Information Technology and Hospital Patient Safety: A Cross-Sectional Study of US Acute Care Hospitals

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ABSTRACT

Objectives

To determine whether health information technology (IT) systems are associated with better patient safety in acute care settings.

Study Design

In a cross-sectional retrospective study, data on hospital patient safety performance for October 2008 to June 2010 were combined with 2007 information technology systems data. The sample included 3002 US non-federal acute care hospitals. Electronic health record (EHR) system was coded as a composite dichotomous variable based on the presence of 10 major clinical and administrative applications that (if in use) could potentially meet stage 1 "meaningful use" objectives. The surgical IT system was measured as a dichotomous variable if a hospital used at least 1 of the perioperative, preoperative, or postoperative information systems. Hospital patient safety performance was measured by risk-standardized estimated rates per 1000 admissions. Statistical analyses were conducted using an estimated dependent variable methodology with gamma-log link–based weighted generalized linear models, adjusting for hospital characteristics, historical composite process quality, and propensity for EHR adoption.

Results

We found that the use of surgical IT systems was associated with 7% to 26% lower rates for 7 of 8 patient safety indicators (incidence rate ratio [IRR] range from 0.74 to 0.93; all *P* values <.01). Further, stage 1 meaningful use-capable EHR systems were associated with 7% to 11% lower rates on 3 of 8 measures (IRR range from 0.89 to 0.93; all *P* values <.01).

Conclusions

Our results suggest that the use of IT is associated with modestly lower rates of adverse events in hospitals. However, the cross-sectional design limits our ability to make causal conclusions.

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Patient safety remains a major challenge in the US healthcare system, recently drawing renewed attention as a national priority.[1] About one-third of hospitalized patients experience adverse events,[2] and these rates are alarmingly higher at high-quality hospitals.[2,3] The HHS recently announced a $1-billion national initiative, Partnership for Patients, aimed at reducing preventable complications and hospital-acquired conditions by 40%, which could result in about 1.8 million fewer injuries and more than 60,000 saved lives over 3 years.[4]

Recognizing the potential role that health information technology (IT) could play in improving patient safety and quality of care,[5,6] the Obama administration committed $27 billion to promote the implementation and meaningful use (MU) of electronic health records (EHRs).[7] The widespread and effective use of health IT is expected to help foster an environment of safe, patient-centered care through improved clinical performance; access to timely, relevant clinical information; and better communication between and among caregivers and patients.

Especially in the context of surgical care, the EHR and functional systems like surgical IT (eg, perioperative systems, preoperative systems, and postoperative systems) can improve patient safety through multiple mechanisms such as providing timely and comprehensive health information that may prevent errors or allow for rapid corrections.[8,9] For example, recent studies have shown the beneficial impact of health IT on safety outcomes, including timely discontinuation of postoperative antibacterials[10]; improved adherence to evidence-based guidelines[11]; enhanced work flow and management of surgical team members[12]; effective communication to all providers during transitions and across specific phases of care delivery[12]; and facilitating retrospective analysis of 3 adverse events to guide future improvement efforts.[8] Despite such growing evidence of health IT benefits,[13-20] recent systematic reviews raised concern over the paucity of generalizable evidence of health IT for patient safety and quality outcomes.[21,22]

Take-Away Points

A retrospective cross-sectional analysis of a large national sample of nonfederal acute care hospitals suggests that the use of health information technology (IT)—specifically surgical IT systems, and electronic health record (EHR) systems capable of meeting Stage 1 meaningful use requirements—is associated with moderate, but statistically significant, reductions in adverse patient safety outcomes.

- Hospitals using surgical IT had lower relative rates on 7 of 8 patient safety indicators while those using Stage 1 EHRs had lower rates on 3 measures.
- Health IT including surgical systems and Stage 1-capable EHRs could likely benefit hospitals seeking to improve patient safety.

In this cross-sectional retrospective study, we investigate the relationship between hospital IT systems and performance on a subset of Agency for Health Research and Quality (AHRQ) patient safety indicators (PSIs) that include various adverse events such as serious, but potentially preventable, complications related to inpatient medical or surgical care, and deaths for select treatments or conditions. Using a large national sample of nonfederal acute care hospitals, we observed that health IT is associated with modestly lower rates of adverse events. While to the best of our knowledge, this is one of the first studies to demonstrate evidence of a positive relationship between health IT and hospitals' patient safety measures using national data, the cross-sectional design of this observational study does not allow us to draw causal conclusions about the relationship.

METHODS

Data Sources

We combined data from 3 sources. Hospital performance data came from the October 2011 release of CMS Hospital Compare on 8 AHRQ indicators related to patient safety and inpatient quality outcomes. These data include facility-level risk-standardized rate estimates, adjusting for patient characteristics, for each measure along with 95% confidence intervals and the number of patients hospitalized (ie, "population" at risk) for each hospital during the sampling period of October 2008 to June 2010.[23]

Hospital IT systems data came from the 2008 release of the Health Information and Management Systems Society (HIMSS) Analytics Database, which includes hospital characteristics and the operational status of health IT achieved by the end of 2007. HIMSS is the most comprehensive database of hospital IT adoption decisions,[24,25] and has been used extensively in health IT research.[13,15,25] The HIMSS data are taken from 2007, while CMS hospital safety performance data are taken from the subsequent period (2008-2010) to avoid an overlap of the quality measurement period with the initial deployment of new technology.[13,26] Lastly, data on hospitals' organizational characteristics, used as control variables in our analyses, were obtained from the 2009 CMS Acute Inpatient Prospective Payment System Impact file and HIMSS. Our final sample included 3002 nonfederal acute care US hospitals.

Measurement of Surgical IT Systems

In hospital settings, several types of IT systems are deployed to manage and facilitate care delivery to surgical patients. In this study, we focus on 3 applications: perioperative, preoperative, and postoperative information systems. Perioperative systems provide clinical documentation and management of relevant real-time surgery procedures, and include functionalities such as clinical order management, decision support, anesthesia documentation, integration to anesthesia systems, smart cabinets, imaging systems, and potentially smart surgical instruments for image-guided surgery. It may also provide support for management of relevant operating room supplies and medications during surgery. Preoperative systems provide clinical documentation and management of relevant presurgery information and patient preparation for surgery. It also provides for the management of relevant presurgery room preparation, operating room supplies and medications, and staff. Postoperative systems provide clinical documentation and management of relevant follow-up procedures as well as transfers to step-down or intensive care units.

In this study, we constructed a linear composite of these 3 technologies as a dichotomous variable to indicate if a hospital had at least 1 of these 3 types of surgical IT systems in use as of 2007. While these 3 technologies may potentially influence patient care outcomes through different modalities, our focus is on the associative relationship between any such aggregate level IT capability supporting surgical care with the select set of AHRQ indicators.

Measurement of EHR MU Capability

Within the ambit of the federal incentive program, providers are expected to demonstrate the MU of EHR systems based on specific criteria set forth at various stages, with the first stage defined by the 2011 standards. Accomplishing these objectives requires the use of several EHR functionalities—for example, clinical decision support should provide for basic drug-drug,

drug-allergy, and drug-formulary checks.[27] Based on the functionalities required to demonstrate Stage 1 MU, 10 major clinical and administrative systems are needed.[13,27] These systems include admission/discharge/transfer systems; auxiliary information systems (laboratory, pharmacy, and radiology); e-prescribing; clinical data repository; clinical decision support; nursing documentation; electronic medication administration record; and computerized physician order entry systems. Hospitals were categorized as having an EHR system capable of 2011 MU functionality if they had all of the above applications in use by 2007, otherwise as not (serving as the reference group). While complete satisfaction of the 2011 MU objectives requires demonstrating routine clinical and administrative activities *using* the EHR system, here we measure only whether a hospital had the necessary functional capabilities to carry out those activities.

Measurement of Hospital Patient Safety Performance

Hospital patient safety performance was measured by 8 adverse event indicators developed by AHRQ. These indicators refer to serious but potentially preventable complications from inpatient medical or surgical care; and deaths from select treatment or conditions. These include death among surgical patients with serious, treatable complications; collapsed lung that results from medical treatment (iatrogenic pneumothorax); breathing failure after surgery (postoperative respiratory failure); blood clots in the lung or a large vein after surgery (postoperative pulmonary embolism or deep venous thrombosis); wounds that split open after surgery (postoperative wound dehiscence); accidental cuts and tears (accidental puncture or laceration); death after a surgery to repair a weakness in the abdominal aorta (abdominal aortic aneurysm mortality rate); and death among patients with hip fractures (hip fracture mortality rate).

Hospital Compare reports risk-standardized rates per 1000 patients at risk for each hospital facility based on Medicare Fee-for-Service claims data. Hospital Compare reports these rates based on prediction models implemented in AHRQ-PSI software and risk-adjusted for patient characteristics (age, gender), severity of illness, and 25 comorbidities as covariates (with associated 95% confidence intervals). The details of the risk-adjustment algorithm are described elsewhere.[23] To ensure adequate reliability in this study, only those hospitals for which PSI rate estimates were based on at least 30 patients at risk were included in our analyses.[28,29]

Measurement of Hospital Characteristics

Care outcomes are affected by organizational structures, processes of care, and patient characteristics.[30-32] Since the use of IT systems may also be correlated with hospital characteristics leading to selection bias, we estimated propensity scores for having an EHR system in use, employing data from the previous year (2007 HIMSS release), and then constructed dummy variables representing quintiles of EHR system propensity. Likewise, performance on patient safety measures may be influenced by overall hospital quality such that hospitals performing highly on process quality measures are expected to have fewer adverse events.[33,34] To account for such confounding effects, we constructed dummy variables representing quintiles of facility-specific historical performance (2005-2007) on composite process quality scores for acute myocardial infarction, heart failure, pneumonia, and surgical care infection prevention.

We also used a comprehensive set of control variables to account for potential confounding effects: teaching status (academic and minor teaching hospitals); profit status; membership in a multihospital integrated delivery system; magnet status for nursing excellence; presence of cardiac intensive care unit; participation in stroke registry and nursing registry; having a Patient Safety Officer; staffed bed size; rural location; and whether the hospital qualified for Medicare disproportionate share payments.[13,16,35] All hospital characteristic variables were operationalized as dichotomous variables, except staffed bed size which was categorized into 5 groups (6-99 beds, 100-199 beds, 200-299 beds, 300-399 beds, and 400+ beds).

Statistical Analysis

We used an estimated dependent variable (EDV) modeling approach.[36] Our dependent variables were risk-standardized *rates* of adverse events obtained from patient-level data using the AHRQ-PSI algorithm, and were reported in Hospital Compare as rate estimates along with 95% CI (ie, Lower Confidence Level = estimated rate – 1.96*SE, and Upper Confidence Level = estimated rate + 1.96*SE; where SE is standard error of estimate). More specifically, we employed a weighted least-square method within the EDV approach for estimating the relationship between hospital-level PSI rates and IT measures, where the inverse of SE estimates were obtained from algebraic manipulation of upper and lower limits of the CI as facility-specific weights in each regression. Furthermore, since PSI measures are rate variables, each PSI was modeled as a nonlinear regression model with a log link function and gamma distribution using the *glm* command in STATA

■ **Table 1.** Description of IT Systems and Characteristics for 3002 US Acute Care Hospitals as of 2007

Characteristics	Proportion or Mean (SD)
Health Information Technology Use	
EHR stage 1 capability (%)[a]	20.6
Surgical IT system (%)[b]	77.0
Hospital Characteristics	
For profit (%)	19.0
Academic (%)	09.0
Teaching (%)	25.0
Multihospital system membership (%)	63.0
Rural (%)	34.0
Cardiac registry participation (%)	32.0
Nursing registry participation (%)	45.0
Stroke registry participation (%)	43.0
Patient safety officer (%)	28.0
Nurse to bed ratio	1.24 (1.32)
Staffed bed size	204.7(172.9)
6-99 beds (%)	33.2
100-199 beds (%)	27.1
200-299 beds (%)	17.3
300-399 beds (%)	09.8
400+ beds (%)	12.7

[a]EHR Capability: indicates use of an EHR system with functional capabilities necessary to meet stage 1 meaningful use objectives, including: ADT (admission, discharge, transfer) system, auxiliary information systems (laboratory, pharmacy, and radiology), e-prescribing, clinical data repository, clinical decision support, nursing documentation, electronic medication administration record, and computerized physician order entry system.
[b]Surgical IT system indicates use of at least 1 of the perioperative, preoperative, or postoperative information systems.

12.0. This is consistent with the notion that safety-related adverse events, if measured as count variables with access to patient-level data, should be modeled using a negative binomial regression[37] in which the Poisson parameter (ie, mean rate for individual patients) across each facility is considered gamma distributed.[38]

For each PSI, we performed 3 separate regression models: with EHR and surgical IT system as separate primary predictors (Model 1 and Model 2), and then with both as primary predictors (Model 3). In addition to controlling for hospital characteristics identified above, in each regression we clustered errors at hospital referral region[29] (as defined in Dartmouth Atlas) level to account for potential confounding effects of factors at the local market level. We report results of the marginal effects of EHR and surgical IT systems in terms of the relative risk-standardized rates for each PSI.

RESULTS

Descriptive Statistics

Descriptive statistics are reported in Table 1. In the study sample, about 21% of hospitals had EHR systems capable of meeting the Stage 1 MU objectives, and 77% had at least 1 surgical IT system in operational status by 2007. The mean staffed bed size of hospitals was 205 (SD = 173), with one-third of hospitals having fewer than 100 staffed beds.

Descriptive statistics for the 8 hospital patient safety indicators (PSIs), measured as the risk-standardized expected rates per 1000 patient admissions, are reported in Table 2. The number of hospitals for which reliable PSI rate estimates were reported varied substantially (600 to 3000). For the majority of PSIs, the mean risk standardized rates varied between 2 and 10 per 1000 patient admissions. However, for iatrogenic pneumothorax, it was 0.4 per 1000 patient admissions (SD = 0.15) and for death from serious treatable complications after surgery the mean rate was 116 per 1000 patient admissions (SD = 19.6).

Effects of Surgical IT Systems and EHR Capability

The marginal effects of EHR and surgical IT systems on patient safety performance are reported as exponentiated coefficients representing adjusted incidence rate ratios in Table 3 (controlling for hospital characteristics and other confounding factors) for 3 separate regressions: EHR and surgical IT systems considered individually as Model 1 and 2 respectively, and both systems considered jointly in Model 3 (please see eAppendix for detailed results of regression). In addition, we also provide graphical representation, in the Figure, of effect sizes with point estimates (ie, exponentiated coefficients) and their associated 95% CI on Model 3 regressions. For brevity, we discuss the results based on the joint model (Model 3).

As shown in Table 3, the marginal effects of surgical IT systems (including 1 or more of preoperative, perioperative or postoperative systems) were significant across all patient safety indicators except 1—abdominal aortic aneurysm repair mortality. We found that risk-standardized incidence rates at hospitals with surgical IT systems, compared with hospitals without such systems, were lower by 7% to 26% for 7 of 8 patient safety measures (deaths from serious treatable complications: incidence rate ratio [IRR] 0.81, robust standard error [RSE] 0.046; iatrogenic pneumothorax: IRR 0.78, RSE 0.039; postoperative respiratory

■ **Table 2.** Summary Statistics of Hospital Performance on AHRQ Patient Safety and Quality Indicators During October 2008 – June 2010 [N = 3002 hospitals]

Patient Safety / Quality Indicators	n	Mean (SD)
Death-Related Patient Safety/Quality Indicators		
Death from serious treatable complications after surgery	1846	116.06 (19.59)
Death after surgery to repair a weakness in the abdominal aorta (abdominal aortic aneurysm repair mortality rate)	607	14.36 (0.66)
Death among patients with hip fracture (hip fracture mortality rate)	2354	2.96 (0.50)
Non-Death-Related Patient Safety Indicators		
Accidental puncture or laceration rate (accidental cuts/tears from medical treatment)	2998	1.97 (0.90)
Iatrogenic pneumothorax rate (collapsed lung due to medical treatment)	2998	0.39 (0.15)
Postoperative respiratory failure rate (breathing failure after surgery)	2599	10.08 (3.82)
Postoperative pulmonary embolism or deep vein thrombosis rate (serious blood clots after surgery)	2861	5.37 (2.72)
Postoperative wound dehiscence rate (wound splits open after surgery)	2572	2.17 (0.42)

All patient safety/quality indicators are facility level risk standardized rates per 1000 patients at risk.

failure: 0.74, RSE 0.054; postoperative pulmonary embolism: IRR 0.79, RSE 0.48; postoperative wound dehiscence: IRR 0.90, RSE 0.042; accidental puncture or laceration: IRR 0.86, RSE 0.043; and hip fracture mortality: IRR 0.93, RSE 0.036). These effect sizes were consistent even when considering the individual model, albeit the relative risk of adverse events were lower by 9% to 28% for hospitals with surgical IT systems compared with hospitals without such systems (see Model 2 in Table 3).

The risk-standardized incidence rates at hospitals with an EHR system capable of meeting Stage 1 MU objectives, compared with hospitals in the referent group having a lesser or no EHR system, are likely to be lower by 7% to 11% for 3 of the 8 patient safety indicators (postoperative respiratory failure: IRR 0.89, RSE 0.04; postoperative wound dehiscence: IRR 0.93, RSE 0.025; and hip fracture mortality: IRR 0.93, RSE 0.024). These effect sizes were consistent even when considering the individual model, although EHR systems were associated with 5 of 8 patient safety indicators and the relative risks were lower by 9% to 14% (see Model 1 in Table 3).

DISCUSSION

In this retrospective cross-sectional study of a large national sample of acute care hospitals, we investigated the relationship between the use of IT systems and hospital performance on patient safety measures related to inpatient medical or surgical care. We found that compared with those without such systems, hospitals with surgical IT systems had modestly lower incidence rates on all but 1 of the 8 patient safety measures examined. In addition, those with EHR systems capable of meeting Stage 1 MU objectives had lower incidence rates on 3 of 8 patient safety measures. Our findings suggest that surgical IT systems play a positive, albeit clinically modest, role in patient safety for patients who undergo in-hospital surgery.

This study, to the best of our knowledge, is the first to examine the associative relationship between hospital performance on AHRQ patient safety indicators and health IT systems using a large national sample. Our results are consistent with recent studies that find an association between EHR and patient safety indicators using regional or facility-specific data. For example, Menachemi and his colleagues[39] found that Florida hospitals using a comprehensive set of clinical information technologies had better patient safety performance. Several other studies have demonstrated facility-specific benefits of surgical IT systems in improving process compliance and cost-effectiveness, and in reducing adverse events.[40-43]

Furthermore, our study adds to prior research that used a national sample of hospitals, such as that of Parente and McCullough,[44] who found that EHR systems were associated with reduced infections attributable to medical care, but had no effect on postoperative hemorrhage and deep venous thrombosis. Likewise, Jha and colleagues found that use of computerized physician order entry (CPOE) systems were associated with lower mortality rates for acute myocardial infarction, but not for congestive heart failure or pneumonia.[45] In contrast, Jones and his colleagues found that higher usage of CPOE (more than half of all orders electronically) was associated with some reduced mortality rates.[46]

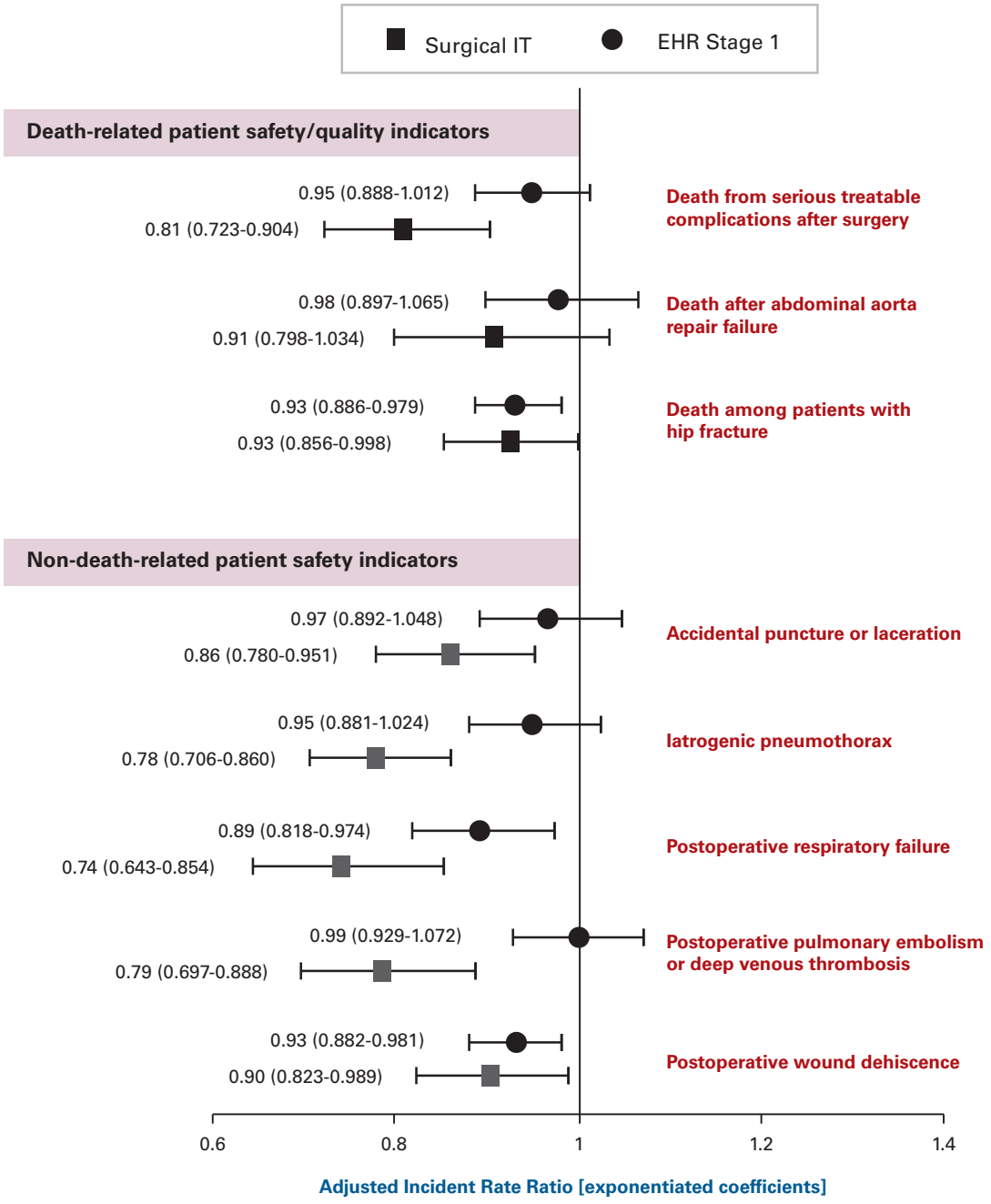
Table 3. The Association of Hospital Performance on AHRQ Patient Safety and Quality Indicators With Their Health Information Technology Use

Variables	Model 1		Model 2		Model 3	
Death-Related Patient Safety/Quality Indicators						
Death From Serious Treatable Complications After Surgery						
EHR stage 1 capability	0.92 (0.035)	**			0.95 (0.032)	
Surgical IT systems			0.80 (0.048)	***	0.81 (0.046)	***
Abdominal Aortic Aneurysm Repair Mortality Rate						
EHR stage 1 capability	0.97 (0.042)				0.98 (0.043)	
Surgical IT systems			0.90 (0.058)		0.91 (0.06)	
Hip Fracture Mortality Rate						
EHR stage 1 capability	0.92 (0.023)	***			0.93 (0.024)	***
Surgical IT systems			0.91 (0.035)	***	0.93 (0.036)	**
Non Death-Related Patient Safety Indicators						
Accidental Puncture or Laceration Rate						
EHR stage 1 capability	0.95 (0.037)				0.97 (0.04)	
Surgical IT systems			0.85 (0.041)	***	0.86 (0.043)	***
Iatrogenic Pneumothorax Rate						
EHR stage 1 capability	0.91 (0.034)	***			0.95 (0.036)	
Surgical IT systems			0.77 (0.037)	***	0.78 (0.039)	***
Postoperative Respiratory Failure Rate						
EHR stage 1 capability	0.86 (0.038)	***			0.89 (0.04)	***
Surgical IT systems			0.72 (0.051)	***	0.74 (0.054)	***
Postoperative Pulmonary Embolism (PE) or Deep Vein Thrombosis (DVT) Rate						
EHR stage 1 capability	0.96 (0.035)				1.00 (0.037)	
Surgical IT systems			0.79 (0.047)	***	0.79 (0.048)	***
Postoperative Wound Dehiscence Rate						
EHR stage 1 capability	0.91 (0.026)	***			0.93 (0.025)	***
Surgical IT systems			0.88 (0.042)	***	0.90 (0.042)	**

** $P \leq .05$.
*** $P \leq .01$.
AHRQ indicates Agency for Healthcare Research and Quality; EHR, electronic health record; IT, information technology.
All effect sizes are exponentiated coefficients, representing adjusted incidence rate ratios, from weighted generalized linear model based regression with gamma-log link function. Robust standard errors clustered at hospital referral region level are noted in parentheses. The dependent variables (AHRQ patient safety indicators and inpatient quality indicators) are facility-level estimates of risk-standardized rates per 1000 patients at risk. For each dependent variable 3 separate regressions were estimated with meaningful EHR capability, and surgical IT system as primary predictors individually (Model 1 and Model 2) and both as primary predictors (Model 3). All regressions were adjusted for confounding factors including for-profit status, teaching status, urban location, member of a multihospital system, participation in national registries (cardiac, nursing, and stroke), staffed bed capacity, nurse to beds ratio, historical composite process quality, propensity of EHR adoption, and patient safety leadership position. In all regressions, inverse of hospital-specific standard error of risk-standardized rates, obtained from 95% confidence intervals reported by Hospital Compare were used as weights.

Our study should be interpreted in the context of the following limitations. Most importantly, the relationships of EHR and surgical IT systems with hospital patient safety performance were examined using a cross-sectional design limiting our ability to make causal claims about the relationships. We used IT system usage in 2007, and studied the association with patient safety indicators from 2008 to 2010, and incorporated propensity scores for EHR adoption, as well as levels of historical process quality to attempt to reduce selection bias effects in which higher-quality hospitals are more likely to both use IT and have lower rates of adverse events. Future research using a longitudinal study design may help clarify whether adoption of specific features of EHR and surgical IT systems are associated with patient safety improvement over time. A second limitation is that EHR systems were defined in terms of a composite index of IT systems with functionality to meet the MU criteria, rather than the actual measures of MU defined under the Health Information Technology for Econom-

Figure. The Association of Hospital Performance on AHRQ Patient Safety and Quality Indicators With Their Health Information Technology Use



Adjusted incidence rate ratios, from generalized linear model based regression with gamma-log link function (representing Model 3 in Table 3). The dependent variables are facility-level estimates of risk-standardized rates per 1000 patients at risk. All regressions were adjusted for confounding factors including for-profit status, teaching status, urban location, member of a multihospital system, participation in national registries (cardiac, nursing, and stroke), staffed bed capacity, nurse-to-beds ratio, historical composite process quality, propensity of EHR adoption, and patient safety leadership position. In all regressions, inverse of hospital-specific SE of risk-standardized rates, obtained from 95% CIs reported by Hospital Compare, were used as weights.

ic and Clinical Health Act (which requires demonstrating activities via technology use). Recent comparative analyses raised concern about the use of HIMSS and other data sources for consistency of either CPOE or a single-implementation enterprise EHR adoption.[47,48] However, our study defines EHR system based on a composite of several clinical information systems, and thus more closely maps to needed functional require-

ments of Stage 1 MU. Finally, we did not study other potential benefits of EHR or surgical IT systems, but focused specifically on well-established patient safety measures. Other outcomes, such as healthcare-associated infection rates, may be more responsive to the use of EHR and surgical IT systems.

In summary, we found that hospital use of IT systems—specifically surgical IT systems and, to a lesser extent, EHR systems capable of meeting the 2011 MU objectives—was associated with modestly lower rates of select patient safety adverse events.

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REFERENCES

1. Institute of Medicine. *Health IT and Patient Safety: Building Safer Systems for Better Care.* Washington, DC: The National Academies Press; 2012.

2. Classen DC, Resar R, Griffin F, et al. 'Global trigger tool' shows that adverse events in hospitals may be ten times greater than previously measured. *Health Aff (Millwood).* 2011; 30(4):581-589.

3. Landrigan CP, Parry GJ, Bones CB, Hackbarth AD, Goldmann DA, Sharek PJ. Temporal trends in rates of patient harm resulting from medical care. *New Engl J Med.* 2010;363(22):2124-2134.

4. Partnership for patients to improve care and lower costs for Americans [press release]. Washington, DC: HHS; April 12, 2011. http://www.businesswire.com/news/home/20110412006457/en/Partnership-patients-improve-care-costs-Americans#.VEWcm4t4o7Y. Accessed April 5, 2014.

5. Buntin MB, Jain SH, Blumenthal D. Health information technology: laying the infrastructure for national health reform. *Health Aff (Millwood).* 2010; 29(6):1214-1219.

6. Institute of Medicine. *Key Capabilities of an Electronic Health Record System: Letter Report.* Washington, DC: National Academies Press; 2003.

7. The official web site for the Medicare and Medicaid Electronic Health Records (EHR) Incentive Programs. CMS website. http://www.cms.gov/Regulations-and-Guidance/Legislation/EHRIncentivePrograms/index.html?redirect=/ehrincentiveprograms/. Accessed April 5, 2014.

8. Bates DW, Gawande AA. Improving safety with information technology. *New Engl J Med.* 2003;348(25):2526-2534.

9. Hug BL, Witkowski DJ, Sox CM, et al. Adverse drug event rates in six community hospitals and the potential impact of computerized physician order entry for prevention. *J Gen Intern Med.* 2010;25(1):31-38.

10. Haynes K, Linkin DR, Fishman NO, et al. Effectiveness of an information technology intervention to improve prophylactic antibacterial use in the postoperative period. *J Am Med Inform Assoc.* 2011;18(2):164-168.

11. St Jacques P, Rothman B. Enhancing point of care vigilance using computers. *Anesthesiol Clin.* 2011;29(3):505-519.

12. Ellner SJ, Joyner PW. Information technologies and patient safety. *Surg Clin North Am.* 2012;92(1):79-87.

13. Appari, A, Johnson ME, Anthony DL. Meaningful use of electronic health record systems and process quality of care: evidence from a panel data analysis of U.S. acute care hospitals. *Health Serv Res.* 2012;48(2, pt 1):354-375.

14. DesRoches CM, Campbell EG, Vogeli C, et al. Electronic health records' limited successes suggest more targeted uses. *Health Aff (Millwood).* 2010;29(4):639-646.

15. McCullough JS, Casey M, Moscovice I, Prasad S. The effects of health information technology on quality in U.S. hospitals. *Health Aff (Millwood).* 2010;29(4):647-654.

16. Appari A, Carian EK, Johnson ME, Anthony DL. Medication administration quality and health information technology: a national study of US hospitals. *J Am Med Inform Assoc.* 2012;19(3):360-367.

17. Buntin MB, Burke MF, Hoaglin MC, Blumenthal D. The benefits of health information technology: a review of recent literature shows predominantly positive results. *Health Aff (Millwood).* 2011;30(3):464-471.

18. Wolfstadt JI, Gurwitz JH, Field TS, et al. The effects of computerized physician order entry with clinical decision support on the rates of adverse drug events: a systematic review. *J Gen Intern Med.* 2008;23(4):451-458.

19. Shamliyan TA, Duval S, Du J, Kane RL. Just what the doctor ordered. review of the evidence of the impact of computerized physician order entry system on medication errors. *Health Serv Res.* 2008; 43(1, pt 1):32-53.

20. Maslove DM, Rizk N, Lowe HJ. Computerized physician order entry in the critical care environment: a review of current literature. *J Intensive Care Med.* 2011;26(3):165-171.

21. Black AD, Car J, Pagliari C, et al. The impact of eHealth on quality and safety of health care: a systematic overview. *PLoS Medicine.* 2011; 8(1):e1000387.

22. Reckmann MH, Westbrook JI, Koh Y, Lo C, Day RO. Does computerized provider order entry reduce prescribing errors for hospital inpatients? a systematic review. *J Am Med Inform Assoc.* 2009; 16(5):613-623.

23. Geppert J, Rhoda D, Morara M. Quality indicator empirical methods (revised by Battelle, under Contract No. HHSA290201200001C). Rockville, MD: Agency for Healthcare Research and Quality; 2013. http://www.qualityindicators.ahrq.gov/Downloads/Resources/Publications/2013/Empirical_Methods_r.pdf. Accessed April 5, 2014.

24. McCullough JS. The adoption of hospital information systems. *Health Econ.* 2008;17:649-664.

25. Jones SS, Adams JL, Schneider EC, Ringel JS, McGlynn EA. Electronic health record adoption and quality improvement in US hospitals. *Am J Manag Care.* 2010;16(12 suppl HIT):SP64-SP71.

26. Miller AR, Tucker CE. Can health care information technology save babies? *J Polit Econ.* 2011;119(2):289-324.

27. Davis MW. Health Information Management Systems and Society Analytics. The state of U.S. hospitals relative to achieving meaningful use requirements. http://www.himssanalytics.org/research/AssetDetail.aspx?pubid=79224&tid=129. Published October 2009. Accessed April 5, 2014.

28. Jha AK, Li Z, Orav EJ, Epstein AM. Care in U.S. hospitals—the Hospital Quality Alliance program. *N Engl J Med.* 2005;353(3):265-274.

29. Wennberg JE, Fisher ES, Goodman DC, Skinner JS. *Tracking the Care of Patients with Severe Chronic Illness: The Dartmouth Atlas of Health Care 2008.* Lebanon, NH: The Dartmouth Institute for Health Policy and Clinical Practice; 2008.

30. Armstrong K, Laschinger H, Wong C. Workplace empowerment and magnet hospital characteristics as predictors of patient safety climate. *J Nurs Care Qual.* 2009;24(1):55-62.

31. Donabedian A. *An Introduction to Quality Assurance in Health Care.* New York, NY: Oxford University Press; 2003.

32. Lehrman WG, Elliott MN, Goldstein E, Beckett MK, Klein DJ, Giordano LA. Characteristics of hospitals demonstrating superior performance in patient experience and clinical process measures of care. *Med Care Res Rev.* 2010;67(1):38-55.

33. Isaac T, Jha AK. Are patient safety indicators related to widely used measures of hospital quality? *J Gen Intern Med.* 2009;23(9):1373-1378.

34. Ryan AM, Burgess JF Jr, Tompkins CP, Wallack SS. The relationship between Medicare's process of care quality measures and mortality. *Inquiry*. 2009;46(3):274-290.

35. Furukawa MF, Raghu TS, Spaulding TJ, Vinze A. Adoption of health information technology for medication safety in U.S. hospitals, 2006. *Health Aff (Millwood)*. 2008;27(3):865-875.

36. Lewis JB, Linzer DA. Estimating regression models in which the dependent variable is based on estimates. *Political Analysis*. 2005;13:345-364.

37. Singer S, Lin S, Falwell A, Gaba D, Baker L. Relationship of safety climate and safety performance in hospitals. *Health Serv Res*. 2009;44(2, pt 1):399-421.

38. Gardner W, Mulvey EP, Shaw EC. Regression analyses of counts and rates: Poisson, overdispersed Poisson, and negative binomial models. *Psychol Bull*. 1995;118(3):392-404.

39. Menachemi N, Saunders C, Chukmaitov A, Matthews MC, Brooks RG. Hospital adoption of information technologies and improved patient safety: a study of 98 hospitals in Florida. *J Healthc Manag*. 2007;52(6):398-409.

40. Fahy BG, Bowe EA, Canigliaro J. Perioperative antibiotic process improvement reaps rewards. *Am J Med Qual*. 2011;26(3):185-192.

41. O'Reilly M, Talsma A, VanRiper S, Kheterpal S, Burney R. An anesthesia information system designed to provide physician-specific feedback improves timely administration of prophylactic antibiotics. *Anesth Analg*. 2006;103(4):908-912.

42. Maddox RR, Oglesby H, Williams CK, Fields M, Danello S. Continuous respiratory monitoring and a 'smart' infusion system improve safety of patient-controlled analgesia in the postoperative period. In: Henriksen K, Battles JB, Keyes MA, Grady ML, eds. Advances in Patient Safety: New Directions and Alternative Approaches (Vol. 4: Technology and Medication Safety). AHRQ Publication No. 08-0034-4. Rockville, MD: Agency for Healthcare Research and Quality; 2008.

43. Schwann NM, Bretz KA, Eid S, et al. Point-of-care electronic prompts: an effective means of increasing compliance, demonstrating quality, and improving outcome. *Anesthesia & Analgesia*. 2011;113(4):869-876.

44. Parente ST, McCullough JS. Health information technology and patient safety: evidence from panel data. *Health Aff (Millwood)*. 2009;28(2):357-360.

45. Jha AK, Orav EJ, Ridgeway AB, Zheng J, Epstein AM. Does the Leapfrog program help identify high-quality hospitals? *Jt Comm J Qual Patient Saf*. 2008;34(6):318-325.

46. Jones SS, Heaton P, Friedberg MW, Schneider EC. Today's 'meaningful use' standard for medication orders by hospital may save few lives; later stages may do more. *Health Aff (Millwood)*. 2011;30(10):2005-2012.

47. Kazley AS, Diana ML, Menachemi N. The agreement and internal consistency of national hospital EMR measures. *Health Care Manag Sci*. 2011;14(4):307-313.

48. Diana ML, Kazley AS, Menachemi N. An assessment of Health Care Information and Management Systems Society and Leapfrog data on computerized provider order entry. *Health Serv Res*. 2011;46(5):1575-1591. ■

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eAppendix. Supplemental Material

Information Technology and Hospital Patient Safety: A Cross-Sectional Study of US Acute Care Hospitals

In this online supplement, we report complete results of all regressions analyses performed in this study. The dependent variable are facility-level estimates of risk-standardized rates per 1000 patients at risk, as reported in the CMS Hospital Compare. For each of the dependent variables, we performed 3 separate regressions using weighted generalized linear model based regression with gamma-log link function in STATA 12.1. The 3 regression models corresponds to including EHR stage 1 Capability and Surgical Information Technology (IT) systems individually (Model 1 and Model 2) and both as primary predictors (Model 3). In all regressions, inverse of hospital-specific standard error of risk-standardized rates, obtained from 95% confidence intervals reported by Hospital Compare were used as weights. In each regression, to account for confounding effects, we used a comprehensive set of hospital characteristics including dedicated patient safety leadership, academic status, teaching status, for-profit status, member of a multihospital system, participation in national registries (cardiac, nursing, and stroke), urban location, nurse to beds ratio, staffed bed capacity, and historical composite process quality. Additionally, we also included propensity to adopt EHR systems as covariate to account for potential endogeneity in the sense that high quality hospitals may be early adopters. All effect sizes are exponentiated coefficients, representing adjusted incidence rate ratios, and robust standard errors clustered at hospital referral region level are noted in parentheses.

Death-Related Patient Safety Measures

Death from serious treatable complications after surgery

Variables	Model 1		Model 2		Model 3	
EHR stage 1 capability	0.922(0.035)	**			0.948(0.032)	
Surgical information systems			0.796(0.048)	***	0.808(0.046)	***
Dedicated patient safety leadership	0.949(0.028)	*	0.946(0.027)	**	0.948(0.027)	*
Academic hospitals	1.024(0.07)		1.028(0.07)		1.027(0.07)	
Teaching hospitals	1.03(0.029)		1.03(0.029)		1.027(0.029)	
For-profit hospitals	1.067(0.083)		1.05(0.081)		1.055(0.08)	
Multihospital system membership	0.92(0.061)		0.927(0.06)		0.925(0.059)	
Cardiac registry participation	0.595(0.027)	***	0.6(0.028)	***	0.6(0.028)	***
Nursing registry participation	0.917(0.031)	***	0.923(0.03)	***	0.926(0.03)	**
Stroke registry participation	0.936(0.033)	*	0.932(0.032)	**	0.935(0.032)	**
Urban	0.972(0.059)		0.981(0.055)		0.978(0.055)	
Nurse-to-bed ratio	0.809(0.025)	***	0.809(0.024)	***	0.811(0.025)	***
Staffed beds size						
<100 [reference]	–		–		–	
100 – 299	0.707(0.084)	***	0.71(0.081)	***	0.709(0.081)	***
300 – 399	0.523(0.085)	***	0.528(0.082)	***	0.528(0.082)	***
400 – 499	0.421(0.072)	***	0.423(0.069)	***	0.423(0.069)	***
500+	0.309(0.05)	***	0.311(0.048)	***	0.311(0.049)	***
EHR adoption propensity						
First quintile [reference]	–		–		–	
Second quintile	1.628(0.229)	***	1.52(0.238)	***	1.546(0.223)	***
Third quintile	1.711(0.31)	***	1.581(0.302)	**	1.622(0.292)	***
Fourth quintile	1.832(0.421)	***	1.695(0.4)	**	1.743(0.394)	***
Fifth quintile	1.727(0.487)	**	1.582(0.448)		1.627(0.447)	*
Historical composite quality						
First quintile [reference]	–		–		–	
Second quintile	0.859(0.05)	***	0.87(0.05)	**	0.869(0.05)	**
Third quintile	0.865(0.054)	**	0.87(0.055)	**	0.872(0.055)	**
Fourth quintile	0.769(0.048)	***	0.772(0.048)	***	0.772(0.048)	***
Fifth quintile	0.763(0.051)	***	0.765(0.05)	***	0.767(0.05)	***
Constant	3.967(0.651)	***	4.832(0.902)	***	4.806(0.849)	***

*** $P \leq .01$; ** $P \leq .05$; * $P \leq .10$.

Abdominal Aortic Aneurysm Repair Mortality Rate

Variables	Model 1		Model 2		Model 3	
EHR stage 1 capability	0.969(0.042)				0.978(0.043)	
Surgical information systems			0.903(0.058)		0.908(0.06)	
Dedicated patient safety leadership	0.992(0.042)		0.99(0.042)		0.991(0.042)	
Academic hospitals	0.917(0.058)		0.923(0.059)		0.923(0.059)	
Teaching hospitals	1.037(0.045)		1.037(0.044)		1.038(0.045)	
For-profit hospitals	0.942(0.116)		0.926(0.113)		0.925(0.114)	
Multihospital system membership	0.976(0.106)		0.978(0.105)		0.981(0.107)	
Cardiac registry participation	0.895(0.052)	*	0.896(0.052)	*	0.897(0.053)	*
Nursing registry participation	0.974(0.048)		0.977(0.048)		0.978(0.048)	
Stroke registry participation	0.919(0.039)	**	0.917(0.038)	**	0.917(0.038)	**
Urban	1.011(0.096)		1.023(0.098)		1.019(0.097)	
Nurse-to-bed ratio	0.889(0.023)	***	0.889(0.023)	***	0.89(0.023)	***
Staffed beds size						
<100 [reference]	–		–		–	
100 - 299	1.176(0.199)		1.195(0.196)		1.191(0.198)	
300 - 399	1.074(0.252)		1.11(0.254)		1.11(0.255)	
400 - 499	0.9(0.216)		0.926(0.217)		0.926(0.218)	
500+	0.756(0.173)		0.777(0.173)		0.777(0.175)	
EHR adoption propensity						
First quintile [reference]	–		–		–	
Second quintile	0.5(0.131)	***	0.475(0.124)	***	0.48(0.127)	***
Third quintile	0.547(0.139)	**	0.513(0.128)	***	0.521(0.131)	***
Fourth quintile	0.605(0.206)		0.559(0.187)	*	0.569(0.192)	*
Fifth quintile	0.55(0.241)		0.509(0.22)		0.514(0.224)	
Historical composite quality						
First quintile [reference]	–		–		–	
Second quintile	0.943(0.121)		0.933(0.12)		0.934(0.121)	
Third quintile	0.938(0.121)		0.925(0.12)		0.927(0.121)	
Fourth quintile	0.763(0.096)	**	0.749(0.095)	**	0.75(0.095)	**
Fifth quintile	0.805(0.103)	*	0.792(0.102)	*	0.794(0.102)	*
Constant	0.339(0.08)	***	0.383(0.092)	***	0.382(0.093)	***

*** $P \leq .01$; ** $P \leq .05$; * $P \leq .10$.

Hip Fracture Mortality Rate

Variables	Model 1		Model 2		Model 3	
EHR stage 1 capability	0.92(0.023)	***			0.931(0.024)	***
Surgical information systems			0.907(0.035)	***	0.925(0.036)	**
Dedicated patient safety leadership	0.962(0.026)		0.963(0.026)		0.963(0.026)	
Academic hospitals	1.866(0.129)	***	1.875(0.13)	***	1.871(0.129)	***
Teaching hospitals	1.149(0.039)	***	1.151(0.039)	***	1.146(0.039)	***
For-profit hospitals	1.106(0.072)		1.102(0.071)		1.102(0.072)	
Multihospital system membership	1.025(0.059)		1.028(0.059)		1.028(0.06)	
Cardiac registry participation	0.754(0.033)	***	0.755(0.033)	***	0.756(0.033)	***
Nursing registry participation	0.936(0.032)	**	0.939(0.031)	*	0.939(0.032)	*
Stroke registry participation	0.887(0.032)	***	0.882(0.032)	***	0.886(0.032)	***
Urban	0.945(0.046)		0.951(0.046)		0.947(0.046)	
Nurse-to-bed ratio	0.849(0.018)	***	0.847(0.018)	***	0.849(0.018)	***
Staffed beds size						
<100 [reference]	–		–		–	
100 - 299	0.67(0.061)	***	0.672(0.061)	***	0.671(0.061)	***
300 - 399	0.502(0.07)	***	0.503(0.069)	***	0.505(0.07)	***
400 - 499	0.442(0.063)	***	0.441(0.062)	***	0.445(0.063)	***
500+	0.392(0.057)	***	0.393(0.056)	***	0.395(0.057)	***
EHR adoption propensity						
First quintile [reference]	–		–		–	
Second quintile	1.565(0.588)		1.625(0.559)		1.602(0.575)	
Third quintile	1.571(0.609)		1.622(0.58)		1.616(0.6)	
Fourth quintile	1.554(0.629)		1.613(0.604)		1.602(0.622)	
Fifth quintile	1.442(0.627)		1.494(0.606)		1.48(0.62)	
Historical composite quality						
First quintile [reference]	–		–		–	
Second quintile	0.844(0.04)	***	0.846(0.041)	***	0.848(0.041)	***
Third quintile	0.862(0.044)	***	0.863(0.045)	***	0.867(0.045)	***
Fourth quintile	0.758(0.036)	***	0.76(0.036)	***	0.761(0.036)	***
Fifth quintile	0.758(0.038)	***	0.757(0.038)	***	0.761(0.038)	***
Constant	0.061(0.023)	***	0.06(0.021)	***	0.062(0.023)	***

*** $P \leq .01$; ** $P \leq .05$; * $P \leq .10$.

Non-Death-Related Patient Safety Measures

Accidental Puncture or Laceration Rate

Variables	Model 1	Model 2	Model 3
EHR stage 1 capability	0.945(0.037)		0.967(0.04)
Surgical information systems		0.853(0.041) ***	0.861(0.043) ***
Dedicated patient safety leadership	1.015(0.04)	1.015(0.039)	1.015(0.039)
Academic hospitals	1.334(0.094) ***	1.333(0.093) ***	1.334(0.093) ***
Teaching hospitals	1.14(0.057) ***	1.136(0.056) ***	1.136(0.056) ***
For-profit hospitals	0.983(0.106)	0.985(0.105)	0.985(0.106)
Multihospital system membership	1.067(0.087)	1.063(0.087)	1.064(0.087)
Cardiac registry participation	0.751(0.044) ***	0.758(0.044) ***	0.757(0.045) ***
Nursing registry participation	0.956(0.045)	0.96(0.046)	0.963(0.046)
Stroke registry participation	0.795(0.045) ***	0.791(0.045) ***	0.792(0.045) ***
Urban	0.997(0.075)	1.014(0.077)	1.011(0.076)
Nurse-to-bed ratio	0.979(0.012) *	0.977(0.012) **	0.977(0.011) **
Staffed beds size			
<100 [reference]	–	–	–
100 - 299	0.447(0.081) ***	0.446(0.083) ***	0.448(0.082) ***
300 - 399	0.322(0.08) ***	0.322(0.081) ***	0.325(0.081) ***
400 - 499	0.27(0.068) ***	0.268(0.068) ***	0.27(0.068) ***
500+	0.191(0.046) ***	0.191(0.047) ***	0.192(0.047) ***
EHR adoption propensity			
First quintile [reference]	–	–	–
Second quintile	0.634(0.159) *	0.66(0.159) *	0.662(0.159) *
Third quintile	0.617(0.187)	0.661(0.193)	0.664(0.194)
Fourth quintile	0.621(0.227)	0.668(0.238)	0.67(0.239)
Fifth quintile	0.554(0.233)	0.598(0.247)	0.599(0.247)
Historical composite quality			
First quintile [reference]	–	–	–
Second quintile	0.892(0.053) *	0.903(0.055 *	0.903(0.055) *
Third quintile	0.92(0.056)	0.928(0.056	0.93(0.057)
Fourth quintile	0.811(0.053) ***	0.821(0.054 ***	0.821(0.054) ***
Fifth quintile	0.865(0.061) **	0.872(0.06) **	0.874(0.061) **
Constant	0.002(0.001) ***	0.002(0.001) ***	0.002(0.001) ***

*** $P \leq .01$; ** $P \leq .05$; * $P \leq .10$.

Iatrogenic Pneumothorax Rate

Variables	Model 1	Model 2	Model 3
EHR stage 1 capability surgical	0.905(0.034) ***		0.95(0.036)
Information systems		0.766(0.037) ***	0.779(0.039) ***
Dedicated patient safety leadership	1.009(0.04)	1.011(0.039)	1.01(0.039)
Academic hospitals	1.283(0.076) ***	1.28(0.075) ***	1.282(0.075) ***
Teaching hospitals	1.203(0.058) ***	1.194(0.055) ***	1.192(0.055) ***
For-profit hospitals	0.963(0.097)	0.979(0.098)	0.978(0.098)
Multihospital system membership	1.166(0.087) **	1.146(0.086) *	1.149(0.086) *
Cardiac registry participation	0.681(0.038) ***	0.689(0.038) ***	0.689(0.038) ***
Nursing registry participation	0.895(0.038) ***	0.906(0.04) **	0.91(0.039) **
Stroke registry participation	0.824(0.048) ***	0.815(0.046) ***	0.818(0.047) ***
Urban	1.051(0.071)	1.084(0.073)	1.08(0.072)
Nurse-to-bed ratio	0.989(0.011)	0.987(0.011)	0.987(0.011)
Staffed beds size			
<100 [reference]	–	–	–
100 - 299	0.472(0.07) ***	0.463(0.07) ***	0.468(0.07) ***
300 - 399	0.34(0.07) ***	0.334(0.07) ***	0.338(0.07) ***
400 - 499	0.262(0.056) ***	0.256(0.055) ***	0.26(0.056) ***
500+	0.209(0.041) ***	0.205(0.041) ***	0.208(0.041) ***
EHR adoption propensity			
First quintile [reference]	–	–	–
Second quintile	0.688(0.144) *	0.743(0.148	0.743(0.147
Third quintile	0.599(0.15) **	0.685(0.164)	0.686(0.164)
Fourth quintile	0.618(0.187)	0.717(0.21)	0.716(0.209)
Fifth quintile	0.558(0.198) *	0.657(0.226)	0.654(0.224)
Historical composite quality			
First quintile [reference]	–	–	–
Second quintile	0.852(0.04) ***	0.869(0.041) ***	0.871(0.041) ***
Third quintile	0.862(0.045) ***	0.875(0.046) ***	0.878(0.047) **
Fourth quintile	0.799(0.045) ***	0.816(0.046) ***	0.817(0.046) ***
Fifth quintile	0.761(0.044) ***	0.773(0.044) ***	0.775(0.045) ***
Constant	0(0) ***	0(0) ***	0(0) ***

*** $P \leq .01$; ** $P \leq .05$; * $P \leq .10$.

Postoperative Respiratory Failure Rate

Variables	Model 1	Model 2	Model 3
EHR stage 1 capability	0.857(0.038) ***		0.893(0.04) ***
Surgical information systems		0.719(0.051) ***	0.741(0.054) ***
Dedicated patient safety leadership	0.94(0.04)	0.935(0.039)	0.938(0.039)
Academic hospitals	1.22(0.099) **	1.218(0.098) ***	1.22(0.098) ***
Teaching hospitals	1.278(0.07) ***	1.27(0.067) ***	1.262(0.066) ***
For-profit hospitals	0.991(0.119)	0.991(0.119)	0.989(0.118)
Multihospital system membership	1.085(0.107)	1.077(0.105)	1.083(0.106)
Cardiac registry participation	0.513(0.043) ***	0.517(0.045) ***	0.517(0.045) ***
Nursing registry participation	0.829(0.046) ***	0.838(0.046) ***	0.841(0.047) ***
Stroke registry participation	0.84(0.055) ***	0.828(0.053) ***	0.833(0.054) ***
Urban	0.868(0.077)	0.89(0.078)	0.881(0.078)
Nurse-to-bed ratio	0.794(0.027) ***	0.792(0.026) ***	0.797(0.027) ***
Staffed beds size			
<100 [reference]	–	–	–
100 - 299	0.656(0.124) **	0.646(0.118) **	0.654(0.12) **
300 - 399	0.558(0.155) **	0.552(0.149) **	0.563(0.153) **
400 - 499	0.449(0.135) ***	0.441(0.13) ***	0.452(0.133) ***
500+	0.341(0.095) ***	0.337(0.091) ***	0.344(0.094) ***
EHR adoption propensity			
First quintile [reference]	–	–	–
Second quintile	2.143(0.629) ***	2.124(0.629) ***	2.133(0.638) ***
Third quintile	2.137(0.707) **	2.198(0.728) **	2.225(0.743) **
Fourth quintile	1.732(0.695)	1.82(0.724)	1.83(0.733)
Fifth quintile	1.362(0.64)	1.441(0.667)	1.439(0.671)
Historical composite quality			
First quintile [reference]	–	–	–
Second quintile	0.824(0.067) **	0.836(0.069) **	0.837(0.069) **
Third quintile	0.791(0.064) ***	0.795(0.066) ***	0.801(0.067) ***
Fourth quintile	0.644(0.053) ***	0.651(0.055) ***	0.653(0.054) ***
Fifth quintile	0.669(0.058) ***	0.676(0.059) ***	0.679(0.059) ***
Constant	0.07(0.021) ***	0.079(0.024 ***	0.08(0.025) ***

*** $P \leq .01$; ** $P \leq .05$; * $P \leq .10$.

Postoperative Pulmonary Embolism (PE) or Deep Vein Thrombosis (DVT) Rate

Variables	Model 1		Model 2		Model 3	
EHR stage 1 capability	0.962(0.035)				0.998(0.037)	
Surgical information systems			0.786(0.047)	***	0.787(0.048)	***
Dedicated patient safety leadership	0.98(0.035)		0.978(0.034)		0.978(0.034)	
Academic hospitals	1.512(0.106)	***	1.519(0.108)	***	1.519(0.108)	***
Teaching hospitals	1.219(0.063)	***	1.211(0.06)	***	1.21(0.061)	***
For-profit hospitals	0.851(0.093)		0.845(0.092)		0.845(0.092)	
Multihospital system membership	1.242(0.099)	***	1.247(0.099)	***	1.247(0.099)	***
Cardiac registry participation	0.449(0.027)	***	0.454(0.028)	***	0.454(0.028)	***
Nursing registry participation	0.961(0.044)		0.969(0.045)		0.969(0.045)	
Stroke registry participation	0.878(0.046)	***	0.874(0.045)	***	0.874(0.046)	***
Urban	0.835(0.059)	***	0.846(0.06)	**	0.846(0.06)	**
Nurse-to-bed ratio	0.786(0.024)	***	0.788(0.024)	***	0.788(0.024)	***
Staffed beds size						
<100 [reference]	–		–		–	
100 - 299	0.518(0.078)	***	0.523(0.079)	***	0.524(0.079)	***
300 - 399	0.474(0.105)	***	0.486(0.107)	***	0.486(0.107)	***
400 - 499	0.395(0.091)	***	0.404(0.094)	***	0.404(0.093)	***
500+	0.315(0.067)	***	0.322(0.068)	***	0.322(0.068)	***
EHR adoption propensity						
First quintile [reference]	–		–		–	
Second quintile	0.804(0.264)		0.826(0.265		0.826(0.265	
Third quintile	0.61(0.212)		0.651(0.222)		0.651(0.222)	
Fourth quintile	0.519(0.201)	*	0.556(0.213)		0.556(0.213)	
Fifth quintile	0.369(0.164)	**	0.392(0.172)	**	0.392(0.172)	**
Historical composite quality						
First quintile [reference]	–		–		–	
Second quintile	0.767(0.05)	***	0.787(0.053)	***	0.787(0.053)	***
Third quintile	0.765(0.054)	***	0.781(0.056)	***	0.781(0.056)	***
Fourth quintile	0.665(0.044)	***	0.679(0.046)	***	0.679(0.046)	***
Fifth quintile	0.621(0.045)	***	0.633(0.045)	***	0.633(0.045)	***
Constant	0.049(0.017)	***	0.052(0.017)	***	0.052(0.018)	***

*** $P \leq .01$; ** $P \leq .05$; * $P \leq .10$.

Postoperative Wound Dehiscence Rate

Variables	Model 1		Model 2		Model 3	
EHR stage 1 capability	0.912(0.026)	***			0.93(0.025)	***
Surgical information systems			0.881(0.042)	***	0.902(0.042)	**
Dedicated patient safety leadership	0.979(0.029)		0.98(0.029)		0.98(0.029)	
Academic hospitals	1.114(0.114)		1.111(0.113)		1.112(0.114)	
Teaching hospitals	1.126(0.049)	***	1.125(0.047)	***	1.12(0.046)	***
For-profit hospitals	1.104(0.061)	*	1.102(0.061)	*	1.102(0.061)	*
Multihospital system membership	1.055(0.057)		1.057(0.057)		1.056(0.058)	
Cardiac registry participation	0.543(0.03)	***	0.545(0.03)	***	0.545(0.03)	***
Nursing registry participation	0.896(0.028)	***	0.902(0.029)	***	0.904(0.029)	***
Stroke registry participation	0.846(0.044)	***	0.838(0.043)	***	0.843(0.043)	***
Urban	0.999(0.049)		1.007(0.05)		1.003(0.049)	
Nurse-to-bed ratio	0.801(0.02)	***	0.8(0.02)	***	0.802(0.02)	***
Staffed beds size						
<100 [reference]	–		–		–	
100 - 299	0.614(0.056)	***	0.613(0.055)	***	0.614(0.055)	***
300 - 399	0.475(0.064)	***	0.473(0.063)	***	0.476(0.063)	***
400 - 499	0.396(0.058)	***	0.393(0.057)	***	0.397(0.057)	***
500+	0.289(0.041)	***	0.289(0.041)	***	0.29(0.041)	***
EHR adoption propensity						
First quintile [reference]	–		–		–	
Second quintile	1.494(0.266)	**	1.512(0.274	**	1.505(0.276	**
Third quintile	1.501(0.295)	**	1.522(0.303)	**	1.526(0.307)	**
Fourth quintile	1.404(0.312)		1.431(0.32)		1.434(0.323)	
Fifth quintile	1.328(0.346)		1.349(0.352)		1.351(0.356)	
Historical composite quality						
First quintile [reference]	–		–		–	
Second quintile	0.904(0.038)	**	0.91(0.038)	**	0.909(0.038)	**
Third quintile	0.877(0.04)	***	0.882(0.041)	***	0.884(0.041)	***
Fourth quintile	0.805(0.036)	***	0.811(0.036)	***	0.81(0.036)	***
Fifth quintile	0.766(0.042)	***	0.77(0.041)	***	0.77(0.041)	***
Constant	0.044(0.008)	***	0.045(0.009)	***	0.046(0.009)	***

*** $P \leq .01$; ** $P \leq .05$; * $P \leq .10$.