A Behavioral Evaluation of the Transition to Electronic Prescribing in a Hospital Setting

Thomas R. Cunningham

Thesis submitted to the faculty of the Virginia Polytechnic Institute and State University in partial fulfillment of the requirements for the degree of

Master of Science
In
Psychology

E. Scott Geller, Ph.D.

Jack Finney, Ph.D.

Russell T. Jones, Ph.D.

April 18, 2006
Blacksburg, VA

Keywords: medication error, CPOE, behavioral interventions in hospitals, medical error, patient safety

A Behavioral Evaluation of the Transition to Electronic Prescribing in a Hospital Setting

Thomas R. Cunningham

Abstract

The impact of Computerized Physician Order Entry (CPOE) on the dependent variables of medication-order compliance and time to first dose of antibiotic was investigated in this quasi-experimental study of a naturally-occurring CPOE intervention. The impact of CPOE on compliance and time to first dose was assessed by comparing measures of these variables from the intervention site and a non-equivalent control before and during intervention phases. Medication orders placed using CPOE were significantly more compliant than paper-based medication orders ($p<.001$), and first doses of antibiotic ordered using CPOE were delivered significantly faster than antibiotic orders placed using the paper-based system ($p<.001$). Findings support previous research indicating the positive impact of CPOE on patient safety as well as justify and enable future interventions to increase CPOE adoption and use among physicians. Additionally, data collected in this study will be used to provide behavior-based feedback to physicians as part of CPOE adoption and use intervention strategies to be explored in the forthcoming research.

Table of Contents

Page

List of Tables and Figures

Page

Tables

Figures

A Behavioral Evaluation of the Transition to Electronic Prescribing in a Hospital Setting

Introduction

Estimates of the number of U.S. deaths each year as a result of medical errors range from between 44,000 and 98,000 (Institute of Medicine [IOM], 1999) to 195,000 (Health Grades, 2004). Mortality rates due to medical errors are both startling and disturbing. Even with the lower estimate of 44,000 deaths, more people in the U.S. die each year as the result of medical errors than from motor vehicle crashes (43,458), breast cancer (42,297), or AIDS (16,516) (IOM, 1999).

The total national cost associated with preventable adverse medical events is estimated to be between $17 billion and $29 billion (IOM, 1999). Again, still using the more conservative source of estimates on death by medical error (the IOM report), medication errors alone are estimated to be responsible for 7,000 deaths annually in the United States (IOM, 1999). This is higher than the number of Americans who die annually as the result of workplace injuries (i.e., 5,575 in 2003; OSHA, 2005).

The increased U.S healthcare costs attributable to preventable adverse drug events (ADEs) are estimated to be around $2 billion (IOM, 1999). In a time of seemingly insurmountable healthcare costs in the only industrialized nation with a private/for profit healthcare system, the prevention of medication errors has nationwide implications. In 2003, the National Practitioners Data Bank (NPDB) calculated the total national payout on malpractice claims was $4.5 billion. Additionally, the National NPDB reports the average malpractice payment in 2003 was $294,814. Another report indicates for those malpractice suits that do go to trial judgment, the median verdict more than doubled between 1995 and 2000 to approximately $1,000,000 per case, and the mean was even higher (Bovbjerg & Bartow, 2003).

Medication errors can result from several sources, including: 1) incorrect dosage administration (i.e., the patient is given the incorrect dosage of their prescribed medication), 2) incorrect medicine administration (i.e., the patient is given the wrong medication altogether), and 3) incorrect patient administration (i.e., the patient is given medication targeted for a different patient). Although not all medication errors lead to death; research suggests between 12.2% (Barker, 1982) and 19% (Barker, 2002) of all medications administered in hospitals are done so in error. These errors cost an estimated $76.6 billion yearly, in comparison to the $45 billion annual cost of diabetes in the U.S. (Johnson & Bootman, 1995).

An analysis of ADEs by Leape (Clancy, 2004), who analyzed 334 medication errors over a six-month period in 11 units of two tertiary care hospitals, found that 39% of errors occurred during physician ordering, 38% during nurse administration, and the remainder were evenly distributed among transcription and dispensing errors. At the time, electronic bar-code verification of medication and patient identification was not available.

Prescribing error is the primary source of ADEs (Koppel *et al.*, 2005). The medication-ordering process includes multiple phases, including prescribing, dispensing, administering, monitoring, and management control (IOM, 1999). This process involves a complex set of communications and behaviors, usually involving physicians, pharmacists, and nurses, as well as additional medical staff (e.g., pharmacy clerks, PCAs).

Communicating Medication Orders

Modern healthcare usually involves multiple professionals communicating within a system. As medical researchers have noted, “Patient management involves complex investigation and coordination of care by a myriad of medical specialists. Clinical medicine thus involves multiple handoffs where critical information must be communicated” (Sutcliffe, Lewton, &

Rosenthal, 2004, p.187). Accurate and effective communication is absolutely necessary. Any breakdown in this vital network of communication links could result in a medical error.

A great deal of communication between physicians and other medical staff (i.e., nurses, pharmacists, etc.) is transmitted as written orders. This method of communication affords many opportunities for miscommunication. Not only is there the possibility of error due to interpretation of a physician's handwriting, but the communication between nurses, pharmacists, and physicians is complicated by a hierarchical organizational structure where multitasking and disruptions are routine, and different perceptions of communication effectiveness exist. For example, in an examination of inter-professional communication, Thomas and colleagues surveyed 320 nurses and physicians in eight non-surgical intensive care units and found while 73% of physicians reported the quality of collaboration was high or very high, only 33% of nurses responded in kind (Burke, Boal, & Mitchell, 2004). In addition, the hierarchical structure of inter-professional communication of healthcare workers has the potential for reducing "upward" communication within this hierarchy (i.e., nurse to physician) that may be interpreted as questioning a physician's orders. Expected and actual negative consequences because of these communications only serve to reduce communication. Thus, it is critical for a physician's written orders to be as legible and standardized as possible.

The traditional paper approach. In a paper system, a physician writes a medication order by hand after examining a patient. Or, the physician dictates this order over the phone to a transcriber (usually a nurse copying by hand). A copy of this order is given to the pharmacy, where the medications listed are entered into an electronic record, checked for errors (i.e., drug interactions, allergies, proper dosing and route), and dispensed to the nursing staff. It is then the nursing staff's responsibility to re-check the dispensed medication against their own copy of the

medication order to assure it is the medication prescribed (more recently done by barcode matching of medication and patient). Then a nurse administers the medication to the patient.

Errors occur at each point of this process, and fortunately most of these errors are caught and corrected by the "stop and check" behaviors at the various phases of the medication-ordering process. Thus, most errors do not actually result in a negative patient outcome. However, given the sheer quantity of medication orders processed in a single hospital (i.e., millions per year), there remains the very real possibility of an error impacting patient safety. For this reason, all phases of the medication-ordering process would benefit from an intervention to reduce the probability of error. Measures are already in place to reduce the probability of errors occurring at the administration phase of the medication-ordering process. It is also critical to reduce the probability of error at the medication-ordering phase of physician prescribing.

Hospitals have employed a number of strategies to reduce medication errors. Among these are: a) developing and promoting a voluntary system for reporting errors and close calls, b) placing greater emphasis on patient safety as a part of accountability to certain regulatory agencies (i.e., JCAHO), and c) applying information technology to improve medication ordering practices (Clancy, 2004). While these strategies are currently being used to varying degrees throughout the healthcare industry, the latter is of particular interest because it represents a fundamental change in the way physicians operate within the healthcare system. Thus, transitioning from a paper to an electronic medication-ordering system involves changing physicians' habitual prescribing behavior. Strategies are needed to motivate physicians to make this fundamental change in medication ordering. The research proposed to follow from the current study evaluates behavior-based strategies designed to make this change.

The computer-based approach. CPOE refers to a variety of computer-based systems used for ordering medications, each sharing techniques for automating the medication-ordering process (Kaushal & Bates, 2005). The basic objective of these computerized systems is to ensure standardized, legible, and complete orders by only accepting typed orders in a standardized and complete format. Nearly all CPOE systems are interfaced with a clinical decision support system (CDSS). This additional aspect of the computerized system usually includes suggestions or default values for drug doses, routes, and frequencies. More sophisticated systems also perform drug-allergy, drug-laboratory value, and drug-drug interaction checks, in addition to providing reminders for the user to order glucose checks after ordering insulin (Kaushal & Bates, 2005).

Adoption of CPOE is a major emphasis of the Leapfrog Group, a coalition of over 130 public and private organizations. This group's mission is to save lives and reduce preventable medical errors by mobilizing employer purchasing power to initiate breakthrough improvements in the safety of healthcare through a series of leaps forward in healthcare safety, affordability, and effectiveness (Leapfrog Group, 2005). One of the first three "leaps" or specific strategies recommended is the implementation of CPOE.

The CPOE method is also the most prominent of seven evidence-based practices to reduce medication errors as recommended by AHRQ, which include: a) use of CPOE, b) use of clinical decision support systems (CDSS), c) eliminating the prescription blank, d) use of protocols for high-risk drugs, e) use of clinical pharmacists, f) use of unit-dose drug distribution, and g) use of bar-coding and automated medication dispensing devices (Nelly, 2004). The Leapfrog Group (2001) asserts CPOE can reduce prescribing errors in hospitals by more than 50%.

A number of studies indicate CPOE is an effective and efficient means of reducing medication errors. For example, a study by Bates *et al*. (1999) indicated use of CPOE reduced non-missed dose medication error rates by 81%, from 142 to 26.6 per 1,000 patient days in a 700-bed academic tertiary care hospital. A study of the impact of implementing CPOE in a pediatric hospital (Upperman *et al*., 2004) found that following CPOE implementation, verbal order regulatory compliance increased from 80% to 95%, transcription errors were eliminated entirely, and ADEs were reduced from 0.5 to 0.03 per 1,000 doses. In a similar study at a pediatric hospital, implementation of CPOE resulted in a 40% reduction in medication errors (King *et al*., 2003).

In another study by Bates *et al.* (1998), implementation of CPOE was compared to the implementation of CPOE with an added team-intervention component. This added team-intervention component targeted the administration and dispensing of drugs through many small interventions by teams of physicians, nurses, and pharmacists. The results of this study indicated serious medication errors decreased by 55%, from 10.7 per 1,000 patient days to 4.86 per 1,000 patient days. Additionally, preventable ADEs declined 17%, from 4.69 to 3.88 per 1,000 patient days, and non-intercepted ADEs declined 84%, from 5.99 to .98 per 1,000 patient days. These impressive improvements were reported as due solely to the implementation of CPOE; the additional team-intervention did not show any additional benefit (Bates *et al.*, 1998).

An additional study demonstrating evidence for CPOE contributing to improvements patient safety reported the following results for Queen's Medical Center in Honolulu: 75% reduction in transcription errors, 30% reduction in wrong medication or route, 75% reduction in inappropriate vancomycin (type of antibiotic) use, 60% decrease in time to first dose of antibiotic, 98% compliance with JCAHO standards for orders for restraints, 85% reduction in

unsigned orders, and 40% reduction in turnaround time for STAT medications (Healthcare Benchmarks and Quality Improvement [HBQI], 2003).

Another suggested benefit of CPOE (as shown at Queen's Medical Center above) is faster delivery of medication orders. Even if a lack of efficiency is not significant enough to be considered an error, slow delivery can certainly be considered less than optimal healthcare. For this reason, the intervention site has a goal that all antibiotics be administered within 240 minutes of their order. Research shows that antibiotic delivery within four hours of arrival at the hospital is associated with reduced in-hospital mortality as well as reduced mortality within 30 days of admission (Houck, Bratzler, Nsa, Ma, & Bartlett, 2004). Battleman, Callahan, and Thaler (2002) also found quicker administration of antibiotics to be associated with a shorter length of stay in the hospital. Shorter length of stay is not only more convenient for the patient, but also means reduced treatment costs for the healthcare system.

Given the results of these studies, it is reasonable to conclude that adopting CPOE technology is a viable solution to the reduction of medication errors and ADEs, as well as quality of care improvement. However, a possible limitation of these evaluations has been the lack of an independent evaluation of implementation of CPOE. Thus, there is a need for a more objective evaluation of CPOE's impact on medication errors, a primary aim of the proposed research.

Most importantly, while this technology has the potential to greatly reduce the frequency of medication errors and ADEs, CPOE is slow to be adopted. For example, a survey of 627 randomly-selected U.S. hospitals indicated CPOE was not available in 83.7% of hospitals that responded (Ash, Gorman, & Seshardi, 2004). Further, it is reported that as of 2005, fewer than 5% of hospitals in the U.S. had functioning CPOE systems in place (Cutler, Feldman, & Horwtiz, 2005). Thus, there is a need for research to evaluate strategies for facilitating the

transition to CPOE adoption and use in hospitals that implement this technology. To the extent effective strategies for motivating physicians to use CPOE can be developed and disseminated, the adoption of this technology will be hastened. In addition, it is likely a majority of U.S. hospitals will soon face the challenges of implementing CPOE systems in the near future.

Barriers to adoption of CPOE. A number of factors may contribute to the lack of CPOE adoption**.** In a study which analyzed 57 transcripts of interviews with management officials at 25 U.S. hospitals, the two most significant barriers were identified as cost and physician resistance (Poon *et al.*, 2003).

The most obvious barrier, a lack of funds to implement a CPOE system, is best countered by a heavy emphasis on patient-safety throughout the hospital as a justification of cost (Poon *et al.*, 2004). There seems to be an increasing salience of patient-safety issues in the American media. For example, a survey of 1,004 adults nationwide conducted by the American Society of Health-System Pharmacists found Americans are “very concerned” about being given the wrong medicine (61%) and being given two or more medicines that interact in a negative way (58%) (Agency for Healthcare Research and Quality [AHRQ], 2005; American Society of Health-Systems Pharmacists, 2002). Additionally, a national poll of 1,513 Americans conducted by the National Patient Safety Foundation found 42% of respondents had been affected by a medical error, either personally or through a friend or relative, and 32% of respondents indicated the patient experienced a permanent negative effect due to the error (Harris, 1997; AHRQ, 2005). Given these concerns, the added cost of CPOE implementation is arguably justifiable.

Overcoming physician resistance to CPOE use will require the expertise of behavioral scientists to develop and test strategies to overcome resistance. This study represents the necessary preliminary work for an initial test of behavior-based strategies that have been

effective in other settings, and have been quite successful in improving safety in workplace settings (see Geller, 2001a, 2005). From the behavioral perspective, the main cause for physician resistance is an added response effort associated with learning to use a new method of medication ordering.

Frameworks for Adoption of Information Technologies

A number of theories explain the differential adoption rates of a new information technology (IT). The more prominent theoretical models are reviewed and discussed in a literature review by Kukafka *et al*. (2003). Kukafka *et al*. propose a framework for improving the success of IT implementation that includes five assessment phases: 1) organization needs and goals, 2) organization needs amenable to IT system solutions, 3) behaviors linked with IT system use, 4) environmental and motivational factors associated with IT-related behaviors, and 5) strategies that will motivate IT system use.

Given the hospital administration at the intervention site has already addressed the first two assessment phases of IT implementation, this study along with the research to follow is focused on the last three stages of IT adoption: a behavioral understanding of consequences related to CPOE adoption and use (Phases 3 and 4), and the development of strategies to motivate adoption and continued use of CPOE (Phase 5).

Several theoretical approaches could be used to design interventions to motivate adoption of CPOE (i.e., Diffusion of Innovation **(**Rogers, 1995); Theory of Reasoned Action (Azjen & Fishbein, 1980; Azjen & Madden, 1986); Theory of Planned Behavior (Azjen, 1991); Technology Acceptance Model (Davis, 1993); Social-Cognitive Theory (Bandura, 1977); and Task-Technology Fit Model (Dishaw, 1999)). However, these approaches rely on strategies that target individual perceptions and expectations of the targeted technology among potential

adopters, and require intensive one-on-one or small group interventions that are labor intensive and do not fit well in most organizational settings (Geller, 2001a).

In addition, while these theories may explain and predict behavior, they do not provide the tools to initiate and sustain behavior change, nor techniques for measuring and changing factors that influence behavior. A more efficient and practical solution to motivating adoption of CPOE has been very successful in producing large-scale community and organizational change — applied behavior analysis.

Behavior-based strategies to increase safety. The three-term contingency, or A-B-C model (for antecedent, behavior, consequence) is the foundation upon which most behavior-based interventions are developed, especially in the realm of occupational safety (e.g., Alavosius & Sulzer-Azaroff, 1986; Geller & Williams, 2001; Komaki, Collins, & Penn, 1982; Streff, Kalsher, & Geller, 1993). An antecedent (A) is a stimulus that comes before a behavior (B) and encourages performance of that behavior (Daniels, 1994). These can take many forms, such as signs, reminder prompts, or even noises that *direct* behavior (Geller, 1996). Goal setting is one example of an antecedent strategy shown to be useful in improving safety, and several studies have consistently demonstrated the positive effects of goal setting on a variety of organizational performances (see Locke & Latham, 2002 for a review of the goal-setting literature).

A consequence (C) is an event that follows a given behavior and increases the probability the behavior will occur again in the future. Like antecedents, consequences can take many forms, such as feedback, monetary rewards, or a manager's praise for a job well done. For this reason, it can be said consequences *motivate* behavior (Geller, 1996), as we act in response to the consequences we receive (or expect to receive).

Behavior-based feedback. One type of consequence used in numerous settings to affect behavior change is feedback. In general, a feedback intervention consists of measuring a targeted behavior, and then delivering a message relevant to the assessed behavior of a person or group (e.g., frequency, percent correct). This message, providing information about targeted behavior, functions as a consequence of this targeted behavior. Examples of non-healthcare settings where feedback interventions have been employed to improve safety-related behavior in organizations include: a plastics manufacturing plant (Sulzer-Azaroff & de Santamaria, 1980), a metal fabrications company (Zohar *et al*., 1980), a bakery (Komaki *et al*., 1978), a public works department (Komaki *et al*., 1980), and a university cafeteria (Geller *et al*., 1980).

Behavioral maintenance. Establishing behavior change during an intervention phase is not sufficient. A long-term objective of an intervention designed to establish desired behavior should be to promote organizational contingencies needed to support the desired behavior after the intervention agents are no longer present (Boyce & Geller, 2001; McSween & Matthews, 2001). By doing so, the intervention techniques become part of the day-to-day practices of the organization, thereby becoming institutionalized. Behavioral maintenance, or the sustained impact of an intervention's behavioral effect, is determined by the institutionalization of the behavior-change intervention. Several factors are important to institutionalize an intervention, including: a) education and training, b) involving employees in customizing an intervention for their culture, c) developing organizational structure to monitor the intervention process, d) providing social and organizational consequences (e.g., feedback) to support the process, and e) generating "self-rules" individuals can use to motivate their own behavior (Boyce & Geller, 2001; McSween & Matthews, 2001).

Behavior is also maintained within an organization when influenced by natural (or intrinsic) contingencies. That is, when the natural (i.e., intrinsic or inherent) consequences of a behavior are rewarding, external contingencies (e.g., feedback from another source) are not necessary for motivation. Regarding the target behaviors of the research proposed to follow the current study, this occurs when the physician learns how to use the CPOE system and eventually finds it to be an efficient and organized system for ordering prescriptions. However, it often takes time for one to experience the intrinsic reinforcing consequences of a behavior. People need to engage in the behavior enough to be fluent and experience the natural, beneficial consequences of performing the behavior.

Thus, external contingencies are often necessary to motivate *initiation* of the behavior. The task of the behavior analyst is to develop interventions which use external contingencies that will not *over-control* the target behavior. Monetary incentives are a primary example of this type of external contingency; they work well initially to motivate the target behavior but when the incentive is withdrawn, the target behavior often decreases (Kohn, 1993; Lepper & Green, 1978; Pounds, 2006). Although as Mawhinney (1990) points out, some individuals, for whom an externally reinforced task is also naturally reinforcing, are not as likely to exhibit any post-extrinsic reinforcement decrement to intrinsic motivation.

The more an individual can be provided with information (i.e., feedback or a group goal) which prompts self-persuasion to engage in the target behavior, the more likely their behavior will be maintained by intrinsic consequences after the external contingencies are withdrawn. Indeed, long-term behavior change is determined by an individual's awareness of intrinsic consequences, and by the degree of self persuasion (Aronson, 1999) and self-perception (Bem, 1972) associated with the target behavior (Geller, 2005). Research has shown the more external

control exerted to influence behavior (as in top-down CPOE implementation mandate), the less internal control developed (Arronson & Carlsmith, 1963). Furthermore, decreases in perceived choice resulting from top-down mandates can decrease self-accountability (Geller & Johnson, in press).

The A-B-C Model and Healthcare

The A-B-C model can be readily applied to the behavior of healthcare workers. For example, physicians write quickly (and often illegibly) and use abbreviations when filling out prescription orders primarily because it takes less time to do so. They are avoiding the negative consequence of "wasting time" or missing a deadline. Another example: nurses decide not to question a physician's orders because they assume such behavior will result in negative consequences. To increase desired behaviors and decrease undesired behaviors, practical interventions must alter the behavioral consequences already in place.

Let us examine the physician behavior of prescribing medication with a paper system when the more desirable electronic system is available. The physician who chooses to write a medication order by hand is likely doing so because this behavior has been reliably reinforced in the past. That is, the physician's order-writing behavior is under the control of operant conditioning. This means the consequences of the physician's order-writing behavior are responsible for maintaining this behavior. Physicians become fluent at preparing handwritten medication orders because this behavior has been reliably reinforced by the natural consequence of order completion (for a relevant description of operant conditioning, see Geller, 2001b; Poling & Braatz, 2001).

Analogously, negative consequences may serve as punishment for learning a new IT approach. For example, a physician's behavior of trying to place orders using CPOE for the first

time may be followed by the negative consequence of requiring more time and effort than the existing paper-based system. Thus, a physician may avoid placing orders using CPOE to avoid the negative consequences of expending additional time and effort. That is, unless clear benefits of CPOE adoption and use are presented to physicians and related to his or her behavior of placing medication orders using CPOE, resistance to switching from the traditional paper-and-pen system can be expected.

Several successful applications of behavior analytic techniques in healthcare settings provide the foundations for designing interventions to initiate and maintain behaviors instrumental in delivering improved healthcare (Geller & Johnson, in press). In one example, Alavosius and Sulzer-Azaroff (1990) compared dense and intermittent feedback schedules to determine which best supported acquisition and maintenance of three health-care routines, including feeding, positioning, and transferring physically disabled patients. They reported both feedback schedules were effective in changing and maintaining desirable behavior, but densely scheduled feedback produced more immediate behavior change.

Babcock, Sulzer-Azaroff, Sanderson, and Sciback (1992) found that an intervention consisting of goal setting and reviewing feedback rates increased nurses' use of feedback to promote infection-control practices in a head-injury treatment center. Another study targeting infection control improved nurses' compliance with glove wearing in potentially infectious situations in the emergency room by implementing a performance feedback system (DeVries, Burnette, & Redmon 1991). Building on this line of research, Cunningham and Austin (2005) designed and implemented a highly successful intervention package including goal-setting, feedback, task clarification, and peer prompting to increase safe handling of sharps among hospital operating room teams.

The common aim among the studies reviewed above was to improve healthcare employee safety by changing the behavior of individuals within the organization. However, these demonstrations of behavioral control also achieve a much nobler cause, an improvement in patient safety. Fewer injuries among care providers reduce patient risk as well (e.g., fewer injuries to surgical team members during surgery results in fewer opportunities for patient infection). It seems the application of behavioral techniques aimed at changing healthcare employee behavior can indirectly improve patient safety. Given the clear evidence of this phenomenon, it seems logical to focus on changing the behavior of healthcare professionals as a means of reaching the targeted outcome of improved patient safety.

Increasing CPOE use. Completing medication orders using CPOE rather than writing orders by hand is one physician behavior clearly connected to improved patient safety, and more specifically, a reduction in medication errors and related ADEs. With a clearly observable and measurable behavior linked to a potential reduction in medication errors, an application of behavior analysis is warranted. For example, Levick and Stillman (2005) evaluated a number of strategies to increase the use of CPOE among physicians at a 750-bed tertiary community hospital, including: a) presenting studies that support CPOE as a means of care improvement, b) rewarding CPOE use with small trinkets, c) providing individual access to computers, d) adding clinical decision support, e) instigating relevant peer pressure to increase use, and f) providing financial compensation for extra time required to use and become proficient with the CPOE system.

The latter of these techniques was referred to as “the Recognition of Effort (ROE) program” (p.73), and was described as a “radical approach” (p. 73). This program “paid the physicians over a four-month period as recognition for using the system” (p.73). It seems these

authors had arranged pay-for-performance contingencies, although they misleadingly labeled the behavior-change program to link performance with social recognition for expending additional effort beyond the behaviors necessary for obtaining their existing compensation. The ROE program was most effective over the short term, as CPOE use increased from 35% to 57% when financial compensation was available. CPOE use declined to 42% several months after financial compensation was discontinued, but it didn't drop below baseline. Contrary to assertions by Kohn (1993), these results support the prior findings of organizational behavior management research (see reviews by Mawhinney, 1990 and Cameron & Pierce, 1994) which shows the target behavior does not drop below baseline following the withdrawal of intervention. In this case, there was some maintenance, probably because some physicians experienced intrinsic, or natural reinforcement from using the CPOE system.

One could certainly argue the reason increases in CPOE use were not fully maintained following the withdrawal of the financial incentive contingencies is because the external consequences of the financial incentive over-controlled the behaviors of increasing CPOE use for some physicians. Thus, less intrinsic consequences for increased CPOE use developed for some physicians because their increased CPOE use had been overly controlled by presentation of the monetary incentive following their CPOE use. At the same time, other physicians experienced more intrinsic consequences resulting from CPOE use which maintained their increased CPOE use following the withdrawal of the monetary incentive.

Of the approaches to increasing CPOE use tested by Levick and Stillman (2005), some were moderately successful (i.e., monetary incentives) yet failed to maintain behavior change completely (increased rates of CPOE use). Others, such as peer pressure, elicited a reactive response by many of the resident physicians, only using CPOE when being directed to do so by

an attending physician and otherwise avoiding the system. These approaches did not lead to development of natural reinforcement for increased CPOE use among the majority of physicians. They mainly consisted of authorities either suggesting use or directly rewarding increased CPOE use monetarily.

A more effective strategy might have been to collect objective quality and efficiency data on the behavioral results of CPOE use and present this information to physicians as a feedback intervention to motivate CPOE use. While this approach would have involved a significant amount of additional data collection, it would have been a valuable contribution to this body of research. Motivating use of this promising patient-safety tool may be better activated by providing physicians with objective data about theirs and/or their peers' performance. This approach could be useful for multiple reasons: 1) it provides a way of monitoring the system's impact on the medication ordering process; 2) meaningful data provide physicians with evidence of the benefits of using CPOE; and 3) it may be more cost-effective than providing financial incentives.

While this study clearly demonstrated arranging environmental contingencies could increase the frequency of CPOE use, the full effects of the intervention were only maintained as long as financial compensation was available. This suggests additional behavioral interventions are necessary, not only as a way to reduce costs but also to maintain a more stable pattern of desired behavior change. As indicated earlier, it is believed this can be accomplished by bringing physicians in touch with intrinsic consequences (Horcones, 1987), and using intervention components that promote self-persuasion (Aronson, 1999). The research proposed to follow the current study will address this issue and contribute to the literature reviewed by hospital administrators facing the implementation of CPOE.

This study is a crucial step prior to intervening to increase physicians' adoption and use of CPOE. If one is designing an intervention to increase CPOE use, one should take measures to be sure CPOE really is a more effective method of medication ordering. This objective can be met by using archival data to obtain measures of behavioral results and their impact on the medication ordering process. Specifically, measures of overall order compliance with safe ordering standards and time to first dose of antibiotic taken for medication orders placed either through handwritten paper orders or using CPOE meets this crucial preliminary objective.

The objectives of this study were to: 1) evaluate a natural CPOE implementation/ intervention in a hospital setting from a behavioral perspective of resulting impact on the medication ordering process; and 2) produce meaningful data and results for the purpose of providing feedback and rationale to physicians participating in interventions designed to increase CPOE adoption and use.

The results of this study inform the differential efficacy of using CPOE rather than traditional paper medication orders. It was expected CPOE orders would result in safer medication orders in comparison to paper orders based on the following criteria: 1) CPOE orders show a greater compliance percentage; 2) more CPOE orders are error-free (100% compliant); 3) CPOE first-dose-of-antibiotic orders are delivered faster; 4) more CPOE first-dose-of-antibiotic orders are delivered within 240 minutes; and 5) overall compliance of all medication orders is higher at a CPOE-intervention hospital than at a non-CPOE control hospital.

Method

Participants

The participants were physicians working at one of two hospitals (intervention vs. control) as either consulting physicians under contract or as hospitalists directly employed by the

hospital. They were drawn from overall physician populations of 194 (intervention site) and 159 (control site).

Setting

The settings were two medical centers located in Virginia, both of which are owned and operated by the same corporate entity. The intervention site was a 521-bed hospital, and the control site was a 146-bed hospital. The intervention hospital has established the organizational goal of achieving a 50% rate of CPOE use for all medication orders by the end of 2006, while the control hospital is expected to implement CPOE some time in 2007.

Procedure

Data Collection

Data were collected by research assistants in the Center for Applied Behavior Systems (CABS), working in teams of two or three. Data collection sessions occurred three to four days weekly at each hospital, usually lasting two to three hours each. The principal investigator (i.e., the author) and two research assistants working as data collection leaders were trained in accessing and interpreting relevant medication ordering records by hospital personnel from the pharmacy and information systems departments, and then subsequently these data-collection leaders trained 12 other research assistants who rotated in their assignments to data collection at each hospital. The research assistants had access to pharmacy personnel for clarification of specific information on written medication orders (i.e., alternate drug names, physician signature identification, abbreviation meanings, etc.).

Dependent Variables

*Compliance***.** The percent compliance per medication order was collected systematically with a behavioral checklist (see Appendix A for Order Compliance Data Collection Form).

These data were collected from both handwritten paper orders and electronic orders, using copies of the paper orders and printouts of electronic orders in the pharmacy. For each patient medication order set reviewed, the checklist includes a space to mark "yes" or "no" for date, time, drug name, drug dosage, drug route (when needed), frequency of administration, prescriber signature, non-use of "do-not-use" abbreviations, no leading decimals, no trailing zeros, PRN orders are qualified, and HOLD orders use clear criteria. At the bottom of the checklist, the total numbers of items checked marked as "yes" or "no" were summed, as well as the total number of medications ordered, and these numbers were used to calculate a compliance percentage.

*Efficiency***.** Time to first dose of antibiotic was also collected (i.e., from systematic examination of written orders and the hospital medication order database; see Appendix B for Time to First Dose of Antibiotic Data Collection Form). This key variable was selected because of the implications of antibiotic delivery within four hours of hospital arrival (Houck *et al*., 2004; Battleman *et al*., 2002) as well as because the corporation that owns both hospitals has established first-dose-of-antibiotic delivery within four hours as an organizational goal.

The dependent variable was the delay between ordering the antibiotic to the time it was administered to the patient. Written antibiotic orders were tagged by pharmacists so they could be easily retrieved from files by research assistants. Research assistants were provided with a list of all antibiotic names in use at the hospital. The antibiotic name was recorded from the written form and verified through the hospital medication order database. The time and date of the order being written were gathered from the written order. Some physicians did not record the time of ordering, thereby making those ordering times impossible to determine and thus limiting the sample for paper-order efficiency data.

The time of administration was obtained from the hospital medication order database, where the administration time is automatically recorded by the existing Electronic Medication Administration Record (eMAR) system. Time to first dose of antibiotic for paper orders was calculated by subtracting the order entry time from the administration time. Time to first dose of antibiotic for electronic orders was obtained from a report generated by hospital personnel from information systems.

Rater Reliability. To obtain measures of reliability, two research assistances worked independently to collect information on the same medication orders. The frequency that two independent observers agreed and disagreed on each particular behavioral category was totaled and a percentage of agreement was calculated. This allowed for the calculation of inter-rater reliabilities on the compliance and efficiency data.

Inter-rater reliability data were gathered for 198 order sets used for collecting compliance data (23% of total sample), yielding an overall inter-rater agreement of 90%. Reliability data were gathered for 53% of paper-based antibiotic orders, indicating 97.5% agreement between two independent observers. Although reliability data would ideally have been gathered on at least 30% of order sets used for compliance data, it is reasonable to assume both the compliance and efficiency data are reliable given the high rates of agreement between independent observers.

Experimental Design

This was a quasi-experimental study of a naturally occurring CPOE intervention. An AB design with a non-equivalent control was observed.

Baseline

Baseline consisted of collecting compliance and efficiency data for paper orders at both the intervention hospital and the control hospital. Baseline data collection lasted for

approximately five weeks at the intervention hospital and four weeks at the control hospital. Baseline conditions at both hospitals consisted of an existing paper-based medication ordering system.

Intervention

The intervention observed was the implementation of CPOE. The specific product name of the CPOE system put in place is Electronic Physician Order Management, or ePOM. The beginning of the intervention phase was defined as the day all physicians could gain access to CPOE voluntarily. Data collection on compliance and efficiency for CPOE orders went on for approximately five weeks following CPOE implementation, and compliance and efficiency data for paper orders continued for one week at the intervention hospital and three weeks at the control hospital following CPOE implementation.

At the intervention site, a self-selected group of 20 physicians were the first to begin using the system. Within four weeks of implementing the ePOM system for these physicians, the ePOM system was available for all physicians working at both hospitals. This initial period of pilot use with self-selected participants was used to work out unforeseen technical difficulties and familiarize support staff with the system.

The intervention included a basic promotional effort by hospital administration. CPOE use was promoted in the intervention hospital with a general awareness campaign, consisting of newsletter inserts, posters, and signs with talking points stating “ePOM is simpler and safer” and illustrations of the differences in the steps involved between the existing paper medication ordering process and the ePOM ordering process, showing how ePOM is safer and faster. In addition, training on using the ePOM system has been readily available on a voluntary basis throughout this intervention period, and will continue to be throughout the research following

from this project. Thus, lack of available training should not be a barrier to CPOE adoption and use.

Results

Compliance

To determine medication order compliance percentages, a random sample of 889 individual patient medication order sets was reviewed at the CPOE-intervention hospital, including 3,553 medications ordered. At the control hospital, a random sample of 587 patient medication order sets were reviewed, including 2,112 medications ordered. These data were graphed as weekly mean percentages in a time-series format (see Figure 1), and visual inspection suggested significant differences in mean order compliance between hospital, format, and phase.

Medication order compliance data from the intervention and control hospitals were grouped by hospital, phase, and order-entry format to test for differences in mean percent compliance. A series of t-tests were used to detect differences in mean percent compliance both within the intervention hospital pre-and post-intervention and between the intervention and control hospitals before and after the intervention.

Baseline medication order compliance data were grouped by hospital (intervention vs. control) to test for a difference in mean compliance prior to CPOE implementation. T-test results indicated the baseline mean compliance rates for paper orders at the intervention hospital (59.0%, $n = 409$, $SD = 39.6$) and control hospital (61.4%, $n = 206$, $SD = 41.8$) did not significantly differ, $t\ (613) = 0.70$, $p > .40$.

Medication order compliance data from the intervention hospital were grouped by phase (baseline vs. intervention) to test for an overall difference in mean compliance during the intervention. T-test results, using Levene's correction for equal variances not assumed, indicated

the mean compliance rate for the intervention phase (74.9%, n = 480, SD = 35.1) was significantly higher than during baseline (59.0%, n = 409, SD = 39.6), t (823) = 6.28, p < .001.

Medication order compliance data from the intervention hospital were grouped by format (CPOE vs. Paper) to test for between-format differences in mean percent compliance following the intervention. T-test results, again using Levene's correction for equal variances not assumed, indicated the mean compliance rate for CPOE orders (79.1%, n = 320, SD = 32.1) was significantly greater than mean compliance for Paper orders (66.5%, n = 160, SD = 39.2), t (268) = 3.53, p <.001.

Intervention medication order compliance data were grouped by hospital (intervention vs. control) to test for a difference in mean compliance following CPOE implementation. T-test results, again using Levene's correction for equal variances not assumed, indicated the mean compliance rate during the intervention phase for the intervention hospital (74.9%, n = 480, SD = 35.1) was significantly greater than the mean compliance rate for the control hospital (63.7%, n = 381, SD = 41.1), t (748) = 4.23, p <.001.

To detect differences in the rate of orders meeting criteria for 100% compliance v. less than 100% compliance post-intervention, data were classified as either 100% compliant or not. A 2 Compliance (100% vs. <100%) x 3 Group (Control Hospital Paper Orders vs. Intervention Hospital Paper Orders vs. Intervention Hospital CPOE Orders) Pearson Chi-square was calculated to determine differences in complete (100%) compliance across intervention and control conditions. Results indicated CPOE orders at the intervention site had the highest rates of 100% compliance (59.1%, n = 320), followed by paper orders at the intervention site (49.4%, n = 160) and control site paper orders (34.4%, n = 314), χ^2 (2) = 39.01, p <.001.

Additionally, the frequencies at which medication orders met specific compliance criteria are displayed in Table 1 below. This table displays a comparison of the rate at which each of the different compliance criteria contributing to the overall compliance percentage were achieved between CPOE and Paper orders at the intervention hospital. This table is included to address factors contributing to CPOE medication orders averaging less than 100% compliance.

Efficiency

To evaluate the duration of time to first dose of antibiotic, a total of 173 first-dose-of-antibiotic orders were examined. These data were graphed as three histograms (Intervention Hospital Paper Orders, Intervention Hospital CPOE Orders, and Control Hospital Paper Orders) indicating distributions of order delivery times classified by 120-minute (2-hour) intervals (see Figure 2). Additionally, the percentage of first-dose-of-antibiotic orders delivered within 240 minutes (4 hours) was calculated for each ordering format at each hospital. The efficiency results for each ordering format used at each hospital are as follows:

Intervention Hospital Paper Orders: Mean = 326.17 minutes; n = 93, SD = 301.4; 55.9% of first dose of antibiotic orders delivered within 240 minutes.

Intervention Hospital CPOE Orders: Mean = 185.04 minutes; n = 51, SD = 91.4; 78.4% of first dose of antibiotic orders delivered within 240 minutes.

Control Hospital Paper Orders: Mean = 269.14 minutes; n = 29, SD = 319.2; 75.9% of first dose of antibiotic orders delivered within 240 minutes.

Efficiency data for the intervention hospital were grouped by format (CPOE vs. Paper) to test for any difference in mean duration to first dose of antibiotic. T-test results, using Levene's correction for equal variances not assumed, indicated the mean duration to first dose of antibiotic for CPOE orders (185.04 minutes, n = 51, SD = 91.4) was significantly shorter than the mean

duration to first dose of antibiotic for paper orders (326.17 minutes, $n = 93$, $SD = 301.4$), $t\ (119) = 4.18$, $p<.001$.

Discussion

The findings of this study demonstrate clear improvements in key patient-safety variables. CPOE orders have been shown to be significantly safer and more effective than traditional paper orders in previous research (Bates *et al*., 1998, 1999; Upperman *et al*., 2004; King *et al*., 2003; HBQI, 2003), and the findings of this study provide additional evidence for the benefits of CPOE. While the majority of these previous studies measured CPOE's impact with outcome measures of medication error incidence and ADEs (i.e., Bates *et al*., 1998, 1999; Upperman *et al*., 2004; King *et al*., 2003), this study measured the impact of CPOE with measures of medication-order compliance with standards for safe ordering and efficiency of medication delivery following order entry. Specifically, this study showed medication orders placed by physicians using CPOE rather than the traditional paper ordering system resulted in more complete, unambiguous, legible, and therefore safe medication prescriptions for pharmacists to deliver and nurses to administer, and enabled the entire process to be completed in a reduced period of time.

Safer Prescribing with CPOE

Baseline rates of medication-order compliance did not vary significantly between the two hospitals, and during the intervention condition, medication-order compliance was significantly higher at the intervention hospital. Additionally, CPOE orders at the intervention hospital were significantly more compliant than paper orders at both the intervention and control sites.

The sample sizes for CPOE orders and paper orders at the intervention site were not proportional to the percentage of total medication orders entered using CPOE vs. Paper formats,

and during the intervention phase, hospital information systems personnel estimated the proportion of total orders entered using CPOE to be 5-10%. Thus, ideal sampling would have included hundreds more paper-based order sets rated for compliance. This would have enabled detection of any possible changes in paper-order compliance as more physicians begin using CPOE.

It is possible some physicians who continue to write orders by hand do so at a higher rate of compliance than those physicians who are quick to adopt CPOE. To assess this possibility compliance data for paper medication orders will continue to be collected in the research at these hospitals to follow from this study. Despite these limitations, the impact of CPOE on overall compliance with medication-order standards in the intervention hospital suggests even having just a portion of the physician population adopting CPOE has an immediate and significant impact on the safety of medication ordering.

Many would not have anticipated the finding that CPOE order compliance was anything less than 100%. Although this was an admitted possibility due to the free-text option in the current CPOE system, and therefore justified compliance data collection for CPOE orders, it was not expected that CPOE order compliance would be below 80%. Explanation for this finding can be found in Table 1, as only 18% of PRN, or “as needed” orders were qualified on CPOE medication orders. It is possible this particular compliance issue, or potential error, could be eliminated by altering programmed contingencies for submitting electronic order entries to require some type of qualifier be entered for PRN orders. However, this finding brings to light the possibility of physicians possibly over-relying on the CPOE system to force them into producing compliant medication orders, and the necessity for continued data collection to monitor changes in CPOE order compliance as a part of future research.

First dose of antibiotic orders entered using CPOE were administered significantly sooner than first dose of antibiotic orders entered using the paper-based approach. Also, CPOE caused a significant increase in the percentage of first doses of antibiotic delivered within the organizational goal of under 240 minutes at the intervention hospital (see Figure 2). This is likely due to much more efficient processing of electronic medication orders, as they are: a) instantly delivered to the pharmacy as opposed to being left in a tray to be processed in any length of time (i.e., whenever a nurse or pharmacist sees the order copy in the tray and enters it into the medication ordering database), b) much easier to read as compared to carbon copies of physicians' handwriting, c) more complete due to forced field entry, and d) less likely to contain ambiguous information which further delays medication administration by necessitating a call to the physician for clarification. These findings have multiple implications for the benefits of CPOE, including reduced in-hospital mortality, reduced mortality within 30 days of admission (Houck, Bratzler, Nsa, Ma, & Bartlett, 2004), shorter length of stay (Battleman, Callahan, and Thaler, 2002), and therefore reduced healthcare costs.

It is also noteworthy that the percentage of first doses of antibiotic delivered within 240 minutes was not significantly different between paper orders at the control hospital and CPOE orders at the intervention hospital. One could argue CPOE would not have a significant impact on medication delivery efficiency at the control hospital based on the similarity of mean first dose times between paper orders at the control hospital and CPOE orders at the intervention hospital. However, it is important to note the control hospital (146 beds) is much smaller than the intervention hospital (521 beds), and the differences in delivery times for paper orders between the two sites could be largely due to differences in number of medications ordered and proximity of pharmacy to patient locations. Furthermore, it should be noted that CPOE has the

potential to eliminate first-dose delivery time lags far beyond the four-hour goal which tend to occur with paper orders (see Figure 2). This is due to CPOE orders being delivered to pharmacists instantly rather than being delivered when discovered by a nurse or pharmacist as is the case with paper orders.

The data collection methods used in this study were developed in collaboration with hospital personnel. This has implications for the value of this study's contribution to the literature on patient-safety improvement and specifically the literature on CPOE. Nearly every evaluation of CPOE has been conducted by medical professionals at the hospitals where they are employed or under contract. This study demonstrates the ability of a behavioral research team to make a contribution to the field of patient-safety improvement. Data collectors were not trained medical personnel. However, they were either trained by medical personnel or data-collection leaders that had been trained by medical personnel, and were able to access relevant medical experts throughout data collection to ask questions, clarify information from medication orders, and ultimately learn about the medication-ordering process. At the same time, these research assistants were able to collect objective and reliable data on key patient-safety variables as a third party, without any vested interest in the findings.

This process of evaluating the impact of the newly implemented CPOE system also makes a valuable contribution in that it is easily handed over to hospital personnel. This process could be replicated with ease by hospital employees working in nearly any department (i.e., pharmacy, information systems, or quality management). A hospital implementing CPOE could incorporate the evaluation process described in this study and not only gain valuable information about the resulting impact of CPOE implementation, but also produce meaningful data for use in interventions designed to increase CPOE use. Given the possible reduced cost of this type of

intervention strategy compared to other interventions such as monetary incentives, there is greater opportunity for institutionalization (Boyce & Geller, 2001), and therefore behavioral maintenance.

Limitations

While the findings of this study shows strong evidence for the improvement of patient safety, it does have several limitations in addition to those already acknowledged (i.e., limited efficiency data sample, lack of adequate sample of paper-order compliance data at intervention site and reliability data for only 23% of compliance data). One clear limitation is the lack of experimental control which accompanies any quasi-experimental study of a naturally occurring intervention, particularly with a non-equivalent control. There likely may have been pre-existing differences between the physicians working in the intervention and control hospitals, as well as the medication-ordering infrastructure at each hospital which could have influenced medication-ordering compliance and efficiency regardless of the CPOE intervention.

This study is also limited by the use of group data on physician ordering behavior rather than tracking individual physicians' medication orders to assess compliance and efficiency results separately for each physician. Individual data would enable identification of specific physicians to be targeted for intervention as well as personalized data to be used in providing performance feedback. While this is a regrettable limitation, it is also a necessary one due to the sensitive nature of the data being collected. Essentially, this study is an attempt to quantify potential errors in medication prescribing, and any data identifying individual physicians committing any number of potential prescribing errors would surely come under extensive legal and ethical scrutiny. Thus, hospital administrators would not allow for any sort of individually identifiable data collection. Additionally, hospital administrators concerns regarding the

dissemination of potential error data were alleviated to some extent by the positive labeling of medication-order data as compliance rather than non-compliance or even potential-error data.

Another limitation is the lack of behavioral observations of physicians placing medication orders using both CPOE and traditional paper methods. Observing physicians engaging in both types of ordering behavior would allow for measurement of variables such as duration of order entry, environmental factors at location of order placement, and activating events (i.e., preceding patient consultations). This limitation is also regrettable yet necessary, as reliable observation of physicians' medication-ordering behavior would be highly intrusive, would require much more time and effort, might possibly interfere with work-flow, and could elicit reactance from participants. The use of archival measures in this study alleviates these problems as "the performers do not have to be present for their behaviors to be observed" (Daniels, 1989, p. 140). Data were collected on the meaningful consequences, or "valuable accomplishment" (Gilbert, 1978, p. 17) resulting from the targeted behavior of medication-order writing. Using archival data also allowed for rapid collection of larger amounts of data than would be possible using behavioral observations.

One more limitation is the lack of identification of specific medications being prescribed in non-compliant orders, or being reported in incidents of error. It would be very useful information to know which medications were being ordered in the more noncompliant order sets, particularly for providing more meaningful information about specific behaviors to physicians in future interventions to increase CPOE use. Identification of specific medications within order sets would have been difficult to add to the compliance data collection method used in this study because the percent compliance score was calculated from several medications ordered in a single set. Thus, there may have been no particular medications which stood out as being more

frequently prescribed with noncompliance. The latter portion of this limitation is a product of the difficulty in obtaining highly sensitive data from hospital administrators, as they are extremely hesitant to release any data regarding errors or even potential errors. Even if these data were attainable, it may not be especially informative due to the unreliable nature of error reporting systems which rely on voluntary disclosure of errors.

Despite these limitations, the results of this study suggest CPOE is having a significant beneficial impact on patient safety at one hospital, and therefore interventions to increase physician adoption of CPOE are warranted. The next step in this line of research has already been planned, and the findings supporting the positive impact of CPOE will enable this research to move forward.

Future Direction for Research

Given that CPOE has been shown to be effective and is being used at a relatively low rate, there is a clear need for interventions to increase CPOE adoption and use among physicians. The findings of the current research have been included as a preliminary study in a grant application recently resubmitted to the Agency for Healthcare Research and Quality.

The overarching goal of the proposed research is to increase patient safety by developing and evaluating interventions that will increase and sustain CPOE adoption and use in hospital settings. The specific aims of the proposed research are to: 1) develop behavior-based interventions designed to increase and sustain CPOE adoption and use among physicians working in two large medical centers; 2) replicate the intervention strategies found to be most successful in an additional hospital setting that implementing CPOE in 2007; 3) continue to evaluate the impact of CPOE on compliance and efficiency of medication orders as well as on overall frequency of medication errors; and 4) continue developing a program of research

incorporating principles from community and organizational safety into the culture of healthcare professionals and patient safety (cf. Geller & Johnson, in press).

The current research suggests adoption of CPOE will reduce medication-related errors in the intervention hospital and therefore improve patient safety. The proposed research will explore three behavior-based interventions (goal awareness; goal awareness/group feedback; goal awareness/group feedback/social comparison) designed to increase CPOE adoption and use among two groups of physicians working in either the current 521-bed intervention hospital or a 470-bed hospital, and continue to compare the efficacy of using the new CPOE system with the existing paper-based system. The group feedback component in the proposed research will the data obtained in the current study. Physicians will receive graphic feedback on their group compliance and efficiency rates, and this group-specific feedback on relevant medication-ordering behavior is expected to motivate increased physician adoption and use of CPOE. The results of the proposed study will inform the development of large-scale interventions to increase hospital-wide use of CPOE, and thus prevent various medication-related errors.

The data obtained from the proposed research will be used to provide an objective rationale for adopting the CPOE system among physicians working at the intervention hospitals, as well as add to the body of literature used to guide decisions regarding the implementation of CPOE in hospitals nationwide. Physicians will receive group feedback on their overall CPOE system use, as well as the daily percentages of group members placing at least one order on the CPOE system per day. Successful intervention strategies will be refined and disseminated so other hospitals considering CPOE implementation can benefit.

The external validity (or *institutionalization*, Boyce & Geller, 2001) of the various interventions will be evaluated with group discussions among hospital personnel, including

members of a CPOE Research Advisory Board. A replication of successful intervention strategies from this research will be implemented at a control hospital, which will implement CPOE in 2007. After a baseline period, managers at this hospital will then use an implementation manual (a deliverable from this project) to design and implement their own behavior-based intervention to increase CPOE use at their hospital. Thus, the generalizability (or external validity) of certain behavior-based interventions will be evaluated by comparing the hospital's baseline CPOE-use data to the rate of CPOE use following an intervention process developed from our initial findings.

This process of conducting an initial evaluation comparing the results of two types of medication-ordering behavior, although somewhat cumbersome, is absolutely necessary prior to intervening to increase CPOE adoption and use. Without the evidence supporting CPOE's added benefits from the hospital in which it has been implemented, blindly intervening to increase CPOE use could actually increase the likelihood of errors occurring and thus violate the most important directive of the medical profession, "First, do no harm" (*Hippocrates*, as cited in IOM, 1999).

References

Agency for Healthcare Research and Quality. (2005). *Medical errors: The scope of the problem*. Retrieved January 26, 2005, from http://www.ahrq.gov/qual/errback.htm

Alavosius, M. P., & Sulzer-Azaroff, B. (1986). The effects of performance feedback on the safety of client lifting and transfer. *Journal of Applied Behavior Analysis, 19*, 261-267.

Alavosius, M. P., & Sulzer-Azaroff, B. (1990). Acquisition and maintenance of healthcare routines as a function of feedback density. *Journal of Applied Behavior Analysis, 23*, 151-162.

American Society of Health-System Pharmacists. (2002, July 17). *Survey reveals patient concerns about medication related issues.* Retrieved April 26, 2005, from the http://ashp.org/news/ShowArticle.cfm?id=2996

Aronson, E. (1999). The power of self-persuasion. *American Psychologist, 54*, 875-884.

Aronson, E., & Carlsmith, J. M. (1963). Effect of severity of threat on the valuation of forbidden behavior. *Journal of Abnormal and Social Psychology*, *66*, 584-588.

Ash, J. S., Gorman, P. N., & Seshardi, V. (2004). Computerized physician order entry in U.S. hospitals: Results of a 2002 survey. *Journal of the American Medical Informatics Association, 11*(2), 95-99.

Azjen, I., & Fishbein, M. (1980). *Understanding attitudes and predicting social behavior*. Englewood Cliffs, NJ: Prentice-Hall.

Azjen, I., & Madden, T. J. (1986). Prediction of goal –directed behavior: Attitudes, intentions, and perceived behavioral control. *Journal of Experimental Social Psychology, 22*, 453-474.

Azjen, I. (1991). Theory of planned behavior. *Organizational Behavior and Human Decision Processes, 50*, 179-211.

Babcock, R. A., Sulzer-Azaroff, B., & Sanderson, M. (1992). Increasing nurses' use of feedback to promote infection-control practices in a head-injury treatment center. *Journal of Applied Behavior Analysis, 25*, 621-627.

Barker, K. N., Mikeal, R. L., Pearson, R. E. Illig, N. A., & Morse, M. L. (1982). Medication errors in nursing homes and small hospitals. *American Journal of Hospital Pharmacology, 39*, 987-991.

Barker, K. N., Flynn, E. A., Pepper, G. A., Bates, D. W., & Mikeal, R. L. (2002). Medication errors observed in 36 healthcare facilities. *Archives of Internal Medicine, 162*, 1897-1903.

Bandura, A. (1977). *Social learning theory.* Englewood Cliffs, NJ: Prentic-Hall.

Bates, D. W., Leape, L., Cullen, D. J., Laird, N., Petersen, L. A., Teich, J. M., et al. (1998). Effect of computerized physician order entry and a team intervention on prevention of serious medication errors. *Journal of the American Medical Association, 280*(15), 1311-1316.

Bates, D. W., Teich, J. M., Seger, D., Kuperman, G. J., Ma'Luf, N., Boyle, D., et al. (1999). The impact of computerized physician order entry of medication error prevention. *Journal of the American Medical Informatics Association, 6*(4), 313-321.

Battleman, D., Callahan, M., & Thaler, H. (2002). Rapid antibiotic delivery and appropriate antibiotic selection reduce length of hospital stay of patients with community-acquired pneumonia. *Archives of Internal Medicine*, *162*(6), 682-688.

Bem, D. J. (1972). Self-perception theory. In L. Berkowitz (Ed.), *Advances in experimental social psychology*, Vol. 6 (pp.1-60). New York: Academic Press.

Bovbjerg, B., & Bartow, A.. (2003). *Understanding Pennsylvania's Medical malpractice crisis.* Philadelphia, PA: The Pew Charitable Trust.

Boyce, T. E., & Geller, E. S. (2001). Applied behavior analysis and occupational safety: The challenge of response maintenance. *Journal of Organizational Behavior Management, 21*(1), 31-60.

Burke, M., Boal, J., & Mitchell, R. (2004). Communicating for better care: Improving nurse-physician communication. *American Journal of Nursing, 104*(12), 40-47.

Cameron, J. & Pierce, W.D., Reinforcement, reward, and intrinsic motivation: A meta-analysis. *Review of Educational Research, 64,* 363-423.

Clancy, T. R. (2004). Medication error prevention: Progress of initiatives. *Jona's Healthcare, Law, Ethics, and Regulation, 6*(1), 3-12.

Cutler, D. M., Feldman, N. E., & Horwitz, J. R. (2005). U.S. adoption of computerized physician order entry systems. *Health Affairs, 24*(6), 1654-1664.

Cunningham, T. R., & Austin, J. (2005). Increasing the use of an injury reduction technique in a hospital operating room. Paper presented at the meeting of the Association for Behavior Analysis, Chicago, IL.

Daniels, A.C. (1989). *Performance management: Improving quality productivity through positive reinforcement.* (3rd ed.). Tucker, GA: Performance Management Publications.

Daniels, A. C. (1994). *Bringing out the best in people*. New York: McGraw-Hill, Inc.

Davis, F. D. (1993). User acceptance of information technology: System characteristics, user

perceptions and behvioural impacts. *International Journal of Man-Machine Studies, 38*, 475-487.

Devries, J. E., Burnette, M. M., & Redmon, W. K. (1991). AIDS prevention: Improving nurses' compliance with glove wearing through performance feedback. *Journal of Applied Behavior Analysis, 24*, 705-711.

Dishaw, M. T., & Strong, D. M. (1999). Extending the technology acceptance model with task-technology fit constructs. *Information Management, 36*, 9-21.

Geller, E. S. (1996). *The psychology of safety: How to improve behaviors and attitudes on the job*. Rednor, PA: Chilton Book Company.

Geller, E. S. (2001a). *Working safe: How to help people actively care for health and safety*. (2nd ed., pp. 83-110). Boca Raton, FL: CRC Press.

Geller, E. S. (2001b). Behavior-based safety in industry: Realizing the large-scale potential of psychology to promote human welfare. *Applied and Preventive Psychology, 10*, 87-105.

Geller, E. S. & Williams, J.H. (Eds.) (2001). *Keys to behavior-based safety from Safety Performance Solutions*. Rockville, MD: Government Institutes.

Geller, E. S. (2005). *People-based safety: The source*. Virginia Beach, VA: Coastal Training Technologies Corporation.

Geller, E. S., Eason, S., Phillips, J., & Pierson, M. (1980). Interventions to improve sanitation during food preparation. *Journal of Organizational Behavior Management, 2*, 229-240.

Geller, E. S., & Johnson, D. (in press). *Anatomy of medical errors: A people-based approach to improving healthcare.* Virginia Beach, VA: Coastal Training and Technologies Corporation.

Gilbert, T.F. (1978). *Human competence: Engineering performance*. New York: McGraw-Hill.

Horcones (1987). The concept of consequences in the analysis of behavior. *The Behavior Analyst, 10*, 291-294.

Harris, L. (1997). *National patient safety foundation at the AMA: Public opinion of patient safety issues research findings*. Retrieved April 26, 2005, from the National Patient Safety Foundation Web site: http://www.npsf.org/publications.html

Health Grades. (2004). *Health Grades quality study: Patient safety in American hospitals.* Retrieved February 1, 2006, from http://www.healthgrades.com/media/ nglish/pdf/HG_Patient_Safety_Study_Final.pdf

Healthcare Benchmarks and Quality Improvement. (2003). *Report: CPOE adoption a long-term process.* Retrieved December 17, 2005, from FIND ARTICLES database.

Houck, P., Bratzler, D., Nsa, W., Ma, A., & Bartlett, J. (2004). Timing of antibiotic administration and outcomes for medicare patients hospitalized with community-acquired pneumonia. *Archives of Internal Medicine, 164*, 637-644.

Institute of Medicine. (1999). To err is human: Building a safer health system. Washington, D.C.: National Academy Press.

Johnson, J. A., & Bootman, J. L. (1995). Drug-related morbidity and mortality: A cost-of-illness model. *Archives of Internal Medicine, 155*, 1949-1956.

Kaushal, R. B., & Bates D. W. (2005). *Computerized Physician Order Entry (CPOE) with Clinical Decision Support Systems (CDSS).* Agency for Healthcare Quality and Research, Rockville, MD. Retrieved April 17, 2005, from the World Wide Web: http://www.ahcpr.gov/clinic/ptsafety/index.html

King, W. J., Paice, N., Rangrej, J., Forestall, G. J., & Swartz, R. (2003). The effect of computerized physician order entry on medication errors and adverse drug events in pediatric inpatients. *Pediatrics, 112*(3), 506-509.

Komaki, J. L., Barwick, K. D., & Scott, L. R. (1978). A behavioral approach to occupational safety: Pinpointing and reinforcing safe performance in a food manufacturing plant. *Journal of Applied Behavior Analysis, 11*, 434-445.

Komaki, J. L., Collins, R. L., & Penn, P. (1982). The role of performance antecedents and consequences in work motivation. *Journal of Applied Psychology, 67*(3), 334-340.

Komaki, J. L., Heinzmann, A. T., & Lawson, L. (1980). Effects of training and feedback: A component analysis of a behavioral safety program. *Journal of Applied Psychology, 65*, 261-270.

Kohn, A. (1993). *Punished by rewards: The trouble with gold stars, incentive plans, A's, praise, and other bribes*. Boston: Houghton Mifflin.

Koppel, R., Metlay, J. P., Cohen, A., Abaluck, B., Localio, A. R., Kimmel, S.E., & Strom, B.L. (2005). Role of computerized physician order entry systems in facilitating medication errors. *Journal of the American Medical Association, 293*(10), 1197-1203.

Kukafka, R., Johnson, S. B., Linfante, A., & Allegrante, J. P. (2003). Grounding a new information technology implementation framework in behavioral science: A systematic analysis of the literature on IT use. *Journal of Biomedical Informatics, 36*, 218-227.

The Leapfrog Group. (2001). *Fact Sheet*. Retrieved January 27, 2006, from http://leapfroggroup.org/factsheets/If_factsheet.pdf.

The Leapfrog Group. (2005). *The Leapfrog Group: About us*. Retrieved April 7, 2005, from http://www.leapfroggroup.org/about_us

Lepper, M., & Green, D. (1978) *The hidden cost of reward*. Hillsdale, NJ: Erlbaum.

Levick, D., Lukens, H. F., & Stillman, P. L. (2005). You've led the horse to water, now how do you get him to drink: Managing change and increasing utilization of computerized provider order entry. *Journal of Health Information Management, 19*(1), 70-75.

Locke, E.A., & Latham, G.P. (2002). Building a practically useful theory of goal setting and task motivation: A 35-year odyssey. *American Psychologist*, *57,* 9, 705-717.

Mawhinney, T.C. Decreasing intrinsic 'motivation' with extrinsic rewards: Easier said than done. *Journal of Organizational Behavior Management, 11(1),* 175-191.

McSween, T., & Matthews, G. A., (2001). Maintenance in safety behavior management. *Journal of Organizational Behavior Management, 21*(1), 75-83.

National Practitioner Data Bank Annual Report. Retrieved January 30, 2006, from http://www.npdb-hipdb.com/pubs/stats/2003_NPDB_Annual_Report.pdf

Nelly, N. K. (2004). Medication errors: Lessons learned and actions needed. *Professional Safety*, 35-41.

Occupational Safety and Health Administration. (2005). *OSHA fact sheet*. Retrieved April 5, 2005, from http://www.osha.gov/OshDoc/data_General_Facts/jobsafetyandhealth-factsheet.pdf

Poling, A. Braatz, D. (2001). Principles of learning: Respondent and operant conditioning and human behavior. In C.M. Johnson, W. K. Redmon, & T.C. Mawhinney (Eds.), Handbook of organizational performance (pp. 23-49). New York: The Haworth Press.

Poon, E. G., Blumenthal, D., Jaggi, T., Honour, M. M., Bates, D. W., & Kaushal, R. (2003).

Overcoming the barriers to the implementing of computerized physician order entry systems in US hospitals: Perspectives from senior management. Paper presented at the American Medical Informatics Association Annual Symposium Proceedings.

Poon, E. G., Blumenthal, D., Jaggi, T., Honour, M. M., Bates, D. W., & Kaushal, R. (2004). Overcoming barriers to adopting and implementing computerized physician order entry systems in U.S. hospitals. *Health Affairs, 23*(4), 184-190.

Pounds, J. (2006). *Praise for profit: How rewards and incentives are demotivating America's workforce.* Atlanta, GA: Quality Safety Edge.

Rogers, E. M. (1995). *Diffusion of innovation* (4th ed.). New York, NY: Free Press.

Streff, F. M., Kalsher, M. J., & Geller, E. S. (1993). Developing efficient workplace safety programs: Observations of response covariation. *Journal of Applied Behavior Analysis, 13*(2), 3-15.

Sulzer-Azaroff, B., & de Santamaria, M. C. (1980). Industrial safety hazard reduction through performance feedback. *Journal of Applied Behavior Analysis, 13,* 287-295.

Sutcliffe, K. M., Lewton, E., & Rosenthal, M. M. (2004). Communication failures: An insidious contributor to medical mishaps. *Academic Medicine, 79*(2), 186-194.

Upperman, J. S., Staley, P., Friend, K., Neches, W., Kazimer, D., Benes, J., et al. (2004). The impact of hospital wide computerized physician order entry on medical errors in a pediatric hospital. *Journal of Pediatric Surgery, 40*, 57-59.

Wood, J. V. (1989). Theory and research concerning social comparisons of personal attributes. *Psychological Bulletin, 106*(2), 231-248.

Zohar, D., Cohen, A., & Azar, N. (1980). Promoting increased use of ear protectors in noise through information feedback. *Human Factors, 22,* 69-79.

Table 1. Frequencies of selected individual compliance criteria achieved at Intervention Hospital (expressed as percentage of total orders for which criteria apply).

Criteria:	**Format**:	
	Paper	CPOE
Legible	83.7%, n = 541	100%, n = 320
Resume or Continue	97.4%, n = 541	100%, n = 320
Date is indicated	99.1%, n = 541	100%, n = 320
Time is indicated	50.6%, n = 541	100%, n = 320
Drug name	99.1%, n = 541	100%, n = 320
Drug dosage	79.9%, n = 541	88.4%, n = 320
Drug route	81.3%, n = 541	99.7%, n = 320
Frequency of Administration	92.8%, n = 541	95.9%, n = 320
Signature	97.0%, n = 541	100%, n = 320
Do-not-use Abbreviations: HS, QD, and QOD	HS: 99.7%, n = 541 QD: 86.3%, n = 541 QOD: 99.6%, n = 541	HS: 99.7%, n = 320 QD: 100%, n = 320 QOD: 100%, n = 320
No leading decimals (ex: .125)	99.1%, n = 541	100%, n = 320
No trailing zeroes (ex: 5.0)	99.6%, n = 541	100%, n = 320
PRN orders are qualified	52.4%, n = 191	18.0%, n = 150

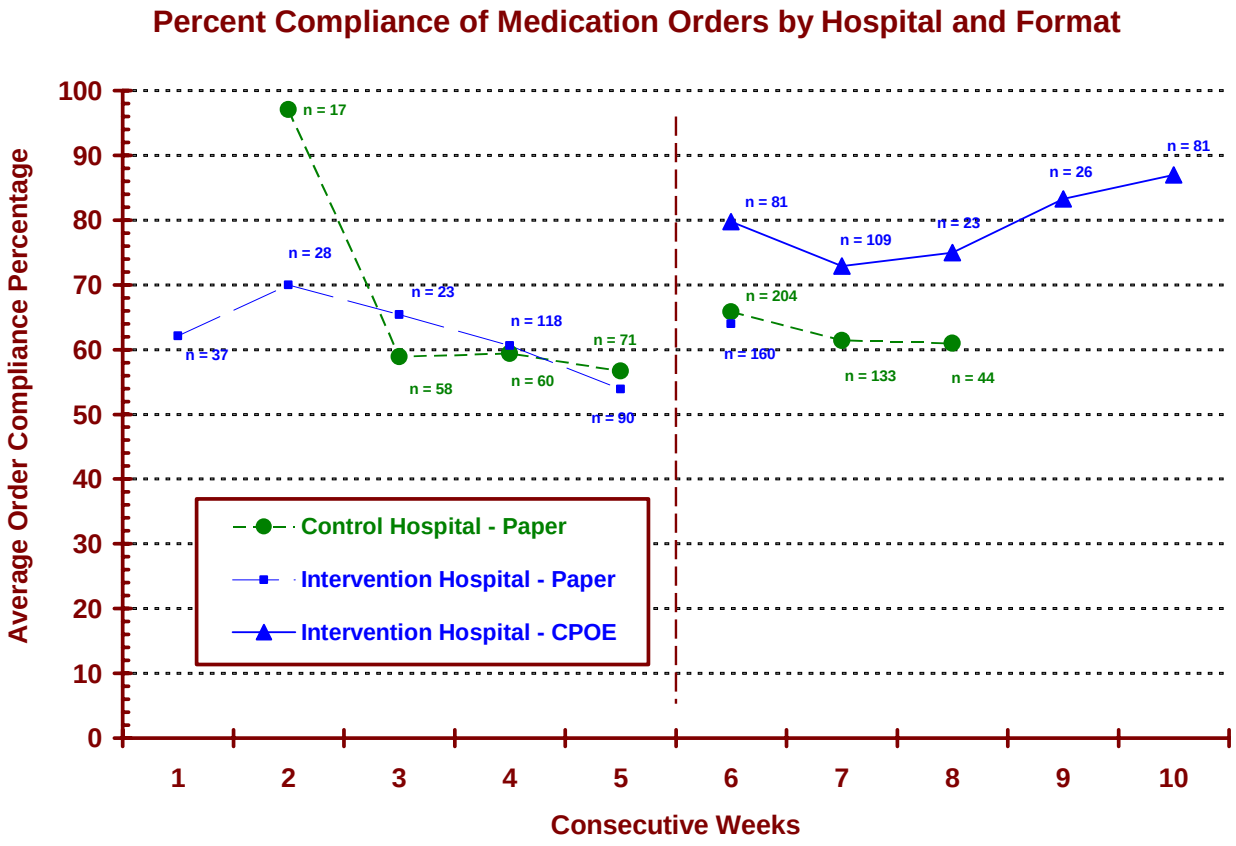
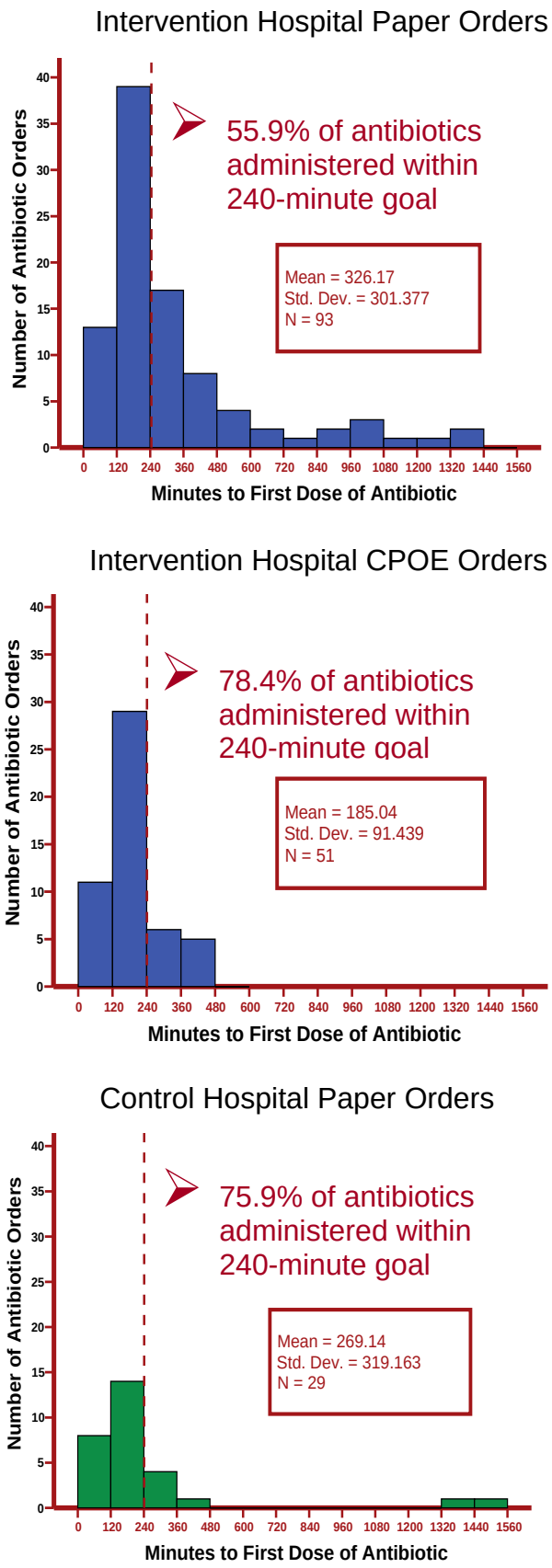


Figure Caption

Figure 1. Average weekly compliance percentages for both CPOE and paper medication orders at intervention and control hospitals. The sample size is included with each data point.

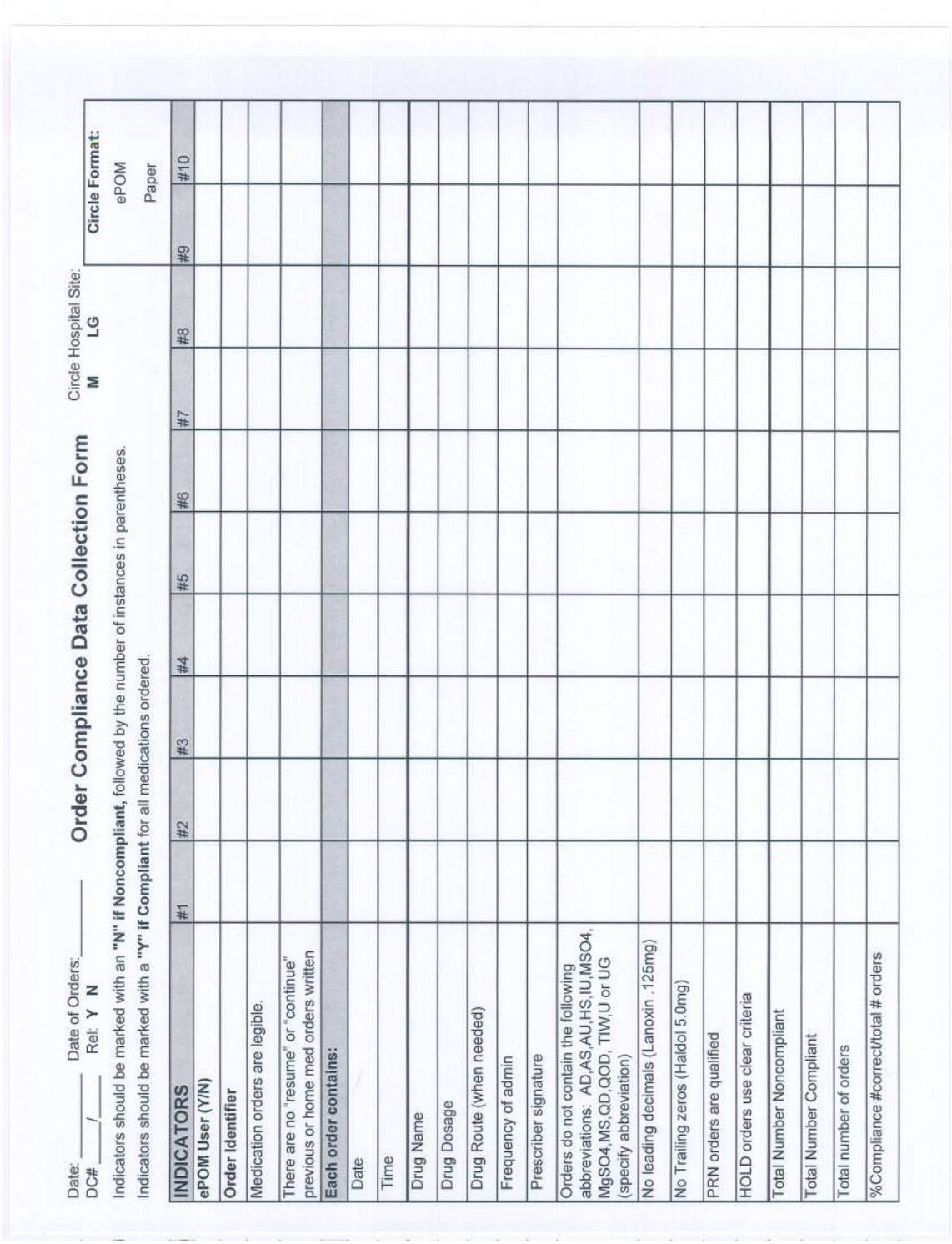
Figure Caption

Figure 2. Distributions of Minutes to First Dose of Antibiotic by Hospital and Ordering Format.



Appendix A

Order Compliance Data Collection Form



Date: _____ Date of Orders:_____
DC# ____/____ Rel: Y N

Order Compliance Data Collection Form

Circle Hospital Site:
M LG

Indicators should be marked with an **"N" if Noncompliant,** followed by the number of instances in parentheses.

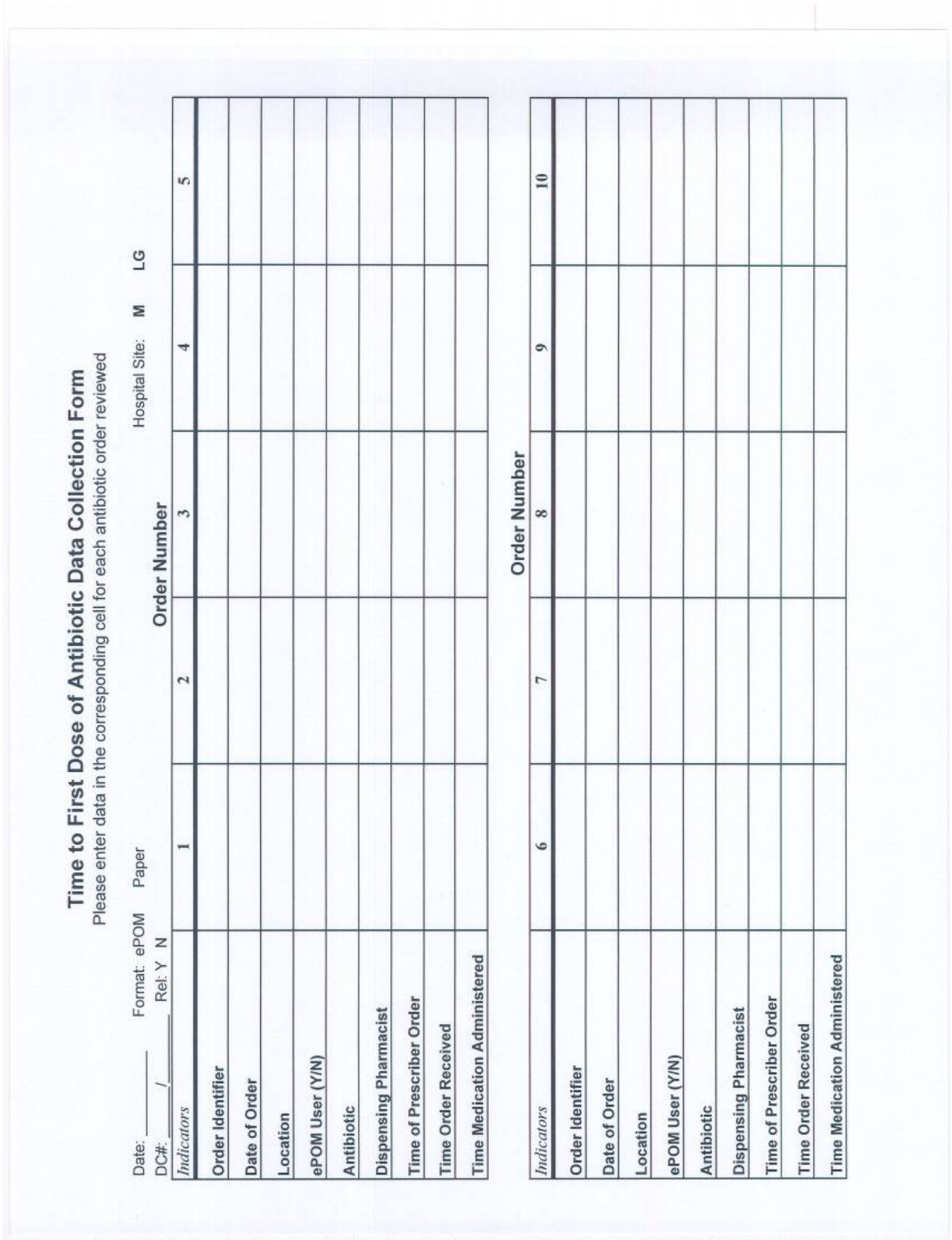
Indicators should be marked with a **"Y" if Compliant** for all medications ordered.

Circle Format:
ePOM
Paper

INDICATORS	#1	#2	#3	#4	#5	#6	#7	#8	#9	#10
ePOM User (Y/N)										
Order Identifier										
Medication orders are legible.										
There are no "resume" or "continue" previous or home med orders written										
Each order contains:										
Date										
Time										
Drug Name										
Drug Dosage										
Drug Route (when needed)										
Frequency of admin										
Prescriber signature										
Orders do not contain the following abbreviations: AD,AS,AU,HS,IU,MSO4, MgSO4,MS,QD,QOD, TIW,U or UG (specify abbreviation)										
No leading decimals (Lanoxin .125mg)										
No Trailing zeros (Haldol 5.0mg)										
PRN orders are qualified										
HOLD orders use clear criteria										
Total Number Noncompliant										
Total Number Compliant										
Total number of orders										
%Compliance #correct/total # orders										

Appendix B

Time to First Dose of Antibiotic Data Collection Form



Time to First Dose of Antibiotic Data Collection Form

Please enter data in the corresponding cell for each antibiotic order reviewed

Date: _____ Format: ePOM Paper Hospital Site: M LG

DC#: ____/_____ Rel: Y N

	Order Number									
Indicators	1	2	3	4	5	6	7	8	9	10
Order Identifier										
Date of Order										
Location										
ePOM User (Y/N)										
Antibiotic										
Dispensing Pharmacist										
Time of Prescriber Order										
Time Order Received										
Time Medication Administered										