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Decrease in Hospital-wide Mortality Rate After Implementation of a Commercially Sold Computerized Physician Order Entry System

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Decrease in Hospital-wide Mortality Rate After Implementation of a Commercially Sold Computerized Physician Order Entry System

WHAT'S KNOWN ON THIS SUBJECT: Despite widespread enthusiasm for CPOE as a tool to help transform quality and patient safety, no published study results to date have associated CPOE implementation with significant reductions in hospital-wide mortality rates.

WHAT THIS STUDY ADDS: Implementation of a locally modified, commercially sold CPOE system was associated with a statistically significant reduction in the hospital-wide mortality rate at a quaternary care academic children's hospital.

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KEY WORDS
safety, electronic records, mortality rates

ABBREVIATIONS
IOM—Institute of Medicine
EMR—electronic medical record
CPOE—computerized physician order entry
ADE—adverse drug event
LPCH—Lucile Packard Children's Hospital
CMS—Centers for Medicare and Medicaid Services
PHIS—Pediatric Health Information System
O:E—observed-to-expected
ARIMA—autoregressive integrated moving average
RRT—rapid-response team
CI—confidence interval

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abstract

BACKGROUND: Implementations of computerized physician order entry (CPOE) systems have previously been associated with either an increase or no change in hospital-wide mortality rates of inpatients. Despite widespread enthusiasm for CPOE as a tool to help transform quality and patient safety, no published studies to date have associated CPOE implementation with significant reductions in hospital-wide mortality rates.

OBJECTIVE: The objective of this study was to determine the effect on the hospital-wide mortality rate after implementation of CPOE at an academic children's hospital.

PATIENTS AND METHODS: We performed a cohort study with historical controls at a 303-bed, freestanding, quaternary care academic children's hospital. All nonobstetric inpatients admitted between January 1, 2001, and April 30, 2009, were included. A total of 80 063 patient discharges were evaluated before the intervention (before November 1, 2007), and 17 432 patient discharges were evaluated after the intervention (on or after November 1, 2007). On November 4, 2007, the hospital implemented locally modified functionality within a commercially sold electronic medical record to support CPOE and electronic nursing documentation.

RESULTS: After CPOE implementation, the mean monthly adjusted mortality rate decreased by 20% (1.008–0.716 deaths per 100 discharges per month unadjusted [95% confidence interval: 0.8%–40%]; $P = .03$). With observed versus expected mortality-rate estimates, these data suggest that our CPOE implementation could have resulted in 36 fewer deaths over the 18-month postimplementation time frame.

CONCLUSION: Implementation of a locally modified, commercially sold CPOE system was associated with a statistically significant reduction in the hospital-wide mortality rate at a quaternary care academic children's hospital. *Pediatrics* 2010;126:14–21

After the Institute of Medicine (IOM) published the landmark reports *To Err Is Human*[1] and *Crossing the Quality Chasm*,[2] many pediatric hospitals embarked on multiyear electronic medical record (EMR) implementations in an effort to enhance patient safety and quality of care.[3] This rush to adopt EMRs was further accelerated by the Leapfrog Group, which promotes computerized physician order entry (CPOE) as a tool to enhance patient safety.[4] Early literature supported these recommendations, including evidence that comprehensive EMRs with CPOE can decrease medication errors and adverse drug events (ADEs),[5,6] improve nursing documentation efficiency,[7] and improve laboratory, radiology, and medication turnaround times.[8,9] As a result of the safety, quality, and efficiency promises of CPOE, 28% of US hospitals have implemented CPOE for medications on at least 1 patient care unit.[10]

In 2005, serious questions were raised about the legitimacy of the EMR-enabled quality-improvement promise when Han et al[11] concluded that the rapid implementation of a minimally modified, commercially available CPOE system in a pediatric critical care unit was associated with an increase in mortality rate for children admitted via interfacility transport over a 5-month period. Medical informaticists and health policy researchers responded immediately to this report with both concern and cautious optimism.[12–15] Several groups subsequently published study results that showed that similar CPOE implementations in their own hospitals were not associated with an increase in mortality rates.[16,17] Many experts have since attempted to identify key differences associated with the conflicting outcomes, with most concluding that these findings highlight the importance of careful workflow redesign when implementing CPOE.[18,19] However, no published results from studies of either children or adults have shown reductions in hospital-wide mortality rates.[20] In this study our goal was to evaluate the effects of implementation of a locally modified commercial CPOE system on the hospital-wide mortality rate of pediatric inpatients at an academic children's hospital.

METHODS

Design/Setting/Patients

To determine the effect of CPOE implementation on the hospital-wide mortality rate, we conducted a cohort study using historical controls at the main campus of the Lucile Packard Children's Hospital (LPCH) at Stanford University. The LPCH is presently a 303-bed quaternary care children's hospital; 225 nonobstetric beds are located on the main campus. At the time of EMR implementation, the LPCH had 271 beds, of which 193 nonobstetric beds were located at the main campus. The analysis reported here was reviewed and approved by the Stanford University School of Medicine's institutional review board.

Patients were included if they were admitted between January 1, 2001, and April 30, 2009. The preintervention period was between January 1, 2001, and October 31, 2007, and the postintervention period was between November 1, 2007, and April 30, 2009. The CPOE implementation occurred on November 4, 2007. All obstetric patients were excluded from analysis.

Intervention

In 2004, the LPCH embarked on a multiyear EMR-implementation effort. The first implementation stage was focused on replacement of preexisting functionality for results-viewing and nonmedication unit-clerk–based order entry provided by a legacy hospital information system with software from a commercial vendor (Cerner Corporation, Kansas City, MO). This foundational phase was activated September 11, 2005. The second phase, activated on November 4, 2007, was focused on achieving sustainable improvements in patient safety and quality, operational efficiency, regulatory compliance, and research capabilities through implementation of CPOE with clinical decision support and comprehensive nursing and support service documentation.

In the absence of evidence-based best practices to guide our activation approach, we developed an acuity-based activation strategy that included a rapid, "big-bang" activation for 90% of inpatient beds at the main campus on a single day (November 4, 2007). Units included in this activation were all nurseries, including the NICU, and all medical, surgical, and obstetric wards. Excluded were the PICU and the cardiovascular intensive care unit (CVICU). CPOE was activated in the PICU 10 months later (September 2008). As of April 30, 2009, the only inpatient unit at the main LPCH campus that had not implemented CPOE was the CVICU.

Main Outcome Measures

The primary outcome measure was the hospital-wide mortality rate excluding obstetrics. An eligible patient admission was defined as any admission during which a patient spent at least 1 day on 1 of the nonobstetric units at the LPCH. Case-mix index (CMI), based on the US Centers for Medicare and Medicaid Services (CMS) cost weights, was assessed monthly for the hospital (well-infant nursery and obstetric patients were excluded as defined in the CMS pediatric methodology) and compared before and after the intervention to determine if significant differences in severity of illness existed.[21] Observed-to-expected (O:E) mortality ratios were obtained from

the Pediatric Health Information System (PHIS), an administrative database that contains inpatient data from 42 not-for-profit tertiary care pediatric hospitals affiliated with the Child Health Corporation of America (Shawnee Mission, KS). In this database, the likelihood of mortality for each discharge is based on the assigned 3M all-patient refined diagnosis-related group (APR-DRG) and risk-of-mortality (ROM) level. The likelihood of mortality for a specific combination of APR-DRG and ROM is the national pediatric mortality rate calculated by the Thomson Reuters Corporation from its normative pediatric database of publicly available inpatient data. The values are assigned to each discharge in the PHIS and summed across a population of interest to determine the number of expected mortalities.[22]

Statistical Analysis

A quasi-experimental approach was used to assess the impact of the implementation of CPOE on mortality rate.[23,24] Because the mortality-rate outcomes are reported monthly, time-series modeling was performed to model the potential autocorrelations in time. Autoregressive integrated moving average (ARIMA) models with a 12-month seasonality effect were implemented, with the Akaike Information Criterion used for covariance model selection to avoid overparameterization of the time-series model while maintaining adequate fit. Normalized prediction errors from the full model were evaluated to ensure model accuracy. The estimated coefficient of the preintervention versus postintervention periods was interpreted as the impact of the intervention, expressed as the number of additional or decreased deaths per 100 discharges that have occurred per month since the date of implementation. Identical time-series methodology has also been used to evaluate the effect of a rapid-response team (RRT) (a multidisciplinary precode team available 24 hours/day for consultation within 15 minutes of a request) on the hospital-wide mortality rate at our own institution.[25] All models were adjusted for monthly case-mix index and for the RRT intervention that had previously been associated with a significant improvement in mortality rates.[21,25] Average O:E ratios from the LPCH and the PHIS database were analyzed by using a 2-sample *t* test and a paired *t* test when appropriate. SAS 9.1 statistical software (SAS Institute, Cary, NC) was used for statistical analysis.[26]

TABLE 1 Demographic Characteristics of Pre-EMR and Post-EMR Intervention Populations

Characteristic	Preintervention ($n = 80\,063$)	Postintervention ($n = 17\,432$)	*P*
Age, mean (SD) y[a]	3.2 (5.5)	3.5 (5.7)	<.001
Female, *n* (%)	37942 (47.4)	8362 (48.0)	.3432
Race/ethnicity, *n* (%)[b]			<.001
White, non-Hispanic	35577 (44.4)	6570 (37.7)	
White, Hispanic	17757 (22.2)	5748 (33.0)	
Black	2363 (3.0)	576 (3.3)	
Asian	12076 (15.1)	3492 (20.0)	
Native American	169 (0.2)	71 (0.4)	
Native Hawaiian/Pacific Islander	656 (0.8)	315 (1.8)	
Other	8021 (10.0)	657 (3.8)	
Unknown	3444 (4.3)	3 (0.02)	
Length of stay, mean (SD), d[a]	5.9 (12.2)	6.3 (14.0)	<.001
Case-mix index, mean (SD)[a,c]	1.74 (0.13)	1.89 (0.10)	<.001

The preintervention period was between January 1, 2001, and October 31, 2007, and the postintervention period was between November 1, 2007, and April 30, 2009.

[a] Two-sample *t* test assuming equal variances was used for age, length of stay, and case-mix index.

[b] The χ^2 test was used for race/ethnicity.

[c] CMI excludes obstetric and normal newborn populations.

RESULTS

There was no significant difference between pre-CPOE and post-CPOE populations on the basis of patient gender (47.4% females versus 48.0% females; $P = .34$) (Table 1). Statistically significant differences were noted for age (mean [SD]: 3.2 [5.5] vs 3.5 [5.7] years), severity of illness as represented by case-mix index (mean [SD]: 1.74 [0.13] vs 1.89 [0.10]), and race/ethnicity, with fewer individuals identified as white or of unknown ethnicity and more Hispanic and Asian individuals in the postintervention group. There was a significant increase in length of stay during the postimplementation period (mean [SD]: 5.9 [12.2] vs 6.3 [14.0] days; $P < .001$).

As a result of participation in the PHIS database, the LPCH was able to compare local O:E mortality ratios before and after the intervention and compare LPCH mortality ratios to those of the 41 other not-for-profit tertiary care pediatric hospitals affiliated with the Child Health Corporation of America that contribute data to PHIS. O:E ratios at the LPCH decreased significantly between the 82 months before and the 18 months after the intervention (0.89–0.45 [95% confidence interval (CI) for difference: 0.302–0.591]; $P < .001$). Preintervention O:E ratios were similar for the LPCH and PHIS (0.89 vs 0.90; $P = .90$). However, the postintervention LPCH O:E ratios were significantly lower than the postintervention PHIS O:E ratios (0.45 vs 0.72 [95% CI for difference: 0.144–0.397]; $P = .0003$).

Mean monthly unadjusted mortality rates before and after the intervention were 1.008 and 0.716 deaths per 100 discharges, respectively (Table 2). Results of a simple *t* test that used only 18 months of pre– and post–CPOE-implementation data indicated a significant decrease of 24.5% in house-

TABLE 2 Outcomes Before and After EMR Implementation

Outcome	Preintervention	Postintervention	*P*
No. of deaths	806	125	NA
No. of discharges	80063	17432	NA
Hospital-wide mortality rate per 100 discharges[a]	1.008	0.716	.03[b]

The preintervention period was between January 1, 2001, and October 31, 2007, and the postintervention period was between November 1, 2007, and April 30, 2009.

[a] Defined as the mean of the number of deaths per calendar month divided by the number of discharges per calendar month; excludes obstetric patients.

[b] ARIMA model intervention analysis, adjusting for case-mix index and RRT implementation on September 1, 2005.

TABLE 3 Parameter Estimates of the Impact of the EMR Implementation on Mortality Rate

Parameter[a]	Estimate (SE)	*P*
Intercept	0.87 (0.45)	.06
RRT intervention	−0.11 (0.06)	.08
EMR implementation	−0.20 (0.10)	.03
Case-mix index	0.10 (0.26)	.70

Autoregressive lags and seasonal autoregressive lags are not shown.

[a] ARIMA model parameter estimates.

wide mortality rate ($P = .04$). Evaluating mortality rates in just the units that went live during this time frame also revealed a significant decrease (1.09 vs 0.61; $P = .02$). By using a more appropriate time-series analysis of the whole study period, which allowed adjustment for the RRT intervention and severity of illness when using CMI, a significant decrease of 20% occurred after implementation of CPOE (95% CI: 0.8%–40.0%; $P = .03$) (Fig 1). The ARIMA (2,0,0)(1,0,0) model contained an intercept term, 2 autocorrelation terms, a yearly seasonal effect, and a significant step intervention that started in November 2007. Examination of model fit showed small, normalized prediction errors; all were <2.5 in magnitude. Results of predictor error autocorrelation, partial autocorrelation, and inverse autocorrelation were insignificant at all time lags, which indicates that the model prediction errors had no significant patterns that had not been modeled. The white-noise test indicated that no significant patterns in the model prediction errors existed, and stationarity of the prediction errors was observed by the unit root and seasonal root tests. There was no evidence of a linear trend before or after the intervention. Parameter estimates of the ARIMA intervention model are shown in Table 3. Given that previous studies that evaluated CPOE impacts on mortality rates focused on patients admitted to the PICU, we also stratified our crude mortality data by using the same criteria as Del Beccaro et al.[16] In this analysis, there was no statistically significant correlation between CPOE implementation and PICU mortality rates for either the November 2007 CPOE implementation in non-PICU areas (18 months pre [4.82] vs 10 months post [4.98] implementation; $P = .91$) or the September 2008 implementation in the PICU (28 months pre [4.88] vs 8 months post [3.77] implementation; $P = .40$).

The impact of the CPOE intervention, as evaluated by using statistical modeling, was a decrease of 0.204 (95% CI: 0.008–0.400) deaths per 100 discharges or 2.04 deaths per 1000 discharges. The average number of discharges per month in our hospital during the entire study period was 975. Therefore, during the 18-month postintervention period, our findings suggest, when using statistical modeling, that implementation of CPOE and

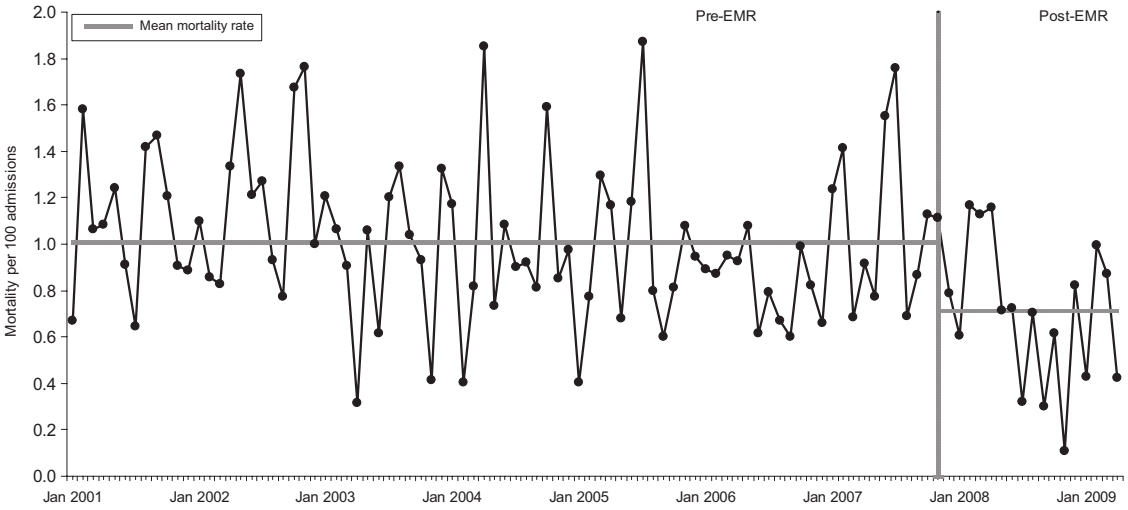

FIGURE 1
Hospital-wide mortality rate per 100 discharges according to month (excluding the obstetrical population). The pre-EMR period was between January 1, 2001, and October 31, 2007, and the postintervention period was between November 1, 2007, and April 30, 2009.

related documentation at the LPCH could have resulted in 36 fewer deaths on the basis of expected versus observed mortality.

DISCUSSION

To our knowledge, these are the first published study results to show significant reductions in hospital-wide mortality rate after implementation of CPOE. These data support the recommendations made by the IOM, the Leapfrog group, the US Department of Health and Human Services, and the National Coordinator for Health Information Technology to implement CPOE as a strategy for improving patient safety and quality of care at a national level.[1,2,4,27,28] These recommendations have not been without controversy, because they are expensive[10] and have been challenged as a result of limited published evidence supporting quality and safety-outcomes improvements.[29,30] Our results add important information to this debate by providing evidence that CPOE can have a significant impact in a relatively short time frame on hospital-wide mortality.

Multiple components of the EMR intervention could have contributed to the decrease in mortality rates witnessed at the LPCH. First, although we designed and deployed ~300 intranet-based standardized paper order sets to prepare for CPOE,[31] implementation of the EMR "hard-wired" these order sets, which made them easier to use and drove consistency in care.[32] Second, all patient care orders were standardized. Although many authors have touted the safety benefits of CPOE with clinical decision support on medication orders,[5,6,33] fewer researchers have investigated the effect of structuring information collection on patient care orders and how the resulting standardization may result in better communication with staff. Third, all orders, vital-sign documentation, and medication-administration data became remotely accessible in real time, which is a fundamental shift in basic care processes. Finally, introduction of CPOE eliminated the redundant transcription of medication orders by pharmacists, which improved accuracy and decreased turnaround times.[9] Indeed, in our solid-organ transplant unit and PICU, we found reductions of 19% and 5%, respectively, from stat medication order to administration. Because many authors[12,18,19] now point to vasoactive medication-administration delay as the most proximate cause of the mortality-rate increase described by Han et al, it seems highly plausible that such clinically tangible improvements in turnaround times could have the reverse effect. The manifestations of these EMR-enabled interventions include increased care standardization, enhanced communication, and increased access to more timely information at the point of care. All 3 of these outcomes have been identified by the Institute for Healthcare Improvement as critical for decreasing mortality rates,[34] and all 3 were cited as critical for promoting increased situational awareness and highly reliable patient care.[35,36]

Although the manifestations discussed above could conceivably affect mortality rates, no other groups have published a hospital-wide mortality-rate decrease similar to the one described here. The variation in CPOE outcomes has been hypothesized previously to be the direct result of the implementation process.[16,18] Similar to those who used an evidence-based approach to EMR-system selection,[37] we actively sought to undertake an evidence-based approach to EMR implementation by closely adhering to published guidelines for best-practice CPOE implementation.[38] We focused on achieving quality improvement by designing an outcomes dashboard informed by peer-reviewed scientific literature[9] and redesigning our care processes to help drive these desired benefits. At the same time, we actively worked to mitigate unintended consequences by considering evidence-based recommendations for recognizing and preventing these issues.[39–41] The successful implementation of CPOE, at least on the basis of our mortality-rate declines, lends credence to these recommendations.

Our study limitations are similar to those of other cohort studies that used historical controls. In particular, there are 3 relevant biases that could have affected the results. First, it is possible that the reduced mortality rate was simply the result of differences in the preintervention and postintervention populations and is independent of the CPOE intervention. We found no difference between control and intervention populations related to gender, and the case-mix index increased in the intervention population, which suggests that the intervention population was at higher risk for mortality than the control population. In addition, results of a comparison of preintervention and postintervention O:E mortality ratios using the PHIS severity-adjustment methods reflected a statistically significant decrease in mortality ratios. Both of these findings support the argument that decreasing severity of illness is not likely to be the reason for the decreased mortality rates in our study population. Although the large sample size resulted in small differences in age and race between the preintervention and postintervention populations, we do not think that these differences are clinically significant or likely to bias our main outcome measures. Emerging literature suggests that minority patients are at higher risk for poor outcomes during an inpatient stay than are non-Hispanic white

patients.[42] Furthermore, any theoretical age risk factors are adjusted for in the O:E mortality ratio where statistical significance remains. Thus, the slightly higher percentage of minority patients and the marginal increase in patient age are not likely to be the cause of the improved mortality rate.

Second, it is possible that there were 1 or more other interventions implemented contemporaneously that might have decreased house-wide mortality rates. Indeed, over the past 9 years at the LPCH we have implemented multiple interventions based on recommendations from the Institute for Healthcare Improvement, IOM, CMS, Agency for Healthcare Research and Quality, Joint Commission on Accreditation of Healthcare Organizations, and the Leapfrog Group. These interventions include catheter-associated bloodstream infection (CABSI) and surgical-site infection (SSI) reduction interventions, ADE-reduction interventions, hospitalist-program creation, and RRT implementation. Our infection-reduction efforts have been somewhat successful over the years; however, with the exception of the NICU setting, no significant decreases in CABSI or SSI rates have been witnessed (data not shown). Our ADE-reduction work has yielded outstandingly low rates of drug-related harm,[43,44] yet local and national data suggest that drug-related harm is a rare cause of mortality in the pediatric population[44]; thus, it is an unlikely cause of the mortality decreases we have witnessed. Our hospitalist program, initiated in 2003, is an important component of our quality-improvement program, yet our local data have shown no evidence of mortality-rate changes associated with the program's inception. It is important to note that the mortality-rate trends in our PICU suggest that our hospital-wide mortality-rate decrease was not a result of substantial changes in PICU mortality rates for the 10 months when other units had CPOE but the PICU did not. A nonsignificant decrease in mortality rate occurred in the 8 months after CPOE implementation in the PICU.

Finally, our RRT implementation was associated with a decreased mortality rate[25]; however, we adjusted for this intervention in our model and statistical significance remained. Although these other interventions remain a potential source of mortality-rate decline in combination, it would be an unlikely coincidence that they would have a profound effect on mortality rates at the exact time that the CPOE intervention was introduced. Also, results of a postintervention analysis of O:E ratios comparing the LPCH to 41 other children's hospitals in the PHIS database suggest that secular trends cannot explain the significant declines witnessed. We recognize that these data represent a single center's experience; therefore, the results cannot necessarily be generalized to other hospitals.

CONCLUSIONS

Implementation of a locally modified CPOE system in our freestanding, quaternary care academic children's hospital was associated with a statistically significant reduction in the hospital-wide mortality rate. This reduction cannot be explained by differences in patient characteristics or severity of illness between the control and postintervention population, nor can it be explained by secular trends or the implementation of other interventions known to be associated with mortality-rate reduction. On the basis of our findings, we estimate that 36 children's lives were saved in 18 months at the LPCH in association with the CPOE implementation. The potential implications of these findings on national mortality statistics in children are dramatic. Future research should focus on replicating these findings in other inpatient settings and populations and evaluating the cost-effectiveness of this intervention.

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Adult Primary Care Physicians Earn Millions Less Than Specialists: *Doctors who choose adult primary care fields can expect to earn $2.7 million less over their lifetime than those who choose a specialty field—according to a Duke University study reported in the* Triangle Business Journal *(Gallagher J, May 4, 2010). The study modeled lifetime income of not just MDs but also physician's assistants, MBAs and college graduates, factoring in years of schooling and work, student debt, income and investment income potential. Results showed that a cardiologist could potentially accumulate $5.2 million in lifetime wealth compared with only $2.5 million for physicians in family or internal medicine primary care. MBAs would amass $1.7 million, a physician's assistant $850 000, and a college graduate $340 000 over their lifetimes. According to the study published in* Health Affairs *(Vaughn B and De Vrieze S), cardiologists would need to take a $148 000 pay cut or primary care would need about a $122 000 pay increase to close the gap between these two different career pathways for physicians. Whether these numbers are as dramatic in pediatrics has yet to be studied.*

Noted by JFL, MD

Decrease in Hospital-wide Mortality Rate After Implementation of a Commercially Sold Computerized Physician Order Entry System

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