Clinical Decision Support Simulations for Medication Administration

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Abstract

Purpose and Scope: The specific aims of this study were to develop a methodology and tools for the design of clinical decision support systems to decrease the incidence of medication administration errors. **Methods:** A mixed-methods design was utilized in this study. First, observations of medication administration practice were used to inform the design of a simulated information system with a variety of decision support tools. Then, nurses were observed administering medications in a simulated environment using the simulated system. Finally, the nurses participated in focus groups to provide input into system tools design. Observations of nurses' use of the decision support tools as well as semistructured focus groups were used to evaluate nurses' use and perceptions of the utility of the system decision support tools. **Results:** Nurses' evaluation of the medication administration decision support tools as well as their actual performance revealed a tendency to underestimate their need for support. Their preferences were for decision support that was short, color coded, and easily accessed. Observations of medication administration showed that nurses exhibit a variety of work processes to prepare and administer medications to patients and access system decision support tools at a variety of points in this process. This study was performed in one hospital, and results may not generalize beyond this setting. However, this method used to design and test decision support could be transferred to other settings. System design should allow flexibility of multiple points and types of information delivery to accommodate variations in workflow to minimize the tendency for system workarounds.
Keywords: Decision support, medication error, system design, simulation, usability testing

I. Purpose

The overall aim of this study was to develop a methodology and tools for the design of clinical decision support systems to decrease the incidence of medication administration errors. To improve the decision support design process, we developed a simulated system that includes the relevant and realistic elements of the actual clinical environment and used teams of nurses from several units within a hospital to test its applicability to real-world settings.

The specific aims of this study were to:

1. Modify a simulated clinical information system to include a suite of decision support tools for medication administration within intensive care.
2. Engage teams of intensive care unit nurses to participate in a protocol to identify how these tools can be customized for optimal decision support within their clinical environment
3. Produce a detailed manual, instructions for customization in a broad range of settings, and other supporting materials to allow the tools to be used as a contextually sensitive system analysis tool for general use.

II. Scope and Background

A. Medication Administration Errors in Intensive Care

Error is particularly prevalent in highly technical specialties such as critical care, vascular surgery, cardiac surgery, and neurosurgery, where the rate of adverse events is significantly higher than in other areas of acute care (4). Intensive care units may be one of the most dangerous places in acute care settings with respect to medication errors. The rate of preventable ADEs in intensive care can be twice as much as in non-intensive care units (5). Errors in medication administration in intensive care settings also have the potential to be more deadly than those on other hospital units due to the large amount of intravenous medications given (5-7). Adverse events occur when nurses push intravenous medications at the wrong rate, through a catheter of an inappropriate gauge for the medication, or through IV lines that carry

incompatible drugs; prepare medications with the wrong diluents; and fail to recognize commonly occurring side effects or drug interactions (8).

The Institute for Safe Medication Practices and AHRQ (9) have recommended the use of three medication technologies to reduce ADEs at the point of administration: unit dose dispensing, barcode medication administration (BCMA), and smart infusion pumps. These combined strategies can reduce the incidence of medication errors related to the administration of drugs to the wrong patient, wrong drug, wrong drug amount, and wrong administration time (10-12). Unit dose dispensing, BCMA, and smart infusion pumps do not address, however, the ADEs that can occur because of lack of knowledge of the drug on the part of the administering nurse or those errors that result from information that the nurse knows but has forgotten or does not use during the actual patient care situation. In a description of errors by stage of medication process, Kopp et al. (13) report that lack of drug knowledge was the cause of 10% of errors, and slips and memory lapses were responsible for 40% of errors at the administration stage.

It is not surprising that some medication administration errors are attributable to slips and memory lapses, as healthcare work occurs within an interrupt-driven environment, where workers are carrying on more than one communication task simultaneously (14-16). Such disruptions can cause memory lapses, even when only 10 seconds separates the intention from the interruption (17). Although nurses who have long experience in a setting might be expected to prevent many errors because of familiarity with the drugs, dosages, and patient population, older and more experienced nurses are leaving the workforce (18), and hospitals increasingly rely on novice nurses, transfers among settings, and the use of agency nurses to staff units (19, 20). Traditional educational interventions alone are insufficient to decrease the errors committed during medication administration; new drugs become available, some drugs are infrequently given, and interruptions, fatigue, and overwork are prevalent in current practice environments (9).

B. Clinical Decision Support Design

Clinical Decision Support Systems (CDSS) include a variety of computer-based systems designed to assist clinicians with clinical decision making (21). CDSS include systems to assist with diagnosis as well as therapy, although most of the recent research has focused on CDSS related to therapeutic decision making and integrating decision support capabilities with CPOE systems (22). These CDSS can provide alerts related to medication orders (drug-drug, drug-allergy interactions) (23) and can critique orders or remind clinicians about procedures or tests that should be ordered (e.g., prophylactic antibiotics prior to surgery (24) for a given patient).

Relatively little research has been conducted on the use of CDSS to aid decision making in acute care nursing practice (25). Most CDSS studies involving nurses have been targeted at the prescribing and patient management practices of nurse practitioners (26-29). Some attention has been focused on the use of clinical alerts embedded in clinical information systems. Clinical alerts and reports have been found to be an effective mechanism for prompting nurses to remember clinical routines (30) or to provide information regarding a patient's progress on a care pathway (31).

Research has shown that many hospitals with information systems that have decision support capabilities often do not implement them and that, when they are used, they are frequently overridden or ignored (23, 32-34). Rapid prototyping and assessment of user input into system design is an accepted strategy for software development (35, 36), but, because CDSS is a new and evolving function in nursing clinical systems, there are few clear models for their assessment and the input of users. Prototyping and

testing systems through simulation and observation can minimize the risk of introducing a system into the clinical area that could cause more problems than it would solve. This paper describes the results of a user-centered design model to develop point-of-care decision support for intravenous medication administration.

III. Methods

A. Simulated Information System

The information system used for simulation in this study was the Veterans Health Information Systems and Technology Architecture (VistA). Developed by the United States Veterans Affairs (VA) administration over the past 25 years, VistA is in the public domain and is in use at many private and public healthcare facilities throughout the United States and the world. VistA is an open-system, client-server based environment that takes full advantage of commercial solutions, including those provided by internet technologies (37). The system supports the kind of decision support we developed, but the same type of CDS could also be used on other systems.

B. Design of Simulated Cases

To design the simulated cases and to determine the opportunities for decision support, we observed nurses' medication administration patterns in five intensive care units in a large academic health center hospital in the southeastern United States.

An electronic observation data collection tool was developed to capture aspects of medication administration in terms of administration duration, mode (i.e., peripheral, jugular, subbclavian), delivery (i.e., push, drip, soluset), and preparation of each medication (i.e., pre-mix, extract from vial, reconstitute, infusion). Data regarding medication orders were abstracted from actual medication administration records regarding the types and numbers of regularly scheduled medications. In addition, information regarding medication errors in these units was collected via an anonymous questionnaire (38). Through an examination of these data, we were able to describe the medication administration practices used by intensive care nurses within this context, including medications, preparation, delivery methods, information accessed, and integration of task into workflow. These data, reported previously (38), provided information regarding the necessary configuration of the simulated information system and decision support tools used in this study.

We developed 12 patient scenarios that were exemplars of the types of patients in the five intensive care units where we conducted observations. The scenarios were structured in the form of patient shift reports and linked to data describing each patient in terms of medical orders, physiological data, laboratory data, and medication orders in the simulated information system. Each simulated patient record had 10 to 12 medication orders, with four to five of the intravenous orders due for administration during the simulation time period. The medications ordered were varied to include medications that required various preparations (e.g., admixtures, extracted from multi-dose, pre-mix bags) and administration (e.g., push, intermittent drip, continuous drip) methods.

B. Decision Support Tools

The decision support tools were incorporated into the simulated information system and linked to the medication administration record in the simulated patient record. All medication references and alerts were reviewed by a pharmacist consultant and three nurses familiar with intensive care practice for determination of content and risk-severity assignment. Three different types of medication administration support information were included in the simulated system:

1) *Hyperlinked, risk-adjusted drug references.* Medication references could be accessed on each drug by clicking on the drug name in the medication administration record (MAR) in the information system. Each medication reference was preceded by an index listing the components of the reference, such as drug actions, contraindications, route and dosage, administration, incompatibilities, and adverse effects. These categories were color coded according to the potential level of risk associated with that particular aspect of the drug and hyperlinked to that corresponding portion of the reference. Aspects of administration that posed the highest risk for error or to the patient were listed in red; those considered moderate risk were in yellow; and lower-risk items were printed in green. For one medication, for instance, administration might be listed in red as posing the highest risk, whereas, for another drug, contraindications might pose the most risk. Listing the reference in this manner allowed the nurse to read the entire reference, but, for a quick review, also allowed the nurse to hyperlink directly to aspects of the drug that may be particularly troublesome.
2) *Barcode-linked medication alerts.* To address the types of administration process problems we had observed at the point of care, we also designed short medication alerts (eight to 10 words) that were linked to a barcode medication scanning system. These alerts were 'pushed' to the nurse at the point of medication administration when the patient's arm band and medication were scanned. Each message was related to the administration of the medication or monitoring the patient for particularly dangerous aspects associated with administration. Alerts had to be acknowledged by the nurse before the documentation process could be completed.
3) *Short alert message on MAR*. The same message that was linked to each drug in the barcode bedside alert system was placed under each medication listing on the MAR and printed in black at the medication cart computer and red at the bedside computer. Varying the color of messages at different points in the system tried to gauge if message color influenced the nurses attention to the message.

C. Simulation Laboratory

The simulation laboratory was built to resemble an actual patient care area on an intensive care unit. Components of the patient care area included: 1. Nursing station with computer to access the simulated information system and a printer; 2. Medication preparation area with a mock medication cart equipped with a laptop computer with access to the information system, printed reference material, calculator, medication preparation supplies (i.e., syringes, admixture fluids, blank medication labels); and 3. Patient area with a bed, bedside table, computer with information system access, barcode scanner, and mannequin with intravenous lines and barcode wrist identification. The three computer screens (nursing station, medication cart, and patient bedside) were projected on the laboratory walls for viewing by all present during each simulation.

Expert acute care nurses reviewed the simulated information system configuration, the patient scenarios, the decision support tools, and the laboratory setup prior to the deployment of the simulation. Minor changes were made to the simulation prior to deployment based on their comments.

D. Participants

In total, 17 nurses from five different intensive care units were observed administering medications in a simulated environment using a set of simulated patients represented in the information system. The five teams of nurses were drawn from the following hospital units: neurological intensive care (NICU, 26 beds), medical intensive care (MICU, 12 beds), surgical intensive care (SICU, 20 beds), coronary intensive care (CCU, 20 beds), and cardiovascular surgery intensive care (CICU, 20 beds). In this hospital, nurses routinely had access to medication administration record (MAR)-linked medication references and the

internet but did not have system-integrated medication alerts and were not using barcode medication administration devices or smart pumps at the time of the study.

E. Simulation Deployment

Five simulation sessions (one for each ICU team) were conducted over approximately 7 hours each. First, the nurses were oriented to the purpose of the study and results of the prior observational piece of the study (38), were allowed to ask any questions, and signed consents to participate in the study. Basic demographic information related to age, level of education, and experience was then collected from each nurse. A tutorial on how to access the system, move between informational screens, use the barcode scanner, and document medication was conducted by study staff.

Each of the nurses was then individually given 'report' on a simulated patient and asked to give medications to the simulated patient. Selection of simulated patients for each team was designed to reflect patients that each ICU team specialty would be familiar with and to include types of patients that would be unfamiliar to the team. For example, nurses from the neurological intensive care unit were assigned simulation patients with neurological disorders but also a patient experiencing a coronary bypass graft. The nurses were free to proceed with medication administration in any manner they chose and to use any, or none, of the decision support tools or printed references available.

Observations of the medication administration process in the hospital had shown a high rate of interruptions during the preparation and administration of medications (38). During the simulated medication administration periods, we interrupted the nurses at least twice. For each simulated patient, the simulated patient's bedside phone rang, and the caller asked a simple question regarding the patient. The second type of interruption was a person (simulating another nurse, physician, administrator, etc.) walking up to the nurse and asked a question regarding the patient. These interruptions were framed as typical interruptions, such as a patient's family wanting information, a physician needing something from the nurse, etc.

F. Data Collection

The research team observed and recorded the process through which each nurse progressed through the medication administration simulation including steps used in the administration process, use of the simulated information system, information accessed from the information system, and any handwritten notes compiled by the nurses prior to or during medication administration. During the administration phase of the simulation, the researchers also utilized the electronic data collection tool used previously to observe medication administration in the intensive care units to characterize the simulated medication administration.

After all the nurses in the team completed their specific simulation, the unit teams were asked to critique the decision support design, its usability, and its usefulness in practice through a researcher-led, semistructured focus group. During these focus groups, the nurses were asked to critique the decision support tools within the simulation, including but not limited to content, usability, timing, delivery on desktop or tablet computer, and links to other system information. Nurses were also asked to suggest other types of potential decision support tools that might be advantageous for ensuring safe medication administration. The focus group discussion was recorded and transcribed for data analysis.

G. Data analysis

Data were analyzed through a combination of quantitative and qualitative techniques. The transcribed data from the focus group sessions were analyzed using a form of inductive content analysis. Content

analysis involves the use of two interrelated processes: identifying specific characteristics of concepts to be measured and employing explicit rules for identification, coding, and recording of concept characteristics (39). First, three members of the research team independently coded the focus group interviews into broad categories. Then, these same three researchers compared their individual data categories and combined common categories, resulting in a final set of three broad themes. Then, qualitative data analysis software, XSight 2, was used to code the transcribed focus group data into subcategories and to refine the organization of the data.

The categorical and quantitative data collected through the observational data collection tool were analyzed using simple descriptive statistics and measures of association. These data were examined in conjunction with detailed notes on each nurse's work process throughout each individual patient scenario.

IV. Results and Discussion

A. Participant Characteristics

Seventeen nurses from five intensive care units participated in the study. Simulation participants were overwhelmingly female (94.1%) and ranged in age from 23 to 47 years, although 52.9% of the nurses were between 23 and 30 years of age. The majority of participants reported that they were White (76.5%), followed by African American (17.6%) and two or more races (5.9%). All held a bachelor's degree in nursing except for one participant whose highest degree was an associate degree in nursing and one participant who held a diploma degree in nursing. Experience in intensive care nursing practice ranged from 1 to 23 years; however, most (70.6%) had 5 or fewer years of practice experience, and almost half (47.1%) had 2 or fewer years of practice experience. More than three quarters of the nurses (76.5%) had been in their current intensive care unit for 5 or fewer years, and more than half of the nurses (58.8%) had been in their current positions for 2 or fewer years.

B. Observations of Work Process

Study participants administered 63 intravenous medications; each participant administered three to five intravenous medications during their patient simulation. Administration of the simulated patient's medications ranged from 16.46 minutes to 40.25 minutes, with a mean administration time of 26.6 minutes. During the medication administration simulations, nurses used no medication reference 47.6% of the time during administration of medications to be given during their individual simulation, used the MAR-linked medication reference 47.6% of the time, used available printed references 3.2% of the time, and asked another nurse 1.6% of the time. All nurses (100%) who were assigned a patient whose diagnosis was outside their practicing specialty accessed the electronic decision support tools embedded in the information system at least once during the course of their simulation. No calculation method was used for determining correct administration dosage in 71.4% of the medications administered, a calculator was used 12.7% of the time, and paper and pen were used for 3.2% of medication administrations. When interrupted by the study staff during medication preparation and administration, 28.5% of participants chose to ignore the interruption when it occurred via phone, but none of the participants ignored the interruption when in person. Across all types of interruptions, 28.6% of the nurses left medications unattended to respond to the interruption task.

C. Barcode Scanner Use

Study nurses were instructed to scan the patient and medication prior to administration during orientation to the study. However, close to half of the nurses (42.9%) scanned the medication after administering the drug, thereby receiving the medication administration alert after the fact. The

majority of participants (78.6%) scanned the entire set of medications to be administered at once, rather than one at a time, either prior to or after administering the medications.

D. Use of Hyperlinked, Severity-Coded Drug References

The simulation was designed so that all barcode medication alerts were pushed to the nurse and had to be acknowledged when the medication was scanned. The hyperlinked, severity-coded drug references had to be accessed by the nurses through a link to the medication on the MAR. Most nurses (78.6%) accessed the hyperlinked drug references on at least one workstation (nursing station, medication cart, bedside) during their medication administration scenario; fewer (21.4%) accessed the drug references at two stations; and some (28.6%) did not access the drug information at all. Most (64.3%) nurses did not use the nursing workstation at all and progressed directly to the medication cart station before accessing the barcode medication scanning at the bedside.

E. Focus Groups

The content analysis of the focus group transcriptions revealed that participants touched on three major themes related to decision support for medication administration: 1. format, 2. content, and 3. usability and workflow. Focus group results for each of the major themes are presented below in terms of each decision support tool.

F. Hyperlinked, risk-adjusted drug references

1) Format

Participants responded very favorably to the hyperlinked, risk-adjusted drug references. They particularly liked that the reference was linked directly with the medication in the MAR. As one nurse remarked:

> *"Having the link direct with the medication and information about the medication in one easy link was very good for me: being able to say, Oh I'm not familiar with that medicine and just click on the medicine and not having to go through 10 different pathways or look for a book or look in another computer system."*

The nurses felt that the index at the beginning of the full reference allowed them to easily find information regarding medication administration and monitoring without having to read the entire text of the reference. Color coding and hyperlinking the particularly dangerous aspects of the drug were thought to be a way to alert the nurse in a time-effective manner. Another nurse commented:

> *" It calls your attention to it, so apparently it's, well, like in school when they tell you if the teacher repeated it, it's important – so if you see it in highlights of some sort, then it must be important. So you need to go look at it. It's better to look at it and know that it doesn't apply to you then to not look at it and find out later that it did."*

Many of the nurses mentioned that color coding the hyperlinked reference according to risk particularly caught their attention. Another nurse explained why she used the color-coded hyperlinks in the MAR-linked thiamine reference:

> *"I used them all on my thiamine, because it said something about being incompatible with a lot of drugs, I think. And up there, it was highlighted, and so it was: don't use this drug with that drug. It's just…when I see red, I always think "stop," and so I was just kinda like… ok, well maybe I need to figure out what's going on."*

The nurses also used the hyperlink index of the reference even when it was not identified as a particularly risky aspect of the drug (not color coded) to quickly find a part of the reference that they were not familiar with. As one nurse commented:

> *"It's better than having to scroll down and read about everything 'cause I might not need to know about unlabeled uses and all of that; I just need to know how to give it."*

2) Content

Focus group participants were most likely to seek information in the hyperlinked, risk-adjusted drug references related to administration of the drug, particularly the compatibility of the drug with other drugs running in the same intravenous access.

> *"We just think of compatibility so much 'cause we have so many things going that are incompatible. Because we have so many drips."*

Other areas of immediate concern when administering drugs were also related to administration, such as what admixture to use to prepare the drug and how rapidly the drug can be administered.

> *"The compatibility of the drug that you're trying to give, you know, how much diluents and how fast you should give it, that's what we usually call pharmacy about."*

Another nurse commented:

"*I would want to look at compatibility first. That would be my first thing. And then…ah…administration. And then adverse effects."*

One of the options that nurses would like to have available in a CDSS is a mechanism for showing which intravenous medications would be compatible in the same intravenous access line across the MAR. One nurse explained this below:

> *"You know how when you go – when you put incompatibilities in and you put all the names of all the drugs that you're giving…and it tells you which ones are compatible and which ones are not? Can't they just do the whole MAR that way? Just to make sure everything is compatible?"*

Others suggested that compatibilities of the drugs that their patients were receiving could be linked to actual patient intravenous access available to provide a mapping of how multiple drugs could be given simultaneously.

> *"You could have a series of the rules and the compatibilities, and draw a picture, and say hey, here's how you've gotta set up. The number of ports, the drugs…and link that. Cause it's time consuming standing in there and trying to figure out how you're gonna give your drugs in what lines."*

3. Usability and Workflow

Focus group participants stated that they were more likely to use drug references during the course of their work if they were unfamiliar with the medication, the dosage, the patient population, or the purpose for its use with a particular type of patient. Two nurses explain this use below:

> *Nurse one: "I think I'd use it more like…well we've had a lot of neuro patients and drugs like mannitol that we don't give….. I mean, we've been having to give it a lot, but I don't do it all the time; it just depends on if I know the medication or not." Nurse two: "Yea, and most of the time I use it when it's an unfamiliar drug. Or…I look at some med and I'm like…"Hmmm….should I give this or not…let me read on it."*

Whether or not drug information is easily accessible, there is still the tendency of the nurse to ask others instead of accessing the reference directly. One nurse explains why she often does this, below:

> "*In our unit, we have a lot of resource people. Pharmacy's on our unit, there's always doctors on our unit, there's a lot of experienced nurses on our unit, so sometimes, it's probably lazy, but I'll just go ask somebody. Like, how fast can I give this mag? I know I could look it up, but I'm more apt to just go ask somebody."*

A few nurses remarked that they were more apt to access the reference directly when they had more time or when they were already working on the computer.

> *"It just depends on how busy I am. If I'm really busy, I'll ask someone. But if I have time, I'll look it up myself. If I'm sitting there charting, and I can just pull up the internet and pull up one of the medical sites and look at the disease process for my patient, and I can go print something out on it, and be reading up on it. And I can ask other people around me, but it may be easier for me to print something out while I'm charting and look at it when I have a minute."*

G. Barcode-linked medication alerts

1) Format

Focus group participants reacted favorably to the length and format of the barcode-linked medication alerts. One nurse described them as:

"Short and sweet. You get what you need to, you know…and if you need any more information you can always go back and look at your information for your drug."

Another nurse went on to explain:

> *"I think they were probably about the right length. Because, you're not gonna read a big long alert. You're gonna ignore it. Um…after you're here…you hear so many bells and whistles, that…that unless it's, you know, a blurb…you'll look at a blurb, but if you're gonna have to read any amount of time you're gonna not concentrate on it and you'll just go to the next task."*

2) Content

Participants had suggestions for additional content that could be linked to the barcode-linked medication alerts, such as vital sign data, electrolyte values, and drug level values.

> *"If I'm giving calcium, if it would actually pull it from the lab values and say current calcium level is 1.09, then at least it's showing that to me. I don't have to go look it up, and it would remind me either yes or no I need it. That would be very helpful, because we treat electrolytes, you know, all the time, just as a secondary…default."*

3) Usability and Workflow

Each specialty group had a long discussion about whether it was always important to have nurses read the barcode-linked medication alerts and how to accomplish this. With very few exceptions, the nurses felt that the alerts should not be switched off or minimized based on the nurse's expertise. A participant explained her reasoning:

> *"Well my thing is, even experts, even with their 25 and 30 years experience, they still have days where it's just off-kilter, and they kind of work like a novice sometimes. You know, you just kind of have that day that…you kind of come in*

scattered. No matter what you do, you know, your alarm clock went off late, and it just kind of messes up your whole day. You come in feeling like you're behind constantly, and you may be a little bit more scattered and have a tendency to not think of things that would have been simple to you before, you might not be so quick to think of that day. You know, and so if you have the alert that's gonna come up, you know, it'll remind you, and then in hindsight you'll be "oh my gosh…I'm so glad that was there 'cause today I just was not thinking I don't know where my mind was."

A suggestion made by several nurses to decrease the possibility of alert fatigue was to limit the number of times the same alert might appear in a day.

"Like based on frequency in a shift. Maybe it shows up the first or two times. But then it kind of resets for the PM shift, because they're gonna be new so they've not seen the alert. So it might show up once or twice for them."

The participants had some experience with system alerts in their current system when removing a drug from the automatic medication vending machine for administration and suggested that nurses might be less likely to click off an alert without reading if they were required to enter information prior to being able to exit.

"People are gonna get used to the pop up. Maybe if you had to answer something, like actually type in the INR. That's what we have now. You have to type in your INR."

Although another nurse admitted to not always complying with this system.

"*There are days when I'm having a bad day and I'm in a hurry and I just …I mean, I'll just type "XYZ" in there, because I have to put something in the block."*

There was some disagreement between participants on the importance of barcode medication scanning in decreasing the possibility of error in intensive care units. The small nurse/patient ratio in intensive nursing units was cited as one reason that there was less chance that a medication would be given to the wrong patient.

"When you just have two patients, I don't think it would be an issue. And if you just get out meds for one patient at one time and give 'em, and check the arm band, that's good."

Another nurse was positive regarding barcode medication scanning, because her experience during the simulation made her remember how easily one can be distracted when confronted with a new situation.

"What surprised me I guess …the most was trying to learn this system and doing different drugs and stuff over there…and the distractions. It makes you go back to realize that when you were new, what the distractions can be to you. Like now, I feel more able to handle the distractions, because we know what most of what our drugs are and most of what our patients get, so we can get back on task so easy, but it's…when you're learning something new and for these new people…how…disturbing those distractions are."

Some of the participants viewed the medication scanning process as less of a check that the right medications were being given and more of a documentation tool; scanning the medication documents that it has been given. Although these nurses were not using barcode scanning in their current practice, one was already trying to think of a workaround to scanning medications at the patient bedside.

"If there was some way that would allow you to scan the armband and then just get all the meds, and then…like if I had all my medicine and I just had the

armband and scanned it and just scanned all the meds at one time, and then gave it to them. Not having to be at the bedside."

H. Short alert message on the MAR

1) Format

Short message alerts were written below each medication order on the MAR. They appeared in black on the medication cart computer and red at the bedside computer. Several nurses did not remember reading a short message on the MAR when asked about this reference during the focus group sessions. Others both noticed and appreciated the messages.

"Yes. It's like directions. All I need is one sentence. I don't care about all the rest of that stuff. I need to know about what fluids I need to dilute my stuff in. And how much fluid do I need?"

The color of the alert made a difference to most of the nurses.

" It drew attention to it more…here, than there, because there (medication cart), it kind of blended with the order, because it was in black. But over here, it was red, so it made you kind of read because it's a different color. Red usually means stop and read. It draws attention to it.

Overwhelmingly, the participants felt that the message should be posted in red.

"It draws your attention and it's easy to read. It's…it's red. So you're gonna read it. You know anything that's red, in the hospital, you look at."

2) Content

The content of the short alert messages was exactly the same as the barcode-linked medication alerts. However, in every focus group session, this had to be pointed out to the participants; few of them noticed that the information was identical. One nurse who did not realize that the same information listed on the MAR was also in the barcode-linked medication alert would have changed her process if she had known.

"And I wrote it down. You know, ok this has to go over 2 minutes, this has to go over 5 minutes, if I knew that it was gonna pop up, it would help me. I wouldn't have to write it down. I didn't know what was gonna pop up."

3) Usability and Workflow

The majority of participants felt that the short alerts should be both on the MAR and on the barcode-linked medication alerts. They thought that it was useful to have the information in both places.

"But it's nice to have the double-check system, 'cause, like you said, you get distracted and that probably just left your mind, totally, …and so it's nice to actually see it in both places. Probably more so at the med carts. What would alert you the most is if it was a drug you never gave and you're thinking, well why am I pulling this…and the rest of 'em you would kind of know 'cause you would know your patient and you know, if they were septic , and all your antibiotics, but if it's something strange, like a psych med, you would think, well what is this, and especially if you hadn't seen it and then once you saw it was an antipsychotic you'd say, "oh my patient has a history of…" and that's good. Yea. In both places. And that's I think what now too we try to reiterate with new nurses is you check it, and you check it again, and if you're still having problems, then you check it again, and I think that's where come in with so many drug errors is that people don't double check themselves."

V. DISCUSSION

A. Work Processes

The mean time of medication administration in the simulation (26.6 minutes) was much greater than we observed in actual practice (9.99 minutes). Factors that may have contributed to the increased time include unfamiliarity with the simulation information system, unfamiliarity with the environment, more need to pre-mix medications, and the addition of BCMA and CDSS. In addition, because the nurses were being observed, they may have tried to be especially careful, lengthening the time it took to prepare and administer a drug.

Compared with our observations of nurses in practice who only used a drug reference 20% of the time during administration (38), the nurses using the simulated system assessed reference material at more than double the rate (52.2%). In practice, nurses only accessed electronic sources of drug information 1.6% of the time compared with 47.6% of the time during simulated administration. In our observations of practice in the clinical setting, nurses were more apt to ask another healthcare team member for information regarding administration (38). Through an integrative review of the literature, Spenceley et al. ranked information sources nurses used to inform practice (40). They ranked other nurses as the most likely source of practice information, and physicians as information sources ranked seventh (40). In our observations of practice, physicians were the most likely source of information, followed by nurses. That physicians' were more frequently a source of drug information could have been because, in the environment we studied (intensive care units), nurses have more contact with and access to physicians.

Although electronic references were available to the nurses in practice, they were not severity coded, hyperlinked, or directly linked to the medication name in the MAR. Participants overwhelmingly cited the ease of use of the simulated CDSS design as a key factor in their decision to access electronic references during administration. It is possible, however that participants' increased use could be in part due to observation of their practice during the simulation. In their rankings of information use by nurses, Spenceley et al. ranked the use of computer references as tenth in their list of information sources. This is consistent with our observations of information use in practice (38), when nurses used computer references only 1.6% of the time, behind all other sources of information.

Although observation may have made the nurses more vigilant, their performance was not error free. Although the nurses were explicitly instructed to scan the patient and drug prior to administration, 28.6% administered the drug prior to scanning the patient, and 42.9% administered drugs prior to scanning the drug. This was true across and within every specialty group. Also, there was great variation in styles of medication administration across and within groups. That is, although nurses could view the other nurses in their group completing the simulation, they did not exhibit the same process behavior as the others in their group. That nurses viewed the scanner less as a patient safety tool and more of a documentation tool could influence their tendency to develop workarounds to a medication barcode scanning system.

When discussing the benefits and challenges to BCMA during the focus group sessions, nurses did reflect on their practices during the simulation, and some did comment that scanning prior to administration could decrease administration error and that they should change their individual processes. Using self-reflection has been shown to be a valuable tool that allows practitioners to uncover and expose their thoughts and feelings and forces them to face incongruities in their practice (41). Perhaps reflection of practice combined with education on error reduction could be used as a technique to gain greater compliance and decrease workarounds reported with the use of BCMA in the actual clinical environment. In a study of workarounds to medication administration technology, Vogelsmeier et al.

found that the formation of a medication safety team to address issues related to medication technology implementation and compliance helped foster a culture of safety and discussion regarding methods to decrease medication errors (42). The use of simulations such as the ones described here can help focus the reflection to actual, rather than theoretical, process differences.

Other aspects of variability in participant medication administration practice were evident across and between each nursing specialty group. For example, half of the nurses prepared medications in the medication cart area, and half prepared medications at the bedside prior to administration. In addition, nurses were found to access the decision support tools either at the medication cart computer or at the bedside. Unless tailoring of the decision support for each individual's unique workflow and style can be done (which is likely to be impractical), this variability and the nurses' own perceptions of where they might need decision support points show the need to include these tools across all medication and information technology systems that are accessed during the process, at the nursing station, the medication dispensing area, and at the bedside.

Participants' comments regarding their lack of need to access information regarding medication administration and barcode administration to reduce error may reflect overconfidence in their knowledge level. Choosing not to access decision support tools due to overconfidence has been cited as one reason for poor CDSS use in physician practice (43), and the same phenomena could decrease the use and acceptance of CDSS for nursing practice. However, participants did recognize how distractions and interruptions during medication preparation and administration could increase error rates and acknowledged that forced barcode alerts at the bedside could help minimize these types of errors. Providing information at the point of decision making is more likely to have an impact on care processes than providing this information at from centralized information systems (44). It was interesting that some of the participants managed interruptions by phone by ignoring the interruption but were distracted from their task when the interruption was in person, resulting in them often leaving medications unattended.

B. Format and Content of Medication Decision Support

The use of color in the design of the hyperlinked, risk-adjusted drug references and short medication alerts in the MAR was cited by participants as increasing their awareness of potentially important information related to medication administration. In fact, some participants commented that they did not notice the same short medication alerts in the MAR when they were presented in black text instead of red. In a recent study comparing the use of the color blue and the color red on cognitive performance, Mehti and Zhu found that using the color red enhanced performance on a detail-oriented task (45). Participants' noted that they had a previous mental model associated with the color red that alerted them that an item was potentially dangerous and that they should stop and pay attention to the information prior to proceeding with preparation and administration of the medication.

Participants stated that they were more likely to read references when they could hyperlink directly to only the portion of the reference they wanted to read, avoiding the need to search an entire reference for the information they needed. In addition, they responded very favorably to the study alerts being short in length and pertaining to the task they were completing, administering medications at the bedside. These findings correlate with those reported by Hewitt et al., who found that students in an online course were less likely to read computerized messages and more likely to scan messages as the length of the message increased (46).

C. Nurses' Suggestions for Decision Support Design

The nurses acknowledged that eventually they may suffer from alert fatigue and fail to read medication alert pop ups. They did, however, have many suggestions regarding the presentation and frequency of alerts. For example, they suggested that an alert only be displayed once or twice a shift for each nurse, be turned off after this frequency was met, and then be reset on the next shift. When asked, however, if the number of alerts should be decreased as the nurse has more experience as a way to decrease alert fatigue, they thought the alerts should not be tailored to an individual nurse's experience. They felt that this would decrease the potential to avoid errors when the nurse was overly busy, was distracted, or was in a new clinical situation.

In our focus groups, study nurses suggested that they would be more likely to read the alert if they were queued to respond in some way, such as to enter a laboratory value. They also admitted, however, to putting in any value when asked to respond in the current system connected to their medication dispensing machine, if they were in rush. This is consistent with the findings of Ash et al. in their study of the unintended consequences of CDSS. They found that requiring a numerical entry to move through an electronic process can interrupt workflow and may cause physicians to use workarounds to move more quickly through the process (47). Requiring the entry of additional data prior to allowing access to medications in intensive care units could have the added unintended consequence of slowing response to emergent patient situations.

Pulling information from another portion of the record and integrating these data into the CDSS system was a frequent suggestion made by the nurses during focus group sessions. Showing laboratory data related to ordered medications to assist in decisions regarding whether to give or hold medications would decrease the time needed to give the drug and would also decrease the risk to the patient if a drug is given without considering related data. For example, nurses could benefit from viewing the latest potassium level pulled from laboratory data to the medication administration record prior to giving non-potassium-sparing diuretics. Other data, such as heart rate or blood pressure values pushed as alerts when values are inconsistent with safe administration of drugs such as digoxin or antihypertensive medications, could avert potential harm to patients.

VI. SUMMARY

This study used a simulated clinical information system combined with simulated medication administration to evaluate the use, content, and format of three types of decision support tools for medication administration: hyperlinked, risk-adjusted drug references; barcode-linked medication alerts; and short alert messages on the MAR. Nurses' evaluations of the medication administration decision support tools as well as their actual performances revealed a tendency to underestimate their need for support, but their preferences were for decision support that was short, color coded, and easily accessed. Observations of medication administration showed that nurses exhibit a variety of work processes to prepare and administer medications to patients. System design should allow flexibility of multiple points and types of information delivery to accommodate variations in workflow so as to minimize the tendency for system workarounds.

VII. Study Outputs

- Moss J, Berner S, Sobko H, Watts P. Evaluating Clinical Decision Support Tools for Medication Administration Safety in a Simulated Environment. (In preparation for submission to JAMIA)
- Moss, J, Berner, E, Bothe O, Rymarchuk I. Intravenous medication administration in intensive care: Opportunities for technological solutions. Proceedings of the American Medical Informatics Association Annual Symposium, Washington, DC; 2008. p 495-499. (Winner-Harriet

Werley Award for the paper making the greatest contribution to advance the field of nursing informatics)

- Moss, J. (2008). Improving patient safety through simulation research: Meet the experts. National Patient Safety Foundation Annual Patient Safety Congress, Nashville, TN.
- Moss, J., Berner, E. (2008). Designing Clinical Decision Support for Medication Administration Safety. Poster presented at the AHRQ Annual Conference, Bethesda, MD.
- Moss, J., Berner, E. (2008). Intravenous medication administration in intensive care. Poster presented at the 22nd Annual SNRS Research Conference, Birmingham, AL.
- Simulated Clinical Information System for decision support usability testing and training in electronic medical record use and patient data documentation
- Electronic manual for use and administration of simulated information system
- Electronic data collection tool for medication administration process analysis

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