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14. ABSTRACT CPOE represents a major step in the transition of healthcare providers from a paper to an electronic process for submitting orders. This study examined the impact of the transition from paper order entry to CPOE on patient care by the adoption of CPOE by 100% of the medical staff in a large community hospital. Our results demonstrated significant improvements in the rate of medication order rejection as unfillable by pharmacy, the rate of order replacement by radiology, the occurrence and the management of drug interaction alerts, the turnaround time on medication orders, and the adoption of evidence- and consensus-based order sets. Because of the widely held belief that CPOE slows down clinical workflow for providers, we also examined the effect of CPOE implementation on provider order entry time. We found no significant impact on the time it takes providers to enter their orders using paper versus CPOE, although there was a trend toward an advantage to using CPOE when submitting larger numbers of orders in a given ordering session. We found trends toward improvement in catheter-related bloodstream infections, ventilator associated pneumonia, and methicillin resistant staph aureus infections. No significant change was identified in ICU length of stay or case mix adjusted cost per case across the transition. Importantly, immediately following CPOE implementation we observed a statistically significant decline in the mortality rate index over the next four consecutive quarters, representing a 19% decline in the index from 0.84 to 0.68. Much of this benefit is thought to be attributable to the embedding of meaningful decision support at the point of order entry. During a time when many healthcare institutions are considering CPOE implementation, it is hoped that the reporting of this objective process and outcomes data may be helpful in guiding decision making, resource allocation, and clinician adoption for the institutional transformation around this important element in information technology.					
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Introduction

Computerized Physician Order Entry (CPOE) is widely acknowledged to be an important element in the growing field of medical information technology and is thought to have the capacity to mitigate the rate of unsustainable growth in the cost of healthcare, while improving clinical process and quality outcomes. In theory, CPOE derives its capacity to positively impact these goals by incorporating best practice paradigms in the form of embedded clinical decision support at the point of order entry. CPOE is also expected to improve the clarity of physician orders and the speed of downstream order fulfillment. Despite these claims, conflicting reports have emerged questioning the effectiveness of CPOE in improving the quality and outcomes in patient care. Furthermore, adoption of CPOE has been challenging for many hospitals, owing to the complexity and cost of implementation as well as to substantial physician resistance.

This study reports the impact of CPOE implementation on a range of variables that included CPOE adoption, order clarity, patient medication ordering safety, workflow efficiencies, and quality outcomes. In April, 2008, Mission Hospital, a 730-bed community hospital with 673 physicians, implemented CPOE across its entire suite of inpatient services with adoption by 100% of the medical staff. This implementation was particularly significant because very few staff physicians are shielded by residents or other intermediary providers from the primary responsibility of order entry.

Statistical Analysis

For the analysis of physician order entry times, initial data sampling pre- and post-CPOE order entry were based on approximate process values for mean and standard deviation. Using a 95% confidence interval and a statistical power of 90%, the initial data collection required a minimum of 529 order entry observations. The sampling method was based on a convenience sample, but was also randomized to include multiple physicians, units, and various time periods throughout the day in order to minimize any potential bias.

Comparisons of other process indicators potentially impacted by the implementation of CPOE were also monitored for statistically significant change. A representative time period both before and after implementation were chosen to avoid any influence of pilot areas prior to implementation and to allow processes to normalize after CPOE implementation. When possible, samples were collected one year apart to avoid seasonal bias. Anderson-darling normality tests were performed on final data sets to validate the use of normal distribution rules for data comparisons. All statistical analysis was completed using Minitab 14. Comparisons were generally made using either a two sample T-test or a 2-Proportion test as

appropriate. All hypothesis tests were 2-sided comparisons with a 95% confidence interval ($\alpha = 0.05$).

1.1 Mortality Rate Index

The Mortality Rate Index was monitored for the four quarters immediately preceding the pilot introduction of CPOE and the first four consecutive quarters following system-wide CPOE implementation. **Figure 1.2** displays the results during these quarters, including two quarters that spanned the transition to CPOE.

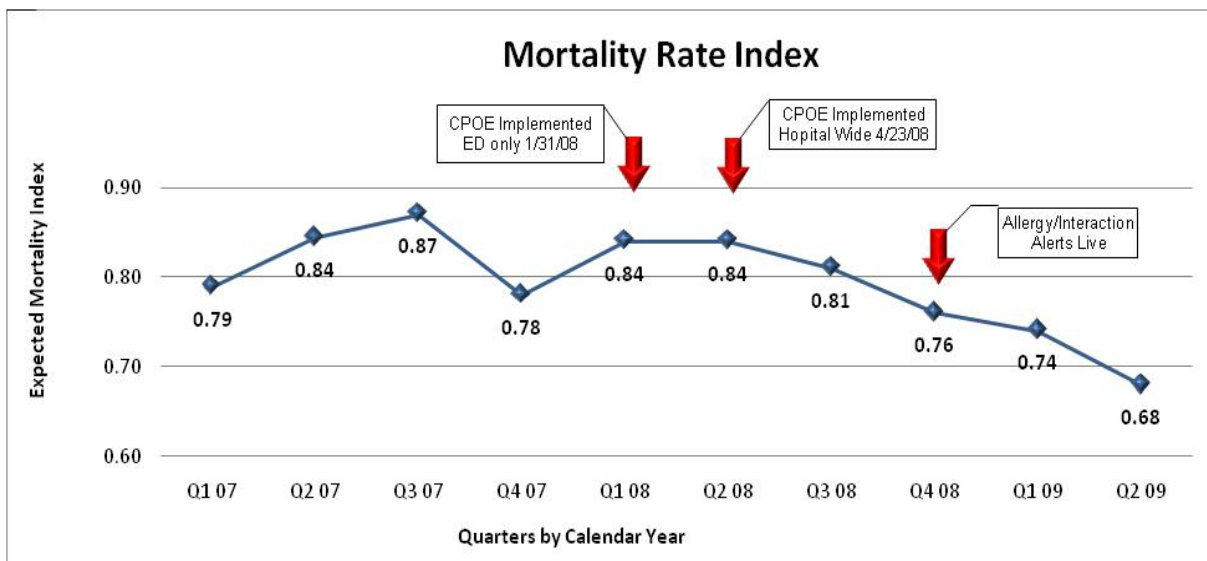


Figure 1.1

The Mortality Rate Index fell successively each quarter for the four quarters following the implementation of CPOE, reflecting a 19% reduction in mortality over the entire interval. This represents a statistically significant reduction in Mortality Rate Index following the implementation of CPOE ($p=0.035$).

1.2 Infection Rates

1.2a Catheter Related Bloodstream Infections (CLABSI)

The rate of CLABSI was monitored as part of the hospital's ongoing National Infection Surveillance reporting throughout the interval pre- and post-CPOE. **Figure 1.2a** depicts the results of this monitoring, including the timing of the Blood Stream Infection (BSI) Bundle Project, which was more likely to impact this outcome variable.

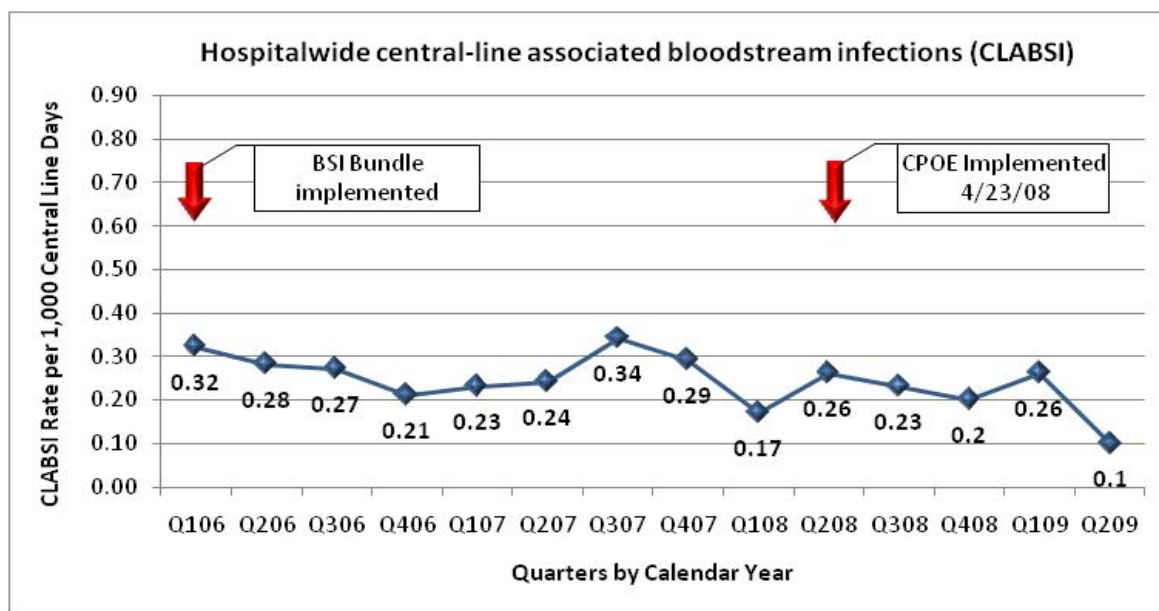


Figure 1.2a

No significant difference was observed in the CLABSI rate over this time interval ($p = 0.374$).

1.2b Ventilator Associated Pneumonia (VAP) Rate

The VAP rate was monitored as part of the hospital's ongoing National Infection Surveillance reporting throughout the interval pre- and post-CPOE. **Figure 1.2b** depicts the results of this monitoring, including the timing of the implementation of the VAP/Ventilator Bundle Project, which is considered likely to impact this outcome variable.

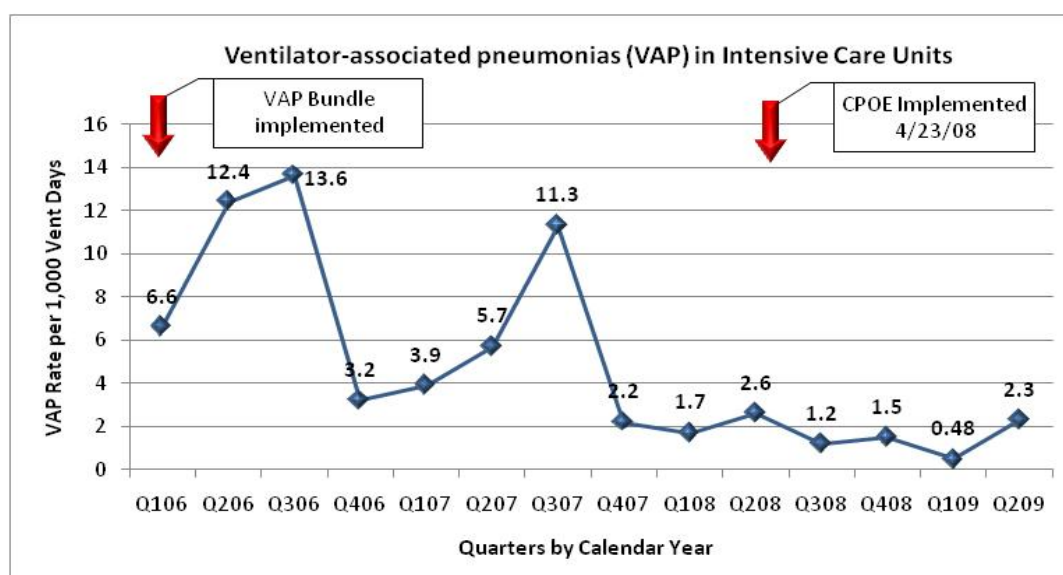


Figure 1.2b

As can be seen from **Figure 1.2b**, the VAP rate has trended downward from a mean of 5.775 pre-CPOE to a mean of 1.520 post-CPOE, but the decrease is not statistically significant ($p=0.128$). The decreasing trend in the VAP rate preceded CPOE implementation by more than six months. Improvement in the VAP rate appears temporally more related to implementation of the VAP/ Ventilator Bundle Project than to the CPOE implementation, which falls well after the observed decline in the VAP rate.

1.2c Methicillin Resistant Staphylococcus Aureus (MRSA) Infection Rate

The rate of MRSA infections was monitored as part of the hospital's ongoing National Infection Surveillance reporting throughout the interval pre- and post-CPOE. **Figure 1.2c** depicts the results of this monitoring, including the timing of the implementation of the MRSA Screening Project, which is considered likely to impact this outcome variable.

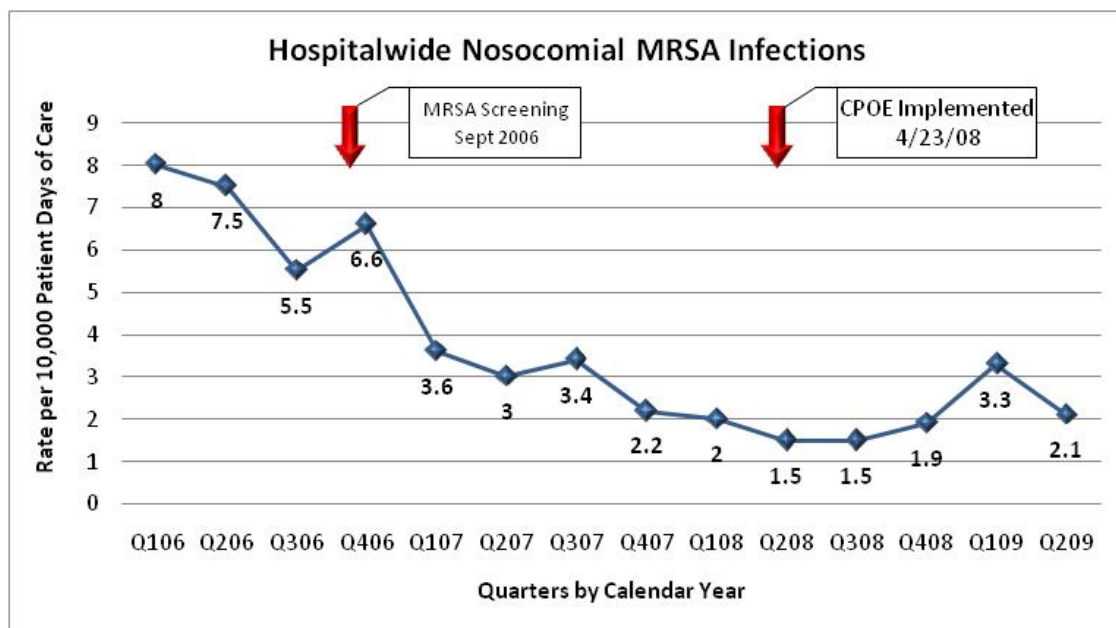


Figure 1.2c

As can be seen from **Figure 1.2c**, a downward trend was observed in the MRSA rate from a mean of 3.05 pre-CPOE to 2.20 post-CPOE, but the decrease is not statistically significant ($p=0.146$). As can be seen, the downward trend in the MRSA rate was ongoing during the two years prior to CPOE implementation, and coincided more closely with the implementation of an MRSA screening program.

1.3 ICU Average Length of Stay (ICU LOS)

ICU Average Length of Stay is monitored as an ongoing part of the hospital's Premier data reporting program. **Figure 1.3** depicts the results of this monitoring throughout the CPOE implementation.

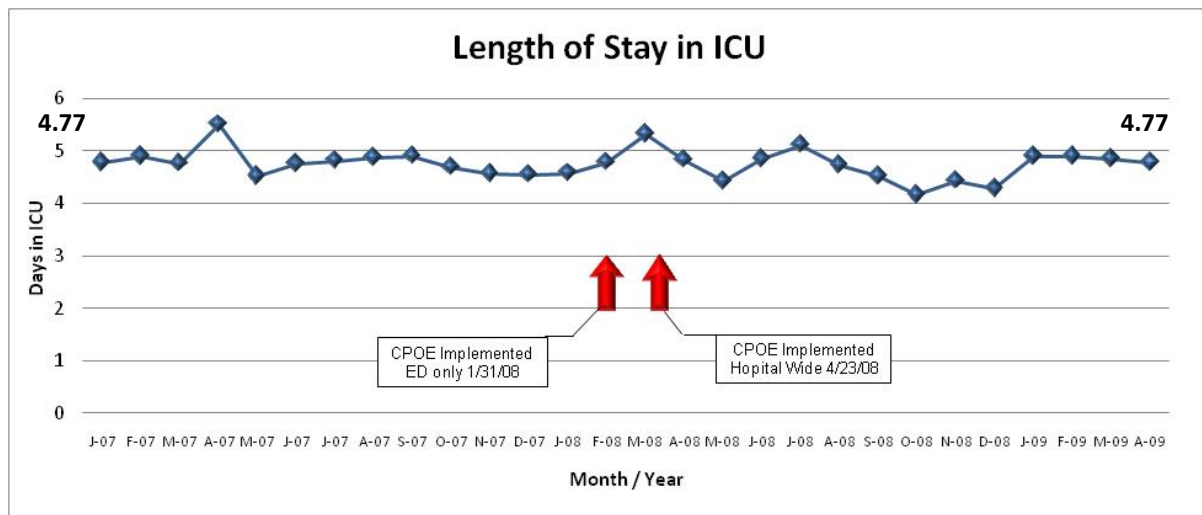


Figure 1.3

No statistically significant change in ICU LOS was observed throughout the period before and after CPOE implementation ($p=0.222$).

1.4 Costs per Case

Cost per Case is monitored as an ongoing part of the hospital's dashboard data reporting program and is measured using Operating Expenses/Case-Mix-Index (CMI) discharges. Cost is defined as the assignment of general ledger expenses to hospital services based on the Case Mix Index, reflecting the relative intensity of the service provided. For the purposes of this study, cost may be aggregated via the total cost. **Figure 1.4** depicts the results of this monitoring throughout the CPOE implementation.

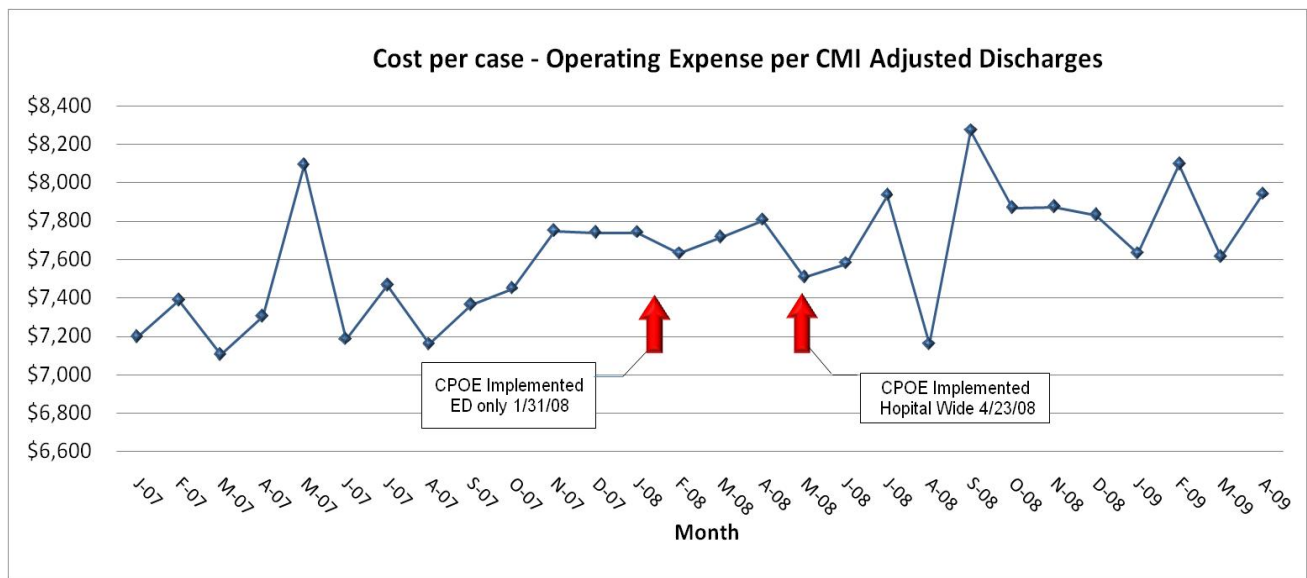


Figure 1.4

Although there may be a trend toward increasing cost, no change of statistical significance in Case Mix Adjusted Cost per Case was observed throughout the period before and after CPOE implementation ($p=0.31$).

2.1 Percent of Medication Orders Not Fulfilled by Pharmacy

Medication orders were evaluated by chart review for the occurrence of order defects that result in orders that cannot be fulfilled by pharmacy, usually requiring clarification from the ordering physician. Written medication orders pre-CPOE and electronic orders post-CPOE were evaluated. Defects are defined as order sentences containing:

- Missing elements that are essential to order verification
 - Illegible elements such that the pharmacist is unable to decipher the order
 - Unapproved abbreviations (based on our hospital's published list)
 - Allergy history, medication interaction, patient-drug interaction, or inappropriate drug dose range violations that represent a contraindication to dispensing.
 - Weight based order with unavailable updated height and weight.
- CPOE order entry errors, including orders entered on the wrong patient, orders with incorrect start date/time, and orders with conflicting information

Results of this analysis are tabulated in Table 2.1 and graphically displayed in Figure 2.1.

PRE-CPOE RESULTS			
Analysis period: 3/2/2008 - 3/7/2008		New orders entered during study period: 27,733	
Reason Group	Number	Percent of Orders	Avg. Time on Hold (minutes)
Missing Element	303	1.09%	393
Illegible/Unapproved Abbreviation	62	0.22%	142
Allergy/Interaction Contraindication	804	0.16%	203
Weight based order with unavailable height and weight	18	0.06%	432
CPOE order entry error	N/A	N/A	N/A
Total	1187	4.28%	351

POST-CPOE RESULTS			
Analysis period: 3/2/2009 - 3/17/2009		New CPOE orders entered during study period: 99,859	
Reason Group	Number	Percent of CPOE Orders	Avg. Time on Hold (minutes)
Missing Element	290	0.29%	310
Illegible/Unapproved Abbreviation	N/A	N/A	N/A
Allergy/Interaction Contraindication	536	0.54%	139
Weight based order with unavailable height and weight	18	0.02%	124
CPOE order entry error	27	0.03%	86
Total	902	0.90%	194

Table 2.1

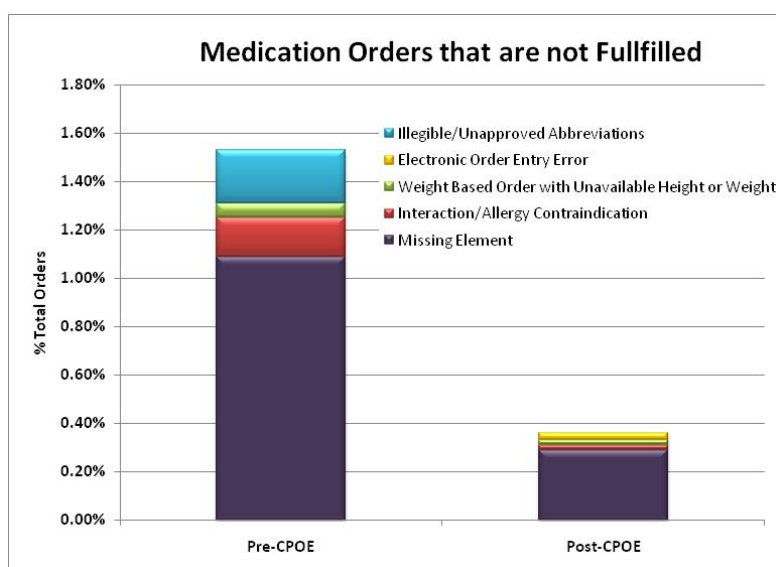


Figure 2.1

These results demonstrate a 79% reduction in medication orders that could not be fulfilled by the pharmacy ($p<0.001$). Similarly, significant reductions were observed in the occurrence of missing elements ($p<0.001$), illegible/unapproved orders ($p=0.044$), and allergy/interaction contraindications ($p<0.001$). No significant difference was observed in weight-based orders with unavailable height and weight ($p=0.413$).

2.2 Unapproved Abbreviations and Illegible Orders Requiring Physician Callback from the Pharmacy

Pre-CPOE, from 3/2/2008 to 3/7/2008 and post-CPOE from 3/2/2009 to 3/17/2009, paper orders were reviewed for the occurrence of illegibility and unapproved abbreviations (**Figure 2.2a**). Because of the nature of CPOE, no violations were observed in electronic orders post-CPOE. However, the use of some paper orders persisted post-CPOE. These consisted of chemotherapy orders not supported by the CPOE vendor, “Written/Pop off” orders (see Section 3.2), and admission orders submitted for patients admitted from non-affiliated physician offices and hospitals. These residual paper orders were evaluated post-CPOE for illegibility and unapproved abbreviation violations.

PRE-CPOE RESULTS			
Analysis period: 3/2/2008 - 3/7/2008		New orders entered during study period: 27733	
Reason Group	Number	Percent of Orders	Average Time on Hold (minutes)
Illegible/unapproved	62	0.22%	142

POST-CPOE RESULTS			
Analysis period: 3/2/2009 - 3/17/2009		New orders entered during study period: 104,416	
Reason Group	Number	Percent of Orders	Average Time on Hold (minutes)
Illegible/unapproved	31	0.03%	217

Table 2.2

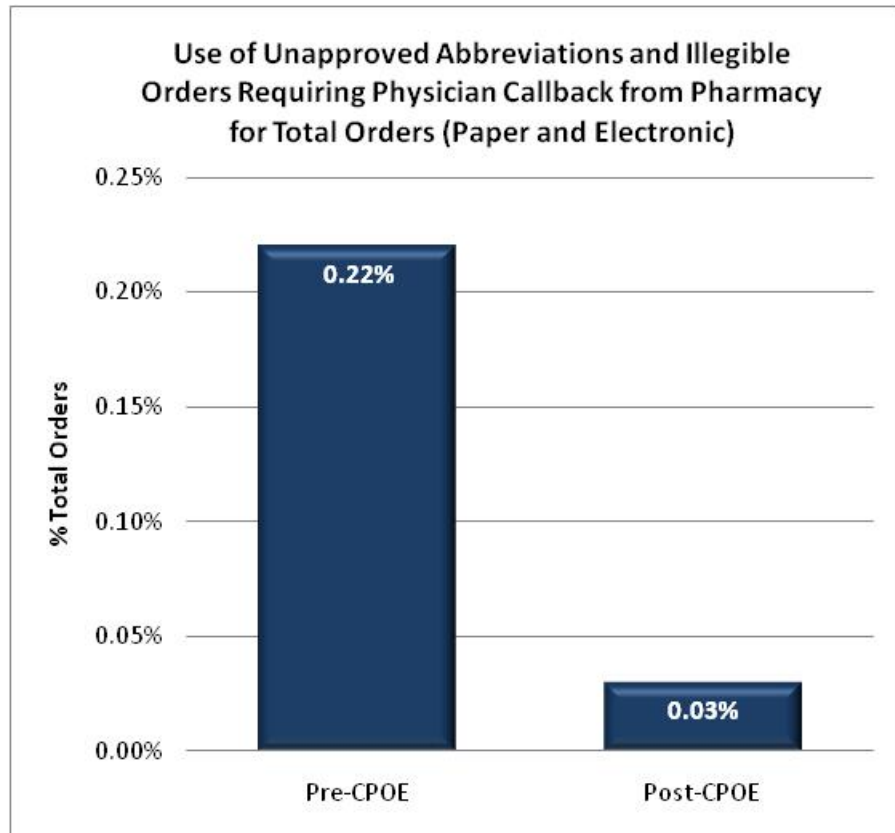


Figure 2.2a

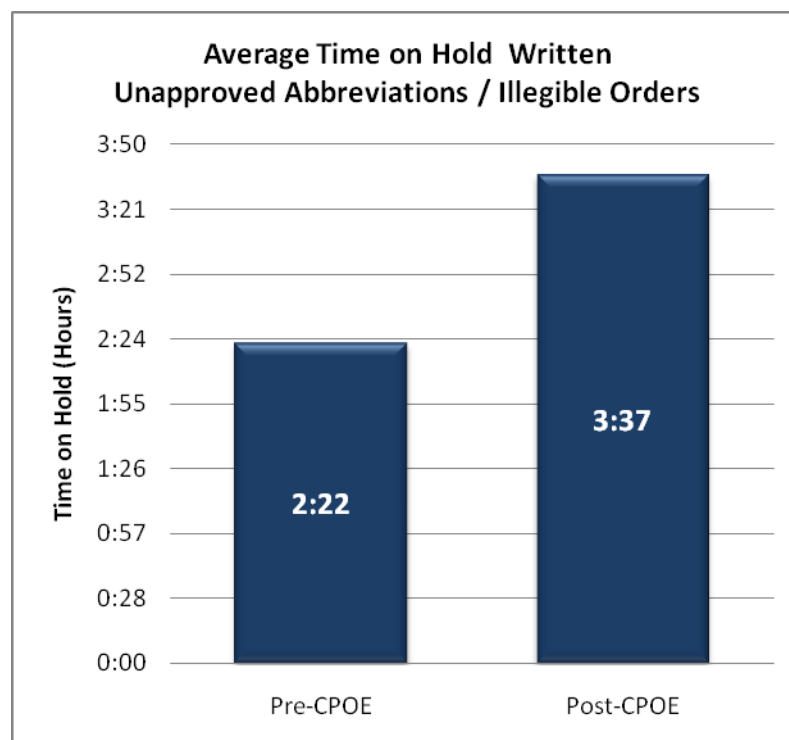


Figure 2.2b

The illegible/unapproved abbreviations were analyzed pre- and post-CPOE as a percent of both electronic and paper medication orders. Illegible/unapproved abbreviations were found to have decreased from 0.22% to 0.03%, representing an 86% decline ($p=0.044$).

Whenever written orders that contain illegible information or unapproved abbreviations are submitted to pharmacy, they may not be fulfilled until the orders are clarified. We sought to assess the impact on workflow efficiency for the verification and dispensing of these medications pre- and post-CPOE. Once placed on hold, there was an average delay of 2 hours, 37 minutes pre-CPOE, and this time delay increased post-CPOE to 3 hours, 2 minutes. This was not statistically significant ($p = 0.339$) due to the wide spread in data values.

2.3 Percent of Records on Admission with Availability of Updated Allergy History

In order to optimally assure patient safety, the availability of updated, validated allergy information is expected to be present in the patient's record on admission and available for review by the admitting physician prior to entering the first medication orders. The percent of records demonstrating presence of an updated, validated allergy history or an updated, validated history of "No Known Drug Allergy" (NKDA) was evaluated pre- and post-CPOE. The results of this assessment are displayed in **Figure 2.3**.

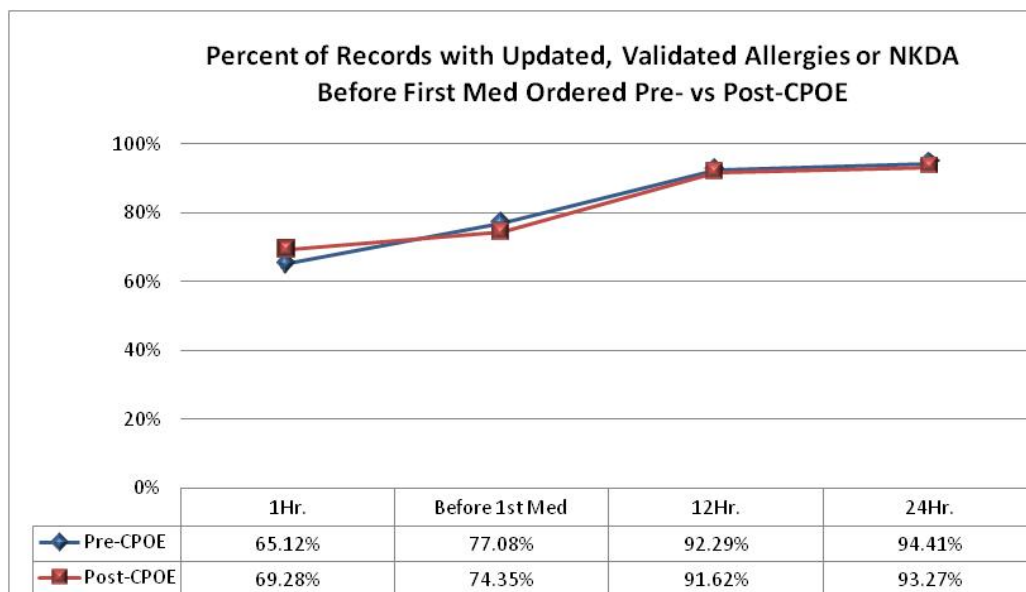


Figure 2.3

These results demonstrate that patient records commonly lack updated allergy information for physicians when entering admission medication orders. There was a significant difference prior

to entering the first medication when comparing the pre- to post-CPOE intervals, indicating a slightly lower availability of updated allergy information post-CPOE ($p=0.027$).

2.4 Percent of Records on Admission with Availability of an Updated, Current Patient Weight When Weight-Based Medication Orders are Placed

In order to optimally assure patient safety, the availability of an updated, current weight is expected to be present in the patient's record on admission and available for review by the admitting physician prior to entering the first medication orders. The availability of a current weight is essential when weight-based medications are ordered. The percent of records demonstrating presence of a current weight associated with an admission order for a weight-based medication was evaluated pre- and post-CPOE. The results of this assessment are displayed in **Figure 2.4**.

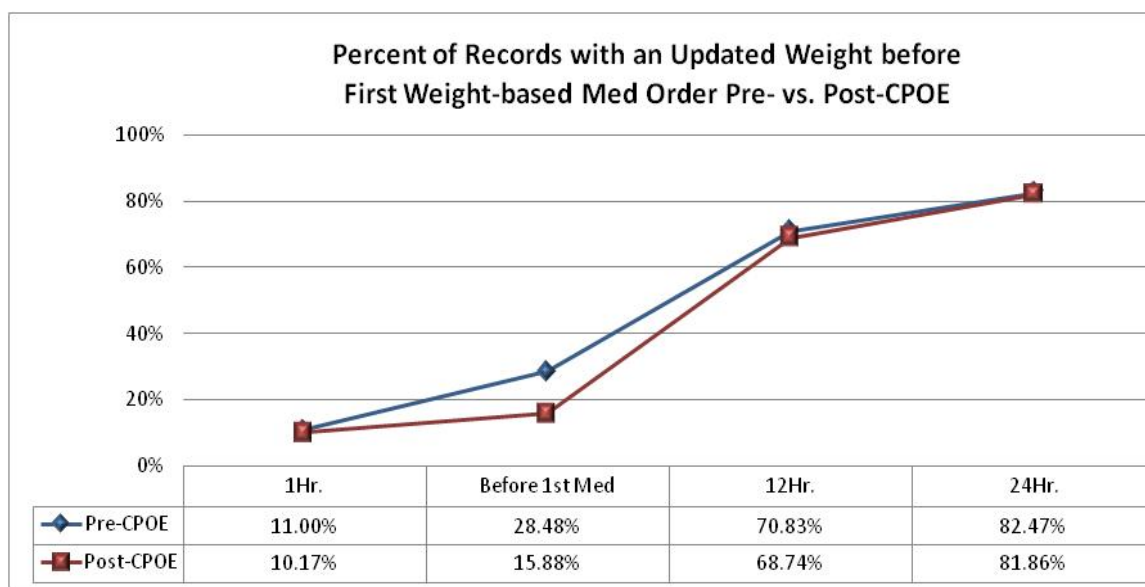


Figure 2.4

These results demonstrate a frequent lack of updated current patient weight information for physicians when entering admission weight-based medication orders. There was a significant difference prior to entering the first medication when comparing the pre- to post-CPOE intervals, indicating a lower availability of updated weight information post-CPOE ($p < 0.001$).

2.5 Percent of Records on Admission with Availability of an Updated Home Medications List

For patients being admitted to the Hospital, the availability of an updated Home Medications List, or validation that the patient takes “No Home Medications”, is expected to be present in the patient’s record and available for review by the admitting physician prior to entering the first admission medication orders. The percent of records demonstrating presence of an updated Home Medications List was evaluated pre- and post-CPOE. The results of this assessment are displayed in **Figure 2.5**.

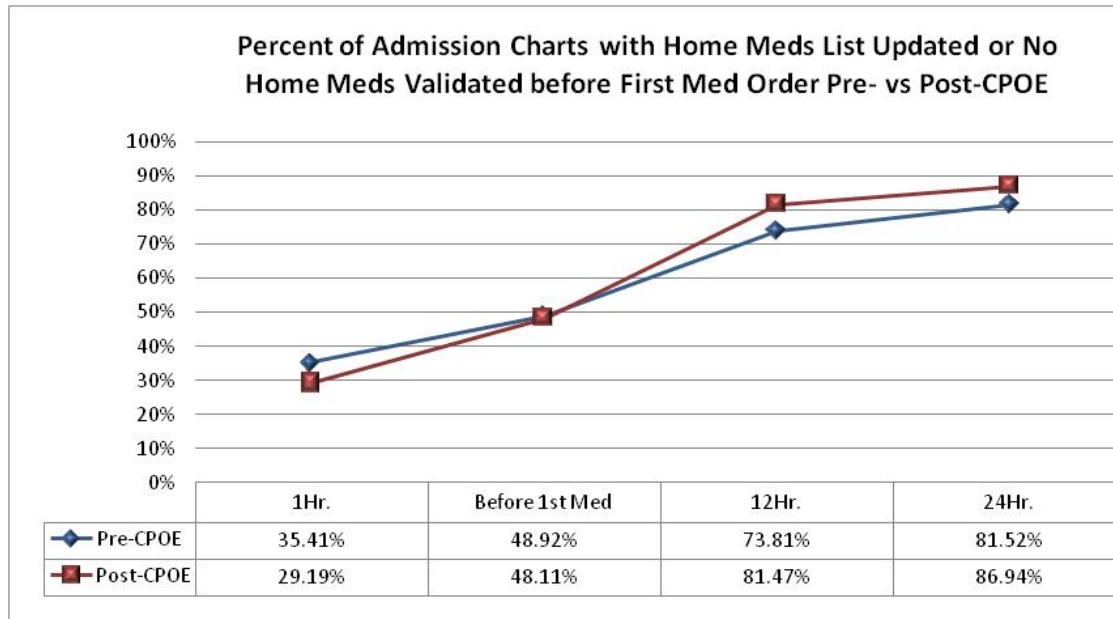


Figure 2.5

These results demonstrate a frequent lack of an updated Home Medications List for physicians when entering admission medication orders. There was no significant difference in the availability of an updated Home Medications List prior to entering the first medication when comparing the pre- to post-CPOE intervals ($p= 0.575$).

2.6a Frequency of Major Contraindicated Medication Alerts (MCAs) to the Pharmacy and Percent of MCAs that Result in a Modification to Correct the Original Order

Major contraindicated alerts represent the highest level of alerts, indicating a possible drug-drug interaction which is **likely** to harm the patient and should not be given unless there are overriding circumstances. As such, MCAs represent the greatest threat to patient safety if ignored. Pre-CPOE, these alerts were not reviewed by physicians, since the paper ordering process afforded no practical means to provide these alerts at the time of order entry. Therefore, pre-CPOE, these alerts were reviewed by the pharmacist. Post-CPOE, these alerts were presented first to the physician at the time of order entry, but those not modified were

presented to the pharmacist at the time of medication order verification. We therefore sought to assess:

- The occurrence of MCAs expressed as a percent of total medication orders pre- and post-CPOE (**Figure 2.6a-1**)
- The percent of MCAs that were modified to correct the original order pre- and post-CPOE (**Table 2.6**)
- The occurrence of MCAs that were bypassed and therefore reached the patient, posing a potential risk, pre- and post-CPOE (**Figure 2.6a-2**)
- The relative contributions of physicians and pharmacists pre- and post-CPOE who contributed to the modification of MCAs (**Figure 2.6a-3**)

The supporting data for these graphs are presented in **Table 2.6**.

	Pre-CPOE			Post-CPOE		
	Count	% of Alerts	% total orders	Count	% of Alerts	% total orders
Total MCAs	878	100%	1.28%	1050	100%	1.05%
MCAs Presented to Physician	0	0%	0%	1050	100%	1.05%
MCAs Presented to Pharmacy	878	100%	1.28%	801	76.2%	0.802%
MCAs Acted Upon by Physician	0	0%	0%	249	23.7%	0.249%
MCAs Acted Upon by Pharmacy	261	29.7%	0.379%	10	0.952%	0.010%
MCAs Acted Upon Total	261	29.7%	0.379%	259	24.7%	0.259%
MCAs Bypassed Total	617	70.3%	0.896%	791	75.3%	0.792%
Total Orders	68,850			99,859		

Table 2.6

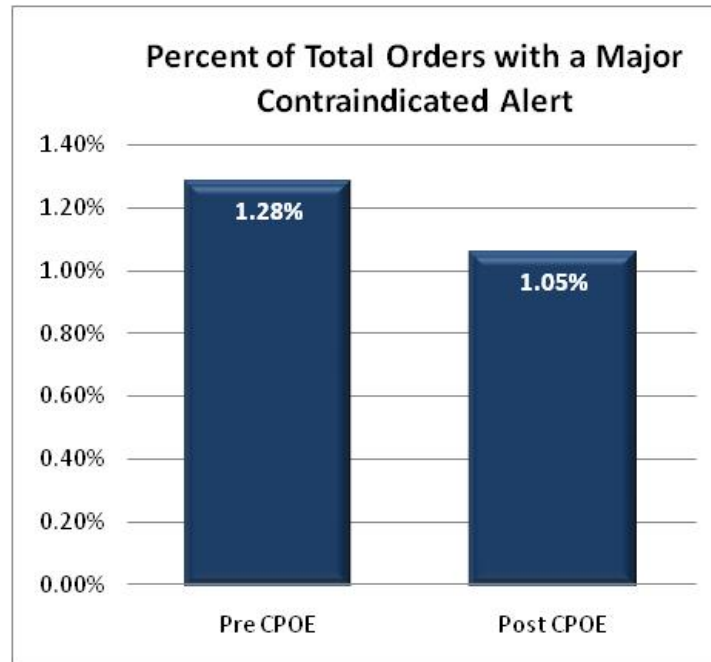


Figure 2.6a-1

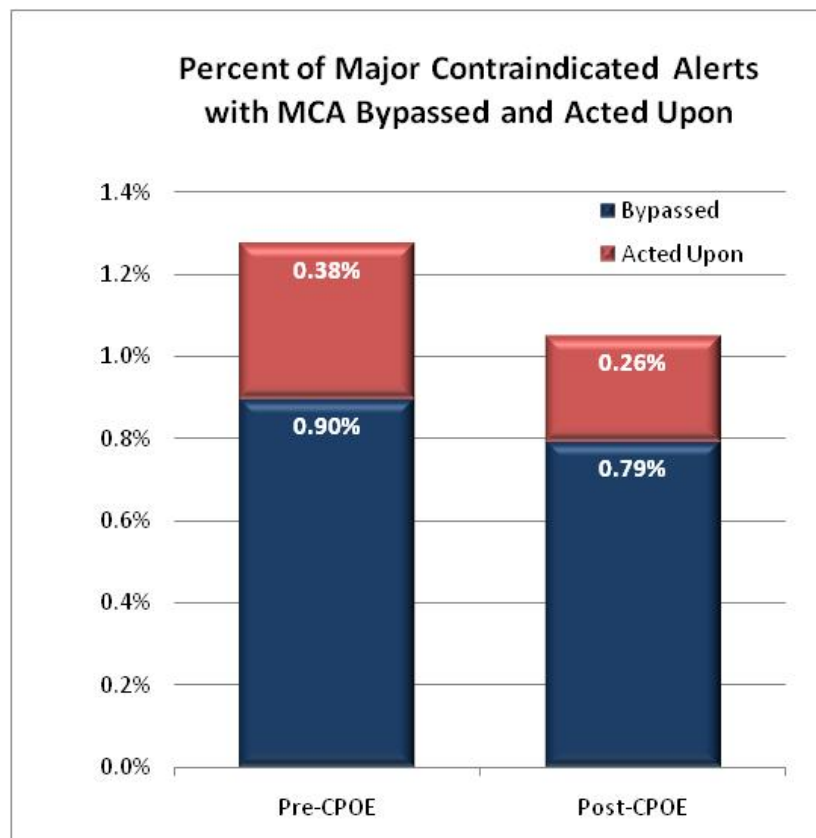


Figure 2.6a-2

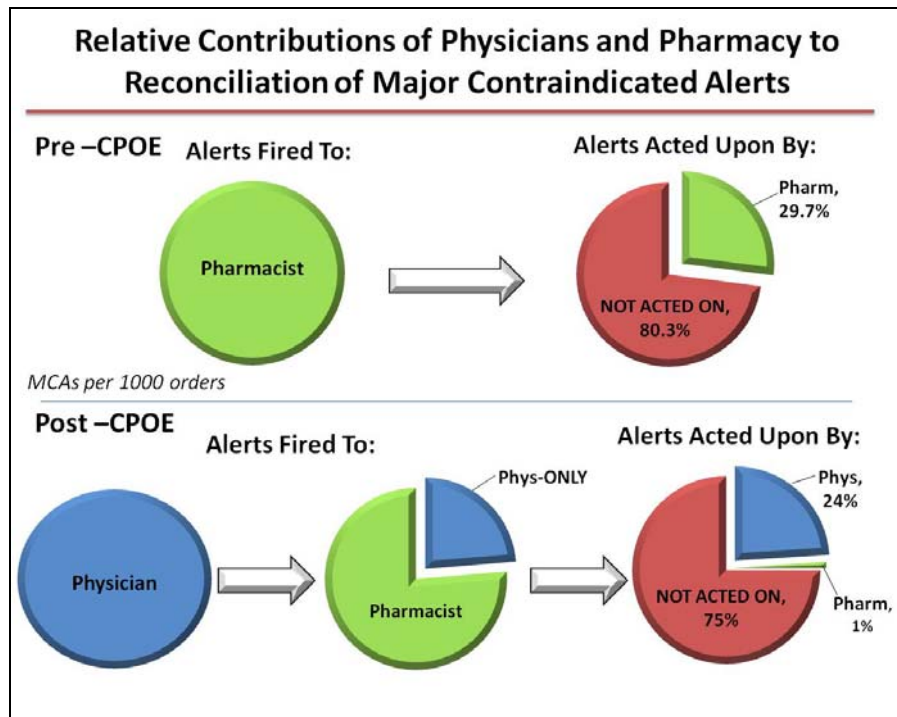


Figure 2.6a-3

These results demonstrate a 17.6% reduction in the total number of MCAs post-CPOE as compared with pre-CPOE ($p < 0.001$). The percent of MCAs acted upon to correct the order, however, decreased from 29.7% pre-CPOE to 24.7% post-CPOE ($p < 0.001$). Nevertheless, the occurrence MCAs that are unmodified and reach the patient as a percent of total orders decreased from 0.896% pre-CPOE to 0.792% post-CPOE ($p < 0.001$). The alerts with no action taken are those that after review are either ignored or deemed a necessary risk in the treatment of the patient.

2.6b Frequency of Major Medication Alerts (MAs) to the Pharmacy and Percent of MAs that Result in a Modification to Correct the Original Order

A major alert is the second level of alert which indicates a possible drug-drug interaction which could **potentially** harm the patient. Unlike MCAs, MAs are much more frequent and are generally associated with less serious drug interactions. As can be seen in **Figure 2.6b-1**, more than 20% of medication orders are associated with MAs. For these reasons and because of the risk of provoking alert fatigue, the decision was made well in advance of CPOE implementation to turn off MAs for the ordering providers. MAs, however, were turned on for pharmacists verifying medication orders both pre-CPOE and post-CPOE. Results of this analysis are displayed in **Figures 2.6b-1** and **2.6b-2**.



Figure 2.6b-1

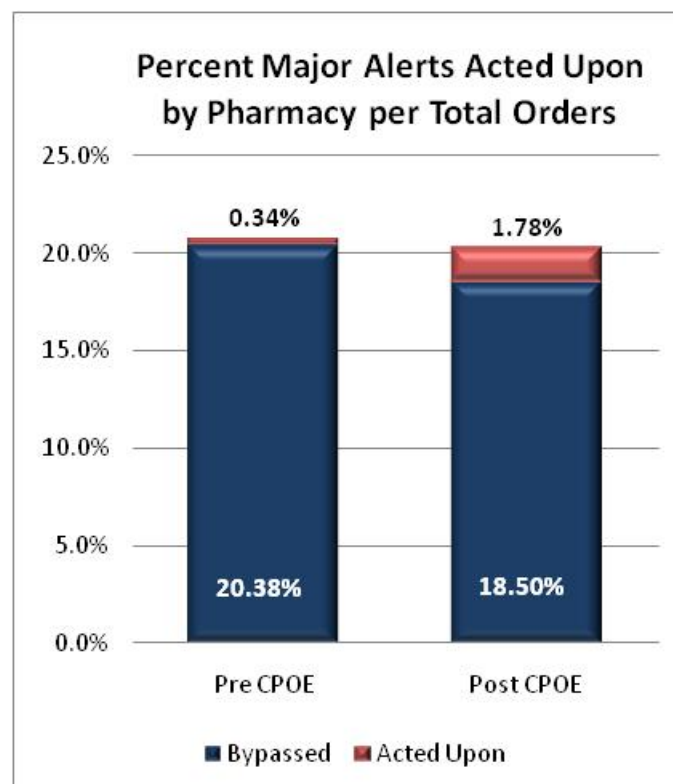


Figure 2.6b-2

These results demonstrate a significant change in the percent of MAs pre-CPOE compared with post-CPOE ($p = 0.028$). Pharmacists ignored most MAs pre-CPOE, but acted upon significantly more MAs post-CPOE ($p < 0.001$), resulting in significantly fewer unmodified MAs reaching the patient compared with pre-CPOE ($p < 0.001$).

2.7 Percent of Admission Records that demonstrate Use of Evidence and Consensus-based Preapproved Admission(ECBPA) Order Sets

ECBPA order sets represent best practice and supply physicians with significant, timely embedded decision support, while limiting unnecessary variation in care. Therefore, the adoption of ECBPA order sets supporting admission orders is an important tool to assure best practice standards of care. The purpose of this part of the study was to assess the degree of adoption of ECBPA order sets during the admission ordering process. The results are shown in **Figure 2.7**.

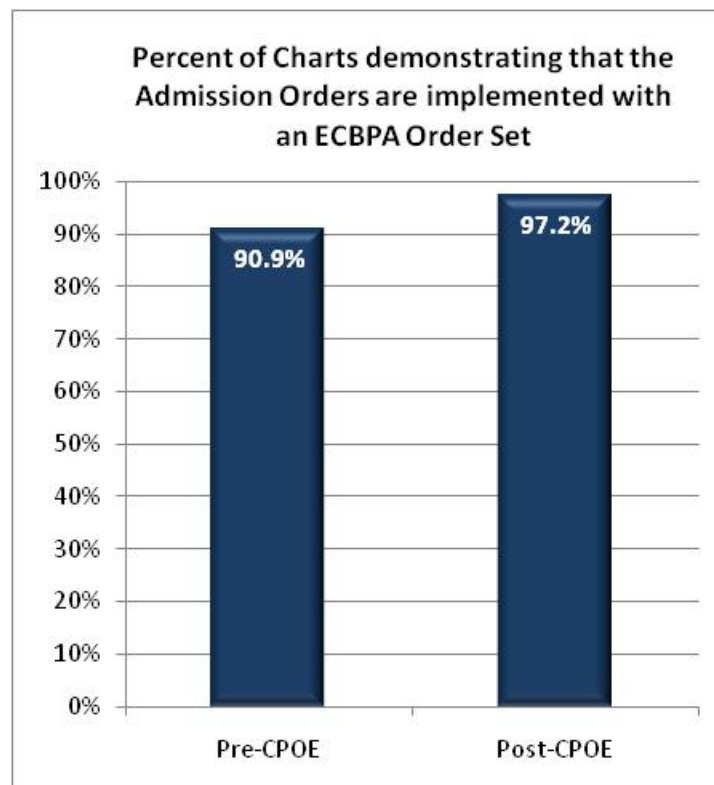


Figure 2.7

These results demonstrate a pre-CPOE adoption rate of 90.9% indicating significant use of ECBPA order sets; however, post-CPOE, the adoption rate increased significantly to 97.2% ($p < 0.001$).

Section 3.1: Physician Workflow and Productivity

3.1a Physician Order Entry Time (POET)

Physician order entry time is the time a physician takes to write orders on paper or enter orders into a computer. This time is defined by the interval from the start of the order entry process until the order(s) are signed. Depicted in **Figure 3.1a-1** are the results of this comparison.

Figure 3.1a-2 depicts the distribution of observations by the number of orders entered in one ordering session (1-40 orders entered per observation).

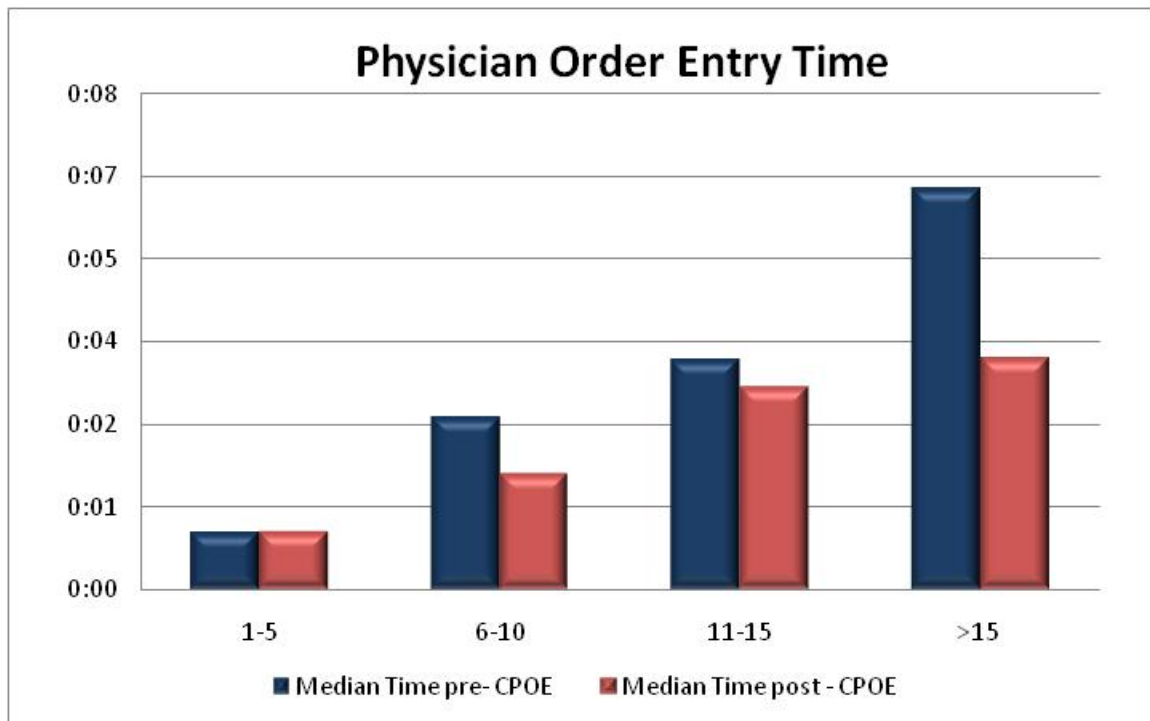


Figure 3.1a-1

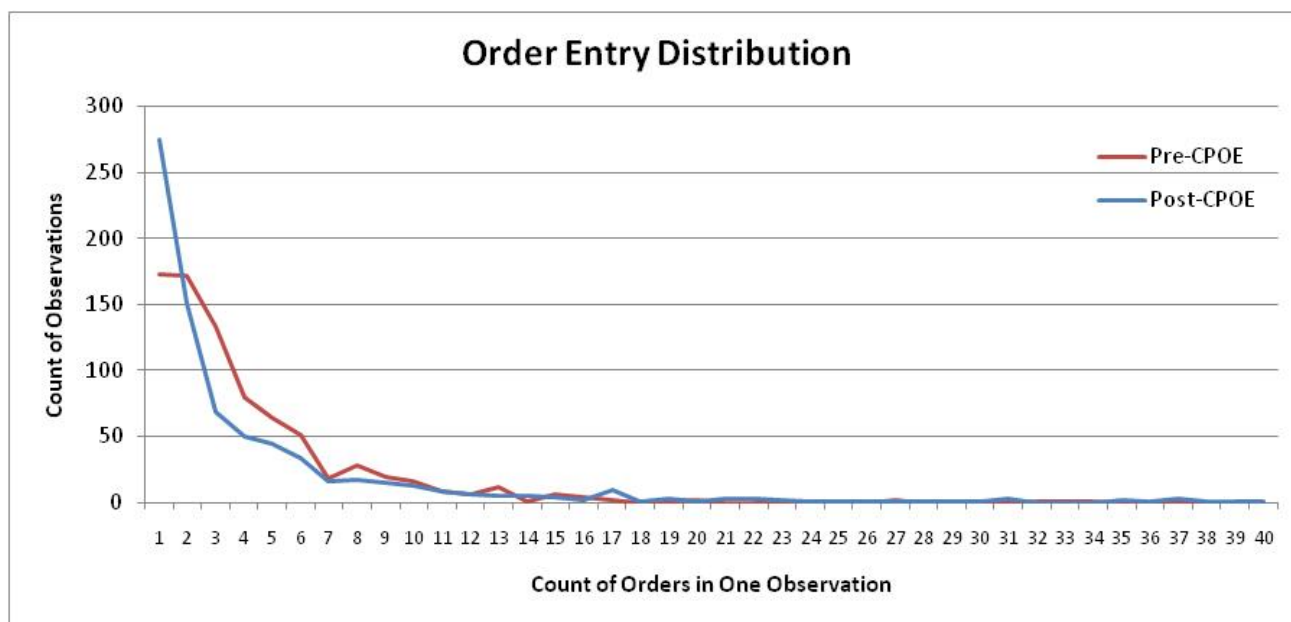


Figure 3.1a-2

These results suggest that the order entry time pre- and post-CPOE is very similar for submission for five or fewer orders. The vast majority of orders submitted during daily rounds both pre- and post-CPOE fall into the category of one to five orders per ordering session; however, physicians entered one to five orders per session much more frequently post-CPOE, as shown in **Figure 3.1a-2**. As demonstrated in Figure 3.1a-1, providers are able to submit orders with greater efficiency post-CPOE when six or more orders are entered. Overall, there was not a statistically significant difference in the average order entry time pre- vs. post-CPOE.

3.1b Medication Order Turnaround Time

Medication Order Turnaround time is defined as the time that elapses from when the medication order is signed by the ordering provider until the medication is made available for administration by the nurse. Pre-CPOE, after the order on the paper chart is signed by the provider, the paper chart typically remains in a rack until it can be reviewed by the unit clerk, who then scans the order to the pharmacy. The pharmacist then reviews the scanned order and enters it into the electronic pharmacy record, by utilizing the pharmacy medication order entry application. After entering the order the pharmacist verifies and dispenses the medication by sending an electronic message to the medication dispensing device on the clinical nursing unit. This allows the medication to be released for administration by the nurse to the patient. The time from when the provider signs the order to the time the order is scanned to the pharmacy is termed the “rack time”. The time from scanning to

verification/dispensing is called the “verification time”. Post-CPOE, the study measured the time elapsed from the physician’s placement of the electronic signature until the order is verified and dispensed by the pharmacist. Note that the time elapsing from when the nurse physically accesses the medication and administers it to the patient is not captured either pre- or post-CPOE, since the amount of time to administer the medication once available is not dependent on the method of order entry. Depicted in **Figure 3.1b** are the medication turnaround time results.

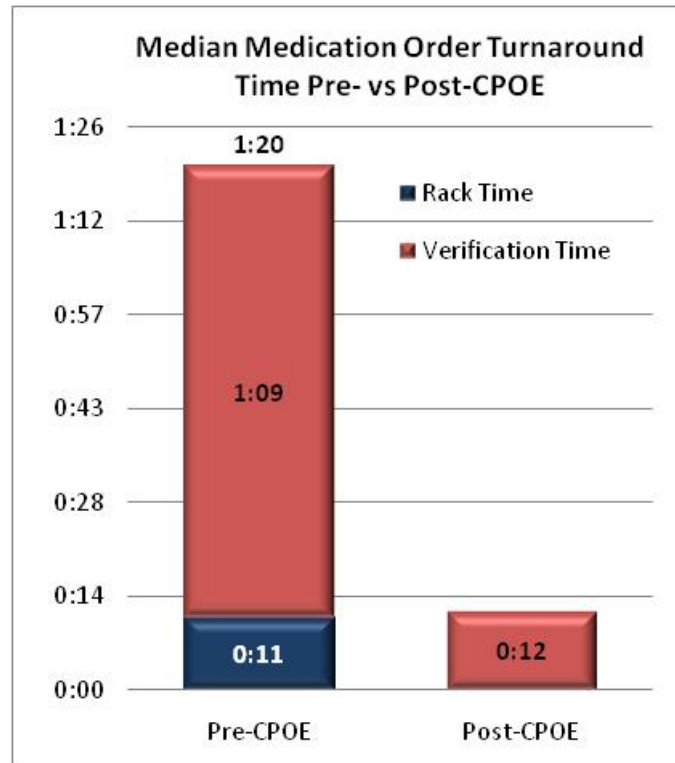


Figure 3.1b

These results demonstrate a remarkable 85% decrease in medication order turnaround time ($p < 0.001$), reflecting both the elimination of the rack time and a substantial reduction in the pharmacy verification time.

3.2 Percent of Orders Not Entered by a Physician or Licensed Midlevel Provider

The measure of physician and midlevel provider CPOE adoption was calculated as the number of CPOE orders entered by providers divided by the maximum number of orders that they could have potentially entered using CPOE during the month of December, 2008. This measure

excludes orders that could not possibly be entered by providers, such as per protocol orders or orders sent from independent physician offices. Phone, verbal, and “Written/Pop-off” orders represent those orders that the providers could potentially enter via CPOE, but choose not to do so. “Written/Pop off” orders are paper orders intended as a last resort for providers during times of unusual stress, or when they could not discern how to correctly submit an order by computer during the CPOE transition. Results are shown in **Figure 3.2**.

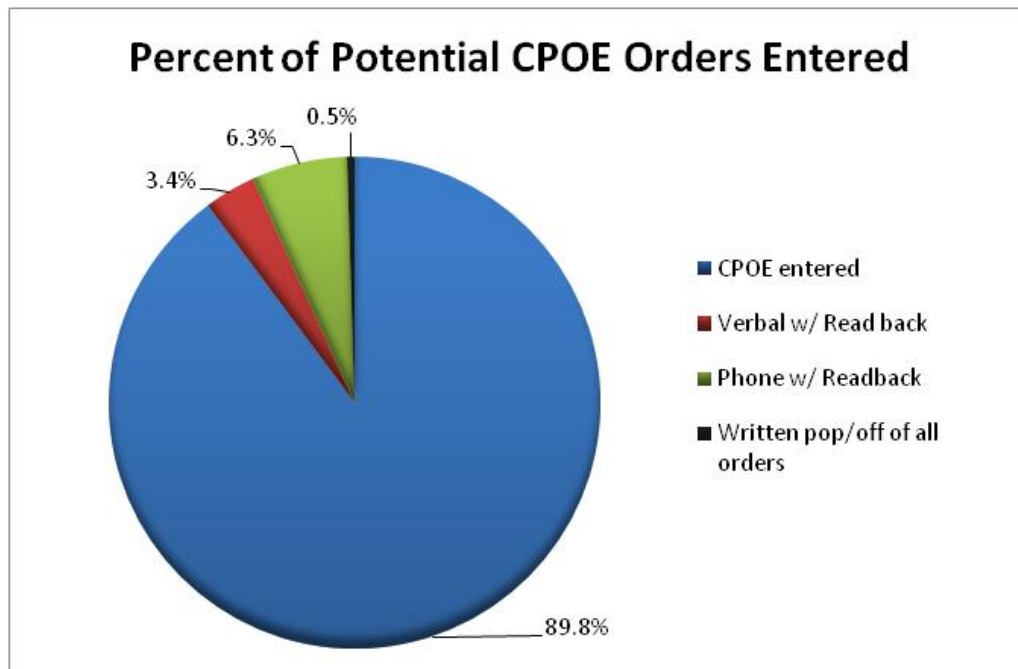


Figure 3.2

More than six months after CPOE implementation providers entered 89.8% of all potential orders using the CPOE method. Conversely, 3.5% of these orders were entered as verbal with read back, 4.6% of orders were entered as phone with read back, and 0.5% of orders were entered as “written/pop-off.”

3.3 Percent of Total Orders Submitted as Verbal and Phone Orders

Recognizing the risk that some providers may not embrace CPOE, the frequency with which providers would attempt to evade CPOE utilizing verbal and phone order options by having non-physician clinical staff enter orders on their behalf was assessed pre- and post-CPOE in the months of December, 2007 and December, 2008. The data shown in **Figure 3.3** indicate a large

increase in verbal and phone orders from 0.67% pre-CPOE to 7.0% post-CPOE, representing nearly a ten-fold increase ($p < 0.001$).

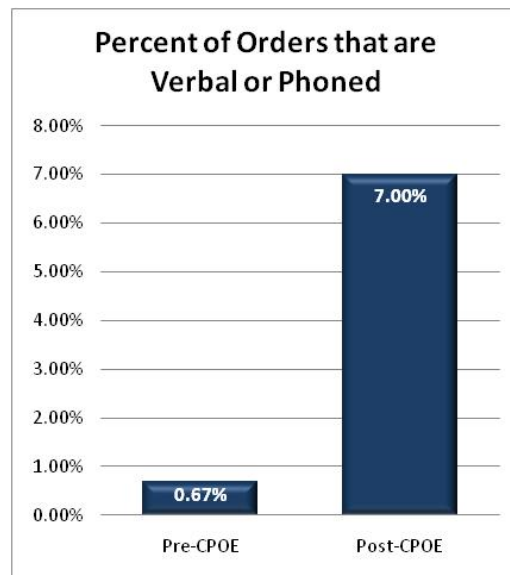


Figure 3.3

3.4 Percent of Lab Orders Cancelled

The majority of cancelled lab orders result from orders for duplicate lab tests that are cancelled in effort to minimize costs, charges, and blood draws for unnecessary tests. Duplicate ordering alerts were implemented post-CPOE to minimize the number of order cancellations with CPOE. Depicted in **Figure 3.4** are the results of the monitoring of cancelled lab orders as a percent of total lab orders pre- and post-CPOE.

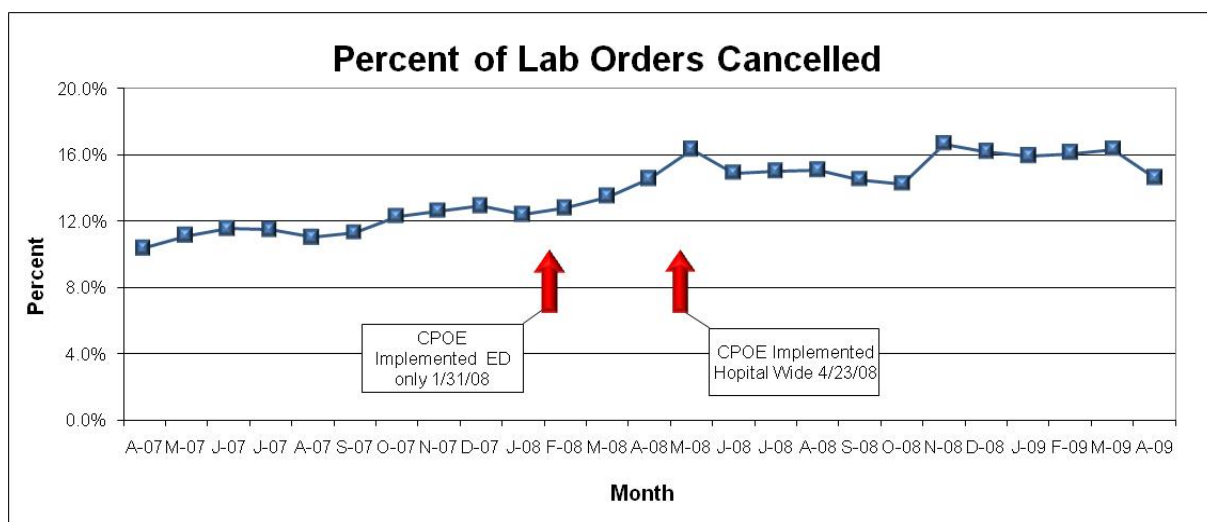


Figure 3.4

As reflected by the graph, there has been a gradual rise in cancelled lab orders from pre- to post-CPOE, despite the implementation of duplicate alert checking for lab orders post-CPOE. This rise in the percent of lab orders that are cancelled comparing pre- to post-CPOE is statistically significant ($p=0.001$).

3.5 Percent Rejected/Replaced Radiology Orders

Radiology orders are commonly rejected and replaced by more appropriate orders when the order submitted does not accurately describe the examination required or when the order submitted is not the best examination to evaluate the clinical problem in question. The percent of total submitted order requests for radiology examinations that are replaced is depicted in **Figure 3.5**.

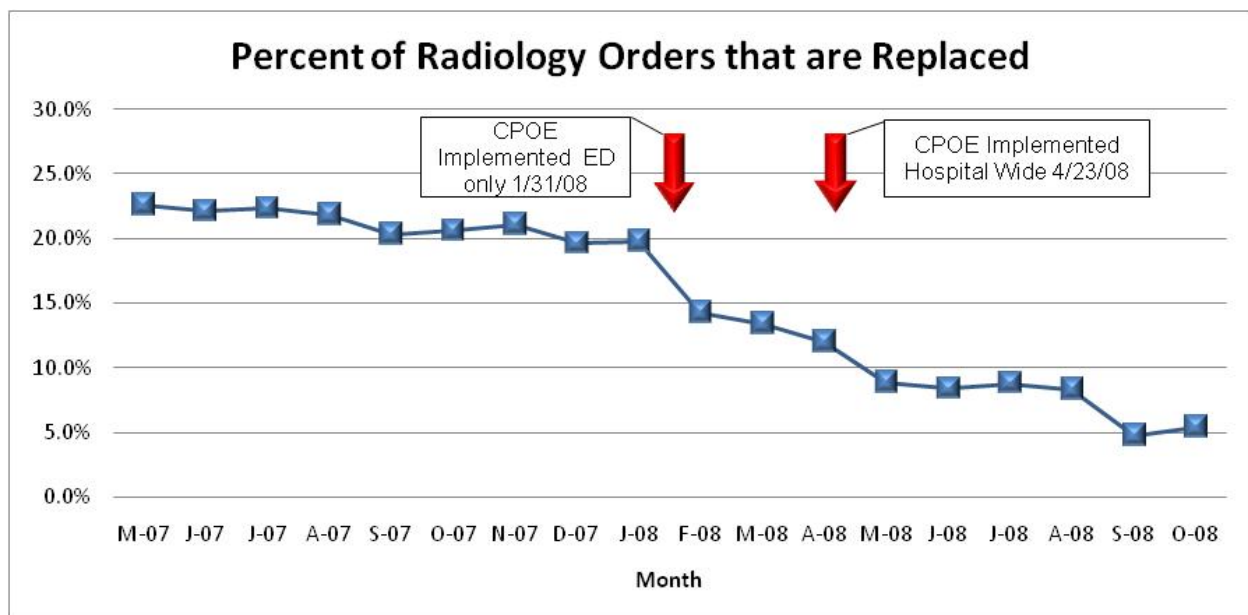


Figure 3.5

There is a pronounced decline in replaced radiology orders beginning in February, 2008, when the CPOE pilot was initiated in the Emergency Department, where a significant number of replaced orders had typically originated. This decline in replaced radiology orders from pre- to post-CPOE is statistically significant for the time interval of April, 2008, through October, 2008 ($p < 0.001$).

Conclusions

CPOE along with other healthcare information technology applications has demonstrated the potential to improve the quality, safety, efficiency and the cost of healthcare ⁽¹⁻¹⁰⁾; however, published literature has been divided on the benefits emerging from this technology ⁽¹¹⁻¹⁵⁾.

These outcomes likely depend heavily upon the depth of implementation, the usability of the software application, level of adoption, and the extent to which useful decision support is embedded into the design and build of the ordering formats. CPOE was implemented in a 765-bed community hospital with mandatory 100% adoption by all medical staff credentialed to enter orders following a pilot trial of 12 weeks. Data collections were obtained before and after CPOE implementation to evaluate the impact of CPOE on each of the variables identified below:

- CPOE adoption
- Physician/midlevel provider ordering workflow
- Order clarity
- Medication ordering safety
- Medication order turnaround time
- ECBPA order sets adoption
- General patient outcomes

Physician/Midlevel Provider CPOE Adoption

Full CPOE adoption by providers is important to achieve the maximum benefits of CPOE. Full adoption facilitates avoidance of illegible orders while fully leveraging the benefits afforded by the range of decision support devices embedded within the CPOE ordering environment. Full adoption is likewise essential to the goal of providing uniform, consistent care, while limiting unnecessary variation in care. As such, a very high degree of provider adoption of CPOE was observed, at 89.8% of total orders that could potentially be entered through CPOE by providers.

The frequency with which providers would attempt to evade CPOE utilizing verbal and phone order options and by having non-physician clinical staff enter orders on their behalf was assessed pre- and post-CPOE. Due to differing workflow processes for reporting the method of order entry pre- vs. post-CPOE, it is possible that the data presented is inaccurate. The post-CPOE data is almost certainly accurate, because for every phone or verbal order, the nurse who takes the order would generally enter the order and click a communication type of “phone” or “verbal”, allowing for accurate classification. However, pre-CPOE, the nurse took the verbal or phone order, but wrote the order in the paper chart and then placed the chart in the rack for the unit clerk to enter the order into the computer. Because the unit clerk did not personally take the verbal or phone communication, and was confronted then with a written order, we

must consider the possibility that the unit clerk may have often misclassified these orders as “written”. If this were a common occurrence, pre-CPOE phone and verbal orders may have been significantly under-reported, leaving the results and conclusions from this aspect of the study open to speculation.

Physician/Midlevel Provider Ordering Workflow

Provider ordering workflow is of special significance, because much of physician resistance to CPOE adoption has been based on concerns that the CPOE process would be considerably slower than paper order entry. Physician ordering sessions during daily rounds were timed in both arms of this study. Measurements were made in exactly the same fashion pre- and then one year post-CPOE, yielding an assessment of the relative impact on the time taken to enter orders. These results demonstrate a trend toward improvement in order entry efficiency with CPOE that did not reach statistical significance. This trend may possibly be explained by the more liberal use of order sets post-CPOE, which are universally available on the computer and facilitate rapid order entry.

The precision of this comparison may be criticized because of the timing devices used, which measured order entry time to only the nearest minute and not the nearest second. Nevertheless, given the identical method with which these measurements were made pre- and post-CPOE, these findings provide evidence that ordering times for paper order entry vs. CPOE are very similar and support the conclusion that there was no significant detrimental effect of CPOE on provider workflow.

Furthermore, this study design was not expected to capture two other anticipated improvements in provider workflow efficiencies. First, CPOE orders can be submitted from any location at any time without locating the patient’s paper chart or waiting for others to complete their work in the paper chart. Second, owing to improved order clarity, fewer calls to the providers for clarification may be anticipated with CPOE. In conclusion, in contrast to widely held opinion, a well-designed CPOE system may be expected to offer some improvements in physician workflow efficiency.

Order Clarity

Order clarity was measured as medication orders not fulfillable by pharmacy, rejected/replaced orders by radiology, and cancelled orders by the laboratory. Medication orders not fulfillable by the pharmacy were defined as those that lacked a necessary element in the medication order sentence, contained an element out of range for acceptable dosing, contained a disallowed abbreviation, violated a serious drug interaction or allergy, or contained illegible

content. From this perspective, improvements in order clarity can be seen to address patient safety at a fundamental level. Dramatic improvements in order clarity related to illegibility and disallowed abbreviations were observed post-CPOE as expected. A substantial 79% reduction was observed in the occurrence of medication orders not fulfilled. Likewise, replaced orders in radiology were observed to decline by 78%. The decline in replaced radiology orders is likely due to the requirement of more complete clinical information for order entry post-CPOE. These substantial improvements in order clarity for medications and radiology exams may be expected to result in improved safety in the ordering process as well as improved efficiency resulting from fewer required callbacks for order clarification.

Conversely, a slight, gradual increase was observed in the occurrence of cancelled lab orders, despite the use of alerts that fire when placing redundant lab orders. One possible for the failure of these alerts may relate to the counter-intuitive design of the medication alert format leading providers to click through them without canceling unnecessary orders. A possible explanation for the cancelled lab orders may be related to the transfer of patients to a new location of care where certain details in the lab orders are no longer correct. Pre-CPOE physicians typically wrote paper lab orders which accompanied the patient to their new location. There the new orders were entered where they were associated with the correct order details for that location. Post-CPOE the lab had already received the orders prior to patient relocation, forcing the lab to cancel the original orders and replace them with new orders with the appropriate details.

Medication Ordering Safety

In addition to the clarity of medication orders, medication ordering safety was assessed by two additional evaluations pre- and post-CPOE. The first analyzed whether or not the physician had access to updated allergy information, an updated home medications list, and a current weight prior to entering the first medication orders for patients being admitted to the hospital. Although the availability of this information is expected to be essential for physicians to safely order medications, the acquisition and presentation of this information depends on correct and consistent hospital processes. Our study demonstrates that very commonly there were serious omissions in these data elements before providers entered their first admission medication orders both pre- and post-CPOE, however access to this information improved at 12 and 24 hours post admission. There was a significant decrease in the percent of records with an updated weight before the first-weight-based medication order is placed. There was no significant difference in availability of updated allergy information and a current home medications list between pre- and post-CPOE. The risk of an adverse patient outcome related to unavailability of medication order supporting information, in fact, may be higher post-CPOE

owing to the observation that pharmacy receives and verifies orders much more quickly, increasing the probability that the requisite information would neither be available to the pharmacist at the time of order verification. While the process for collecting weight, allergy and home medication data may be largely in line with existing practice standards at the local and state level, they become increasingly out of synch with the admission medication ordering and verification process when CPOE is implemented. This highlights the need to look at quality improvement in patient care as part of the total care delivery system rather than focusing on process fragments in isolation.

The second evaluation focused on the process of managing medication orders that invoke major contraindicated drug interaction alerts (MCAs). These interactions represent the most serious risk of incurring adverse patient outcomes. Our results demonstrated a significant 17.6% reduction in number of MCAs that fired post-CPOE compared with pre-CPOE. Pre-CPOE, pharmacists screened 100% of MCAs, acting upon 29.3%. Post-CPOE, physicians assumed the role of screening these alerts, but modified only 23.7%. Physician decisions in screening these alerts should translate into better care for patients, since presumably the physician would be expected to have much better knowledge of the patient's condition and requirements for treatment as compared with a pharmacist. Because physicians screen alerts initially, the pharmacists' interventions in response to MCAs decreased post-CPOE from 29.3% to 1.25%. Despite decrease in the percent of MCAs modified post-CPOE, the number of MCA order combinations overridden and dispensed to the patient dropped 11.6% from 0.896% to 0.792% of orders. This observed decrease may be attributable to the overall decrease in MCAs fired.

The explanation for the observed decline in the frequency of MCAs post-CPOE is unclear. One possible explanation is that when ordering medications, providers are able to see the list of other actively ordered medications at the time of order entry, whereas with paper order entry this was not easily done. This ease of review during the ordering process, representing a subtle form of additional decision support post-CPOE, may have allowed the providers to make better medication choices. Whatever the explanation, the observation that MCAs decreased significantly with CPOE implementation suggests an important additional mechanism by which CPOE may improve patient safety.

Major Alerts (MAs) are much more frequent and less serious. These alerts were turned off pre- and post-CPOE for ordering physicians and midlevel providers due to the real risk of provoking alert fatigue. These alerts remained active for pharmacist review pre- and post-CPOE. A significant decrease was observed in the percent of MAs fired pre-CPOE compared with post-CPOE. Pharmacists ignored most MAs pre-CPOE, but acted upon significantly more MAs post-CPOE, resulting in a significant 9.2% decrease in unmodified MAs reaching the patient

compared with pre-CPOE. This may be attributed the physician screening of MCAs, which shifts the pharmacists' attention from MCAs to MAs.

Medication Order Turnaround Time

Similar to what other studies have shown⁽¹⁶⁻¹⁹⁾, we observed a striking 85% decrease in the median medication order turnaround time. The magnitude of this workflow improvement not only represents a major improvement in operational efficiency, but also has important implications for patient care resulting from much more timely bedside administration of medications. Although not measured, similar improvements in turn-around-time may also be expected for non-medication orders.

ECBPA Order Sets Adoption

Results on the use of Evidence- and Consensus-based Pre-approved (ECBPA) Order Sets pre- and post-CPOE deserve special mention. These order sets represent consistent and complete sets of orders that provide a clear opportunity to facilitate optimal patient care across the spectrum of presenting clinical problems and across the range of complex medication orders and clinical interventions. Therefore the degree of provider adoption of these order sets into daily practice is of special value in leveraging their potential benefit. Although our results demonstrate an excellent degree of adoption of these order sets in the paper environment pre-CPOE, we observed a significant increase in adoption post-CPOE, approaching 100%. At this level of adoption, the ability to embed valuable evidence-based decision support, while limiting unnecessary variation in care, represents an extraordinary opportunity to positively impact current and future quality outcomes.

General Patient Outcomes

In terms of general patient outcomes, we found documented trends toward improvement in catheter-related bloodstream infections, ventilator-associated pneumonia, and MRSA infections. These improvements however appear to have correlated temporally with specific projects targeted to address these clinical concerns prior to the CPOE go-live. Nevertheless, the key features of these projects were embedded into workflow solutions through order sets and decision support devices incorporated into and facilitated by CPOE, making CPOE an important element in sustaining these gains.

Perhaps the most remarkable finding of the study was the successive four quarter 19% decline in the Mortality Rate Index. Starting from a very respectable index of 0.84, this index fell in the fourth quarter after CPOE go-live to 0.68, a level 32% lower than our peer comparison hospitals. Although the Mortality Rate Index decline is a very broad indicator and may be influenced by many factors, the fact that this decline began precisely after CPOE implementation and continued to decline for four consecutive quarters strongly suggests that CPOE implementation was a major contributing factor. The timing of the decline in the Mortality Rate Index when combined with other observed outcomes that have demonstrated improvements in workflow efficiency and patient safety provides a persuasive argument for the existence of a causal relationship. The sustained and gradual nature of the decline in mortality may be explained by the combination of progressive user acclimation to CPOE and successively added CPOE decision support, such as medication allergy and interaction checking, venous thromboembolism prophylaxis alerting, and anticoagulation management order sets. This decline in the mortality index stands in contrast to an observed increase in mortality following CPOE implementation in a pediatric hospital, where the same CPOE vendor was used ⁽²⁰⁾. There may be several reasons for the difference in these findings. First, the pediatric study was performed four years ago, during which time significant advancements in CPOE have emerged. Second, the study observations were limited to a pediatric population. Third, there may have been significant differences in features of the CPOE build and implementation workflow.

In conclusion, the implementation of CPOE with 100% provider adoption in a large community hospital has been shown to be associated with statistically significant improvements in a range of clinical processes and outcomes. These gains appear to be related to a high level of adoption, in addition to marked improvements in order clarity, medication order safety, embedded decision support within orders and order sets, and medication order turnaround time, while minimally disrupting physician workflow.

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