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Frontiers of **Nursing**

Development and application of a closed-loop medication administration system in University of Hongkong-Shenzhen Hospital[†]

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Abstract: **Objective:** This study aimed to develop and apply a closed-loop medication administration system in a hospital in order to reduce medication administration errors (MAEs).

Methods: The study was implemented in four pilot general wards. We used a before-and-after design to collect oral medication administration times before and after the implementation of the closed-loop medication administration system, evaluated MAE alert logs after the intervention, and conducted a survey of the nurses' satisfaction with the system in the pilot wards.

Results: (a) Nursing time of oral medication administration: before the adoption of the closed-loop medication administration system, the average nursing time was 31.56 ± 10.88 minutes ($n = 78$); after the adoption of the system, the time was 18.74 ± 5.60 minutes ($n = 54$). Independent sample t-tests showed a significant difference between two groups ($t = 8.85$, $P < 0.00$). (b) Degree of nurses' satisfaction with the closed-loop medication administration system: 60.00% ($n = 42$) of nurses considered the system to be helpful for their work and nearly half of the nurses (47.14%, $n = 33$) believed that the system could facilitate clinical work and reduce workload; 51.43% ($n = 36$) believed that the system could reduce checking time and enhance work efficiency; 82.86% ($n = 58$) believed that the system was helpful in improving checking accuracy to reduce MAEs and ensure patient safety. More than 60% of the nurses considered the system to be a method that could help to track MAEs to improve nursing quality. (c) The MAE alert logs during observation period: it revealed only 27 alerts from the repeated scans of 3,428 instances of medication administration.

Conclusions: The nurses were satisfied with the closed-loop medication administration system because it improved their work efficiency and reduced their workload. The current investigation was limited by time; therefore, further research is needed to more closely examine the relationship between the system and MAEs.

Keywords: *medication error • medication administration • closed-loop system • computerized physician order entry system*

1. Introduction

A medication administration error (MAE) is defined as a medication error occurring during the bedside administration of a medication.[1] Studies have shown that MAEs cannot be prevented by any combination of computerized physician order entry (CPOE), electronic health record (EHR), clinical decision support system, or an automated dispensing system but can only be mitigated by a closed-loop medication administration system.[2-5] The closed-loop medication administration system includes automated identification technology

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such as radio-frequency identification (RFID) and/or barcodes.[6,7] It is used to verify the so-called "five rights" (5R; right patient, right drug, right dose, right route, and right time) of medication administration at the bedside by cross-checking patients' identification, prescription information, and dispensed drugs using a hand-held point-of-care device with RFID and/or a barcode reader.[8,9]

In 1999, the Institute of Medicine[10] reported that medical errors result in 44,000–98,000 preventable deaths and more than 1,000,000 injuries each year in US hospitals. Medication errors can occur at any stage of the medication process, including prescribing, transcribing, dispensing, and administration.[11]

Previous research has indicated that closed-loop medication administration systems reduce non-intravenous MAEs to 39% and also reduce the administration of the wrong dose as well as omission errors.[12] However, personal digital assistant (PDA) or hand-held point-of-care devices have been adopted in only 27.19% hospitals in China due to difficulties with application, high implementation costs, and maintenance fees.[13]

The present study was conducted at the University of Hongkong-Shenzhen Hospital (HKU-SZH) from August 1, 2016, to December 31, 2016. The hospital is a general teaching hospital affiliated with the University of Hongkong and owned by Shenzhen government. It opened in 2012 and has 2,000 beds and an out-patient capacity of 8,000–10,000 patients. The HKU-SZH has set up a wireless environment since its beginning and has adopted a clinical information system including CPOE, EHR, a clinical decision support system, and picture archiving and communication systems.

In 2015, the HKU-SZH reported 105 medication errors out of 515 incidents (20.39%). The aim of this study was to determine whether the development and implementation of a closed-loop medication administration system could reduce MAEs in the hospital.

2. Methods

Prior to commencing the study, a literature review was performed in order to analyze the workflow of medication administration in clinical settings and a diverse project team was set up, which consisted of an information technology (IT) manager, IT engineers, pharmacists, doctors, head nurses, and registered nurses (RNs). The project plan had four steps: (a) preparation period: develop the system and finish PDA procurement; (b) pilot study: apply the system in pilot wards and modify the system accordingly; (c) nurse training and application of the system to whole hospital; and (d) data collection and analysis and summarization of the findings in a paper.

2.1. System development and technology support

2.1.1. System development

The closed-loop medication administration system was developed using Microsoft Visual Studio Net 2005. The system adopted an object-oriented design, programmed with Microsoft Foundation Classes; repacked the controls; and perfected the system function. The client and server system consisted of three layers of logically separated frameworks: the user interface (UI) layer, the Buss' rule layer, and the data access layer.

The closed-loop medication administration system requires technical support to obtain clinical information, which mainly includes the following: (a) in-patients wear barcoded wristbands, from which patient information can be read; (b) the closed-loop medication system is based on a CPOE system in order to achieve intelligent and structured prescription records; (c) an automatic drug dispensing system is applied to the pharmacy in order to integrate drug and patient information; and (d) nurses use PDAs and mobile workstations to identify patients, drug and prescription information, and match information and automatically obtain execution confirmation.

2.2. Workflow

In the traditional paper-driven process of medication administration, two nurses manually double-check the medication information including name, dose, time, route of medication, and the patient's identity before the medication is administered.[14]

With the closed-loop medication administration system, the process of medication administration requires nurses to scan the barcodes on the patient's wristband as well as the barcodes on the medication before it is administered.[15,16] If the dose being scanned corresponds with the approved medication order of a pharmacist and the patient is due to receive this medication, the administration is automatically documented in real time. However, if the medication does not correspond to a valid order, the system issues a warning.

Since the closed-loop medication administration system provides an additional layer of safety with the real-time scanning of barcodes,[17] we changed the process of medication administration after application of the system from requiring two nurses at the bedside to perform the double-check to the following two methods: a single nurse (a) manually checked as routine at the bedside and (b) scanned the barcodes on both patient's wristband and the medication before medication administration.

2.3. Study design

The study was implemented in four pilot general wards. We used a before-and-after design and collected data on oral medication administration times before and after the system implementation. We also evaluated the MAE alert logs after the implementation and surveyed the nurses' satisfaction with the system.

2.4. Survey tool

Self-reported satisfaction questionnaires were used for the survey. A brainstorming meeting of the clinical head nurses was used to design the first draft of the questionnaire. A pretest of the questionnaire was conducted in the pilot wards; based on the results of the pretest, we further modified the questionnaire to develop the formal version. The formal questionnaire contained questions from five perspectives, including the quality of nursing, patient safety, nurse workload, work efficiency, and nurses' views of the PDA. Each question was answered according to five degrees: strongly disagree, disagree, neutral, agree, and strongly agree.

2.5. Data collection

Four nursing students observed and recorded the oral medication administration times in the four pilot wards respectively before and after intervention (December 12–16, 2016, and January 2–6, 2017). The satisfaction questionnaire survey was conducted in the four pilot wards on January 6, 2017, using the Wenjuanxing Internet platform (https://www.sojump.com/).

2.6. Statistical analysis

IBM SPSS Statistics for Windows, version 20.0, was used for analysis. The nursing time required for medication administration was presented as the mean ± standard deviation. We applied two independent sample t-tests to analyze the difference in nursing time before and after implementation of the closed-loop medication system. The degree of satisfaction of the nurses in the pilot wards was calculated as frequencies and percentages.

3. Results

3.1. Nursing time

The nursing times required for oral medication administration before and after implementation of the closed-loop medication administration system are shown in

Table 1. The average nursing time of the four wards before the new system was 31.56 ± 10.88 minutes, which was reduced to 18.74 ± 5.60 minutes after the implementation of the system.

3.2. Nurses' satisfaction

The nurses' satisfaction with the closed-loop medication administration system is shown in Table 2.

3.3. MAE alert logs

There were only 27 MEA alert logs from the repeated scans of 3,428 instances of medication administration during the observation period.

4. Discussion

4.1. The closed-loop medication administration system incorporates several technologies into the workflow of the nursing staff to improve the nurses' work efficiency

As Table 1 shows, there was a significant difference ($t = 8.85$, $P < 0.00$) between the two groups. The closed-loop system provides an additional layer of safety by real-time scanning of barcodes, which relieves one nurse during medication administration. Medication administration could be performed by a single nurse, who manually checks at the bedside and scans both the barcodes (on patient's wristband and on the medication).[18] This system can provide nurses more time to focus on the professional steps of medication administration, such as monitoring for adverse events and continuous patient assessment. The system offered a significant improvement in this aspect.

Ward	Average nursing time (M ± SD), min	
	Before system adoption	After system adoption
Medical Ward 1	32.57 ± 8.72	15.73 ± 4.57
Medical Ward 2	41.89 ± 5.44	20.07 ± 2.25
Surgical Ward 1	29.33 ± 9.46	18.83 ± 7.25
Surgical Ward 2	22.70 ± 9.83	20.75 ± 6.80
Total	31.56 ± 10.88	18.74 ± 5.60

Table 1. Average nursing times for oral medication administration before and after implementation of the system in the pilot wards.
Note: Two independent samples t-tests showed a significant difference between the two groups. ($t = 8.85$, $P = 0.00$).

Items	Strongly disagree		Disagree		Neutral		Agree		Strongly agree	
	n	%	n	%	n	%	n	%	n	%
The system can facilitate your work and reduce your workload	5	7.14	11	15.71	21	30.00	19	27.14	14	20.00
The system can reduce check time and enhance work efficiency	3	4.29	9	12.86	22	31.43	19	27.14	17	24.29
The system can help to improve checking accuracy and reduce MAEs	2	2.86	0	0	10	14.29	34	48.57	24	34.29
The system can track MAEs to improve nursing quality	3	4.29	6	8.57	16	22.86	25	35.71	20	28.57
The degree of helpfulness of the system to your work	4	5.71	1	1.43	23	32.86	28	40.00	14	20.00

Table 2. Nurses' satisfaction with the system ($n = 70$).

4.2. Nurses' satisfaction with the closed-loop medication administration system

Table 2 shows that 60.00% ($n = 42$) of nurses considered the system to be helpful for their work and 82.86% ($n = 58$) thought that the system was helpful to improve checking accuracy and reduce MAEs to ensure patient safety. This is a key point for the development and customization of such systems. Developers and implementers must consider nursing workflow in order to make the system easy to access.

4.3. The closed-loop medication administration system can help nurses achieve safe care

The MAE alert rate was 1.22% during the one-year observation period in a previous study, suggesting that the closed-loop medication administration system contributed to improving patient safety by preventing potential MAEs.[2] In the limited time since the implementation in the present study, there were only 27 MAE alert logs among 3,428 medication administrations during the observation period. The full impact of the closed-loop medication administration system on patient safety will be evaluated and analyzed in future studies.

5. Conclusions

Successful implementation and adoption of the closed-loop medication administration system are more likely to happen only when the developers and implementers understand the complexities and unpredictability of the nurses' workflow. For instance, an inability to ensure the compatibility of the system with nursing workflow may lead to unintended consequences. Clearer guidance is required from hospitals on the use of the systems by physicians, nurses, and other medical staff. Without clear policies, well-developed systems that are well implemented and designed may hinder nursing workflow and impact patient safety and care. A key policy priority, therefore, is to plan for the long-term use of these systems.

5.1. Strengths and weaknesses of the study

This study had three limitations. First, the main weakness of this study is that data were only collected from four pilot wards. Second, the system has only been trialed for half a month, since the open tender process of the PDA was unsuccessful. Third, the project failed to follow the schedule. The MAE alert logs have been evaluated for half a month, which is insufficient for further analysis. The success of the pilot work has laid the foundation for further research and implementation of the system throughout the hospital.

Acknowledgments

Conflicts of interest

All contributing authors declare no conflicts of interest.

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