Circulation

ORIGINAL RESEARCH ARTICLE

Safely Identifying Emergency Department Patients With Acute Chest Pain for Early Discharge

HEART Pathway Accelerated Diagnostic Protocol

BACKGROUND: The HEART Pathway (history, ECG, age, risk factors, and initial troponin) is an accelerated diagnostic protocol designed to identify low-risk emergency department patients with chest pain for early discharge without stress testing or angiography. The objective of this study was to determine whether implementation of the HEART Pathway is safe (30-day death and myocardial infarction rate <1% in low-risk patients) and effective (reduces 30-day hospitalizations) in emergency department patients with possible acute coronary syndrome.

METHODS: A prospective pre-post study was conducted at 3 US sites among 8474 adult emergency department patients with possible acute coronary syndrome. Patients included were ≥21 years old, investigated for possible acute coronary syndrome, and had no evidence of ST-segment–elevation myocardial infarction on ECG. Accrual occurred for 12 months before and after HEART Pathway implementation from November 2013 to January 2016. The HEART Pathway accelerated diagnostic protocol was integrated into the electronic health record at each site as an interactive clinical decision support tool. After accelerated diagnostic protocol 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 non-low risk (appropriate for further in-hospital evaluation). The primary safety and effectiveness outcomes, death, and myocardial infarction (MI) and hospitalization rates at 30 days were determined from health records, insurance claims, and death index data.

RESULTS: Preimplementation and postimplementation cohorts included 3713 and 4761 patients, respectively. The HEART Pathway identified 30.7% as low risk; 0.4% of these patients experienced death or MI within 30 days. Hospitalization at 30 days was reduced by 6% in the postimplementation versus preimplementation cohort (55.6% versus 61.6%; adjusted odds ratio, 0.79; 95% CI, 0.71–0.87). During the index visit, more MIs were detected in the postimplementation cohort (6.6% versus 5.7%; adjusted odds ratio, 1.36; 95% CI, 1.12–1.65). Rates of death or MI during follow-up were similar (1.1% versus 1.3%; adjusted odds ratio, 0.88; 95% CI, 0.58–1.33).

CONCLUSIONS: HEART Pathway implementation was associated with decreased hospitalizations, increased identification of index visit MIs, and a very low death and MI rate among low-risk patients. These findings support use of the HEART Pathway to identify low-risk patients who can be safely discharged without stress testing or angiography.

CLINICAL TRIAL REGISTRATION: URL: http://www.clinicaltrials.gov. Unique identifier: NCT02056964.

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Key Words: acute coronary syndrome ■ clinical decision making ■ decision support systems, clinical ■ electronic health records ■ emergency medicine ■ risk assessment

Sources of Funding, see page 2467

https://www.ahajournals.org/journal/circ

Clinical Perspective

What Is New?

- Among the 30.7% of patients identified by the HEART Pathway (history, ECG, age, risk factors, and initial troponin) as low risk, the rate of all-cause death and myocardial infarction was 0.4%.
- Implementation of the HEART Pathway was associated with increased detection of index visit myocardial infarctions, with an adjusted odds ratio of 1.36 (95% CI, 1.12–1.65).
- Hospitalizations from the index visit through 30 days were decreased by 6% after HEART Pathway implementation.
- HEART Pathway implementation increased early discharge from the emergency department by 5.6%, decreased the median index visit length of stay by 2.1 hours, and reduced stress testing and angiography at 30 days by 3.8%.

What Are the Clinical Implications?

- These findings demonstrate that the HEART Pathway is safe and effective at increasing early emergency department discharges and decreasing hospitalizations, stress testing, and index visit length of stay in patients with acute chest pain.
- Given its ability to safely reduce healthcare utilization outcomes, the HEART Pathway may provide a model for health systems to provide safe and high-value care to patients presenting to emergency departments with chest pain.

Emergency departments (EDs) in the United States care for 8 to 10 million patients with acute chest pain annually.[1] To avoid missing acute coronary syndrome (ACS), providers liberally hospitalize patients with chest pain for comprehensive cardiac evaluations (serial cardiac biomarkers and stress testing or angiography). However, <10% of ED patients with chest pain are ultimately diagnosed with an ACS;[2–6] with testing costing $10 to $13 billion annually.[5,7] Although accelerated diagnostic protocols (ADPs) are designed to improve the quality and value of chest pain risk stratification, they lack sufficient prospective safety and effectiveness data. Therefore, current guidelines continue to recommend comprehensive cardiac evaluations, even for low-risk patients.[7]

The HEART Pathway (history, ECG, age, risk factors, and troponin) is an ADP that incorporates elements of the Chronic Care Model framework (decision support and clinical information systems) by providing test ordering and disposition decision support to ED practitioners and personalized care planning for patients with acute chest pain.[8–10] In prior efficacy studies, the HEART Pathway significantly increased the percent of ED patients with acute chest pain identified for early discharge and decreased objective cardiac testing (stress testing and angiography), hospital length of stay (LOS), and cost.[11–14] Although these studies also provided data suggesting safety, they were not adequately powered to provide tight CIs around safety event rates. Although a matter of debate, many believe that a successful risk stratification strategy must achieve <1% missed events among low-risk patients within a 30-day follow-up.[15] Our objective was to determine the safety and effectiveness of the HEART Pathway ADP by conducting an implementation study within a 3-center health system.

METHODS

Study Design and Oversight

We compared risk stratification of ED patients with acute chest pain before and after implementation of the HEART Pathway ADP. Participants were prospectively accrued under a waiver of informed consent from November 2013 to January 2016. This study was approved by our Institutional Review Board with a waiver of informed consent and registered with ClinicalTrials.gov (NCT02056964). Methods were previously described.[16] The data, analytical methods, and study materials will not be made available to other researchers for purposes of reproducing the results or replicating the procedure.

Study Setting and Population

The study was done at 3 hospitals in North Carolina: Wake Forest Baptist Medical Center, with ≈114 000 ED visits annually; Davie Medical Center, with ≈12 000 annual ED visits; and Lexington Medical Center, with ≈37 000 annual ED visits. The target population was adult ED patients (≥21 years of age) investigated for possible ACS but without evidence of ST-segment–elevation myocardial infarction (MI) on ECG. Inclusion criteria were the same throughout the preimplementation and postimplementation periods. Patients with a chief complaint of chest pain and at least 1 troponin ordered, without evidence of a ST-segment–elevation MI on ECG, were accrued. This included patients with known coronary artery disease (CAD; prior MI, prior coronary revascularization, or known coronary stenosis ≥70%). In addition, patients with other complaints that were concerning for ACS were included if the provider used a study-specific electronic health record (EHR) flowsheet for possible ACS, which was available in both the preimplementation and postimplementation cohorts.

At Wake Forest Baptist Medical Center and Davie Medical Center, participants were accrued into the preimplementation cohort (November 2013-October 2014) or the postimplementation cohort (February 2015-January 2016). A wash-in period (November 2014- January 2015) was used to train providers and β-test an electronic health record (EHR)–based HEART Pathway clinical decision support (CDS) tool. Lexington Medical Center accrued patients into the preimplementation (January–July 2015) and postimplementation (August 2015–January 2016) cohorts, with a 1-month wash-in period. Patients were accrued into each cohort on the basis of the date of their initial ED visit; later visits for chest pain were considered recurrent care. To prevent accruing more ED repeat users/high users (who often have more comorbid

conditions) into the preimplementation cohort, patients with an ED visit for possible ACS at each site in the year before the study began (n=523) were excluded from analysis. Patients transferred within the network or visiting multiple sites were classified on the basis of their original ED visit. For transfers, care at the receiving hospital was considered part of their index encounter.

Data Collection

Index encounter data (from initial ED presentation to discharge from the ED, observation unit, or inpatient ward) were extracted from the EHR data of the health system (Clarity-Epic Systems Corp, Verona, WI). Prevalidated structured EHR variables or diagnoses and procedure codes (Current Procedural Terminology, *International Classification of Diseases, Ninth Revision* and *10th Revision*) were used to obtain patient demographics, medical history, cardiovascular risk factors, comorbidities, troponin results, provider's HEART Pathway assessments, disposition, diagnoses (including MI), and vital status.[17–21] To determine 30-day outcomes, we used the EHR for within-network return visits, insurers' claims data, and state death index data. Claims data were available on patients insured by Blue Cross Blue Shield of North Carolina (the dominant insurer in the state), MedCost, and North Carolina Medicaid. We also used North Carolina State Center for Health Statistics death index data.

HEART Pathway Implementation

After the preimplementation period concluded (during the wash-in period), the HEART Pathway ADP was fully integrated into the Epic EHR as an interactive CDS tool. Thus, for all adult patients with chest pain and at least 1 troponin ordered in the postimplementation period, ED providers saw an interruptive pop-up alert for the HEART Pathway tool as a Best Practice Advisory in the EHR. In addition, during the wash-in period, the HEART Pathway tool was integrated into the study-specific EHR flowsheet. This flowsheet allowed providers to manually access the HEART Pathway in patients presenting with other symptoms concerning for ACS (ie, dyspnea, left arm pain, or jaw pain) or before a troponin order.

The HEART Pathway CDS tool prompted providers to answer a series of questions to prospectively risk-stratify eligible patients in real time (patients with ST-segment–elevation MI were excluded). Patients with known CAD or acute ischemic changes on ECG (eg, new t-wave inversions or ST-segment depression in contiguous leads) were immediately classified as non-low risk for ACS, and no HEAR score (history, ECG, age, and risk factors) calculation was conducted in these patients.

Among patients without ST-segment–elevation MI, known CAD, or acute ischemic ECG changes, providers answered additional flowsheet questions to determine a HEAR score, calculated from the HEART Pathway trial algorithm (Impathiq Inc, Raleigh, NC).[22] Troponin measurements were incorporated through a direct link to laboratory results. The HEART Pathway risk assessment was automatically calculated from the HEAR score and 0- and 3-hour troponin measures.[13,23] Patients with HEAR scores ≤3 and without elevated troponin measures were classified as low risk and recommended for discharge from the ED without objective cardiac testing. Patients with HEAR scores ≥4, elevated troponin, known CAD, or ischemic ECG changes were classified as non-low risk and designated for further testing or admission (Figure 1).

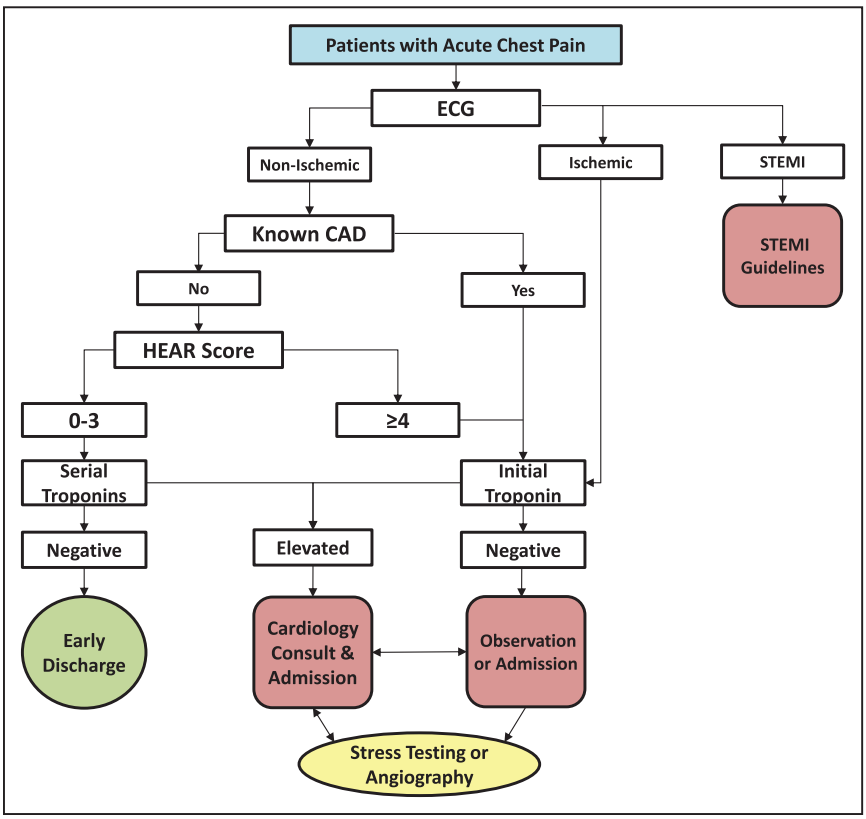

Figure 1. The HEART Pathway (history, ECG, age, risk factors, and initial troponin) algorithm.
CAD indicates coronary artery disease; HEAR, history, ECG, age, and risk factors; and STEMI, ST-segment–elevation myocardial infarction.

During the preimplementation period, the HEART Pathway CDS tool was not available to providers, and HEAR scores were not recorded on patients with chest pain. Serum troponin was measured throughout the study period with the ADVIA Centaur platform TnI-Ultra assay (Siemens, Munich, Germany) or the Access AccuTnI+3 assay (Beckman Coulter, Brea, CA).

Outcomes

The primary effectiveness outcome was hospitalization rate at 30 days (from the index visit through 30 days of follow-up). Hospitalization was defined as an inpatient admission, transfer, or observation stay (including index observation unit care). Secondary outcomes included objective cardiac testing, early discharge rates, index visit LOS, and ED LOS. The objective cardiac testing rate was defined as the proportion of patients receiving stress testing, coronary computed tomography angiography, or invasive coronary angiography. Consistent with prior studies,[12,13,24] early discharge rate was defined as the proportion of patients discharged directly from the ED without receiving objective cardiac testing. Index visit LOS represented the time from the patient's ED arrival to hospital discharge. ED LOS was defined as the time from ED arrival to ED discharge, transfer, or admission. In the postimplementation cohort, the nonadherence rate to the HEART Pathway's disposition guidance was determined. Nonadherence was defined as low-risk patients receiving stress testing or hospitalization or non–low-risk patients receiving early discharge from the ED.

Primary safety outcomes were death or acute MI during the index visit and the 30-day follow-up period. Coronary revascularization rate, a secondary end point, was defined as coronary artery bypass grafting, stent placement, or other percutaneous coronary intervention. MI and coronary revascularization were determined from diagnosis and procedure codes validated by prior cardiovascular trials.[17–21] Major adverse cardiac events, a composite of death, MI, and revascularization, were also evaluated as a secondary end point.

Statistical Analysis

We anticipated a sample size of ≈4000 in each group, allowing us to estimate safety event rates to within ±0.33% assuming an event rate of 1% (based on a large-sample normal approximation to a proportion) and to detect a difference in hospitalization rate of ≥4% with 90% power at the 5% 2-sided level of significance (based on a 2-sample χ^2 test).

We used unadjusted logistic regression to model the relationship between the preimplementation and postimplementation periods and the rates of use and safety events. These models were then adjusted for potential confounders, which were selected a priori: age, sex, race, ethnicity, insurance status, enrollment site, prior known CAD, 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 ACS (EHR flowsheet use). A time effect was initially included for each time period to assess for secular trends. None of the preimplementation cohort slopes were significantly different from zero for any index or 30-day outcome. Thus, time effects were removed from the models so that odds ratios (ORs) could be interpreted as average effects. For illustrative purposes, raw event rates were calculated for each month, and regression models were used to fit 1 slope for the preimplementation period and another slope for the postimplementation period.[25,26] 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.[27,28] No other covariates required imputation. Logistic models were fit for each imputed data set, and results were averaged across sets. Adjusted ORs (aORs) and 95% CIs were derived for each outcome.

After implementation, we calculated the percentage of patients identified as low risk and non-low risk to determine the sensitivity, specificity, and positive and negative predictive values of the HEART Pathway (and its components) for death and MI. Corresponding 95% exact binomial CIs were computed. Likelihood ratios and approximate 95% CIs were calculated with the SAS macro NLEstimate. Consistent with prior studies, patients without 30-day data from the EHR, insurers, or death index were considered free of 30-day safety events.[11–13,29] Sensitivity analyses assessed the impact of missing follow-up data on safety events using multiple imputation based on several assumptions: Patients with incomplete follow-up had the same event rate as patients with complete follow-up from the preimplementation and postimplementation cohorts or the same event rate as the preimplementation cohort (Table I in the online-only Data Supplement). 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. In addition, to evaluate the completeness of EHR follow-up, we determined the number of safety events detected in insurer claims or death index data but absent in the EHR data. To assess whether differences in provider selection of patients into the preimplementation or postimplementation cohorts may have influenced results, a sensitivity analysis was conducted (Tables II and III in the online-only Data Supplement) that excluded all patients accrued by use of the EHR ACS flowsheet (analyzing only patients meeting the Best Practice Advisory criteria of chief complaint of chest pain and troponin ordered). Preimplementation and postimplementation LOS outcomes were described with medians and interquartile ranges (IQRs) and compared with Wilcoxon rank-sum tests. All analyses were performed with R and SAS 9.4 (SAS Institute Inc, Cary, NC).

RESULTS

Patients

Over 24 months, 8474 patients were accrued (Figure 2). The cohort was 53.6% female, 28.6% black, and 17.5% uninsured with a median age of 54 years. Cohort characteristics are summarized in Table 1. The

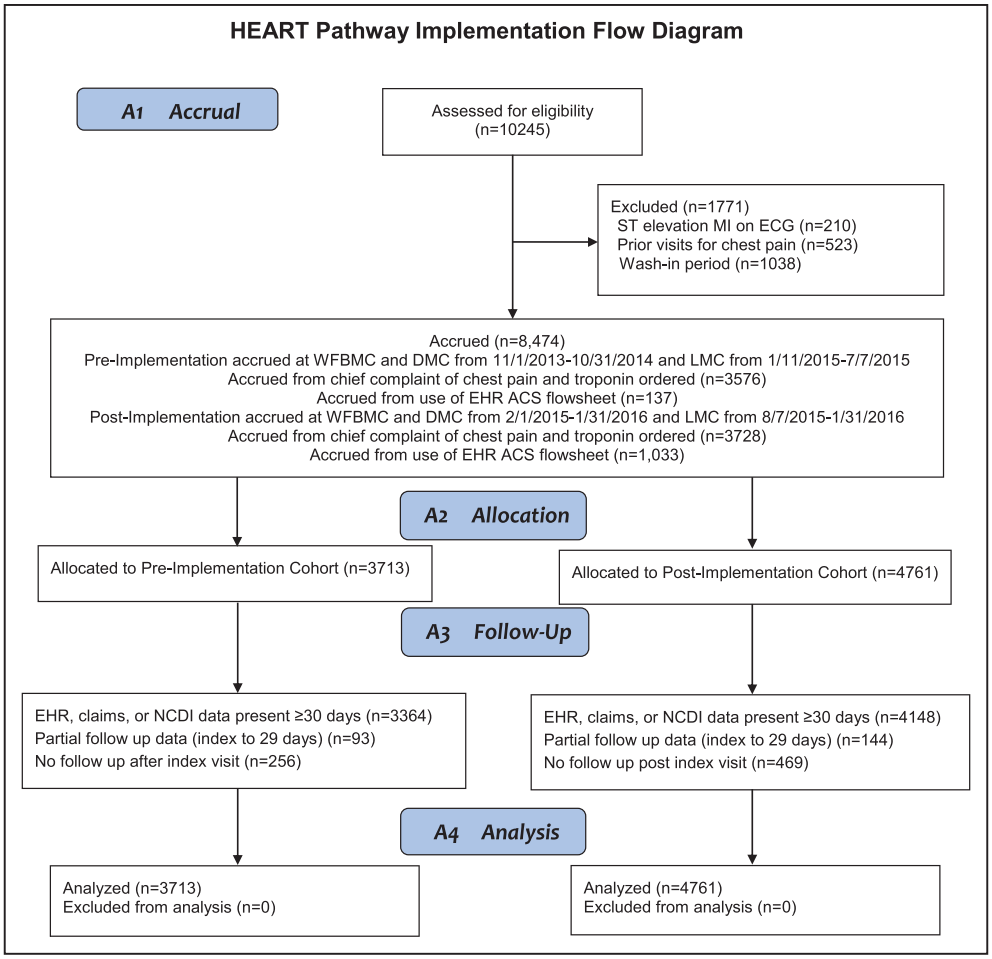

Figure 2. Participant flow diagram.
ACS indicates acute coronary syndrome; DMC, Davie Medical Center; EHR, electronic health record; HEART, history, ECG, age, risk factors, and initial troponin; LMC, Lexington Medical Center; MI, myocardial infarction; NCDI, North Carolina Death Index; and WFBMC, Wake Forest Baptist Medical Center.

death and MI rate of the cohort from index through 30 days was 6.5%, and revascularization occurred in 3.9% of patients.

Safety

The HEART Pathway identified 30.7% (1461 of 4761) as low risk and 53.2% (2531 of 4761) as non-low risk Another 7.0% (333 of 4761) had low-risk HEAR scores but lacked serial troponin measurements, and 9.2% (436 of 4761) had an incomplete or absent HEAR score. Among those classified as low risk, 0.4% (6 of 1461; 95% CI, 0.2–0.9) experienced death or MI from index through 30 days. Two of these events were MIs (2 of 1461, 0.1%; 95% CI, 0.0–0.5). Test characteristics of the HEART Pathway and adverse events among low-risk patients are summarized in Tables 2 and 3, respectively.

During the index visit, MIs were detected in 6.6% (314 of 4761) of the postimplementation cohort compared with 5.7% of the preimplementation cohort (211 of 3713; aOR, 1.36; 95% CI, 1.12–1.65). Index visit deaths occurred in 0.3% (15 of 4761) of patients in the postimplementation cohort compared with 0.2% (7 of 3713) of the preimplementation patients (aOR, 2.01; 95% CI, 0.79–5.10). During the 30-day follow-up period (not including the index visit), death or MI rates were similar in the postimplementation cohort (1.1%, 51 of 4761) and preimplementation cohort (1.3%, 50 of 3713; aOR, 0.88; 95% CI, 0.58–1.33). Death or MI at 30 days occurred in 0.3% (6 of 2046) of patients discharged early in the postimplementation cohort compared with 0.6% (8 of 1390) in the preimplementation cohort (aOR, 0.71; 95% CI, 0.22–2.8).

Hospitalizations

In the postimplementation cohort, 55.6% (2649 of 4761) of patients were hospitalized during the index visit and 30-day follow-up compared with 61.6% (2288 of 3713) in the preimplementation cohort, a reduction of 6.0% (95% CI, 3.9–8.1) with an aOR of 0.79 (95% CI, 0.71–0.87; Figure 3)

Table 1. Characteristics of Patients in the Preimplementation and Postimplementation Cohorts

Patient Characteristics	Preimplementation (n=3713), n (%)	Postimplementation (n=4761), n (%)	*P* Value*
Age, median (interquartile range), y	54 (45, 65)	54 (44, 66)	0.330
Female	1965 (52.9)	2579 (54.1)	0.278
Race			0.038
White	2484 (66.9)	3106 (65.2)	
Black	1052 (28.3)	1371 (28.8)	
Other	177 (4.8)	284 (6.0)	
Ethnicity			0.006
Hispanic or Latino	134 (3.6)	230 (4.8)	
Site			<0.001
Wake Forest Baptist Medical Center	2720 (73.3)	3685 (77.4)	
Davie Medical Center	396 (10.7)	512 (10.8)	
Lexington Medical Center	597 (16.1)	564 (11.8)	
Insurance status			0.054
Blue Cross	790 (21.3)	970 (20.4)	
MedCost	209 (5.6)	286 (6.0)	
Medicaid	505 (13.6)	687 (14.4)	
Medicare	1189 (32.0)	1617 (34.0)	
Other insurance	321 (8.6)	413 (8.7)	
Self-pay	699 (18.8)	788 (16.5)	
EHR ACS flowsheet used	137 (3.7)	1033 (21.7)	<0.001
Risk factors			
Prior coronary artery disease	1036 (27.9)	1280 (26.9)	0.297
Diabetes mellitus	1031 (27.8)	1290 (27.1)	0.491
Hyperlipidemia	1528 (41.2)	1993 (41.9)	0.512
Hypertension	2406 (64.8)	2986 (62.7)	0.048
Smoking	2356 (63.5)	2878 (60.5)	0.005
Body mass index ≥30 kg/m^2	1694 (45.6)	2198 (46.1)	0.302
Peripheral vascular disease	450 (12.1)	635 (13.3)	0.096
Cerebrovascular disease	456 (12.2)	594 (12.5)	0.787
Comorbidities			
Chronic obstructive pulmonary disease	1173 (31.6)	1543 (32.4)	0.424
Cancer	570 (15.4)	746 (15.7)	0.689
Chronic kidney disease	416 (11.2)	576 (12.1)	0.204

ACS indicates acute coronary syndrome; and EHR, electronic health records.

*Chi-square tests were used for categorical variables, and Wilcoxon rank-sum tests were used for continuous variables.

Secondary Use End Points

Early discharge occurred in 43.0% (2046 of 4761) of the postimplementation cohort versus 37.4% (1390 of 3713) in the preimplementation cohort, an increase of 5.6% (95% CI, 3.4–7.6) with an aOR of 1.24 (95% CI, 1.12–1.37). Stress testing and angiography from index visit through 30 days were completed in 30.7% (1462 of 4761) of patients in the postimplementation cohort compared with 34.5% (1281 of 3713) in the preimplementation cohort, a decrease of 3.8% (95% CI, 1.8–5.8) with an aOR of 0.89 (95% CI, 0.81–0.99). Median index visit LOS was lower in the postimplementation cohort compared with the preimplementation cohort (15.5 hours [IQR, 5.2–37.6 hours] versus 17.6 hours [IQR, 5.0–40.5 hours]; *P*=0.003). However, median ED LOS was similar before and after implementation (4.0 hours [IQR, 2.8–5.2 hours] versus 3.6 hours [IQR, 2.6–5.0 hours]; *P*=0.15). Nonadherence to the disposition guidance of the HEART Pathway occurred in 15.6% (258 of 1461) of low-risk patients and 1.2% (360 of 2531) of non–low-risk patients. Unadjusted and

Table 2. Test Characteristics of the HEART Pathway and Its Components for Detection of Death and Myocardial Infarction From Index Through 30 Days

	Sensitivity	Specificity	Positive Predictive Value	Negative Predictive Value	Positive Likelihood Ratio	Negative Likelihood Ratio
HEART Pathway	98.3 (96.3–99.4)	39.9 (38.3–41.5)	13.5 (12.2–14.9)	99.6 (99.1–99.9)	1.64 (1.59–1.68)	0.04 (0.01–0.08)
HEAR score	83.6 (78.9–87.6)	43.0 (41.4–44.7)	11.0 (9.7–12.3)	96.9% (95.9–97.7)	1.47 (1.38–1.55)	0.38 (0.29–0.49)
Troponin	91.8 (88.4–94.5)	87.7 (86.6–88.8)	42.6 (39.0–46.2)	99.1 (98.7–99.4)	7.49 (6.81–8.23)	0.09 (0.07–0.13)

Values indicate % (95% CI).

HEART Pathway (history, ECG, age, risk factors, and troponin): low risk determined by HEAR score (history, ECG, age, and risk factors) <4, no known coronary artery disease, no acute ischemic electrocardiographic changes, and no troponin elevation at 0 or 3 hours. Non–low risk determined by HEAR score ≥4, known coronary artery disease, an acute ischemic electrocardiographic change, or a troponin elevation at 0 or 3 hours.

HEAR score: low risk determined by a HEAR score <4, no known coronary artery disease, and no acute ischemic electrocardiographic changes. Non–low risk determined by HEAR score ≥4, known coronary artery disease, or an acute ischemic electrocardiographic change.

Troponin: low-risk determined by no troponin elevation at 0 or 3 hours. Non–low risk determined by a troponin elevation at 0 or 3 hours.

adjusted models of safety and use endpoints are listed in Table 4. The comparison of outcomes in the postimplementation cohort among low-risk and non–low-risk patients is summarized in Table 5.

Sensitivity Analyses

Sensitivity analyses conducted with various assumptions for patients with incomplete follow-up data did not substantively change the aORs for safety outcomes (Table I in the online-only Data Supplement). Analysis of the completeness of EHR follow-up found that most safety events were captured in the EHR, with the death index and claims data identifying only 16 safety events that were not already accounted for in the EHR data. A sensitivity analysis excluding all patients accrued by use of the EHR ACS flowsheet (patients without chest pain selected by the provider) from analysis did not meaningfully change the study conclusions (Tables II and III in the online-only Data Supplement). Analyses conducted with models with fewer covariates as a precaution for overfitting did not substantively change results.

DISCUSSION

The primary finding of this multisite implementation study is that the HEART Pathway is a safe strategy for identifying patients with acute chest pain for early discharge from the ED setting. The HEART Pathway classified 31% of ED patients with acute chest pain as low risk; among these, only 0.4% died or had an MI at 30 days. There is some consensus that an ADP should achieve a missed adverse event rate of <1% at 30 days.[15] Our findings demonstrate that the miss rate of the HEART Pathway is well below this threshold. Furthermore, a closer evaluation of adverse events in low-risk patients (Table 3) suggests that many of the deaths were likely noncardiac in nature, occurring in patients hospitalized for non-ACS conditions (eg, metastatic cancer). Only 2 events were MIs, yielding a missed MI rate of just 0.1% for the HEART Pathway among low-risk patients.

Prior studies demonstrating the efficacy of the HEART Pathway had encouraging safety data but were not designed to address effectiveness or powered to definitively demonstrate safety. This study estimates the adverse event rate among low-risk patients with tight 95% CIs and an upper bound of <1%. Previously, the lack of sufficient prospective safety data on chest pain ADPs such as the HEART Pathway was a significant driver of inefficiency and overtesting. However, this study provides evidence that could change current practice patterns and guidelines; recommendations that noninvasive objective testing should occur in low-risk patients may be obsolete.[7]

The HEART Pathway identified more patients with MI during the index visit compared with the preimplementation cohort when adjusted for potential confounding covariates. This finding suggests that the HEART Pathway not only identifies a large proportion of patients as low risk who can be safely discharged but also identifies patients at a higher risk of MI who may otherwise have been missed. Enhanced detection of MIs was not driven by changes in troponin assays, cut points, or measurement techniques; these remained stable throughout the study. However, increased use of serial troponin measurements after HEART Pathway implementation or greater awareness of MI after HEART Pathway training sessions may have increased the rate of MI detection.

Our study also demonstrates that the HEART Pathway reduced healthcare use. This finding is timely, given the high cost of delivering care to patients with

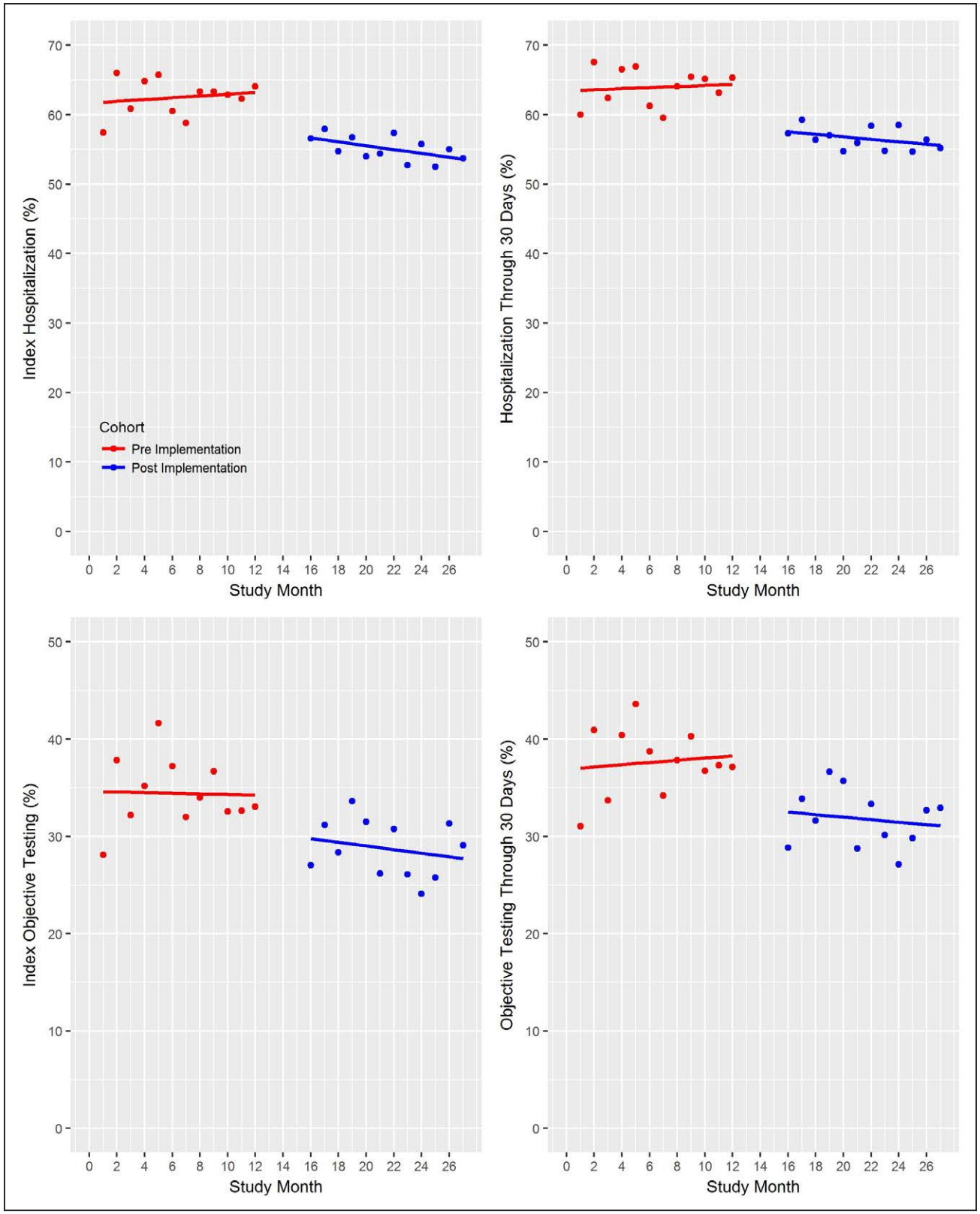

Figure 3. Hospitalization and objective cardiac testing rates at Wake Forest Baptist Medical Center and Davie Medical Center sites during the index visit and through the 30-day follow-up period with fitted regression lines.
Data from the Lexington Medical Center are excluded from this plot because of asynchronous accrual times.

Table 3. Summary of Death and Myocardial Infarction Events Among Patients Classified as Low Risk by the HEART Pathway

Age, y	Sex	Race	Comorbidities	Site	HEAR Score	Cardiac Troponin I, ng/mL*		Index Visit Emergency Department Disposition	Index Cardiac Testing	Event
						0 h	3 h			
41	Female	White	Hypertension, hyperlipidemia, diabetes mellitus, obesity, family history of early acute coronary syndrome	Davie Medical Center	3	0.035	0.040	Transfer to WFBMC for admission	Coronary angiography; multivessel disease >70% stenosis	Index visit non–ST-segment–elevation myocardial infarction; troponin peak at 0.045 ng/mL; 3-vessel coronary artery bypass graft during follow-up period
76	Female	Black	Hypertension, autoimmune hepatitis	WFBMC	3	0.007	<0.006	Discharged	None	Death on day 28; admitted to outside hospital for acute encephalopathy
57	Female	Black	Metastatic uterine cancer, deep vein thrombosis on Lovenox	WFBMC	3	0.011	0.033	Admitted to intensive care unit, intubated for respiratory failure	None	Death during index hospitalization; care withdrawn
73	Male	White	Chronic obstructive pulmonary disease	WFBMC	2	<0.006	<0.006	Discharged	None	Death on day 6; returned to emergency department with altered mental status from large subarachnoid hemorrhage
50	Male	Black	Hypertension, tobacco, cocaine abuse	WFBMC	3	0.007	0.017	Discharged	None	ST-segment–elevation myocardial infarction on day 12; returned to emergency department with chest pain, ECG consistent with ST-segment–elevation myocardial infarction, coronary angiography with diffuse mild nonobstructive coronary artery disease (maximum stenosis, 25%)
43	Male	White	None	WFBMC	0	<0.006	<0.006	Admitted for hypoxemia and wheezing	None	Death during index visit, respiratory failure, and pulseless electric activity arrest

HEAR indicates history, ECG, age, and risk factor; and HEART, history, ECG, age, risk factors, and initial troponin.
*cTnI at WFBMC and Davie Medical Center has upper reference limit and 99th percentile value of 0.040 ng/mL and <10% coefficient of variation at 0.040 ng/mL.

acute chest pain and the current focus on delivering high-value care.[30] Although efficiency gains (reductions in hospitalizations, objective cardiac testing, and index visit LOS and an increase in early discharge rate) from the HEART Pathway were modest, when they are extrapolated to the 8 to 10 million patients with chest pain seen in a US ED annually, substantial savings in healthcare resources are possible. Furthermore, even small reductions in early discharge rate, LOS, and objective cardiac testing rates can have a large impact on ED/hospital crowding and resource stewardship.[31] In addition, our modest reductions in utilization outcomes should be interpreted in the context of the prior experience of our health system with the HEART Pathway. Our research conducted before this study introduced the HEART Pathway to most of our ED providers, and some of them were informally using it during the preimplementation period. Therefore, it is possible that "contamination" may have decreased the effect size of our intervention, and hospitals that are "naïve" to the HEART Pathway may realize larger reductions in healthcare utilization outcomes.

As the first prospective multisite evaluation in the United States of a chest pain ADP designed to identify low-risk patients for early discharge, this study substantively adds to a growing body of literature suggesting the safety of such processes. An evaluation of a national clinical pathway in patients with

Table 4. Proportion of Patients With Events in the Preimplementation and Postimplementation Cohorts

Outcomes	Preimplementation (n=3713), n (%)	Postimplementation (n=4761), n (%)	Unadjusted Odds Ratio (95% CI)	Adjusted Odds Ratio (95% CI)*
Safety				
Index visit				
Death	7 (0.2)	15 (0.3)	1.67 (0.68–4.11)	2.01 (0.79–5.10)
MI	211 (5.7)	314 (6.6)	1.17 (0.98–1.40)	1.36 (1.12–1.65)
Revascularization	119 (3.2)	154 (3.2)	1.01 (0.79–1.29)	1.17 (0.90–1.52)
Death+MI	217 (5.8)	325 (6.8)	1.18 (0.99–1.41)	1.37 (1.13–1.66)
Death+MI+revascularization	257 (6.9)	355 (7.5)	1.08 (0.92–1.28)	1.25 (1.04–1.50)
Follow-up period				
Death	37 (1.0)	24 (0.5)	0.50 (0.30–0.84)	0.49 (0.28–0.86)
MI	18 (0.5)	29 (0.6)	1.26 (0.70–2.27)	1.55 (0.85–2.83)
Revascularization	25 (0.7)	38 (0.8)	1.19 (0.72–1.97)	1.43 (0.85–2.42)
Death+MI	50 (1.3)	51 (1.1)	0.79 (0.54–1.17)	0.88 (0.58–1.33)
Death+MI+revascularization	69 (1.9)	77 (1.6)	0.87 (0.63–1.20)	0.98 (0.70–1.39)
At 30 d (index+follow-up)				
Death	44 (1.2)	39 (0.8)	0.69 (0.45–1.06)	0.73 (0.46–1.16)
MI	223 (6.0)	324 (6.8)	1.14 (0.96–1.36)	1.34 (1.11–1.62)
Revascularization	143 (3.9)	190 (4.0)	1.04 (0.83–1.29)	1.23 (0.97–1.57)
Death+MI	258 (6.9)	353 (7.4)	1.07 (0.91–1.27)	1.24 (1.03–1.48)
Death+MI+revascularization	303 (8.2)	395 (8.3)	1.02 (0.87–1.19)	1.17 (0.99–1.39)
Use				
Index visit				
Hospitalization	2231 (60.1)	2582 (54.2)	0.79 (0.72–0.86)	0.80 (0.72–0.88)
Early discharge	1390 (37.4)	2046 (43.0)	1.26 (1.15–1.38)	1.24 (1.12–1.37)
Objective cardiac testing	1145 (30.8)	1307 (27.5)	0.85 (0.77–0.93)	0.90 (0.81–0.99)
Follow-up period				
Hospitalization	241 (6.5)	271 (5.7)	0.87 (0.73–1.04)	0.92 (0.76–1.11)
Objective cardiac testing	199 (5.4)	206 (4.3)	0.80 (0.65–0.98)	0.86 (0.70–1.06)
At 30 d (index+follow-up)				
Hospitalization	2288 (61.6)	2649 (55.6)	0.78 (0.72–0.85)	0.79 (0.71–0.87)
Objective cardiac testing	1281 (34.5)	1462 (30.7)	0.84 (0.77–0.92)	0.89 (0.81–0.99)

MI indicates myocardial infarction.

*Models adjusted for the following variables: age, sex, race, ethnicity, body mass index, emergency department location, insurance status, smoking, history of coronary artery disease, diabetes mellitus, hyperlipidemia, hypertension, cerebrovascular disease, peripheral vascular disease, chronic obstructive pulmonary disorder, chronic kidney disease, cancer (excludes nonmelanoma skin cancer), and presence of chest pain versus other symptoms concerning for acute coronary syndrome.

chest pain in New Zealand also reported a significant increase in early discharge rate while maintaining safety.[32] Thus, cumulatively, there is now evidence of safe prospective use of chest pain ADPs in almost 25 000 patients.

However, a recent study evaluating the use of the HEART score in the Netherlands did not find a significant increase in early discharge rate and reported a 2% major adverse cardiac events rate among low-risk patients.[33] This finding may be the result of several key differences between the HEART score and our HEART Pathway. First, the HEART score incorporates a single troponin measure. Although rare, patients with an elevated troponin level could have a low-risk score. Second, the HEART score can be low risk in patients with acute ischemic changes on ECG or known CAD. The HEART Pathway CDS uses serial troponin measurements and prioritizes troponin elevation, ischemic ECG changes, and prior CAD; patients with any of these are considered non-low risk regardless of score. Finally, the HEART score has subjective criteria and is manually calculated, which decrease its reproducibility and reliability.[34,35] The HEART Pathway CDS replaces subjective components of the HEART score with objective binary questions and uses an algorithm to determine each HEAR score component.

Table 5. Proportion of Patients With Events in the Postimplementation Cohort Based on HEART Pathway Risk Assessment

Outcomes	Low Risk (n=1461), n (%)	Non–Low Risk (n=2531), n (%)	Incomplete (n=769), n (%)	Percent Difference, Low: Not Low (95% CI)*	Percent 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 (0)	12.3 (11.0 to 13.6)	–0.1 (–0.2 to 0.1)
Revascularization	1 (0.1)	151 (6)	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)
Follow-up period					
Death	2 (0.1)	19 (0.8)	3 (0.4)	0.6 (0.2 to 1.0)	0.3 (–0.2 to 0.7)
MI	1 (0.1)	26 (1)	2 (0.3)	1.0 (0.5 to 1.4)	0.2 (–0.2 to 0.6)
Revascularization	1 (0.1)	34 (1.3)	3 (0.4)	1.3 (0.8 to 1.7)	0.3 (–0.1 to 0.8)
Death+MI	3 (0.2)	43 (1.7)	5 (0.7)	1.5 (0.9 to 2.0)	0.4 (–0.2 to 1.1)
Death+MI+revascularization	4 (0.3)	66 (2.6)	7 (0.9)	2.3 (1.7 to 3.0)	0.6 (–0.1 to 1.4)
At 30 d (index+follow-up)					
Death	4 (0.3)	31 (1.2)	4 (0.5)	1.0 (0.4 to 1.5)	0.2 (–0.3 to 0.8)
MI	2 (0.1)	320 (12.6)	2 (0.3)	12.5 (11.2 to 13.8)	0.1 (–0.3 to 0.5)
Revascularization	2 (0.1)	183 (7.2)	5 (0.7)	7.1 (6.1 to 8.1)	0.5 (–0.1 to 1.1)
Death+MI	6 (0.4)	341 (13.5)	6 (0.8)	13.1 (11.7 to 14.4)	0.4 (–0.3 to 1.1)
Death+MI+revascularization	7 (0.5)	378 (14.9)	10 (1.3)	14.5 (13.0 to 15.9)	0.8 (–0.1 to 1.7)
Use					
Index visit					
Hospitalization	241 (16.5)	2095 (82.8)	246 (32)	66.3 (63.9 to 68.7)	15.5 (11.7 to 19.3)
Early discharge	1203 (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)	1148 (45.4)	43 (5.6)	37.4 (35.0 to 39.8)	–2.3 (–4.5 to –0.2)
Follow-up period					
Hospitalization	43 (2.9)	199 (7.9)	29 (3.8)	4.9 (3.6 to 6.3)	0.8 (–0.8 to 2.4)
Objective cardiac testing	43 (2.9)	145 (5.7)	18 (2.3)	2.8 (1.5 to 4.0)	–0.6 (–2.0 to 0.8)
At 30 d (index+follow-up)					
Hospitalization	268 (18.3)	2128 (84.1)	253 (32.9)	65.7 (63.3 to 68.2)	14.6 (10.7 to 8.4)
Objective cardiac testing	156 (10.7)	1248 (49.3)	58 (7.5)	38.6 (36.1 to 41.1)	–3.1 (–5.6 to –0.7)

HEART indicates history, ECG, age, risk factors, and initial troponin; and MI, myocardial infarction.
*Proportions and associated 95% CIs were calculated without adjustment for potential confounders.

Limitations

Our study design has limitations compared with a traditional randomized design. For example, secular trends and provider maturation effects are potential threats to the validity of our results. However, event rates were fairly consistent over time (Figure 3). Using our EHR to collect events may have decreased event rates compared with traditional methods of follow-up. However, supplementing the EHR data with death index and claims data identified only 16 additional 30-day safety events. This suggests that our EHR identified most events and justifies including all patients in the analysis rather than limiting the analysis to only patients with insurance claims data. More patients were accrued into the postimplementation phase compared with the preimplementation phase. This imbalance occurred because providers used an EHR flowsheet for patients with non–chest pain presentations more frequently once the HEART Pathway tool was available in this flowsheet. It is possible that inclusion of these patients produced a selection bias; however, a sensitivity analysis excluding these patients did not significantly affect study conclusions. In addition, although our 3 sites were diverse in size and location (urban and suburban), results may not be generalizable to, or feasible in, all US health systems. However, given the size and scope of this pragmatic implementation study, our design had the advantages of feasibility, cost-effectiveness, and generalizability compared with a

traditional randomized trial. Some differences existed in baseline risk factors present in the preimplementation versus postimplementation cohorts. However, our regression analyses adjusted for these potential confounders. In addition, one of our sites (Lexington Medical Center) did not implement the HEART Pathway on the same time schedule as the others, and it is possible that this asynchrony may have influenced our results. Finally, it is possible that safety events related to the index visit care occurred beyond the 30-day follow-up period. To address this concern, 1-year follow-up data were collected on each participant, and a separate analysis of 1-year safety and use outcomes is planned.

Conclusions

The HEART Pathway was associated with decreased hospitalizations and death and MI rates well below 1% among low-risk patients. This study may provide a model for US health systems to provide safe and high-value care to the 8 to 10 million patients who present to a US ED with acute chest pain each year. Our data add to a growing body of evidence suggesting that current practice guidelines should be changed so that stress tests or cardiac imaging is no longer recommended for most low-risk patients presenting to the ED with chest pain.

ARTICLE INFORMATION

Received June 21, 2018; accepted August 2, 2018.

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Acknowledgments

The authors give special thanks to William B. Applegate, MD, MPH; Robert F. Riley, MD, MS; Erin N. Harper, MS; Jason P. Stopyra, MD; Stephanie Elliott, BS; Russell M. Howerton, MD; and Bob Mckee, BS for their assistance with and support for HEART Pathway implementation.

Sources of Funding

This project was funded by the Donaghue Foundation and the Association of American Medical Colleges. The funding sources had no role in the design or conduct of this investigation. This includes no role in the collection, management, analysis, and interpretation of data or preparation, review, or approval of the article. The authors acknowledge the assistance of the Wake Forest Clinical and Translational Science Institute, supported by the National Center for Advancing Translational Sciences, National Institutes of Health, through UL-1TR001420 (Donald McClain, principal investigator). The Wake Forest Clinical and Translational Science Institute assisted with data extraction, study design, project management, and medical editing.

Disclosures

Dr Mahler receives research funding from Abbott Point of Care, Roche Diagnostics, and Siemens; has received consulting honoraria from Roche Diagnostics; and is the chief medical officer for Impathiq Inc. Dr Mahler also receives research support from National Heart, Lung, and Blood Institute (1 R01 HL118263-01, L30 HL120008) and Patient-Centered Outcomes Research Institute PCORI. Dr Mahler has a conflict of interest management plan in place for research through the Conflict of Interest Office at the Wake Forest School of Medicine. Dr Miller receives research support from Siemens, Abbott Point of Care, and 1 R01 HL118263. The other authors report no conflicts.

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