Chapter 47. Patient Safety and Health Information Technology: Role of the Electronic Health Record

Nancy Staggers, Charlene Weir, and Shobha Phansalkar

Background

An electronic health record (EHR) is a real-time, point-of-care, patient-centric information resource for clinicians[1] that represents a major domain of health information technology (HIT). More recently, an EHR has been defined as "a longitudinal electronic record of patient health information, produced by encounters in one or more care settings."[2] It includes patient information such as a problem list, orders, medications, vital signs, past medical history, notes, laboratory results, and radiology reports, among other things. The EHR generates a complete record of a clinical patient encounter or episode of care and underpins care-related activities such as decisionmaking, quality management, and clinical reporting. Some distinguish between the terms EHR and electronic medical record (EMR), with EMR focusing on ambulatory care systems. However, in practice, the terms are interchangeable. In this chapter, the term EHR relates to computerized patient health records stored within and among institutions.

This chapter first presents a review of the literature about orders management—also called computerized provider (or physician or practitioner) order entry. The next section addresses barcoding, an area closely related to orders management. Third, the chapter synthesizes the literature about the impact of orders-related clinical decision-support systems on nursing practice.

Ordering and associated functions in EHRs is a salient focus for several reasons. First, EHRs are a current centerpiece in contemporary health informatics. A nationwide emphasis exists to install these clinical systems over the next decade, largely because of a 2004 statement by President Bush that most Americans would have an EHR in 10 years.[3] Second, the benefits of EHRs are becoming more well known. For instance, a 2006 systematic review of the literature concluded that overall use of HIT increased adherence to guidelines for care, increased surveillance and monitoring of patients, yet had mixed effects for medication errors and time utilization.[4] Third, nurses in the United States are now or will be using EHRs in the near future. Understanding orders management through the EHR is imperative because the effect on nursing practice promises to be great.

Orders management is an interdisciplinary activity crossing organizational boundaries; therefore, the literature review for this topic was broad, including all care settings and providers other than nurses. The ordering process inherently involves nurses, especially in acute care settings, as recipients of medical orders and initiators of nursing orders. However, this relationship may not be acknowledged in the design of empirical studies.

The Institute of Medicine (IOM) recommended computerized orders and decision-support applications as main HIT mechanisms for increasing patient safety in the future.[5] Existing research about the nursing impact of orders, barcoding, and decision support within EHRs needs to be examined and then expanded in near-future research. This chapter reviews EHR ordering and the associated, more researched areas, and suggests EHR areas for future research. The authors chose to concentrate this section on information-intense versus technology-focused impacts.

Orders Management in EHRs

Orders for patients are the connective tissue in any EHR. They are necessarily complex, integrating patient-specific interventions across departments. Orders are written by members of the health care team, primarily physicians and nurses. Orders management crosses customary boundaries, and it is just as likely to integrate computerized applications and functions as it is to disintegrate traditions. For example, information once the purview of one department becomes shared across many disciplines. Who owns data, such as a patient's allergies or weight, becomes a topic of vigorous discussion. New work processes are crafted. Because of the complexity of orders management, computerized provider (physician) order entry (CPOE) has been a topic of research.

The genesis for the recent increase in publications in this area was the IOM's *To Err Is Human: Building a Safer Health System* report on errors in medicine. The IOM recommended information technology as a major mechanism to reduce errors.[6] Likewise, the IOM's *Crossing the Quality Chasm: A New Health System for the 21st Century*[5] had a profound message for the information technology community and recommended, among other things, the installation of CPOE and decision support to improve patient safety. In its most recent publication, *Preventing Medication Errors: Quality Chasm Series*,[7] the IOM recommends that clinicians make greater use of information technology for prescribing and dispensing medications. Thus, it is imperative to understand the practice impacts of CPOE and its related functions of barcoding and clinical decision support.

Research Evidence—CPOE

The CPOE studies were analyzed using a quality instrument specific to informatics called QUASII.[8] This instrument assesses informatics study qualities across construct, internal, external, and statistical conclusion validity areas. The CPOE studies may be divided by QUASII scores into two tiers: Tier 1 (with QUASII scores at or above 61) and Tier 2 (with scores at or below 54). No scores between 54 and 61 were observed, and studies with QUASII scores below 30 were excluded from consideration. Tier 1 includes studies that have more reported rigor in study design and controls with fewer possible threats to construct, internal, external, and statistical conclusion validity. Tier 2 includes studies with less reported rigor and increased possible threats to validity. Studies with less rigor are included here because they are often widely cited and have even dominated the literature.

The studies were sorted by dependent variables into medication errors, efficiency impacts (time and length of stay), and quality care. The studies are summarized in Tables 1 and 2. In Table 3 a sample of qualitative studies is listed to show the contrast in the types of variables examined in these studies compared to quantitative CPOE studies.

Varying Definitions of CPOE

The term CPOE is used imprecisely. Researchers have used the same term to mean orders with these differing capabilities:

- Electronic orders, including electronic transmission to appropriate ancillary departments[9]
- Electronic orders without an interface to one or more ancillary departments, requiring either order transcription to paper or order entry by others into systems with different functional capabilities[10–12]
- Orders including order sets[13]
- Orders with no order sets[14]
- Orders without capability for complex medications, such as intravenous (IV) orders, total parenteral nutrition (TPN), or complex functions such as oncology protocols
- Orders with integrated alerts, reminders, and decision support to assure order completeness and accuracy, especially for medications[15]
- Orders with no checks, alerts, reminders, or decision-support capabilities[16, 17]
- Orders without a pharmacy interface or any decision-support capabilities[18]
- Orders with or without associated clinical documentation
- Orders with full capabilities, complete decision support, documentation (especially an electronic medication administration record, or eMAR), and complete support for all orders, including complex protocols
- No description of existing capabilities

Researchers report conclusions as if the CPOE capabilities were equivalent, when these varying instantiations, in effect, amount to very different strengths of CPOE as an independent variable. In particular, the lack of appropriate departmental interfaces and integration in one study, such as a pharmacy interface in a study tracking medication error rates, is very much in contrast to a study examining medication errors using a system with an existing pharmacy interface. CPOE requiring order transcription of any kind—to a medication administration record (MAR) or foreign pharmacy system—necessarily increases errors, and these very transcription errors are typically included in the count of overall medication errors rates.

The same notion can be applied to the presence or absence of computerized decision support in its most basic form. Basic decision support can allow checking for order completeness and accuracy. If medications errors are being examined, a CPOE study of an application with no basic order checking is not equivalent to studying one with any decision support integrated into CPOE. More advanced decision support for drug-drug or drug-allergy interactions, and checks for other interactions or dosing accuracy, add yet another level to CPOE applications. Researchers are led to conflicting conclusions if this variability of functions is not taken into consideration. At best, the broad scope of CPOE systems (and lack of specific descriptions in the studies of the features of systems) leads to confusion in the interpretation of results. These differing capabilities are noted when reported by researchers.

CPOE Impacts and Variables Studied: Quantitative Studies

Sites and CPOE applications. CPOE evaluations have been concentrated at large academic medical centers, particularly at Brigham & Women's Hospital in Boston and the Ohio State University medical center in Columbus. The unique, "homegrown" systems at Brigham, Vanderbilt University in Nashville, and the Regenstrief Institute at the Indiana University School of Medicine (Indianapolis) populated earlier literature—although, more recently, vendor systems have been studied. Studies of vendor systems include the Siemens, Eclipsys, General Electric (GE), and Cerner CPOE applications, in descending order of frequency.

Medication errors and adverse drug events. The relationship of CPOE to medication errors, adverse drug events (ADEs), and subsets of those categories is reported in 12 studies (see Table 1). Of these, three systematic reviews addressed the effect of CPOE on medication errors and/or ADEs. The systematic reviews concluded that CPOE (and isolated clinical decision-support systems) can reduce medication errors.[19–21] However, since these reviews were published, researchers have published conflicting conclusions about the topic.[22, 23]

Studies on inpatient units in five different settings reported significant decreases in medication errors after CPOE implementation.[11] More specifically, all medication errors and non-missed-dose errors decreased in two sites,[10, 18] and potential and nonintercepted ADEs significantly decreased with the homegrown application at Brigham and Women's Hospital.[15] Shulman and colleagues[11] reported a lower proportion of medication errors with CPOE, and King and colleagues[18] reported a 40 percent reduction in errors. Transcription errors were reduced or entirely eliminated.[17, 20, 24]

In contrast, two researchers found no differences in rates for ADEs with CPOE.[16, 18] In the outpatient arena, no differences were found in total errors, ADEs, or rules violations,[16] although the system in this one setting lacked any order checking for completeness or accuracy and lacked basic decision support. The differences in ADE detection may be due to underpowered studies[19] and also to the differences in functionality discussed earlier and the differing definitions for ADEs. Moreover, studies used varying scales to rate errors and ADEs ranging from self-developed categorical scales of minor/major/serious to the American System of Health-Systems Pharmacists classification.

Increases in medication error rates after implementation of CPOE have also been reported. In 2005, Spencer and colleagues[12] reported an increase in one type of error (i.e., pharmacy processing) on two inpatient medicine units, while other medication errors were unchanged from pre-CPOE implementation. Unfortunately, this site had no system interface to pharmacy, and the researchers acknowledge that the increased error rate may have been related to the need to transcribe orders in the pharmacy. Without the interface or a method to ensure orders were complete and accurate, the only seeming advantage of CPOE at this site was the speed of communication to the pharmacy for transcription. Researchers in Portugal[17] concluded that CPOE eliminated their transcription errors, but other errors continued—such as right class/wrong drug, and other errors likely solvable by the basic decision support they lacked (e.g., unclear orders, missing frequency, incorrect dosages, drug interactions, and duplicative therapies).

Life-threatening errors and serious ADEs were higher in the early years at Brigham and Women's, when no decision support was installed. For example, a screen for potassium orders allowed new, potentially very serious errors to occur.[15] These potential errors were intercepted by either nursing or pharmacy before the drugs were administered. Likewise, CPOE at one institution in London created three major errors that could have resulted in harm or death of a patient had they not been intercepted.[11] Again, this site had no decision support in place to prevent a reported error of 7 mg/kg of morphine being ordered instead of 7 mg, a potential overdose of 70 times the normal range. This site also saw an increase in minor, nonintercepted errors with CPOE, from 43 for handwritten orders to 93 with CPOE. That said, with all errors combined, the overall rate of errors was lower with CPOE. However, the details behind that overall rate show increases in potential major errors if decision-support capabilities are not available. This statement is in contrast to the conclusion by Chaudhry and colleagues,[4] perhaps

because his literature review concentrated on the years before these newer studies were published.

In all studies, the researchers did not include external forces, contextual variables, or organizational forces that may have contributed to changes in medication errors. For example, several studies extended over multiple years, through changes in chief information officers, national changes about patient safety, and increased emphasis on medication errors. Especially with the more recent studies, changes in error rates could have been due to these factors as well as information technology implementations.

The variability in conclusions may also be explained by the differences in available functions, particularly the lack of pharmacy interfaces and basic decision support. Therefore, the previous researchers' conclusions about CPOE decreasing medication errors must be modified: CPOE can reduce medication errors if appropriate functions are available to prevent new errors. Transcription errors can be eliminated with electronic communication and interfaces together with structured order entry. CPOE can substantially reduce overall (and many serious) medication errors if (1) electronic communication and automatic order interfaces are in place, (2) basic order checks for completeness are present, and (3) decision support at its most basic level is available—checking for drug–drug and drug–allergy interactions and for dosing ranges.

Clinical efficiency measures—time and length of stay. Eleven studies examined the effects of CPOE on efficiency measures of time and/or hospital length of stay (LOS) (see Table 2). CPOE offers clear benefits in processing efficiency for orders management and availability of electronic laboratory and radiology results. CPOE reduced the time from order entry to results availability for laboratory and radiology orders in four sites.[13, 25–27] Another clear benefit is that CPOE decreased the time from pharmacy ordering to medication administration time.[13, 25, 26, 28]

Likely because of timely availability of results and faster order processing, patients' hospital LOS was shorter.[26, 29] One systematic review concluded that one of the benefits of CPOE is reduced LOS.[20] Other clinical efficiencies are related to use of CPOE. For example, Ohio State University hospital saw a significant improvement in the number of patients whose abnormal potassium levels were normalized within 24 hours.[24]

On the other hand, order entry itself takes longer using CPOE than with paper. A systematic review of the impact of computers on time efficiency concluded that the use of central desktops for CPOE was not efficient, consuming 98.1 percent to 328.6 percent more time per working shift.[30] CPOE took 2.2 minutes longer per patient, but after duplicative tasks were removed, the extra time per patient was shortened to an average of 0.43 min.[31] At Brigham and Women's, CPOE took 44–73 minutes longer per day, especially for entering one-time orders.[32] However, this study was done before order sets were widely used. At Regenstrief, an early CPOE application took interns 33 minutes longer during a 10-hour period.[29] Interns entered orders on microcomputers and then printed them, using them as traditional paper documents afterwards. Likewise, a more recent study at Massachusetts General Hospital[33] demonstrated an increase in medical interns' ordering time, among other time-related variables. Prior to CPOE, interns spent 2.1 percent of their time ordering; after CPOE, they spent 9 percent of their time ordering. Two of these studies were published about early CPOE applications in the 1990s, and all four measured homegrown systems. None of the studies examined time for order sets or vendor-based solutions. Of note, CPOE may take providers somewhat longer to enter orders, but efficiencies are obtained later in the orders management cycle—in nursing, ancillary departments' order processing, and in reduced time for results availability and administrative tasks.[33]

Quality care variables. Three studies examined variables not reported by others, namely the quality of documentation and one particular patient outcome (see Table 3). In one study, a significant increase occurred in the number of documented consents for do-not-resuscitate orders.[34] In another study, researchers conducted a randomized controlled trial to examine the effect of medical students' rotations in a CPOE site versus traditional sites on the quality of orders written on a fictitious patient[50] They found that the quality scores for orders during an academic examination were significantly higher for students using CPOE.

A third study produced alarming results that conflict with other, more promising benefits of CPOE. A recent article reported an increased mortality coincident to a CPOE implementation at a pediatric hospital.[14] The researchers reported a direct association between CPOE and increased mortality among pediatric patients admitted through interfacility transport. However, this facility experienced substantial workflow changes in conjunction with CPOE installation. For example, no preregistration was available, delaying order entry until full registration was completed after the patient physically arrived. This process change delayed therapies and diagnostic testing.

Important human–computer interaction issues impacted treatment times. The new ordering system required substantially more order entry time during a critical period of patient care, and the wireless bandwidth capacity was often exceeded during peak periods. Crucial aspects of work organization changed with all medications being centralized, meaning that nurses were unable to access medications locally and the pharmacy could not process medication orders until they had been activated. Sadly, when the pharmacy accessed CPOE to process an order, other clinicians were locked out of the application. The researchers also reported a decrease in face-to-face communications that provided relevant information for patient care management post-CPOE.

In this study, CPOE was likely a proxy variable for significant, but untoward, process changes in that particular institution. The lesson from this article is that work processes must be thoroughly examined before CPOE "goes live," and projected, substantial treatment delays are an excellent reason to delay going live until work design is safe for patient care. For critically ill patients in emergency departments (EDs), intensive care units (ICUs), and pediatric units, new processes cannot delay treatment. Workflow and usability analyses can preclude the kinds of impacts seen in this article.

CPOE and a Sampling of Qualitative Studies

A sampling of qualitative studies shows a contrast in variables addressed by these researchers versus the researchers of quantitative studies (see Table 4). While not usual to include as evidence, these qualitative studies provide insights for future studies and as well as interesting aspects of CPOE. Koppel and colleagues[23] interviewed 261 clinicians, including nurses, about CPOE and its perceived role in medication errors. Clinicians reported new errors with CPOE because of fragmented data and processes, lack of integration among systems, and human–computer interaction issues. For example, obtaining a summary view of all the medications a patient was receiving was difficult because providers had to scroll through multiple screens to view medications. In another example, the fit between computer and workflow processes was a problem because nurses typically charted medications at the end of a shift using global commands instead of charting at the time medications were actually given. And in another study of CPOE, Sittig and colleagues[35] found that negative emotions about CPOE prevailed for both nurses and physicians.

One study concluded that communication was broadly affected by CPOE, from interpersonal to intrainstitutional.[36] Significant impacts on team and physician-nurse communication occurred with CPOE. Nurses felt that CPOE degraded communication among the dyad of doctor and nurse, and thought that it took more effort post-CPOE to get residents to come see patients needing attention. A multisite study of the Veterans Affairs' (VA's) early CPOE application showed that nurses thought the quality of care had improved with CPOE, but the control over their jobs and roles decreased.[37]

Quantitative studies examined more easily definable and, perhaps, more simplistic variables, such as measurable medication errors and ADEs, timed processes of order entry to results posted, and mortality. The qualitative studies, on the other hand, examined richer aspects of processes and interdependent variables, such as types of errors created by CPOE, interdependent communication patterns, and perceptions of role changes. With the complexity created by orders management, both methods are needed in the future research.

Evidence-Based Practice Implications

Silence about nursing impacts cuts across the CPOE quantitative studies. Only one quantitative study mentions nursing impacts with CPOE: changes associated with CPOE resulted in medications not being available on patient units in a timely manner, resulting in missed doses.[10] Bates and colleagues acknowledged the increase in missed doses but deemed these minor, and the missed-dose errors were excluded from summary findings of the study.

Impacts of CPOE on nursing were examined in the sample of qualitative studies. The sample of qualitative studies indicated that (1) nurses at three sites in one study had negative emotional perceptions of CPOE, (2) interpersonal communication between nurses and physicians was disrupted by CPOE, and (3) nurses perceived that the quality of care improved with CPOE.

Even with few studies specifically addressing nursing issues, implications are evident. Nurses can expect improved speed for results availability with CPOE. The elapsed time from writing an order to available results is a clear and expected benefit. Although not surprising, this is a benefit to the care team and the patient. Obviously, legibility of orders and improved availability of information occurs as well, by virtue of orders being typed and available electronically. Nurses can expect more efficient treatment related to results availability and decreases in hospital LOS for patients post-CPOE.

Whether medication errors and ADEs are impacted by CPOE depends upon available application functionality. Thus, all nurses will want to be aware of available functional and technical support and their implications. If, for example, the CPOE system has no pharmacy interface or integrated decision-support capabilities, aggressive monitoring systems will need to be in place to intercept medication errors ranging from transcription errors and interaction issues (drug-drug, drug-allergy interactions) to dosage issues (dose range, right class/wrong drug, frequency) and more serious errors. If no eMAR exists, then errors associated with transcription will be present because transcription to a paper medication administration record is required. Serious medication errors can increase with CPOE if no decision support is available. As functionality increases with computerized applications and electronic transmission, provider-based error-monitoring mechanisms can be tailored down in scope. Medication errors can decrease if interfaces and appropriate documentation using an eMAR are available, along with decision-support capabilities for order accuracy, dosing issues, and interaction checking. In fact,

given the implications of CPOE without interfaces and decision support, nurses should actively support a CPOE installation only if adequate functionality will be installed.

That said, no health information technology is a panacea. When lower-level errors are solved, such as results availability and transcription errors, a new level of issues will emerge, some beneficial and some prompting concern. CPOE creates professional interdependence and slices across departmental boundaries. Thus, changes in work design, roles, and communication will occur. Work processes need to be carefully analyzed for potential detrimental changes before going live, and either the work design or the EHR design must be tailored for patient safety and quality. Nurses can expect to feel the impact of more electronic and less face-to-face communication, especially from physicians. Knowing this, alternative communication channels and opportunities can be constructed. Roles will need to be renegotiated among medicine, pharmacy, and nursing for order activation, allergy entry, weight documentation, and other interdependent issues.

Research Implications

Study descriptions and designs. Identifying and specifying the capabilities of CPOE is imperative. Future studies should indicate the exact functions in the article and abstract as well, and in the title, if at all possible. Chaudhry and colleagues.[4] noted this same issue with general HIT studies. Careful conclusions are necessary when CPOE does not provide basic functionality such as pharmacy, laboratory, or eMAR interfaces. CPOE capabilities are not equivalent, so they should be treated like the different independent variables they are. Adequate descriptions of these study characteristics are needed, at minimum.

Broadening the definition of CPOE would allow researchers to conceptualize future studies differently. The term "order entry" misrepresents the concept by implying that only the entry portion of the whole process is important. Ordering is a process starting with entry, to communication, to processing by various recipients, and then to documenting actions against specific orders. By conceptualizing ordering in this way, future studies can be designed to measure impacts across the health team.

Potential external influences need to be taken into account in study design as potential confounding variables. Studying CPOE in a natural environment is challenging research. However, rather than ignore these variables, as has been done in the past, future researchers should want to identify and control, or at least measure, these variables. This notion is stressed by Snyder and colleagues.[38] External forces outside the institution should also be considered in study conclusions—for example, the influence of national trends for increasing patient safety with concomitant information technology installations.

Future research themes. Three major themes for future research emerged: (1) nursing impacts from computerized orders management, (2) human-computer interaction issues, and (3) implementation science. The concept of CPOE needs to be expanded to encompass an orders management cycle. To date, the concept has been studied primarily as order entry in quantitative studies. The ordering process is a complex, interdependent, and interactive process composed of at least these multiple, intersecting elements: systems design, interpersonal and intersystems communication, implementation processes, and organizational structures. Thus, orders management needs to be examined in the future as the interdependent, interdisciplinary, and interactive process that it is. A few authors of qualitative studies have started that process.

Because orders management is a complex process, identifying only simple outcomes variables does not do the phenomenon justice. Multiphased studies with multiple process and outcome variables are needed to begin to understand orders management and its impact.

Nursing impacts of computerized orders management. From the nursing perspective, nearly any study of orders management with nursing impacts will be novel. Ideally, an interdisciplinary study of orders management should be crafted using both quantitative and qualitative methods. Crucial variables include the impact on workflow, cognitive processes for information synthesis across disparate systems, and patient safety issues with various vendors' CPOE applications. A standardized method for medication error reporting is needed to facilitate reporting across institutions and vendor applications. In concert with recommendations from Kaushal, Shojania, and Bates,[19] commercial products should be compared and key implementation factors identified. Mixed methods in future studies are very desirable since quantitative and qualitative methods would provide a powerful mechanism to uncover information about orders management as a complex process.

Human–computer interaction issues. A second theme of future research relates to usability and human–computer interaction impacts of orders management and clinical decisionmaking. Human-computer interaction within EHRs is a critical area to explore in HIT. For at least a decade, health informatics experts have stated that user interface design and other related areas of human–computer interaction are understudied and, in fact, an area in desperate need of attention.[39, 40] Yet, research in this area has moved at a glacial speed. In some recent literature, serious user interface issues have surfaced related to CPOE.[14, 41] In particular, the rigid, linear, structured computing processes reflected in user interfaces did not adequately address clinicians' work processes, which are nonlinear, interruptive, and flexible. These findings accentuate the need for research in user interface design.

Research in human–computer interaction is beginning in health informatics, but more is immediately needed. Two researchers outlined detrimental effects of the usability aspects of order applications.[14, 42] Patel[40] studied issues surrounding physicians' cognitive structures and stressed the importance of cognitive science to informatics. Ash and colleagues examined aspects of CPOE, such as unintended consequences of CPOE and other human-systems issues.[41, 43, 44] Staggers[45–48] studied effective screen designs as they related to the efficiency (response time) and effectiveness (accuracy) of various EHR designs. Future research needs to focus on systems usability to understand what designs facilitate safer orders management; what vendors offer safe, usable, and accurate orders management applications; how vendor applications compare in efficient and effective designs for interdisciplinary applications, such as orders management; what designs facilitate effective clinical decisionmaking; and what work design needs to be in place for successful implementation of CPOE.

Implementation science. Clinical systems implementation in health settings should be a third focus of future research. Anecdotal guidelines exist for systems implementation, but little evidence is available to guide institutions across the nation as they implement EHRs. As of late 2005, only about 20 percent of U.S. institutions had installed EHRs, HIMSS Analytics reported only 3 percent of institutions had CPOE by 2007 and none had a full EHR; therefore, research into the science of implementation can be of benefit in the future.[49] At the very least, we should uncover factors crucial for implementation success in health settings, especially from the organization and system design perspective. Funding should be made available for implementation studies outside academic medical centers and urban areas.

Evidence Table 1. CPOE Effects on Medication Errors

Source	Setting	CPOE	Study Design	Study Intervention	Key Finding(s)	Quality Score	Considerations
Bates 1998[15]	Brigham & Women's (medical and surgical units)	Homegrown	Pretest, post-test	CPOE plus team effect on nonintercepted, potential, and all adverse drug events (ADEs).	Nonintercepted serious ADEs decreased by 55%. Preventable ADEs declined 17% (not significant). Nonintercepted potential ADEs decreased 84%. CPOE plus team offer no additional benefit over CPOE only. No differences seen for all ADEs.	48	CPOE and a "team effect" were intertwined in effects.
Bates 1999[10]	Brigham & Women's (3 medical units)	Homegrown: Transcription to a paper medication administration record required	Time series (1 pretest and 3 post-tests over 4 years)	Medication errors for pre- and post-CPOE x 3.	All errors decreased. Nonmissed dose errors decreased by 81%. Nonintercepted serious errors fell 86%. Nursing workflow impacted negatively and missed-dose errors increased.	43	Study spanned 4 years, during which national trends for patient safety changed. System design changed substantially.
Cordero 2004[25]	Ohio State Univ. neonatal ICU Inpatient	Vendor (Siemens)	Pretest, post-test with controls	CPOE effect on accuracy of Gentamicin doses.	Reduced medication errors for selected NICU drugs.	77	Results for select orders only.
Gandhi 2005[16]	Brigham & Women's 4 outpatient clinics	Homegrown: CPOE without checks or decision support	Cross-sectional	Prescribing errors, potential ADEs, and rule violations.	No differences in total errors, ADEs, or rules.	74	CPOE design had no checks for missing data, dosing, frequency, interactions.

Source	Setting	CPOE	Study Design	Study Intervention	Key Finding(s)	Quality Score	Considerations
Kaushal 2003[19]	N/A	Various forms	Systematic review	Effect of CPOE and clinical decision support on medication safety.	CPOE and isolated clinical decision-support systems (CDSS) can reduce medication errors. Studies under-powered to detect differences in ADEs and have studied "homegrown" systems.	N/A	
King 2003[18]	Children's Hospital, Toronto, Inpatient	Vendor (Eclipsys). No interface with pharmacy. No decision support.	Retrospective cohort study over 6 years	Rate of medication errors on 2 CPOE medical units versus 1 medical and 2 surgical units over 3 years post-implementation.	Medication errors were 40% lower on CPOE units, but no difference for ADEs.	90	Medication study but no EHR interface to pharmacy. No decision support.
Kuperman 2003 [20]	N/A	Various forms	Systematic review	CPOE impact on LOS and medication errors.	CPOE reduces medication errors (incorrect dosing, interactions), transcription errors.	N/A	
Mirco 2005[17]	Portugal, internal medicine units, institution not named	Application not stated. Unit dose available, but no decision support or interaction checking.	Pretest, post-test, no controls reported	CPOE effect on medication errors.	CPOE eliminates transcription and patient identification errors. Errors were right class/wrong drug and unclear orders. Smaller % of errors due to frequency, incorrect dose, drug interaction, duplicative therapy, length of therapy.	37	No interaction checks or decision support available. Study spanned 2 years.
Papshev 2001[21]	Electronic prescribing in ambulatory practice	N/A	Systematic review	Electronic prescribing (including CPOE) effect on medication errors.	Reduces medication errors.	N/A	

Source	Setting	CPOE	Study Design	Study Intervention	Key Finding(s)	Quality Score	Considerations
Potts 2004[9]	Vanderbilt	Homegrown "Wiz" order system	Pre/post with controls	CPOE effect on potential ADEs, medication prescribing errors (MPE), and rules violations (RV).	Reduced ADEs, MPEs, and RVs.	60	Unique homegrown CPOE design.
Shulman 2005[11]	Univ. College in London, ICUs	Vendor (GE systems)	Time series (1 pre and 4 post over 37 weeks)	CPOE without decision support and handwritten orders effect on medication errors and type of error.	Lower proportion of errors with CPOE. Reduced major/moderate outcomes for nonintercepted and intercepted errors combined. Two errors with CPOE resulted in patient harm. Increase in minor intercepted errors with CPOE (43 versus 93).	44	Errors tracked by one ICU pharmacist. No decision support in place.
Spencer 2005[12]	U. North Carolina, Chapel Hill, 2 medicine units	Vendor (Siemens). No pharmacy interface.	Pretest, post-test with controls	Effect of CPOE without decision support and handwritten orders on medication error rates.	Increase in reported errors for pharmacy processing. Other errors unchanged. Errors include drug allergy, duplicate orders.	50	Medication errors voluntarily reported. No pharmacy interface. Errors attributed to the lack of the pharmacy interface.

Evidence Table 2. Computerized Physician Order Entry (CPOE) Effects on Process Efficiency (Time and Length of Stay)

Source	Setting	CPOE	Study Design	Study Intervention	Key Finding(s)	Quality Score	Considerations
Bates 1994[32]	Brigham & Women's (medicine and surgery house staff)	Homegrown	Pretest, post-test with no reported controls	Pre/post CPOE medicine and surgery house staff time spent in order entry activities.	CPOE takes more time (44–73 min/day), especially for one-time orders.	50	Unknown % of order sets, which speed CPOE times.
Cordero 2004[25]	Ohio State Univ. neonatal intensive care unit (NICU), inpatient	Vendor (Siemens)	Pretest, post-test with controls	CPOE effect on radiology result times for abdominal, chest films, medication turnaround times for caffeine loading doses, accuracy of Gentamicin doses.	Reduced medication and radiology turnaround times, medication errors for selected NICU drugs.	77	Results for select orders only.
Kuperman 2003[20]	N/A	Various	Systematic review	CPOE impact on length of stay (LOS).	CPOE reduces LOS.	N/A	
Lehman 2001[28]	Rush Presbyterian	Vendor (Siemens). No pharmacy interface.	Pretest, post-test with no controls	CPOE impact on pharmacy order turnaround time (order to medication delivery on unit).	Over 60% faster with CPOE.	74	Orders were printed in pharmacy and transcribed into pharmacy system.
Mekhjian 2002[26]	Ohio State Univ, transplant unit, medical intensive care unit, and surgical ICUs	Vendor (Siemens). CPOE plus eMAR.	Pretest, post-test with no controls	CPOE impact on medication turnaround times, radiology procedures, lab results.	Reductions in medication turnaround times, transcription errors. More timely results reporting for radiology and lab. Severity adjusted LOS decreased in 1 hospital but not another.	65	For selected medication orders only.
Ostbye 1997[27]	Univ. Western Ontario	Vendor (Siemens from Norway)	Quasi-experimental parallel comparison, descriptive	CPOE effects on results reporting on 2 similar surgical units.	Average time to complete and transmit lab tests decreased from 7 to 1.5 minutes. Results availability decreased by about 3 hours.	76	Good study design, but elected to not analyze data.

Source	Setting	CPOE	Study Design	Study Intervention	Key Finding(s)	Quality Score	Considerations
Overhage 2001[31]	Regenstrief Institute	Homegrown. Used in 11 primary care clinics.	Randomized controlled trial. Time-motion study.	Time for CPOE compared to paper. Perceptions about order entry.	CPOE is 2.2 min per patient longer, but when duplicative tasks are removed, only 0.43 min per patient longer. Perceptions that work is done faster, quality of care and documentation is improved.	108	Unique homegrown CPOE application.
Papshev 2001[21]	N/A	N/A	Systematic review	Electronic prescribing (including CPOE) effect on time	Can eliminate the time gap between point of care and point of service.	N/A	
Shu 2001[33]	Massachusetts General Hospital	Homegrown	Pre/post with pager reminders for time recording	CPOE impact on physician time.	Interns spent 9% of their time ordering vs. 2.1% pre-CPOE. Counterbalanced by less time spent for nursing, pharmacy and quality and efficiency changes.	54	
Tierney 1993[29]	Regenstrief (Wishard Memorial Hospital) 6 inpatient internal medicine services	Homegrown. Orders printed and not sent electronically to departments.	Randomized controlled trial with time-motion study	Effects of orders entered by interns into a computer workstation compared to paper.	Mean LOS was 0.89 day shorter. CPOE interns spent 33 minutes longer per 10-hour period (5.5 min/pt/day).	110	Orders routed to printers in pharmacy. Otherwise printed and treated like paper records.
Thompson 2004[13]	St. Paul's Hospital, Vancouver, 11-bed ICU	Vendor (Eclipsys)	Pretest, post-test	Effect of CPOE on the timeliness of urgent lab and imaging test results.	Improved test turnaround time for stat lab and radiology orders.	54	Used order sets.

Evidence Table 3: Quality Care Variables

Source	Setting	CPOE	Study Design	Study Intervention	Key Findings	Quality Score	Considerations
Han 2005[14]	Univ. Pittsburgh, inpatient pediatrics	Vendor (Cerner)	Pretest, post-test with controls	Effect of CPOE on pediatric mortality rates.	Mortality rate increased from 2.8% to 6.57%.	61	New workflows substantially delayed treatment for critically ill patients. ICU order sets not available. Unclear how CPOE was measured. Possible colinearity between CPOE and severity of illness, shock.
Salmasy & Marx 1997[34]	Urban academic center	Not stated	Pretest, post-test with controls (over 4 years)	CPOE effect on documented consents.	Increased from 75% to 90%.	74	Significant differences in patients' severity of illness. Increased national emphasis on DNR orders during the study duration.
Stair & Howell 1995[50]	Georgetown Univ. medical students on emergency medicine rotations	Not stated	Randomized controlled trial. Students randomly assigned to 4 different locations.	CPOE effect on quality of orders for an imaginary patient.	Quality scores for medical students at CPOE sites better than manual.	94	

Evidence Table 4: Qualitative and Descriptive Studies

Author(s)	Site	CPOE	Study Design	Study Intervention	Key Finding(s)
Ash 2004[41]	Sites in the Netherlands, Australia, and 4 hospitals in the United States	Various applications	Qualitative description of unintended errors	Unintended effects of patient care information systems.	Unsuitable human–computer interfaces for interrupted tasks, cognitive overloads with structured or complete information entry, work fragmentation, overcompleteness; misrepresentation of workflows as linear, clearcut and predictable, inflexibility, rigid requirements for medication orders, work-arounds, loss of communication & feedback, decision support overload, and a decrease in redundancies for error catching.
Dykstra 2002[36]	Univ. of Virginia, El Camino Hospital, Puget Sound and American Lake VA Hospitals	Various systems	Qualitative	CPOE's role on communication patterns.	Impacts on physician–nurse communication without a physical presence, availability of information for the care-team and patient increases, "black box" may mask errors.
Koppel 2005[42]	Urban tertiary care teaching hospital	Vendor (Eclipsys)	Qualitative – interviews, focus groups, observations on 261 physicians, nurses, and pharmacy leaders	CPOE's role in medication errors.	CPOE facilitated 22 medication error sources due to fragmentation of data, lack of systems integration, and human-machine interface flaws.
Sittig 2005[35]	U. Virginia, VA Hospital, El Camino hospitals with recent and long-standing CPOE installations	Various systems	Qualitative – interviews with 50 people (physicians, physician assistants, and nurse practitioners)	Emotional responses to CPOE installations.	Prevalent negative emotions. Implications for CPOE design (irrelevant alerts, slow systems, focusing making "the right thing the easiest to do").
Weir 1995[37]	VA	Homegrown	Descriptive survey	Nurses' perceptions of work, quality of care, and physician–nurse communication.	Positive impact on the quality of care, less job control.

Barcode Medication Administration in EHRs

Background

To Err Is Human focused attention on the frequency of medical errors occurring in U.S. hospitals.[6] In response, the health care industry has been counting upon the strengths of technological innovations to improve patient safety and decrease medical errors. Before the IOM report, the Harvard Medical Practice Study revealed that medication errors most frequently occurred in hospitals.[51] Medication errors can occur at any stage of the medication administration process—starting at the ordering of the drug by the physician, followed by dispensing of the drug by the pharmacist, and ultimately ending in the actual administration of the drug by the nurse to the patient. However, a 1995 study showed that 38 percent of potential and preventable ADEs occurred at the time of administration by nursing personnel.[52] Further evaluation of these errors found that wrong dose, followed by wrong route and wrong drug, were the most common administration errors.[53]

As discussed in the previous section of this chapter, the implementation of CPOE systems is targeted to eliminate errors occurring at the ordering phase. On the other hand, barcode medication administration (BCMA) systems work toward decreasing errors that arise further into the medication administration process. Integration of the two technologies, that is, BCMA systems with CPOE systems, can lead to significant improvements in patient safety and efficiency of medication administration.

National organizations leading the patient safety efforts have recognized the improvements brought about by the implementation of barcode technology in hospitals. The IOM, National Patient Safety Foundation, and the American Society of Health-System Pharmacists have recommended the implementation of BCMA systems as a means for improving patient safety. In 2004, the U.S. Food and Drug Administration (FDA) mandated the barcoding of all medications and blood components to decrease adverse events.[54] This rule requires pharmaceutical companies to provide a National Drug Code (NDC) on most prescription medications and some over-the-counter medications. Additionally, in compliance with the Joint Commission's (formerly the Joint Commission on Accreditation of Healthcare Organizations, or JCAHO) patient safety goals, all hospitals are required to implement barcoding technology for patient identification and for matching patients to their medications by 2007.[55]

Thus, BCMA systems are strongly associated with efforts to bring about a culture of safety in health care. BCMA systems particularly impact the role of nursing in the administration of medications at the bedside. In this section, the empirical evidence surrounding the use of BCMA systems is evaluated, describing the integral role it has come to play in nursing care, and suggesting future directions for research.

Use of BCMA for Medication Administration

Barcoding technology has a variety of applications in health care. It has been used previously for a broad array of applications, such as transfusion and blood bag matching,[56–59] tracking laboratory specimens,[60] and inventory control,[61–63] etc. However, the application of barcoding to medication administration is newer.

Barcode technology can be used as a stand-alone application or linked to the CPOE or EHR system in the hospital. If the BCMA system is not integrated into the EHR, there would be

limited capability to have real-time alerts to detect discrepancies of the medications administered against the orders entered by the physician or to maintain an accurate documentation of medications administered.

In an integrated EHR environment, there is a seamless flow of information following every stage of the medication administration cycle, making it possible for BCMA systems to become part of the medication process workflow. Upon admission, every patient receives a barcoded wristband. These bands identify patients as they are steered through various tests and procedures at the hospital. After examining the patient, the provider enters medications electronically into the CPOE system. Following verification, the pharmacist packages unit doses of the ordered medications into barcoded containers and sends these to the nursing floor. The barcoding on the medication containers has information regarding type of medication, recommended dosage, and the frequency of administration.

The unit doses sent by the pharmacy are stored in a medication cart, which also carries a wireless laptop computer and a hand-held scanner. In an integrated EHR environment, the barcode scanning is linked to the clinical databases via a wireless network. At the patient's bedside, nurses scan their badges, or log into the BCMA system, scan the patient's wristband, and scan the medication. The BCMA system validates whether the "five rights" of medication administration—right patient, right drug, right dose, right frequency, and right route[64]—match the order entered in the CPOE system. If there is a discrepancy, an alert is displayed on the computer screen. Once a medication is scanned it is automatically documented in the medication administration record (MAR) as having been administered to the patient. In most BCMA systems, the nurse has the capability to record missed medications or changes in the time that the medication was administered. Thus, the BCMA system not only offers real-time validation at the point of care, it can also reduce nurses' workloads by creating an automatic and accurate log of the medications administered to the patient.

Research Evidence for BCMA

The research evidence on the use of BCMA systems is limited. The majority of the studies reporting outcomes related to implementation of BCMA technology were conducted in Veterans Health Administration (VHA) facilities; the VHA is a pioneer in the implementation of barcode technology for medication administration. The BCMA system currently used at the VHA is a homegrown system that has undergone several modifications. BCMA technology was first prototyped at a Topeka, Kansas, facility in 1996. In 1999, the BCMA system was integrated with the Computerized Patient Record System (CPRS), which is the CPOE system used at the VHA.[65] By 2000, the system and the associated hardware were implemented in 92 percent of the VHA inpatient wards. The following section discusses the evidence related to key variables associated with BCMA.

Decrease in medication errors. The most commonly measured variable was the change in medication error rate. Four studies described the measurement of this variable: three showed a decrease, and one study recorded an increase in medication error rate post-BCMA implementation. Coyle and colleagues[66] described the implementation of a BCMA system at one VHA facility—some of the refinements and upgrades that the system had undergone based on nursing recommendations. The changes were made to address specific workflow issues to increase acceptance of BCMA in routine practice. A survey administered to the nursing staff evaluated the acceptance of BCMA technology after 3 years of implementation. Results showed

that 97 percent of the nursing staff agreed that BCMA had decreased the risk of medication errors. Additionally, in the first year, the medication errors decreased by 23 percent, and, by the fifth year, by 66 percent. Consistent with these results, another VHA study by Johnson and colleagues[65] compared the overall medication error rates in 1993 and 2001 and found an 86 percent decrease over this period. Anderson and Wittwer[67] conducted a similar study in a non-governmental setting and found that the medication error rate decreased to less than 50 percent of its baseline value within 6 months of implementation of the BCMA system.

Another study measuring medication error rates was conducted in the medical-surgical units of a Midwest government hospital.[68] This study examined whether there was a difference in the medication error rate 1 year before and after implementation of BCMA. The error rates at the administering and dispensing stages were specifically examined. The study showed an 18 percent increase in the medication error rate. However, this increase was explained by the ability of the BCMA system to record any discrepancies in the medication administration, such as late or missed doses, which were previously underreported or went undocumented.

Discrepancies in documentation. The documentation functionality of BCMA systems enables the creation of an accurate and complete MAR, which can then become part of the patient's EHR. However, large discrepancies exist in medication documentation, even in an electronic environment. Only one study compared the discrepancies in documentation that arise upon implementation of a BCMA system. An examination of the discrepancies between MAR and patient billing records for large-volume intravenous solutions identified three types of discrepancies.[69] Failure to document administration to a patient occurred 38 percent of the time, the rate of failure to credit the patient for returned solution was 37 percent, and the rate of administration of solution to a patient other than for whom it was dispensed was 25 percent. This study also examined the potential for BCMA technology to decrease these discrepancies in documentation. A 19-percent improvement in the consistency of documentation was observed after introducing BCMA technology.

Impact on nursing workflow. A supplementary finding of the study by Barry and colleagues[69] was that the lowest scanning rates for items were achieved by the nursing personnel, largely because BCMA has such a huge impact on the workflow of nurses. In this study, the scanning capability was available only at the nursing station, requiring nurses to return to the station each time they wanted to scan an item. Lack of consideration of nursing workflow processes can result in low rates of adoption of BCMA technology. Another study of the medication administration process from the perspective of nurses found ways to make the technology less disruptive to nurses' workflow.[70] The researchers described strategies to improve acceptance of the technology among nurses and hypothesized that a tangible measurement of this acceptance would be seen in the increase in scanning rates. Patient armband scans went up by 7 percent, and medication label scanning showed a 15-percent increase over a 5-month period. The increase in scanning rates was small, but the study lacked a clear description of what the exact intervention was, and hence it is difficult to make conclusions about why it failed to have a larger impact on the scanning rates.

Using human factors theories to guide an ethnographic evaluation, before and after implementation of a BCMA system, the analysis and process-tracing protocols derived five negative, unintended effects of introducing this technology.[71] The investigators found that BCMA technology can lead to the creation of work-arounds that might result in new paths to occurrence of ADEs. This study is the first of its kind to conduct an in-depth analysis of the

design modifications, organizational policies, and elements of training that need to be in place for BCMA technology to fit seamlessly into the nurses' workflow.

Thus, the range of variables assessing the impact of BCMA technology on the workflow of nurses is broad and complex. An example of a simplistic variable is the measurement of the nurses' acceptance of BCMA technology by number of medication and patient identification scans.[70] Complex variables surrounding nurses' workflow have been measured using conceptual frameworks derived from the human factors engineering domain, such as recognition-primed decisionmaking (RPD), human-automation interaction, workload, authority-responsibility double-binds, and mutual awareness among members of the clinical team.[71]

Use of BCMA in the outpatient setting. Only one study described the use of BCMA in the outpatient pharmacy setting.[72] This was a small feasibility study evaluating whether BCMA could be used for automatic verification of medications during dispensing. The study suggested that manual checks could be replaced by barcode technology to improve pharmacist productivity and increase cost savings; however, empirical evidence supporting these conclusions was absent.

Beyond medication error rates. Unlike CPOE systems, there is a fair amount of uniformity when describing a BCMA system. Also, contrary to CPOE interventions—which were conducted largely at urban, academic institutions—BCMA studies are primarily conducted in VA settings. However, the slow penetration of this technology has resulted in very few evaluation studies. In general, there is a paucity of empirical evidence supporting the implementation of BCMA systems. The BCMA technology is advocated as an important safeguard for reducing ADEs, but sufficient evaluation of how this technology affects the dynamics of a complex hospital setting, in ways other than the reduction of medication error rate, is lacking.

Evidence-Based Practice Implications

The implementation and adoption of BCMA systems is slow, perhaps due to disruptions in nurses' workflow. Ease of use is directly linked to technology adoption. Inpatient environments are extremely busy and require technology that can easily adapt to the needs of nurses, enabling them to adopt the new technology readily into routine care.[73] Coyle and Heinen[66] provide a good description of how nursing staff are involved in the design and modification of BCMA software at the VHA. These recommendations helped the information technology team design software to align with workflow needs. Also, there is an effort by vendors to constantly upgrade and update the equipment to make it more user-friendly. The VHA environment has reaped the benefits of involving its nursing staff in the development process and implementing staff recommendations.[71, 74] Other hospitals need to consider this strategy to improve acceptance of BCMA technology by nurses. The VHA also has a national BCMA development team that is entrusted with the responsibility of continuously evaluating and revising the technology.[71]

Impact on nursing workflow. One of the efforts recently suggested was the replacement of the laptop computer with hand-held devices. A field evaluation of usability of this technique with nurses revealed that, while this might be useful for the administration of pain medication and hanging IV fluids, it was not ideal for use with medications in general.[66] Such determinations made from actual field studies serve two purposes. First, they enable nurses to be involved in the process of development and deployment, thus fostering ownership of the technology. Second, evaluation of the technology in a naturalistic setting can help us understand the far-reaching

impact that the introduction of a new technology can have on the workflow patterns—and prevent any new threats to safety that might be introduced by the technology itself.

Changing nurses' perceptions about technology. Adoption of BCMA technology calls for a behavioral change. According to the Technology Acceptance Model,[75] such a change can be brought about by improving perceptions regarding the system, specifically perception of the ease of system use and its usability in routine practice. Tailoring interventions that are geared toward understanding nurses' perceptions will promote adoption. System training should focus on educating nurses about how BCMA serves as a safety net and aids them in preventing errors. Also, organizational policies that support a transparent environment for the reporting of errors—rather than a culture of blame—can improve nurses' perception of BCMA technology. As the nursing shortage increases in hospitals across the nation, nurses need to view safety checks, such as BCMA technology, as aids rather than impediments in their practice.

Enhancing interdisciplinary communication. A seamless integration between the CPOE and BCMA systems can enhance workflow and also build interdisciplinary communication. Information systems have the capability to serve as the common thread linking an interdisciplinary clinical team with the therapeutic decisions driving patient care. Expansion of BCMA into institutions will strengthen nurses' relationship with other members on the clinical team and help other clinical staff to better appreciate nurses' contribution to patient safety.

Research Implications

Nursing practice has undergone a dramatic transformation with the implementation of BCMA systems. BCMA increases the visibility of the nurse's role in the medication administration process and contributes to the organization's commitment to patient safety efforts. Strategies that can be employed to enhance future research efforts in this domain are discussed below.

Medication error rate. A deeper examination is needed for the most commonly evaluated variable characterizing the medication error rate. No study reports an analysis regarding the type of ADEs, such as preventable and potential (often called near misses), that occurred while a BCMA system is in use. Such an evaluation would give us a deeper understanding of the ADEs that are being missed by the system and allow us to create modifications to better capture them.

Need for evaluation of economic outcomes. The policies of the FDA mandating barcoding of medications and the regulatory efforts of other patient safety organizations will, hopefully, encourage adoption of barcode technology. Research in this domain is limited and needs to be expanded to include examination of some core outcomes related to BCMA implementation. Quantitative estimations of return on investment following BCMA implementation and economic outcomes resulting from prevention of medication errors will expedite the adoption of this technology in more hospitals.

Outcomes such as reduced length of stay, decreased number of nursing full-time equivalents needed to perform medication administration, and decreased litigation following administration of incorrect medications are important economic considerations that hospital administrators evaluate when deciding in which technology to invest their health care technology dollars. These outcomes need examination with respect to BCMA technology.

Need for nurse involvement in BCMA implementation and design. As BCMA technology gets deployed in the medication administration process, it will have serious implications for nursing practice. Several issues surrounding the nursing workflow environment

need to be examined when implementing a BCMA system. Issues ranging from the usability of the hardware and software to pragmatic issues, such as the ease of use of the barcode reader and availability of the portable computer, will determine nurses' acceptance of BCMA in their patient care routine. This offers nurse researchers unique opportunities to provide leadership in the development and design of BCMA systems. Active collaboration of nurses with information technology personnel—to provide input on the display of alerts for urgent orders, reports of missing medications, or on recording the missed medications during a shift—can be invaluable to the deployment of BCMA systems.

Sociotechnical evaluation. Evaluation of BCMA technology from a sociotechnical perspective would help gain a deeper understanding of nurses' use of BCMA systems. There is a paucity of literature measuring the sociotechnical issues of compliance with alerts, cognitive load, efficiency, productivity, and emotional aspects of using the technology.

Documentation discrepancies. Besides serving as a safety check for nurses in the medication administration process, BCMA systems also play a key role in creating electronic MARs. Discrepancies in the documentation process have also been evaluated. Such discrepancies arise when medications that have been dispensed by the pharmacy fail to be administered by nurses. The returned medications are not credited back into the patient's billing account. Thus, discrepancies arise between what is dispensed, what is administered, and ultimately what the patient is billed for. Even though documentation discrepancies have been examined, there is no evaluation of the economic impacts of these discrepancies. Such discrepancies could lead to undesirable fiscal outcomes for the hospital, which might affect adoption of these systems. A systems analysis of how these discrepancies arise and what organizational policies can be put in place to inhibit them needs to be conducted.

The implementation of barcode technology can prevent the potential or near-miss errors that would not have been detected otherwise. Nurses must take an active and visible role in the development and deployment of BCMA technology. Participation is the key solution to implementing BCMA technology.

Evidence Table 5. Studies Evaluating Barcode Medication Administration (BCMA)

Source	Setting	BCMA	Study Design	Study Intervention	Key Finding(s)	Quality Score	Considerations
Anderson 2004[67]	St. Mary's Hospital Medical Center	Vendor	Pretest, post-test	Decrease in medication error rate.	The goal of 50% decrease in medication errors in the pilot unit was exceeded within 6 months of implementation. A 44% decrease in medication errors was reported for the entire hospital.	46	Lacks description of implementation process and how medication error rate was measured.
Barry 1989[69]	2 nursing units and 2 controls in a private, not-for-profit hospital	Homegrown	Pretest, post-test with controls	Potential for using barcode technology to reduce documentation errors of IV solution administration.	Errors were traced to three primary sources: (1) failure to document administration of solution (38%), (2) failure to credit patient for IV solutions returned to the pharmacy (37%), and (3) administration of solution to the wrong patient (25%).	48	BCMA was tested specifically on IV solutions. In-service training sessions were conducted.
Coyle 2005 [66]	Various Veterans Affairs Medical Center (VAMC) hospitals	Homegrown	Time series	Survey of nursing staff perceptions about BCMA decreasing risk for medication errors. Decrease in medication errors.	After 3 years, 97% of the nursing staff agreed that BCMA could decrease the risk for medication errors, potential and actual. Medication errors decreased by 23% in the first year and by 66% after 5 years.	44	Description of nursing staff involvement in the design and modification of BCMA system to resolve workflow and software issues. Good description of BCMA functionality. Lacks description of study methodology and study subjects.
Englebright 2005[70]	85 facilities of Hospital Corporation of America	Unknown	Pretest, post-test	Frequency of scanning patient armbands and medication labels.	Patient armband scanning increased by 7%, and medication label scanning increased by 13%.	31	Lacks description of implementation process and a description of how acceptance among nurses was improved.

Source	Setting	BCMA	Study Design	Study Intervention	Key Finding(s)	Quality Score	Considerations
Hokanson 1984[72]	1 outpatient pharmacy service in an ambulatory clinic	Homegrown	Cross-sectional	Feasibility study of using BCMA in the pharmacy setting.	No dispensing errors were made.	39	The study was conducted for a limited time (36 hours) and a single clinic session.
Johnson 2002[65]	VAMC	Homegrown	Time series	Number of medication errors prevented.	Prevented 549,000 medication errors while dispensing 8 million doses, in 6 years.	57	Compared medication rates from the manual medication administration system and the electronic BCMA system.
Low 2002[68]	2 medical surgical units at a Midwest government hospital	Vendor (Tremont BCMA)	Pretest, post-test	Medication error rate 12 months pre- and postimplementation of a BCMA system.	Medication error rate increased by 18% after BCMA implementation due to enhanced reporting by BCMA system.	62	The measurement of medication error rate prior to implementation was using the incident report system, while post-BCMA implementation the system would create automatic logs if any discrepancies arose in the medication administration.
Patterson 2002[71]	Acute care and nursing home wards of three VA hospitals	Homegrown	Cross-sectional, observational study before and after implementation	To identify the negative, unintended side effects resulting from the implementation of BCMA systems that can create new paths to ADE occurrence.	Five negative side effects after BCMA implementation were identified.	98	The outcomes of this study serve as recommendations for design modification of the BCMA system in the VA.

Decision-Support Systems for Nursing

Background

Patient safety researchers view decision-support systems (DSS) as a solution to high rates of medical errors and inappropriate care. Many researchers view embedding DSS systems into well-developed, comprehensive CPOE systems as the only method to significantly impact clinical decisionmaking. Order entry with DSS harnesses the full potential of the computer to provide relevant information, guide decisions, and structure data entry.[6, 76, 77] For this section of the chapter, the main focus is on decision-support interventions for nursing that are embodied within a CPOE system that is linked to a comprehensive electronic health record (EHR). DSS interventions were considered if they were implemented in the context of an existing CPOE system or could easily be integrated into a CPOE system. Decision-support systems are software designed to support or enhance clinical decisions. This is a broad definition and includes changes in information displays, alerts, reminders, or fully developed algorithmic computerized protocols.

Research Evidence

There were two published studies on nursing-specific DSS studies conducted in a CPOE environment.[78, 79] There were many other published studies that reported early development work and validation results for DSS related directly to nursing. However, because so few were implemented, they were not eligible for inclusion here. Overall, there were 31 studies where the DSS intervention either was embedded in an EHR with CPOE or could reasonably be expected to have that capacity (see Table 6). This set of studies could be divided into two groups. The first group includes those studies targeting nursing decisionmaking directly (e.g., prevention of pressure ulcers, incontinence, triage). There were 13 studies in this group; however, only one was actually implemented in a CPOE system. The second group includes those studies largely targeting physicians, but the clinical focus could reasonably be associated with nursing. This judgment is, of course, subjective, as nursing is involved in almost all aspects of care. However, some activities have substantial nursing involvement. There were 18 studies in this second group, covering three broad areas: (1) acute care guidelines for selected topics, (2) critical care, and (3) preventive care. There were many other studies where the role of nursing might be significant, such as coagulation therapy or diabetes management. Because the nursing role was not explicated and would likely vary, these studies could not be included.

Direct decision support for nursing. Out of the 31 studies identified as relevant, 13 focused directly on nursing. Three studies concerned consultant systems for the prevention of pressure ulcers. All three were essentially qualitative or descriptive, presenting very little patient outcome data.[80–82] Decision support for the management of urinary incontinence has been studied as well. Petrucci and colleagues[83] found large increases in knowledge and decreases in episodes of urinary incontinence in a patient care unit where a consultation system was implemented, as compared to a unit in the same hospital where it had not been implemented. Three studies examined the performance of staff conducting telephone triage with the help of algorithmic decision-support systems. All found improved performance, although all three used the weakest design, a pretest, post-test evaluation.[84–86] Two other studies directly addressed alerts and reminders to nursing staff for preventive care. Both of these showed strong results, including

one study that compared standing orders with alerts directed at nursing staff to alerts directed toward physicians.[79, 87]

In another study, the effects of different forms of physiologic data displays in a neonatal ICU were examined in a CPOE environment.[78] In this study, all infants were randomly assigned during an 18-month period to one of four groups: (1) no display of trend data, (2) continuous display of trend data, (3) alternating 24-hour display of trend data starting in the first 24 hours, or (4) the same as the third group starting after the first 24 hours. The number of orders for colloid, blood gases, and ultrasound were measured, as were longer-range variables, such as total time on ventilation, total time on supplemental oxygen, length of stay, and death. No differences in patient outcomes were noted, although surveys found increased knowledge regarding neonatal physiology on the part of the staff. Because patients rather than clinicians were assigned randomly, it is highly likely that there was dispersion of the effects of the independent variable.

Finally, several studies on a clinical decision-support system (CDSS) that guides nurses in identifying patient preferences consistently found improvement in the degree that nurses were able to act in accordance with patient preferences. These studies employed a high-quality design, and although the program was never embodied in an EHR, it is conceivable that one day it might implemented with resultant, improvement in the continuity of care.[88–90]

Indirect decision support for nursing. The remaining 18 studies were selected because they used a computerized intervention that either was instituted in a CPOE environment or used a well-established EMR. In addition, these studies focused in areas where nursing would likely be highly involved. One study[79] contrasted standing orders (to the nursing staff) versus computerized reminders for preventive care for inpatients, finding nearly twice the improvement with standing orders. Three studies focused on the use of guidelines to prevent deep venous thrombi in post-surgical patients, involving both nursing and physician activities. In two of the studies, significant results were found for provider compliance using the guidelines, but no difference was found regarding patient outcomes.[91, 92] In the third study,[93] both compliance with guidelines and patient outcomes were improved.

Four other studies were conducted in critical care settings, involving mostly complex guidelines (e.g., ventilator support). In two other studies, the effects of a computerized guideline for the treatment of adult respiratory distress syndrome were the focus of the investigation. Both were conducted by investigators from the LDS hospital in Salt Lake City, which had an extensive EHR at the time, but not full-scale provider order entry. East and colleagues[94] examined the impact of the computerized guideline in a prospective multi-center randomized trial for 200 patients. No significant differences were found in survival or ICU length of stay between treatment groups. There was a significant reduction in morbidity as measured by a standard scoring system, as well as a lower incidence of over-distension lung injury. In a similar study, a pilot of the study published above at Memorial Hermann Shock Trauma ICU, McKinley and colleagues[95] randomized 67 trauma patients to either being cared for by the protocol or not. No difference was found between patients in terms of survival, length of stay, or morbidity.

In another study conducted in the outpatient setting in the VA, with a complete CPOE system, computerized guidelines for mental health screening resulted in significantly higher compliance than paper guidelines. It was not clear in the description how nurses (not including the advance practice nurses) were involved in the implementation, but they might have been the individuals actually receiving the alerts.[96]

Several studies using qualitative techniques found similar issues. Karfonta[97] used grounded theory to examine the experiences of 23 nurses and 10 physicians using DSS systems in the ICU.

Overall, all interviewees mentioned the role of DSS in assisting in forecasting the outcomes of decisions. Difficulties in learning the system, trusting the output, and understanding the technology were additional themes.[97] Lyons and colleagues[98] examined VA employees' perceptions of guideline implementation and utilization in the VA's CPOE system. Information technology issues were perceived as major barriers to effective guideline implementation. Patterson and colleagues[99] conducted a human factors qualitative analysis of the VHA clinical reminder system and noted that increased workload, training, time, and role divisions were key barriers to success.

The remaining studies all focused on preventive care reminders or hypertension followup, with only two focused mainly on nursing.[87, 100] In most cases, but not all, the studies found improved compliance. Because the studies took place in the outpatient setting, the role of the nursing staff likely varied greatly, but is not elucidated. Further analysis would have to be done to determine if an increased role of nursing in providing followup and initiating immunization was a determinant contributor of success.

Challenges with research evidence. Three main themes can be extracted from the results. First, for the most part, nursing activity is simply not addressed in these studies. Nurses make decisions every day about pain and wound management, whether a patient's symptoms are severe enough to notify a physician. Nurses often have to decide if a patient's symptom is drug related, or if a drug might interact with other drugs before they give them. In many cases, nurses have primary responsibility for patient education and family support. Few decision-support interventions have been developed for any of these high-level, decision-based actions. It is as if nursing decisionmaking is invisible and nurses are viewed as data collectors, rather than decisionmakers. In addition, one of the main roles that nurses fill in an inpatient setting is that of an intermediary between the patient and other providers. This communication role is a crucial function in ensuring quality of care. However, communication has been significantly neglected in EHR designs, as was noted earlier in this chapter and by many other authors.[101, 102] Most of the work to create DSS has focused on structured documentation, order review, or systems designed to force or track nursing actions. For example, one study examined the effectiveness of putting a signal on a nurse and tracking where they were at all times to ensure efficiency.[103] Another study examined the impact of opening locked medicine cabinets (in the room) only when medications were due, to ensure that nurses would give them on time.[104]

Second, the mechanics of providing DSS for nursing in a regular CPOE inpatient setting has not been well explicated. In many settings, the computers are located at the nursing stations, making them unavailable at the time of care. The model of having decision-support software located on computers situated at the nursing station fails to support a nurse who is constantly on the move. Development and exploratory work has been published, examining the use of portable laptops or hand-held computers, but no high-quality studies have reported on an actual implementation directed at nursing.

Third, none of the studies have examined the mechanism of action for DSS interventions. This is true of the DSS literature in general. Because DSS interventions can range from alerting a clinician about something they already know (e.g., a reminder), to alerting the staff to where a patient is in a process (tracking), to providing new information that educates and informs, it is important to measure the intended psychological effect as well as the outcome.[105, 106] Although most studies show significant increases in provider compliance, the effect is small, and the upper limits are in the low 40- or 50-percent levels.

Evidence-Based Practice Implications

The above three themes provide a framework for discussing how to link this work to practice. Because the large body of nursing activity is simply not addressed in these studies, it is difficult to identify the important practice implications. Many clinical interventions are likely designed by nursing for quality improvement purposes using the EHR, and these are not being captured in the formal research literature. In the VHA, there are substantial local initiatives led by nursing to improve patient care using the functionalities provided by the CPOE. Few, if any, are published. If they are published, the focus is on "lessons learned" rather than to provide scientific evidence of efficacy. Nurses in practice can inform themselves of the functionalities of their EHR and volunteer to serve on hospital informatics committees that make strategic decisions. Adapting the system to nursing's needs and adapting to the system is a process of whole-system transformation.[107–109]

The second issue regarding the improvement of practice is how to improve the mechanics of providing DSS for nursing in the inpatient setting, given the fact that nurses are often on the move. Some of the more effective decision support can be arrangements of lists, printouts, and other easy-to-carry tools to simplify and organize data. Most EHRs have the capacity to be customized to individual clinical needs. Nurse managers are in a unique position to evaluate their system and participate in the development of low-resource-impact, decision-support tools. Nurse managers could also be involved in technology planning, to ensure that computers are available at the bedside. In addition, interventions, such as BCMA, structure nursing documentation. But because it is linked to an information system, imbedded DSS could easily be implemented to alert nurses about possible ADEs.

Because DSS is likely to be implemented by administration, it is important that the nurse managers argue for evaluation of the system. Evaluation should focus on measuring the implementation itself, the work process changes, and the outcomes. The evaluation should be started at the same time as the implementation so that the information gleaned will not only minimize any negative impact on patient safety, but also will provide for maximum input by nursing staff during the change process. Ongoing evaluation is essentially a quality management activity and is a practical approach to clarifying the mechanisms of action—and to ensuring that the impact of DSS on nursing practice is formally addressed.

Research Implications

The three themes identified above also provide a framework for discussing future research implications. The work that needs to be addressed immediately is clarification of nursing roles in the implementation and success of DSS systems, especially those implemented in the context of CPOE systems. Most of these interventions are multidisciplinary and involve substantial process reengineering that goes largely unreported. Nurses are in a position to fully comprehend the depth of this reprocessing, and expanding our understanding in this area would be a contribution to the field as a whole. Implementation as a science is expanding, and nursing expertise is crucial.

Secondly, much more work needs to be done to delineate and clarify the actual decisions made by nursing in order to develop effective decision-support systems. This goal can be accomplished in two ways. More qualitative work is needed to describe and analyze nursing decisionmaking using recent theoretical advances in the cognitive sciences. Activity theory,[110]

goal theories,[111] and adaptive rationality[112] are areas that would be very useful as approaches to understanding nursing practice. In addition, although many studies have been published that explore decisionmaking and nursing expertise, some of which have been developed and validated, very few have been actually implemented. Nursing needs to examine the barriers that prevent the outcome of these research projects from reaching higher levels of adoption.

Finally, because the mechanism of action for DSS interventions is not examined, future advancement in the field of decision support is constrained. As described above, mechanisms are likely to be either psychological (e.g., directing attention, decreasing memory loads, or educational) and/or organizational (e.g., changing work processes and role behaviors). Designing studies that measure memory load, manipulate and test the role of attention, and directly assess learning effects as part of a DSS design would greatly advance the science.

Evidence Table 6. Decision-Support Systems Within an Electronic Health Record Related to Nursing

Source	Setting	Study Design	Study Intervention	Key Finding(s)	Quality Score
Barnett 1983[113]	Outpatient	Randomized controlled trial	Reminders for followup for hypertensive patients.	Followup was significantly improved in the group receiving the reminders, in rate of followup attempted or achieved by the responsible physician and in the repeated recording of blood pressure.	90
Barton 1990[114]	Outpatient health maintenance organization	Pretest, post-test	Postcards compared to simple reminders compared to feedback and reminders.	No changes in vaccination rates until computerized reminders were supplemented with feedback to individual providers.	48
Cannon 2000[96]	Outpatient mental health VA	Randomized controlled trial with patients randomized within providers	Computerized vs. paper reminders for screening and documentation of mood disorders using CaseWalker.	The computerized screening reminders resulted in a higher screening rates for mood disorder (86.5 vs. 61 percent, *P* = 0.008) and improved documentation.	90
Clark 2005[80]	Multilevel care in Canadian Health Region	Qualitative, descriptive	Computerized advisory management system to prevent pressure ulcers.	Evaluation indicated an increase in knowledge relating to pressure ulcer prevention, treatment strategies, resources required. Lack of visible senior nurse leadership; time required to acquire computer skills and to implement new guidelines; and difficulties with the computer system were identified as barriers.	N/A
Coe 1977[115]	Outpatient	Cluster case cohort	Blood pressure management in outpatients using computerized reminders.	No significant difference in patient outcomes.	64
Cunningham 1998[78]	Critical care	Randomized control trial	Continuous trend display vs. summative aggregated displays.	None of the short-, medium-, or long-term patient outcomes demonstrated any significant benefit from the provision of computerized physiologic trend monitoring.	102
Dale 2003[116]	Emergency services	Pretest, post-test	Consultant support for nurse triage.	More patients requiring an ambulance were seen in the emergency department for the intervention group as compared to the control (odds ratio = 2.62; 95% CI = 1.78–3.85).	90
Davidson 1984[87]	Outpatient	Pretest, post-test	Specific nurse-targeted reminders.	Significant increases in stool examination for occult blood (32% to 47%), breast examination (29% to 46%), and influenza immunization (18% to 40%).	78

Source	Setting	Study Design	Study Intervention	Key Finding(s)	Quality Score
Dexter 2004[79]	Inpatient	Randomized controlled trial	Compared standing orders to computerized reminders in a CPOE environment.	Patients with standing orders received an influenza vaccine significantly more often (42%) than those patients with reminders (30%) ($P < 0.001$). Patients with standing orders received a pneumococcal vaccine significantly more often (51%) than those with reminders (31%) ($P < 0.001$).	110
East 1999[94]	Critical care	Randomized controlled trial	Computerized guidelines for management of ventilated patients.	No significant difference in survival or ICU length of stay between the two treatment groups ($X^2 = 0.49$, $P = 0.49$) and ($F(1) = 0.88$, $P = 0.37$). There was a significant reduction in morbidity ($F(1) = 4.1$, $P = 0.04$) and severity of over-distension lung injury ($F(1) = 45.2$, $P < 0.001$).	102
Hutchison 1989[100]	Outpatient clinic	Pretest, post-test repeated measures	Printed reminders attached to charts taken from EMR.	Vaccination rate increased from 10.1% to 26.8% and no increase in influenza immunization in the comparison practice.	64
Karfonta 1999[97]	Critical care	Qualitative analysis of nurses and physicians	DSS in general.	DSS was seen to be important for forecasting decisional outcomes. Included four sub-areas: DSS learning, understanding DSS technology, creating DSS inferences, and trusting DSS-derived data. UK.	N/A
Kucher 2005[93]	Inpatient in a CPOE environment	Randomized controlled trial	Alerts given to physicians.	The rate of prophylaxis increased from 14% in the control to 33% in the intervention group. Those receiving prophylaxis had 41% less incidence of DVT than those who did not.	84

Source	Setting	Study Design	Study Intervention	Key Finding(s)	Quality Score
Lyons 2005[98]	Inpatient VA	Qualitative	Perceptions of VA clinicians regarding the role of information technology in implementing guidelines.	Eighteen themes clustered into four domains. Workplace factors were more often discussed by administrators, system design issues discussed most by nurses, and personal concerns discussed by physicians and nurses. Facilitators included guideline maintenance and charting formats. Barriers included resources, attitudes, time and workload, computer glitches, computer complaints, data retrieval, and order entry. Themes with dual designations included documentation, patient records, decision support, performance evaluation, clinical practice guidelines (CPG) implementation, computer literacy, essential data, and computer accessibility.	N/A
McKinley 2001[95]	Critical care	Randomized controlled trial	Computerized guideline to manage ventilated patients.	Outcome measures (i.e., survival, ICU length of stay, morbidity, and barotrauma) were not significantly different between groups. Fio2 > or = 0.6 and Plateau > or = 35 cm H2O exposures were less for the protocol group.	102
Mosen 2004[92]	In patient post-op in highly developed EMR system, but not complete CPOE	Pretest, post-test	Guideline to prevent post-surgical DVT (deep vein thrombosis).	The overall prophylaxis rate increased from 89.9% before implementation of the computerized reminder system to 95.0% after implementation ($P < 0.0001$). The combined 90-day rate of symptomatic DVT, pulmonary embolism (PE), and death attributable to PE remained the same (pre-1.0%; post-1.2%; odds ratio = 1.21; 95% CI = 0.67–2.20).	52
Murray 2004[116]	Outpatient in a CPOE environment	Randomized controlled trial	Computerized suggestions given to (1) physicians, (2) pharmacists, (3) both, or (4) none.	No significant differences found between groups in terms of quality of life, hospitalizations, ER visits, cost, or blood pressure (BP).	110
Patterson 1998[91]	Inpatient in a CPOE environment	Pretest, post-test	Computerized algorithm with protocols for prevention of DVTs.	The preintervention rate of DVT prophylaxis over a 3-month period was 85.2% (785 of 921 eligible cases). For the 3 months following the introduction of the computerized reminder, compliance with DVT prophylaxis increased to 99.3%.	64

Source	Setting	Study Design	Study Intervention	Key Finding(s)	Quality Score
Patterson 2004[99]	Outpatient use of clinical reminders in the VA CPOE system	Qualitative	Human factors analyses were conducted on users across multiple settings and roles.	Significant barriers and issues were identified, including time, workload, nonrelevance, ease of use, training, complicated procedures for refusal, etc.	N/A
Petrucci 1991[83]	Nursing home in a non-CPOE environment	Case control	Disease management consultation for urinary incontinence.	The number of wet occurrences of patients residing on units where nurses consulted UNIS decreased significantly; F (2,9) = 34.67. The knowledge of urinary incontinence also improved significantly when nurses consulted UNIS; F (2,157) = 19.46.	54
Rogers 1982[117]	Outpatient in a non-CPOE environment	Randomized controlled trial	Alerts to manage hypertension, obesity, and renal disease, using printouts only.	Decreased BP, decreases in hospitalization and length of stay.	84
Ruland 1999[88]	Inpatient unit for the elderly	Quasi-experimental nonrandom assignment; groups selected in tandem.	Use of a systematic protocol for eliciting patient preferences given to nurses in experimental group.	Patients whose nurse was given their personal preferences reported care more congruent with their preferences.	68
Ruland 2002[89]	Inpatient	Randomized controlled trial	Use of a hand-held computerized decision support.	Nurses' use of CHOICE made nursing care more consistent with patient preferences (F = 11.4; $P < 0.001$) and improved patients' preference achievement (F = 4.9; $P < 0.05$).	78
Ruland 2003[90]	Outpatient	Randomized controlled trial	Use of a computerized system that collects patient preferences.	Patient reports of topics addressed during the consultations showed greater congruence in the experimental group as compared to control group.	108
Schriger 1997[118]	Emergency services	Time series	Guidelines for treatment of occupational body fluid exposures.	Mean % documentation of essential items increased from 57% to 98% in the intervention phase, and aftercare instruction increased from 31% at baseline to 93% during the intervention phase, but both decreased to baseline when the computer system was removed. Compliance with guidelines increased from 63% to 96% during the intervention phase. Percentage of charges increased from 44% to 81% during the intervention phase and decreased to 36% following the intervention.	78

Source	Setting	Study Design	Study Intervention	Key Finding(s)	Quality Score
Schriger 2000[119]	Emergency services	Time series	Guidelines for care of febrile children.	Percentage of 21 essential history and physical examination items increased from 80% during the baseline period to 92% in the intervention phase (13% increase; 95% CI = 10–15%). Mean percentage documentation of 10 items in the aftercare instructions increased from 48% at baseline to 81% during the intervention phase (33% increase; 95% CI = 28–38%). All decreased to baseline when the computer system was removed.	68
Slovis 1985[85]	Emergency services	Pretest, post-test	Triage DSS using flip charts; users were not clinicians.	The DSS system shortened the average response time from 14.2 minutes to 10.4 minutes for the most urgent cases ($P < 0.05$); resulted in a significant increase in the use of advanced life support units for this group ($P < 0.02$).	44
Strachan 2001[86]	Emergency services	Pretest, post-test	Triage	Effective triage went from 20% to 32%.	44
Tang 1999[120]	Outpatient CPOE environment.	2-yr prospective case control	Reminders for immunization.	Used physician volunteers for CPOE. Compliance rates for the computer-based patient record system (CPR) user group increased 78% from baseline ($P < 0.001$), whereas rates for the paper records (PR) user group did not change significantly ($P = 0.18$).	64
Willson 1995[81]	Inpatient	Pretest, post-test	Implementation of AHCPR guideline on pressure ulcers.	Comparison of computerized protocol with a previously implemented paper protocol. Very little data.	N/A
Zielstorff 1997[82]	Inpatient unit	Case control	Pressure ulcer DSS for nurses used by nurse volunteers; no data on usage.	Dependent variables were knowledge and decisionmaking results from simulations. No patient data provided.	N/A

Conclusion

Across the sections in this chapter, several themes are apparent. First, nursing and nursing impacts are nearly absent in the current empirical studies of work on EHR orders and clinical decision support within ordering systems. Future research is needed to understand the impact of that technology on the role of nurses and workflow methods that are effective for nurses in a computerized orders environment. Nursing clearly participates in the orders process; yet, the assessment of that role is missing to date. More important, nurses and pharmacists serve in roles as protectors against errors in patient care. The counts of intercepted errors speak to this role in a simplistic way. More complex variables and expanded research is needed on this topic. With CDSS, nurses are studied as invisible partners in the care process rather than as decisionmakers themselves. Yet, nurses make thousands of care decisions a day. Borrowing methods from psychology, future researchers could expand the cognitive work in this area.

BCMA is the exception to the absent nursing voice. In BCMA, nurses are integral to the success of the application. Medication error reduction with BCMA is apparent. Additionally, the VHA has effectively included nurses in the design and implementation of technology-assisted medication administration. However, technology assistance in medication administration represents a lower-level cognitive process than, say, decisionmaking about symptom assessment or an independent care intervention. Thus, future research on decision support for higher cognitive processes and the nurse as a full-fledged decisionmaker is warranted.

There are several limitations to this work. A strong effort was made to have well-defined inclusion criteria to make the studies as homogeneous as possible and to allow valid comparisons. However, the inclusion criteria have limited this analysis to implemented solutions, narrowing the possible CDSS applications in particular. Likewise, studies were excluded from areas such as imaging and psychiatry; in the future these areas could be examined. Our results included some qualitative work, not usually considered as evidence, but included here to better describe the phenomena at hand. An analysis without qualitative studies would perhaps come to different conclusions.

Studies in sociotechnical and human-computer interaction are needed in each of these areas. This would help us understand the complex processes inherent in technology design and adoption. Interdisciplinary examinations are needed in future research to understand interdependent roles. With technology becoming an omnipresent participant on today's health care teams, traditional roles on a health care team have been altered. For example, computerized orders management changes roles, and role renegotiation must take place. New process and new issues emerge with complex technologies like CPOE; this interdependence needs to be systematically evaluated in the future. The research in HIT integrative functions is just beginning. Future opportunities are many for areas of great impact to nursing.

Search Strategies

CPOE Search Strategies

A broad search of the literature from 1976 through the end of 2005 was undertaken as part of a larger study to locate articles dealing with the practice impacts of clinical computing applications. Searches were conducted in PubMed®, CINAHL, Cochrane, PsychInfo, DARE, INSPEC, CENTRAL, and HTA databases. The search strategy is located in appendix A. The

search yielded 63,731 references with 1,023 abstracts rated as having empirical data. Abstracts were coded for relevancy and sorted into categories (e.g., clinical decision support, CPOE, EHR adoption). CPOE-coded articles were retrieved as a subset from the larger search results. Search terms were

> online order entry OR computer-based physician workstation OR practitioner order entry OR physician order entry OR electronic health record OR computerized physician documentation OR computer medical records OR medication order entry OR computer based order entry OR CPOE OR POE

The CPOE search yielded 178 potentially eligible articles.

CPOE articles were rated for eligibility with empirical studies of any design and systematic reviews being considered relevant. The relevant studies examined implemented solutions with a concentration on any practice implications of CPOE. Letters, opinions, and editorials were excluded, as were articles dealing with models or theoretical discussions about systems. Further, studies were excluded if they (a) provided only verbal summaries of CPOE impacts or satisfaction with CPOE; (b) focused solely on CPOE costs or ordering volumes; (c) primarily focused on imaging, dentistry, simulations, psychiatry, data mining, or genetics; or (d) focused solely on CPOE or EHR adoption methods. The authors separated studies with a major focus on guidelines and order-related decision support into a separate section of this chapter. This first section targets clinical impacts of paper-based ordering compared to CPOE.

BCMA Search Strategy

A review of studies published in peer-reviewed journals and meeting abstracts was undertaken. The search criteria used for PubMed® was as follows:

> barcode point-of-care technology OR bar code medication administration OR BCMA OR medication bar coding OR barcode medication administration OR barcode point-of-care technology OR eMAR OR electronic medication record

The search was limited to studies with abstracts that were published in the English language and spanning the years 1976 to 2005. This search retrieved 205 abstracts, out of which 29 were relevant. A second search was conducted to look for studies that focused on the nursing domain by combining the above search strategy with "AND nursing." The same limits were applied to this search as well. A total of 33 abstracts were retrieved, out of which 10 were considered relevant for this review. In all, 39 abstracts were considered relevant in our first evaluation.

A second evaluation was conducted by retrieving and reading the full text articles. The inclusion criteria used to determine whether a study was relevant or not were the same as those used for CPOE, as described above. Eight studies provided evidence of actual implementation of a BCMA system and its evaluation; the remaining 31 articles were discarded. Further, quality assessment of the studies was conducted using the QUASII instrument. Table 5 presents a summary of the key findings and variables measured in the nine studies that were finally evaluated.

Decision Support Search Strategy and Methods

The broader search strategy used for this review is described at the beginning of the chapter. The results retrieved from this larger search were further analyzed for relevance to DSS interventions for nursing. To be included in the final round, a study had to be reporting an actual

evaluation or research study conducted with real patients cared for with the intervention in place. Although the focus was on those studies associated with CPOE and an EHR, few have been conducted (especially for nursing). Therefore, studies were included where the intervention could easily be implemented *in the context* of CPOE with an EHR. Studies whose main focus was on nursing interventions designed to improve documentation, care planning, or administration were *not* included. Simulations, early reports of development findings, or validation of DSS software were also not included, nor were studies that were simply descriptive or had a "lessons learned" perspective. However, studies that used methods close to a traditional qualitative methodology or formal human factors analysis were included when appropriate, for example, the focus was on a system implemented in real time.

Inclusionary terms:

Online order entry OR computer-based physician workstation OR practitioner order entry OR computer-based medical record OR electronic health record OR computerized physician documentation OR computer medical records OR decision support computer program OR health maintenance reminder OR CDSS OR computer-aided OR computerized decision making support OR clinical decision support system OR computerized feedback OR computer-assisted dosing OR computer feedback OR predictive instrument OR computer-aided quality assurance OR computer alert OR clinician order entry OR provider order entry OR computerized reminder OR computer reminder OR computer-based monitoring system OR expert system OR computer-based medical decision support OR decision support system OR computer based order entry OR event reporting system OR electronic healthcare record OR electronic monitoring OR electronic health record OR electronic medical record OR electronic incident reporting OR electronic record OR electronic patient record OR electronic record keeping OR medical information system OR computer-predicted OR computer-based monitoring OR computer-based prompt system OR CPOE OR POE OR electronic journal OR medical reminders OR electronic reminders OR medical record alert.

Inclusionary Mesh® terms (for PubMed® only):

"Decision Support Systems, Clinical"[MeSH] OR "Hospital Information Systems"[MeSH] OR "Medical Records Systems, Computerized"[MeSH]

Exclusionary terms:

NOT (X-ray OR biochemistry OR DNA OR RNA OR genome OR tomography OR dentistry OR dental OR simulation OR molecular OR animal OR psychiatric OR biofeedback OR HIPAA OR in-home OR data mining OR algorithm)

Exclusionary Mesh® terms (for PubMed® only):

NOT ("Validation Studies"[Publication Type] OR "Editorial"[Publication Type] OR "Letter"[Publication Type] OR "News"[Publication Type] OR "Comment"[Publication Type] OR "legislation and jurisprudence"[Subheading] OR "Libraries, Medical"[MeSH])

Limits

Articles considered were those published in English during the time period January 1, 1976 to August 1, 2004.

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Author Affiliations

Nancy Staggers, Ph.D., R.N., F.A.A.N., Associate Professor of Informatics, University of Utah College of Nursing, adjunct Associate Professor, School of Medicine. E-mail: Nancy.Staggers@hsc.utah.edu.

Charlene Weir, Ph.D., R.N., Associate Director of Education and Evaluation, VA GRECC, Salt Lake City, UT. E-mail: Charlene.Weir@med.va.gov.

Shobha Phansalkar, R.Ph., Ph.D., Informatician, Partners Healthcare System, Inc., Instructor, Harvard Medical School. E-mail: sphansalkar@partners.org. (This chapter was written while she was a doctoral candidate at the University of Utah Department of Biomedical Informatics.)

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