Master Thesis Health Sciences

Effect-evaluation of a computerized physician order entry system with integrated clinical decision support on medication administration errors.

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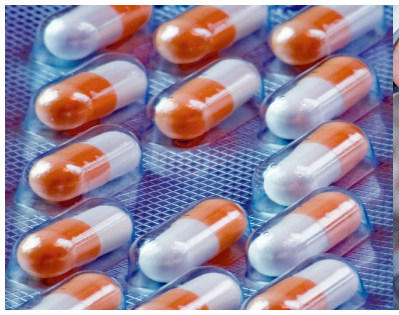

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This thesis is written in article form with the intention to submit it to the 'BMC Health Services Research' journal.

CONTENT

ACKNOWLEDGEMENTS

In the courses I followed, which were part of the track 'Health Services and Management' of the master program 'Health Sciences', I learned more about the different aspects of healthcare. Especially the quality and safety aspect had caught my interest and it became clear to me that I wanted to write a master thesis related to quality and safety. After spending some time on searching for a topic, I found the perfect topic and location what resulted in this article.

This article is the result of a half year of hard work. During the process of defining, executing and scientifically formulating this research, I experienced a lot and gained new skills, insights and new knowledge. Looking back on the process, I am thankful that I had the chance to conduct this research and to write this article. There are some people, who helped me during the entire process by giving me feedback and supporting me. Without them, the end result of this research would not have been the same. Therefore, I would like to thank them.

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Ursula Wegmann
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LIST OF ABBREVIATIONS AND RELEVANT DEFINITIONS

CDS	Clinical decision support
COW	Computer-on-wheels
CPOE	Computerized physician order entry system incl. medication administration registration
e.g.	For example (in Latin: exempli gratia)
etc.	Etcetera
IOM	Institute of Medicine
MAE(s)	Medication administration error(s)
ME(s)	Medication error(s)
MO(s)	Medication order(s)
NCC MERP	National Coordinating Council for Medication Error Reporting and Prevention
No.	Number
OE	Opportunities for error
resp.	Respectively
sd	Standard deviation
SMS	Safety management system
VAS	Visual analogue scale (used for scoring pain on a scale of 0 to 10)
vs.	Versus
WFG	Westfriesgasthuis

Medication error:
"The administration of the wrong medication or dose of medication, drug, diagnostic agent, chemical, or treatment requiring the use of such agents, to the wrong patient or at the wrong time, or the failure to administer such agents at the specified time or in the manner prescribed or normally considered as accepted practice."[1]

Medication administration error:
"A […] deviation from the prescriber's medication order as written on the patient's chart, manufacturers' preparation/administration instructions, or relevant institutional policies."[2]

Opportunity for error:
"Any dose given plus any dose ordered but omitted."[3]

Total opportunities for error:
"Sum of all the doses ordered plus all the unordered doses given."[3]

Medication (administration) error percentage:
"The percentage of medication errors is calculated as the number of actual errors (incorrect in one or more ways) divided by the total opportunities for error. This figure is then multiplied by 100 to arrive a percentage."[3]

Definitions used in the baseline measurement are listed in appendix 1.

Effect-evaluation of a computerized physician order entry system with integrated clinical decision support on medication administration errors.

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ABSTRACT

Objective: To evaluate the effect of computerized physician order entry (CPOE) with integrated clinical decision support (CDS) on medication administration errors (MAE), error types and causes and how these differ between medical and surgical units in a general hospital in the Netherlands (506 beds).
Methods: Effect-evaluation of CPOE/CDS based on disguised observations of 3,402 opportunities for error (OE) at four nursing units (oncology, pulmonology, surgery, orthopedics). Main outcome parameters were differences in MAE percentages between the baseline and the follow-up measurement and between medical and surgical units.
Results: MAE percentages excluding wrong time errors significantly decreased (9.3% to 5.8%) at pulmonology, while at oncology no significant changes were found (11.9% to 10.5%). Including wrong time errors, MAE percentages significantly increased (oncology: 19.7% to 36.4%; pulmonology: 20.3% to 31.1%). No significant differences in MAE percentages were found between surgical (32.5% resp. 9.1%) and medical units (33.6% resp. 8.0%). Most frequently occurring errors were wrong time, omission, unauthorized drug and wrong dosage form errors.
Conclusion: The implementation of CPOE/CDS seems to have had a positive effect on the MAE percentage excluding wrong time errors. However, the error types should be considered separately to see this effect, because it seems to be overshadowed by new cultural issues and impaired coordination of workflows. No significant differences in MAE percentages between medical and surgical units were found.

Keywords: medication administration errors, CPOE/CDS, disguised observations, effect-evaluation, medical versus surgical

BACKGROUND

In 2000, the Institute of Medicine (IOM) published a report on quality of patient care, entitled “To Err Is Human” [4], within which a large study in New York found that adverse events occurred in about 3.7% of hospitalizations, of which 13.6% led to death [4]. Since the publication of this report, patient safety and quality became an issue. In this respect, hospitals started researching their medication distribution systems and medication errors (MEs) gained more attention [2,5,6,7]. MEs can occur at any stage of the medication distribution process. The medication administration is one of the critical steps, because it is the last step in the process and has limited possibilities to correct errors. Non-corrected errors at this stage may directly harm the patient [8]. In a systematic review, median medication administration error (MAE) percentages of 19.1% including and 8.0% excluding wrong time errors are reported [2]. Another study even found MAE percentages of 27.6% including and 7.5% excluding wrong time errors [9].

Interventions like computerized physician order entry (CPOE) systems, with or without integrated clinical decision support (CDS), promise to reduce MEs and are common in many hospitals. Different studies report reductions in ME percentages after implementing a CPOE system [10,11,12]. Moreover, CPOE seems to solve several problems of handwritten orders, such as errors caused by unreadable medication orders (MOs) and by indistinctness of prescription responsibilities [13]. However, some disadvantages of CPOE systems are also reported in scientific literature, like a significantly higher number of MEs after implementing CPOE and different types of medication error risks facilitated by CPOE. Examples of this include medication discontinuation faults, conflicting or duplicative medications, etc. [14,15,16].
It remains unclear what effect the implementation of a CPOE system has on the occurrence of MAEs. Based on the information above, the expectation is that it might reduce the number of omissions, wrong/extra dose errors, wrong drug errors and not identifiable drug errors, because of clearer MOs and limited possibilities for nurses to change MOs. Furthermore, the effect on unauthorized drug errors might be two-sided, because of clearer MOs and obvious prescription responsibilities on the one hand and new types of medication error risks on the other hand.

Niazkhani, Pirnejad, de Bont and Aarts [17] made a qualitative comparison of clinical contexts in the medication process for medical versus surgical specialties working with a CPOE system. They found that medical specialties had a greater medication workload and more diverse information needs than surgical specialties, which resulted in a more intensive interaction with the CPOE system. In comparison to this, surgical specialties reported their interaction with the system as less intensive and less problematic, which means that they had more positive experiences with the system and did not discover as complex problems as medical specialties [17]. Based on this, one might expect that there will be differences in the occurrence of MAEs between medical and surgical units. No studies about the differences between medical and surgical units regarding the impact of CPOE on the clinical outcomes of patient care are found.

This research’s goal is to evaluate the effect of a CPOE/CDS system on the occurrence of MAEs, error types and error causes occurring at two medical units (pulmonology and oncology) of a general hospital in the Netherlands. The second goal is to study potential differences in the occurrence of MAEs and error types, causes and severity between medical (pulmonology and oncology) and surgical units (general surgery and orthopedics) at this hospital.

METHODS

Study setting and population

This study consists of a baseline measurement done in 2002 and a follow-up measurement done in 2013 [7]. Both measurements were conducted at the

"Westfriesgasthuis" (WFG) in Hoorn, the Netherlands. The units of observation were the opportunities for error at the nursing units pulmonology and oncology (both measurements) and general surgery and orthopedics (only follow-up measurement). All nurses of these units who were allowed to administer medication were observed during their medication rounds. Permission was given by the hospital ethical committee to conduct this research and all unit heads agreed to participate.

Intervention

Between 2007 and 2009, the hospital replaced the paper-based system by a CPOE/CDS system, which is integrated in the electronic medical record. The CDS includes pre-defined medication orders (MOs) and different kinds of alerts and medication monitoring. By introducing computer-on-wheels (COWs), it was possible to implement a totally paperless medication distribution process. Appendices 5 and 6 depict the medication distribution process in the paper-based system and the CPOE/CDS system. Summarizing, the responsibilities of the nurses within the medication distribution process became more limited, resulting in nurses now only being responsible for the process of medication administration. Along with implementing the CPOE/CDS system, pharmacy technicians were introduced for processing the MOs at the pharmacy, so that the pharmacists only need to double-check and approve these orders [13].

Outcome parameters

The primary outcome parameters of this research were the medication administration error (MAE) percentages. Other outcome parameters were error types, causes and severity as well as study unit and observation characteristics to determine to what extent the units are similar (table 1 and 2).

Study procedures

Several methods exist for identifying and quantifying MAEs, such as anonymous self-reports, incident reports, chart review and disguised observations [3,5]. Different studies report that the disguised observation method is most efficient and accurate in detecting MAEs [1,5,18,19,20] and is frequently used in scientific research [2,8,9,21]. When using this method, the subjects are observed during their medication rounds without informing them on the actual purpose of the observations. Afterwards, the observations are compared to the original MOs to detect MAEs [3].

In this research, disguised observations were carried out at oncology and pulmonology in 2002 and 2013, and at surgery and orthopedics in 2013. Per patient, a form (appendix 4) was filled out to characterize all opportunities for error (OE). At the moment of observation, the observer was not aware of medication errors (MEs) and did not intervene. Afterwards, the observations were compared to the MOs in the CPOE/CDS system to identify the MAEs. MAEs were classified per error type, cause and severity. The moment when the medication was administered to the patient was observed and thus not the moment when it was taken. Depending on the unit, the medication rounds at 08:00, 12:00, 14:00 and 18:00 were observed during weekdays. Medication in own management (patient uses (parts of) his own medication) was not included in this research. Moreover, 'as-needed' medication was only included when it was administered. At least 500 OE per unit were observed. If several errors were observed at one OE, the error with the greatest impact was chosen. To get used to the disguised observation method and to eliminate mistakes in the learning period, test measurements were done, which were not included in the results [20].

Different categorizations of MAE types are used by different studies [1,2,3,5,8,9,21,22,23,24]. In this research, an amended version of the MAE categorization and definition of Allan and Barker [3] was used, because it is the most frequently used and the most complete (appendix 7). The MAE categorization of the baseline measurement slightly differs and is outlined in appendix 2.

MAEs can usually be caused by one or more error sources. In this research, the PRISMA-method was used to assign the MAEs to their causes. The primary aim of PRISMA is "to build a quantitative database of incidents and process deviations, from which conclusions may be drawn to suggest optimal countermeasures" [25]. During the observations, every conspicuous feature was noted and afterwards, the MAEs and processes that led to MAEs were discussed with a hospital pharmacist, a senior nurse and a hospital-intern consultant to get more insight into the root-causes. For similar errors, PRISMA was only done once. Errors with obvious root-causes were directly classified according to the Eindhoven Classification Model (appendix 8). Error causes of the baseline measurement (appendix 3) were translated to the Eindhoven Classification Model to be able to compare the causes of both measurements.

Each MAE can be assigned to a level of severity depending on the degree of harm to the patient. The National Coordinating Council for Medication Error Reporting and Prevention (NCC MERP) designed an index for categorizing MEs [26], which is used in scientific literature [12] and also in this research (appendix 9). MAEs were categorized in collaboration with a senior nurse and a hospital pharmacist. The baseline measurement did not include categorization of MAE severity.

Statistical analysis

The absolute numbers and the percentages of MAEs, error types, causes and severity were presented per unit. The current MAE percentages of pulmonology and oncology were then compared to those from the baseline measurement. Moreover, the MAEs of the follow-up measurement were combined to be able to compare medical and surgical units. All comparisons were done including and excluding wrong time errors and by using chi-square testing. For all statistical analyses, a significance level of $p \leq 0.05$ was used.

Because of large differences in MAE percentages between surgery and the other observed units, this unit is excluded from the statistical comparison. Surgery has much more omission errors (mainly pain medication) than the other units. The reason is that at this unit, the VAS-score for ranking pain is barely used. Observations showed that nurses usually only asked whether the patient had pain or not instead of ranking it. So they frequently ceded the decision of taking pain medication to the patient, although a patient cannot always evaluate adequately whether pain medication is useful or not.

RESULTS

Study unit and observation characteristics

Table 1 lists the study unit characteristics. There were no differences in type of employment, level of education and number of years of working experience between the nurses with respect to the occurrence of medication administration errors (MAEs).

At oncology and pulmonology, 595 and 622 opportunities for error (OE) were observed at respectively 218 and 249 patients in 2002 (table 1). In 2013, 525 and 573 OE at respectively 184 and 190 patients were observed at these units. At surgery and orthopedics, 546 and 541 OE were witnessed at respectively 204 and 159 patients. At all units, most medication was administered at 08:00. Moreover, most medication was prescribed as oral medication. At pulmonology and orthopedics, only a few medications had to be administered during the medication round at 14:00, which is why fewer observations could be made.

Occurrence of errors

Effect-evaluation: oncology and pulmonology 2002 vs. 2013

The MAE percentages at oncology increased from 19.7% in 2002 to 36.4% in 2013 (table 2). Excluding wrong time errors, they slightly decreased from 11.9% to 10.5%. At pulmonology, MAE percentages also increased from 20.3% to 31.1%, while they decreased from 9.3% in

2002 to 5.8% in 2013 excluding wrong time errors. Comparing the MAE percentages of both measurements per unit, all differences were statistically significant, except the difference between MAE percentages excluding wrong time errors at oncology (p-value=0.44).

Table 1: Study unit and observation characteristics per unit.

	Medical units				Surgical units	
	Oncology		Pulmonology		Surgery	Ortho-pedics
	2002	2013	2002	2013	2013	2013
	N (%)	N (%)	N (%)	N (%)	N (%)	N (%)
No. of beds	27	19	24	23	24	23
Average length of stay	10.1	5.4*	7.9	5.8*	4.1*	4.7*
Average bed utilization	93.3%	80.3%*	82.5%	85.9%*	87.0%*	82.0%*
Average no. of patients per nurse**	3	5	4	4	4	5
No. of days observed	8	8	8	9	8	7
No. of medication administration rounds observed	31	32	31	27	32	22
No. of patients observed***	218 (100.0)	184 (100.0)	249 (100.0)	190 (100.0)	204 (100.0)	159 (100.0)
Male	95 (43.5)	128 (69.6)	110(44.2)	116 (61.1)	115 (56.4)	66 (41.5)
Female	123 (56.5)	56 (30.4)	139 (55.8)	74 (38.9)	89 (43.6)	93 (58.5)
Mean age of patients (sd****)**	-****	69,6 (10.7)	-****	66,4 (13.0)	65,8 (13.5)	67,7 (16.5)
No. of OE***** observed**	595 (100.0)	525 (100.0)	622 (100.0)	573 (100.0)	546 (100.0)	541 (100.0)
No. of OE per administration route						
Oral	491 (82.5)	425 (81.0)	507 (81.5)	495 (86.4)	420 (76.9)	479 (88.5)
Subcutaneous	38 (6.4)	35 (6.7)	30 (4.8)	26 (4.5)	45 (8.2)	23 (4.3)
Inhalation	19 (3.2)	8 (1.5)	47 (7.6)	45 (7.9)	18 (3.3)	18 (3.3)
Rectal	33 (5.5)	21 (4.0)	21 (3.4)	2 (0.3)	20 (3.7)	5 (0.9)
Intravenous	7 (1.8)	17 (3.2)	9 (1.4)	3 (0.5)	28 (5.1)	9 (1.7)
Intramuscular	0	0	0	0	2 (0.4)	0
Stomach tube	0	2 (0.4)	0	0	7 (1.3)	3 (0.6)
Other	7 (1.8)	17 (3.2)	9 (1.4)	2 (0.3)	6 (1.1)	4 (0.7)
No. of OE per medication administration round						
08:00	389 (65.4)	238 (45.3)	368 (59.2)	311 (54.3)	265 (48.5)	313 (57.9)
12:00	47 (7.9)	67 (12.8)	87 (13.9)	110 (19.2)	96 (17.6)	91 (16.8)
14:00	50 (8.4)	64 (12.2)	72 (11.6)	-	51 (9.4)	4 (0.7)
18:00	109 (18.3)	156 (29.7)	95 (15.3)	152 (26.5)	134 (24.5)	133 (24.6)
Average no. of medications per patient per medication round*****	2.7	2.8	2.5	3.0	2.7	3.4

*) Average length of stay and average bed utilization in 2012.

**) This number is given by the unit heads as a guideline for making the work schedule.

***) Each moment of observation is counted as one patient. Thus, in this number the same patients may be included several times.

***) In 2002 (baseline measurement) the age of the patient was not recorded.

*****) Sd = standard deviation; OE = opportunities for error.

******) Equal to no. of OE / no. of patients observed.

Comparison medical vs. surgical units (2013)

MAE percentages for the surgery unit were 48.4% including and 22.2% excluding wrong time errors (table 2). At orthopedics, these were 32.5% including and 9.1% excluding wrong time errors. For the medical units, MAE percentages including wrong time errors were 36.4% at oncology and 31.1% at pulmonology. Excluding wrong time errors, these units had MAE percentages of 10.5% and 5.8% respectively.

The MAE percentages for the surgical units (excluding surgery) were 32.5% including and 9.1% excluding wrong time errors (table 2). For the medical units, these were 33.6% and 8.0% respectively. Results of the chi-square test showed no significant differences in MAE percentages between surgical and medical units.

Table 2: Medication administration errors categorized per type of error and results of the chi-square tests.

	Medical units				**Surgical units*******	
	Oncology		**Pulmonology**		**Surgery**	**Ortho-pedics**
	2002	**2013**	**2002**	**2013**	**2013**	**2013**
	N (%)	N (%)	N (%)	N (%)	N (%)	N (%)
No. of OE* observed	595 (100.0)	525 (100.0)	622 (100.0)	573 (100.0)	546 (100.0)	541 (100.0)
No. of MAEs* observed**	117 (19.7)	191 (36.4)	126 (20.3)	178 (31.1)	264 (48.4)	176 (32.5)
p-value	0.00		0.00		-	-
No. of MAEs observed excluding wrong time errors**	71 (11.9)	55 (10.5)	58 (9.3)	33 (5.8)	121 (22.2)	49 (9.1)
p-value	0.44		0.02		-	-
No. of OE	1098 (100.0)				541 (100.0)	
No. of MAEs observed	369 (33.6)				176 (32.5)	
p-value	0.66					
No. of MAEs observed excluding wrong time errors	88 (8.0)				49 (9.1)	
p-value	0.47					
Type of error***	N=595	N=525	N=622	N=573	N=546	N=541
No error	478 (80.3)	334 (63.6)	496 (79.7)	395 (68.9)	282 (51.6)	365 (67.5)
Omission	40 (6.7)	33 (6.3)	34 (5.5)	19 (3.3)	94 (17.2)	39 (7.2)
Wrong dose	7 (1.2)	2 (0.4)	6 (1.0)	0	1 (0.2)	0
Unauthorized drug	20 (3.4)	10 (1.9)	0	9 (1.6)	8 (1.5)	4 (0.7)
Wrong dosage form	0	6 (1.1)	0	0	11 (2.0)	3 (0.5)
Wrong time *Small (±30 min – 2h)* *Large (±2 h)*	46 (7.7) *18 (3.0)* *28 (4.7)*	136 (25.9) *122 (23.2)* *14 (2.7)*	68 (10.9) *64 (10.3)* *4 (0.6)*	145 (25.3) *120 (20.9)* *25 (4.4)*	143 (26.2) *130 (23.8)* *13 (2.4)*	127 (23.5) *120 (22.2)* *7 (1.3)*
Wrong route	0	2 (0.4)	1 (0.2)	2 (0.4)	2 (0.4)	0
Extra dose	2 (0.3)	0	9 (1.4)	0	4 (0.7)	0
Not identifiable drug****	2 (0.3)	-	3 (0.5)	-	-	-
Wrong drug****	0	-	1 (0.2)	-	-	-
Other	0	2 (0.4)	4 (0.6)	3 (0.5)	1 (0.2)	3 (0.5)

*) OE = opportunities for error; MAEs = medication administration errors.

**) MAE percentage = no. of medication administration errors / no of opportunities of error

***) Errors, which did not occur at any unit, are not listed in this table.

****) Additional category used in 2002.

*****) Only orthopedics, the nursing unit surgery is excluded from surgical units.

Error types

Effect-evaluation: oncology and pulmonology 2002 vs. 2013

Table 2 shows that the most frequent errors at both units in 2013 were wrong time, omission, unauthorized drug and wrong dosage form errors. The amount of small wrong time errors increased over the years by 20.2% at oncology and by 10.6% at pulmonology, while the large wrong time errors decreased by 2.0% at oncology and increased by 3.8% at pulmonology. Moreover, the number of omission errors and wrong dosage form errors slightly decreased at both units. While unauthorized drug errors were nearly halved at oncology (3.4% to 1.9%), they increased from 0.0% to 1.6% at pulmonology. At both units, not identifiable drug errors, wrong drug and extra dose errors were absent in 2013. Other error types were rare or absent.

Comparison medical vs. surgical units (2013)

The most frequent errors for this comparison were wrong time, omission, unauthorized drug and wrong dosage form errors (table 2). Percentages for wrong time errors varied between 23.5% at orthopedics and 26.2% at surgery. While the surgery unit had a relatively high percentage of omission errors (17.2%), the percentages for pulmonology, oncology and orthopedics varied between 3.3% and 7.2%. The smallest percentage of unauthorized drug errors was observed at orthopedics (0.7%) and the highest percentage was observed at oncology (1.9%). The percentage of wrong dosage form errors varied from 2.0% at surgery to none at pulmonology. Other error types were rare or absent.

Error causes

Effect-evaluation: oncology and pulmonology 2002 vs. 2013

At oncology, the most frequent causes in 2002 and 2013 were cultural aspects (OC, e.g. deviating from processes because it better fits into the workflow), patient related factors (PRF) and non-classifiable causes (X, e.g. unexpected workload and unknown causes) (table 3). While in 2002, less frequently occurring causes were unauthorized changes in medication (HRQ), transcription errors (HSS), human external factors (H-EX) and insufficient monitoring (HRM), in 2013 these were human external factors (H-EX), impaired coordination (HRC) and prescription errors (HRI). Only a few errors were caused by technical or other factors.

At pulmonology, in 2002, the most frequent causes were unauthorized changes in medication (HRQ), faulty task planning and execution (HRI) and non-classifiable causes (X) (table 3). Meanwhile, most frequent causes were cultural aspects (OC), patient related factors and non-classifiable causes (X). Less frequently occurring causes in 2002 were human external factors (H-EX) and transcription errors (HSS), while in 2013, these were faulty task planning and execution (HRI), human external factors (H-EX) and organizational factors related to protocols (OP, e.g. deviating from pain protocols). No errors were caused by technical factors and only a few errors were caused by other factors.

Comparison medical vs. surgical units (2013)

Most errors were caused by cultural aspects (OC) and patient related factors (PRF) (table 3). Non-classifiable causes (X) also frequently resulted in errors at all units, except orthopedics.

At the surgical units, less frequently occurring causes were impaired coordination (HRC), faulty task planning and execution (HRI) as well as technical construction factors (TC, e.g. no alerts for duplicate medication, problems with log-in or no integration of pre-surgery medication in the medication list) (table 3). At surgery, other errors were also caused by organizational factors related to protocols (OP). At the medical units, less frequently occurring causes were human external factors (H-EX), impaired coordination (HRC), faulty task planning and execution (HRI) and organizational factors related to protocols (OP). Only a few errors were caused by other factors.

Table 3: Causes of MAEs classified according to the Eindhoven Classification Model.

		Medical units				Surgical units	
		Oncology		Pulmonology		Surgery	Ortho-pedics
		2002**	2013	2002**	2013	2013	2013
Cause of MAEs*	N=no. of MAEs	N(%) N=117	N(%) N=191	N(%) N=126	N(%) N=178	N(%) N=264	N(%) N=176
TC	Construction	0	3 (1.6)	0	0	16 (6.1)	19 (10.8)
O-EX	External	0	0	0	2 (1.1)	4 (1.5)	2 (1.1)
OP	Protocols	0	5 (2.6)	0	9 (5.1)	35 (13.3)	1 (0.6)
OC	Culture	29 (24.8)	113 (59.2)	1 (0.8)	138 (77.5)	109 (41.3)	109 (61.9)
H-EX	External	18 (15.4)	12 (6.3)	14 (11.1)	9 (5.1)	3 (1.1)	5 (2.8)
HKK	Knowledge-based behavior	0	0	0	0	1 (0.4)	0
HRQ	Qualifications	23 (19.7)	0	51 (40.5)	0	0	0
HRC	Coordination	0	11 (5.8)	0	6 (3.4)	33 (12.5)	23 (13.1)
HRV	Verification	0	3 (1.6)	0	0	0	0
HRI	Intervention	1 (0.9)	10 (5.2)	32 (25.4)	11 (6.2)	21 (8.0)	14 (8.0)
HRM	Monitoring	7 (6.0)	0	3 (2.4)	0	1 (0.4)	1 (0.6)
HSS	Slips	18 (15.4)	0	9 (7.1)	1 (0.6)	0	0
PRF	Patient related factor	29 (24.8)	42 (22.0)	1 (0.8)	44 (24.7)	96 (36.4)	29 (16.5)
X	Unclassifiable	64 (54.7)	30 (15.7)	20 (15.9)	23 (12.9)	39 (14.8)	5 (2.8)

*) Multiple causes per error were possible. For definition see appendix 8. Causes, which did not occur at any unit, are not listed in this table.

**) In 2002, the causes were not classified according to the Eindhoven Classification Model. This is done afterwards, based on the causes reported in 2002. Therefore it might be possible that more causes are reported than in the original document.

Severity of errors

Comparison medical vs. surgical units (2013)

Most MAEs were minor and therefore belong to category B, C and D (table 4). The severity of errors did not much differ between the units. However, due to a higher MAE percentage, the surgery unit had a higher number of errors classified in category C. In comparison to the other units, orthopedics had fewer errors classified in category D and was the only unit, which had two errors in category E. One error was related to a case where in the first instance, metoclopramide was not given, but afterwards the patient felt nauseous and got an adhoc administration of metoclopramide. The other error was related to a case where a patient who underwent hip-surgery did not get naproxen, because she became nauseous when taking it, but also did not recover well when not taking it. No errors of severity category F, G, H or I did occur.

Table 4: Clinical severity of administration errors per unit classified according to NCC MERP.

		Surgery	Orthopedics	Oncology	Pulmonology
		N(%)	N(%)	N(%)	N(%)
Clinical severity category*		N=546	N=541	N=525	N=573
No error	A	282 (51.7)	365 (67.5)	334 (63.6)	395 (68.9)
Error, no harm	B	12 (2.2)	15 (2.8)	5 (1.0)	10 (1.8)
	C	219 (40.1)	148 (27.3)	147 (28.0)	132 (23.0)
	D	33 (6.0)	11 (2.0)	39 (7.4)	36 (6.3)
Error, harm	E	0	2 (0.4)	0	0

*) For definitions, see appendix 9. Clinical severity categories, which are not occurring at any unit, are not listed in this table.

DISCUSSION

The medication administration error (MAE) percentages excluding wrong time errors at oncology did not significantly change over the years (11.9% to 10.5%). This is built up of small decreases of wrong dose and unauthorized drug errors and a small increase of wrong dosage form errors. At pulmonology, MAE percentages excluding wrong time errors, however, significantly decreased (9.3% to 5.8%). This decrease is built up of a reduction of omission errors and absence of wrong and extra dose errors in 2013. MAE percentages including wrong time errors significantly increased at both units.

No significant differences in the MAE percentages between surgical and medical units were found. In general, most errors that occurred at oncology, pulmonology, surgery and orthopedics were wrong time (25.9%; 25.3%; 26.2%; 23.5%), omission (6.3%; 3.3%; 17.2%; 7.2%), unauthorized drug (1.9%; 1.6%; 1.5%; 0.7%) and wrong dosage form errors (1.1%; 0.0%; 2.0%; 0.5%).

Effect-evaluation

The MAE percentage including wrong time errors increased over the years from 19.7% to 36.4% at oncology and from 20.3% to 31.1% at pulmonology. In scientific literature, error percentages vary from 19.1% to 27.6%, which are much lower than the observed percentages [2,9,27]. Other studies also report a decrease in MAEs after the implementation of CPOE [10,12]. In this research, increasing MAE percentages are mainly due to increases in small wrong time errors, which might be a result of changes in workflow and cultural problems. Examples are starting the medication round of 18:00 already at about 16:30, because dinner is served at 17:00, or administering medication of two medication rounds at the same time. However, these changes cannot be attributed to the implementation of CPOE/CDS and therefore will be disregarded in the discussion.

In scientific literature, reductions of medication errors (MEs) after the implementation of CPOE are reported [10,12]. At oncology, CPOE/CDS also seems to have had some positive effects on the MAE percentage excluding wrong time errors. The amount of wrong dose errors, for example, slightly decreased. These were nearly eliminated by the introduction of CPOE/CDS, because with CPOE/CDS, medication orders (MOs) became clearer and conscious actions are required for changing parts of the MO. Furthermore, the amount of unauthorized drug errors nearly halved, which is the consequence of a repeated prescription error that cannot occur with CPOE/CDS. Unauthorized drug errors, however, are not fully eliminated, because CPOE/CDS asynchronous work modes between physicians and nurses due to CPOE/CDS [30,31]. This leads to a higher amount of adhoc administrations, which were not authorized by physicians afterwards.

The positive effect of CPOE/CDS at oncology seems to be overshadowed by a small increase in wrong dosage form errors, which are mainly due to patients' preferences (PRF) and cannot be influenced.

While Radley et al. [10] expect a 12.5% decrease in MEs due to CPOE, at pulmonology only a decrease of 3.5% excluding wrong time errors is observed. The amount of omission errors, for example, decreased due to the implementation of CPOE/CDS, because medication lists became clearer and therefore reduced the risk of missing medication. Moreover, wrong and extra dose errors were eliminated at pulmonology, because with CPOE/CDS, transcription and interpretation errors were (nearly) eliminated due to clear MOs and more conscious actions being required when changing parts of MOs (e.g. dose). Asynchronous work modes of physicians and nurses and patient related factors, however, led to an increase in unauthorized drug errors, which might be the reason of a rather small decrease of the MAE percentage excluding wrong time errors.

Along with implementing CPOE/CDS, the hospital started working with a safety management system (SMS), which is a

structural approach for reducing and preventing risks for patients [28]. Three topics of the SMS are directly related to medication safety: “Early recognition and treatment of pain”, “Medication verification on admission and discharge” and “High-risk medication: preparation and administration of parenterals” [29]. The hospital addressed these topics, for example, by employing pharmacy technicians, who are responsible for the medication verification on admission. Furthermore, the hospital annually checks the right preparation of parenterals and implemented the VAS-project for improving the continuous recognition and treatment of pain. All these projects improve the quality and safety of care and therefore might have positively influenced the MAE percentage.

Comparison medical vs. surgical units

Niazkhani et al. [17] state, that based on the different clinical contexts, there are differences in clinicians’ attitudes towards CPOE/CDS and their perceived impact between medical and surgical units. In this research, these differences were eliminated by giving the same training to all physicians and by making agreements about fixed contact and feedback moments between nurses and physicians, as well as moments in time when prescriptions are made or changed. Hereby, physicians were more aware of the importance of medication prescription and the constant synchronization with nurses. Therefore, no significant differences in MAE percentages were found between surgical and medical units.

Different studies report the most frequently occurring errors being wrong time, omission, unauthorized drug and wrong dosage form errors [2,9], as is also the case in this research. High numbers of errors, however, cannot be related to CPOE/CDS. For example, wrong time errors are mainly caused by cultural problems, like systematically starting medication rounds too early, inadequate coordination between nurses during medication rounds and unexpected higher workloads. Other examples are omission and unauthorized drug errors due to medication being spontaneously refused or needed by patients, because of their current health state, and wrong dosage form errors due to patients’ preferences (PRF).

Other errors, however, can be linked clearly to CPOE/CDS. Some kinds of omission errors, for example, are related to construction aspects of the system. Temporary changes in medication due to surgery are only mentioned in the anesthesia patient file, which is separate from the medication administration registration. This creates a large workaround, resulting in medications being counted as omission errors because they deviate from the medication list. Stopping medication before surgery and resuming it after surgery would be a solution, but would lead to failures to provide medications after surgery, as is reported in literature [15]. Other examples are unauthorized drug errors caused by medication not being prescribed yet, because of asynchronous work modes between physicians and nurses due to CPOE/CDS [30,31]. This led to a higher amount of adhoc administrations, which were not authorized by physicians afterwards.

Different studies report that the severity of most errors was rated as minor [2,9,27,32], as was also the case in this research. Nearly all errors were of the lower severity categories B, C or D, thus errors that did not result in harm.

Strengths and limitations

The first strength of this research is the high number of OE per unit that is observed, and which may ensure reliable results. Moreover, sampling bias can be excluded, because nurses are chosen randomly on the basis of who is starting the medication round at that time. For data collection, the disguised observation method is used. Several studies line out that this method is most efficient and accurate in detecting MAEs [1,5,18,19,20].

The first potential limitation of this research is the period between the baseline and the follow-up measurement,

which was very long and which makes it difficult to determine whether other changes over the years had influenced the results. A control-group, which would enable the researchers to detect other influencing factors or process changes that might have distorted the real effect of the intervention, was missing. To exclude as much distortion of the results as possible, we described every known process change and its influence on the results. However, these influences could only be estimated and therefore the real impact of process changes on the results is unknown. Moreover, the baseline measurement had some limitations. In the baseline measurement, error and cause classification was not based on scientific literature, so it was difficult to repeat the measurement in the same way. Because classification could have been done either in a more subjective or a more objective way, the impact on the results is unknown. Furthermore, it was difficult to classify the causes of the baseline measurement according to the Eindhoven Classification Model, because not all causes were root-causes. This led to a risk that causes were assigned to the wrong category. In the baseline measurement, the severity of the MAEs was not included and therefore could not be compared to the follow-up measurement. Furthermore, the baseline measurement and the follow-up measurement were carried out by different observers who might have performed observations and analyses in different ways. It is unknown how this has influenced the results. Carrying out the observations might have influenced the behavior of the nurses. However, different studies report that the effect of the observer on the observed is not significant [2,3,5,9,18]. Finally, the identification of root-causes was limited. The PRISMA-method suggests performing interviews with all stakeholders to identify the root-causes of an incident [25]. This research, however, is about medication errors of minor severity, which partly are not even recognized by the nurses themselves as errors. Consequently, nurses would not have remembered them when they were interviewed about them. Therefore, no interviews were carried out, but errors and processes that led to errors were generally discussed with a hospital-pharmacist, a senior nurse and a hospital-intern consultant to get more insight into the root-causes. Moreover, the researcher also had no had no insights in the electronic patient file. If interviews had been carried out and insight in electronic patient files had been possible, some root-causes might have been different or more specified.

CONCLUSION

The implementation of CPOE/CDS seems to have had a positive effect on the MAE percentage excluding wrong time errors, especially on omission, wrong dose, extra dose and not identifiable drug errors. The different error types should be considered separately to see the effect, because it seems to be overshadowed by new cultural issues and impaired coordination of nurses' and physicians' workflows. Furthermore, no significant difference in MAE percentages between medical and surgical units was found. Most frequently occurring errors were wrong time, omission, unauthorized drug and wrong dosage form errors, which could further be reduced in the future (appendix 10).

The most important recommendations to further reduce the MAE percentages in the future are mentioned below. These are not based on scientific literature, but are merely ideas.

Wrong time errors have to be reduced by minimizing the time between administering medication and taking the medication. This could either be realized by forced culture changes, like forcing nurses to give medication on time by disabling administration registration, if it is given x min/hours too early/late, or by slightly adapting the administration times to the workflow with possible restrictions on specific drug groups and/or a maximum deviation (x min/hours) from original administration time.

When temporary changes in medication due to surgery are integrated in the medication list, workarounds are reduced and therefore a large error risk is eliminated.

Omission errors and unauthorized drug errors, which are due to spontaneous changes in the patient's health state, could further be reduced either by prescribing medication, which is also for sale at the drugstore (e.g. medication for pain, nausea and obstruction), standard 'as-needed' or by giving nurses rights to prescribe these drugs. This creates more possibilities for nurses to respond to patient related factors.

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REFERENCES

1. Barker KN, McConnell WE: **Detecting errors in hospitals.** *American Journal of Hospital Pharmacy* 1970, **19:**361-369.
2. Keers RN, Williams SD, Cooke J, Ashcroft DM: **Prevalence and Nature of Medication Administration Errors in Health Care Settings: A Systematic Review of Direct Observational Evidence.** *The Annals of Pharmacotherapy* 2013, **47:**237-256.
3. Allan EL, Barker KN: **Fundamentals of medication error research.** *American Journal of Hospital Pharmacy* 1990, **47:**555-571.
4. National Research Council: **To Err Is Human: Building a Safer Health System.** Washington, DC: *The National Academies Press*; 2000:26-27.
5. Flynn EA, Barker KN, Pepper GA, Bates DW, Mikeal RL: **Comparison of methods for detecting medication errors in 36 hospitals and skilled-nursing facilities.** *American Journal of Health-System Pharmacy* 2002, **59:**436-446.
6. McNally KM, Page MA, Sunderland VB: **Failure-mode and effects analysis in improving a drug distribution system.** *American Journal of Health-System Pharmacy* 1997, **54:**171-177.
7. Windt L: **Nulmeting Geneesmiddelen Distributie Systeem.** *Dissertation.* Amsterdam: Vrije Universiteit Amsterdam; 2002.
8. Bemt PMLA van den, Fijn R, Voort PHJ van der, Gossen AA, Egberts TCG, Brouwers JRBJ: **Frequency and determinants of drug administration errors in the intensive care unit.** *Critical Care Medicine* 2002, **30:**846-850.
9. Berdot S, Sabatier B, Gillaizeau F, Caruba T, Prognon P, Durieux P: **Evaluation of drug administration errors in a teaching hospital.** *BMC Health Services Research* 2012, **12.**
10. Radley DC, Wasserman MR, Olsho LEW, Shoemaker SJ, Spranca MD, Bradshaw B: **Reduction in medication errors in hospitals due to adoption of computerized provider order entry systems.** *Journal of the American Medical Informatics Association* 2013, **00:**1-7.
11. Shamliyan TA, Duval S, Du J, Kane RL: **Just What the Doctor Ordered. Review of the Evidence of the Impact of Computerized Physician Order Entry System on Medication Errors.** *Health Services Research* 2008, **43:** 32-53.
12. Doormaal JE van, Bemt PMLA van den, Zaal RJ, Egberts ACG, Lenderink BW, Kosterink JGW, Haaijer-Ruskamp FM, Mol PGM: **The influence that computerised prescribing has on medication errors and preventable adverse drug events: an interrupted time-series study.** *Journal of the American Medical Informatics Association* 2009, **16:**816-825.
13. Rootjes I: **Zorgen voor vooruitgang.** *Dissertation.* Rotterdam: Erasmus Universiteit Rotterdam; 2010.
14. Spencer DC, Leininger A, Daniels R, Granko RP, Coeytaux RR: **Effect of a computerized prescriber-order-entry system on reported medication errors.** *American Journal of Health-System Pharmacy* 2005, **62:**416-419.
15. Koppel R, Metlay JP, Cohen A, Abaluck B, Localio AR, Kimmel SE, Strom BL: **Role of Computerized Physician Order Entry Systems in Facilitating Medication Errors.** *Journal of the American Medical Association* 2005, **293:**1197-1203.
16. Redwood S, Rajakumar A, Hodson J, Coleman JJ: **Does the implementation of an electronic prescribing system create unintended medication errors? A study of the sociotechnical context through the analysis of reported medication incidents.** *BMC Medical Informatics & Decision Making* 2011, **29:**1-11.
17. Niazkhani Z, Pirnejad H, Bont A de, Aarts J: **CPOE in Non-Surgical Versus Surgical Specialties: A Qualitative Comparison of Clinical Contexts in the Medication Process.** *The Open Medical Informatics Journal* 2010, **4:**206-213.
18. Barker KN, Flynn EA, Pepper GA: **Observation method of detecting medication errors.** *American Journal of Health-System Pharmacy* 2002, **59:**2314-2316.
19. Dean B, Barber N: **Validity and Reliability of Observational Methods for Studying Medication Administration Errors.** *American Journal of Health-System Pharmacy* 2001, **58:**54-59.
20. Schors TG van der, Windt L, Kleij BM van der: **Informatieoverdracht vormt belangrijkste bron. Medicatieverstrekkingsfouten in een**

algemeen ziekenhuis. *Pharmaceutisch Weekblad* 2004, **139:**623-629.
21. Ridge KW, Jenkins DB, Noyce PR, Barber ND: **Medication errors during hospital drug rounds.** *Quality in Health Care* 1995, **4:**240-243.
22. Coleman IC: **Medication errors: Picking up the pieces.** *Drug Topics* 1999, **143:**83-90.
23. Shulman R, Singer M, Goldstone J, Bellingan G: **Medication errors: a prospective cohort study of hand-written and computerised physician order entry in the intensive care unit.** *Critical Care* 2005, **9:**R516-R521.
24. American Society of Hospital Pharmacists: **ASHP guidelines on preventing medication errors in hospitals.** *American Journal of Hospital Pharmacy* 1993, **50:**305-314.
25. Schaaf TW van der, Habraken MMP: **PRISMA-Medical – A brief description.** Eindhoven University of Technology. Available via: http://www.who.int/patientsafety/taxonomy/PRISMA_Medical.pdf. Cited 2013 march 28.
26. Hartwig SC, Denger SD, Schneider PJ: **Severity-indexed, incident report-based medication error-reporting program**. *American Journal of Hospital Pharmacy* 1991, **48:**2611-2616.
27. Rodriguez-Gonzales CG, Herranz-Alonso A, Martin-Barbero ML, Duran-Garcia E, Durango-Limarquez MI, Hernández-Sampelayo P, Sanjurjo-Saez M: **Prevalence of medication administration errors in two medical units with automated prescription and dispensing.** *Journal of the American Medical Informatics Association* 2012, **19:**72-78.
28. VMS Veiligheidsprogramma: **Wat is een VMS.** VMS zorg 2013. Available via: http://www.vmszorg.nl/veiligheidsmanagement/wat-is-een-vms. Cited 2013 april 9.
29. VMS Veligheidsprogramma: **Thema's.** VMS zorg 2013. Available via: http://www.vmszorg.nl/themas. Cited 2013 april 9.
30. Beuscart-Zéphir MC, Pelayo S, Anceaux F, Meaux JJ, Degroisse M, Degoulet P: **Impact of CPOE on doctor-nurse cooperation for the medication ordering and administration process.** *International Journal of Medical Informatics* 2005, **74:**629-641.
31. Pirnejad H, Niazkhani Z, Sijs H van der, Berg M, Bal R: **Impact of a computerized physician order entry system on nurse-physician collaboration in the medication process.** *International Journal of Medical Informatics* 2008, **77:**735-744.
32. Westbrook JI, Woods A, Rob MI, Dunsmuir WT, Day RO: **Association of interruptions with an increased risk and severity of medication administration errors.** *Archives of Internal Medicine* 2010, **170**(8):683-690.
33. Sanders L: **Doorloop proces** [slides]. Hoorn: Westfriesgasthuis, EVS projectgroep; 2012. 5 slides: color.

APPENDIX 1: Definitions used at the baseline measurement [7]

Medication error:
Administration of a drug to a patient, which deviates from the medication order, or not administering a prescribed drug.

Opportunity for error:
Each medication administration, which took place or had to take place.

Total opportunities for error:
All medication administrations, that took place or had to take place.

Percentage medication errors:
Number of medication errors divided by the 'total opportunities for error', multiplied by 100.

APPENDIX 2: Types of medication administration error and their definitions used at the baseline measurement [7]

Type of medication administration error	Definition
Omission	Any prescribed dose not given by the time the next dose (if any) is due.
Wrong time	Small: Any drug given 30 minutes up to two hours before or after it was ordered.
Wrong time	Large: Any drug given two hours or more before or after it was ordered.
Wrong dose	Any dose either above or below the correct dosage.
Extra dose	Any dose given in excess of the total number of times ordered by a physician.
Wrong drug	Administration of a drug, which is not prescribed and is given instead of another drug.
Unordered drug	The administration to a patient of any medication not ordered for that patient.
Wrong dosage form	Any dosage form, which is different from the one that was ordered
Wrong route	Administration of a drug by a different route than was specified by the physician.
Wrong patient	A drug is administered to the wrong patient.
Deteriorated drug	Administration of a drug that has expired or for which the physical or chemical dosage-form integrity has been compromised.
Not identifiable drug	A drug, whose name and dose cannot be identified.
Other	Any error that does not fall into one of the predefined categories.

APPENDIX 3: Error cause classification used at the baseline measurement [7]

Medication administration error cause	Definition
Unauthorized change by the nurse	The nurse consciously deviates from the medication order, resulting in unauthorized changes.
Medication for unusual medication rounds is administered too early	Medication for unusual medication rounds is administered during the (previous) standard medication round.
No medication order generated or medication order not processed	A new medication order is not generated or the medication order is not processed, while changes in the medical treatment are made. With the latter one, the medication order is not processed at the pharmacy and/or not processed in the kardex.
Workload	Workload means that unexpected extra work has to be done by the nurses or that not enough personnel are scheduled.
Imprecision during medication administration	The nurse is imprecise during medication administration and misses data or misreads data.
Medication not available	Because of different reasons, medication is not available during the medication round.
Transcription error at the unit	Medication data is transcribed incorrectly at the unit.
Transcription error at the pharmacy	Medication data is transcribed incorrectly at the pharmacy.
Medication is not provided (adequately)	Medication is not provided adequately in the medication car or is not provided at all.
Nurse not available during taking	Nurses need to control whether patients take the medication. If this does not happen, it is possible that patients take the medication in a wrong way or do not take it at all.
Insufficient control	Moments of control are performed insufficiently. Examples of moments of control are that provided medication has to be double-checked by the nurses or that hospital pharmacists must control the medication orders.
Inadequate medication preparation at the unit	The nurse inadequately prepares medication before administering it to the patient, e.g. a wrong dose of intravenous medication.
Medication order is unclear	Data on the medication order is unclear or not readable.
Interruption during medication administration	The nurse is interrupted during the medication administration, e.g. by a patient or other nurses.
Error during delivery pharmacy to unit	The pharmacy delivers a wrong drug or a wrong dosage form of a drug.
Unknown	It is impossible to determine the error cause.

APPENDIX 4: Observation form

PATIENT INFORMATION
Name: _____ Date of birth: _____
Gender: m / w Registration number: _____
Patient data checked? o Yes o No

NURSE INFORMATION
Type of employment: o Fixed o Variable o Student
Level of education: _____ Number of years of working experience: _____

GENERAL INFORMATION
Date: _____ Time: _____
Unit: o General surgery o Oncology o Pulmonology o Orthopedics
Medication round: o 08:00 o 12:00 o 14:00 o 18:00

MEDICATION INFORMATION
Number of administrations: _____

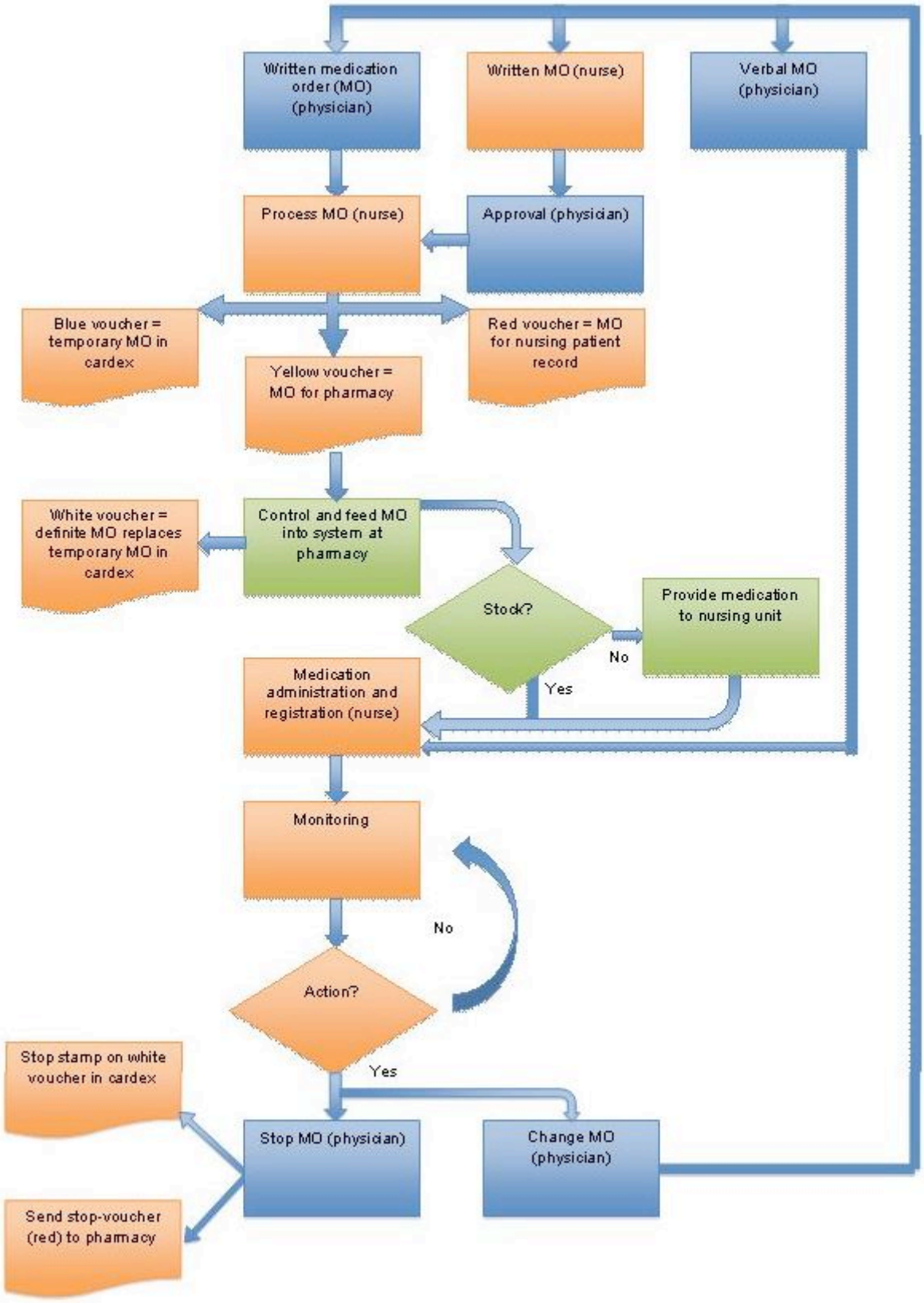
Name	Dose	Dosage form	Route	'as-needed'?	Pump Setting; size IV-bag; (tiv)

Form: tab=tablet; cap=capsule; ol=oral liquid; inj=injection; cr=crème/salve/gel; inh=inhalation; a=other
Route: O=oral; IV=intravenous; IM=intramuscular; SC=subcutaneous; REC=rectal; INH=inhalation, A=others
Administration rate: min/h, mg/h, ml/min

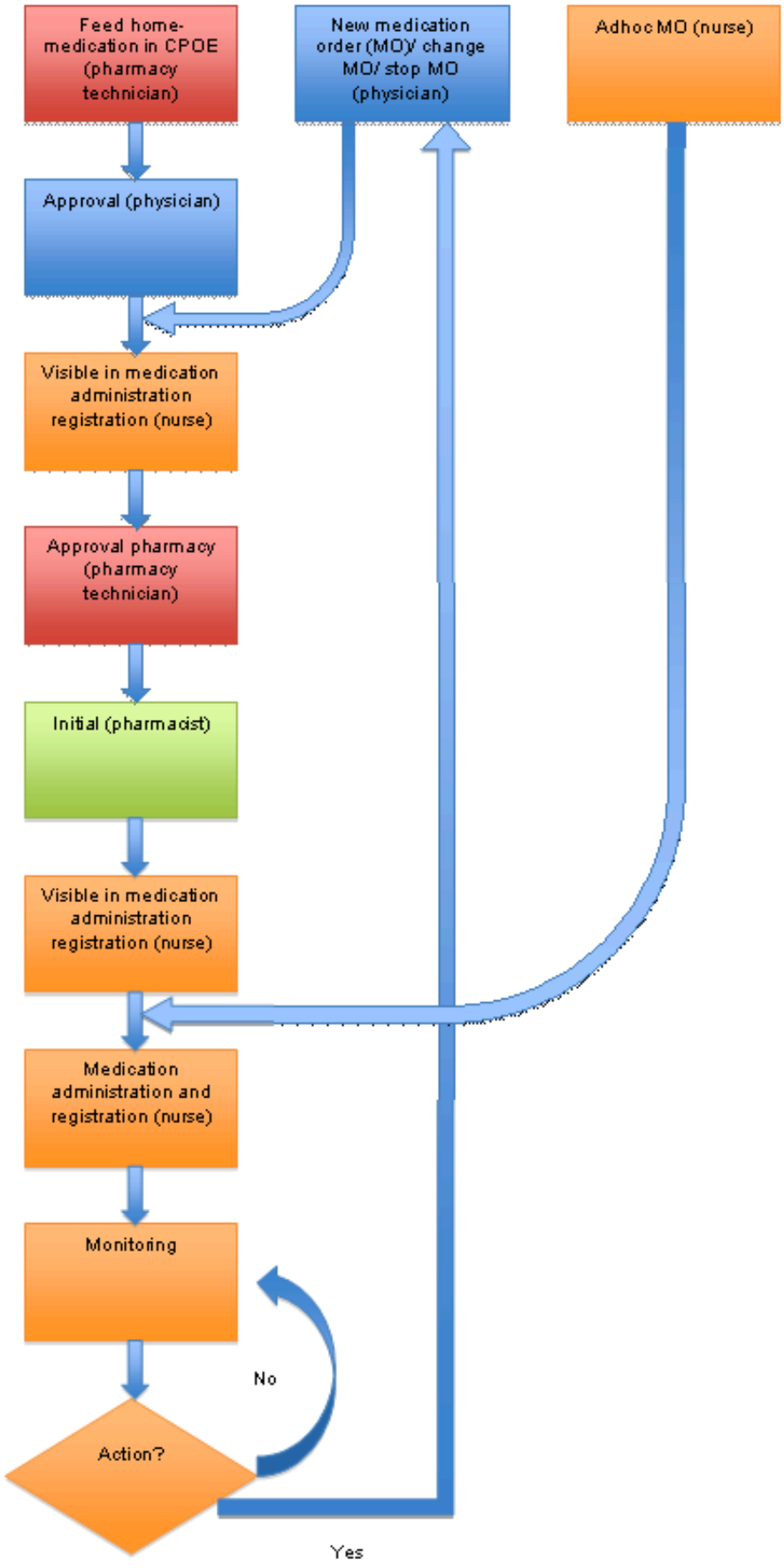
IV-MEDICATION
Two paraphs on yellow label? o Yes o No
Gloves? o Yes o No
Hands disinfected? o Yes o No
Puncture disinfected? o Yes o No

NOTES

APPENDIX 5: Medication distribution process in paper-based order system [13]



APPENDIX 6: Medication distribution process in CPOE/CDS system [33]



APPENDIX 7: Types of medication administration error and their definitions used at the follow-up measurement [1,3,24]

Type of medication administration error	Definition
Omission error	Any dose not given by the time the next dose (if any) is due.
Wrong-dose error	Any dose either above or below the correct dosage by more than five percent.
Unauthorized-drug error	The administration to a patient of any medication not ordered for that patient or not authorized by a legitimate prescriber for the patient.
Wrong-dosage form error	Any dosage form, which is different from the one that was ordered.
Wrong-time error ± 30 minutes	Any drug given 30 minutes up to two hours before or after it was ordered.
Wrong-time error ± 2 hours	Any drug given two hours or more before or after it was ordered, up to the time the next dose of the same medication was ordered.
Wrong-route error	Administration of a drug by a different route than was specified by the physician.
Deteriorated-drug error	Administration of a drug that has expired or for which the physical or chemical dosage-form integrity has been compromised.
Wrong-administration-technique error	Inappropriate procedure or technique during administration of a drug.
Extra-dose error	Any dose given in excess of the total number of times ordered by a physician.
Wrong-drug preparation error	Drug product incorrectly formulated or manipulated before administration.
Other error	Any error that does not fall into one of the predefined categories.

APPENDIX 8: Eindhoven Classification Model [25]

		Code	Category	Definition
Technical		T-EX	External	Technical failures beyond the control and responsibility of the investigating organization.
		TD	Design	Failures due to poor design of equipment, software, labels or forms.
		TC	Construction	Correct design, which was not constructed properly or was set up in inaccessible areas.
		TM	Materials	Material defects not classified under TD or TC.
Organizational		O-EX	External	Failures at an organizational level beyond the control and responsibility of the investigating organization, such as in another department or area (address by collaborative systems).
		OK	Transfer of knowledge	Failures resulting from inadequate measures taken to ensure that situational or domain-specific knowledge or information is transferred to all new or inexperienced staff.
		OP	Protocols	Failures relating to the quality and availability of the protocols within the department (too complicated, inaccurate, unrealistic, absent, or poorly presented).
		OM	Management priorities	Internal management decisions in which safety is relegated to an inferior position when faced with conflicting demands or objectives. This is a conflict between production needs and safety. An example of this category is decisions that are made about staffing levels.
		OC	Culture	Failures resulting from collective approach and its attendant modes of behavior to risks in the investigating organization.
Human		H-EX	External	Human failures originating beyond the control and responsibility of the investigating organization. This could apply to individuals in another department.
	Knowledge-based behavior	HKK	Knowledge-based behavior	The inability of an individual to apply their existing knowledge to a novel situation.
	Rule-based behavior	HRQ	Qualifications	The incorrect fit between an individuals training or education and a particular task.
		HRC	Coordination	A lack of task coordination within a health cares team in an organization.
		HRV	Verification	The correct and complete assessment of a situation including related conditions of the patient and materials to be used *before* starting the intervention.
		HRI	Intervention	Failures that result from faulty task planning and execution
		HRM	Monitoring	Monitoring a process or patient status.
	Skill-based behavior	HSS	Slips	Failures in performance of highly developed skills.
		HST	Tripping	Failures in whole body movements. These errors are often referred to as “slipping, tripping, or falling”.
Other factors		PRF	Patient related factor	Failures related to patient characteristics or conditions, which are beyond the control of staff and influence treatment.
		X	Unclassifiable	Failures that cannot be classified in any other category.

APPENDIX 9: NCC MERP Index for Categorizing Medication Errors [26]

	Category	Definition
No error	A	Circumstances or events that have the capacity to cause error.
Error, no harm[a)]	B	An error occurred but the error did not reach the patient (An "error of omission" *does* reach the patient).
	C	An error occurred that reached the patient but did not cause patient harm.
	D	An error occurred that reached the patient and required monitoring[b)] to confirm that it resulted in no harm to the patient and/or required intervention[c)] to preclude harm.
Error, harm	E	An error occurred that may have contributed to or resulted in temporary harm to the patient and required intervention.
	F	An error occurred that may have contributed to or resulted in temporary harm to the patient and required initial or prolonged hospitalization.
	G	An error occurred that may have contributed to or resulted in permanent patient harm.
	H	An error occurred that required intervention necessary to sustain life[d)].
Error, death	I	An error occurred that may have contributed to or resulted in the patient's death.

a) Harm: Impairment of the physical, emotional, or psychological function or structure or the body and/or pain resulting therefrom.
b) Monitoring: To observe or record relevant physiological or psychological signs.
c) Intervention: May include change in therapy or active medical/surgical treatment.
d) Intervention necessary to sustain life: Includes cardiovascular and respiratory support.

APPENDIX 10: Recommendations

Some recommendations are made about how the MAE percentages can further be reduced in the future. These are not based on scientific literature, but are merely ideas.
First, it is important to learn from each other. By taking a look at which units are performing well on which aspects and discuss this with each other, units might learn from each others' ideas and work practices. This creates conformity between the units and might further reduce the MAE percentage.
For different error types, different recommendations are made and listed below:

- Study the possibilities to integrate temporary changes in medication due to surgery in the medication list. Now, temporary medication changes due to surgery have to be looked up in the anesthesia file, which is a large workaround and an error risk. Integrating these changes in the medication list/medication administration registration would eliminate this workaround and prevent errors (e.g. omission errors).
- Critically discuss the re-activation of some alerts, e.g. for duplicative medication and wrong dose errors. Some alerts might result in physicians being more alert when generating medication orders, which might result in reductions of omission errors and wrong/extra dose errors.
- Critically discuss the implementation of bar-code-assisted medication administration. This might eliminate omission, wrong dose and wrong dosage form errors, but would also introduce limitations for nurses to respond to unforeseen events and patient related factors.
- Critically discuss the prescription of some medication, which are also for sale at the drugstore (e.g. medication for pain, nausea and obstruction), standard 'as-needed' or give nurses rights to prescribe these drugs. This creates more possibilities for nurses to respond to changes in patients' health states and therefore would reduce the amount of omission errors and unauthorized drug errors.
- Critically discuss how to reduce the high numbers of wrong time errors by (forced) cultural changes and/or changes in the CPOE/CDS system, for example:
    - Give nurses rights to slightly adapt administration times to their workflow with possible restrictions on specific drug groups and/or a maximum deviation (x min/hours) from original administration time, so that medication is better integrated in the workflow and is given on time;
    - Let nurses only see the medication of the next medication round, so that they cannot administer medications of two rounds at the same time;
    - Introduce a rule in the CPOE/CDS system to force nurses to give medication on time by disabling administration registration, if it is given x min/hours too early/late.

Last but not least, it is important to review the results critically and brainstorm with all relevant stakeholders about how to act on the results. Ideas will be more accepted if these are generated on your own.