG interpretation and reference standard both positive), true negative (both negative), false-positive (ECG positive, reference negative), and false-negative (ECG negative, reference positive). Further definitions are listed in Supplemental Table S4.

2.4. Statistical analysis

Crude performance metrics (sensitivity, specificity, accuracy, predictive values) were calculated using 2 × 2 contingency tables.

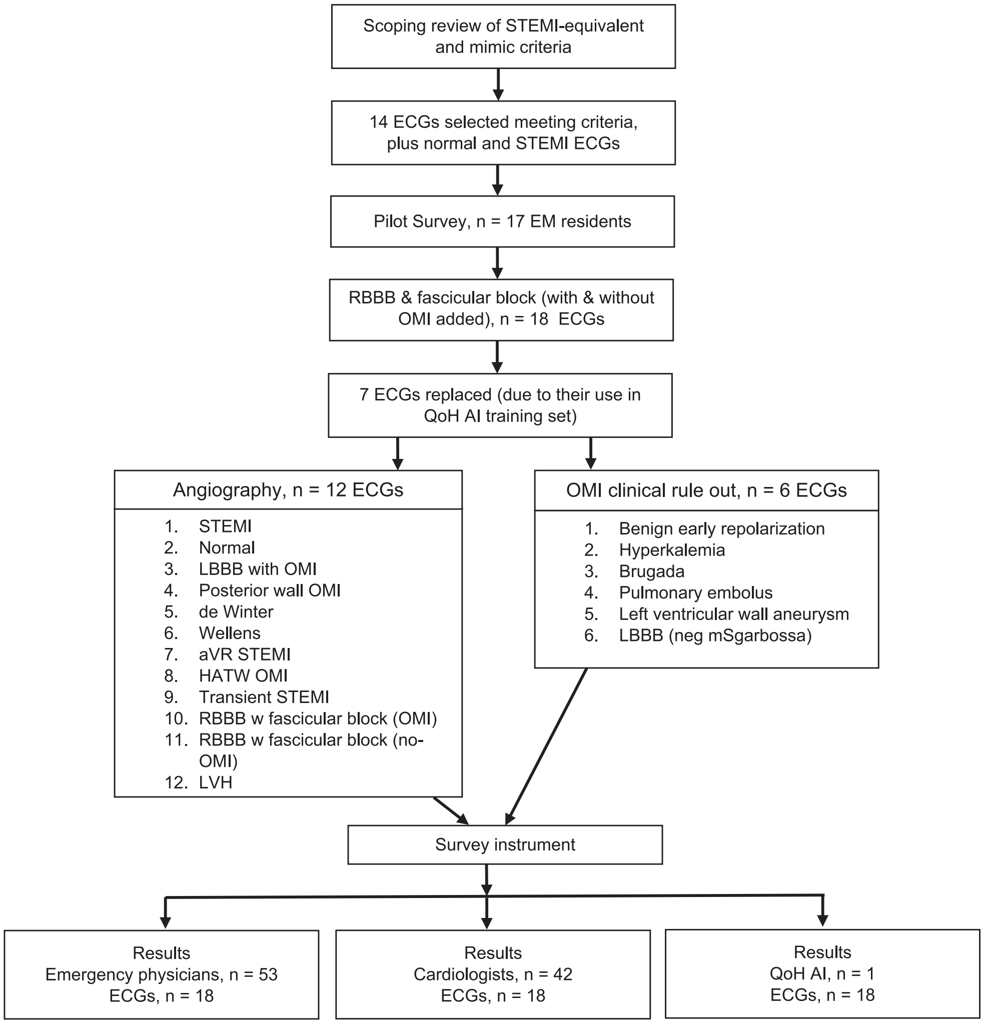

Fig. 1. Methods flow chart.

EP and cardiologist accuracy agreement was assessed using raw agreement. All marginal estimates were also calculated using the creation of multiple logistic regression models to quantify the association between accuracy (yes/no) and group (EP, cardiologists, QoH AI) and ECG type (e.g., STEMI, PW OMI, etc.). Multi-level robust variance estimates were employed to account for clustering resulting from the involvement of multiple raters and ECG types. Linear combinations of parameter estimates were computed to summarize the accuracies by group (percentages and 95 % confidence intervals), as well as compare these accuracies between groups (odds ratios, 95 % confidence intervals). We used our pilot ECG accuracy survey to estimate that 90 total participants (interpreting 18 ECGs each) would provide adequate power to detect significant accuracy differences between physicians and QoH AI. We considered a p-value <0.05 significant. All analyses were performed using R-4.5.0 and the sandwich library.

3. Results

We analyzed the accuracy of 95 ECG interpretations from 53 emergency physicians (EPs) and 42 cardiologists (23 general cardiologists, 15 interventional cardiologists, and 4 electrophysiologists). The median clinical experience was 7 years, IQR (3.0, 15) among EPs and 15 years, IQR (9.2, 21) among cardiologists.

Accuracies of EPs and cardiologists were nearly identical (65.6 %, 95 % CI [51, 78] vs. 65.5 %, 95 % CI [51, 77], respectively; $p = 0.97$). Among the EPs, the mean, median, and SD were 65.6 %, 66.7 %, and 9.35 %; for cardiologists, they were 65.5 %, 66.7 %, and 9.89 %. One physician in each group achieved a high score of 89 %. QoH AI significantly outperformed physicians (89 %, 95 % CI [82, 93] vs. 66 %, 95 % CI [52, 77]; $p < 0.001$). Physicians were < 50 % accurate at interpreting Transient STEMI, HATW OMI, de Winter, and LBBB (±OMI) ECG types, whereas QoH AI correctly classified three of these four (Fig. 2). Physicians were > 80 % accurate at classifying STEMI, pulmonary embolism, PW OMI, and Wellens ECG types.

The EPs were more sensitive than cardiologists (59 % vs. 51 %) for identifying STEMI-equivalent ECGs, but this was not significant; $p = 0.268$. The cardiologists, however, were significantly more specific (80 % vs. 75 %; $p = 0.028$) for STEMI-mimics (Figs. 3 and 5), consistent with their role in ruling out OMI before angiography. Notably, a consensus in our sample (85 % of EPs and 74 % of cardiologists) chose CLA for the Wellens ECG case, indicating that most consider Wellens syndrome a STEMI-equivalent, warranting immediate intervention. These physicians may have recognized that, although Wellens ECG changes reflect

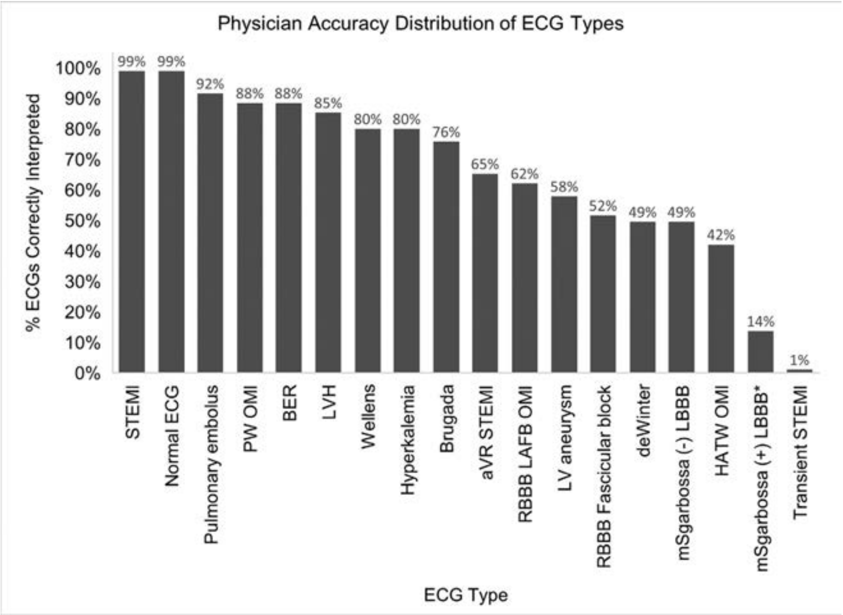

Fig. 2. Distribution of ECG accuracies for STEMI-equivalent and STEMI-mimic ECG types indicating their relative interpretation difficulty among 95 physicians. PW OMI = Posterior wall occlusive myocardial infarction; BER = Benign early repolarization; LVH = Left ventricular hypertrophy; aVR STEMI = aVR ST-segment elevation myocardial infarction; mSgarbossa LBBB = Smith's modified Sgarbossa left bundle branch block; HATW OMI = Hyperacute T wave OMI, RBBB LAFB = Right bundle branch block with left anterior fascicular block; *See Supplemental Table S2 for modified Sgarbossa (+) explanation.

spontaneous reperfusion [15], they also signal a high risk of imminent re-occlusion.

The ECG types generating the most significant disagreement between EPs and cardiologists included HATW OMI (57 %, 95 % CI [43, 69] vs. 24 %, 95 % CI [13, 39], respectively; $p = 0.002$) and right bundle branch block (RBBB) with fascicular block (42 %, 95 % CI [29, 55] vs. 64 %, 95 % CI [49, 77]; $p = 0.030$) making these ECG types the most likely to provoke inter-specialty debate regarding cath lab activation (Fig. 3).

QoH AI misclassified only two ECG types: LBBB OMI (mSgarbossa (+) LBBB*) and left ventricular aneurysm. These same ECG types also challenged physicians, with only 14 % and 58 % of physicians correctly interpreting them (Fig. 4). Notably, most EPs and cardiologists (93 % and 83 %, respectively, Fig. 3), accurately classified PW OMI without the aid of posterior leads V7-V9, calling into question the need to routinely perform an additional posterior lead ECG in all cases of PW OMIs as recommended in some guidelines [13].

In contrast to earlier reports identifying LVH, BER, and LBBB as frequently misclassified STEMI-mimics [12,16,17], we found high physician accuracy for LVH (85 %) and BER (88 %) and the lowest accuracy for bundle branch blocks without OMI (mSgarbossa (−) LBBB (50 %) and RBBB with fascicular block (52 %)) as seen in Fig. 4, highlighting an area where further education may be warranted.

The performance measures for physicians and QOH AI are displayed in Fig. 5 and Supplemental Table S5. Note that EPs missed 41 % of true

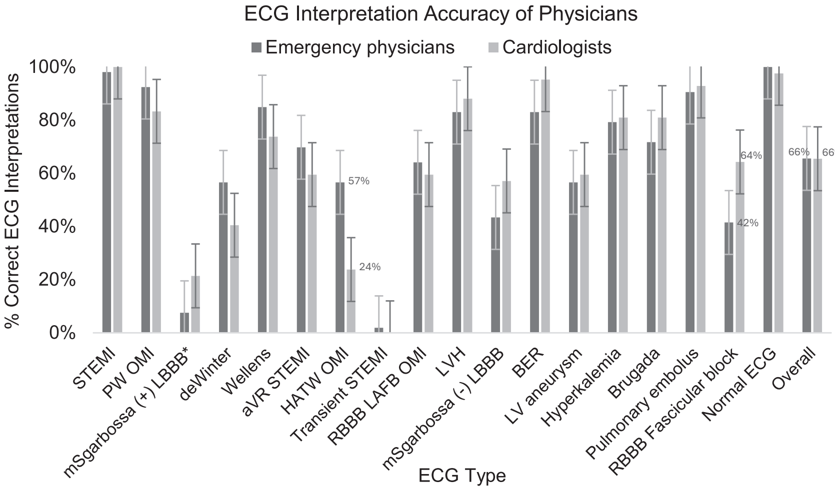

Fig. 3. ECG interpretation accuracy for cath lab activation among 53 emergency physicians and 42 cardiologists. Note the only ECG types with significant EP-cardiologist disagreement (HATW OMI and RBBB with fascicular block).

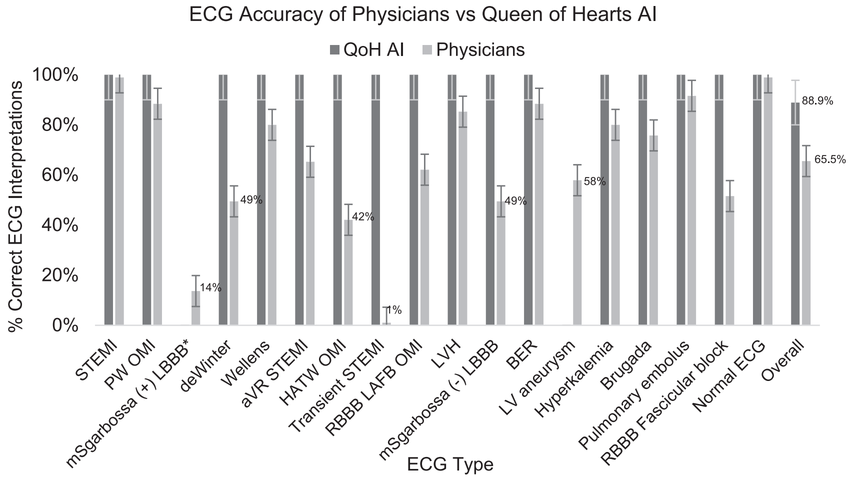

Fig. 4. ECG interpretation accuracy for cath lab activation decisions among 95 physicians compared to QoH AI. Note, QoH AI correctly identified 3 of 4 ECG types that more than 50 % of physicians misclassified but missed mSgarbossa (+) LBBB* and LV aneurysm.

OMIs (195/477) and overcalled 32 % of non-OMIs (133/415), whereas QoH AI missed only 11 % and overcalled 11 %. This suggests the potential for AI to improve patient morbidity and cardiology resource overutilization in a real-world setting.

Sensitivity analysis excluding ECG #3 (intended to represent mSgarbossa (+) LBBB but found to be mischaracterized) showed no significant difference in results for EP, cardiologist, but QoH AI accuracy would improve significantly by excluding ECG #3; $p = 0.005$ (Supplemental Table S3).

4. Discussion

4.1. Key findings

This study characterizes and compares the accuracies of community physicians and QoH AI in interpreting STEMI-equivalent and STEMI-mimic ECGs for CLA. Misclassification results in missed OMIs and in unnecessary CLAs, which can disrupt cath team workflow, exposing patients to procedural risks without benefit. We report three main findings from our analysis: 1) Overall physician accuracy was low (66 %), consistent with prior studies reporting 70 % accuracy using fewer ambiguous ECGs [6,18]. We found nearly identical accuracies between EPs and cardiologists (65.6 % and 65.5 %, respectively; $p = 0.969$). 2) The ECG types most frequently misinterpreted include LBBB (±OMI), Transient STEMI, HATW OMI, and de Winter. 3) The QoH AI algorithm was more accurate than physicians (89 % vs. 66 %, $p < 0.001$), correctly classifying all ECGs except LV aneurysm and LBBB with OMI, indicating potential to improve care and resource utilization.

4.2. Comparison with prior studies

Prior research reports wide variation in ECG interpretation accuracy (5 %–94 %) due to differing reference standards, often relying on expert interpretation of the STEMI criteria rather than an angiographically defined OMI [19], an approach recognized as suboptimal [6]. McCabe et al.'s study aligns more closely with ours, reporting 70 % accuracy using an angiographic OMI definition, but included only 22 % STEMI-equivalent and mimic ECGs. Our lower physician accuracy (66 %) reflects our inclusion of predominantly ambiguous ECG types (16 of 18 ECGs).

4.3. Angiography timing in non-STEMIs

Current cardiology and emergency medicine guidelines recommend treating STEMI-equivalent ECG patterns as STEMIs, which includes immediate angiography and percutaneous coronary intervention (PCI) [9]. However, few studies directly evaluate whether this subset of non-STEMIs benefits from early invasive management. Large,

		Emergency physicians				Cardiologists				Queen of Hearts		
		OMI				OMI				OMI		
		+	-			+	-			+	-	
ECG Interp for Cath Lab	+	282	133	415	+	194	77	271	+	8	1	9
	-	195	344	539	-	184	301	485	-	1	8	9
		477	477	954		378	378	756		9	9	18
Sensitivity		59%	95% CI [36,79]			51%	95% CI [31,71]			89%	95% CI [76,95]	
Specificity		72%	95% CI [57,83]			80%	95% CI [67,88]			89%	95% CI [78,95]	
Accuracy		65.6%	95% CI [51,78]			65.5%	95% CI [51,77]			88.9%	95% CI [82,93]	
Potential unnecessary CLA		32%	of caths			28%	of caths			11%	of caths	
Potential missed OMIs		41%	of OMIs			49%	of OMIs			11%	of OMIs	

Fig. 5. Overall diagnostic performance among emergency physicians, cardiologists, and QoH AI for STEMI-equivalent and STEMI-mimics. Note that in this cohort, QoH AI could reduce emergency physician unnecessary CLAs from 32 % (133/415) to 11 % and missed OMIs from 41 % (195/477) to 11 %.

randomized trials such as TIMACS [20] and VERDICT [21] found no overall mortality benefit from early angiography in general non-STEMI populations, but both demonstrated benefit in high-risk subsets (GRACE scores >140). These studies, however, had several limitations that reduce their applicability to STEMI-equivalent patients in the ED, most important of these being the definition of "early angiography" as having a median time of 4.7 h in VERDICT and 16 h in TIMACS. Attempting reperfusion therapy of occluded vessels in non-STEMI cases after such a delay is unlikely to benefit patients. In contrast, the RIDDLE-NSTEMI trial [22] showed that angiographies performed truly early (<2 h) reduced mortality in non-STEMI patients. Similarly, Khan's meta-analysis [23] reported that 25.5 % of non-STEMIs had total coronary occlusion (TIMI 0 flow) at delayed angiography and had double the mortality of those with patent arteries—despite being younger and having fewer comorbidities—suggesting early reperfusion might have altered outcomes. Moreover, Hung's systematic review found that 34 % of non-STEMIs had coronary occlusion, and this subset experienced a 72 % greater mortality, compared to non-STEMIs with open arteries [24]. Finally, Meyers et al. showed that non-STEMI patients with occluded coronary arteries had twice the mortality of those with classic STEMI (7.6 % vs. 3.3 %) [25]. Collectively, these data support the hypothesis that STEMI-equivalent patterns may represent a high-risk subset of non-STEMIs, who have occluded coronary arteries and would benefit from immediate recognition and reperfusion.

Despite suggestive evidence, no study has directly answered the question relevant to emergency physicians: Does delaying angiography in STEMI-equivalent cases increase the risk of VF arrest, cardiogenic shock, reinfarction, or mortality? This is especially problematic if they are boarded in the ED to await angiography solely because no study has yet proven that delays worsen outcomes.

Although the QoH AI appears promising for identifying STEMI-equivalent cases earlier, prospective studies are needed to confirm whether earlier recognition leads to better clinical outcomes. Until then, adhering to current guidelines recommending CLA for STEMI-equivalent ECGs remains a prudent strategy to avoid adverse events in this high-risk population.

4.4. Unintended consequences

While improving diagnostic accuracy is desirable, greater recognition of false-negative OMIs could unexpectedly increase immediate interventions (CLAs) if not offset by a commensurate reduction in false positives. Although this impact depends on physician sensitivity and OMI prevalence, our model suggests routine use of AI interpretation could modestly shift some planned delayed angiographies to immediate CLAs. Thus, cath lab teams operating at capacity should be prepared for a slight increase in immediate cases, even if the total volume declines.

4.5. Implications

Real-world confirmation of QoH AI's superior accuracy could yield several important clinical benefits. Reducing false-positive CLAs would decrease patient exposure to unnecessary procedural risks, such as bleeding, vessel injury, sedation complications, radiation exposure, and contrast nephropathy. Reducing false-negatives would favor mortality reduction by ensuring earlier reperfusion for patients with OMI. Additionally, consistent and accurate AI-supported diagnoses could enhance cath-team confidence in CLA decisions, reaction speed, and morale. For emergency physicians, AI-based ECG interpretation may reduce cognitive load, potentially improving overall ED decision-making. Lastly, integrating AI into clinical practice could shift educational priorities from memorizing many complex ECG morphology patterns toward more meaningful educational priorities.

5. Limitations

This study has several limitations that merit consideration when interpreting the results. First, we used only one representative ECG per type for interpretation, which cannot represent all ST-T morphology variants for that ECG type, limiting our precision. However, asking physicians to interpret more than 18 ECGs was impractical. Second, our single-center, community-hospital design may limit generalizability. Third, an artificially set OMI prevalence of 50 % with ambiguous ECGs may not accurately reflect predictive values observed in real-world settings, subjecting the study to spectrum bias.

Additionally, the ECG initially selected to represent mSgarbossa (+) LBBB was incorrect, as detailed in Supplemental Table S2; however, a sensitivity analysis excluding this ECG showed no significant impact on our conclusions (Supplemental Table S3). Although angiography was the reference standard for most cases, some mimics did not undergo angiography. For these patients, we relied instead on serial troponins, echocardiography, and clinical follow-up, which can introduce variability in the reference standard. Moreover, cardiologists performing the angiography were not blinded to ECG results, which may have introduced incorporation bias, inflating our sensitivity estimates. Lastly, our controlled survey conditions do not replicate realistic clinical environments, which include physician interruptions and time pressures—factors that could lower real-world accuracy [26,27].

6. Conclusion

Our study demonstrates low accuracy among physicians interpreting STEMI-equivalent and STEMI-mimic ECGs. A machine-learning AI algorithm (QoH AI) significantly outperformed physicians, suggesting a potential to inform CLA processes that improve patient care and cardiology resource utilization. Prospective studies are necessary to confirm these benefits in real-world clinical practice.

Prior presentations

None.

Disclaimers

The views expressed are those of the author and do not reflect the official views or policy of the Department of Defense, its components, or USUHS. The author does not have any financial interest in the companies whose materials are discussed, and no federal endorsement of the companies and materials is intended.

This original contribution has not been published, it is not under consideration for publication elsewhere, its publication is approved by All authors and tacitly or explicitly by the responsible authorities where the work was carried out, and that, if accepted, will not be published elsewhere in the same form, in English or in any other language including electronically without the written consent of the copyright holder.

CRediT authorship contribution statement

Steven Shroyer: Writing – original draft, Data curation, Conceptualization. **Sumeru Mehta:** Project administration, Data curation, Conceptualization. **Nandish Thukral:** Writing – review & editing, Project administration, Data curation. **Kyle Smiley:** Writing – review & editing, Validation, Formal analysis, Data curation. **Nathaniel Mercaldo:** Writing – review & editing, Formal analysis. **H. Pendell Meyers:** Writing – review & editing, Conceptualization. **Stephen W. Smith:** Writing – review & editing, Conceptualization.

Declaration of generative AI and AI-assisted technologies in the writing process

During the preparation of this work, the lead author (Steven Shroyer) used Chat GPT 4.0 for the introduction and discussion sections to clarify, simplify, and shorten those sections. After using this tool/service, all author(s) reviewed and edited the content, and Steven Shroyer takes responsibility for the content of the publication.

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Declaration of competing interest

Authors SRS, SM, KS, NM and NT report no conflicts of interest, including financial support from the PMcardio—Queen of Hearts App developer, Powerful Medical. SWS reports stock ownership in Powerful Medical and has consulted with Rapid AI; HPM reports stock ownership in Powerful Medical and has consulted with Rapid AI.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.ajem.2025.07.061.

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