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RESEARCH LETTER

Emergency department Code STEMI patients with initial electrocardiogram labeled "normal" by computer interpretation: A 7-year retrospective review

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A number of small studies have highlighted the low yield of triage ECGs for ST-elevation myocardial infarction (STEMI),[1] suggested that those labeled "normal" by computer interpretation are "unlikely to have clinical significance that would change triage care"[2] and that immediate review "would not have changed these patients' courses"[3] and hypothesized that ECGs labeled normal or "otherwise normal" would "have no immediate clinical significance."[4] But another study found conflicting results.[5] There is a proposed paradigm shift from STEMI to occlusion MI (OMI)[6] along with warnings that computer labeled normal ECGs could be missing OMI,[7,8] illustrated by dozens of examples.[9] One would expect that an ECG showing subtle occlusion would at least have some abnormality detected by the conventional algorithm and be able to at least give an interpretation of "nonspecific ST-T abnormalities"; when such an algorithm states "normal ECG," it is tempting to believe that there cannot be any serious abnormality.

The incidence, discrepancies, and management of Code STEMI patients and an initial ECG labeled normal is unknown. We reviewed 7 years of ED Code STEMI patients whose initial ECG was labeled normal or otherwise normal by computer interpretation. Our goal was to determine the frequency of this occurrence, compare the computer interpretation to the interpretation of the treating emergency physician, and the overreading blinded cardiologist, and review patient management and outcome.

This retrospective cohort study followed STROBE guidelines. We reviewed charts from 2016 to 2022 from two urban academic EDs, which collectively receive more than 110,000 patients a year. REB exemption (No. 18-0261) was obtained as part of ongoing quality improvement initiative to improve the care of ED patients with acute coronary occlusion.

The cardiac cath lab provided a list of all Code STEMI patients, dichotomized based on the presence or absence of culprit lesion requiring reperfusion. Patients were excluded if they were directly admitted from paramedic or other hospital transfer, if Code STEMI was activated after admission to hospital, or if they died or left against medical advice before angiography. We included all ED Code STEMI patients whose first ED ECG was labeled as normal or otherwise normal by the computer interpretation (GE MAC55 machines using Marquette 12 110 SL ECG analysis).

We recorded the final interpretation of the first ED ECG by the overreading cardiologist who can see the initial computer interpretation as well as patient age and sex but is blinded to emergency physician interpretation as well as patient presentation and outcome. Charts were reviewed to identify the treating emergency physician's interpretation of the ECG and management of the patient, including whether initial ECGs led to a change in patient management or not. If there were serial ECGs before cath

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lab activation, these were also reviewed for automated interpretation, treating emergency physician interpretation, and blinded cardiology interpretation.

Patient hospital course and outcomes were also recorded, including door-to-cath time (from the triage time stamp to the cath lab start time as recorded in the cath lab report), angiographic findings and interventions based on the cath lab report, and first and peak troponin levels. Data were summarized using descriptive statistics. Door-to-cath times were calculated in minutes, presented as means, with 95% confidence intervals (CIs).

There were 536 ED cath lab activations with angiography, including 132 without culprit lesions (24.6%) and 394 with culprit lesions. There were 18 patients whose initial ECG was labeled normal or otherwise normal, including two without culprit lesions (2/132 or 1.5%, 95% CI 0–3.6) and 16 with culprit lesions (16/394 or 4.1%, 95% CI 2.1–6.1).

Table 1 shows all patients with normal or otherwise normal initial ED ECGs. This includes interpretation from the blinded cardiologist, interpretation of the treating emergency physician (or whether the ECG was signed off without interpretation), patient management, and outcome. Patients 1–16 were STEMI with culprit lesion and Patients 17 and 18 were Code STEMI without culprit lesion. Appendix S1 shows all initial ECGs labeled normal or otherwise normal by computer interpretation, with final blinded cardiology interpretation and signs of OMI.

Among the 16 patients with culprit lesions, median age was 63.5 years (IQR 53.8–67.8 years), and 18.8% were female. Fifteen (93.8%) presented with chest pain and one with syncope, and all required percutaneous coronary intervention (but one was unsuccessful in deploying a stent). In six of 16 Code STEMI with culprit lesion (37.5%), emergency physicians identified the first ECG as showing acute ischemia requiring immediate management. The mean door-to-cath time for these patients was 80.2 min (95% CI 51.0–109.4 min), which was significantly faster than Code STEMI with culprit that were not identified (mean 237.7 min, 95% CI 126.5–348.9).

In three of 16 Code STEMI with culprit lesion (18.8%), the blinded cardiologist identified the first ECG as ischemic. Ten of 16 (62.5%) had the cath lab activated (either by emergency physician or by cardiologist) without any ED ECG having a final cardiology interpretation of "STEMI"; these activations were based on factors including ischemic symptoms, ECG changes not meeting STEMI criteria, regional wall motion abnormality on point-of-care ultrasound, and elevated troponin level. The two Code STEMI without culprit lesion with initially normal ECG included one patient with pancreatitis and an erroneous ECG interpretation and one patient with ischemic changes from spontaneous coronary artery dissection who was treated medically, the latter of which was an appropriate cath lab activation because this is an angiographic diagnosis of exclusion.

Our study helps clarify a number of questions about the accuracy of automated interpretation, safety of deferring physician interpretation, and importance of the OMI paradigm shift. First, prior studies could not find cases of normal ECGs with clinical relevance, but these were performed at single centers over very short durations (from 8 days to 16 weeks).[1–4] Instead of reviewing all normal initial ECGs over weeks or months to identify which ones were associated with clinical consequences, we looked at all Code STEMI patients over 7 years: we found that 4% of Code STEMIs requiring coronary intervention had an initial ECG labeled normal or otherwise normal.

Secondly, previous studies were not based on patient outcomes; rather, the outcomes were based on final ED diagnosis without regard to angiographic findings,[1] blinded cardiologist interpretation of the ECG,[2,3] or emergent cardiac catheterization defined as within 4 h of ED presentation (i.e., ignoring those whose angiograms were delayed).[3] Instead, our outcome was Code STEMI requiring coronary intervention. Three of our normal ECGs were identified by blinded cardiologists as showing possible ischemia, but the remainder were not free from clinical relevance because all patients had acute culprit lesions requiring coronary intervention. Three had door-to-cath times of greater than 4 h, which other studies would exclude because they did not have "emergent cardiac catheterization."[3]

Third, prior studies found "no delay in patient care or poor outcome"[2] and suggested that "any delay in EP (emergency physician) review of the computer interpreted normal ECG would not lead to adverse patient outcomes."[3] Another hypothesized that ECG interpretation could "be deferred until the actual patient encounter"[4] and responded to concerns of falsely normal ECGs by stating that "expecting EPs to identify patients with acute coronary occlusion with computer interpreted normal ECGs may be unreasonable."[10] But we found that 37.5% of Code STEMIs with culprits whose first ECGs were labeled as normal were still identified in real time by emergency physicians, despite the false reassurance of the computer interpretation. This altered the triage process and improved patient care, leading to faster reperfusion than those that were not identified.

Our study has several limitations. We reviewed a Code STEMI database, which does not include patients admitted with "non-STEMI" who are later found to have acute coronary occlusion. It is therefore likely that our study underestimates the number of falsely normal ECGs, both because of the larger numbers of non-STEMI and because acute coronary syndrome patients whose ECGs do not meet STEMI criteria are more likely to be admitted as non-STEMI. The fact that 93.8% of patients presented with chest pain and only 18.8% were female suggests that there is a selection bias and that there may be patients with acute coronary occlusion who present with anginal equivalents and normal ECG who were admitted as non-STEMI with even greater reperfusion delay. The results of this study are limited to one conventional (nonneural network) algorithm, namely, the Marquette 12 SL. However, they likely apply to all such algorithms. In a collection of falsely normal cases,[9] the majority were interpreted by the Veritas algorithm. While the risks of computer-labeled normal ECGs are likely generalizable to any ED using conventional algorithm, the benefits of physician review are less generalizable because our two centers have received audit/feedback on advanced ECG interpretation

TABLE 1 ED Code STEMI patients with initial ECG labeled normal or otherwise normal by computer interpretation.

Patient	Computer interpretation	Blinded cardiologist interpretation	Treating emergency physician interpretation	Patient management	Door-to-cath time (min)	Angiogram result	Troponin first and peak (ng/L)
1	Normal sinus rhythm, normal ECG.	Normal sinus rhythm, normal ECG.	ECG not signed off.	Seen after troponin: "ST elevation V1-2" but no STEMI. Stat cardiology consult: cath lab activation.	202 min	100% mid LAD occlusion, PCI performed.	100 to 19,049
2	Normal sinus rhythm, normal ECG.	Normal sinus rhythm, normal ECG.	"Inferior changes: repeat."[a]	Serial ECG: "STEMI" Cath lab activation.[a]	118 min	95% proximal LAD occlusion, PCI performed.	31 to 11,894
3	Sinus bradycardia, otherwise normal ECG.	Sinus bradycardia, otherwise normal ECG.	"ST depression inferior, mild STE i/aVL,? high lateral MI."[a]	Serial ECG dynamic change but no STEMI. Stat cardiology consult: cath lab activation.[a]	95 min	99% obtuse marginal occlusion, PCI performed.	100 to 13,280
4	Sinus rhythm with occasional PVC, otherwise normal ECG.	Sinus rhythm, Otherwise normal ECG.	Signed off.	Recurring chest pain with repeat ECG "STEMI."	183 min	99% mid LAD occlusion, PCI performed.	41 to 18,870
5	Normal sinus rhythm, normal ECG.	Normal sinus rhythm, cannot rule out inferior injury.	"ST elevation II, III, aVF."[a]	Repeat ECG: "STEMI." Cath lab activated.[a]	52 min	100% RCA occlusion, PCI performed.	419 to 7875
6	Normal sinus rhythm, normal ECG.	Normal sinus rhythm, normal ECG.	Signed off.	Seen after troponin. Repeat ECG: "ST elevation in V2?" but not STEMI. Stat cardiology consult: cath lab activated.	145 min	100% distal LAD occlusion, PCI performed.	611 to >50,000
7	Normal sinus rhythm, normal ECG.	Normal sinus rhythm, normal ECG.	"Hyperacute T in V3."[a]	Repeat ECG: "deWinter T." Cath lab activated.[a]	44 min	100% LAD occlusion, PCI performed	4 to >50,000
8	Normal sinus rhythm, normal ECG.	Normal sinus rhythm, normal ECG.	Signed off.	Repeat ECG ST elevation but not STEMI criteria. Cath lab activated, VF defibrillated.	190 min	95% proximal LAD occlusion, PCI performed.	187 to 41,043
9	Normal sinus rhythm, normal ECG.	Normal sinus rhythm, normal ECG.	"Anterior ST depression."[a]	Posterior leads: "STEMI." Cath lab activation.[a]	91 min	100% ramus intermedius occlusion, PCI performed.	183 to 46,226
10	Sinus bradycardia, otherwise normal ECG.	Sinus bradycardia, otherwise normal ECG.	Signed off.	Cardio consult for NSTEMI: cath lab activated for refractory ischemia.	105 min	100% distal RCA occlusion, PCI performed. Discharge diagnosis "NSTEMI."	920 to 40,729
11	Sinus rhythm with first-degree AV block, otherwise normal ECG.	Sinus rhythm with first-degree AV block. Inferior injury pattern cannot rule out.	"ST elevation inferior leads with ST depression in lateral leads."[a]	Repeat ECG: "STEMI." Cath lab activation.[a]	81 min	100% RCA occlusion, PCI performed.	26 to 54,737
12	Sinus tachycardia, otherwise normal ECG.	Sinus tachycardia, otherwise normal ECG.	Signed off.	CT rule out dissection. Repeat ECG: "STEMI." Cath lab activation.	304 min	99% mid LAD occlusion with low flow, PCI performed.	148 to 8171
13	Normal sinus rhythm, normal ECG.	Normal sinus rhythm, normal ECG.	Signed off	Seen after troponin results. Posterior lead no ST elevation. Refer to cardiology as NSTEMI but cath lab activated.	293 min	99% circumflex occlusion, PCI performed.	1190 to 12,219
14	Normal sinus rhythm, normal ECG.	Normal sinus rhythm, early repolarization.	"Unchanged."	Seen after troponin results. "ST elevation V2 1mm, ST elevation V1 < 1 mm." Referred to cardiology as NSTEMI: cath lab activated.	199 min	95% proximal LAD occlusion, no TIMI flow reported, PCI performed.	359 to 2963 but not repeated after
15	Normal sinus rhythm, normal ECG.	Normal sinus rhythm, normal ECG.	"Normal"	Refer to cardiology as NSTEMI: cath lab activated for dynamic ST change.	639 min	100% obtuse marginal occlusion with collateral circulation, TIMI not reported. PCI performed.	2819 then declined

TABLE 1 Continued

Patient	Computer interpretation	Blinded cardiologist interpretation	Treating emergency physician interpretation	Patient management	Door-to-cath time (min)	Angiogram result	Troponin first and peak (ng/L)
16	Normal sinus rhythm, normal ECG.	Normal sinus rhythm, ST elevation consider anterior injury or acute infarct.	Signed off.	Seen after troponin result with ongoing pain, new Q wave and anterior regional wall motion abnormality; cath lab activated.	117 min	100% mid LAD occlusion with collateral circulation, TIMI flow not reported. PCI not successful.	97 to 8227
17	Normal sinus rhythm, normal ECG.	Normal sinus rhythm, normal ECG.	"ST elevation in aVL with ST depression inferior."[a]	Repeat ECG: "STEMI." Cath lab activated.[a]	85 min	SCAD of second diagonal, medical treatment.	64 to 21,923
18	Normal sinus rhythm, normal ECG.	Normal sinus rhythm. T-wave abnormality, consider inferior ischemia.	"ST elevation V1-V2, ST depression II, III, aVF."	Cath lab activated.	118 min	No significant coronary artery disease. Diagnosed pancreatitis.	6 to 8

Note: "Signed off" indicates that the ECG was signed by the physician without interpretation.

Abbreviations: LAD, left anterior descending; NSTEMI, non–ST-elevation myocardial infarction; PCI, percutaneous coronary intervention; RCA, right coronary artery; SCAD, spontaneous coronary artery dissection; STEMI, ST-elevation myocardial infarction.

[a]Discrepancies correctly identified, leading to immediate management.

since 2019.[11] Future studies can look at all patients with OMI, from both STEMI and non-STEMI databases, and can use emerging automated intelligence interpretation to identify normal ECGs diagnostic of OMI, which would be generalizable beyond centers with ECG audit/feedback.

Despite these limitations, we found that 4% of ED Code STEMI patients with acute culprit lesions requiring coronary intervention had an initial ECG labeled normal or otherwise normal. More than a third of these ECGs were identified in real time by emergency physicians, leading to rapid reperfusion, and nearly two-thirds of these cases had the cath lab activated without ever meeting STEMI criteria. Rather than the hazards of deferring ECG interpretation for those labeled normal by the computer, emergency physicians should be trained in advanced ECG interpretation as part of the OMI paradigm shift.

AUTHOR CONTRIBUTIONS

All authors contributed to the conceptualization of the project. Jesse T. T. McLaren performed data analysis and wrote the initial draft. H. Pendell Meyers, Stephen W. Smith, and Lucas B. Chartier contributed critical review and editing.

CONFLICT OF INTEREST STATEMENT

HPM has been a paid consultant to Rapid AI and Baxter/Veritas and holds stocks from Powerful Medical; SWS reported personal fees from Cardiologs, HEARTBEAM, Rapid AI, and Baxter/Veritas and holds stocks from Powerful Medical. The other authors declare no conflicts of interest.

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SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.

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