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Full Implementation of Computerized Physician Order Entry and Medication-Related Quality Outcomes: A Study of 3364 Hospitals

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Summary

This study compares quality of care measures for hospitals with fully implemented computerized physician order entry (CPOE) systems with hospitals that have not fully implemented such a system. Using a cross-sectional design, this study linked hospital quality data from the Centers for Medicare and Medicaid Services to the Health Information Management Systems Society Analytics database, which contains hospital CPOE adoption information. Performance on quality measures was assessed using univariate and multivariate methods. In all, 8% of hospitals have fully implemented CPOE systems; CPOE hospitals were more frequently larger, not-for-profit, and teaching hospitals. After controlling for confounders, CPOE hospitals outperformed comparison hospitals on 5 of 11 measures related to ordering medications and on 1 of 9 nonmedication-related quality measures. Using a large sample of hospitals, our study found significant positive associations between specific objective quality indicators and CPOE implementation.

Background

Since the release of several high-impact Institute of Medicine (IOM) reports on health care quality and safety, national attention has focused on improving the quality of care.(1,2)

Researchers and policy makers have touted health information technology (HIT) as a potential solution to improve care in the United States. (3–6) One particular HIT application, computerized physician order entry (CPOE) systems, has received much media and public attention following the decision by a large consortium of health care purchasers (i.e., the Leapfrog Group) to encourage CPOE adoption by hospitals as a means to improve care and reduce costs.(3)

The decision to encourage CPOE adoption was based on growing evidence suggesting that CPOE, along with clinical decision support systems, enhances patient safety and quality,(7–11) and positively affects health care quality indicators.(12,13) However, a large number of previous studies have been limited by a narrow focus on a single institution or a limited number of outcomes, rendering their generalizability suspect.(14–16) Further, the relative rarity of complete CPOE implementation by hospitals has made the use of traditional experimental methods (e.g., randomized control trials) difficult to apply across institutions. (17) Thus, the question remains: Is CPOE implementation associated with improved outcomes across a large nationally representative sample of hospitals?

In this study, we leverage a large observational data set of 3364 hospitals to assess the association of CPOE with quality of care. Doing so provides a complementary view to the smaller experimental studies that have examined a similar research question in a single institution. In the current study, we use well-accepted quality of care data collected by the Centers for Medicare and Medicaid Services (CMS). We hypothesized that hospitals with universal CPOE adoption would perform better using these objective quality measures. We further hypothesized that quality measures that assess medication administration (a common target process of CPOE) would be more closely associated with CPOE than other types of quality indicators.

METHODS

Study Design and Sample of Hospitals

We performed a cross-sectional study of US hospitals that participated in the CMS-led Hospital Quality Alliance (HQA) initiative. We linked data provided by CMS to information on CPOE implementation available from the 2004 Health Information Management Systems Society (HIMSS) Analytics database.

The HQA initiative, entitled “Improving Care through Information,” is a CMS-led project that aims to provide a national repository of normalized data on the quality of health care delivery in US hospitals. This national reporting effort endorses a set of 20 quality measures for 3 medical conditions (i.e., acute myocardial infarction [AMI], congestive heart failure, pneumonia). (8) Through this initiative, measures are reported concerning patients admitted through participating hospitals identified using local discharge codes in administrative data. The patient sampling strategy was developed by CMS and the Joint Commission to provide nationally representative data. Data submitted by 4628 hospitals to the HQA from July 2003 to June 2004 were available.

Data on CPOE implementation were derived from the 2004 HIMSS Analytics Database (derived from the Dorenfest IHDS+ Database; www.himssanalytics.com). It contains data from 3989 hospitals, excluding Veterans Administration hospitals, and includes detailed descriptions of hospital information system implementation, such as hardware and software installations as well as other organizational and strategic information technology information. This data set has been used extensively in a number of studies pertaining to technology diffusion and health services research. (18, 19)

Our study sample included all hospitals with data available on the performance measures and CPOE status. We used hospital Medicare ID codes to link the HQA and HIMSS data sets, and then manually checked the hospital names and addresses to confirm accurate linkage. Thus, our final study sample included 3364 hospitals (73% of all hospitals participating in HQA).

Performance Measures (Outcome Measures/Dependent Variables)

Our dependent variables include 20 quality measures developed by CMS. (20, 21) Each measure defined a set of “ideal candidates” or patients who need the clinical intervention and have no contraindications, an approach proposed by Ellerbeck et al (20) for Medicare patients. These measures have been published on the CMS Web site (www.hospitalcompare.hhs.gov). (22, 23) We calculated the performance measures at the hospital level from the HQA data set. Each performance measure represents the ratio of the number of patients who received the intervention to the number for whom the intervention was deemed appropriate (i.e., aspirin at arrival = the proportion of all AMI patients without aspirin contraindications who received aspirin within 24 hours before or after hospital arrival). Eligible patients were identified using International Classification of Diseases, Ninth Revision, Clinical Modification (ICD-9-CM) codes for AMI, heart failure, and pneumonia. Data were collected at each hospital using the CMS Abstraction and Reporting Tool (CART). Hospitals use the CART to submit data to the quality improvement organization’s clinical data warehouse. A random sample of charts was double-abstracted to confirm data quality. (8)

CPOE Implementation and Hospital Characteristics (Independent Variable)

Our independent variable was a binary measure identifying CPOE hospitals as those that reported entering all orders via CPOE on the HIMSS Analytics survey. We used a conservative approach to define our independent variable by considering only those hospitals with “universal” CPOE implementation as having a complete CPOE system. Previous research suggests that hospitals reporting partial implementation may over report, as some facilities misunderstand the definition of CPOE. (24,25) Furthermore, given the nature of the data, partial implementation of CPOE is too imprecise and may represent varying degrees of implementation. Thus, by selecting only complete CPOE implementation and leaving partial implementers in the comparison group, our definition of CPOE implementation yields a measure of greater specificity.

Hospital Covariates

Hospital characteristics were taken from the 2004 Hospital Cost and Information System (HCRIS) files maintained by CMS. The covariates of interest included hospital ownership, teaching status, and bed size. Hospital ownership and teaching status have been shown to affect certain quality indicators. (26, 27) Three categories of hospital ownership were defined: not-for-profit (defined as all nongovernment institutions), for-profit (those with individual, partnership, or corporate structures), and government hospitals (those with city, county, or state affiliations). Teaching hospitals were defined as hospitals with federally supported medical residency training programs. Statistical Analysis

We first compared the organizational characteristics of hospitals with CPOE systems and comparison hospitals using χ^2 tests. To assess the representativeness of our subsample, we also compared the characteristics of hospitals and results of performance measures in our study sample to those in the HQA without CPOE data available for linkage.

The 20 quality measures were divided into medication-related (11 indicators) and nonmedication-related measures (9 indicators). For each set of measures, we assessed whether CPOE hospitals had better performance. We first analyzed the difference in mean performance for each quality measure, comparing CPOE hospitals with other hospitals using independent sample t tests.

For each measure, we developed a multivariate linear regression model to assess the association of CPOE and quality measure performance. We conducted a series of analyses introducing each hospital covariate into the model and testing for model fit, interactions, and collinearity. All statistical analyses were executed using SPSS (SPSS Inc, Chicago, IL) and STATA (StataCorp LP, College Station, TX).

RESULTS

Among the 3364 hospitals in our data set, 264 (7.8%) reported universal CPOE adoption. When evaluated against comparison hospitals, a higher proportion of CPOE hospitals were not-for-profit (79% vs 66%; $P < .001$), and a smaller proportion were for-profit hospitals (4% vs 21%; $P < .001$). CPOE hospitals were more frequently teaching hospitals (59% vs 33%; $P < .001$), and were more frequently larger in terms of bed size (25% were more than 300 beds vs 12% of comparison hospitals; Table 1).

Comparing the 3364 hospitals with CPOE status data available with the other 1264 hospitals in the HQA representative sample that did not have available CPOE data, we observed some notable differences in hospital characteristics. Hospitals within our sample were more frequently not-for-profit (66.5% vs 47.4%) and more likely to be teaching hospitals (31.6% vs 3.1%), $\chi^2 P < .001$ for both. In addition, in univariate analyses, hospitals in our study sample outperformed the other hospitals without CPOE status data in 15 of the 20 performance measures (Table 2).

Quality Measure Performance

Among the 11 medication-related measures, the mean performance on 6 cardiovascular-related measures was higher among CPOE hospitals versus the comparison hospitals (Table 3). Also, for one pneumonia measure, administering “Antibiotics within 4 hours of arrival for patients with pneumonia,” performance was lower for hospitals with full CPOE implementation. For nonmedication-related measures, CPOE hospitals performed better than comparison hospitals in 3 measures, including “Left Ventricular Assessment” for heart failure patients, “Smoking Cessation” for patients diagnosed with AMI, and “Oxygenation Assessment” for patients with pneumonia.

To assess the independence of these associations, we adjusted for other hospital characteristics known to be associated with quality measures. Teaching hospital status was significantly associated with hospital ownership and number of beds. We also noted interactions with teaching status and the other covariates in models for 5 of the 20 measures. Because of the issues of collinearity and interactions, we present 2 adjusted models, model A (adjusted for teaching status), and model B (adjusted for ownership and number of hospital beds) in Table 4. Each cell represents the Beta (B) coefficient of the main association of CPOE status and the dependent variable from a separate multivariate linear regression model, adjusted as described. After adjusting for teaching status (see model A column), CPOE hospitals were again associated with higher performance on 6 of the 7 cardiovascular medication-related measures as they were in the univariate analysis. Results were similar when adjusting for ownership and number of beds (see model B column), but 1 measure, “Angiotensin-Converting Enzyme (ACE) Inhibitor for LVSD (Heart Failure),” was no longer significant.

Consistent with the univariate analysis, only 1 nonmedication-related measure, “Left Ventricular Assessment (Heart Failure),” was significantly associated with being a CPOE hospital (Table 4). After adjustment, CPOE hospitals did not outperform comparison hospitals in the “Discharge Instructions (Heart Failure)” and “Antibiotic within 4 hours of arrival (Pneumonia)” measures.

DISCUSSION

Interest in CPOE as a method to improve quality of care in hospitals is mounting. Research evidence suggests that, when properly installed, CPOE systems can improve the medication ordering process and result in fewer errors. (28–32) However, despite a growing number of articles examining the effects of CPOE, many studies have been confined to a select number of academic institutions whose decades-long commitment to IT and unique operating environments may not be generalizable to the typical US hospital.(15,17) The current study was conducted to supplement the existing literature by observing whether complete CPOE adoption in a large sample of hospitals was associated with desirable outcomes.

Our main finding suggests that hospitals that enter all orders via a CPOE system tend to outperform their counterparts on a set of objective medication-related outcomes measures. CPOE is designed to streamline medication ordering by standardizing the process, introducing controls, eliminating bad handwriting, making an order easily traceable to a

provider; additionally, with decision support installed, CPOE can also help assure adherence to evidence-based guidelines. (33–35) Thus, our study observed better rates in such quality indicators as aspirin at arrival and discharge for AMI patients, and *B*-blockers at arrival and discharge for AMI patients, which suggests that CPOE may play an important role in improving care for processes that such a system is specifically designed to target.

Given our observational findings, a skeptical interpretation may suggest that hospitals that have advanced CPOE installations may also possess other unmeasured characteristics (e.g., effective leadership, other existing efforts that promote quality) that can relate to both our independent and dependent variables. However, our empirical findings refute this hypothesis because hospitals with complete CPOE implementations did not systematically outperform the comparison group on other more general quality of care measures. In fact, complete CPOE implementation was significantly associated with only 2 of 9 “general” (e.g., nonmedication-related) quality measures, one of which was in an undesirable direction.

Although our general findings support previously published studies, our data also showed different results. Single institution studies show that CPOE positively affected the timeliness of ordering medical interventions such as medication administration. (36, 37) In our study, CPOE did not consistently influence measures of timing for certain clinical services. For example, one measure, “Antibiotics within 4 hours” for pneumonia, was negatively associated with CPOE implementation. This measure depends on the efficiency of organizational processes to address urgent conditions such as in emergency departments (EDs); hence, the effect may not be attributable to CPOE but to other factors in the ED. For instance, order entry systems in the ED are designed differently than the traditional CPOE systems deployed for inpatient settings, where direct order communication to the pharmacy almost certainly has a major impact on medication turnaround time; in the ED, many other issues are at play. (38–40) Overcrowding in the ED is another potential contributor particularly because many hospitals with CPOE may be teaching facilities that frequently suffer from ED over-crowding. (41) In addition, although there is general agreement that the measures used in the study are clinically useful, recent data suggest that some of the current measure specifications, such as the “Antibiotic within 4 hours” for pneumonia, are debatable markers for quality care in the clinical setting. (42) For instance, Fee and Weber (43) found that this measure may have inherent flaws in its current design (i.e., inclusion criteria, denominator), citing that some of the clinical presentation of patients with pneumonia are not obvious enough (i.e., atypical, subclinical) to be detected at the time of admission to the ED, resulting in an impractical performance goal that can lead to antibiotic over-use. The lack of specificity of the measure definition may be another reason why our study did not find any difference among hospitals of interest.

Despite the new contributions of our study, we acknowledge several limitations. First, the cross-sectional nature of our study does not lend itself to detecting causality. The reported quality measures used in the study were not specifically designed to measure performance of HIT implementation. It is possible that institutions with high-performing manual processes can still excel in the given quality measures. Although not available to the study, a detailed assessment of the system’s level of clinical decision support (i.e., presence of drug-to-drug, drug-to-health condition, logic or algorithms) would be a distinctive measure of CPOE

functionality. As pointed out by Chaudhry et al, (15) the gold standard randomized trial cannot be easily applied to studies examining a large number of institutions. Instead, our findings are observational and should be interpreted as associations. Second, inherent to most studies relying on secondary data, we recognize that the accuracy of self-reported measures such as CPOE adoption may be suboptimal. To address this, we used a conservative approach when identifying CPOE hospitals as described above. Next, although widely accepted, the CMS developed quality measures used in the current study have known limitations. As process indicators, the measures we utilized may not perfectly predict patient outcomes. (44) We also acknowledge that some of the quality measures as currently designed are not without flaws and must be further refined to meet the intended goals. (45, 46) Moreover, the indicators are calculated by CMS using data from hospital chart abstractions submitted to them. The reliability of chart abstractions may be sensitive to the methodology used to generate this data and may not be consistent across hospitals. Lastly, we recognize that selecting the correct and available covariates to adjust for in our statistical analyses can be challenging. Often, given the multicollinear nature of many hospital variables (i.e., teaching hospitals are almost always urban, large, not-for-profit hospitals with higher nurse-to-bed ratios), it is difficult to specify a model that does not potentially violate some of the assumptions of linear statistical analysis.

In conclusion, we believe our analysis provides a real-world look at CPOE installations. The 264 hospitals in our data set with complete installations are likely to have widely differing CPOE systems, representing various vendors, and with differing levels of deployed clinical decision support. Despite this assortment of CPOE system types, we were able to observe a general association for several medication-related quality measures. This analysis provides additional support to existing single-institution and experimental studies demonstrating the link between CPOE and improved outcomes.

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Table 1

Characteristics of Hospitals With Complete Computerized Physician Order Entry (CPOE) Adoption and Comparison Hospitals

	Comparison Hospitals		CPOE Hospitals ^a		Pearson χ^2 , <i>P</i>
	n/Total N ^b	Percentage	n/Total N ^b	Percentage	
Ownership					<.001
Not-for-profit	1844/2871	66.30%	193/243	79.40%	
For-profit	571/2871	20.50%	10/243	4.10%	
Government	366/2871	13.20%	43/243	16.50%	
Teaching					<.001
No	1840/2760	66.70%	100/244	41.00%	
Yes	920/2760	33.30%	144/244	59.00%	
No. of beds					<.001
<100	1060/2812	37.70%	66/250	26.40%	
100–199	959/2812	34.10%	72/250	28.80%	
200–299	458/2812	16.30%	50/250	20.00%	
300–399	191/2812	6.80%	28/250	11.20%	
400+	144/2812	5.10%	34/250	13.60%	

^aCPOE hospitals are those that enter *all* orders through the computerized physician order entry system.

^bTotal N varies slightly due to missing values (<10% for all).

Comparing Performance of HSAG Hospitals That Were Not in Study Sample^a and Those Found in the Study

Table 2

	HSAG Hospitals Not Present in HIMSS Analytics			HSAG Hospitals Present in HIMSS Analytics			P
	N	Mean (%)	SD (%)	N	Mean (%)	SD (%)	
Indicators related to medication orders							
Aspirin at arrival (AMI)	400	87	19	2305	92	9	<.001
Discharge aspirin (AMI)	378	78	25	2294	88	14	<.001
ACE inhibitor for LVSD (AMI)	267	71	33	2112	75	22	.023
"-Blockers at discharge (AMI)	383	76	28	2291	86	15	<.001
"-Blockers at arrival (AMI)	396	76	25	2300	86	14	<.001
Thrombolytic agent within 30 minutes of arrival (AMI)	100	29	36	601	33	32	.225
ACE inhibitor for LVSD (HF)	546	70	27	2492	74	17	<.001
Antibiotic within 4 hours of arrival (PNE)	669	77	17	2573	72	13	<.001
Appropriate antibiotic selection (PNE)	480	68	24	1404	74	24	<.001
Pneumococcal vaccination (PNE)	661	41	29	2573	44	25	.023
Influenza vaccination (PNE)	454	41	33	1270	43	36	.153
Other indicators							
PCI within 120 minutes of arrival (AMI)	17	30	28	510	32	27	.734
Smoking cessation (AMI)	231	58	40	1977	70	29	<.001
Discharge instructions (HF)	610	29	29	2416	42	28	<.001
Left ventricular assessment (HF)	619	61	27	2542	80	17	<.001
Smoking cessation (HF)	528	47	35	2349	61	27	<.001
Blood culture within 24 hours of arrival (PNE)	489	55	26	1417	67	26	<.001
PNE: blood culture before antibiotic (PNE)	644	78	18	2455	81	11	<.001
Smoking cessation (PNE)	611	47	31	2432	56	26	<.001
Oxygenation assessment (PNE)	676	80	122	2580	74	53	.038

Abbreviations: HSAG, Health Services Advisory Group; HIMSS, Health Information Management Systems Society; AMI, acute myocardial infarction; ACE, angiotensin-converting enzyme; LVSD, left ventricular systolic dysfunction; HF, heart failure; PNE, pneumonia; SD, standard deviation.

^a HSAG hospitals not reporting to HIMSS analytics.

Differences in Mean Performance on Quality Indicators for Acute Myocardial Infarction (AMI), Heart Failure (HF), and Pneumonia (PNE) by Complete Computerized Physician Order Entry (CPOE) Status

Quality Indicators	Comparison Hospitals				CPOE Hospitals ^a	
	N = 3100 ^b	Mean Performance ^c (SD), %	N = 264 ^b	Mean Performance ^c (SD), %	t Test	P
Indicators related to medication orders						
Aspirin at arrival (AMI)	2829	91 (13)	250	94 (9)	-4.54	<.001
Discharge aspirin (AMI)	2767	86 (18)	250	92 (12)	-7.05	<.001
ACE inhibitor for LVSD (AMI)	2419	74 (23)	250	80 (20)	-4.17	<.001
%-Blockers at discharge (AMI)	2780	84 (19)	249	91 (11)	-8.57	<.001
%-Blockers at arrival (AMI)	2814	84 (17)	251	89 (13)	-5.77	<.001
Thrombolytic agent within 30 minutes of arrival (AMI)	778	32 (33)	78	38 (33)	-1.47	.141
ACE inhibitor for LVSD (HF)	2847	73 (18)	254	77 (15)	-3.92	<.001
Antibiotic within 4 hours of arrival (PNE)	2974	72 (14)	257	68 (14)	4.39	<.001
Appropriate antibiotic selection (PNE)	1812	74 (27)	125	74 (25)	0.15	.880
Pneumococcal vaccination (PNE)	2956	41 (26)	256	41 (26)	-0.41	.684
Influenza vaccination (PNE)	1535	42 (37)	112	43 (34)	-0.38	.701
Other indicators						
PCI within 120 minutes of arrival (AMI)	597	32 (27)	73	33 (23)	-0.44	.660
Smoking cessation (AMI)	2315	68 (32)	225	72 (28)	-1.99	.047
Discharge instructions (HF)	2921	39 (29)	253	38 (27)	0.633	.527
Left ventricular assessment (HF)	2927	78 (20)	256	86 (13)	-8.87	<.001
Smoking cessation (HF)	2718	59 (28)	252	60 (25)	-0.47	.636
Blood culture within 24 hours of arrival (PNE)	1862	66 (29)	130	70 (25)	-1.56	.121
PNE: blood culture before antibiotic (PNE)	2900	81 (12)	252	80 (10)	0.95	.341
Smoking cessation (PNE)	2837	55 (27)	253	54 (27)	0.34	.736
Oxygenation assessment (PNE)	2977	98 (6)	257	99 (5)	-2.09	.038

^aCPOE hospitals are those that enter *all* orders through the computerized physician order entry system.

$b_{\text{Total N}}$ varies due to some missing values.

c, Mean performance _ mean proportion of appropriate patients with documentation of receipt of each service.

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Table 4

Association of Computerized Physician Order Entry (CPOE) Hospitals on Performance Using Objective Quality Indicators, Multivariate Linear Regression Analyses

Quality Indicators	Model A: Adjusted for Teaching Status		Model B: Adjusted for Ownership and Number of Beds	
	B ^a (95% CI)	P	B ^b (95% CI)	P
Indicators related to medication orders				
Aspirin at arrival (AMI)	0.017 (0.002, 0.032)	0.023	0.019 (0.006, 0.032)	.004
Discharge aspirin (AMI)	0.036 (0.014, 0.058)	0.002	0.039 (0.019, 0.059)	<.001
ACE inhibitor for LVSD (AMI)	0.042 (0.010, 0.075)	0.011	0.036 (0.002, 0.071)	.039
"-Blockers at Discharge (AMI)	0.042 (0.019, 0.065)	< 0.001	0.031 (0.009, 0.053)	.005
"-Blockers at Arrival (AMI)	0.013 (0.009, 0.052)	< 0.001	0.021 (0.001, 0.040)	.036
Thrombolytic agent within 30 minutes of arrival (AMI)	0.074 (−0.002, 0.151)	0.057	0.017 (−0.081, 0.115)	.738
ACE inhibitor for LVSD (HF)	0.026 (0.003, 0.048)	0.025	0.024 (−0.0005, 0.048)	.055
Antibiotic within 4 hours of arrival (PNE)	−0.018 (−0.034, −0.002)	0.025	−0.028 (−0.045, −0.011)	.001
Appropriate antibiotic selection (PNE)	0.013 (−0.037, 0.063)	0.617	0.019 (−0.070, 0.033)	.479
Pneumococcal vaccination (PNE)	0.015 (−0.018, 0.049)	0.370	0.003 (−0.033, 0.039)	.877
Influenza vaccination (PNE)	0.012 (−0.060, 0.084)	0.743	0.008 (−0.070, 0.087)	.837
Other indicators				
PCI within 120 minutes of arrival (AMI)	0.018 (−0.048, 0.083)	0.596	0.023 (−0.056, 0.102)	.564
Smoking cessation (AMI)	0.020 (−0.023, 0.063)	0.357	0.022 (−0.018, 0.066)	.270
Discharge instructions (HF)	−0.028 (−0.065, 0.009)	0.139	−0.042 (−0.082, 0.001)	.044
Left ventricular assessment (HF)	0.043 (0.022, 0.064)	< 0.001	0.038 (0.017, 0.059)	<.001
Smoking cessation (HF)	−0.002 (−0.038, 0.034)	0.908	0.012 (−0.027, 0.052)	.538
Blood culture within 24 hours of arrival (PNE)	0.020 (−0.033, 0.072)	0.459	−0.009 (−0.063, 0.045)	.739
PNE: blood culture before antibiotic (PNE)	−0.008 (−0.022, 0.005)	0.231	−0.011 (−0.025, 0.004)	.144
Smoking cessation (PNE)	−0.003 (−0.038, 0.032)	0.854	−0.004 (−0.043, 0.034)	.820
Oxygenation assessment (PNE)	0.004 (−0.002, 0.009)	0.211	0.002 (−0.005, 0.008)	.599

Abbreviations: AMI, acute myocardial infarction; ACE, angiotensin-converting enzyme; LVSD, left ventricular systolic dysfunction; HF, heart failure; PNE, pneumonia; PCI, percutaneous coronary intervention; CI: confidence interval.

^aModel A: each Beta (B) coefficient is from a separate linear regression model adjusted for teaching status and represents the association of the main independent variable (CPOE) with the continuous outcome measure at the left.

Model B: each Beta (β) coefficient is from a separate linear regression model adjusted for ownership and number of beds, and represents the association of the main independent variable (CPOE) with the continuous outcome measure at the left.

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