Implementation of an All-Day Artificial Intelligence—Based Triage System to Accelerate Door-to-Balloon Times

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Abstract

Objective: To implement an all-day artificial intelligence (AI)—based system to facilitate chest pain triage in the emergency department.

Methods: The AI-based triage system encompasses an AI model combining a convolutional neural network and long short-term memory to detect ST-elevation myocardial infarction (STEMI) on electrocardiography (ECG) and a clinical risk score (ASAP) to prioritize patients for ECG examination. The AI model was developed on 2907 twelve-lead ECGs: 882 STEMI and 2025 non-STEMI ECGs.

Results: Between November 1, 2019, and October 31, 2020, we enrolled 154 consecutive patients with STEMI: 68 during the AI-based triage period and 86 during the conventional triage period. The mean ± SD door-to-balloon (D2B) time was significantly shortened from 64.5±35.3 minutes to 53.2±12.7 minutes (*P*=.007), with 98.5% vs 87.2% (*P*=.009) of D2B times being less than 90 minutes in the AI group vs the conventional group. Among patients with an ASAP score of 3 or higher, the median door-to-ECG time decreased from 30 minutes (interquartile range [IQR], 7—59 minutes) to 6 minutes (IQR, 4—30 minutes) (*P*<.001). The overall performances of the AI model in identifying STEMI from 21,035 ECGs assessed by accuracy, precision, recall, area under the receiver operating characteristic curve, F1 score, and specificity were 0.997, 0.802, 0.977, 0.999, 0.881, and 0.998, respectively.

Conclusion: Implementation of an all-day AI-based triage system significantly reduced the D2B time, with a corresponding increase in the percentage of D2B times less than 90 minutes in the emergency department. This system may help minimize preventable delays in D2B times for patients with STEMI undergoing primary percutaneous coronary intervention.

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ST-segment elevation myocardial infarction (STEMI) is a medical emergency, and early reperfusion with primary percutaneous coronary intervention (PPCI) is essential to improve the clinical outcomes of patients with STEMI. Previous studies have demonstrated that shortened door-to-balloon (D2B) times for patients with STEMI undergoing PPCI significantly reduced mortality and morbidity rates.[1-3] Therefore, the 2013 American College of Cardiology Foundation/American Heart Association guideline gave a class I recommendation that the first medical contact—to-device time should be less than 90 minutes for patients with STEMI undergoing PPCI.[4] The latest 2017 European Society of Cardiology STEMI guidelines even recommend that the target time delay from STEMI diagnosis to wire crossing should be less than 60 minutes in PCI-capable institutes.[5] However, this D2B time goal is often compromised by failure to perform or interpret electrocardiograms (ECGs) efficiently.

To accelerate D2B times, we implemented an all-day, continuously running

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artificial intelligence (AI)—based triage system consisting of an AI-assisted diagnosis of STEMI on ECGs and a computer-generated scoring tool to identify high-risk patients requiring prompt ECG examination. Compared with conventional computerized ECG algorithms for STEMI detection with large variations in sensitivity and specificity,[6,7] AI models with deep learning technologies have been shown to surpass the performance of commercial autodiagnostic algorithms reaching the cardiologist level in providing a timely STEMI diagnosis.[8] With the AI-based approach, all emergency department (ED) ECGs can be quickly and correctly interpreted on an all-day basis to overcome the ECG-related impediments in STEMI diagnosis.

We previously developed a bidirectional long short-term memory (LSTM) deep learning model to detect 12 major heart rhythms.[9] Based on this model, we further developed a new model with a multilabeling capability to identify STEMI and 12 different heart rhythms,[8] and the proposed AI model outperformed board-certified physicians with different specialties, including cardiologists, emergency physicians, and internists. Therefore, in June 2020, we implemented an all-day AI-based triage system consisting of AI technology to detect STEMI on ECGs and a computerized risk scoring tool in the ED. The purpose of the present study was to compare total D2B times and individual components of D2B time between patients with STEMI enrolled before and after introducing the AI-based triage system. In addition, we also examined whether the automated scoring tool can effectively identify high-risk patients requiring prompt ECG examination. The ultimate goal was to provide real-world evidence by assessing how the AI-based triage system may affect chest pain triaging and clinical decision-making in our daily practice.

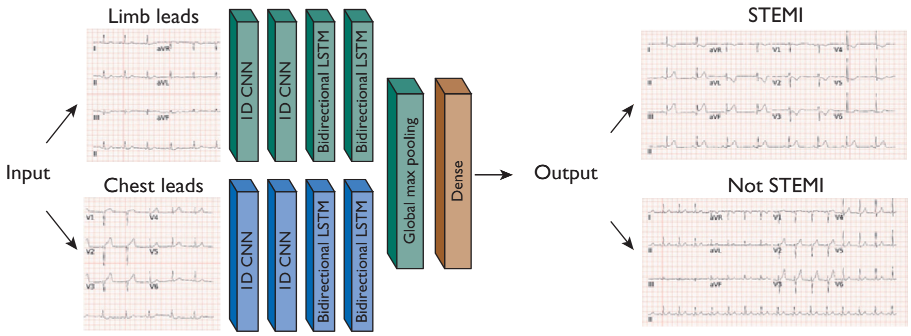
METHODS

AI-Assisted STEMI Detection on ECGs and ED Triage

Data Collection and Labeling. We first retrieved 12-lead ECG data from the digital ECG core laboratory database at China Medical University Hospital between January 15, 2009, and December 31, 2018. The 12-lead ECGs were recorded according to a standardized protocol and lead position at a sampling rate of 500 Hz using a computerized ECG machine (MAC 2000/3500/5500, GE Healthcare). The digital ECG was transmitted to and stored at the ECG core laboratory of China Medical University Hospital. In total, 3296 twelve-lead ECGs were retrospectively retrieved in an extensible markup language (XML) format as inputs to develop the AI model.

The 3296 twelve-lead ECGs of the training data set were labeled simultaneously by 3 board-certified cardiologists, with their consensus serving as the ground truth. Of these ECGs, 999 were labeled “STEMI” according to the standard diagnostic criteria[10] and 2297 were categorized as “non-STEMI.” We further excluded noisy ECGs from the original 3296 ECGs as judged by the ground truth committee, and the remaining 2907 ECGs containing 882 STEMI ECGs and 2025 non-STEMI ECGs were used for model training (80%) and validation (20%).

Proposed Deep Learning Model. A new model combining a convolutional neural network (CNN) and LSTM was used to facilitate STEMI ECG diagnosis in this study (Figure 1). In this model, 6 chest leads were fed into one 1-dimensional (1D) CNN and 6 limb leads were fed into another 1D CNN. The outputs of the two 1D CNNs were connected to 2 layers of LSTM, and the outputs of the 2 LSTMs were concatenated and connected to a fully connected layer. The binary cross-entropy loss function and Adam optimizer were used during model training. F1 scores, precision, and recall were monitored to retain the best model in the validation set. To evaluate the model’s performance before its deploying, an additional 4007 twelve-lead ECGs from patients in the ED were tested against the consensus (ground truth) of 3 board-certified cardiologists, and these 4007 twelve-lead ECGs were the internal test cohort. The overall performance of the proposed AI model was



	Predicted false	Predicted true
Actual false	3974	2
Actual true	0	31

Internal test

	Predicted false	Predicted true
Actual false	20,818	42
Actual true	4	171

External test

	F1	Recall	Precision	AUC	Accuracy	Specificity
Internal test (N=4007)	0.968	1.000	0.939	0.986	0.999	0.999
External test (N=21,035)	0.881	0.977	0.802	0.999	0.997	0.998

FIGURE 1. Diagram of the deep learning model architecture and the model's performance. The model was a combination of a convolutional neural network (CNN) and long short-term memory (LSTM). Six chest leads and 6 limb leads were fed into 2 separate 1-dimensional (1D) CNNs. The outputs of the two 1D CNNs were connected to 2 layers of LSTM, and the outputs of the 2 LSTMs were concatenated and connected to a fully connected layer. The binary cross-entropy loss function and Adam optimizer were used during model training. To evaluate the model's performance before its deploying, an additional 4007 twelve-lead electrocardiograms (ECGs) from patients in the emergency department before June 2020 were tested against the consensus (ground truth) of 3 board-certified cardiologists, and these 4007 twelve-lead ECGs were the internal test cohort. The performance of the proposed artificial intelligence (AI) model in the internal test is illustrated by a confusion matrix, and the accuracy, precision, recall, area under the receiver operating characteristic curve (AUC), and F1 score were 0.999, 0.939, 1.0, 0.986, and 0.968, respectively. After using the AI system, 21,035 emergency department ECGs were interpreted by the proposed AI system from June 9, 2020, through October 31, 2020, and these 21,035 twelve-lead ECGs were the internal test cohort. In the external test, the overall performances of the AI model in identifying ST-elevation myocardial infarction (STEMI) from 21,035 ECGs assessed by accuracy, precision, recall, AUC, F1 score, and specificity were 0.997, 0.802, 0.977, 0.999, 0.881, and 0.998, respectively.

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Patients Presenting Chest Pain. For every patient presenting chest pain at ED triage, a digital 12-lead ECG examination was performed immediately. Before implementing the AI-based triage system in the ED, when patients presented chest pain, a digital 12-lead ECG was performed immediately and was interpreted by an emergency physician. If the ECG was suspected of STEMI, the emergency physician would call the on-duty

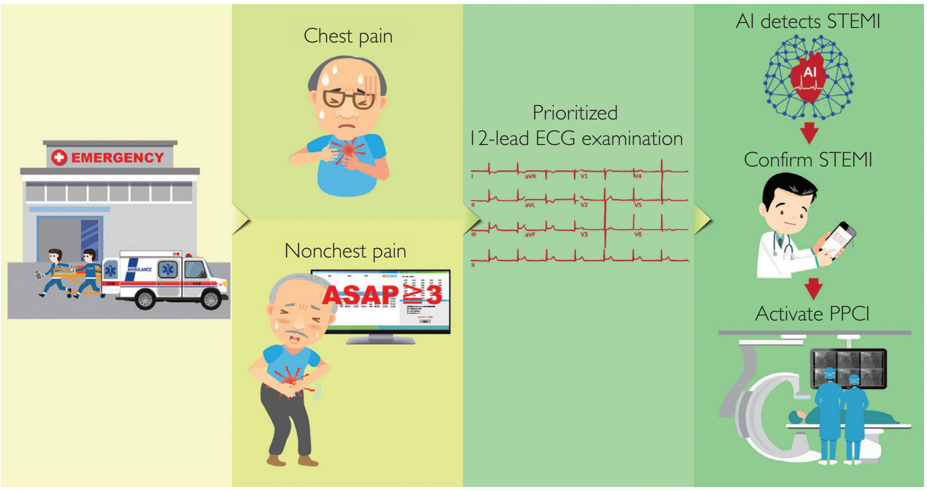

FIGURE 2. Flowchart of the artificial intelligence (AI)—based triage system. For every patient presenting chest pain at emergency department (ED) triage, a digital 12-lead electrocardiography (ECG) examination was performed immediately and subjected to AI interpretation. When the AI model identified ST-elevation myocardial infarction (STEMI) on an ECG, the system automatically sent a warning message along with a link to the specific ECG to ED physicians and on-duty cardiologists on their mobile phones to confirm STEMI and to determine whether to activate primary percutaneous coronary intervention (PPCI). For patients presenting non—chest pain symptoms, a computerized scoring tool was used to identify high-risk patients requiring an immediate 12-lead ECG examination. The ASAP risk score incorporated 4 risk categories: age, sex, atypical presentation, and past medical history. For age and sex, we assigned 1 point for men older than 50 years or women older than 60 years. For atypical symptoms, 1 point was given for each of the following symptoms: an altered state of consciousness, generalized weakness, and abdominal pain or nausea/vomiting. For past medical history, 1 point was assigned for each of the following diseases: hypertension, diabetes, and a history of coronary artery disease.

cardiologist for confirmation and to decide whether to activate PPCI. After applying the AI model to ED triage, each ECG was instantly interpreted by AI (Figure 2). When the AI model identified STEMI on an ECG, the system automatically sent a warning message along with a link to the specific ECG to ED physicians and on-duty cardiologists on their mobile phones. Once STEMI was confirmed by a cardiologist on duty, he or she initiated PPCI treatment for patients reporting ischemic chest pain onset within 12 hours in the ED.

ASAP Score to Identify High-Risk Patients Presenting Atypical Symptoms. For patients presenting non—chest pain symptoms, we designed a scoring tool to identify high-risk patients requiring an immediate 12-lead ECG examination. The ASAP risk score incorporates 4 risk categories: *a*ge, *s*ex, *a*typical presentation, and *p*ast medical history (Supplemental Table 1, available online at http://www.mayoclinicproceedings.org). For age and sex, we assigned 1 point for men older than 50 years or women older than 60 years according to risk assessment indicators delineated by the Global Registry of Acute Coronary Events score.[11] For atypical symptoms, 1 point was given for each of the following symptoms: an altered state of consciousness, generalized weakness, and abdominal pain or nausea/vomiting according to a chest pain unit database. For past medical history, 1 point was assigned for each of the following diseases: hypertension, diabetes, and a history of coronary artery disease (CAD).[12] After inputting clinical data, including age, sex, clinical symptoms, and past medical history, into an online triage system, a pop-up reminder of a prioritized 12-lead ECG examination to be taken immediately appeared on the screen if the computer-generated ASAP score was 3 points or higher.

Comparison Between AI-Based and Conventional ED Triage

We compared total D2B times, individual components of D2B time, and percentages of D2B times less than 90 minutes between the AI-based triage period (June 9, 2020, through October 31, 2020) and the conventional triage period (November 1, 2019, through June 8, 2020). Individual components constituting the total D2B time and inclusion/exclusion criteria for PPCI are defined in the Supplemental Method (available online at http://www.mayoclinicproceedings.org).

Statistical Analysis

Continuous data with normal distribution are expressed as the mean ± SD, and non-normally distributed data are reported as median (25th—75th percentile). Differences in continuous data were analyzed using the Student *t* test between the pre-AI and the post-AI groups. Categorical data are expressed as numbers (percentages) and were compared using the χ^2 test or the Fisher exact test between the pre-AI and post-AI groups. The statistical significance level was set at a 2-tailed $P<.05$. All analyses used SAS software, version 9.4 (SAS Institute Inc). The study protocol was reviewed and approved by the Research Ethics Committee of China Medical University Hospital.

RESULTS

Between November 1, 2019, and October 31, 2020, a total of 154 consecutive patients with STEMI were enrolled and constituted the study population after excluding 23 patients who either met the exclusion criteria at the ED (n=20) or had no significant angiographic CAD (n=3). Among the study population, 68 patients (mean ± SD age, 60±13 years; 58 men) were enrolled during the AI-based triage period and 86 patients (mean ± SD age, 60±14 years; 74 men) were enrolled during the conventional triage period. The Table shows the demographic features, baseline clinical characteristics, and comorbidities of the study patients. No significant differences in age, male-to-female ratio, or initial blood pressure and heart rate values recorded in the ED were found between the 2 patient groups. The percentage of Killip class II through IV patients, the Global Registry of Acute Coronary Events score, and the prevalence of CAD risk factors, including hypertension, diabetes, hyperlipidemia, and smoking, were equivalent between the 2 groups. The ratio of the left anterior descending coronary artery as the culprit artery was higher in the conventional group, but there was no statistically significant difference in the percentage of initial Thrombolysis in Myocardial Infarction 0 or 1 flow in the culprit artery between the conventional and the AI groups. The proportion of patients presenting to the ED during off-hours was also similar between the 2 groups.

The mean D2B time, the individual components of D2B time, and the percentage of D2B times less than 90 minutes are presented in Figure 3 and Supplemental Table 2 (available online at http://www.mayoclinicproceedings.org). Compared with those in the conventional group, the mean ± SD D2B time was shorter (53.2±12.7 minutes vs 64.5±35.3 minutes; P=.007) and the percentage of D2B times less than 90 minutes was higher (98.5% vs 87.2%; P=.009) in the AI group. We further analyzed these parameters during regular hours and off-hours and found no significant differences in mean ± SD D2B time (50.2±15.6 minutes vs 53.1±33.9 minutes; P=.69) or the percentage of D2B times less than 90 minutes (95.5% vs 93.3%; $P>.99$) between the AI group and the conventional group during regular hours. However, during off-hours, the mean ± SD D2B time was shorter (54.6±10.9 vs 70.4±34.8 minutes; P=.002) and the percentage of D2B times less than 90 minutes was higher (100% vs 83.9%; P=.003) in the AI group than in the conventional group. Among the individual components of D2B time, the mean ± SD door-to-ECG time (2.3±2.2 minutes vs 5.0±10.8 minutes; P=.03), TABLE. Demographic and Clinical Characteristics[a,b]

Characteristic	Conventional group (n=86)	AI-based group (n=68)	*P* value
Age (y), mean ± SD	60.2±14.2	59.9±13.5	.77
Sex (No. [%])			
Male	74 (86.0)	58 (85.3)	.90
Female	12 (14.0)	10 (14.7)	
ED presentation, mean ± SD			
Systolic blood pressure (mm Hg)	135.2±25.0	129.9±27.4	.22
Diastolic blood pressure (mm Hg)	84.4±18.5	81.8±16.7	.37
Heart rate (beats/min)	79.7±20.3	78.6±18.8	.71
Respiratory rate (breaths/min)	20.1±1.7	20.2±1.1	.55
Killip classification (No. [%])			
Class I	70 (81.4)	44 (64.7)	.10
Class II	7 (8.1)	13 (19.1)	
Class III	3 (3.5)	5 (7.4)	
Class IV	6 (7.0)	6 (8.8)	
GRACE score, mean ± SD	114.3±36.5	107.2±36.0	.23
CAD risk factors (No. [%])			
Hypertension	38 (44.2)	31 (45.6)	.86
Diabetes	18 (20.9)	19 (27.9)	.31
Hyperlipidemia	5 (5.8)	8 (11.8)	.19
Smoking	47 (54.7)	41 (60.3)	.48
Stroke	1 (1.2)	1 (1.5)	.81
Culprit artery (No. [%])			.005[c]
LAD	44 (53.7)	31 (47.7)	
LCX	1 (1.2)	11 (16.9)	
LM	1 (1.2)	0	
RCA	36 (43.9)	23 (35.4)	
Culprit artery initial TIMI flow grade (No. [%])			.11
TIMI 0 + TIMI 1	65 (76.5)	44 (64.7)	
TIMI 2 + TIMI 3	20 (23.5)	24 (35.3)	
Off-hours (No. [%])	56 (65.1)	46 (67.7)	.74

[a] AI, artificial intelligence; CAD, coronary artery disease; ED, emergency department; GRACE, Global Registry of Acute Coronary Events; LAD, left anterior descending; LCX, left circumflex; LM, left main; RCA, right coronary artery; TIMI, Thrombolysis in Myocardial Infarction.

[b] Continuous data were compared using the Student *t* test. Categorical data were compared using the χ^2 test or the Fisher exact test.

[c] Statistically significant.

catheterization laboratory activation time (8.6±6.5 minutes vs 11.6±11.8 minutes; *P*=.046), and door-to-activation time (10.5±7.3 minutes vs 16.1±16.6 minutes; *P*=.006) were significantly shorter in the AI group than in the conventional group. The catheterization laboratory preparation time and ED transfer time were comparable between the AI and conventional groups. Similarly, the overall reductions in the catheterization laboratory activation time, door-to-activation time, and door-to-ECG time were driven by abbreviation of these times during off-hours.

Throughout the study period, 2601 patients presented to ED triage due to non–chest pain symptoms, of whom 1590 had a retrospectively calculated ASAP score of 3 or higher and 1011 had a prospectively computerized ASAP score of 3 or higher. Among these high-risk patients, the percentage undergoing a 12-lead ECG examination within 10 minutes of their presentation steadily increased monthly from 24.0% at

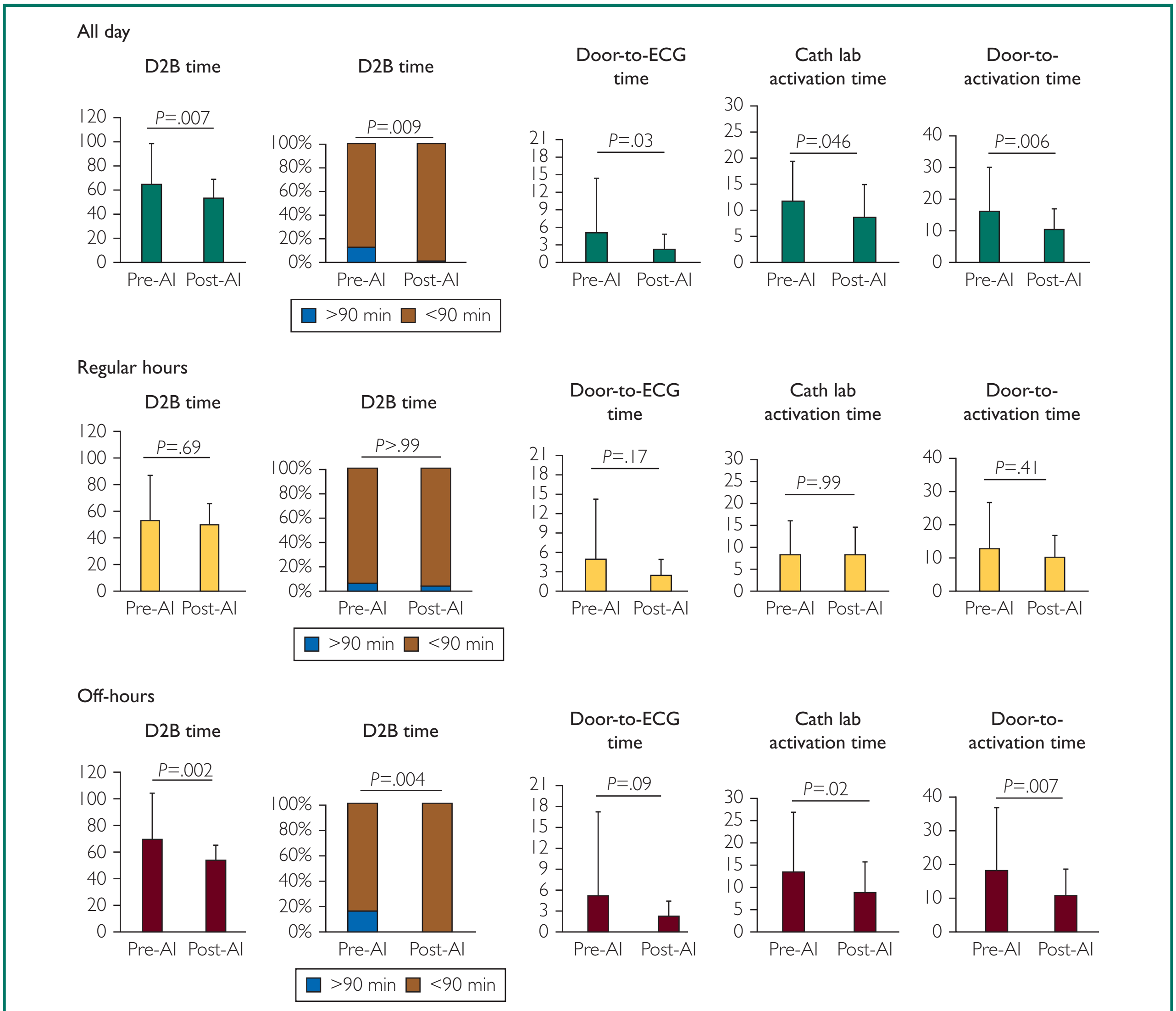

FIGURE 3. Comparisons of door-to-balloon (D2B) time and its components between the artificial intelligence (AI)—based triage group and the conventional triage group. Compared with those in the conventional group, the mean D2B time was shorter and the percentage of D2B times less than 90 minutes was higher in the AI group. No significant differences in the mean D2B time or the percentage of D2B times less than 90 minutes were identified between the AI group and the conventional group during regular hours. However, during off-hours, the mean D2B time was shorter and the percentage of D2B times less than 90 minutes was higher in the AI group than in the conventional group. Among the individual components of D2B time, the mean door-to-electrocardiography (ECG) time, catheterization laboratory (cath lab) activation time, and door-to-activation time were significantly shorter in the AI group than in the conventional group. The cath lab activation time and ED transfer time were comparable between the AI group and the conventional group. Similarly, the overall reductions in the cath lab activation time, door-to-activation time, and door-to-ECG time were mainly driven by abbreviation of these times during off-hours.

baseline before introducing the ASAP score to 43.4%, 56.2%, 62.0%, 57.8%, and 63.4% (*P* for trend <.001) after incorporating the ASAP score for chest pain triage (Supplemental Figure 1, available online at http://www.mayoclinicproceedings.org).

Notably, the median door-to-ECG time decreased from 30 minutes (interquartile range [IQR], 7−59 minutes) before to 6 minutes (IQR, 4−30 minutes) (*P*<.001) after the introduction of the ASAP score (Supplemental Figure 2, available online at http://www.mayoclinicproceedings.org). Furthermore, in 8 of 1011 patients with ASAP scores of 3 or higher who presented non—chest pain symptoms, a timely 12-lead ECG examination motivated by an alert from the AI system led to a prompt diagnosis of STEMI (n=3) and non-STEMI (n=5), and the 3 patients with STEMI received subsequent PPCI successfully.

After using the AI system, 21,035 ED ECGs were interpreted by the proposed AI system from June 9, 2020, through October 31, 2020, and these 21,035 twelve-lead ECGs were the external test cohort. Of these, 213 ECGs (1.0%) were labeled as STEMI by AI, 171 (80.3%) of which were confirmed to be STEMI; and the remaining 42 ECGs (19.7%) were judged to be false-positive results by board-certified cardiologists considering ECG findings, high-sensitivity troponin-I levels, and coronary angiography data to reach the final diagnosis. The false-positive ECGs (Figure 4) were most likely due to early repolarization (n=20), old myocardial infarction (n=14), ventricular pacing (n=3), ventricular tachycardia (n=2), bundle branch block (n=2), or severe baseline drifting (n=1). Four ECGs were erroneously labeled as non-STEMI by AI, 3 of which displayed similar ECG patterns mimicking early repolarization, and the remaining 1 ECG showed hyperacute T waves in precordial leads (Figure 4). Therefore, the overall performances of the AI model in identifying STEMI from 21,035 ECGs assessed by accuracy, precision, recall, area under the receiver operating characteristic curve, F1 score, and specificity were 0.997, 0.802, 0.977, 0.999, 0.881, and 0.998, respectively, in a real-world setting.

DISCUSSION

Door-to-balloon time (or door-to-wire time) is widely recognized as a useful metric and quality indicator for patients with STEMI receiving PPCI to improve disease outcomes.[13-19] To our knowledge, our institute is the first to implement a 24/7 AI-based triage system in the ED to shorten D2B times for patients with STEMI. In contrast to the conventional strategies,[20-29] the proposed AI model not only requires no additional manpower but also provides a cardiologist-level STEMI ECG diagnosis to facilitate chest pain triage in the ED.

AI-Based STEMI ECG Diagnosis in the ED

We have previously shown the usefulness of applying an AI-based approach with a multilabeling capability to identify both STEMI and 12 heart rhythms based on 12-lead ECGs in competitive testing against board-certified physicians with different specialties (internists, emergency physicians, and cardiologists).[8] We demonstrated that the AI tool outperformed cardiologists in detecting STEMI and rhythm classes on 12-lead ECGs, which may be useful for chest pain triage and facilitate decision-making in the ED. Similarly, Zhao et al[30] used a machine learning—based diagnostic model to detect STEMI using 12-lead ECG signals with sensitivity of 97% and specificity of 99%, which surpassed the performance of a commercial autodiagnostic tool. In the present study, we found that after institution of the AI-assisted STEMI ECG diagnostic algorithm in the ED, the mean D2B time was significantly shortened, with a parallel increase in the percentage of D2B times less than 90 minutes to 100% compared with those before the AI system was in service. Of note, the overall performance of the AI system in identifying STEMI among 21,035 ECGs during the study period in the ED was highly accurate (99.7%) with an extremely low false-negative rate (0.1%), reflecting the AI model's value as a tool for diagnostic STEMI screening in EDs. We believe that the current AI-based approach, which reaches the cardiologist level in diagnosing STEMI on ECGs on a 24/7 basis, is a useful tool to facilitate patient triage and can minimize preventable delays for patients with STEMI undergoing reperfusion therapy. In the real world, there is usually limited manpower during off-hours to perform and interpret ECGs correctly in a timely manner, which would result in delayed diagnosis of STEMI and preparation of patients with STEMI for PPCI.[31] It has also been reported that the differences in D2B time between regular hours

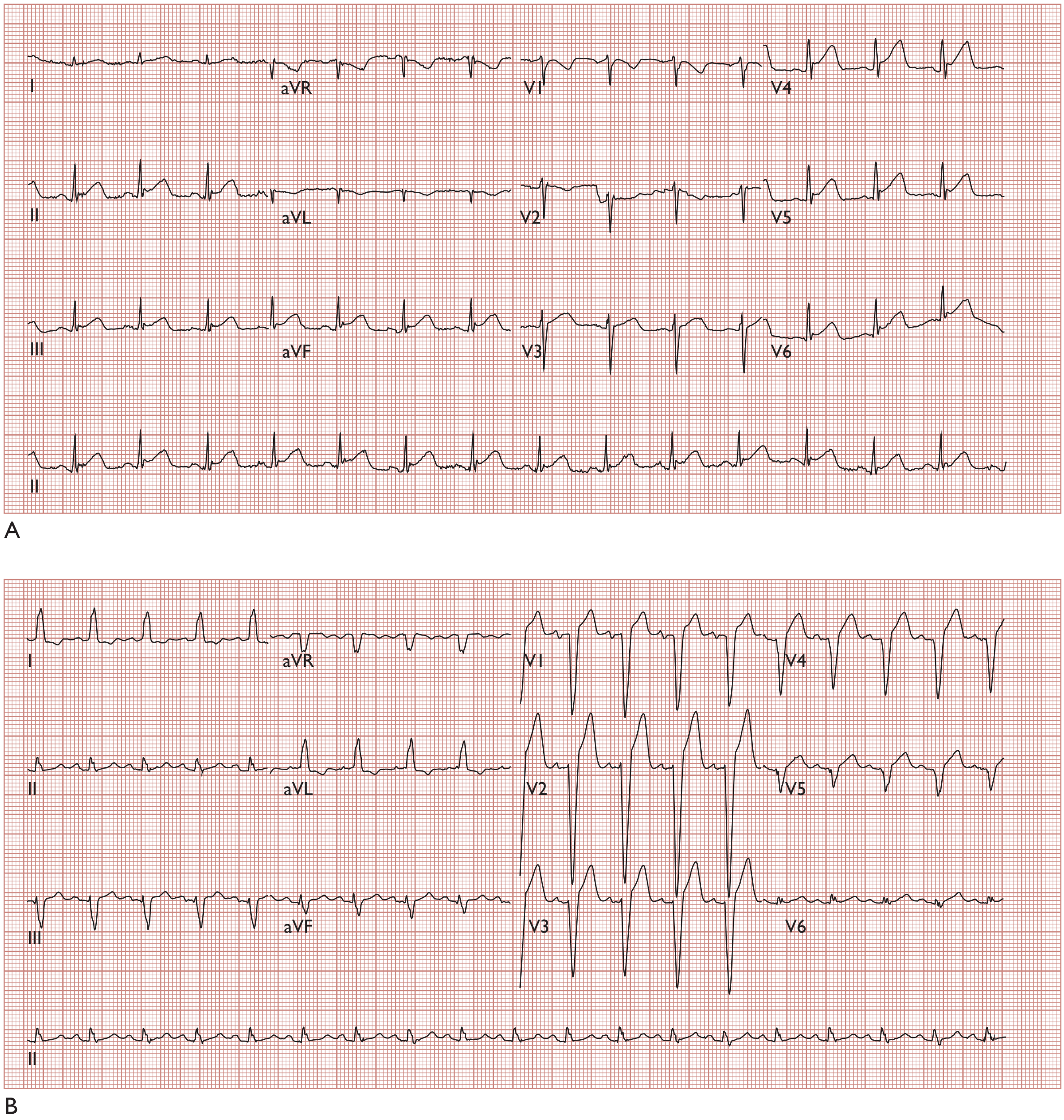

FIGURE 4. Representative electrocardiograms (ECGs) of false-positive and false-negative labeling of the artificial intelligence model. A, False-positive ECG showing concave ST elevation in the inferior and lateral leads indicative of early repolarization. B, False-positive ECG exhibiting complete left bundle branch block. C, False-negative ECG mimicking early repolarization. D, False-negative ECG displaying hyperacute T waves in precordial leads.

and off-hours were accounted for by delays in ECG-to—arterial access time.[32] In concert with these observations, we found a more favorable impact of the AI system on expediting STEMI triage during off-hours than during regular hours, which was mainly driven by the abbreviations of door-to-ECG and door-to-activation time. Therefore, the benefits of an AI-based triage system would be more obvious during off-hours to overcome the human resources—dependent delay in D2B times.

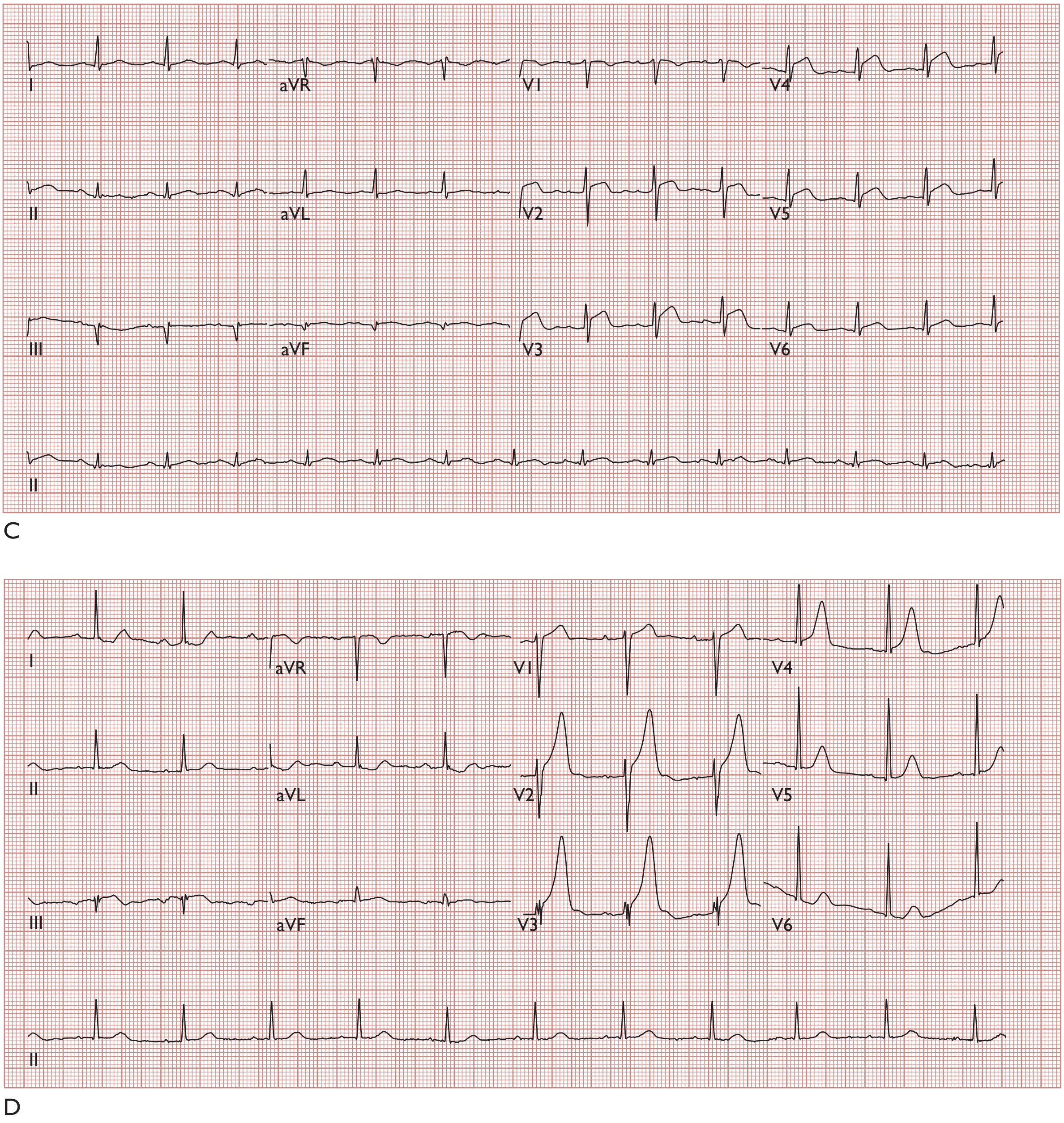

FIGURE 4. (Continued).

ASAP Score to Facilitate Timely ECG Examinations

We designed a computerized risk calculator called the ASAP score, which targets high-risk patients presenting non−chest pain symptoms who require an immediate ECG in the ED. Because the ASAP scoring items—age, sex, atypical presentation, and past medical history—have been built into the online emergency triage system, we can easily screen out high-risk patients through simple software settings. The concept of constructing a computerized risk score, such as the ASAP score, to identify high-risk patients presenting non−chest pain symptoms and thus requiring ECG examination has been demonstrated in the present study. By using the ASAP score, we demonstrated that the median door-to-ECG time dramatically decreased from 30 minutes before to 6 minutes after implementation of this scoring tool. Notably, the ASAP score successfully identified 8 of the 1011 patients with ASAP scores of 3 or more presenting non−chest pain symptoms, which led to early diagnosis of STEMI in 3 patients and unstable non-STEMI in 5 patients for subsequent revascularization therapy. Thus, with the combination of AI-based STEMI ECG diagnostic technology and the ASAP score to facilitate timely ECG examinations, we believe that the proposed 24/7 AI system can provide a robust solution to fulfill unmet clinical needs and minimize preventable delays in D2B times for patients with STEMI undergoing PPCI.

Limitations

This study has several limitations. First, although the proposed AI model showed high diagnostic accuracy (99.7%) with an extremely low false-negative rate (0.1%), the false-positive rate (∼20%) seems to be nonnegligible. An expert panel consisting of 3 board-certified cardiologists carefully examined each case. Most false-positive cases (81%) were due to early repolarization or recent/old myocardial infarction, which requires consideration of other clinical data rather than an ECG alone, including medical history and laboratory data, to exclude the possibility of STEMI. Second, in clinical scenarios, a 12-lead ECG may contain information other than STEMI, such as concurrent atrial fibrillation, atrioventricular block, or ventricular arrhythmias. The proposed AI model was not developed to perform this compound labeling. Indeed, further improvements in AI modeling are still necessary to overcome these limitations. Finally, this is a single-center pilot study with a relatively small number of patients, and future large-scale, multicenter studies are needed to confirm the beneficial effects of implementing an all-day AI-based triage strategy for patients with STEMI undergoing PPCI in emergency departments.

CONCLUSION

We demonstrated the usefulness of implementing an all-day AI-based triage system in the ED by combining AI-assisted STEMI ECG diagnostic technology and the computerized ASAP score for ECG prioritization. This system significantly shortened the mean D2B time with a parallel increase in the percentage of D2B times less than 90 minutes for patients with STEMI undergoing PPCI. The proposed 24/7 AI system may help minimize preventable delays in D2B times for patients with STEMI in emergency departments.

POTENTIAL COMPETING INTERESTS

The authors report no competing interests.

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Drs Wang and Chen contributed equally to this work.

SUPPLEMENTAL ONLINE MATERIAL

Supplemental material can be found online at http://www.mayoclinicproceedings.org. Supplemental material attached to journal articles has not been edited, and the authors take responsibility for the accuracy of all data.

Abbreviations and Acronyms: **1D,** 1-dimensional; **AI,** artificial intelligence; **CAD,** coronary artery disease; **cath lab,** catheterization laboratory; **CNN,** convolutional neural network; **D2B,** door-to-balloon; **ECG,** electrocardiography; **ED,** emergency department; **GRACE,** Global Registry of Acute Coronary Events; **LSTM,** long short-term memory; **PPCI,** primary percutaneous coronary intervention; **STEMI,** ST-segment elevation myocardial infarction; **TIMI,** Thrombolysis in Myocardial Infarction

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