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HEART Pathway Implementation Safely Reduces Hospitalizations at One Year in Patients With Acute Chest Pain

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Abstract

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Author contributions: JPS, DMH, BCH, CDM, and SAM were responsible for study concept and design. JPS, BCH, CDM, and SAM were responsible for acquisition of data. JPS, ACS, KML, and SAM were responsible for analysis and interpretation of data. JPS, ACS, KML, CDM, and SAM were responsible for drafting the article. All authors were responsible for critical revision of the article. ACS and KML provided statistical expertise. SAM was responsible for acquisition of funding. JPS takes responsibility for the paper as a whole.

All authors attest to meeting the four [ICMJE.org](https://www.icmje.org) authorship criteria: (1) Substantial contributions to the conception or design of the work; or the acquisition, analysis, or interpretation of data for the work; AND (2) Drafting the work or revising it critically for important intellectual content; AND (3) Final approval of the version to be published; AND (4) Agreement to be accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved.

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Study objective: We determine whether implementation of the HEART (History, ECG, Age, Risk Factors, Troponin) Pathway is safe and effective in emergency department (ED) patients with possible acute coronary syndrome through 1 year of follow-up.

Methods: A preplanned analysis of 1-year follow-up data from a prospective pre-post study of 8,474 adult ED patients with possible acute coronary syndrome from 3 US sites was conducted. Patients included were aged 21 years or older, evaluated for possible acute coronary syndrome, and without ST-segment elevation myocardial infarction. Accrual occurred for 12 months before and after HEART Pathway implementation, from November 2013 to January 2016. The HEART Pathway was integrated into the electronic health record at each site as an interactive clinical decision support tool. After integration, ED providers prospectively used the HEART Pathway to identify patients with possible acute coronary syndrome as low risk (appropriate for early discharge without stress testing or angiography) or nonlow risk (appropriate for further in-hospital evaluation). Safety (all-cause death and myocardial infarction) and effectiveness (hospitalization) at 1 year were determined from health records, insurance claims, and death index data.

Results: Preimplementation and postimplementation cohorts included 3,713 and 4,761 patients, respectively. The HEART Pathway identified 30.7% of patients as low risk; 97.5% of them were free of death and myocardial infarction within 1 year. Hospitalization at 1 year was reduced by 7.0% in the postimplementation versus preimplementation cohort (62.1% versus 69.1%; adjusted odds ratio 0.70; 95% confidence interval 0.63 to 0.78). Rates of death or myocardial infarction at 1 year were similar (11.6% versus 12.4%; adjusted odds ratio 1.00; 95% confidence interval 0.87 to 1.16).

Conclusion: HEART Pathway implementation was associated with decreased hospitalizations and low adverse event rates among low-risk patients at 1-year follow-up.

INTRODUCTION

The evaluation of patients presenting to the emergency department (ED) with possible acute coronary syndrome in the United States is heterogeneous, inefficient, and costly.^{1–3} Greater than 50% of the 8 to 10 million patients presenting annually to the ED for chest pain are hospitalized or observed for lengthy evaluations with serial cardiac biomarker and objective cardiac testing (stress testing or coronary angiography).⁴ However, less than 10% of these patients ultimately receive a diagnosis of acute coronary syndrome, and this inefficient care costs an estimated \$10 to 13 billion annually.^{5–8}

Frequent hospitalizations for objective cardiac testing in patients with chest pain are driven in large part by studies demonstrating that such testing modalities have a high negative predictive value (95% to 99%) for acute coronary syndrome at 1 year.^{9–13} These studies are the foundation of Class IIa American College of Cardiology/American Heart Association guideline recommendations, which state that patients with chest pain should have objective cardiac testing even if they are at low risk for acute coronary syndrome.^{14,15} However, objective cardiac testing in low-risk patients is associated with a substantial number of false-positive and nondiagnostic test results, without clear evidence of improved health outcomes.^{3,16–19} Thus, new risk-stratification strategies, which avoid hospitalizations and objective

cardiac testing while maintaining a high 1-year negative predictive value for adverse cardiac events, are needed.

The HEART (History, ECG, Age, Risk Factors, Troponin) Pathway is an accelerated diagnostic protocol designed to identify low-risk ED patients who can be safely discharged early from the ED without objective cardiac testing.^{20,21} The HEART Pathway has demonstrated safety and effectiveness at 30 days.^{22,23} However, there are limited data regarding its safety and effectiveness at 1 year. To address this evidence gap, we completed a preplanned 1-year analysis of the multisite HEART Pathway Implementation study. We hypothesized that the HEART Pathway will decrease hospitalizations and objective cardiac testing at 1 year while achieving a high negative predictive value for death and myocardial infarction.

MATERIALS AND METHODS

Study Design and Setting

A preplanned 1-year analysis of the HEART Pathway Implementation study was conducted. Participants were prospectively accrued under a waiver of informed consent from November 2013 to January 2016. This study was institutional review board approved. Methods of the HEART Pathway Implementation study, a prospective pre-post interrupted time series, have been previously published.^{20,24} The study was conducted at 3 hospitals in North Carolina: Davie Medical Center, with approximately 12,000 annual ED visits; Lexington Medical Center, with approximately 37,000 annual ED visits; and Wake Forest Baptist Medical Center, with approximately 114,000 annual ED visits.

Selection of Participants

Adult ED patients (≥ 21 years) evaluated for possible acute coronary syndrome, but without evidence of ST-segment elevation myocardial infarction on ECG, were the target population. At Wake Forest Baptist Medical Center and Davie Medical Center, participants were accrued into the preimplementation cohort from November 2013 to October 2014, and then a 3-month wash-in phase, followed by the postimplementation cohort from February 2015 to January 2016. Patients were accrued at Lexington Medical Center into the preimplementation and postimplementation cohorts from January 2015 to July 2015 and August 2015 to January 2016, respectively. Patients were accrued into each cohort according to the date of their initial ED visit; any subsequent visits for chest pain were considered recurrent care. Patients with an ED visit for possible acute coronary syndrome at each site in the year before the study began (N=523) were excluded in an effort to prevent accruing a disproportionate number of ED high utilizers into the preimplementation cohort. Patients were classified according to their original index ED visit for patients transferred within network or visiting multiple sites. Care at the receiving hospital was considered part of the index encounter for patients who were transferred.

As previously described, index encounter data were extracted from the electronic health record (Clarity-Epic Systems Corporation, Verona, WI).²⁵ Patient demographics, comorbidities, troponin results, HEART Pathway assessments, dispositions, diagnoses, and

vital status were obtained with prevalidated structured electronic health record variables or diagnoses and procedure codes (Current Procedural Terminology, *International Classification of Diseases, Ninth Revision [ICD-9]*, and *ICD-10*).^{26–30} To determine 1-year outcomes, we used the electronic health record for within-network events and insurers' claims and state death index data for events occurring outside of network. Claims data were available for patients insured by Blue Cross Blue Shield of North Carolina (the dominant insurer in North Carolina), MedCost, and North Carolina Medicaid. The North Carolina State Center for Health Statistics death index data were also used.

Interventions

The HEART Pathway accelerated diagnostic protocol was fully integrated into Epic as an interactive clinical decision support tool after the preimplementation period concluded. ED providers saw an interruptive pop-up alert for the HEART Pathway tool in the electronic health record for all adult patients with chest pain and at least one troponin-level test ordered in the postimplementation period. In addition, providers had the ability to manually access the HEART Pathway tool for patients presenting with other symptoms concerning for acute coronary syndrome (eg, dyspnea, left arm pain).

Providers were prompted to answer a series of questions to prospectively risk stratify patients without ST-segment elevation myocardial infarction in real time by the HEART Pathway clinical decision support tool (Figure 1). Patients were immediately classified as nonlow risk if they had known coronary artery disease (previous myocardial infarction, previous coronary revascularization, or known coronary stenosis ≥70%), or acute ischemic ECG changes (eg, new T-wave inversions or ST-segment depression in contiguous leads) as interpreted by the treating provider. For all other patients, providers answered additional flow sheet questions to determine a History, ECG, Age, and Risk Factor score (HEAR score), calculated according to the HEART Pathway trial algorithm (Impathiq Inc., Raleigh, NC).³¹ A direct link to laboratory results incorporated troponin measurements. The HEART Pathway risk assessment was automatically calculated according to the History, ECG, Age, and Risk Factor score and 0- and 3-hour troponin-level measurements.^{23,32} Patients with a History, ECG, Age, and Risk Factor score greater than or equal to 4, an elevated troponin level, known coronary artery disease, or ischemic ECG changes were classified as nonlow risk and specified for further testing. Patients with History, ECG, Age, and Risk Factor scores less than or equal to 3 and without elevated troponin levels were classified as low risk and recommended for discharge without objective cardiac testing (Figure 1). The HEART Pathway clinical decision support tool was not available to providers and History, ECG, Age, and Risk Factor scores were not recorded during the preimplementation period. Serum troponin level was measured with the ADVIA Centaur platform TnI-Ultra assay (Siemens, Munich, Germany) or the Access AccuTnI+3 assay (Beckman Coulter, Brea, CA).

Outcome Measures

The composite of death or myocardial infarction at 1 year (inclusive of the index visit) was the primary safety outcome for this preplanned secondary analysis. Coronary revascularization, a secondary endpoint, was defined as coronary artery bypass grafting, stent placement, or other percutaneous coronary intervention. Diagnosis and procedure

codes validated by previous cardiovascular trials were used to determine myocardial infarction and coronary revascularization.^{26–30} Major adverse cardiac events, a composite of death, myocardial infarction, and revascularization, were also evaluated.

The primary effectiveness outcome of this preplanned analysis was hospitalization at 1 year (from index visit through 1-year follow-up). Hospitalization was defined as an inpatient admission, transfer, or observation stay (including index observation unit care). Secondary outcomes included objective cardiac testing rates (patients receiving stress testing, coronary computed tomographic angiography, or invasive coronary angiography) and early discharge rate (patients discharged from the ED without objective cardiac testing.)

Primary Data Analysis

Statistical design for the overall study was described previously.^{24,25} For this preplanned secondary analysis, with approximately 4,000 patients enrolled in each cohort (pre- and postimplementation), a difference in hospitalization rate at 1 year of 3.1% could be detected with at least 80% power, assuming a 5% 2-sided level of significance with a χ^2 test. In addition, assuming a death plus myocardial infarction rate at 1 year in the preimplementation cohort of 10%, with approximately 4,000 patients per cohort, a reduction in the postimplementation cohort to 8.2% (or a reduction of 1.8%) could be detected with 80% power and a 5% 2-sided level of significance.

Patient characteristics were described by pre- and postimplementation cohorts, using median and interquartile range or percentages. For this preplanned 1-year analysis, we used absolute percentage differences and unadjusted logistic regression to compare safety and use outcomes before and after implementation of the HEART Pathway. Logistic regression models were then adjusted for potential confounders, which were selected a priori: age, sex, race, ethnicity, insurance status, enrollment site, previous known coronary artery disease, diabetes mellitus, hypertension, hyperlipidemia, chronic kidney disease, chronic obstructive pulmonary disease, cerebral vascular disease, peripheral vascular disease, cancer, smoking, body mass index, and presence of chest pain versus other symptoms concerning for acute coronary syndrome (electronic health record flow sheet use). Body mass index was missing for 2.9% of patients, so multivariate imputation, with replacement by predictive mean matching using all predictors and outcome variables, was used to create 10 data sets with complete body mass index data.³³ No other covariates required imputation. Logistic models were fit for each imputed data set, and results were averaged across sets. Adjusted odds ratios (ORs) and 95% confidence intervals (CIs) were derived for each outcome.

To evaluate the performance of the HEART Pathway, in the postimplementation cohort we calculated the percentage of patients identified as low risk and nonlow risk to determine the sensitivity, specificity, and positive and negative predictive values of the HEART Pathway (and its components) for death and myocardial infarction through 1 year. Corresponding 95% exact binomial CIs were computed. For positive and negative likelihood ratios, 95% CIs were calculated with the method of Simel et al.³⁴ Also in the postimplementation cohort, safety and use outcomes were compared between low-risk and non low-risk patients, as well as between low- and incomplete-risk patients (as determined by the HEART Pathway), using absolute percentage differences with corresponding 95% CIs. Finally, safety and use

outcomes were described for low-risk patients who were discharged early from the ED without objective cardiac testing, using percentages and exact 95% CIs.

Consistent with previous studies, patients without 1-year data from the electronic health record, insurers, or death index (18.9%; 1,604/8,474) were considered free of 1-year safety events.^{20,23,35,36} Sensitivity analyses assessed the effect of missing follow-up data on safety events by excluding patients lost to follow-up or using multiple imputations, assuming patients with incomplete follow-up had the same event rate as those with complete follow-up from the pre- and postcohorts, or assuming patients with incomplete follow-up had an event rate predicted by covariates. Proc MI in SAS was used to generate 25 imputed data sets for each scenario, and Proc MIAnalyze was used to combine the results from the logistic regression analysis of each imputed data set. All analyses were performed with R (<http://www.R-project.org>; The R Foundation, Auckland, New Zealand) or SAS (version 9.4; SAS Institute, Inc., Cary, NC).

RESULTS

Characteristics of Study Subjects

A total of 8,474 patients were accrued during the study period (Figure 2). The cohort was 34.0% nonwhite (2,884/8,474) and 53.6% women (4,541/8,474), with a median age of 54 years. Characteristic of the cohort are summarized in Table 1. The 1-year death and myocardial infarction rate of the cohort was 11.9% and revascularization occurred in 4.7% of patients.

Main Results

The HEART Pathway identified 30.7% (1,461/4,761) of the postimplementation cohort as low risk; 53.2% (2,531/4,761) were nonlow risk, another 7.0% (333/4,761) had low-risk History, ECG, Age, and Risk Factor scores but lacked serial troponin measurements, and 9.2% (436/4,761) had an incomplete or absent History, ECG, Age, and Risk Factor score. Among patients classified by the HEART Pathway as low risk, 2.5% (36/1,461; 95% CI 1.7% to 3.4%) experienced death or myocardial infarction from the index visit through 1 year. Five of these events were myocardial infarctions (5/1,461, 0.3%; 95% CI 0.1% to 0.8%). Thus, the negative predictive value of the HEART Pathway for death or myocardial infarction at 1 year was 97.5% (95% CI 96.6% to 98.3%). The diagnostic performance of the HEART Pathway at 1 year is summarized in Table 2. Among the 1,461 low-risk patients, 1,203 were discharged early from the ED without objective cardiac testing. Of the 1,203 patients, 1.6% (19/1,203) experienced death or myocardial infarction at 1 year. Two of these events were myocardial infarctions (2/1,203, 0.2%; 95% CI 0.02% to 0.6%). Revascularization occurred in one patient (0.1%; 1/1,203). Outcomes among low-risk patients with early discharge are summarized in Table 3.

Rates of death and myocardial infarction at 1 year (including index visit events) were similar in the post- and preimplementation cohorts (11.6% versus 12.4%; adjusted OR 1.00; 95% CI 0.87 to 1.16). However, during the 1-year follow-up period (not including the index visit), death and myocardial infarction occurred less frequently in the postimplementation cohort

(5.6%, 266/4,761) compared with the preimplementation cohort (6.9%, 258/3,713; adjusted OR 0.77; 95% CI 0.64 to 0.94). The proportion of patients with events in the pre- and postimplementation cohorts is summarized in Table E1 (available online at <http://www.annemergmed.com>).

In the postimplementation cohort, 62.1% of patients (2,955 of 4,761) were hospitalized at 1 year (including index) compared with 69.1% (2,566 of 3,713) in the preimplementation cohort, a reduction of 7.0% (95% CI 5.0% to 9.1%), with an adjusted OR of 0.70 (95% CI 0.63 to 0.78). In low-risk patients with an early discharge from the ED, 13.5% (162/1,203; 95% CI 11.6 to 15.5) were hospitalized through 1 year of follow-up.

Objective cardiac testing from the index visit through 1 year was completed in 36.3% of patients (1,728 of 4,761) in the postimplementation cohort compared with 39.9% (1,481 of 3,713) in the preimplementation cohort, a decrease of 3.6% (95% CI 1.5% to 5.7%), with an adjusted OR of 0.90 (95% CI 0.82 to 0.99). The comparison of 1-year outcomes in the postimplementation cohort among low-risk and nonlow-risk patients is summarized in Table 4.

A sensitivity analysis was conducted for the primary safety outcome of death or myocardial infarction at 1 year. Rates were similar in the post- and preimplementation cohorts no matter how missing data were handled (Table 5). This supports the overall conclusion that the rate of death and myocardial infarction at 1 year did not differ significantly between pre- and postimplementation.

LIMITATIONS

Our study design has limitations. Secular trends and provider maturation effects are potential threats to the validity of our results. However, as previously reported in the primary analysis, event rates were fairly consistent over time. The use of our electronic health record to collect events may have decreased event rates compared with traditional methods of follow-up, but the electronic health record data were supplemented with death index and claims data to address this. The 3 sites in this study were diverse in size and location (urban and suburban), but results may not be generalizable to all US health systems. Nonetheless, given the size and scope of this pragmatic implementation study, our design had advantages of feasibility, cost-effectiveness, and generalizability compared with a traditional randomized trial. The exclusion of high utilizers from analysis could be considered a limitation, but this was done to avoid including these patients in the preimplementation cohort, which would have biased results in favor of the HEART Pathway. Differences existed in baseline risk factors present in the pre- versus postimplementation cohorts, but our regression analyses adjusted for these potential confounders. Finally, one of our sites (Lexington Medical Center) did not implement the HEART Pathway on the same schedule as the others, and it is possible that this asynchrony influenced our results.

The HEAR score and the HEART Pathway differ in 4 very important ways. The HEAR score uses a single troponin measure at ED arrival, which may miss early presentations of myocardial infarction. Next, with the HEAR score patients with elevated troponin levels or

ischemic ECG changes can be deemed low risk with scores of 3 or less. The History component of the HEAR score is subjective, leading to poor interobserver agreement. Finally, the HEAR score does not differentiate patients with known coronary artery disease (previous myocardial infarction or coronary revascularization) from those who do not have known coronary artery disease. The evidence supporting the use of the HEART Pathway cannot be applied to the HEAR score.

DISCUSSION

Results of this preplanned 1-year analysis of the multisite HEART Pathway Implementation study demonstrate that the HEART Pathway decreases 1-year hospitalizations and objective cardiac testing while achieving a high negative predictive value for adverse cardiac events. The HEART Pathway classified 31% of ED patients with acute chest pain as low risk, with a negative predictive value of 97.5% for 1-year death or myocardial infarction. Although there is some consensus that an accelerated diagnostic protocol should achieve a negative predictive value greater than 99% at 30 days, the threshold at 1 year is less clear.¹⁵ Studies of stress-testing modalities have demonstrated negative predictive values ranging from 95% to 99%. Thus, in this study the HEART Pathway was able to achieve a negative predictive value similar to those reported in stress-testing trials.

Rates of death and myocardial infarction at 1 year (including index visit events) were similar before and after HEART Pathway implementation. However, during the 1-year follow-up period, not including the index visit, the composite rate of death and myocardial infarction was significantly decreased. HEART Pathway implementation was associated with an absolute reduction of death and myocardial infarction events of 1.3% and a relative reduction of 18.8%. This suggests that the accuracy of risk stratification at the index visit using the HEART Pathway may have important implications for downstream safety events. Risk classification using the HEART Pathway may have guided providers to more aggressively medically manage nonlow-risk patients and avoid unnecessary and potentially harmful testing and treatments for patients at low risk.

Improved downstream rates of death and myocardial infarction by the HEART Pathway were not associated with increased health care use. This analysis demonstrates that HEART Pathway implementation reduces hospitalization and objective cardiac testing during 1 year of follow-up. Previous studies have shown that hospitalization at the index visit and 30 days was significantly reduced by the HEART Pathway compared with usual care.^{25,37} In this study, implementation of the HEART Pathway was associated with a 5.9% reduction of hospitalization during the index visit, which increased to a reduction in hospitalization of 7.0% during the 1-year follow-up. Similarly, objective cardiac testing was reduced by 3.3% at the index visit and 3.6% at 1 year. These results differ from our 1-year analysis of the HEART Pathway randomized controlled trial, in which reductions in hospitalizations and objective cardiac testing were attenuated over time.³⁸ Thus, the results of this analysis suggest that concerns that the HEART Pathway will increase downstream health care use are unwarranted.

The literature evaluating 1-year outcomes among low-risk chest pain patients after an ED evaluation are limited, especially for those discharged without objective cardiac testing. Thus, this study provides important data for cardiologists and primary care physicians tasked with determining whether low-risk patients need outpatient objective cardiac testing after a negative ED evaluation result for chest pain. The high negative predictive value of the HEART Pathway at 1 year supports a less aggressive approach to outpatient objective cardiac testing. Reducing objective cardiac testing in low-risk patients has the potential to improve the quality and value of care by reducing false-positive test results, radiation exposure, iatrogenic complications, and health care costs. In our cohort, 8% of low-risk patients received potentially avoidable objective cardiac testing in the year after the patient's index visit. Our study adds important 1-year data to an increasing body of evidence suggesting that objective cardiac testing is of limited utility in low-risk patients.^{3,16–18,38,39}

In summary, the results of this multicenter study suggest that the HEART Pathway's predictive abilities extend beyond the traditional 30-day follow-up period. The HEART Pathway had a sensitivity of 93.1% and negative predictive value of 97.5% for death and myocardial infarction among patients with acute chest pain at 1 year. Furthermore, the negative predictive value achieved by the HEART Pathway is similar to that reported in previous objective cardiac testing trials. Use of the HEART Pathway decreased hospitalizations by 7% and objective cardiac testing by 3.6% at 1 year. Thus, our data suggest that the HEART Pathway can decrease health care use up to 1 year. However, opportunities remain to improve the efficiency of outpatient objective cardiac testing after early discharge from the index ED visit for chest pain. The data presented in this article add further support to an increasing body of evidence suggesting that current practice guidelines should be improved so that objective cardiac testing is no longer endorsed for low-risk patients presenting to the ED with chest pain.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

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Editor's Capsule Summary**What is already known on this topic**

Many emergency departments (EDs) use standardized approaches to safely discharge low-risk chest pain patients with guideline-recommended outpatient cardiac stress testing.

What question this study addressed

This 8,474-patient pre-post interrupted time series measured the effect of the HEART Pathway integration on safely discharging low-risk chest pain patients without outpatient cardiac testing.

What this study adds to our knowledge

Although limited by 16% missing outcome data, the HEART Pathway performed reasonably well at identifying patients at low risk for 1-year adverse outcomes and was associated with decreased hospitalizations.

How this is relevant to clinical practice

This article provides further support that not all low-risk chest pain patients need outpatient stress testing. Guideline revisions should advocate selective, not universal, testing.

Figure 1.
The HEART Pathway algorithm. *STEMI*, ST-elevation myocardial infarction; *CAD*, coronary artery disease.

Figure 2.

Participant flow diagram. *WFBMC*, Wake Faorest Baptist Medical Center; *LMC*, Lexington Medical Center; *DMC*, Davie Medical Center; *EHR*, electronic health record; *ACS*, acute coronary syndrome.

Table 1.

Characteristics of patients in the pre- and postimplementation cohorts.

Patient Characteristics	Pre, N=3,713 (%)	Post, N=4,761 (%)
Age, median (IQR)	54 (45–65)	54 (44–66)
Women	1,965 (52.9)	2,579 (54.1)
Race		
White	2,484 (66.9)	3,106 (65.2)
Black	1,052 (28.3)	1,371 (28.8)
Other	177 (4.8)	284 (6.0)
Ethnicity		
Hispanic or Latino	134 (3.6)	230 (4.8)
Site		
WFBMC	2,720 (73.3)	3,685 (77.4)
DMC	396 (10.7)	512 (10.8)
LMC	597 (16.1)	564 (11.8)
Insurance status		
Blue Cross	790 (21.3)	970 (20.4)
Medicare	1,189 (32.0)	1,617 (34.0)
Self-pay	699 (18.8)	788 (16.5)
Medicaid	505 (13.6)	687 (14.4)
Other insurance	321 (8.6)	413 (8.7)
MedCost	209 (5.6)	286 (6.0)
EHR ACS flow sheet used*	137 (3.7)	1,033 (21.7)
Risk factors		
Hypertension	2,406 (64.8)	2,986 (62.7)
Smoking	2,356 (63.5)	2,878 (60.5)
BMI ≥ 30 kg/m ²	1,694 (45.6)	2,198 (46.1)
Hyperlipidemia	1,528 (41.2)	1,993 (41.9)
Previous CAD	1,036 (27.9)	1,280 (26.9)
Diabetes	1,031 (27.8)	1,290 (27.1)
Cerebrovascular disease	456 (12.2)	594 (12.5)

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Patient Characteristics	Pre, N=3,713 (%)	Post, N=4,761 (%)
Peripheral vascular disease	450 (12.1)	635 (13.3)
Comorbidities		
COPD	1,173 (31.6)	1,543 (32.4)
Cancer	570 (15.4)	746 (15.7)
Chronic kidney disease	416 (11.2)	576 (12.1)

IQR, Interquartile range; *BMI*, body mass index; *COPD*, chronic obstructive pulmonary disease.
 χ^2 Tests were used for categoric variables and Wilcoxon rank sum tests were used for continuous variables.
* The EHR ACS flow sheet allowed providers to manually access the HEART Pathway for patients presenting with other symptoms concerning for ACS.

Table 2.

Test characteristics of the HEART Pathway and its components for detection of death and myocardial infarction from the index visit through 365 days.

Patient Category	365-Day Death and MI				Total
	Yes (n)	No (n)			
HEART Pathway nonlow risk	486	2,045			2,531
HEART Pathway low risk	36	1,425			1,461
HEAR score nonlow risk	379	1,899			2,278
HEAR score low risk	91	1,810			1,901
Troponin elevated	371	367			738
Troponin nonelevated	143	3,154			3,297
Tool/Test	Sensitivity (95% CI), %	Specificity (95% CI), %	PPV (95% CI), %	NPV (95% CI), %	+LR (95% CI) -LR (95% CI)
HEART Pathway	93.1 (90.6–95.1)	41.1 (39.4–42.7)	19.2 (17.7–20.8)	97.5 (96.6–98.3)	1.58 (1.52–1.64) 0.17 (0.12–0.23)
HEAR score	80.6 (76.8–84.1)	48.8 (47.2–50.4)	16.6 (15.1–18.2)	95.2 (94.2–96.1)	1.57 (1.49–1.66) 0.40 (0.33–0.48)
Troponin	72.2 (68.1–76.0)	89.6 (88.5–90.6)	50.3 (46.6–53.9)	95.7 (94.9–96.3)	6.92 (6.20–7.74) 0.31 (0.27–0.36)

MI, Myocardial infarction; *HEAR*, History, ECG, Age, and Risk Factor; *PPV*, positive predictive value; *NPV*, negative predictive value; *+LR*, positive likelihood ratio; *-LR*, negative likelihood ratio.

HEART Pathway: Low risk determined by HEAR score less than 4, and no known CAD, and no acute ischemic ECG changes, and no troponin-level elevation at 0 or 3 hours. Nonlow risk determined by HEAR score greater than or equal to 4, or known CAD, or an acute ischemic ECG change, or a troponin-level elevation at 0 or 3 hours. HEAR score: Low risk determined by a HEAR score less than 4, and no known CAD, and no acute ischemic ECG changes. Nonlow risk determined by HEAR score greater than or equal to 4, or known CAD, or an acute ischemic ECG change. Troponin: Low risk determined by no troponin elevation at 0 or 3 hours. Nonlow risk determined by a troponin elevation at 0 or 3 hours.

Table 3.

One-year outcomes among low-risk patients in the postimplementation cohort who were discharged early from the ED without objective cardiac testing (N=1,203).

Outcomes	No. (%)	95% CI
Safety		
1-y follow-up period		
Death	17 (1.4)	(0.8–2.3)
MI	2 (0.2)	(0.02–0.6)
Revascularization	1 (0.1)	(0.002–0.5)
Death+MI	19 (1.6)	(1.0–2.5)
Death+MI+revascularization	19 (1.6)	(1.0–2.5)
1-y follow-up period		
Hospitalization	162 (13.5)	(11.6–15.5)
Objective cardiac testing	99 (8.2)	(6.7–9.9)

Table 4.
Proportion of patients with events in the postimplantation cohort according to HEART Pathway risk assessment.

Outcomes	Low Risk, N=1,461 (%)	Nonlow Risk, N=2,531 (%)	Incomplete, N=769 (%)	Absolute Percentage Difference, Low:Nonlow (95% CI) *	Absolute Percentage Difference, Low:Incomplete (95% CI) *
Safety					
Index visit					
Death	2 (0.1)	12 (0.5)	1 (0.1)	0.3 (0.0 to 0.7)	0.0 (-0.3 to 0.3)
MI	1 (0.1)	313 (12.4)	0	12.3 (11.0 to 13.6)	-0.1 (-0.2 to 0.1)
Revascularization	1 (0.1)	151 (6.0)	2 (0.3)	5.9 (5.0 to 6.8)	0.2 (-0.2 to 0.6)
Death+MI	3 (0.2)	321 (12.7)	1 (0.1)	12.5 (11.2 to 13.8)	-0.1 (-0.4 to 0.3)
Death+MI+revascularization	4 (0.3)	348 (13.7)	3 (0.4)	13.5 (12.1 to 14.8)	0.1 (-0.4 to 0.6)
1-y follow-up period					
Death	29 (2.0)	149 (5.9)	23 (3.0)	3.9 (2.7 to 5.1)	1.0 (-0.5 to 2.5)
MI	4 (0.3)	68 (2.7)	7 (0.9)	2.4 (1.7 to 3.2)	0.6 (-0.2 to 1.5)
Revascularization	2 (0.1)	80 (3.2)	4 (0.5)	3.1 (2.3 to 3.8)	0.4 (-0.3 to 1.0)
Death+MI	33 (2.3)	204 (8.1)	29 (3.8)	5.8 (4.4 to 7.2)	1.5 (-0.1 to 3.2)
Death+MI+revascularization	34 (2.3)	252 (10.0)	31 (4.0)	7.7 (6.3 to 9.1)	1.7 (0.01 to 3.4)
1-y (index+follow-up)					
Death	31 (2.1)	161 (6.4)	24 (3.1)	4.3 (3.0 to 5.5)	1.0 (-0.5 to 2.5)
MI	5 (0.3)	362 (14.3)	7 (0.9)	14.0 (12.5 to 15.4)	0.6 (-0.3 to 1.4)
Revascularization	3 (0.2)	219 (8.7)	6 (0.8)	8.5 (7.3 to 9.6)	0.6 (-0.2 to 1.3)
Death+MI	36 (2.5)	486 (19.2)	30 (3.9)	16.7 (15.0 to 18.5)	1.4 (-0.2 to 3.1)
Death+MI+revascularization	37 (2.5)	533 (21.1)	33 (4.3)	18.6 (16.7 to 20.4)	1.8 (0.02 to 3.5)
Use					
Index visit					
Hospitalization	241 (16.5)	2,095 (82.8)	246 (32.0)	66.3 (63.9 to 68.7)	15.5 (11.7 to 19.3)
Early discharge	1,203 (82.3)	360 (14.2)	483 (62.8)	-68.1 (-70.5 to 65.7)	-19.5 (-23.5 to 15.6)
Objective cardiac testing	116 (7.9)	1,148 (45.4)	43 (5.6)	37.4 (35.0 to 39.8)	-2.3 (-4.5 to 0.2)
1-y follow-up period					
Hospitalization	221 (15.1)	713 (28.2)	164 (21.3)	13.1 (10.5 to 15.6)	6.2 (2.7 to 9.7)
Objective cardiac testing	116 (7.9)	411 (16.2)	55 (7.2)	8.3 (6.2 to 10.3)	-0.7 (-3.1 to 1.6)
1-y (index+follow-up)					

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Outcomes	Low Risk, N=1,461 (%)	Nonlow Risk, N=2,531 (%)	Incomplete, N=769 (%)	Absolute Percentage Difference, Low:Nonlow (95% CI) *	Absolute Percentage Difference, Low:Incomplete (95% CI) *
Hospitalization	410 (28.1)	2,217 (87.6)	328 (42.7)	59.5 (56.8 to 62.2)	14.6 (10.3 to 18.9)
Objective cardiac testing	227 (15.5)	1,406 (55.6)	95 (12.4)	40.1 (37.3 to 42.8)	-3.1 (-6.3 to 0.1)

* Proportions and associated 95% CIs were calculated without adjustment for potential confounders.

Table 5.

Sensitivity analysis for 1-year death plus myocardial infarction.

Analysis	Pre, Death+ MI, %	Post, Death+ MI, %	Unadjusted Absolute Percentage Difference (95% CI)	Unadjusted OR (95% CI)	Adjusted OR (95% CI)
Primary analysis; patients lost to follow-up assumed to not have event	12.4	11.6	-0.8 (-2.2 to 0.7)	0.93 (0.81 to 1.06)	1.00 (0.87 to 1.16)
Patients lost to follow-up excluded	14.3	14.9	0.6 (-1.1 to 2.3)	1.05 (0.92 to 1.20)	1.13 (0.97 to 1.31)
Imputation based on separate pre- and postevent rates in patients with complete follow-up	14.3	14.9	0.6 (-1.0 to 2.1)	1.05 (0.91 to 1.20)	1.12 (0.97 to 1.29)
Imputation based on predicted event rate from covariates	14.2	14.7	0.5 (-1.0 to 2.0)	1.04 (0.91 to 1.18)	1.12 (0.97 to 1.29)