Original Article

Modest Associations Between Electronic Health Record Use and Acute Myocardial Infarction Quality of Care and Outcomes

Results From the National Cardiovascular Data Registry

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***Background*—**In 2009, national legislation promoted wide-spread adoption of electronic health records (EHRs) across US hospitals; however, the association of EHR use with quality of care and outcomes after acute myocardial infarction (AMI) remains unclear.

***Methods and Results*—**Data on EHR use were collected from the American Hospital Association Annual Surveys (2007–2010) and data on AMI care and outcomes from the National Cardiovascular Data Registry Acute Coronary Treatment and Interventions Outcomes Network Registry-Get With The Guidelines. Comparisons were made between patients treated at hospitals with fully implemented EHR (n=43 527), partially implemented EHR (n=72 029), and no EHR (n=9270). Overall EHR use increased from 82.1% (183/223) hospitals in 2007 to 99.3% (275/277) hospitals in 2010. Patients treated at hospitals with fully implemented EHRs had fewer heparin overdosing errors (45.7% versus 72.8%; $P<0.01$) and a higher likelihood of guideline-recommended care (adjusted odds ratio, 1.40 [confidence interval, 1.07–1.84]) compared with patients treated at hospitals with no EHR. In non–ST-segment–elevation AMI, fully implemented EHR use was associated with lower risk of major bleeding (adjusted odds ratio, 0.78 [confidence interval, 0.67–0.91]) and mortality (adjusted odds ratio, 0.82 [confidence interval, 0.69–0.97]) compared with no EHR. In ST-segment–elevation MI, outcomes did not significantly differ by EHR status.

***Conclusions*—**EHR use has risen to high levels among hospitals in the National Cardiovascular Data Registry. EHR use was associated with less frequent heparin overdosing and modestly greater adherence to acute MI guideline-recommended therapies. In non–ST-segment–elevation MI, slightly lower adjusted risk of major bleeding and mortality were seen in hospitals implemented with full EHRs; however, in ST-segment–elevation MI, differences in outcomes were not seen. **(*Circ Cardiovasc Qual Outcomes*. 2015;8:576-585. DOI: 10.1161/CIRCOUTCOMES.115.001837.)**

Key Words: acute coronary syndrome ■ electronic health records ■ myocardial infarction ■ quality improvement ■ registries

The Health Information Technology for Economic and Clinical Health Act of 2009 appropriated $19.2 billion to increase the use of electronic health records (EHRs) in the United States.[1] Despite a wealth of funding dedicated to increase the use of EHRs, previous studies have shown mixed results about the effect of EHR on quality of care and outcomes. Although some studies have suggested advantages associated with use of EHRs, such as improved quality of care,[2–4] decreased medication errors,[5–8] and improved efficiency of resource utilization,[9–11] other analyses have reported no improvement in quality of care with EHR[12–15] with disadvantages, including increased costs,[10,16–19] impaired workflow,[20,21] and lower provider satisfaction.[3,13]

Concurrent with US government policies to incentivize EHR use, hospital reimbursement from the Centers for Medicare and Medicaid Services has become increasingly tied to specific quality and performance metrics. Nearly 4 million hospitalizations for cardiovascular diagnoses occur annually in the United States, comprising more hospitalizations than for any other category of disease.[22] Along with its

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WHAT IS KNOWN

- US legislation has appropriated tens of billions of dollars to promote the use of electronic health records (EHRs).
- Although EHR use may improve the quality of care for some disease states, previous analyses of the associations between EHR use and acute myocardial infarction quality of care and outcomes have yielded conflicting findings.

WHAT THE STUDY ADDS

- More than 99% of US hospitals in the ACTION Registry-GWTG used EHRs by 2010.
- EHR use was associated with less heparin overdosing and slightly greater adherence to acute myocardial infarction guideline-recommended therapies.
- In non–ST-segment–elevation myocardial infarction, slightly lower adjusted risk of major bleeding and mortality was seen in patients from hospitals with full EHRs; however, in ST-segment–elevation myocardial infarction, differences in outcomes were not seen.

frequent incidence, acute myocardial infarction (AMI) is also accompanied by widely adopted evidence-based guidelines to drive care[23,24]; thus, AMI has become an area of specific focus for performance metrics. Previous analyses of the association of EHR use with quality of care and outcomes for patients with AMI have yielded conflicting findings.[19,25–28] Moreover, previous studies have derived their conclusions from administrative databases of claim-based data. Compared with patient-level data, such administrative databases often lack the ability to provide in-depth clinical information about patients, treatments, processes of care, and outcomes.[29,30] It has been suggested that such administrative data be used only as screening tools to guide further in-depth investigations.[29] Clarification of whether EHR use is independently associated with better quality of care and outcomes after AMI is of crucial importance in determining whether EHR use in its existing form has been effective in improving patient care or whether further improvements are necessary to leverage more meaningful benefits from this technology. Using data from the National Cardiovascular Data Registry Acute Coronary Treatment and Interventions Outcomes Network Registry-Get With The Guidelines (ACTION Registry-GWTG) and the American Hospital Association Annual Surveys, we sought to address these significant gaps in knowledge. We compared AMI treatments, processes of care, and outcomes of major bleeding and mortality among patients treated at hospitals with and without EHRs. We hypothesized that patients with AMI treated at hospitals with EHRs would have modestly greater adherence to performance metrics and better outcomes, although EHR would not be associated with improved timeliness of revascularization in patients presenting with ST-segment–elevation MI (STEMI) because that process is already highly protocolized and unlikely to be improved by EHR use.

Methods

Data Collection and Definitions

Data were obtained from 2 separate databases, the ACTION Registry-GWTG and the American Hospital Association annual survey. ACTION Registry-GWTG is a large AMI database with trained data collectors at each participating center abstracting patient characteristics, treatments, and in-hospital outcomes using established standard definitions that have been previously described.[31] Data were collected for the purpose of quality improvement and were deidentified before analysis; study authors had no access to patient identifiers; thus, institutional review board approval was waived.

The second data source for this study was the American Hospital Association annual survey, which includes data from ≈6500 hospitals across the United States, with detailed data on hospital personnel, facilities, organizational structure, and services. For the purposes of this study, site-level data were linked through the American Hospital Association Annual Survey database and ACTION Registry-GWTG. The independent variable, EHR use, was defined by the American Hospital Association survey as that which integrates electronically originated and maintained patient-level clinical health information, derived from multiple sources, into one point of access. An EHR replaces the paper medical record as the primary source of patient information.[32] EHR status was self-reported based on hospital administrator categorization of their hospital as having (1) fully implemented EHR, (2) partially implemented EHR, or (3) no EHR. Specific criteria for full and partial implementation were not defined by the survey instrument.

Study Population

Consecutive patients admitted with AMI between January 1, 2007, and December 31, 2010, were included in this study. Starting with a population of 245 883 patients collected using the long data collection form, we excluded patients who transferred in (n=75 456) or transferred out (n=13 108) of ACTION Registry-GWTG hospitals and those patients from hospitals with missing EHR status (n=32 493), so that a complete assessment of all AMI performance measures, including those within 24 hours and at discharge, could be made. Thus, the analyses are based on 124 826 patients from 414 participating sites across the United States (Figure 1). Given that this study was an exploratory analysis, sample size calculations and predetermined quantitative thresholds for clinically meaningful improvements in care were not prespecified.

Primary (Patient-Level) Analyses

Baseline patient demographics, clinical characteristics, in-hospital treatments, processes of care, and outcomes were compared between patients according to hospital EHR status at the time of care. Through standard reporting of patient weights and anticoagulation dose administered, rates of overdosing are routinely calculated and reported in ACTION Registry-GWTG. A standard composite process of care metric called defect-free care was calculated for each patient as whether the patient received all of the following therapies for which they were eligible (yes/no): aspirin at arrival, aspirin prescribed at discharge, β-blocker prescribed at discharge, statin prescribed at discharge, evaluation of left ventricular systolic function, angiotensin-converting enzyme inhibitor or angiotensin-receptor blocker for left ventricular systolic dysfunction, adult smoking cessation advice/counseling, and cardiac rehabilitation patient referral from an inpatient setting. For patients with STEMI, defect-free care also required reperfusion therapy to be initiated for eligible patients, with a time to primary percutaneous coronary intervention ≤90 minutes or a time to fibrinolytic therapy administration ≤30 minutes. Continuous variables were presented as means or medians with interquartile ranges and categorical variables expressed as percentages. Statistical comparisons were made between groups, with EHR status evaluated as an ordinal variable, using the appropriate Cochran–Mantel–Haenszel statistics to test for trend across categories.

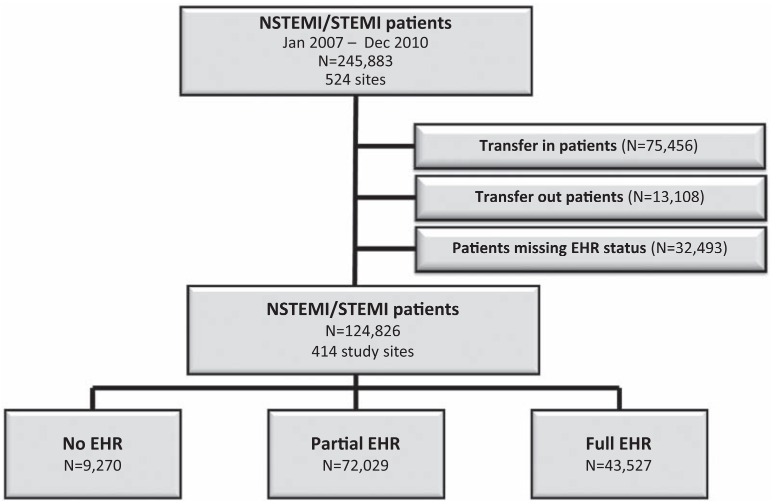

Figure 1. Study population. EHR indicates electronic health record; NSTEMI, non–ST-segment–elevation myocardial infarction; and STEMI, ST-segment–elevation myocardial infarction.

To evaluate the relationship between EHR use and the primary in-hospital outcomes of all-cause mortality and major bleeding (which have been previously defined),[31] multivariable logistic regression with generalized estimating equations was used to account for patient clustering within hospitals.[33] Exchangeable working correlation matrices were specified, and the covariates were identified from previously developed and validated ACTION Registry-GWTG mortality and bleeding models.[34,35] These models are well fitted to the ACTION Registry-GWTG data set with good discriminative ability. The covariates from the ACTION Registry-GWTG mortality and bleeding models included demographics (age, sex, race, and weight), ECG findings (STEMI, ST-segment changes versus no ST-segment changes), heart failure (heart failure only, shock only, or shock with heart failure), heart rate, systolic blood pressure, past medical history (hypertension, diabetes mellitus, peripheral arterial disease, tobacco use, dyslipidemia, previous MI, previous percutaneous coronary intervention, previous coronary artery bypass graft surgery, heart failure, and stroke), laboratory findings (baseline hemoglobin, baseline serum creatinine, and baseline troponin), home medications (aspirin, clopidogrel, warfarin, β-blocker, angiotensin-converting enzyme inhibitor, angiotensin-receptor blocker, aldosterone-blocking agent, statin, and nonstatin lipid-lowering agent), and insurance status. In addition, the following hospital characteristics were included for the primary in-hospital outcome models: hospital ownership, number of beds, teaching hospital status, hospital capabilities, geographic region, and proportion of patients on Medicare/Medicaid. To evaluate the relationship between EHR use and the secondary outcome of defect-free care, multivariable logistic regression with generalized estimating equations was used. The covariates from the ACTION Registry-GWTG mortality and bleeding models were included within the defect-free care model because they have been previously demonstrated and validated to account for potentially confounding differences between patients, providers, and hospitals in the ACTION Registry-GWTG data set. Also, the defect-free care model included the previously mentioned hospital characteristics and the number of defect-free care opportunities per patient. Because hospital EHR status could change over the study period, adjusted analyses were performed with the patient as the unit of analysis with each patient categorized by the hospital's EHR status at the time of his/her presentation; thus, at any hospital, some patients could be classified to the no EHR category and others to an EHR category throughout the study period if the hospital changed EHR status over time.

Secondary (Hospital-Level) Analysis

Among hospitals with no EHR between 2007 and 2010 who adopted EHR (move from no EHR to partial/full EHR) between 2007 and 2010, the change in defect-free score from 1 year before adoption to 1 year after adoption was assessed using a matched case/control analysis. These hospitals were matched to control hospitals that did not change EHR status over the time period using the following hospital characteristics: region, teaching hospital, for profit (yes/no), no services or catheterization only versus percutaneous coronary intervention only or percutaneous coronary intervention/coronary artery bypass graft, and hospital size. The controls had to match exactly on all characteristics except for hospital size. For hospital size, the number of hospital beds for the control was required to be within 110. For each control hospital matched to a case hospital, the same 1-year period of time before EHR adoption and 1-year period of time after adoption was used. A difference-in-difference analysis was conducted comparing the change in defect-free care score for case hospitals with that for control hospitals. All analyses were performed with SAS software (version 9.2; SAS Institute, Cary, NC). $P<0.05$ was considered statistically significant for all tests, and all tests of statistical significance were 2-tailed.

Results

Trends in EHR use over time, categorized as fully implemented, partially implemented, and no EHR, are shown in Figure 2. Overall EHR use (fully implemented plus partially implemented) increased from 82.1% of hospitals (183/223) in 2007 to 99.3% of hospitals (275/277) in 2010. Characteristics of hospitals with no EHR, partially implemented EHR, or fully implemented EHR are described in Table 1, with *P* values reflecting trend across ordinal EHR groups. There were no statistically significant differences in size, teaching status, ownership, payer source, region, or cardiovascular services provided seen between hospitals when stratified by EHR status; however, nonstatistically significant trends toward larger hospital size, a greater percentage of academic/teaching hospitals, and a greater percentage of Medicaid/Medicare patients were observed in the fully/partially implemented EHR groups compared with hospitals that had no EHR (Table 1).

Primary (Patient-Level) Analyses

Demographics and clinical characteristics of patients by EHR status are compared in Table 2. There were no clinically significant differences in demographics (age, sex, race, or insurance status) or AMI presentation (symptom onset, heart failure/shock, or blood pressure) by EHR status. However, patients treated at hospitals with EHRs had slightly higher rates of comorbidities, including hypertension, dyslipidemia, chronic lung disease, previous MI, heart failure, cerebrovascular disease, and initial and peak troponin levels, which,

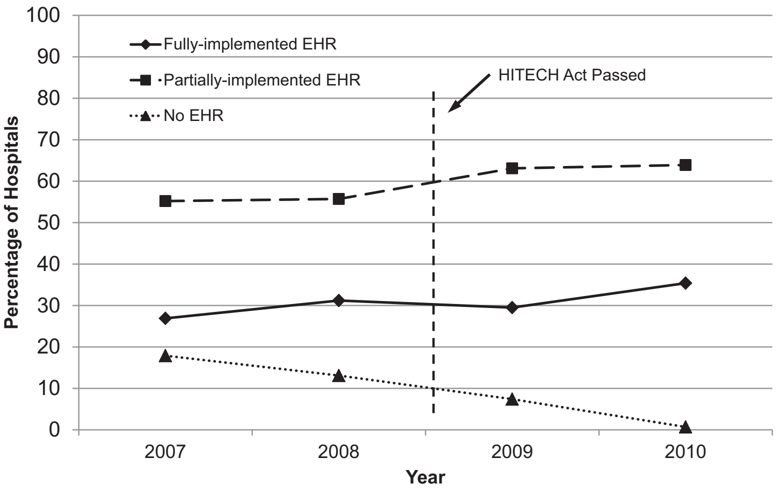

Figure 2. Trends in electronic health record (EHR) use from 2007 through 2010. HITECH indicates Health Information Technology for Economic and Clinical Health.

although statistically significant, were of small magnitude of difference.

Treatments and Processes of Care

Comparisons of the unadjusted rates of in-hospital treatments and processes of care by EHR status are shown in Table 3. There were no clinically meaningful differences in unadjusted rates of guideline-based medication administration within the first 24 hours or at discharge. Patients treated at hospitals with EHRs were slightly more likely to receive unfractionated heparin (UFH) anytime during the hospitalization. Rates of overdosing of parenteral anticoagulants strongly associated with the degree of EHR implementation as a graded, inverse relationship of significantly fewer errors in UFH overdosing seen in patients treated at hospitals with partially implemented EHRs and fully implemented EHRs compared with those treated at hospitals without an EHR. An opposite, although lesser magnitude, trend was seen in the use of low molecular weight heparin (LMWH), with slightly more dosing errors associated with EHR use.

After adjustment for potential confounders, patients were more likely to receive defect-free care when treated at hospitals using either partially implemented EHRs (adjusted odds ratio, 1.49 [95% confidence interval (CI), 1.20–1.84]) or fully implemented EHRs (adjusted odds ratio, 1.40 [95% CI, 1.07–1.84]), when compared with patients at hospitals without an EHR.

Adverse Cardiovascular Outcomes

Comparison of unadjusted adverse cardiovascular events rates showed no significant differences by EHR status. However,

Table 1. Characteristics of Hospitals by EHR Status (Q4 2008)

	No EHR (n=19)	Partially Implemented EHR (n=101)	Fully Implemented EHR (n=49)
Hospital beds, median (IQR)	285 (208–529)	349 (222–555)	351 (248–431)
Academic/teaching hospital, %	10.5	21.8	20.4
Ownership, %			
Government	10.5	14.9	12.2
Not for profit	79.0	76.2	85.7
Investor owned	10.5	8.9	2.0
Medicaid/Medicare patients, median, % (IQR)	21.0 (17–41)	30.0 (21–42)	29.0 (18–41)
Region, %			
West	26.3	8.9	14.3
Northeast	10.5	8.9	10.2
Midwest	26.3	45.5	44.9
South	36.8	36.6	30.6
Cardiovascular services, %			
No services	0.0	5.9	2.0
Cath laboratory only	5.3	2.0	2.0
PCI, no surgery	15.8	12.9	16.3
Surgery	79.0	79.2	79.6

EHR indicates electronic health record; IQR, interquartile range; and PCI, percutaneous coronary intervention.

Table 2. Baseline Patient Characteristics By Hospital EHR Status

	No EHR (n=9270)	Partially Implemented EHR (n=72 029)	Fully Implemented EHR (n=43 527)
Age, median (IQR)	66 (55–78)	65 (54–77)	65 (55–77)
Male sex, %	62.7	63.6	62.8
Body mass index, kg/m^2, median (IQR)	28.0 (24.5–32.1)	28.2 (24.7–32.4)	28.2 (24.7–32.4)
Race, %			
White	82.5	83.4	82.5
Black	8.1	10.0	11.0
Asian	1.5	1.5	1.5
Hispanic	6.4	3.8	3.7
Other	1.0	0.8	0.8
Insurance status, %			
Private	58.6	56.7	57.5
Medicare	26.3	28.1	26.8
Military	1.0	1.0	1.0
Medicaid	3.1	3.6	3.8
Self-pay/none	10.2	9.9	10.4
Current/recent smoker (<1 y), %	32.1	33.9	32.8
Hypertension, %	70.8	71.7	72.9
Dyslipidemia, %	54.0	58.7	60.1
Currently on dialysis, %	2.6	2.4	2.4
Chronic lung disease, %	13.6	13.9	15.0
Diabetes mellitus, %	31.1	30.5	32.1
Previous myocardial infarction, %	25.4	26.3	27.3
Previous heart failure, %	14.1	13.2	14.8
Previous PCI, %	23.8	24.1	23.8
Previous CABG, %	15.2	15.0	15.3
Atrial fibrillation/flutter, %	7.9	8.0	8.3
Cerebrovascular disease, %	11.2	12.1	13.6
Peripheral arterial disease, %	9.6	9.9	11.4
ST-segment–elevation MI	35.8	39.6	36.6
Symptom onset to arrival, median, h (IQR)	2.2 (1.1–5.8)	2.0 (1.1–4.8)	2.1 (1.1–5.2)
Signs of heart failure, %	18.3	17.1	17.9
Cardiogenic shock, %	2.7	4.1	3.7
Heart rate, bpm, median (IQR)	82.0 (69–98)	82.0 (69–97)	82.0 (69–98)
Systolic blood pressure, mm Hg, median (IQR)	142.0 (121–163)	143.0 (122–164)	143.0 (123–164)
Initial CrCl (Cockcroft–Gault), median (IQR)	75.4 (48.0–104.5)	77.8 (50.5–108.0)	76.7 (49.4–106.9)
Troponin, times upper limit of normal, median (IQR)			
Initial	1.2 (0.3–7.0)	1.4 (0.3–8.7)	1.9 (0.4–11.7)
Peak	35.9 (7.8–154.3)	38.8 (8.7–180.6)	48.3 (9.5–231.2)
Initial BNP, median, pg/mL (IQR)	270.5 (77.0–816.5)	275.0 (75.0–783.0)	266.0 (71.5–741.0)

BNP indicates B-type natriuretic peptide; CABG, coronary artery bypass graft surgery; CrCl, creatinine clearance; EHR, electronic health record; IQR, interquartile range; MI, myocardial infarction; and PCI, percutaneous coronary intervention.

after adjustment for baseline differences and other potential confounders, patients with non–ST-segment–elevation MI (NSTEMI) treated at hospitals with fully implemented EHR had slightly lower risk of mortality and major bleeding in NSTEMI, whereas those treated at hospitals with partially implemented EHRs had slightly lower rates of major bleeding compared with patients treated at hospitals with no EHR (Figure 3). Among patients presenting with STEMI, there were no significant differences in adjusted risk of mortality or major bleeding by EHR status.

Table 3. Comparison of Treatments and Processes of Care by EHR Status

	No EHR (n=9270)	Partially Implemented EHR (n=72 029)	Fully Implemented EHR (n=43 527)	*P* Value (Trend)
Medications within 24 h				
Aspirin, %	97.4	97.1	97.4	0.13
Any oral antiplatelet agent, %	96.9	96.6	96.8	0.11
β-blocker, %	93.6	90.5	90.9	<0.01
ACE inhibitor or ARB, %	54.2	49.7	52.4	<0.01
Statin, %	63.0	63.2	66.7	<0.01
Anticoagulation (anytime during hospitalization)				
Unfractionated heparin	60.9	66.2	66.1	<0.01
LMWH heparin	33.6	26.8	29.2	0.26
Any anticoagulant agent	90.5	92.2	92.0	0.13
Overdosing errors				
UFH initial bolus	72.8	59.4	45.7	<0.01
UFH initial infusion	44.5	34.1	29.7	<0.01
LMWH dose	9.6	11.8	13.1	<0.01
Discharge medications				
Aspirin	96.3	97.5	97.5	<0.01
Any oral antiplatelet	96.5	97.3	97.4	0.75
β-blocker	95.7	95.6	96.4	<0.01
ACE/ARB for left ventricular dysfunction	87.2	84.6	87.1	<0.01
Statin	86.5	89.5	90.5	<0.01
Aldosterone-antagonist (ideal patients)	8.3	6.1	7.5	<0.01
Invasive therapies				
STEMI overall reperfusion	91.5	95.1	95.4	<0.01
STEMI door to balloon, <90 min, %	76.4	84.6	84.8	<0.01
Diagnostic catheterization	79.2	82.6	81.1	0.03
Catheterization within 48 h	67.7	73.7	71.3	0.03
Percutaneous coronary intervention (NSTEMI)	42.9	44.1	42.4	<0.01
Coronary artery bypass graft surgery	8.4	8.1	8.7	0.01
Other performance metrics				
Evaluation of left ventricular dysfunction	91.6	92.7	92.2	0.24
Cardiac rehab referral	75.0	77.5	72.7	<0.01
Smoking cessation advice	95.8	96.9	97.1	<0.01
Performance composites				
Defect-free care				
Overall	59.7	63.4	62.0	0.32
STEMI	57.6	64.5	63.8	<0.01
NSTEMI	60.9	62.7	60.9	<0.01

ACE indicates angiotensin-converting enzyme inhibitor; ARB, angiotensin-receptor blocker; EHR, electronic health record; LMWH, low molecular weight heparin; NSTEMI, non–ST-segment–elevation myocardial infarction; STEMI, ST-segment–elevation myocardial infarction; statin, HMG-coA reductase inhibitor; and UFH, unfractionated heparin.

Secondary (Hospital-Level) Analysis

For sites that adopted EHR (partial or full) between 2007 and 2010 and matched controls (14 sites in each group), the difference in defect-free care was compared from 1-year before to 1-year after EHR adoption. Adoption of EHR was associated with a mean increase in defect-free care of 12.1% (95% CI, 5.2–19.0). In the cohort of matched controls that did not change EHR status, a mean increase of 5.8% (95% CI, −4.6 to

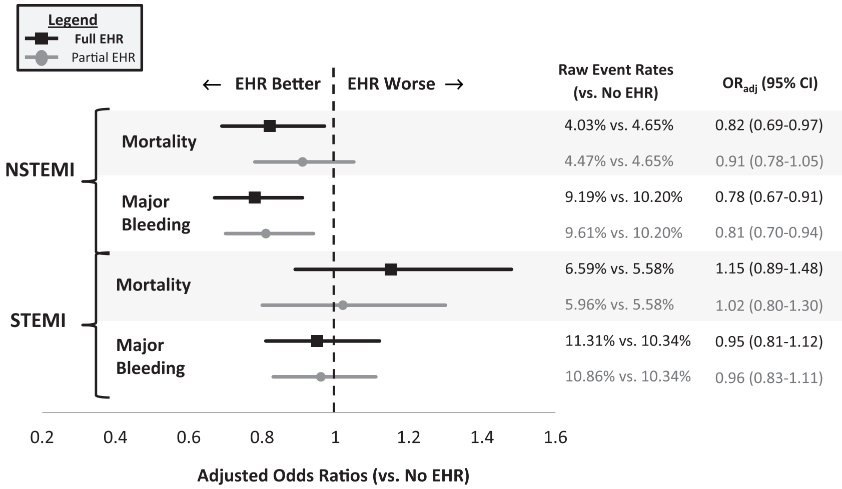

Figure 3. Association of electronic health record (EHR) with adverse outcomes. CI indicates confidence interval; NSTEMI, non–ST-segment–elevation myocardial infarction; OR_{adj}, adjusted odds ratio; and STEMI, ST-segment–elevation myocardial infarction.

16.2) was observed. Although the difference between groups was not statistically significant (12.1% versus 5.8%; *P*=0.34), a confidence interval for the difference in differences is wide (95% CI, −6.7–19.6%) and reflects a lack of power and precision with only 14 hospitals in each group.

Discussion

During a period of immense change in healthcare in the United States with >$19 billion invested in the proliferation of EHRs since 2009,[1] we observed an evolution from high to virtually universal EHR use in a large national AMI registry, with nearly all participating hospitals (>99%) having some form of an EHR by 2010. We found that EHR use may be associated with some aspects of higher quality AMI care, such as less heparin overdosing and more frequent receipt of evidence-based therapies; however, these findings may not reliably translate into a lower risk of adverse events across all subtypes of MI and outcomes measured.

Comparison With Previous Knowledge and Data

Previous studies assessing the relationship between EHR use and AMI quality of care have yielded conflicting findings. Although some studies have described an association between EHR use and better AMI quality of care,[5] other studies have suggested that EHR use may be of marginal benefit,[19,27] no benefit,[26] or even associated with a decline in quality (with advanced EHRs).[27] Amarasingham et al[25] suggested that EHR use is associated with reduced mortality after MI; however, this study and the others have relied on administrative data. Although administrative data, derived primarily from International Classification of Diseases, 9th revision, codes, are much easier to acquire than clinical data, the limitations of administrative data in assessing quality of care have been well described to include significant omissions in clinical information and notable concerns of the accuracy and completeness.[29,30] This study addresses the need for better data by using clinical, patient-level data from ACTION Registry-GWTG.

Previous analyses have attempted to assess the effects of EHR on a composite of multiple disease conditions at once, often reporting on quality of care or outcomes for AMI, heart failure, pneumonia, and surgical care within the same analysis.[5,19,25–28] Focusing on the association of EHR with quality of care and outcomes specifically for AMI, as in this analysis, allows us to understand the associations of EHR use with the unique and intricate disease-specific AMI treatments, processes of care, and complications. Significant heterogeneity in EHR effects has been previously reported for different conditions[19,26,36]; therefore, the degree of reliance on the EHR for affecting quality improvement may likely vary depending on the disease or condition—it may even vary for MI subtypes, that is, NSTEMI versus STEMI—a distinction made in this study but not in any previous analysis. Finally, this study is one of the few to report data on the association of EHR use with AMI quality of care after the Health Information Technology for Economic and Clinical Health Act was enacted in 2009.[27] The previously reported effects of EHR use reported from early adopters may not be reflective of the effect of EHR use in the modern era of wide-spread use as described in this study.

Mixed Associations Between EHR and Quality of Care

Rates of UFH overdosing were significantly higher among patients treated at hospitals without EHRs, with almost three fourth of patients at non-EHR hospitals receiving excessive bolus doses of UFH compared with less than half of patients at EHR-equipped hospitals. Furthermore, a graded, inverse relationship was observed, with progressively lower rates of heparin overdosing seen in sequence from no EHR, to partially implemented EHR, and to fully implemented EHR. Reduction of excessive anticoagulation is of immense clinical importance as such overdosing has been linked to significantly higher bleeding risk, longer length of stay, and higher mortality among patients with AMI.[37] Of note, EHR use was associated with slightly more LMWH dosing errors; however, far more patients were treated with UFH than with LMWH, and differences in dosing errors of LMWH were of lesser magnitude than those seen in the UFH groups. One possible explanation for differences seen between UFH and LMWH errors is that EHR ordering of UFH may routinely facilitate calculation of specific weight-based dosing for UFH boluses/rates; however, EHR ordering of LMWH may be more likely to prompt selection of ordinal predispensed doses that may inadvertently facilitate overdosing.

To account for differences at the patient and hospital levels that could affect in-hospital treatments and processes of care, multivariable regression was used to identify the independent association of EHR use with adherence to evidence-based therapies. After adjustment, patients treated at hospitals with EHRs were more likely to receive defect-free care (adjusted odds ratio, 1.40 [95% CI, 1.07–1.84] for full EHR) when compared with patients treated at hospitals without EHRs (Table 3). This higher quality of care could potentially be mediated by features of the EHR, such as electronic order sets with integrated features like decision-support elements, links to existing guidelines, and computerized order entry checks, which have been described to improve the use of best practices and reduce medical errors.[38,39] The findings from the patient-level analysis are supported by a large sample size of >120 000 patients resulting in immense statistical power; however, the positive findings from the patient-level analysis were unable to be significantly confirmed by the hospital-level analysis, which showed nonstatistically significant differences between groups, limited by a small sample size of only 14 hospitals in each group and, therefore, low statistical power.

Mixed Associations Between EHR and Risk of Adverse Events

After adjustment, patients with NSTEMI treated at hospitals with fully implemented EHRs had slightly lower risk of major bleeding and in-hospital mortality (Figure 3) when compared with patients treated at hospitals with no EHR. Although EHR use may be associated with lower risk of mortality and bleeding after NSTEMI, we did not observe such an association among patients with STEMI. A priori, we hypothesized that no difference would be observed because mortality in STEMI is highly influenced by timeliness of revascularization, which is already highly protocolized and determined by many factors unlikely to be affected by an EHR, such as close proximity of the cardiologist and catheterization laboratory staff, involvement of the page operator, and leadership by emergency department physicians.[40] In contrast to the focus on emergent revascularization in STEMI care, care of the patient with NSTEMI remains a broader and more complex process, with greater variation based on individual physician and institutional practice preferences. Such practice variation may leave greater room for systems-level interventions, like the EHR, to improve quality of care and outcomes.

Although the markedly lower rates of UFH overdosing seen with EHR use likely contribute to lower risk of major bleeding in NSTEMI, explaining the lower risk of in-hospital mortality after NSTEMI associated with EHR use is more complex. EHR could potentially mediate lower risk of AMI mortality via improvements in AMI quality of care as previously described by Peterson et al[41] using data from the Can Rapid Risk Stratification of Unstable Angina Patients Suppress Adverse Outcomes with Early Implementation of the American College of Cardiology/American Heart Association Guidelines (CRUSADE) registry. They reported that every 10% increase in adherence to a composite of AMI core measures corresponded to a 10% reduction in in-hospital mortality; however, other data from Bradley et al[42] from the National Registry of Myocardial Infarction demonstrated that hospital attainment of combined AMI core measures only explained a small percentage (6%) of hospital-level variation in 30-day mortality. Because many of the standardized AMI performance metrics are related to treatments and processes of care that occur late in the hospitalization or at discharge (ie, discharge medication prescription, smoking cessation counseling, and cardiac rehab referral), these are unlikely to influence in-hospital mortality; however, EHRs could still influence other elements of acute care for AMI and, thus, improve AMI outcomes. It is also possible that unmeasured residual confounders, in part, may contribute to the observed differences in bleeding and mortality outcomes.

Limitations

Our findings should be interpreted in the context of several potential limitations. Hospitals that use EHRs may also be more likely to have advantages in other unmeasured factors, such as systems of care, culture, clinical skills of providers, hospital resources, or patient characteristics, when compared with hospitals without EHRs (or with missing EHR status) that may in part contribute to observed differences in achievement of performance measures and outcomes; however, we attempted to minimize bias by using rigorous multivariable adjustment for potential patient-level and hospital-level confounders. The hospital-level analysis was limited by low statistical power with the small number of hospitals available to compare data before and after EHR adoption; however, because of the ubiquitous use of EHRs across US hospitals participating in the ACTION Registry-GWTG, larger contemporary hospital-level analyses may not be feasible in patient-level data registries. It is also likely that some of the improvements in care associated with EHR use reflect improved documentation and improvements in actual care.

The most significant limitation of this study is our reliance on a nonadjudicated survey of EHR use; however, potential misclassification arising from survey responses would introduce a bias toward the null; therefore, we feel that the significant differences we observed are still valid. It is also not possible to determine whether the observed differences between groups by EHR use is mediated by benefits conferred by the EHR or whether the lack of EHR use may instead be a marker of lower quality of care or higher risk among institutions not equipped with EHRs.

Conclusions

The use of EHRs in participating hospitals in the ACTION Registry-GWTG was ubiquitous as of late 2010. EHR use was associated with some markers of patient safety, such as less frequent heparin overdosing, and slightly greater use of evidence-based therapies; however, associations with adverse outcomes after MI were mixed. In NSTEMI, fully implemented EHR use was associated with slightly lower risk of major bleeding and mortality; however, no significant differences were seen in STEMI. Further determination of the optimal methods of EHR utilization is likely needed to leverage more consistent gains across AMI quality of care and outcomes.

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Disclosures

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