

Evaluation of the Impact of a CPOE System on Nurse-physician Communication

A Mixed Method Study

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Keywords

CPOE, interoperability, patient safety, medication error, workaround

Summary

Objectives: To assess the impact of a CPOE system on medication-related communication of nurses and physicians.

Methods: In six internal medicine wards of an academic medical center, two questionnaires were used to evaluate nurses' attitudes toward the impact of a paper-based medication system and then a CPOE system on their communication in medication-related-activities (medication work). The questionnaires were analyzed using t-tests, followed by Bonferroni correction. Nine nurses and six physicians in the same wards were interviewed after the implementation to determine how their communication and their work have been impacted by the system.

Results: The total response rates were 54% and 52% for pre- and post-implementation questionnaires. It was shown that after im-

plementation, the legibility and completeness of prescriptions were significantly improved ($P < .001$) and the administration system had a more intelligible layout ($P < .001$), with a more reliable overview ($P < .001$). The analysis of the interviews supported and confirmed the findings of the surveys. Moreover, they showed communication problems that caused difficulties in integrating medication work of nurses into physicians'. To compensate for these, nurses and physicians devised informal interactions and practices (workarounds), which often represented risks for medication errors.

Conclusion: The introduction of CPOE system with paper-based medication administration system improved prescription legibility and completeness but introduced many workflow impediments and as a result error-inducing conditions. In order to prevent such an effect, CPOE systems have to support the level of communication which is necessary to integrate the work of nurses and physicians.

systems play an increasingly important role in patient safety [3], and among them, computerized physician order entry (CPOE) systems have gained extraordinary attention in reducing medication errors and increasing the efficiency of the medication process. For instance, in a recent IOM report, "Preventing Medication Errors", it is recommended that all pharmacists and prescribers use e-prescriptions by 2010 [1].

However, there have been concerns about the extent to which these systems can prevent errors and the conditions under which they can improve the medication process. Recent studies have reported several adverse CPOE system effects on patient safety [4–8], which were explained as having "less to do with the software problems" [9] and more to do with their "problematic implementations" [10]. Nevertheless, studies have suggested ways whereby CPOE systems actually contribute to compounding medication errors [4–6, 11, 12]. Beuscart-Zephir et al. [13] and Kopel et al. [4], for example, demonstrated how these systems can present problems and cause errors in nurse-physician collaboration in their medication-related activities, medication work. Moreover, reports on the conditions under which medication errors have been facilitated by CPOE systems have been increasing in the literature [14–17]. Thus, there seems to remain much to learn about when and how such information systems, which are designed to reduce medication errors, may in fact be counterproductive [9].

We evaluated the impact of a CPOE system on nurse-physician communication and collaboration throughout the medication process, focusing on the whole procedure as an interrelated work. The impact of the system on nurse-physician collaboration was

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1. Introduction

Medication errors are both harmful to patients and costly for healthcare systems [1, 2]. In hospitals, these errors are common during

every step of the medication process – prescribing, procuring, transcribing, dispensing, administering, and monitoring – but they occur most frequently during the prescribing and administering stages [1]. Information

published somewhere else [18]. In this paper, we sought to answer the following questions:

1. How was nurse-physician communication changed after the CPOE system was implemented?
2. How may this change affect patient safety?

Both quantitative and qualitative approaches were used to answer the research questions. The quantitative section was presenting a part of a pre- and post-implementation survey study that evaluated the impact of a CPOE system on nurses' communication and medication workflow. The data from surveys was then triangulated, i.e. supplemented and combined, by a series of in-depth semi-structured interviews with nurses and physicians.

2. Theoretical Background

The role of CPOE systems in reducing errors at the prescription phase of the medication process has been evaluated very well in the literature [14–18]. The medication process, however, is a loop of interrelated phases, where each phase determines how the next will be carried out [14]. In this multi-step dynamic process, any intervention in one phase (e.g., prescription) will inevitably affect the others as well [19]. Nevertheless, many of the evaluation studies failed to take the dynamic and interrelated feature of the medication process into account [6, 20], and the scope of their evaluations has rarely been extended to include the impact of the system on the entire medication process cycle.

The interrelated nature of medication process requires highly collaborative work of nurses and physicians that has to be coordinated and integrate in a dynamic manner. While such collaborative efforts are paramount to accomplish medication work and to avoid errors [6, 21], they inevitably raise differences with regard to perspectives on the structure and organization of the work [22] and jeopardize evaluation of a system's effect. Therefore, it is advocated to focus on the *communicative processes* of healthcare professionals instead of on notions of tasks or goals as basic units of analysis [22].

Proper communication is required for the necessary coordination and integration in dynamic processes such as medication work [23, 24], and constructing an effective system of communication, as Strauss [25] argues, is

in fact a generalized work articulation strategy. However, successful communication is not simply a matter of an information-transaction but involves the usability of the transacted information; it is a process that helps to establish, test, and maintain relationships, meaning, and coordination [6, 26, 27]. The usability of the communicated information, therefore, requires physicians and nurses to attain a common understanding of the data [28, 29]. In fact, work consistency in the medication process depends both on an appropriate and timely information transaction and on a proper understanding of it [30].

Interoperability is defined as “the ability of parties, *either human or machine*, to exchange data or information” [26]. In this study, an extended application of “interoperability” was used to imply nurse-physician *mutual intelligibility* in their medication-related communication, either directly or through using a paper-based or an electronic medication system [29]. In accordance with the discussion by Bannon et al. [28] about *Common Information Space*, nurse-physician interoperability can provide a framework for our understanding of the properties of medication-related information that crosses the professional boundaries of nurses and physicians [29]. Such an understanding can be

used to highlight the effort that is needed to transfer information from one community into a shared arena [22].

3. Study Context

Erasmus Medical Center is a 1237-bed tertiary medical institute in Rotterdam, The Netherlands. A CPOE system, *Medicatie/EVS*[®], was implemented in 34 wards from September 2003 until March 2005. The system has the capability to recognize and to issue alerts on drug overdoses, interactions, and double medications, based on the pharmacy drug database and the national drug database (the Z-index of the Royal Dutch Association of Pharmacists) [31]. Before the CPOE system was implemented, a paper-based medication system (TIMED) had been used in the internal medicine wards. More detailed information about the paper-based and COPE systems can be found in [18].

In principle, no medication can be given by nurses unless there is a corresponding physician logged in. As soon as the prescribing physician clicks on a print button and/or logs out, a 3.5 × 10 cm self-adhesive prescription label for each medication is printed out on a special printer (► Fig. 1). The rest of the

The figure shows a sample of a Kardex card. On the left, there are two prescription labels. The top label is for MORFINE HCL 3-WATER INFU 1MG/ML 60ML, with a dose of 4 mg and a start date of 11-10-06. The bottom label is for ACETYSALICYLZUUR TABL 80MG, with a dose of 80 mg and a start date of 13-10-06. On the right, there are administration records for the dates 11/10, 12/10, and 13/10. Handwritten notes and initials are present in the records. Arrows point to various fields: 'Patient Name' points to the patient's name on the label; 'Medicine & Administration form' points to the medication name and dose; 'Unit Code' points to the unit code '12CD'; 'Remarks Place' points to the bottom of the label; 'Start and possibly stop dates' points to the start and stop dates; and 'Dose-Time' points to the dose and time on the label.

Fig. 1 A Kardex-card consists of prescription labels on the left-hand side and spaces to record administration information on the front of each prescription-label. (Note: This figure was reproduced from [18] with the permission of Elsevier BV.)

Pag.	*SESOP*	P-AZR-P01-	A0 09-03-2007	38 (1)	User	Vra	MEDI 15	Lijst MEDI 500	P
Actueel Medicatie Overzicht voor						Patientnr:	Printdatum/tijd: 09-03-07/11:		
6501662	091746	Start: 07-03-07/15:36 Stop :	AMOXICILLINE TABL 750MG AMOXICILLINE			ORAAL	08:00 14:00 22:00	750 mg 750 mg 750 mg	
6403399	091746	Start: 06-03-07/18:39 Stop :	DEXAMETHASON CAPS 1MG DEXAMETHASON			ORAAL	08:00 12:00 18:00 22:00	2 mg 2 mg 2 mg 2 mg	
6701763	091746 091746	Start: 09-03-07/00:00 Stop : 09-03-07/23:59	DEXAMETHASON CAPS 1MG DEXAMETHASON ;1e dag postoperatief			ORAAL	08:00 12:00 18:00 22:00	2 mg 2 mg 2 mg 2 mg	
6801755	091746 091746	Start: 10-03-07/00:00 Stop : 10-03-07/23:59	DEXAMETHASON CAPS 1MG DEXAMETHASON ;2e dag postoperatief			ORAAL	08:00 12:00 18:00 22:00	1 mg 1 mg 1 mg 1 mg	
6901751	091746 091746	Start: 11-03-07/00:00 Stop : 11-03-07/23:59	DEXAMETHASON CAPS 1MG DEXAMETHASON ;3e dag postoperatief			ORAAL	08:00 14:00	1 mg 1 mg	

Fig. 2 Current Medication Overview (AMO) list

medication process – including procurement of drugs, distribution, administration, and monitoring – is handled by nurses, who use a paper-based medication management system, called the Kardex-card, for registration and coordination purposes. They can look at patients' current medication data in the CPOE system through HIS and can make lists, but they cannot make any changes to the data. Due to the problems that direct communication of medication orders from physicians to pharmacy department caused, this feasibility of the CPOE system has been turned off. Commonly used drugs are kept in the ward's medication stock supply, and prescribed items that are not included in the stock are ordered by Hospital Information System (HIS) from the pharmacy department by nurses. Nurses are not allowed either to administer drugs from the ward stock or to order non-stock medications unless they have their prescription labels at hand.

The prescription labels contain a variety of information including the name of the patient and the physician, the ward code, and medication, including its administration route, dosage, intervals, and the start and stop date; entering the stop date is not mandatory, however, except for critical items such as antibiotics. At the bottom of a prescription label is a small space where physicians can enter

necessary notes and remarks that nurses need to bear in mind while administering the medication. Every nurse picks up her own patients' prescription labels from the printer and sticks them on a Kardex-card. On the front of each label on the Kardex-card are empty spaces where nurses are to sign whenever the medication is given to patients or to record remarks when necessary (Fig. 1).

Another important output of the CPOE system is called the AMO^a list, which contains an overview of current medications for each patient (► Fig. 2). This overview is printable through HIS and contains the changes in patient medication data. Every midnight (around 12 a.m.), nurses print out AMO lists and use them to check against each patient's Kardex-card and medication cabinet.

4. Methods

To achieve interoperability during the medication work, nurses and physicians exchange information either directly (i.e., verbal conversation) or indirectly (i.e., through recording on any kind of patient care information

system) [29]. Therefore, any problem in either form of the information exchange can cause problem in nurse-physician interoperability and as a result in the medication work. Vice versa, it is possible to trace the problems in medication work of nurses and physicians back to the probable problems on their interoperability.

All six internal medicine wards, with a total of 174 beds, were included in our study on the grounds that the medication-related work of nurses and physicians in these wards is considerable. Since nurses play a significant part in almost all phases of the medication process and have a pivotal role in articulating different healthcare providers' tasks, our research was more nurse-oriented. A questionnaire was used to record nurses' attitudes toward the effects of the former paper-based system on their medication work and communication prior to implementation of the CPOE system in internal medicine wards in November and December 2003. In the same manner, in April 2004, a second but slightly different questionnaire evaluated nurses' attitudes towards the system five months after its implementation. The questionnaires were in paper form, were optionally anonymous, and were in the Dutch language. They contained 28 and 40 questions designed to evaluate the paper-based and CPOE systems, respectively.

^a AMO stands for Actueel Medicatie Overzicht (Current Medication Overview).

The questions were either multiple-choice or were based on the five-point Likert scale, and covered topics ranging from system usability to the effect of the systems on nurses' medication work. In developing the main questionnaires, published surveys such as that of Murff et al. [32] about CPOE systems were considered, and the relevancy and understandability of the questions were tested with two nurses.

All 140 nurses active in the internal medicine wards were included in our surveys. The head nurse in each ward was assigned to distribute the questionnaires, to motivate the nurses to fill them in, and then to collect and return the completed forms. We followed up on the returning of the completed questionnaires one, three, and five months after their distribution. Seventy-six and 75 questionnaires were returned, for before and after the implementation, respectively.

In 2006, the data was extracted from the questionnaires and analyzed. We carefully selected those questions that were related to the quality and usability of medication data – in prescriptions, AMO lists, and Kardex-cards – as well as to the reliability of the system's function. Eight questions were common in both pre- and post-implementation questionnaires, while four were specific for post-implementation; all of the chosen questions were based on the five-point Likert scale

(Tables 2 and 3). Other questions have been reported upon in other papers [18]. The dependent variables in both surveys had normal distribution using the Shapiro-Wilk test and graphical methods. Thus, t-tests were used to analyze the questions. And to avoid the effect of multiple-comparison, the significance of t-tests was compared to Bonferroni-adjusted α (.006). This part of the study evaluated how nurses perceived physical appearance and structure (i.e., syntactic aspect) of the prescription data (questions 1, 2, and 3) and administration registration system and its data (questions 4, 5, 6, 7, and 8) before and after implementation of the CPOE system. Therefore, they were used to inform how the paper-based and the CPOE systems impact *syntactic interoperability* in the medication process.

In 2006 and 2007, assuming that the system had been adopted and fully integrated into the medication work, we performed a qualitative study. The first and the second authors conducted 15 interviews with nurses ($n = 9$) and physicians ($n = 6$) from internal medicine wards who had working experience with both systems. The interviews were conducted at interviewees' working environment where they could show to the interviewers if they find something difficult to explain and support their claims with examples. The interviews were in-depth, semi-structured,

one-to-one, and face-to-face, and each one lasted 45–60 minutes. The questions were focused on interviewees' medication work and the impact of the CPOE system on each phase of the medication process. Moreover, the effect of the system on nurse-physician communication and collaboration in routine medication work was discussed in detail. In the event that a problem in the medication process was perceived, the interviewees' compensating actions were discussed in depth. Whenever it was appropriate, interviewees were requested to compare the CPOE and TIMED systems on the basis of their experience. This part of the research triangulated our methodology because many of our topics for the interviews were those of the questionnaires; the data was also triangulated in the sense that we asked nearly the same questions of both nurses and physicians.

The interviews were voice-recorded, transcribed, and prepared for analysis. Each transcript was then reviewed for obtaining general impression, evaluating its credibility, and understanding the use of its information. The data were coded based on Bowling [33] by the two interviewers independently in order to differentiate general themes, i.e. the problems in medication work of nurses and physicians. The analysis proceeded with recognizing: whether the considered problems were because of a problem in nurse-physician inter-

Table 1
Demographics of respondents. (Note: Some part of this table's data was reproduced from [18] with permission of Elsevier BV.)

		Pre-implementation (N = 76)		Post-implementation (N = 73)	
		Frequency	Percentage	Frequency	Percentage
Gender	Male	14	18	12	16
	Female	61	80	60	82
	Missing data	1	1	1	1
Age	≤23 years old	11	15	13	18
	24–33	24	32	25	34
	34–43	17	22	15	21
	44–53	20	26	18	25
	≥54 years old	2	3	1	1
	Missing data	2	3	1	1
Professional position	Practicing nurse	62	83	55	75
	Nurse manager	3	4	6	8
	Nurse student	8	11	10	14
	Other	2	3	1	1
	Missing data	1	1	1	1

Table 2 The table represents the translated questions based on the five-point Likert scale and their statistical analysis using the t-test. Questions 1 to 8 were common in pre- and post-implementation surveys.

	Questions	Scales	Mean	Std. Deviation	t	Sig. (2-tailed)
Questions about prescription data	1 The layout of prescriptions is:	Confusing 1 2 3 4 5 Clear	3.67 3.63	.985 .999	.282	>.006
	2 The legibility of prescriptions is:	Bad 1 2 3 4 5 Good	2.75 4.01	.940 .993	-7.98	<.001
	3 The completeness of prescriptions is:	Bad 1 2 3 4 5 Good	3.37 4.03	.892 .897	-4.49	<.001
Questions about administration data	4 The arrangement of data in the administration registration system is:	Cumbersome 1 2 3 4 5 Efficient/practical	3.68 3.85	.897 .844	-1.20	>.006
	5 The layout of the administration registration system is:	Confusing 1 2 3 4 5 Clear	3.35 3.86	.849 .787	-3.83	<.001
	6 The overview of medication data in the administration registration system is:	Unreliable 1 2 3 4 5 Reliable	3.11 3.79	.841 .781	-5.10	<.001
	7 Administration records in the administration registration system are:	Confusing 1 2 3 4 5 Clear	3.09 3.42	.957 .896	-2.23	>.006
	8 Administration records in the administration registration system are:	Unreliable 1 2 3 4 5 Reliable	3.09 3.23	.900 1.14	-.903	>.006

In the "Mean" and "Std. Deviation" columns the upper values belong to the pre-implementation survey and the lower values belong to the post-implementation survey.

The significance of tests was compared to Bonferroni adjusted α (.006).

operability; if yes, whether the interoperability problem was introduced by the CPOE system; and what were the actions on the part of nurses and physicians developed in response to those problems. The inter-rater agreement between the two coders over the above-mentioned issues was assessed by calculating Cohen's Kappa. The non-agreed items were then discussed between the authors and compromised upon.

5. Results

5.1 Questionnaires

A total of 76 questionnaires (response rate 54%) on pre-implementation and 73 (response rate 52%) on post-implementation were used for the analysis. ► Table 1 represents the demographics of the respondents in both surveys; the majority of the respondents were female, practicing nurses, and between 24 and 33 years old.

The means, standard deviations, t-values, and 2-tailed significance of the t-tests for questions 1 to 8 were presented in ► Table 2.

The analysis showed that nurses judged CPOE system prescriptions to be significantly better than those from the paper-based system with regard to legibility ($P < .001$) and completeness ($P < .001$). However, there was no statistically significant difference between prescription layout in the two systems ($P > .006$).

The overall layout of the Kardex-card was considered significantly clearer ($P < .001$) and the overview on medication data was thought to be significantly more reliable ($P < .001$) in comparison to TIMED system. However, the efficiency of data arrangement on Kardex-cards was not substantially changed in comparison to the paper-based administration registration system ($P > .006$). Moreover, administration records on Kardex-cards were not considered to differ significantly with respect to clarity and reliability in comparison to the paper-based administration system ($P > .006$).

Questions 9 to 12 were specific for the post-implementation questionnaire, and one sample t-test was used to analyze them by comparing them to 3 (the middle value of the five-point Likert scale). The result of the

analysis is presented in ► Table 3. The AMO list was rated significantly clearer ($P < .001$) and more reliable ($P < .001$) by nurses, who also considered that HIS and the network support working with the CPOE system were reliable ($P < .001$). The function of the system's printer was evaluated as a further check on the process. Nurses considered the printer's work to be significantly reliable ($P < .001$).

Although the presented results provided a good insight into the improvements in medication data communication, especially with respect to its syntactic aspect, they did not provide sufficient insight into how the system impacted nurse-physician interoperability. To determine how interoperability was changed and to triangulate the quantitative findings, we conducted interviews with nurses and physicians. The following sections present the results of the qualitative study.

5.2 Interviews

The chance-corrected agreement between the two independent coders was good ($\kappa = 0.69$; 95% confidence interval (CI), 0.84–0.56).

Table 3

Questions 9 to 12 were specific for the CPOE system. One sample t-test was used to compare the mean of each question with the hypothesized value of 3.

	Questions	Scales	One sample t-test (test value = 3)			
			Mean	Std. Deviation	t	Sig. (2-tailed)
9	Information in AMO is:	Confusing 1 2 3 4 5 Clear	3.60	1.14	4.52	<.001
10	Information in AMO is:	Unreliable 1 2 3 4 5 Reliable	3.75	.852	7.47	<.001
11	HIS and network support for working with the CPOE system is:	Unreliable 1 2 3 4 5 Reliable	3.64	.747	7.09	<.001
12	The performance of the prescription-labels' printer is:	Unreliable 1 2 3 4 5 Reliable	3.71	.819	7.23	<.001

AMO stands for Actueel Medicatie Overzicht (Current Medication Overview).

The interviews, in general, revealed that both nurses and physicians considered the system to be an improvement in their medication work compared to the old paper-based system. They however complained about problems in coordination and collaboration. These problems forced them to develop informal^b rules and work methods (i.e. work-

arounds) and to adapt the system in a way that it met their work requirements. As this later part of our finding was not reflected by the quantitative research, we report on it explicitly.

5.2.1 Physicians' Perspective

Physicians especially appreciated the system with respect to its decision support during prescribing or adjusting medications, to the possibility to prescribe from different locations in the hospital, and to the good docu-

mentation of patients' prescription data. In practice, however, prescription labels and AMO lists had generated several communication problems that hindered interoperability (► Table 4). First, AMO lists were produced only once every 24 hours and during night shifts, and depending on the routines of different wards, the older AMO lists were either archived in nursing records or discarded. They did not convey the most recent changes in patients' medications if they had occurred after midnight. They also provided no information about changes older than 24

^b Informal is used here to represent the rules and manners in working with a system that were not formally considered and outlined in the system design.

Table 4

Some workflow impediments due to interoperability problems, the CPOE system-related source of the problems, and physicians' compensatory reactions.

Workflow impediments due to problems in interoperability	Source of interoperability problems	Compensatory reactions
Physicians could not be sure whether nurses had picked up and filled prescription orders that were sent through the system.	The system could not inform nurses that new prescription-labels had been printed out.	Physicians informed nurses directly or through phone calls that new prescription-labels had been issued.
Changes older than 24 hours and the most recent changes in patients' medications were not accessible through AMO lists for physicians at the bedside (missing data).	AMO lists were produced to check and control the mechanism of nursing medication work. For physicians these AMO lists were not sufficiently updated.	Physicians had to work with an abstract form of information and make brief notes.
In working with the system, there was no way for physicians to monitor and prevent giving wrong medication to the wrong patient or to adjust their prescriptions according to the patient's medication administration history.	There was no link between patients' current medication data and their administration records.	Physicians had to leave the drug monitoring task to nurses, rely on their bedside reports in their decision making, or ask patients.
Patients' clinical data (e.g., pulse, weight, temperature, etc.) was not easily accessible for physicians at the time of prescribing.		
Nurses failed to pay special attention to the details on physicians' medication orders.	Information on prescription-labels was printed in small letters in black and white.	As regards special timing, route, and particular attention to the administration of a drug, physicians had to inform the nurses directly, as well as enter a note at the bottom of prescription-labels.

hours: it was not clear, for example, what medications a patient had used two days ago. Second, AMO lists contained no medication administration records. The Kardexcard in working with the CPOE was the only administration reference, but it was not available for physicians at patient bedside or where they entered their prescriptions into the system. By using AMO list as the source of patient medication data during medical rounds, physicians in effect had no proper overview and frequently had to rely on their own memory, on nurses' reports, or on a patient's verbal information. Therefore, working with the system prevented physicians from participating in monitoring phase.

"... What the system does (support) and what is good about the system is especially that it has a good signaling function for interactions or for the moment when one adjusts several drugs. What it does not (support is that) there is no way to use the system to prevent giving wrong medications to the wrong patients. There is no coupling between my prescription and a patient administration registration reference" (a senior physician).

If they were to fulfill their function in linking the work of nurses and physicians, prescription labels had to be picked up and processed by nurses, otherwise the prescription data was not formally transferred to them in the medication process loop. However, there was no way for nurses to be informed by the system that new prescription labels were printed out and waiting for them. As a result, physicians had to inform nurses, directly or through phone calls, every time they issued a new prescription label; this was not always possible for them. Physicians, moreover, had to inform nurses directly in the event that they prescribed medication that was not in accordance with ward routine, or when they requested special attention be paid to the administration of a particular drug at the bottom of the prescription label. Without direct communication, there was a high risk that those instructions would not be seen by the nurses.

There were several reasons why orders were not usually entered into the system timely. First, entering medication orders into the CPOE system was time-consuming es-

pecially when new patients were admitted and medications were prescribed for the first time. Second, writing medication orders interfered with the other duties of physicians working under high pressure contingency, for example, with their academic and training responsibilities. Third, physicians sometimes had to wait for more information or evidence before they could decide upon an appropriate medication therapy. Nevertheless, these delays could not be easily coordinated with nurses' duties and so resulted in problems in their medication work.

5.2.2 Nurses' Perspective

Nurses believed that the CPOE system prescriptions were more legible, complete and reliable, and they did not experience the problems they had had with the paper-based system. They also believed that the Kardexcard provided them with much clearer, readable and reliable data. Many nurse-physician arguments involving problems with those issues were dissolved with the implementation of the CPOE system. Nurses, however, were concerned that physicians did not enter their orders into the system in a timely fashion, and so prescription labels might be delayed by up to few hours. This was quite disruptive to nurses' work, especially as in principle, and following implementation of the CPOE system, they were not permitted to accept verbal instructions given by physicians. Moreover, nurses could not order non-stock medications in case they did not have their prescription labels at hand. In practice, for medication work to run smoothly, nurses developed informal strategies to deal with the communication of orders. For one thing, they still accepted verbal instructions, though this approach was informal and highly dependent on the professional relationship and trust in the physician (► Table 5). Moreover, a special paper-based form at nursing stations, called *appointment form*, was used for physicians to write down and sign their medication orders if time was an issue or it was impossible to enter prescriptions directly into the system. However, these orders had to be entered later by the physicians.

The physicians' delay in prescribing medications caused nurses to receive prescription labels late, which in turn held up their medication work, an issue that became a part of

routine. Hence, nurses were used to phoning the physicians frequently, requesting that they enter their orders into the system and issue the labels. For many of the routine medication orders, nurses might not wait to receive the labels, but would work on the basis of notes that they took during medical rounds. Nevertheless, they continued to call the physicians because they still needed prescription labels to authorize their work. Nurses also frequently found that physicians changed or forgot details of their verbal orders when they prepared to enter them into the system, and as a result they issued prescription labels that did not tally with their verbal instructions.

The medication order entry for newly admitted patients was normally delayed because the first entry into the system could be time-consuming, especially if physicians had to enter several of their patients' home-used medications as well. For patients admitted from the emergency ward (EW), the situation was even worse; since EW physicians were exceedingly busy, the admitted patients were usually sent to the wards without medication orders being entered into the system. In one head nurse's rough estimation, one out of every five patients admitted daily was from the emergency ward. In these instances, because nurses were not formally allowed to start a patient on medication with only a paper-based prescription, they were forced to call the physician who admitted the patient to the ward or to find another physician who could enter the patient's medication into the system. Until they could do this, nurses sometimes asked patients to use their usual medications, which they normally brought with them to the hospital. If a patient needed to be started quickly on a new medication, nurses did not wait for the prescription label to arrive; they began to administer that medicine out of their ward supply. If the medication was not in stock, they would borrow it from another ward.

Prescription labels and AMO lists were communicated data from the electronic to the paper-based system. Prescription labels, however, had many shortcomings as an effective method of communication. They were small pieces of black and white paper that contain a great deal of information in small print (Fig. 1). This made nurses potentially prone to errors in reading and working with

Table 5 Some workflow impediments due to interoperability problems, the CPOE system-related reasons for the problems, and nurses' compensatory reactions.

Workflow impediments due to problems in interoperability	Source of interoperability problems	Compensatory reactions
Nurses' medication work delayed because in routine work, they received prescription-labels late.	Logging on to the system and entering medication orders was time consuming for physicians and interfered with physicians other responsibilities.	<ul style="list-style-type: none"> • Nurses frequently had to interact with physicians either directly or through phone calls. • Nurses did not wait for the prescription-labels and began medication work based on the notes they took during medical rounds. • Nurses had to accept verbal instructions but wrote down them on paper-based forms both for legal purposes and to remind physicians to enter them into the system.
For newly admitted patients, especially from the emergency ward (EW), nurses were often confused about medication orders, since they were not entered into the system.	Entering medication orders into the system for the first time was time consuming and was not compatible with busy working condition of EW.	<ul style="list-style-type: none"> • Nurses at wards had to find a physician to enter the newly admitted patients' medication orders into the system. • Nurses borrowed out-of-stock emergency medicines from other wards. • Nurses had to request patients to use their usual medications until a physician entered their new medications into the system.
Nurses could not be sure why a patient's medication plan had been changed.	The system failed to synchronize the medication work of physicians with the medication work of nurses.	<ul style="list-style-type: none"> • Nurses frequently had to interact with physicians either directly or through phone calls.
Nurses could not be sure when physicians were going to issue prescription-labels.		<ul style="list-style-type: none"> • Nurses frequently had to check the system's printer. • Nurses handed over each other's prescription-labels to colleagues. • Nurses frequently had to interact with physicians either directly or through phone calls.
Nurses made mistake in reading (e.g. confusion between look-alike names, etc.) and distributing prescription-labels.	Prescription-labels for different patients and by different doctors were printed in random order.	<ul style="list-style-type: none"> • Nurses warn each other about existing patients with look-alike names in the ward and have to double-check each other's medication work.
Nurses made mistake in executing the orders.	Too much information was presented on a small prescription-label in black and white.	<ul style="list-style-type: none"> • Extra checks by other colleagues were designed into the process to detect and improve the mistakes.
Certain information that could not be registered quickly in the system was lost.	Nurses could not work with the system and their information was not integrated into the system.	<ul style="list-style-type: none"> • Special paper-based forms were used to record physicians' medication orders in special conditions such as time pressing condition. • Nurse had to accept written order in certain circumstances.
The timing shown on prescriptions was not compatible with a ward's routine.	The timing of medication plan in the system was not compatible with ward routine	<ul style="list-style-type: none"> • Nurses had to change administration plans according to their work routine and sometimes based on patients' medical condition.

prescription labels. These kinds of mistakes were more likely to happen when nurses had to read and distribute many prescription labels quickly: for example, during busy shifts, when a patient was transferred from one ward to another, or when prescription labels were held up by physicians. When the names of patients were similar, it was highly probable that prescription labels got mixed up, and a wrong one was placed on the wrong patient's Kardex-card. It was also possible that the names, routes of administration, and timing of the drugs were misunderstood or misinter-

preted. Many of these errors were normally discovered and corrected during the evening or night shifts when patients' Kardex-cards were checked against their medicine cabinet and AMO lists. However, other mistakes might not come to light for some time and patients might receive wrong medications or incorrect doses.

"During the night shifts, nurses distribute 24 hours' worth of patients' medications into their medication cabinets. After 24 hours the cabinets have to be empty, but

sometimes they are not. Then we have to check (with AMO lists and Kardex-cards) and see what happened and what the reason is. Sometimes you discover that some of the stickers are missing, or are put in wrong positions or on wrong Kardex-cards. But sometimes you have no idea why it is so" (a head nurse).

To avoid these kinds of errors, nurses passed their logbooks on to colleagues during a shift change or they put a notice in the nursing station which says, for example, "Patients

with similar names had been admitted to the ward". Recently, nurses had also been instructed to check both the patients' names and their date of birth before administering medications.

Nurses could not easily communicate their feedback and comment to physicians. Physicians, especially junior physicians and residents, might make prescription errors that were detected by nurses. However, informing physicians about these errors had become difficult since the CPOE system was implemented. Because nurses were receiving prescriptions asynchronously, the only way for them to correct these errors was to pick up the printed labels and then found the prescribing physician directly or by phone.

There was an increased possibility that part of a patient's medication data would be lost during medication activities. Physicians were used to complying with the medication timing offered by the system. However, in routine medication work, nurses might consider that some drug administration plans did not fit in with their ward routine or with the conditions of the patients, and they had to adjust them, especially with regard to timing. Therefore, nurses simply put cross mark over the timing indicated on prescription labels and on the Kardex-card they wrote down the administration timing they considered more suitable. However, physicians were rarely informed of these alterations in patient medication plans and the changes were not registered in the CPOE system, especially if they were temporary or due to ward routine. As a result, this information was not practically accessible and was lost to the physicians. It was the same for PRN^c medications. There was no way for physicians to know through the CPOE system how much of a PRN medication a patient had received unless they asked nurses or looked at the nursing records. Another common area where information could be lost in the medication process loop was physicians' verbal instructions. Nurses normally filled verbal orders, and they registered them in nursing records and/or on the appointment form to remind physicians to enter them into the system. However, nurses sometimes forgot to remind physicians, especially if they were delayed and a shift

change took place. Verbal orders were considered important in facilitating the medication workflow, especially when physicians did not have access to the CPOE system. They represented an informal method of order communication that was still common between physicians and nurses and helped them to build interoperability, though at the same time running the risk of information loss.

6. Analysis

An analysis of the questionnaires showed that the layout of the medication orders was not significantly changed in comparison to the paper-based medication system. Likewise, the interviews showed that nurses claimed the presentation of information on prescription labels caused them to make mistakes in reading and executing the prescription orders. The surveys showed that nurses did not consider arrangement, clarity, and reliability of administration data to be changed significantly. Likewise, the interviews demonstrated that during medical rounds nurses and physicians usually use an AMO list instead of a Kardex-card to inform them as to what medications patients use. Nurses' ad hoc adjustments and adaptation to administration plans were rarely communicated to physicians. And physicians did not have access to administration data during the time they prescribe through the system. As a result they felt that they had lost control of the monitoring phase of the medication process. While nurses believed that they had little influence on physician's prescriptions. Communication problems after the CPOE system restricted nurses-physicians synchronization and coordination and as a result restricted their work integration. The shift from one phase of the medication process to another was not as smooth as previously, required nurses and physicians to remind each other to fulfill their medication tasks. Nurses had no idea when physicians issued prescription labels and for what reasons; this caused work consistency problem and required them to call physicians frequently. For their part, physicians cannot be sure whether the prescriptions that they entered into the system were picked up by nurses; this requires them to inform nurses by a phone call or in face-to-face communication.

The interviews showed that nurses had problems in communicating information to physicians, including their feedback on prescriptions (syntactic interoperability problem). More importantly, it became clear that despite improved clarity and completeness (improved syntactic interoperability), medication orders in many instances do not accomplish their desired intentions, i.e. semantic interoperability problem. The interoperability problems have produced problems at medication workflow and required nurses and physicians to develop workarounds and to make extra efforts to solve the problems.

7. Discussion

Our study has shown that although the system improved nurse-physician syntactic interoperability at the prescription phase to a large extent, considering the interconnected nature of the medication process, this interoperability was problematic throughout. The system produced interoperability problems at the administration and monitoring phases; even in the prescription phase there were interoperability problems due to a problematic information flow from nurses to physicians. The interoperability problems led to problems at medication workflow. To compensate for workflow problems and to facilitate interoperability, many informal interactions, ad hoc rules, and informal practices (workarounds) were developed. In a situation involving damaged interoperability and a different, informal use of the system, there is considerable potential for nurses and physicians to make mistakes.

The implementation of a CPOE system is critical for its successful application, and implementation problems can explain many of the system's counterproductive effects on healthcare processes [10]. However, there are also other, and mostly hidden, factors amounting to adverse influences of a CPOE system. We evaluated a CPOE system after approximately three years of its successful implementation and use, and found many interoperability problems that led its users to adopt error-prone compensatory strategies. The devised workarounds in working with the system may predispose nurses and physicians to err in their practice.

^c PRN means 'whenever a patient needs it'.

The developing workarounds in working with IT systems and their effects is a growing concern in the field of medical informatics. These compensatory reactions are meant to repair workflow breakdowns and to facilitate work process [34, 35]. They however can increase cognitive efforts and lead to instability, workload [34], and compromise patient safety [36]. Vogelsmeier et al. [35] evaluated the mechanisms that led to the development of workarounds during the implementation of an electronic administration record system, and they conclude that an understanding of the workarounds is an important consideration in comprehending the risk to medication safety. Likewise, we have seen that many of them can be a potential source of medication errors. Although we did not quantify the errors due to the developed workarounds, we brought into attention the conditions that may induce medication errors. Such conditions are not recognized in the ordinary methods of evaluating an information system, unless the effect of the system on the entire process is considered and the implementation environment is seen as a dynamic condition that can compensate for many of the system's shortcomings. In this dynamic environment, many of the potential errors due to the system application are corrected by care providers before they reach to patients. However, those potential errors are posing grave risk to patient safety and are not usually recorded in any patient care information system. Moreover, the recorded information does not necessarily represent the real events as the records can be changed or adjusted on ad hoc base. Therefore, recording errors retrospectively can never be representative of the real condition and the real risk to patient safety.

Workarounds and their impacts can be escalated if they are not recognized and their sources are not managed properly [34]. Practically, it is not possible to stop workarounds, since without them a system's work grinds to a halt [37]. The sources of workflow breakdowns in working with a system have to be recognized and improved if workarounds have to be managed. Interoperability problems in our study were the main source of many workflow breakdowns, and those problems emerged because prescribing was not considered within the interconnected phases' loop of the medication process. Appropriate

communication mechanisms, therefore, were not designed into the CPOE system to support the necessary level of integration between nurses' and physicians' tasks throughout the medication process. Printing medication orders turned out to be a problematic mechanism for integrating information from the prescription phase into other phases of the medication process, and the possibility to integrate information from other phases into the prescription phase was also not designed into the system. Although many of those problems can be addressed in a system redesign, performing required technical adjustments to commercially-sold systems is usually hard and a time-consuming process. Therefore, in many cases organizational appropriations to improve nurse-physician interoperability are the most feasible improvement measures. Moreover, the nature of our findings emphasize on the importance of policies and decisions in post-implementation period that may cause more interoperability problems for a system's users, persuading them to devise unsafe workarounds.

We believe that interoperability problems are not specific for the system we implemented or for the environment that we studied. Similar concerns about nurse-physician communication and collaboration have been reported in evaluating CPOE systems being implemented in different locations [11, 13, 38]. Our findings in this study are also in line with Koppel et al. [4] and Beuscart-Zephir et al. [13], in the sense that they help to understand and to improve the impact of hidden factors that can lead to a CPOE system having unintended negative effects [39]. Therefore, evaluating the impact of a CPOE system on interoperability can be used to inform about the effect of the system on coordination and collaboration throughout the medication process and, as a result, about whether the system reduces errors in practice.

Healthcare systems are now moving from paper-based to electronic. As full automation of many healthcare processes, such as that of medication, is extremely difficult, if not impossible, incremental IT interventions like CPOE systems are inevitable. The incremental steps however run the risk of care processes disintegration and discontinuation. Several promising health information technologies, such as automated bar coding and electronic administration registration sys-

tems, may help to get better medication data exchange between nurses and physicians. However, they need to take into account that technology per se is not a panacea and always has its own disadvantages [40, 41]. There is a great possibility that the interoperability of healthcare providers will be damaged if such systems do not integrate appropriately into the entire process. Therefore, the important yet less often discussed question is: How should these systems be designed, implemented, and integrated into highly cooperative settings and not hinder healthcare work by, for example, creating automated islands?

Our study had several limitations. As with any survey study, a self-selection bias was inevitable. The survey respondents, for example, may have more positive attitude toward the intervention and to be more motivated than non-respondents. Another important limitation of survey study concerns the self-report bias. Considering the possible effect of these biases, we deliberately designed a qualitative study to test the validity of the quantitative findings. Moreover, the system we evaluated did not have bedside prescription feasibility. Although this deficit compounded interoperability problems, we have ignored them in this paper. In addition, there was no central Electronic Patient Record or electronic medication administration recording system to register and retrieve whole medication-related data, which could provide more live view of medication data and reduce the nurse-physician interoperability problems. And finally we did not quantify errors caused by interoperability problems.

8. Conclusion

We focused on the effect of a CPOE system on nurse-physician interoperability in the medication process and found many conditions where working with the system produced interoperability problems and contributed to error-prone practices. To reinforce interoperability, the system needs to support integrating the work of physicians and nurses throughout the whole medication process. This means that as well as a mechanism to integrate physicians' medication orders into nurses' medication management systems, there must be an appropriate mechanism for nurses to integrate their information into

CPOE systems. Moreover, our study shows that interoperability between care providers can be used to evaluate the impact of an information system on the highly collaborative work such as medication process.

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