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Emergent cardiac outcomes in patients with normal electrocardiograms in the emergency department

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ABSTRACT

Background: Emergency physicians (EP) are frequently interrupted to screen electrocardiograms (ECG) from Emergency Department (ED) patients undergoing triage. Our objective was to identify discrepancies between the computer ECG interpretation and the cardiologist ECG interpretation and if any patients with normal ECGs underwent emergent cardiac intervention. We hypothesized that computer-interpreted normal ECGs do not require immediate review by an EP.

Methods: This was a retrospective study of adult (≥ 18 years old) ED patients with computer-interpreted normal ECGs. Laboratory, diagnostic testing and clinical outcomes were abstracted following accepted methodologic guidelines. The primary outcome was emergent cardiac catheterization (within four hours of ED arrival). All ECGs underwent final cardiologist interpretation. When cardiology interpretation differed from the computer (discrepant ECG interpretation), the difference was classified as potentially clinically significant or not clinically significant. Data was described with simple descriptive statistics.

Main findings: 989 ECGs interpreted as normal by the computer were analyzed with a mean age of 50.4 ± 16.8 years (range 18–96 years) and 527 (53%) female. Discrepant ECG interpretations were identified in 184 cases including 124 (12.5%, 95% CI 10.4, 14.7%) not clinically significant and 60 (6.1%, 95% CI 4.6, 7.7%) potentially clinically significant. The 60 potentially clinically significant changes included: ST/T wave changes 45 (75%), T wave inversions 6 (10%), prolonged QT 3 (5%), and possible ischemia 10 (17%). Of these 60, 21 (35%) patients were admitted. Six patients had potassium levels >6.0 mEq/L, with one having a potentially clinically significant ECG change. No patient (0%, 95% CI 0, 0.3%) underwent immediate (within four hours) cardiac catherization whereas two underwent delayed cardiac interventions.

Conclusions: Cardiologists frequently disagree with a computer-interpreted normal ECG. Patients with computer-interpreted normal ECGs, however, rarely had significant ischemic events. A rare number of patients will have important cardiac outcomes regardless of the computer-generated normal ECG interpretation. Immediate EP review of the ECG, however, would not have changed these patients' ED courses.

1. Introduction

Emergency physicians (EPs) are frequently interrupted throughout their shifts for multiple reasons. Studies demonstrate EP interruptions occur 6–13 times per hour, almost three times more than primary care physicians [1-3]. Furthermore, one-third of these hourly interruptions are low-priority tasks [1,2]. One common source of interruption is the review of triage electrocardiograms (ECG) for abnormalities warranting immediate patient evaluation [4]. These interruptions are distractions that increase cognitive load, decrease efficiency, slow patient care and increase the potential for error [1-3,5]. Identifying a subgroup of ECGs that do not require immediate review by an EP during the triage process would decrease interruptions in workflow and physician cognitive burden without impacting patient safety or management.

Automated computer ECG interpretation is routinely provided for all ECGs at the time of printout. The computer interpretation is believed to decrease time of ECG interpretation as well as limit errors [6-8]. Recommendations suggest that computer interpretation should only be used in conjunction with the physician interpretation as errors, including clinically important errors, in computer interpretation still occur [9].

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Some evidence suggests that when the computer interprets the ECG as normal, changes in triage care are unlikely [10]. Prior literature does not, however, determine the extent to which important clinical errors occur when the computer interprets the ECG as normal. Most concerning would be a misinterpretation of an ECG as normal in patients with acute myocardial infarction as that may delay appropriate care [11]. A recent study has called for future investigation of computer interpreted normal ECGs to determine if any abnormalities actually occur warranting immediate EP interpretation [4].

The current study's objective was to identify discrepancies between the computer-interpreted normal ECG and the final cardiologist interpretation and determine if these discrepancies were clinically significant. We hypothesized that computer-interpreted normal ECGs do not require immediate review by an EP as patients with computer-interpreted normal ECGs rarely require emergent cardiac interventions.

2. Methods

2.1. Study design

This was a retrospective chart review of adult (≥ 18 years old) ED patients with computer-interpreted normal ECGs. The study was approved by the site's Institutional Review Board.

2.2. Study population and setting

Patients 18 years of age or older evaluated at the study site's Emergency Department (ED) with computer-interpreted normal ECGs were eligible. The study site is an urban center that provides care for approximately 85,000 patient visits annually. The center is certified by The Joint Commission as a Primary Heart Attack Center which includes being able to provide first ECG within 10 min of patient arrival and primary percutaneous coronary intervention within 90 min. A computer-interpreted normal ECG was defined as an interpretation of "Normal sinus rhythm, Normal ECG" by proprietary cardiology software on MUSE Cardiology Information System (General Electric Product Version 8.0 SP2). Exclusion criteria included any of the following: pregnancy, prisoners, and cognitively impaired individuals.

2.3. Study protocol

All ECGs performed at the study site ED between February 1, 2018 and April 30, 2018 were queried. Any normal ECG collected during a patient's ED encounter was included in the data set; if more than one normal ECG was collected on the same patient during a single ED encounter, each ECG was included in the data set as a discrete encounter. From the data query, a subset of computer-generated normal ECGs was identified to calculate the percentage of normal ECGs collected at the study site's ED. All computer interpreted normal ECGs underwent final review and interpretation by a board certified/eligible cardiologist. For study purposes, the cardiologist interpretation was considered the gold standard ECG interpretation.

Medical records were reviewed for all patients and data was abstracted following accepted methodologic requirements for retrospective studies [12]. Variables were defined prior to abstraction and abstractors were trained on all study definitions prior to data abstraction. Laboratory and clinical outcome data were entered into a standardized database. Laboratory data included potassium and troponin levels. During this time, the site used a conventional cardiac troponin I (TnI-Ultra, Siemens, Malvern, PA) with levels ≤40 ng/L considered normal. Hyperkalemia was defined as a potassium level greater than 6.0 mEq/L. Clinical outcomes collected included ED disposition, cardiac stress testing, cardiac catheterization and coronary artery intervention. Abstractors were blinded to the cardiologist interpretation (gold standard) at the time of their review.

2.4. Measurements

The primary outcome of interest was the number of patients taken emergently/urgently for cardiac catheterization (within four hours of ED presentation). Secondary outcomes included 1) patients requiring cardiac interventions [percutaneous coronary intervention (PCI), coronary artery bypass graft (CABG)] and 2) potentially clinically significant ECG overreads by the cardiologist. In those instances where the cardiologist interpretation was discrepant (i.e. a finding different than normal ECG), the disagreement was further classified by trained staff as potentially clinically significant or not clinically significant. Potentially clinically significant changes included any of the following: non sinus rhythm, ST/T wave changes, T wave inversions, prolonged QT intervals, or indications of ischemia. Disagreements considered not clinically significant included "PACs are no longer present", "rate has decreased", "nonspecific T wave abnormality no longer evident in lateral leads", "PR has shortened", "criteria for infarct are no longer present."

2.5. Data analysis

Data was described with simple descriptive statistics. Continuous data are reported as the mean ± one standard deviation (SD). Ninety-five percent confidence intervals (CI) are calculated where appropriate. A sample of medical records were reviewed by a second abstractor to confirm inter-rater reliability of the primary outcome (emergent cardiac catheterization) and classification of ECG discrepancies as clinically significant or not. Inter-rater reliability was measured using the kappa statistic.

The sample size was calculated to provide an acceptable upper bound of the 95% confidence interval around the true rate of patients requiring emergency/urgent cardiac intervention based on the following assumptions: alpha error of 0.05, a proportion of normal ECGs that are determined to require emergent/urgent intervention of 0.1%, and power of 0.99. These calculations yielded a necessary sample size of 800 ECGs.

3. Results

A total of 8306 ECGs were performed at the site during the study period, of which 1747 (21%) were interpreted by the computer as "Normal sinus rhythm, Normal ECG". Of these 1747 normal ECGs, a consecutive series of the most recent (in reverse chronological order) ECGs were reviewed by trained study staff. Eleven subjects met exclusion criteria and were not further analyzed. Therefore, the study dataset contained 989 ECGs interpreted as normal by the computer program. The mean age was 50.4 ± 16.8 years (range 18–96 years), and 527 (53%) were female.

After cardiologist review, 184 (18.6%, 95% CI 16.3, 21.2%) of the 989 ECGs had discrepant interpretations (at least one abnormality identified by the cardiologist). Of the 184 discrepant ECGs, 124 (12.5%, 95% CI 10.4, 14.7%) were defined as not clinically significant. Conversely, 60 (6.1%, 95% CI 4.6, 7.7%) were defined as potentially clinically significant changes (Table 1). Of these 989 patients, 10 (1.0%, 95% CI 0.5, 1.9%) had their ECG interpreted as possible ischemia by the cardiologist. In these 10 patients, four patients did not have troponins measured, and the remaining six had normal troponin levels. In addition, none of

Table 1
Discrepancies between the cardiologist interpretation and the computer interpretation of normal ($n = 184$)

Clinically significant finding	$n = 60$	% (95% CI)
ST/T wave changes	45	75% (62, 85)
Possible ischemia	10	17% (8, 29)
T wave inversions	6	10% (4, 21)
Prolonged QT interval	3	5% (1, 14)

these 10 patients underwent cardiac risk stratification during this ED/hospital visit.

Of all 989 encounters, no patient (0%, 95% CI 0, 0.3%) had their cardiac rhythm interpretation changed from sinus rhythm to any other rhythm by the cardiologist. Furthermore, no patient (0%, 95% CI 0, 0.3%) was taken emergently for cardiac catheterization (within 4 h of ED arrival). Six (0.6%, 95% CI 0.2, 1.3%) patients ultimately underwent non-emergent cardiac catheterization (Table 2), and two had cardiac interventions. The first patient was a 77-year-old male presenting with chest pressure, whose ECG was re-interpreted by the cardiologist to include the following: "criteria for inferior infarct are no longer present, nonspecific T wave abnormality no longer evident in lateral leads." Due to patient risk features and elevated troponin values, he was taken for cardiac catheterization. At catheterization, he received three PCI stents to a prior CABG graft. The second patient was a 62-year-old male presenting with chest pain. His initial ECG was completed in the ED and noted "nonspecific ST changes." He had a repeat ECG 6 h later that was read as a normal ECG by both the computer and cardiologist. He had already been scheduled for an outpatient cardiac catheterization, but his cardiologist preferred the patient be admitted at the time of ED presentation for cardiac catherization. At cardiac catheterization, he was found to have multivessel disease, and ultimately underwent a three-vessel CABG.

Six patients had hyperkalemia with potassium levels >6.0 mEq/L. The cardiologist interpreted five of these six ECGs also as normal. The one ECG with hyperkalemia (potassium level = 6.6 mEq/L) interpreted as abnormal by the cardiologist was interpreted as "Normal sinus rhythm with occasional premature atrial complexes; Nonspecific ST and T wave abnormality." No peaked T waves, QT changes or PR lengthening were identified on any of the computer interpreted normal ECGs.

A second abstractor reviewed a sample of discrepant ECG interpretations to measure inter-rater agreement. The two abstractors were found to have moderate agreement for classification of ECG discrepancies as clinically significant or not, with a kappa of 0.60. Abstraction agreement of the primary outcome (emergent/urgent cardiac catheterization) was perfect.

4. Discussion

In the current study of a large, consecutive sample of patients, clinical outcomes of patients with computer interpreted normal ECGs were assessed. Measurable disagreements were identified between computer interpreted normal ECGs and the cardiologist re-interpretations. Despite these somewhat frequent differences (approximately 1 in 5), the changes in ECG interpretations likely had little clinical impact, similar to prior studies [10,13,14]. Most importantly, however, no patient with a computer interpreted normal ECG underwent emergent cardiac intervention.

The majority of the discrepancies between the initial computer interpretation of normal ECG and the cardiologist re-interpretation were considered clinically not significant. These discrepancies included such findings as changes in heart rate, PACs no longer present, nonspecific T wave abnormality no longer present. Some of these discrepancies, however, were considered potentially clinically significant. The most concerning of these potentially clinically significant changes was the change from normal to "possible ischemia" which occurred in approximately 1% of the ECGs initially interpreted as normal by the computer. Despite this change, none of these patients had elevated troponin levels in the ED and none had positive cardiac stress testing during that ED visit or hospital admission. This finding suggests any delay in EP review of the computer interpreted normal ECG would not lead to adverse patient outcomes.

The computer interpreted all ECGs in this study as normal sinus rhythm. The cardiologist reviewing all these ECGs agreed on the rhythm. This is important as certain abnormal rhythms including both second- and third-degree heart block would require immediate review by the EP and likely instituting emergent cardiac monitoring. Computer interpretation errors in the rhythm most often occur when the rhythm is non-sinus as sinus rhythms are readily identified by the computer programs [15]. ECGs are additionally used to screen for other abnormalities besides ischemia and cardiac rhythm. Hyperkalemia provides characteristic ECG changes including peaked T waves and a prolonged QRS interval. In this study, none of the six patients with computer interpreted normal ECGs and hyperkalemia had findings suggesting immediate evaluation for hyperkalemia was necessary.

EDs are now frequently dealing with increasing patient volumes and overcrowded conditions. These factors contribute to the increasing demands placed on EPs as they provide care for multiple critically ill and injured patients. Physician burnout is now recognized as a substantial problem in medicine, and Emergency Medicine has the highest burnout rate of all specialties [16]. Methods to promote physician wellness and combat burnout, especially for EPs, are needed. Avoiding/minimizing interruptions to the physician is one method to improve the workplace environment and limit EP burnout [17]. This study does not suggest that EPs should stop reviewing ECGs interpreted as normal by the computer program; as per AHA guidelines and other expert recommendations, all computer-interpreted ECGs require physician over-reading [6,18]. However, it suggests that immediate review (by an EP) of computer-interpreted normal ECGs during the triage process is not likely to impact immediate patient care and is perhaps unnecessary. Eliminating immediate physician review of these normal ECGs would decrease physician distractions and likely improve physician satisfaction [19]. In addition, it would potentially increase patient safety as interruptions in the middle of a high-risk task (i.e. placing orders, etc.) can lead to errors and potential adverse outcomes for other patients [2,3,5,20].

The study has certain limitations. The retrospective chart review is subject to the limitations of such a study. Due to the design, abstractors

Table 2
Patients undergoing cardiac catherization after a computer interpreted normal ECG in the ED

Age (years)	Sex	Indication for cardiac cath	Coronary artery findings	Cardiac intervention	Time to cath (hours)
76	F	Possible stent thrombosis	Patent pre-existing stent	None	N/a
72	M	Possible stent thrombosis	Patent pre-existing stent	None	N/a
75	F	NSTEMI	Severe three vessel disease (LAD, RCA, LCX)	Medical management	N/a
70	F	Abnormal outpatient stress test	30% occlusion of LAD	None	N/a
76	M	NSTEMI	80% occlusion of OM graft	Stent placement	7.5
62	M	Outpatient Cardiologist request for inpatient catheterization	Severe multivessel disease (LAD, LCX, OM, RCA)	CABG	16

NSTEMI: non-ST elevation myocardial infarction.
LAD: left anterior descending artery.
RCA: right circumflex artery.
LCX: left circumflex artery.
OM: obtuse marginal artery.
CABG: coronary artery bypass graft.
N/a: not applicable.

were aware that all ECGs were interpreted by the computer as normal. In addition, coding of discrepant ECG interpretations was categorized as potentially clinically significant versus not clinically significant by one abstractor. Any ambiguous ECG overreads were, however, coded by research group consensus. Cardiologist interpretation was considered the gold standard, however, significant interobserver variability is well known [21] and no specific training of the cardiologist was done for this study. The primary outcome of interest was defined a priori as cardiac catheterization within four hours of ED presentation. The times to catheterization, however, are provided in Table 2. Finally, computer interpretation of the ECG is based on a programmed algorithm. As each algorithm is proprietary, providers were not permitted to review the computer algorithm. In addition, computer algorithms likely vary between different software programs, thus generalizability of this study's findings may not be possible to other computer algorithms. Calls for standardizing manufactures' algorithms have been made which would resolve this limitation [6].

5. Conclusions

Cardiologists frequently disagree with a computer-interpreted normal ECG. Patients with computer-interpreted normal ECGs, however, rarely had significant ischemic events. A rare number of patients will have important cardiac outcomes regardless of the computer-generated normal ECG interpretation. Immediate EP review of the ECG, however, would not have changed these patient's ED courses.

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None (COVID cancelled meetings).

Declaration of Competing Interest

The authors have no conflicts of interest.

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