Clinical Information Technologies and Inpatient Outcomes

A Multiple Hospital Study

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Background: Despite speculation that clinical information technologies will improve clinical and financial outcomes, few studies have examined this relationship in a large number of hospitals.

Methods: We conducted a cross-sectional study of urban hospitals in Texas using the Clinical Information Technology Assessment Tool, which measures a hospital's level of automation based on physician interactions with the information system. After adjustment for potential confounders, we examined whether greater automation of hospital information was associated with reduced rates of inpatient mortality, complications, costs, and length of stay for 167 233 patients older than 50 years admitted to responding hospitals between December 1, 2005, and May 30, 2006.

Results: We received a sufficient number of responses from 41 of 72 hospitals (58%). For all medical conditions studied, a 10-point increase in the automation of notes and records was associated with a 15% decrease in the adjusted odds of fatal hospitalizations (0.85; 95% confidence interval, 0.74-0.97). Higher scores in order entry were associated with 9% and 55% decreases in the adjusted odds of death for myocardial infarction and coronary artery bypass graft procedures, respectively. For all causes of hospitalization, higher scores in decision support were associated with a 16% decrease in the adjusted odds of complications (0.84; 95% confidence interval, 0.79-0.90). Higher scores on test results, order entry, and decision support were associated with lower costs for all hospital admissions (–\$110, –\$132, and –\$538, respectively; $P < .05$).

Conclusion: Hospitals with automated notes and records, order entry, and clinical decision support had fewer complications, lower mortality rates, and lower costs.

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In recent years, American health care has been criticized as fragmented, expensive, unsafe, and unfair.[1] Clinical or "health" information technologies, such as electronic medical records, computerized provider order entry systems, and clinical decision support systems, have emerged as one antidote, promising reductions in waste, gains in communication, improvements in quality, and new accountabilities through automated performance measurement. Benefits have emerged.[2,3] However, studies examining the impact of these technologies are not easily generalized; most studies are limited to single-site evaluations, often academic hospitals that have developed their systems internally and incrementally, sometimes for decades.[3] In contrast, most US hospitals must consider purchasing commercially developed information systems with a broad range of electronic capabilities. Few studies have been performed across multiple hospitals to forecast the effect of clinical information technologies in these settings.

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The clinical information system of a hospital can be divided into 4 principal subdomains: notes and records, test results, order entry, and decision support. Information in each of these areas would ordinarily be managed through paper-based systems; to the degree that a hospital is "paperless," these functions are automated. We previously developed a physician-based assessment tool that quantifies the degree to which a hospital has effectively computerized these 4 subdomains. The instrument has demonstrated reliability and validity.[4] In this study, we examined the association between a hospital's automation and inpatient mortality, complications, costs, and length of stay

(LOS) among patients with 4 medical conditions in a diverse group of Texas hospitals. It has been argued that automating the various domains of a hospital's clinical information system will improve communication among health care providers, quicken responses to abnormal diagnostic test results, enhance clinical decision making, and improve adherence to guidelines. The 4 medical conditions included in this study—myocardial infarction, congestive heart failure, coronary artery bypass grafting, and pneumonia—are common and are thought to be sensitive to clinical guidelines. We hypothesized that greater levels of automation would be associated with better outcomes.

METHODS

STUDY DESIGN

We conducted a cross-sectional study of urban hospitals in Texas. We sampled from 72 general acute-care hospitals located within 10 geographically dispersed metropolitan statistical areas in Texas: Abilene, Austin, Dallas, El Paso, Houston, Laredo, Lubbock, McAllen, San Angelo, and San Antonio. We selected Texas as the site for study because it contains a large and diverse patient population and a wide range of hospitals for which specific clinical outcomes could be obtained. We excluded pediatric, specialty, or long-term care hospitals; hospitals that were in the process of closing or merging with another facility; and hospitals for which we could not obtain discharge data for the targeted diagnosis related groups. The Johns Hopkins University School of Medicine Institutional Review Board approved the research protocol.

INDEPENDENT VARIABLES

We measured automation in the hospitals using the Clinical Information Technology Assessment Tool (CITAT), which is a questionnaire-based tool administered to physicians who provide inpatient care. The CITAT was produced in 8 steps according to rigorous methods of instrument development. This instrument has been tested and validated in 4 US hospitals and demonstrates discriminant validity, convergent validity, reliability, and precision.[4,5] The CITAT assesses a system's automation, or the degree to which clinical information processes in the hospital are computerized. Automation is divided into the 4 subdomains: test results, notes and records, order entry, and decision support.[4] The instrument contains several items for each information technology subdomain; 3 factors are required to achieve a high score on any individual item: the information process must be available as a fully computerized process; the physician must know how to activate the computerized process; and he or she must choose the computerized process over other alternatives, such as using paper-based documentation, making a telephone call, or referring to a clinical textbook. These subdomain scores, scaled from 0 (lowest possible score) to 100 (maximum possible score), served as independent variables in this study.

Using the American Medical Association Physician Masterfile, we selected a 50% random sample of physicians from those who had practice locations in the designated metropolitan statistical areas and who practiced internal medicine (including 9 subspecialties), general surgery (including 10 subspecialties), or family practice (n = 7432). We mailed surveys to each of the selected physicians between December 1, 2005, and May 30, 2006. Physicians indicated whether they practiced inpatient medicine and, if so, selected the hospital in which they provided most of their inpatient care. To be eligible, physicians had to actively practice in 1 of 72 hospitals selected for this study. As guided by prior work,[5] hospitals for which we did not receive 5 randomly sampled physician responses were eliminated from further analysis owing to the possibility of unstable estimates. For each respondent, 4 separate subdomain scores were calculated using previously described methods.[4,5] Each hospital was then assigned the median value of the scores derived from respondents affiliated with that hospital.

DEPENDENT VARIABLES

We examined inpatient mortality, complications, costs, and LOS among patients older than 50 years who were admitted between December 1, 2005, and May 30, 2006, at any of the 72 study hospitals. Discharge-level data for 167 233 patients, including information on all 4 outcomes, were obtained from a hospital claims data file (provided by the Texas Hospital Association and compiled by Solucient, Evanston, Illinois) and merged with the CITAT data. Total costs were derived from charges using hospital-specific cost to charge ratios for each discharge.

OTHER VARIABLES

Hospital characteristics were obtained from the 2005 survey of the Texas Hospital Association and the American Hospital Association annual survey of Texas hospitals. For each hospital in our sample, we obtained the ownership status (public, private/nonprofit, and private/for-profit), bed size (number of beds), and total margin. Estimates of the risks of complication and mortality for each hospitalization were obtained from the risk-adjusted complication index and risk-adjusted mortality index variables provided in the hospital claims data file. These previously validated indices adjust for severity and case-mix differences based on age, sex, principal diagnoses, and procedures performed and are stratified by similar hospitals (ie, number of beds, urban vs rural, teaching status, and census tract).[6,7] The hospital-level data (CITAT scores and hospital characteristics) were linked by hospital to the discharge data.

STATISTICAL ANALYSIS

We compared the characteristics of hospitals with 5 or more physician responses with excluded hospitals using Pearson χ^2 and t tests for categorical and continuous variables, respectively. We examined the association between each hospital's automation subdomain scores with each of the 4 dependent variables (mortality, complications, costs, and LOS). Independent variables were interpreted using 10-point increments. For each of the dependent variables, analyses were performed for all discharges and for those discharges with the following principal *International Classification of Diseases, Ninth Revision*, codes: myocardial infarction (410.xx), heart failure (428.xx, 398.91, 402.01, 402.11, 402.91, 404.00, 404.01, 404.03, 404.10, 404.11, 404.13, 404.90, 404.91, and 404.93), coronary artery bypass graft (36.10-36.17 and 36.19), and pneumonia (480.0-483.8, 485-486, and 487.0).[8]

Logistic regression was used to estimate odds ratios (ORs) for death or complication for each 10-point increase in the automation and subdomain score. Costs and LOS were examined with linear regression after log transformation and retransformed by the Duan smearing method for presentation.[9] Multivariable adjustment included risk (risk-adjusted complication and mortality indices) and hospital characteristics associated with the independent variables. We accounted for possible within-hospital clustering of patient outcomes in all discharge-level analyses by

Table 1. Characteristics of 41 Urban Texas Hospitals[a]

Characteristic	Value
Ownership	
Church/nonprofit	24 (60.0)
Government/authority	3 (7.5)
Private	13 (32.5)
Teaching hospital	
No	35 (85.4)
Yes	6 (14.6)
Safety net hospital	
No	37 (90.2)
Yes	4 (9.8)
IT operating expense, $	
<1 Million	10 (25.0)
≥1 Million	30 (75.0)
No. of beds, mean (SD)	402.4 (291.8)
Operating margin, mean (SD)	0.02 (0.13)
Total margin, mean (SD)	0.05 (0.10)
CITAT subdomain scores, mean (SD)	
Notes and records	28.5 (9.9)
Test results	50.1 (19.7)
Order entry	3.7 (14.9)
Decision support	2.6 (4.8)
Outcomes, for all hospitalizations	
Mortality, mean, %	3.7
Complications, mean, %	5.4
LOS, median, d	4
Costs, median, $	7061

Abbreviations: CITAT, Clinical Information Technology Assessment Tool; IT, information technology; LOS, length of stay.
[a] Data are given as the number (percentage) of hospitals unless otherwise indicated and reflect hospital-level averages, with the exception of Outcomes, which are patient-level estimates.

obtaining robust variance-covariance matrix estimates for all models.[10,11] When there was a statistically significant relationship between the dependent and independent variables, we performed a sensitivity analysis to test the linearity assumptions; subdomain scores were divided into tertiles. Statistical significance was set at $P \leq .05$. Because of the possibility of false-positive relationships owing to multiple hypothesis testing, a Bonferroni correction was performed as an additional sensitivity analysis to adjust for the investigation of 4 automation subdomains for each disease condition and outcome. STATA statistical software, version 9.2, (STATA Corp, College Station, Texas) was used for all analyses.

RESULTS

CHARACTERISTICS OF STUDY HOSPITALS

We received 5 or more physician responses for 41 of 72 targeted hospitals (58% response rate; mean number of responses, 9) (**Table 1**). There were no statistically significant differences in hospital ownership, operating margin, total margin, safety net status, or information technology operating expenses between responding and nonresponding hospitals. However, responding hospitals tended to be larger (mean number of beds, 402 vs 216 for nonresponders; *P* = .001) and more academic (6 teaching hospitals [15%] vs 0 teaching hospitals, respectively; *P* = .03). There were no statistically significant differences between responders and nonresponders with respect to their hospital mortality rate (*P* = .41), complication rate (*P* = .86), or median costs (*P* = .14). Hospitals for which we did not receive a response had a longer median LOS (3 days longer; *P* = .04).

Overall, hospitals scored low on most CITAT subdomains; higher scores were observed for the test results and notes and records subdomains (mean scores, 50.2 and 28.5, respectively) compared with order entry and decision support (3.7 and 2.6, respectively).

CLINICAL INFORMATION AUTOMATION

Inpatient Mortality

Across a variety of clinical conditions, higher CITAT scores were associated with decreased adjusted ORs for fatal hospitalizations (**Table 2**). Higher notes and records scores were associated with a statistically significant decrease in the adjusted odds of inpatient mortality in all-cause hospitalizations (OR, 0.85; 95% confidence interval [CI], 0.74-0.97). Hospitals with higher order entry scores were associated with decreased adjusted odds for fatal hospitalizations for patients admitted with myocardial infarction (0.91; 0.83-0.99) and coronary artery bypass graft procedures (0.45; 0.29-0.68). Higher decision support scores were associated with decreased adjusted odds for mortality owing to pneumonia (0.79; 0.63-1.00). Generally, patterns were internally consistent across disease conditions and automation subdomain regardless of statistical significance.

Patient Complications

Of the automation subdomains, a higher decision support score was consistently associated with decreased adjusted odds for complications (**Table 3**). These results were statistically significant for all causes (OR, 0.84; 95% CI, 0.79-0.90) and myocardial infarction (0.63; 0.45-0.87). Contrary to this trend, we observed that a higher notes and records score was associated with increased adjusted odds for complications associated with heart failure (1.35; 1.16-1.57).

Patient Costs

For nearly all clinical conditions, higher scores on decision support, order entry, and test results were associated with lower mean hospital costs (**Table 4**). Higher test results scores were statistically significantly associated with lower adjusted costs for all hospital admissions (OR, −$110; 95% CI, −$181 to −$20) and for heart failure (−$207; −$272 to −$128). A higher order entry score was associated with statistically significantly lower adjusted costs for all conditions (−$132; −$232 to −$13). As with test results and order entry, a higher decision support score was also associated with lower adjusted costs for all conditions (−$538; −$704 to −$333) and for coronary artery bypass grafting (−$1043; −$1729 to −$55).

Length of Stay

No clear pattern emerged in the relationship between CITAT scores and hospital LOS by clinical condition

Table 2. Hospital Automation Subdomain Scores and Patient Mortality[a]

Automation Subdomain	All Patients (N=167 233)	Patients With Myocardial Infarction (n=4728)	Patients With Heart Failure (n=9697)	Patients With Coronary Artery Bypass Graft (n=2298)	Patients With Pneumonia (n=7208)
Notes and records					
Unadjusted	0.94 (0.85-1.05)	0.95 (0.84-1.07)	0.99 (0.88-1.12)	1.00 (0.77-1.29)	0.92 (0.77-1.10)
Adjusted[b]	0.85 (0.74-0.97)[c]	0.88 (0.72-1.08)	0.92 (0.78-1.08)	0.82 (0.57-1.18)	0.91 (0.70-1.17)
Test results					
Unadjusted	0.99 (0.94-1.03)	1.00 (0.96-1.04)	1.01 (0.97-1.05)	0.97 (0.87-1.07)	1.03 (0.94-1.12)
Adjusted[b]	0.99 (0.93-1.06)	1.05 (0.97-1.14)	0.97 (0.89-1.05)	1.05 (0.80-1.39)	0.98 (0.85-1.12)
Order entry					
Unadjusted	0.98 (0.95-1.02)	0.97 (0.93-1.01)	0.89 (0.84-0.94)[d]	0.75 (0.65-0.87)[d]	1.07 (1.01-1.14)[c]
Adjusted[b]	0.99 (0.93-1.05)	0.91 (0.83-0.99)[c]	0.93 (0.80-1.08)	0.45 (0.29-0.68)[d]	0.97 (0.84-1.11)
Decision support					
Unadjusted	0.94 (0.86-1.02)	0.93 (0.76-1.13)	0.83 (0.63-1.08)	0.80 (0.41-1.55)	1.10 (0.93-1.29)
Adjusted[b]	0.98 (0.82-1.17)	0.88 (0.61-1.29)	0.92 (0.67-1.27)	0.53 (0.25-1.11)	0.79 (0.63-1.00)[c]

[a] Data are given as the odds ratio for fatal hospitalization (95% confidence interval) associated with a 10-point increase in Clinical Information Technology Assessment Tool subdomain score.
[b] Adjusted for patient mortality risk (risk-adjusted mortality index) and hospital size (number of beds), total margin, and ownership.
[c] $P < .05$, not Bonferroni corrected.
[d] $P < .05$ with Bonferroni correction for 4 subdomains.

Table 3. Hospital Automation Subdomain Scores and Patient Complications[a]

Automation Subdomain	All Patients (N=167 233)	Patients With Myocardial Infarction (n=4728)	Patients With Heart Failure (n=9697)	Patients With Coronary Artery Bypass Graft (n=2298)	Patients With Pneumonia (n=7208)
Notes and records					
Unadjusted	1.02 (0.93-1.13)	1.20 (1.00-1.44)	1.34 (1.13-1.59)[c]	1.05 (0.90-1.21)	1.03 (0.92-1.16)
Adjusted[b]	1.01 (0.93-1.10)	1.05 (0.86-1.28)	1.35 (1.16-1.57)[c]	0.97 (0.83-1.14)	1.07 (0.93-1.23)
Test results					
Unadjusted	1.06 (1.03-1.10)[c]	1.03 (0.98-1.09)	1.08 (1.02-1.14)[c]	1.04 (0.99-1.10)	1.01 (0.94-1.07)
Adjusted[b]	0.99 (0.94-1.03)	0.92 (0.85-1.00)	1.00 (0.94-1.07)	0.97 (0.91-1.03)	0.96 (0.89-1.04)
Order entry					
Unadjusted	0.99 (0.93-1.06)	0.94 (0.75-1.18)	0.92 (0.85-1.01)	1.11 (0.87-1.41)	1.01 (0.98-1.04)
Adjusted[b]	0.97 (0.93-1.02)	1.01 (0.78-1.31)	0.95 (0.88-1.02)	1.17 (0.82-1.67)	1.03 (0.98-1.07)
Decision support					
Unadjusted	0.86 (0.79-0.95)[c]	0.62 (0.42-0.89)[c]	0.78 (0.60-1.02)	0.83 (0.64-1.09)	0.94 (0.76-1.15)
Adjusted[b]	0.84 (0.79-0.90)[c]	0.63 (0.45-0.87)[c]	0.82 (0.65-1.02)	0.80 (0.65-1.00)	0.91 (0.73-1.14)

[a] Data are given as the odds ratio for complication during hospitalization (95% confidence interval) associated with a 10-point increase in Clinical Information Technology Assessment Tool subdomain score.
[b] Adjusted for patient complication risk (risk-adjusted complication index) and hospital size (number of beds), total margin, and ownership.
[c] $P < .05$ with Bonferroni correction for 4 subdomains.

(**Table 5**). A 10-point increase in score for order entry and decision support was associated with decreased but not clinically meaningful LOS for heart failure (−0.09 and −0.22 days, respectively). In all cases, differences in LOS were modest in either direction.

SENSITIVITY ANALYSES

All adjusted and statistically significant associations in the primary analysis retained the direction of their association when the independent variable was categorized into tertiles, but fewer were statistically significant ($P < .05$ for 7 of 22 associations). As in the primary analysis, higher notes and records scores were associated with lower adjusted rates of mortality (1.9%, 1.6%, and 1.4% in the low, intermediate, and high tertiles, respectively; $P = .02$ for the trend); higher scores for decision support were associated with lower rates of complications (4.1%, 3.8%, and 3.5%, respectively; $P = .045$ for the trend); and higher scores for decision support were associated with lower median costs ($5067, $4966, and $4498, respectively; $P = .008$ for the trend). Similar trends were observed for the relationships between tests results and costs, order entry and costs, and order entry and LOS, which mirrored the primary analysis.

As a separate sensitivity analysis, we performed a Bonferroni correction to account for the investigation of the 4 automation subdomains. Most associations remained statistically significant at the adjusted significance level ($P < .0125$, the overall significance level of .05 divided by 4).

COMMENT

This study provides empirical evidence that greater automation of a hospital's information system may be associ-

Table 4. Hospital Automation Subdomain Scores and Patient Costs[a]

Automation Subdomain	All Patients (N=167 233)	Patients With Myocardial Infarction (n=4728)	Patients With Heart Failure (n=9697)	Patients With Coronary Artery Bypass Graft (n=2298)	Patients With Pneumonia (n=7208)
Notes and records					
Unadjusted	10 (−695 to 1152)	825 (−614 to 3373)	406 (−326 to 557)	1130 (−2035 to 7049)	−428 (−881 to 238)
Adjusted[b]	2 (−225 to 347)	222 (−209 to 923)	182 (−89 to 611)	577 (−66 to 1607)	22 (−189 to 341)
Test results					
Unadjusted	408 (135 to 759)[c]	922 (364 to 1694)[c]	425 (89 to 889)[c]	1386 (284 to 2893)[c]	119 (−129 to 452)
Adjusted[b]	−110 (−181 to −20)[d]	−266 (−406 to −64)[c]	−207 (−272 to −128)[c]	−250 (−487 to 95)	−90 (−175 to 20)
Order entry					
Unadjusted	132 (−205 to 557)	318 (−265 to 1076)	23 (−201 to 304)	1133 (−2155 to 5802)	159 (42 to 296)[c]
Adjusted[b]	−132 (−232 to −13)[d]	−42 (−95 to 24)	−142 (−183 to −92)[c]	124 (−564 to 1082)	−95 (−132 to −51)[c]
Decision support					
Unadjusted	−500 (−1415 to 810)	77 (−1710 to 2719)	−457 (−1318 to 783)	−3767 (−9426 to 6515)	68 (−714 to 1105)
Adjusted[b]	−538 (−704 to −333)[c]	−225 (−609 to 287)	−555 (−702 to −365)[c]	−1043 (−1729 to −55)[d]	−363 (−503 to −186)[c]

[a] Data are given as difference in mean hospital costs in dollars (95% confidence interval) associated with a 10-point increase in Clinical Information Technology Assessment Tool subdomain score.
[b] Adjusted for patient complication risk (risk-adjusted complication index), patient mortality risk (risk-adjusted mortality index), and hospital size (number of beds), total margin, and ownership.
[c] $P < .05$ with Bonferroni correction for 4 subdomains.
[d] $P < .05$, not Bonferroni corrected.

Table 5. Hospital Automation Subdomain Scores and Patient LOS[a]

Automation Subdomain	All Patients (N=167 233)	Patients With Myocardial Infarction (n=4728)	Patients With Heart Failure (n=9697)	Patients With Coronary Artery Bypass Graft (n=2298)	Patients With Pneumonia (n=7208)
Notes and records					
Unadjusted	−0.12 (−0.29 to 0.10)	0.18 (−0.06 to 0.50)	0.13 (−0.15 to 0.55)	0.28 (−0.31 to 1.19)	0.05 (−0.18 to 0.37)
Adjusted[b]	−0.01 (−0.10 to 0.11)	0.06 (−0.12 to 0.31)	0.14 (−0.01 to 0.34)	0.10 (−0.11 to 0.44)	0.13 (−0.01 to 0.32)
Test results					
Unadjusted	−0.03 (−0.11 to 0.06)	0.08 (−0.08 to 0.29)	−0.03 (−0.17 to 0.18)	0.22 (0.05 to 0.43)[c]	−0.07 (−0.17 to 0.06)
Adjusted[b]	−0.03 (−0.08 to 0.02)	0.02 (−0.07 to 0.14)	−0.02 (−0.09 to 0.07)	0.04 (−0.02 to 0.13)	0.03 (−0.05 to 0.14)
Order entry					
Unadjusted	−0.05 (−0.08 to −0.02)[c]	0.05 (0.00 to 0.11)	−0.20 (−0.24 to −0.15)[c]	0.38 (−0.36 to 1.30)	−0.20 (−0.26 to −0.12)[c]
Adjusted[b]	−0.05 (−0.06 to −0.04)[c]	0.05 (−0.01 to 0.13)	−0.09 (−0.11 to −0.06)[c]	0.20 (0.05 to 0.39)[c]	−0.10 (−0.18 to −0.05)[c]
Decision support					
Unadjusted	−0.08 (−0.28 to 0.14)	0.21 (−0.03 to 0.50)	−0.46 (−0.77 to −0.08)[c]	0.00 (−2.87 to 1.16)	−0.37 (−0.67 to 0.00)
Adjusted[b]	−0.07 (−0.17 to 0.04)	0.11 (−0.15 to 0.44)	−0.22 (−0.36 to −0.06)[c]	0.25 (−0.10 to 0.71)	−0.17 (−0.39 to 0.11)

Abbreviation: LOS, length of stay.
[a] Data are given as difference in mean hospital LOS in days (95% confidence interval) associated with a 10-point increase in Clinical Information Technology Assessment Tool subdomain score.
[b] Adjusted for patient complication risk (risk-adjusted complication index), patient mortality risk (risk-adjusted mortality index), and hospital size (number of beds), total margin, and ownership.
[c] $P < .05$ with Bonferroni correction for 4 subdomains.

ated with reductions in mortality, complications, and costs. Higher decision support scores were associated with statistically significant reductions in the odds of complications among all causes and for myocardial infarction specifically, and with reductions in the odds of death for pneumonia. Among the remaining associations that were not statistically significant, all showed trends toward reductions in mortality and complications. Prior reports have suggested that decision support helps health care providers manage large amounts of incoming data, provides context for decision making in light of guidelines, and may help physicians avoid "sins of omission," reputed by some authors to be the largest source of medical errors.[12-16] Knowledge aids provided in this fashion could reduce the risk of complications and possibly death, providing a theoretical basis for the association we observed.

Higher order entry scores were associated with reductions in the odds of death for myocardial infarction and coronary artery bypass graft surgery. Prior studies of order entry at single institutions have shown mixed results with respect to mortality[17,18]; nevertheless, salutary effects have been observed for other end points, including reductions in the number of adverse drug events, improved legibility of orders, and fewer callbacks to ordering physicians.[19] These factors may mediate the reductions in mortality odds we observe with order entry. Some have suggested that the use of information technologies in the clinical environment poses certain risks, noted as "e-iatrogenesis."[20] For example, previous studies have raised concerns that problems in information representation within computerized order entry systems could facilitate errors.[21,22] We found no relationship between the degree to which physicians' orders were computerized and the rate of complications.

Greater automation of test results was not associated with a lower risk of hospital death or complications. With respect to test results, it may be that a minimal level of automation is sufficient to protect patients. Given that a high proportion of hospitals have already automated test results, this minimal level is likely in place for most institutions. Advanced automated test result features, such as user customization or better search and retrieval capabilities, could increase physician satisfaction but may have little effect on patient outcomes.

Our results suggest that the relationship between outcomes and automated notes and records is nuanced but internally consistent. Each 10-point increase in the notes and records score was associated with a 15% reduction in odds of inpatient death for all causes. Hospitals in the highest tertile of the notes and records subdomain score had a 1.4% adjusted rate of mortality, compared with a 1.9% adjusted rate among hospitals in the lowest tertile. This would suggest that for every 1000 patients, 5 fewer patients die at hospitals with the highest notes and records scores. Higher scores on the notes and record subdomain were also associated with reduced odds of death for each of the 4 individual conditions examined in the mortality analysis, although none were statistically significant. Smaller studies suggest that electronic documentation allows clinicians faster and more complete access to the patient record, improves communication among health care providers, and enhances the contributions of supervising physicians.[23] In contrast, increases in the notes and records score were associated with statistically significant increases in the odds of complications for heart failure. Although this may be of concern, another explanation might be that a higher complication rate simply reflects an improved capability to identify adverse events through electronic documentation. A similar mechanism may underlie the relationship between notes and records and costs. The remaining associations tested in the complication analyses retained the direction noted with heart failure, although no others were statistically significant.

Higher scores on test results, order entry, and decision support were overwhelmingly associated with lower hospital costs. Of the 15 associations tested in these categories, 14 demonstrated an inverse relationship between the information technology score and total costs and 10 of these were statistically significant. The associated reduction in costs for some conditions was substantial. Relationships are less clear with respect to LOS, and any effect is modest. Because LOS has decreased substantially during the last several decades, in part because of increased scrutiny by payers, this measure may already be so low as to be resistant to the efficiencies introduced by information technology.[24] However, hospitals for which we had responses had shorter LOS, on average, than did nonresponders. It is possible that for hospitals with longer LOS at baseline, the effect of clinical information technologies might be more profound.

This study has a number of strengths. Our approach incorporates what some have described as the sociotechnical environment of the clinical workplace. This view holds that a successful information technology implementation jointly optimizes the technology and the social aspects of an organization (eg, its policies, values, norms, and culture).[25] To properly account for the impact of clinical information technologies in a way that can be replicated, the information technology variable must be measured in the context of the sociotechnical environment in which it is implemented. This study measures a hospital's level of automation based on physicians' daily interaction with the information system, avoiding simple terminological definitions that may not account for usage, maturation, and capabilities of the information system. If there is insufficient user training, if the technology itself is unfriendly, or if the physician and organizational routines are not aligned with the technology, the information technology score for that hospital will be low, regardless of the cost or scope of the technologic acquisition. This study also includes more hospitals and hospitals of greater organizational variety than prior studies, overcoming criticisms that a small number of specific academic hospitals are overrepresented in examinations of clinical information technology.[3] Finally, our results are congruent with recent studies suggesting that the adoption of clinical information technologies remains low but follows certain patterns.[26,27] Our findings are consistent with these patterns, lending our methods, and measurement tool, an independent measure of validity. For example, the computerized display of laboratory results has been among the first aspects to be automated.[27] In the last decade, digitization of radiological images has also increased.[27] Both of these components fall under the test results subdomain, which in our study showed the greatest degree of adoption. Electronic decision support is perhaps the most challenging component to implement because it requires all other components first. Our results, in which scores for notes and records are higher than order entry and decision support, are consistent with this pattern of adoption.

Despite these strengths, this study has important limitations. First, the design does not consider a number of organizational confounders that could explain superior clinical outcomes, most notably a hospital's emphasis on safety and quality. We adjusted for structural variables that could be related to quality, including number of beds, total margin, and hospital ownership (in our sample, teaching status and number of beds were not associated with the independent variables). Hospitals that do not emphasize a culture of safety or encourage continuous improvement are probably incapable of replicating the type of sociotechnical environment that would produce a high score in this study. In this sense, the distinction between whether a hospital's superior outcomes are because of its emphasis on quality or its investment in clinical information technologies becomes less meaningful because both are likely required to produce a high-functioning sociotechnical environment. Future studies using mixed or qualitative methods at several representative sites may help clarify these relationships.

Second, our analysis explored a number of information technology functions, raising issues of multiple hypothesis testing and the possibility of some false-positive relationships. As with all cross-sectional studies, positive associations will need to be confirmed in repeated studies. Nevertheless, the consistency of our findings suggests that the observed patterns are real. These results may also indicate that, because disease conditions are unique, the factors resulting in better outcomes for these conditions are themselves unique. Indeed, the lack of statistical significance among certain associations may simply indicate that clinical information technology is not a panacea for all disease conditions. Third, it is important to recognize that the observed associations between improved outcomes and information technology subdomains can only be extrapolated for the observed range of CITAT scores in our sample. As we observed with test results, it is possible that at higher ranges of order entry and decision support, differences among hospital outcomes will diminish. Fourth, although we obtained a satisfactory response rate (58%), we experienced higher response rates among larger hospitals, academic hospitals, and hospitals with shorter LOS. This may limit the application of our findings.

Clinical information technologies hold great promise as a tool to improve hospital medicine. We found that, for certain conditions, greater automation of a hospital's information system may be associated with reductions in mortality, complications, and costs, suggesting that information technologies that are properly designed and executed around clinical workflows could meet that promise.

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REFERENCES

1. Institute of Medicine. *Crossing the Quality Chasm: a New Health System for the 21st Century*. Washington, DC: National Academy Press; 2001.
2. Bates DW, Gawande AA. Improving safety with information technology. *N Engl J Med*. 2003;348(25):2526-2534.
3. Chaudhry B, Wang J, Wu S, et al. Systematic review: impact of health information technology on quality, efficiency, and costs of medical care. *Ann Intern Med*. 2006;144(10):742-752.
4. Amarasingham R, Diener-West M, Weiner M, Lehmann H, Herbers JE, Powe NR. Clinical information technology capabilities in four US hospitals: testing a new structural performance measure. *Med Care*. 2006;44(3):216-224.
5. Amarasingham R, Pronovost PJ, Diener-West M, et al. Measuring clinical information technology in the ICU setting: application in a quality improvement collaborative. *J Am Med Inform Assoc*. 2007;14(3):288-294.
6. DesHarnais S, McMahon LF Jr, Wroblewski R. Measuring outcomes of hospital care using multiple risk-adjusted indexes. *Health Serv Res*. 1991;26(4):425-445.
7. DesHarnais SI, Forthman MT, Homa-Lowry JM, Wooster LD. Risk-adjusted quality outcome measures: indexes for benchmarking rates of mortality, complications, and readmissions. *Qual Manag Health Care*. 1997;5(2):80-87.
8. World Health Organization. *International Classification of Diseases, Ninth Revision (ICD-9)*. Geneva, Switzerland: World Health Organization; 1977.
9. Duan N. Smearing estimate: a nonparametric retransformation method. *J Am Stat Assoc*. 1983;78(383):605-610.
10. Wei LJ, Lin DY, Weissfeld L. Regression analysis of multivariate incomplete failure time data by modeling marginal distributions. *J Am Stat Assoc*. 1989;84(408):1065-1073.
11. Localio AR, Berlin JA, Ten Have TR, Kimmel SE. Adjustments for center in multicenter studies: an overview. *Ann Intern Med*. 2001;135(2):112-123.
12. Kaushal R, Shojania KG, Bates DW. Effects of computerized physician order entry and clinical decision support systems on medication safety: a systematic review. *Arch Intern Med*. 2003;163(12):1409-1416.
13. Wensing M, Wollersheim H, Grol R. Organizational interventions to implement improvements in patient care: a structured review of reviews. *Implement Sci*. 2006;1:2 http://www.implementationscience.com/content/1/1/2. Accessed November 24, 2008.
14. Hofer TP, Hayward RA. Are bad outcomes from questionable clinical decisions preventable medical errors? a case of cascade iatrogenesis. *Ann Intern Med*. 2002;137(5, pt 1):327-333.
15. Bates DW, Kuperman GJ, Wang S, et al. Ten commandments for effective clinical decision support: making the practice of evidence-based medicine a reality. *J Am Med Inform Assoc*. 2003;10(6):523-530.
16. Hayward RA, Asch SM, Hogan MM, Hofer TP, Kerr EA. Sins of omission: getting too little medical care may be the greatest threat to patient safety. *J Gen Intern Med*. 2005;20(8):686-691.
17. Del Beccaro MA, Jeffries HE, Eisenberg MA, Harry ED. Computerized provider order entry implementation: no association with increased mortality rates in an intensive care unit. *Pediatrics*. 2006;118(1):290-295.
18. Han YY, Carcillo JA, Venkataraman ST, et al. Unexpected increased mortality after implementation of a commercially sold computerized physician order entry system. *Pediatrics*. 2005;116(6):1506-1512.
19. Ash JS, Sittig DF, Dykstra RH, Guappone K, Carpenter JD, Seshadri V. Categorizing the unintended sociotechnical consequences of computerized provider order entry. *Int J Med Inform*. 2007;76(suppl 1):s21-s27.
20. Weiner JP, Kfuri T, Chan K, Fowles JB. "e-Iatrogenesis": the most critical unintended consequence of CPOE and other HIT. *J Am Med Inform Assoc*. 2007;14(3):387-389.
21. Koppel R, Metlay JP, Cohen A, et al. Role of computerized physician order entry systems in facilitating medication errors. *JAMA*. 2005;293(10):1197-1203.
22. Campbell EM, Sittig DF, Ash JS, Guappone KP, Dykstra RH. Types of unintended consequences related to computerized provider order entry. *J Am Med Inform Assoc*. 2006;13(5):547-556.
23. Embi PJ, Yackel TR, Logan JR, Bowen JL, Cooney TG, Gorman PN. Impacts of computerized physician documentation in a teaching hospital: perceptions of faculty and resident physicians. *J Am Med Inform Assoc*. 2004;11(4):300-309.
24. DeFrances CJ, Hall MJ. 2005 National Hospital Discharge Survey. *Adv Data*. 2007;385:1-19.
25. Wears RL, Berg M. Computer technology and clinical work: still waiting for Godot. *JAMA*. 2005;293(10):1261-1263.
26. Poon EG, Jha AK, Christino M, et al. Assessing the level of healthcare information technology adoption in the United States: a snapshot. *BMC Med Inform Decis Mak*. 2006;6:1 http://www.biomedcentral.com/1472-6947/6/1. Accessed November 24, 2008.
27. Ash JS, Bates DW. Factors and forces affecting EHR system adoption: report of a 2004 ACMI discussion. *J Am Med Inform Assoc*. 2005;12(1):8-12.