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Safely Identifying Emergency Department Patients with Acute Chest Pain for Early Discharge: The HEART Pathway Accelerated Diagnostic Protocol

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Abstract

Background: The HEART Pathway is an accelerated diagnostic protocol (ADP) designed to identify low-risk Emergency Department (ED) 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 ED patients with possible acute coronary syndrome (ACS).

Methods: A prospective pre/post study was conducted at three US sites among 8,474 adult ED patients with possible ACS. Patients included were ≥21 years old, investigated for possible ACS,

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and had no evidence of ST-segment elevation myocardial infarction on electrocardiography. Accrual occurred for 12 months before and after HEART Pathway implementation from November 2013- January 2016. The HEART Pathway ADP was integrated into each site's electronic health record as an interactive clinical decision support tool. Following ADP integration, ED providers prospectively utilized the HEART Pathway to identify patients with possible ACS 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: Pre- and post-implementation 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 post- vs pre-implementation cohort (55.6% vs 61.6%; aOR: 0.79, 95%CI: 0.71–0.87). During the index visit more MIs were detected in the post-implementation cohort (6.6% vs 5.7%; aOR: 1.36, 95%CI: 1.12–1.65). Rates of death or MI during follow-up were similar (1.1% vs 1.3%; aOR: 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 that can be safely discharged without stress testing or angiography.

Clinical Trial Registration: clinicaltrials.gov Identifier: NCT02056964

Keywords

Clinical Decision Support; Medical Decision Making; Electronic Health Records; Emergency Medicine; Acute Coronary Syndrome; Risk Stratification; Accelerated Diagnostic Protocol

Introduction

United States Emergency Departments (ED) care for 8–10 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 $10–13 billion annually.[5, 7] While 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, 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, and cost.[11–14] While these studies also provided data suggesting safety, they were not adequately powered to provide tight confidence intervals around safety event rates. While a matter of debate, many believe that a successful risk stratification strategy must achieve <1% missed events among low-risk patients within 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 three-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- 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, analytic 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 (WFBMC), with approximately 114000 ED visits annually; Davie Medical Center (DMC), with approximately 12000 annual ED visits; and Lexington Medical Center (LMC), with approximately 37000 annual ED visits. The target population was adult ED patients (≥21 years old) investigated for possible ACS, but without evidence of ST-segment elevation myocardial infarction (STEMI) on electrocardiography (ECG). Inclusion criteria were the same throughout the pre- and post-implementation periods. Patients with a chief complaint of chest pain and at least one troponin ordered, without evidence of a STEMI on ECG, were accrued. This included patients with known coronary artery disease (prior myocardial infarction, 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 EHR flowsheet for possible ACS, which was available in both the Pre- and Post-cohorts.

At WFBMC and DMC, participants were accrued into the pre-implementation cohort (November 2013-October 2014) or the post-implementation cohort (February 2015-January 2016). A wash-in period (November 2014- January 2015) was used to train providers and beta-test an electronic health record (EHR)-based HEART Pathway clinical decision support tool. LMC accrued patients into the pre-implementation (January-July 2015) and post-implementation cohorts (August 2015- January 2016), with a 1-month wash-in period. Patients were accrued into each cohort based on the date of their initial ED visit; later visits for chest pain were considered recurrent care. To prevent accruing more ED repeat users/ high utilizers (who often have more co-morbid conditions) into the pre-implementation 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 based on 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 health system's EHR data (Clarity-Epic Systems Corporation, Verona, WI). Pre-validated structured EHR variables or diagnoses and procedure codes (CPT, ICD9, and ICD10) were used to obtain patient demographics, past medical history, cardiovascular risk factors, comorbidities, troponin results, provider's HEART Pathway assessments, disposition, diagnoses (including myocardial infarction), 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 (BCBS) 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 pre-implementation period concluded (during the wash-in period) the HEART Pathway ADP was fully integrated into EPIC as an interactive clinical decision support (CDS) tool. Thus, for all adult patients with chest pain and at least one troponin ordered in the post-implementation 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 flow sheet allowed providers to manually access the HEART Pathway in patients presenting with other symptoms concerning for ACS (i.e. dyspnea, left arm pain, or jaw pain) or prior to 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 STEMI were excluded). Patients with known coronary artery disease, or acute ischemic changes on ECG (e.g. new t-wave inversions or ST-segment depression in contiguous leads) were immediately classified as non-low-risk for ACS and no History, ECG, Age, and Risk factor score (HEAR score) score calculation was conducted in these patients.

Among patients without STEMI, known coronary disease (CAD), or acute ischemic ECG changes, providers answered additional flow sheet questions to determine a History, ECG, Age, and Risk factor score (HEAR score); calculated based on 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 based on the HEAR score and 0 and 3-hour troponin measures.[13, 23] Patients with HEAR scores of 3 or lower and without elevated troponin measures were classified as low-risk and recommended for discharge from the ED without objective cardiac testing. Patients with a HEAR score of 4 greater, an elevated troponin, known CAD, or ischemic ECG changes were classified as non-low-risk and designated for further testing and/or admission (Figure 1). During the pre-implementation 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 using 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, and index visit length of stay (LOS) and ED LOS. The Objective cardiac testing rate was defined as the proportion of patients receiving stress testing, coronary CT 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 post-implementation cohort the non-adherence rate, to the HEART Pathway's disposition guidance was determined. Non-adherence 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 myocardial infarction (MI) during the index visit and the 30-day follow-up period. Coronary revascularization rate, a secondary endpoint, was defined as coronary artery bypass grafting, stent placement, or other percutaneous coronary intervention. MI and coronary revascularization were determined using diagnosis and procedure codes validated by prior cardiovascular trials.[17–21] Major adverse cardiac events (MACE), a composite of death, MI, and revascularization, were also evaluated as a secondary endpoint.

Statistical Analysis

We anticipated a sample size of approximately 4000 in each group, allowing us to estimate safety event rates to within $\pm$ 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% two-sided level of significance (based on a two-sample chi-square test).

We used unadjusted logistic regression to model the relationship between pre- and post-implementation periods and the rate of utilization 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 coronary artery disease, diabetes, hypertension, hyperlipidemia, chronic kidney disease, chronic obstructive pulmonary disease, cerebral vascular disease, peripheral vascular disease, cancer, smoking, body mass index (BMI), and presence of chest pain vs 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 pre-implementation 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 could be interpreted as average effects. For illustrative purposes, raw event rates were calculated for each month and regression models were used to fit one slope for the pre-implementation period and another slope for the post-implementation period.[25, 26] BMI was missing for 2.9% of patients, so multivariate imputation, with replacement by predictive mean matching utilizing all predictors and outcome variables, was used to create 10 datasets with complete BMI data.[27, 28] No other covariates required imputation. Logistic models were fit for each imputed dataset and results averaged across sets. Adjusted odds ratios (aOR) and 95% confidence intervals were derived for each outcome.

Post-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 confidence intervals were computed. Likelihood ratios and approximate 95% CIs were calculated using 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 such as; patients with incomplete follow-up had the same event rate as patients with complete follow-up from the pre- and post-cohorts, or the same event rate as the pre-implementation cohort (Supplemental Table 1). Proc MI in SAS was used to generate 25 imputed datasets for each scenario, and Proc MIAnalyze was used to combine the results from the logistic regression analysis of each imputed dataset. In addition, to evaluate the completeness of EHR follow-up we determined the number of safety events detected based on insurer claims or death index data but absent in the EHR data. To assess whether differences in provider selection of patients into the pre- or post-implementation cohorts may have influenced results, a sensitivity analysis was conducted (Supplemental Tables 2 and 3), which excluded all patients accrued by use of the EHR ACS flowsheet (analyzing only patients meeting the BPA criteria of chief complaint of chest pain and troponin ordered). Pre- and post-implementation LOS outcomes were described using medians and interquartile ranges (IQR) and compared using Wilcoxon rank-sum tests. All analyses were performed using R and SAS 9.4 (Cary, NC).

Results

Patients

Over 24 months, 8474 patients were accrued (Figure 2). The cohort was 53.6% female, 28.6% African American, and 17.5% uninsured with a median age of 54. Cohort characteristics are summarized in Table 1. The 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% (1461/4761) as low-risk and 53.2% (2531/4761) as non-low-risk. Another 7.0% (333/4761) had low-risk HEAR scores but lacked serial troponin measurements, and 9.2% (436/4761) had an incomplete or absent HEAR score. Among those classified as low-risk, 0.4% (6/1461; 95%CI: 0.2–0.9%) experienced death or

MI from index through 30 days. Two of these events were MIs; (2/1461, 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% (314/4761) of the post-implementation cohort compared to 5.7% of the pre-implementation cohort (211/3713); aOR: 1.36 (95%CI: 1.12–1.65). Index visit deaths occurred in 0.3% (15/4761) of patients in the post-implementation cohort compared to 0.2% (7/3713) pre-implementation 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 post-implementation cohort (1.1%, 51/4761) and pre-implementation cohort (1.3%, 50/3713); aOR: 0.88 (95%CI: 0.58–1.33). Death or MI at 30 days occurred in 0.3% (6/2046) of early discharge patients in the post-implementation cohort compared to 0.6% (8/1390) in the pre-cohort (aOR: 0.71 95%CI: 0.22–2.8).

Hospitalizations

In the post-implementation cohort, 55.6% (2649/4761) of patients were hospitalized during the index visit and 30-day follow-up, compared to 61.6% (2288/3713) in the pre-implementation 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)

Secondary Utilization Endpoints

Early discharge occurred in 43.0% (2046/4761) of the post-cohort versus 37.4% (1390/3713) in the pre-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 was completed in 30.7% (1462/4761) of patients in the post-cohort compared to 34.5% (1281/3713) in the pre-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 post-cohort compared to the pre-cohort (15.5 hours; IQR 5.2, 37.6 vs 17.6 hours; IQR 5.0, 40.5; p=0.003). However, median ED LOS was similar post- and pre-implementation (4.0 hours; IQR 2.8, 5.2 vs 3.6 hours; IQR 2.6, 5.0; p=0.15). Non-adherence to the disposition guidance of the HEART Pathway occurred in 15.6% (258/1461) of low-risk patients and 1.2% 360/2531 of non-low-risk patients. Unadjusted and adjusted models of safety and utilization endpoints are listed in Table 4. Comparison of outcomes in the post-cohort among low-risk and non-low-risk patients is summarized in Table 5.

Sensitivity Analyses

Sensitivity analyses conducted using various assumptions for patients with incomplete follow-up data did not substantively change aORs for safety outcomes (Supplemental Table 1). 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 study conclusions (Supplemental Tables 2 and 3). Analyses conducted using 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 accelerated diagnostic protocol should achieve a missed adverse event rate below 1% at 30 days.[15] Our findings demonstrate that the HEART Pathway's miss rate 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 non-cardiac in nature, occurring in patients hospitalized for non-ACS conditions (e.g., metastatic cancer). Only two 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% confidence intervals and an upper bound below 1%. Previously, a lack of sufficient prospective safety data on chest pain ADPs, such as the HEART Pathway, was a significant driver of inefficiency and over-testing. However, this study provides evidence that could change current practice patterns and guidelines: recommendations that non-invasive objective testing occur in low-risk patients may be obselete.[7]

The HEART Pathway identified more patients with MI during the index visit compared to the pre-implementation 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 following HEART Pathway training sessions, may have increased the rate of MI detection.

Our study also demonstrates that the HEART Pathway reduced healthcare utilization. This finding is timely, given the high cost of delivering care to patients with acute chest pain and the current focus on delivering high-value care.[30] While efficiency gains (reductions in hospitalizations, objective cardiac testing, and index visit LOS, and increase in early discharge rate) from the HEART Pathway were modest, when extrapolated to the 8–10 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] Also, our modest reductions in utilization outcomes should be interpreted in the context of our health system's prior experience with the HEART Pathway. Our research conducted prior to this study introduced the HEART Pathway to most of our ED providers, and some of them were informally using it during the pre-implementation period. Therefore, it is possible that "contamination" may have decreased the effect size of our intervention and

hospitals, which are “naïve” to the HEART Pathway may realize larger reductions in healthcare utilization outcomes.

As the first prospective multi-site evaluation in the US 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 chest pain patients 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 use of the HEART score in the Netherlands did not find a significant increase in early discharge rate and reported a 2% MACE rate among low-risk patients.[33] This may be due to 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.

Limitations

Nonetheless, our study design has limitations compared to 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 to 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 post-implementation phase compared to the pre-implementation 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 impact 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 advantages of feasibility, cost-effectiveness, and generalizability compared to a traditional randomized trial. Some differences existed in baseline risk factors present in the pre- versus post-implementation cohorts. However, our regression analyses adjusted for these potential confounders. Also, one of our sites (LMC) 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 was collected on each participant and a separate analysis of 1 year safety and utilization 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 8–10 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 are no longer recommended for most 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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Clinical Perspective

What is new?

- Among the 30.7% of patients identified by the HEART Pathway 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 odd ratio of 1.36 (95%CI: 1.12–1.65).
- Hospitalizations from index visit through 30 days were decreased by 6% following HEART Pathway implementation.
- HEART Pathway implementation increased early discharge from the ED by 5.6%, decreased 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 ED discharges and decreasing hospitalizations, stress testing, and index visit length of stay in patients with acute chest pain.
- Given its ability to safely reduce health care 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.

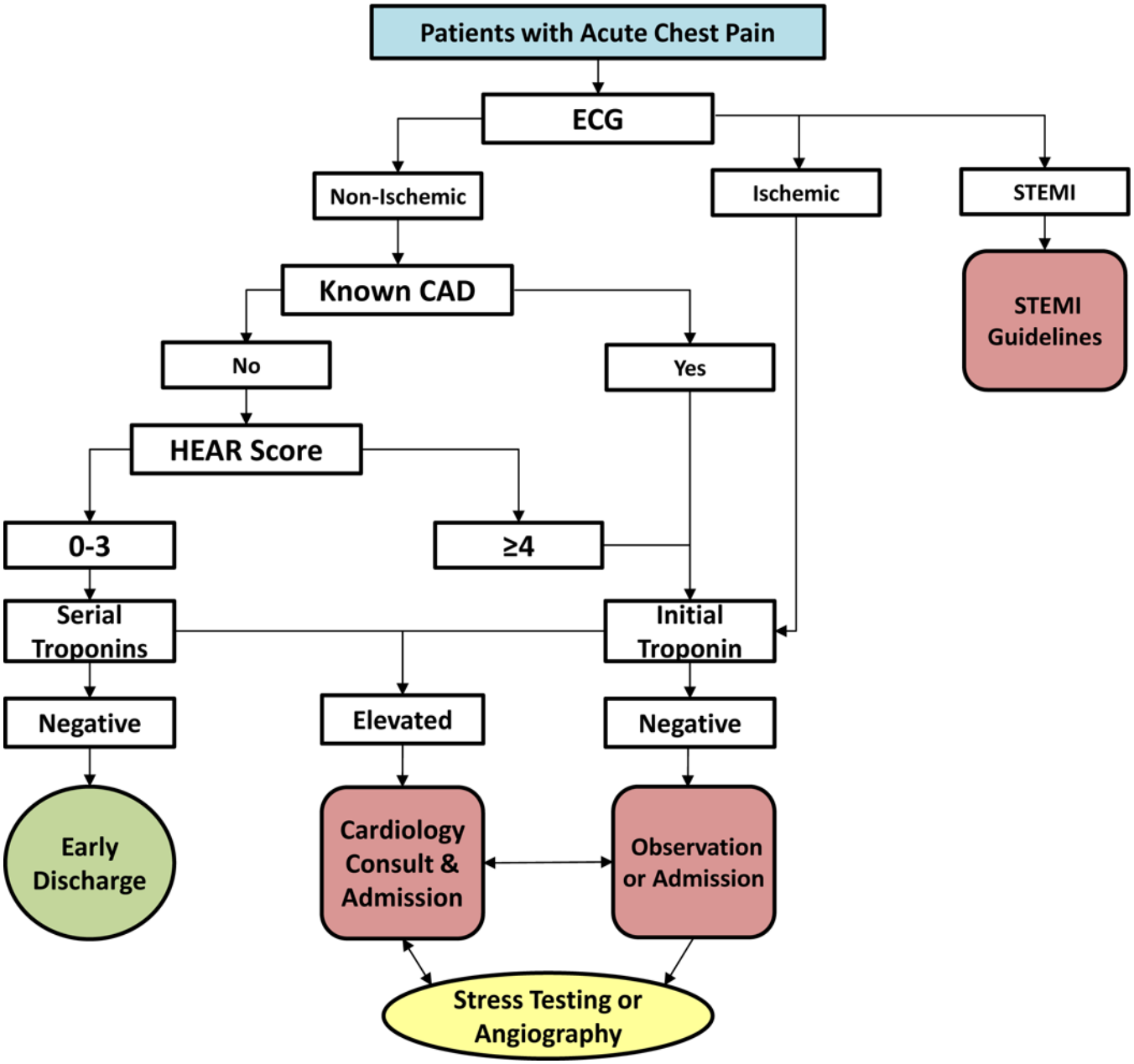

Figure 1:
The HEART Pathway algorithm

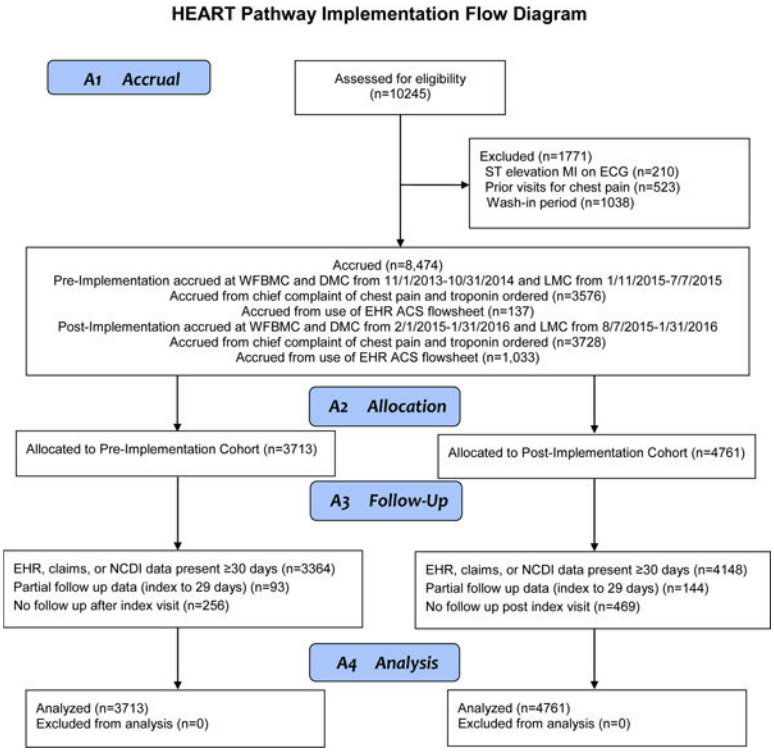

Figure 2.
Participant flow diagram

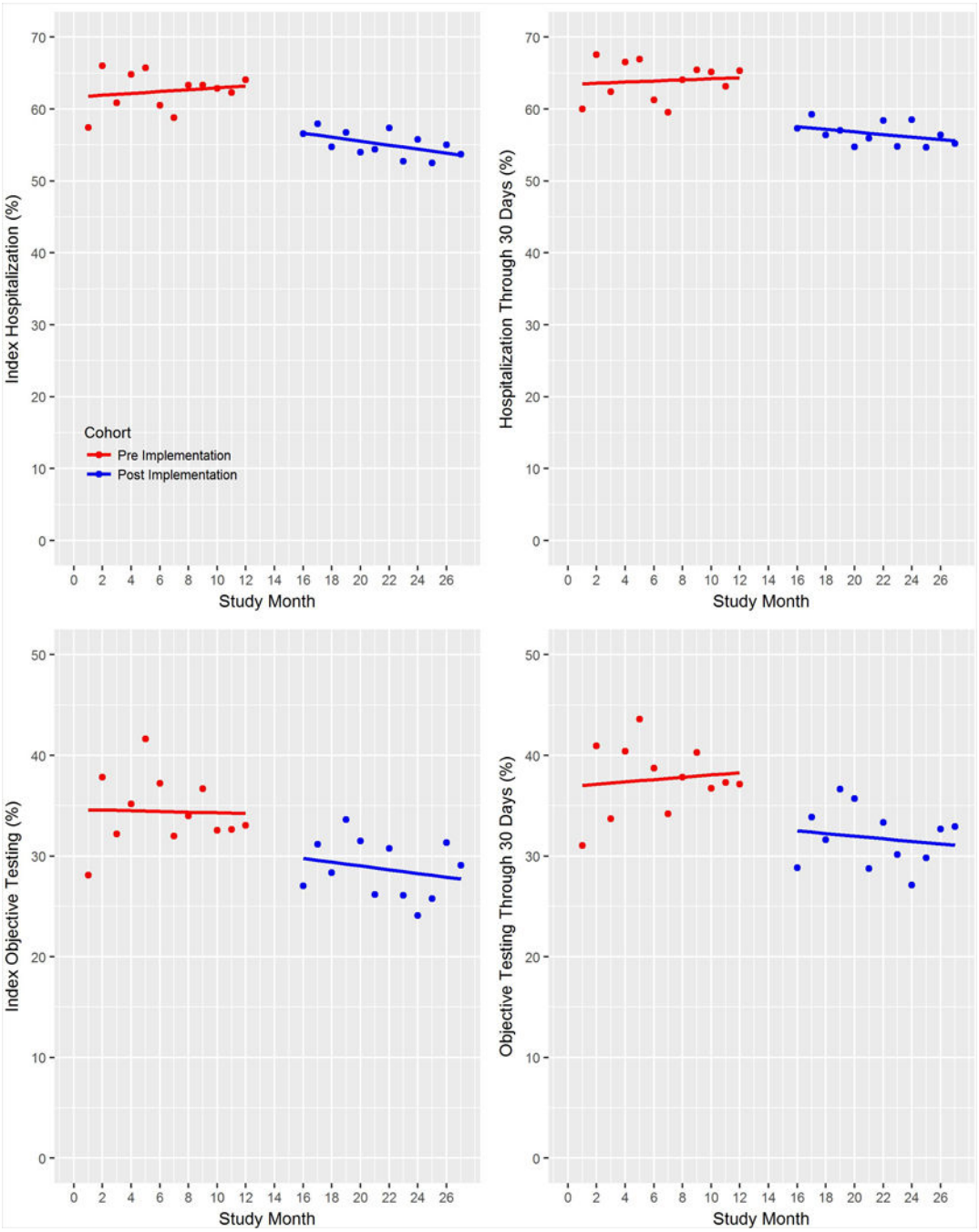

Figure 3.

Hospitalization and objective cardiac testing rates at WFBMC and DMC sites during the index visit and through the 30-day follow-up period, with fitted regression lines. Data from LMC are excluded from this plot due to asynchronous accrual times.

Table 1.

Characteristics of patients in the Pre- and Post-Implementation Cohorts

Patient Characteristics	**Pre N= 3713 (%)**	**Post N= 4761 (%)**	***p* value***
Age –median (IQR)	54 (45, 65)	54 (44, 66)	0.330
Female	1965 (52.9)	2579 (54.1)	0.278
Race			**0.038**
White or Caucasian	2484 (66.9)	3106 (65.2)	
Black or African American	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**
WFBMC	2720 (73.3)	3685 (77.4)	
DMC	396 (10.7)	512 (10.8)	
LMC	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 CAD	1036 (27.9)	1280 (26.9)	0.297
Diabetes	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**
BMI ≥30	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			
COPD	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

*Chi-squared tests were used for categorical variables and Wilcoxon rank-sum tests were used for continuous variables. IQR= Interquartile range, WFBMC= Wake Forest Baptist Medical Center, DMC= Davie Medical Center, LMC= Lexington Medical Center. CAD= Coronary Artery Disease, BMI= Body Mass Index, COPD = Chronic Obstructive Pulmonary Disease

Table 2.

Test characteristics of the HEART Pathway and its components for detection of death and MI from index through 30 days.

	Sensitivity (95% CI)	Specificity (95% CI)	PPV (95% CI)	NPV (95% CI)	+LR (95% CI)	-LR (95% CI)
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)

HEART Pathway; low-risk determined by HEAR score <4, and no known CAD, and no acute ischemic ECG changes, and no troponin elevation at 0 or 3 hours. Non-low-risk determined by HEAR score ≥4, or known CAD, or an acute ischemic ECG change, or a troponin elevation at 0 or 3 hours.

HEAR Score; low risk determined by a HEAR score <4, and no known CAD, and no acute ischemic ECG changes. Non-low-risk determined by HEAR score ≥4, or known CAD, or an acute ischemic ECG 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.

CAD= coronary artery disease, ECG= electrocardiogram, PPV= positive predictive value, NPV=negative predictive value, +LR= positive likelihood ratio, -LR= negative likelihood ratio

Table 3.

Summary of death and MI events among patients classified as low-risk by the HEART Pathway.

Age	Sex	Race*	Comorbidities	Site	HEAR score	0 hr cTnI ng/ml†	3 hr cTnI ng/ml†	Index Visit ED Disposition	Index Cardiac Testing	Event
41	Female	W	Hypertension Hyperlipidemia Diabetes Obesity Family history of early ACS	DMC	3	0.035	0.040	Transfer to WFBMC for admission	Coronary angiography; multivessel disease >70% stenosis	Index visit NSTEMI; troponin peak at 0.045 ng/ml. 3-vessel CABG during follow-up period
76	Female	AA	Hypertension, autoimmune hepatitis	WFBMC	3	0.007	<0.006	Discharged	None	Death on day 28; admitted to outside hospital for acute encephalopathy
57	Female	AA	Metastatic uterine cancer, DVT on Lovenox	WFBMC	3	0.011	0.033	Admitted to ICU, intubated for respiratory failure	None	Death during index hospitalization; care withdrawn
73	Male	W	COPD	WFBMC	2	<0.006	<0.006	Discharged	None	Death on day 6; Returned to ED with altered mental status from large subarachnoid hemorrhage
50	Male	AA	Hypertension, Tobacco, Cocaine abuse	WFBMC	3	0.007	0.017	Discharged	None	STEMI on day 12; Returned to ED with chest pain, ECG consistent with STEMI, coronary angiography with diffuse mild non-obstructive coronary artery disease (maximum stenosis = 25%)
43	Male	W	None	WFBMC	0	<0.006	<0.006	Admitted for hypoxemia and wheezing	None	Death during index visit, respiratory failure and PEA arrest

*Race; W=White, AA= African American,

†cTnI at WFBMC and DMC has upper reference limit and 99th percentile value of 0.040 ng/ml and <10% coefficient of variation at 0.040 ng/ml. cTnI=cardiac troponin I, NSTEMI= non-ST segment elevation myocardial infarction, CABG= coronary artery bypass graft, DVT= deep vein thrombosis, ICU= intensive care unit, STEMI= ST segment elevation myocardial infarction, PEA= pulseless electrical activity.

Table 4.

Proportion of patients with events in the Pre- and Post-implementation cohorts

Outcomes	Pre N= 3713 (%)	Post N= 4761 (%)	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)
30 day (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)
Utilization				
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)
30 day (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)**

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

Table 5.

Proportion of patients with events in the Post-implementation cohort based on HEART Pathway risk assessment

Outcomes	Low-Risk N=1461 (%)	Non-Low-Risk N=2531 (%)	Incomplete N=769 (%)	Percent Difference Low:Non-Low (95% CI)*	Percent Difference Low:Incomplete (95% CI)*
Safety					
Index visit					
Death	2 (0.1)	12 (0.5)	1 (0.1)	0.3 (0.0–0.7)	0.0 (−0.3–0.3)
MI	1 (0.1)	313 (12.4)	0 (0)	**12.3 (11.0–13.6)**	−0.1 (−0.2–0.1)
Revascularization	1 (0.1)	151 (6)	2 (0.3)	**5.9 (5.0–6.8)**	0.2 (−0.2–0.6)
Death + MI	3 (0.2)	321 (12.7)	1 (0.1)	**12.5 (11.2–13.8)**	−0.1 (−0.4–0.3)
Death + MI + Revascularization	4 (0.3)	348 (13.7)	3 (0.4)	**13.5 (12.1–14.8)**	0.1 (−0.4–0.6)
Follow-up period					
Death	2 (0.1)	19 (0.8)	3 (0.4)	**0.6 (0.2–1.0)**	0.3 (−0.2–0.7)
MI	1 (0.1)	26 (1)	2 (0.3)	**1.0 (0.5–1.4)**	0.2 (−0.2–0.6)
Revascularization	1 (0.1)	34 (1.3)	3 (0.4)	**1.3 (0.8–1.7)**	0.3 (−0.1–0.8)
Death + MI	3 (0.2)	43 (1.7)	5 (0.7)	**1.5 (0.9–2.0)**	0.4 (−0.2–1.1)
Death + MI + Revascularization	4 (0.3)	66 (2.6)	7 (0.9)	**2.3 (1.7–3.0)**	**0.6 (−0.1–1.4)**
30 day (Index + follow up)					
Death	4 (0.3)	31 (1.2)	4 (0.5)	**1.0 (0.4–1.5)**	0.2 (−0.3–0.8)
MI	2 (0.1)	320 (12.6)	2 (0.3)	**12.5 (11.2–13.8)**	0.1 (−0.3–0.5)
Revascularization	2 (0.1)	183 (7.2)	5 (0.7)	**7.1 (6.1–8.1)**	**0.5 (−0.1–1.1)**
Death + MI	6 (0.4)	341 (13.5)	6 (0.8)	**13.1 (11.7–14.4)**	0.4 (−0.3–1.1)
Death + MI + Revascularization	7 (0.5)	378 (14.9)	10 (1.3)	**14.5 (13.0–15.9)**	**0.8 (−0.1–1.7)**
Utilization					
Index visit					
Hospitalization	241 (16.5)	2095 (82.8)	246 (32)	**66.3 (63.9–68.7)**	**15.5 (11.7–19.3)**
Early discharge	1203 (82.3)	360 (14.2)	483 (62.8)	**−68.1 (−70.5−−65.7)**	**−19.5 (−23.5−−15.6)**
Objective Cardiac Testing	116 (7.9)	1148 (45.4)	43 (5.6)	**37.4 (35.0–39.8)**	**−2.3 (−4.5−−0.2)**
Follow-up period					
Hospitalization	43 (2.9)	199 (7.9)	29 (3.8)	**4.9 (3.6–6.3)**	0.8 (−0.8–2.4)
Objective Cardiac Testing	43 (2.9)	145 (5.7)	18 (2.3)	**2.8 (1.5–4.0)**	−0.6 (−2.0–0.8)
30 day (Index + follow up)					
Hospitalization	268 (18.3)	2128 (84.1)	253 (32.9)	**65.7 (63.3–68.2)**	**14.6 (10.7–8.4)**
Objective Cardiac Testing	156 (10.7)	1248 (49.3)	58 (7.5)	**38.6 (36.1–41.1)**	**−3.1 (−5.6−−0.7)**

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