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Review

Interventions to reduce nurses' medication administration errors in inpatient settings: A systematic review and meta-analysis

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ABSTRACT

Background and objectives: Serious medication administration errors are common in hospitals. Various interventions, including barcode-based technologies, have been developed to help prevent such errors. This systematic review and this meta-analysis focus on the efficacy of interventions for reducing medication administration errors. The types of error and their gravity were also studied.

Methods: MEDLINE, EMBASE, the Cochrane Library and reference lists of relevant articles published between January 1975 and August 2014 were searched, without language restriction. Randomized controlled trials, interrupted time-series studies, non-randomized controlled trials and controlled before-and-after studies were included. Studies evaluating interventions for decreasing administration errors based on total opportunity for error method were included. Nurses administering medications to adult or child inpatients were considered eligible as participants. Two reviewers independently assessed studies for eligibility, extracted data and assessed the risk of bias. The main outcome was the error rate without wrong-time errors measured at study level. A random effects model was used to evaluate the effects of interventions on administration errors.

Results: 5312 records from electronic database searches were identified. Seven studies were included: five were randomized controlled trials (including one crossover trial) and two were non-randomized controlled trials. Interventions were training-related ($n = 4$; dedicated medication nurses, interactive CD-ROM program, simulation-based learning, pharmacist-led training program), and technology-related ($n = 3$; computerized prescribing and automated medication dispensing systems). All studies were subject to a high risk of bias, mostly due to a lack of blinding to outcome assessment and a risk of contamination. No difference between the control group and the intervention group was found (OR = 0.72 [0.39; 1.34], $p = 0.3$). No fatal error was observed in the three studies evaluating the gravity of errors.

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Conclusions: This review did not find evidence that interventions can effectively decrease administration errors. In addition, most studies had a high risk of bias. More evaluation studies with stronger designs are required.

What is already known about the topic?

- Administration of medications by nurses is the last step before a possible error and its consequences for the patient.
- Numerous interventions have been developed to reduce administration errors, including nurse training and education, automated delivery systems and barcode-assisted medication administration systems.

What this paper adds

- Seven studies using a rigorous design, evaluating an intervention aimed at improving medication administration, have been published. Those studies were at high risk of bias, and a meta-analysis of those studies did not find any effect of the interventions.
- More studies using rigorous designs are needed to evaluate the effectiveness of such interventions.

1. Introduction

Medication errors are common in hospitals and can lead to adverse drug events and a prolonged hospital stay. Medication errors can occur at any of the three steps in the medication process: prescription, medication delivery and administration. In the American MEDMARX (Hicks et al., 2004) database, 21% of the reported errors concern prescription, 22% concern medication delivery and 33% concern administration. The final step in the medication process, administration, is the least well studied, even though it directly concerns nurses and patients and is the last barrier before possible consequences for the patient.

Administration errors are defined as a deviation from the physician's medication order, as written on the patient's chart (Allan and Barker, 1990). They are generally assessed relative to the total opportunity for error, defined as the sum of doses observed plus the doses that were not administered (omission) (Allan, 1987). Administration errors can be detected by spontaneous reporting, a review of patient charts or direct observation. Reporting systems require the person responsible for reporting errors to be aware that an error was made, and the reviewing of patient charts is highly time-consuming. The direct observation is considered to be the gold standard for error detection, as it yields more objective and reliable results than the other methods (Allan and Barker, 1990; Barker and McConnell, 1962). Briefly, an observer follows the nurse responsible for administering medication to patients and notes the administration of each dose. The notes administered are then compared with the prescription. An error is considered to have occurred if the nurse does not carry out the order accurately. A comparison of methods for detecting medication administration errors showed that the direct observation of nurses was more effective and accurate than reviewing charts and incident reports for the detection of medication errors (Flynn et al., 2002). It has been stressed that observers may have an impact on the behavior of the nurse who is observed. Therefore, the practice of the nurse could be better that its current practice. But this effect would be observed in both arms (intervention and control arms) leaving the same magnitude of the opportunity for improvement between the arms. However, Allan and Barker showed that disguised observation decreases the Hawthorne effect on observed nurses (Allan and Barker, 1990). With the direct observation, administration error rates can reach about 26%, falling to about 10% if wrong-time errors are not analyzed (Berdot et al., 2012, 2013; Keers et al., 2013).

Numerous interventions have been developed for decreasing medication errors. They are professional interventions (nurse training and education, safety vest, double checking of medication, etc.) and organizational interventions (computerization of hospital medical systems: automated delivery system, barcode-assisted medication administration systems, etc.).

Reviews concerning medication errors in general (Manias et al., 2012; Rinke et al., 2014; Soe et al., 2013) and administration errors specifically (Hassink et al., 2012; Keers et al., 2014) have been published. Other reviews have focused on a specific intervention, such as barcode-assisted medication administration systems or the double-checking of medication, but the strength of the studies evaluating such interventions is unclear. It is also unclear to know which type of intervention could address which type of error. No systematic review of various interventions focusing on direct observation and rigorous study designs for detecting medication administration errors has been published to date.

This systematic review focuses on interventions aiming at decreasing the number of administration errors detected by the direct observation of nurses administering medications to inpatients. The primary objective of this review was to assess the effect of these interventions on administration error rates. The secondary objectives were to evaluate the impact of interventions on the types of errors made and to describe the clinical impact of errors.

2. Materials and methods

2.1. Search strategy

We conducted a systematic search of MEDLINE, EMBASE and the Cochrane Library, to identify relevant papers published between January 1966 and August 2014, without language restriction (search strategy in Additional file 1).

We searched the reference lists of all the papers identified and of any key papers in the field manually.

2.2. Inclusion criteria and assessment

We included interventions aiming to assess the effectiveness of interventions at reducing medication administration errors. We focused on studies in which the direct observation was used to evaluate the error rate. We included randomized controlled trials, including crossover designs, interrupted time-series studies, non-randomized controlled trials and controlled before-and-after studies. We included studies comparing an intervention with standard practice or with another intervention. Nurses administering medications to adult or child inpatients were considered to be eligible participants. Finally, studies were considered eligible if they reported the error rate according to the total opportunity for error method or the doses observed with the reporting of omission errors. Wrong-time errors were not considered in the analysis, and we included studies for which the data for this type of error could be withdrawn.

Two of the authors of this review (SB, MR) independently screened the titles and abstracts of all the retrieved reports, then sought full-text copies of all papers that were either potentially relevant or for which it was not clear whether the inclusion criteria were met from the title and abstract alone. These two investigators then applied the inclusion criteria, and differences of opinion were resolved by consensus between the review authors (SB, MR, PD and BS). We recorded the number of full-text articles assessed and excluded, specifying the reasons for exclusion (Additional file 2).

We also decided to analyze before-and-after studies separately, because some authors have taken such designs into account in their studies (Hassink et al., 2012) and because recommendations are largely based on studies of this type.

2.3. Data extraction and quality assessment

The data from the studies included were extracted independently by two of the authors of the review (SB, MR). Disagreements were resolved by discussion between the review authors (SB, MR, PD and BS). A data collection form was used. It included the characteristics of the study (author name, publication year, journal name, type of study), participants (setting, number of nurses, etc.), intervention, and outcomes (error rate, types of errors, severity of errors).

Two of the authors of this review (SB, MR) independently assessed the risk of bias of each study, using the suggested risk of bias criteria proposed by the Effective Practice and Organization of Care reviews group of the Cochrane collaboration (Norwegian Satellite of the Cochrane Effective Practice and Organisation of Care Group): we assessed the nine standard criteria for randomized controlled trials, non-randomized controlled trials and controlled before-and-after studies. The risk of bias for each study, and for each criterion, was classified as low, high or unclear. Disagreements were resolved by discussion between the review authors (SB, MR, PD and BS). An overall assessment of the risk of bias was assigned to each of the included studies, by the approach suggested in the *Cochrane Handbook for Systematic Reviews of Interventions* (Higging and Altman, 2008).

2.4. Data synthesis and analysis

The main outcome was the rate of errors, excluding wrong-time errors, measured at study level. We focused on administration error rates, measured as the number of errors relative to the total opportunity for error. The total opportunity for error is the sum of the doses given plus the number of doses missed (omission errors). If the authors did not specify that the denominator used was the total opportunity for error but evaluated the rate of omission errors, then the denominator was considered to be the total opportunity for error. Studies not making use of the total opportunity for error method were not included in this review. The secondary outcomes were the types of errors and their clinical impact. Types of errors were reclassified according to the American Society of Health-System Pharmacists classification (ASHP, 1993), into eight categories (excluding wrong-time errors). Wrong-time errors remain a matter of considerable debate. Some authors have recommended that studies on medication errors should report error rates both with and without timing errors. We chose to exclude wrong-time errors from this analysis. The clinical impact of errors is described by study.

The intervention and control groups were compared before the beginning of the intervention. Given the considerable differences in the type of intervention between studies, a model with a random term was chosen. The intervention and control groups were then compared after the beginning of the intervention, with a model including random effects, and the results are presented as a forest plot for each individual study. For the before-and-after studies, the intervention group was compared before and after the beginning of the intervention, in a forest plot for each individual study.

Due to heterogeneity in study methodology, comparison groups, and intervention settings, we performed a random effect meta-analysis. Heterogeneity was assessed with the Higgins and Thompsons I^2 statistic. A value of 0% indicates no observed heterogeneity, with larger values indicating increasing heterogeneity. We used RevMan software for statistical analyses and forest plots (version 5.3).

3. Results

3.1. Search results

In total, we identified 5312 records from electronic database searches (see the flow diagram for study selection in Fig. 1). We eliminated duplicates and then screened 5306 studies by title and abstract, leading to the exclusion of 5158 studies. We identified 148 full-text articles that appeared to be relevant and four from searches of the references of these articles. We excluded 126 of these articles (see Additional file 2 for the reasons for exclusion). The final analysis included 7 studies (Barker et al., 1984; Cavell and Hughes, 1997; Chapuis et al., 2010; Ford et al.,

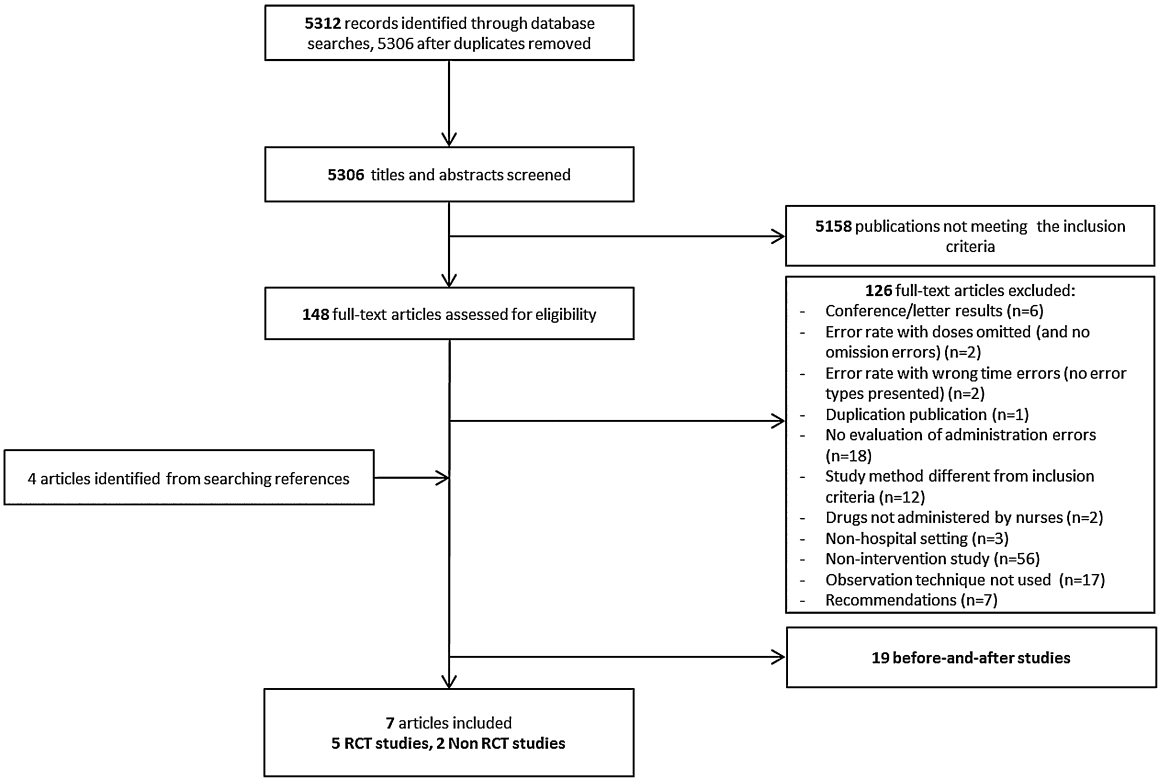

Fig. 1. Flow diagram for study selection.

2010; Greengold et al., 2003; Nguyen et al., 2014; Schneider et al., 2006), and we also retained 19 before-and-after studies.

3.2. Study characteristics

Five of the seven studies retained were randomized controlled trials, including one crossover design (Barker et al., 1984; Chapuis et al., 2010; Greengold et al., 2003; Nguyen et al., 2014; Schneider et al., 2006), whereas the remaining two studies were non-randomized controlled trials (Cavell and Hughes, 1997; Ford et al., 2010). The key features of the seven studies are summarized in Table 1 and Additional file 3. Three of the studies were multicenter studies. Four studies were conducted in the USA, one in the UK, one in France and one in Vietnam. Publication dates ranged from 1984 to 2013. The characteristics of the 19 before-and-after studies retained are presented in Additional file 4.

3.3. Risk of bias in the studies included

The results of the risk of bias assessment are shown in Figs. 2, 3 and Additional file 3 for randomized controlled and non-randomized controlled studies. All studies had a high overall risk of bias, because they had a high risk of bias in at least one domain. The most common source of bias risk was a lack of blinding to outcome, as the observer was aware of the group to which the patient was allocated and the risk, due to the direct observation. The term "other bias" includes bias not addressed in other domains and included the direct observation, as it can affect nurse's behavior. Therefore, the direct observation, despite the fact that it considered to be the standard, can affect both the observer and the person observed.

3.4. Types of intervention implemented

Interventions were training-related ($n = 4$; dedicated medication nurses (Greengold et al., 2003), interactive CD-ROM program (Schneider et al., 2006), simulation-based learning (Ford et al., 2010), pharmacist-led training program (Nguyen et al., 2014)), and technology-related ($n = 3$) (computerized prescribing (Cavell and Hughes, 1997) and automated medications dispensing systems (Barker et al., 1984; Chapuis et al., 2010)) (Table 1).

Three of the 19 before-and-after studies concerned education sessions, three concerned prescription (computerized prescribing system), six concerned dispensing (experimental systems with unit doses ($n = 3$), automated bedside dispensing machines ($n = 1$), medication cart filling ($n = 1$), patients own medications scheme ($n = 1$)) and seven concerned administration (barcode-assisted medication administration systems) (Additional file 4).

3.5. Effects of interventions

3.5.1. Error rates

In two randomized controlled trials and one controlled before-and-after study (with an intervention group and a

Table 1
Characteristics of the randomized controlled trials and non-randomized controlled trials studies included ($n = 7$).

Study	Design	Setting	Country	Intervention description	Observation	Medications studied
Training-related interventions						
Greengold et al. (2003)	RCT	Teaching hospitals (multicenter), 4 mixed units/ hospital	USA	Dedicated medication nurses trained in the medication safety program vs. general nurses	3 trained registered nurses (hospital A), 2 trained pharmacy technicians (hospital B), 12 weeks (5 days, 5 h/day)	All except STAT medicines, total parenteral nutrition, hydration, or bolus medication
Schneider et al. (2006)	RCT	General hospitals (multicenter), 3 medical, medical–surgical units	USA	Educational sessions (CD ROM); nurses in the study group viewed an interactive CD-ROM titled 'Basic Medication Administration'	2 trained observers, 2-week blocks/hospital, 4 h periods	All medications
Ford et al. (2010)	NRCT	Teaching hospital (monocentric), 1 medical ICU (32 beds), 1 CCU (10 beds)	USA	Simulation-based learning educational sessions vs. traditional didactic lecture-based learning (control group)	Two trained pharmacists, 4 weeks 4 sessions	All medications
Nguyen et al. (2014)	CBA	Teaching hospital (monocentric), 1 medical ICU, 1 post-surgical unit	Vietnam	Pharmacist-led training of nurses (lectures, practice-based education, posters)	4 senior pharmacy students, 7 days (12 h)/group	IV medications
Technology-related interventions						
Barker et al. (1984)	Controlled cross-over	General hospital (monocentric), general surgery unit (32 beds)	USA	Automated bedside dispensing machine vs. decentralized satellite unit dose system	One trained pharmacist, 7 days (10 h)/group	All medications
Cavell and Hughes (1997)	NRCT	Teaching hospitals (multicenter), 2 medical units (20 + 31 beds)	UK	Computerized prescribing system	One pharmacist, 35 medication rounds and 42 medication rounds	All medications except parenteral and 'as required' medications given at times other than the nurses' rounds
Chapuis et al. (2010)	RCT	Teaching hospital (monocentric), 2 intensive care units (8 + 10 beds)	France	Automated bedside dispensing machine vs. floor stock distribution system (classic medication cabinet)	One trained pharmacist, 2 months (3–4 h/day, 4 days/ week), days, evenings shifts	All medications

CBA: controlled before-and-after; RCT: randomized controlled trial; NRCT: non-randomized controlled trial.

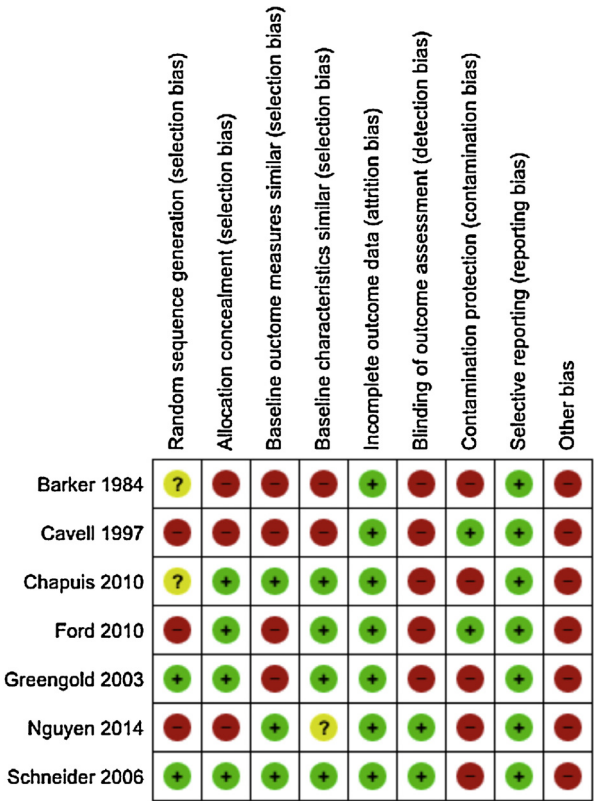

Fig. 2. Risk of bias summary: review of the authors' judgments about each risk of bias item for each randomized controlled and non-randomized controlled study included ($n = 7$).

control group studied before and after the intervention) (Chapuis et al., 2010; Nguyen et al., 2014; Schneider et al., 2006), the intervention and control groups were compared before the beginning of the intervention. A model with a random term was used, due to the considerable heterogeneity between studies ($I^2 = 67.3\%$ [0%; 90.5%]). We found no difference between the two groups before the beginning of intervention (OR = 1.23 [0.69; 2.17], $p = 0.5$), confirming their comparability before the start of the intervention.

The intervention and control groups were compared after the beginning of the intervention in the five randomized controlled trials (Barker et al., 1984; Chapuis et al., 2010; Greengold et al., 2003; Nguyen et al., 2014; Schneider et al., 2006) and two non-randomized controlled studies (Cavell and Hughes, 1997; Ford et al., 2010). A model with a random term was used, given the considerable heterogeneity between studies ($I^2 = 94.9\%$ [91.8%; 96.9%]). We found no difference between the two groups (OR = 0.72 [0.39; 1.34], $p = 0.3$). The forest plot is presented in Fig. 4. We performed a sensitive analysis on the five randomized controlled trials, excluding the two non-randomized controlled studies from the analysis. Again, no difference was found between the two groups (OR = 0.90 [0.42; 1.91], $p = 0.8$). No difference was found between the two groups when excluding the only publication from the 80 s (OR = 0.71 [0.34; 1.46], $p = 0.35$).

Among the four training-related studies, the result was in favor of the control group in two studies, Greengold et al. (2003) and Schneider et al. (2006), and in favor of the intervention group in two studies, Ford et al. (2010) and Nguyen et al. (2014), with exclusion of wrong-time errors in our analysis.

For the study by Greengold et al. (2003), we found an OR of 1.71 [1.47; 1.98] between the intervention group and the control in favor of the control group. The authors concluded that no significant differences in error rates were found between the medication nurses (11.2%) and the general nurses (6.9%) using the sign test which is based on the weekly differences in error rates. For the study by Schneider et al. (2006), we found an OR of 2.73 [1.49; 5.01] in favor of the control group. The authors showed a significant decrease in core 1 error rates (not considered in

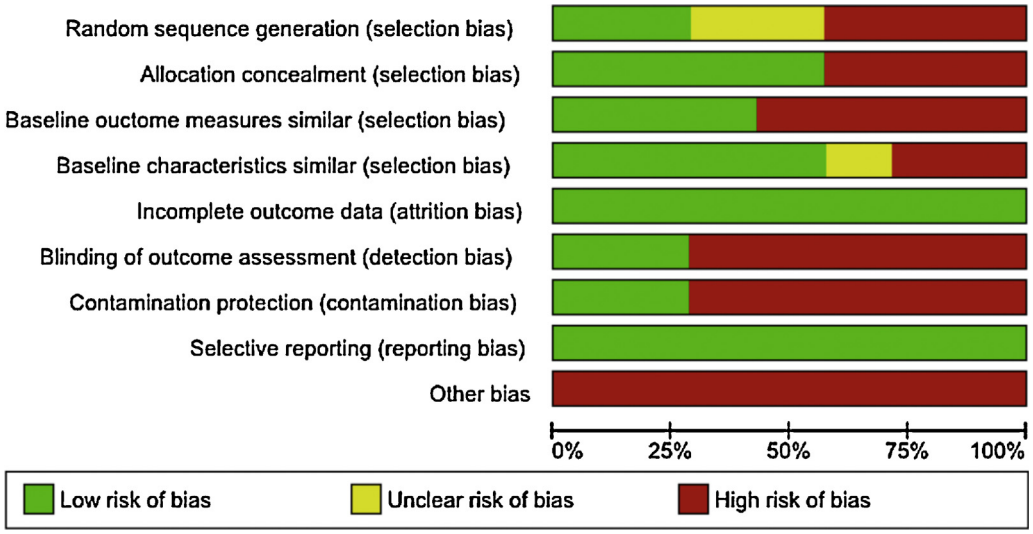

Fig. 3. Risk of bias graph: review of authors' judgments about each risk of bias item, presented as percentages, for all the randomized controlled and non-randomized controlled studies included ($n = 7$).

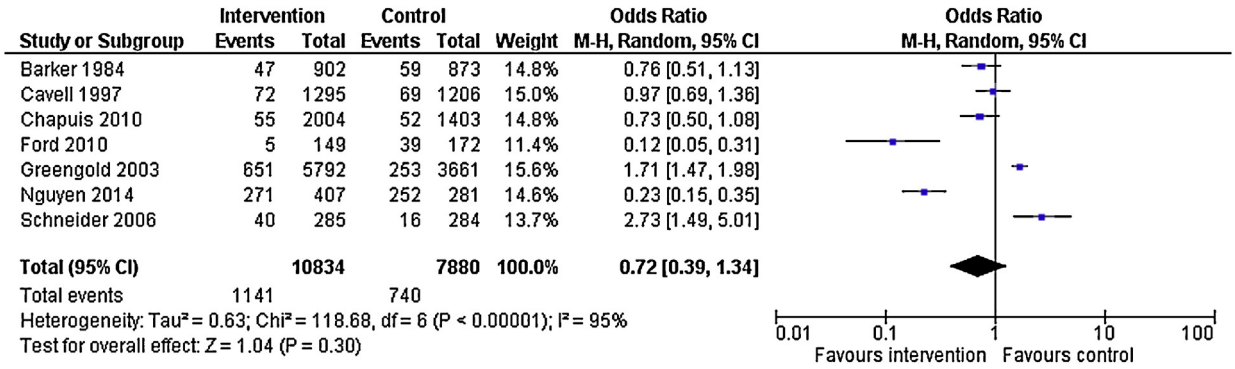

Fig. 4. Forest plot of administration error rates for the randomized controlled and non-randomized controlled studies included ($n = 7$).

our analysis: maintenance of package integrity, checking armbands, witnessing of the dose being taken before documentation) between the baseline and post-intervention periods. Core 2 error rates (wrong-time errors, incorrect preparation and incorrect administration technique) were higher in the study group during the post-intervention period. No conclusions were drawn concerning core 3 errors (wrong drug, wrong dose), as there were few errors of this type.

For the study by Ford et al. (2010), which compared simulation-based learning with traditional lecture-based learning (the control group), we obtained an OR of 0.12 [0.05; 0.31]. The authors concluded that simulation-based learning provided a significant advantage over traditional lecture-based learning in terms of patient care, by decreasing medication administration errors. Finally, for the study by Nguyen et al. (2014), we found an OR of 0.23 [0.15; 0.35] and the authors concluded that the prevalence of clinically relevant erroneous doses was significantly lower in the intervention ward and unaffected in the control ward.

For the three studies in which the intervention was technology-related, we compared our results with those presented by the author. We found no difference between groups for the study by Barker et al. (1984), whereas authors reported a significant difference in mean error rates between groups (10.6% for the experimental group and 15.9% for the control group). However, their results included wrong-time errors, which accounted for 51% of the errors in the experimental group and 33% of those in the control group. We found that the numbers of medication administration errors did not differ significantly between groups in the study by Cavell and Hughes (1997), as concluded by the authors. Finally, in the study by Chapuis et al. (2010), no difference in error rates was found between the two groups whereas the authors reported a lower error rate as a percentage of total opportunity for error in the study group than in the control group (13.5% vs. 18.6%, $p < 0.5$, including wrong-time errors).

For the before-and-after studies, the numbers of errors (excluding wrong-time errors) are presented in Additional file 5. A difference between the before and after conditions was observed in the intervention group, with better results after the intervention, as shown by the forest plot.

3.5.2. Error types

The types of error observed are presented in Additional file 6. Error types could not be determined for the study by Greengold et al. (2003), event after the authors had been contacted. The number of error categories differed between the six studies analyzed, making it difficult to summarize the results. A decrease in the number of wrong-dose errors was observed in the training-related studies. By contrast, in the technology-related studies, the intervention decreased the number of omission errors (trend, no statistical analysis carried out). However, no statistical analysis was possible.

3.5.3. Error severity

Clinical impact was evaluated in three of the seven randomized controlled trials and non-randomized controlled studies. Two studies (Chapuis et al., 2010; Greengold et al., 2003) used a scale derived from the National Coordinating Council for Medication Error Reporting and Prevention classification and the third (Nguyen et al., 2014) used a validated scale running from 0 to 10. Clinical impacts are reported in Additional file 7. For training-related interventions, no harm to patients was detected in the study by Greengold et al. (2003), and significantly smaller numbers of clinically relevant errors were observed after the intervention than before it, in the intervention group (64% vs. 48.9%, $p < 0.001$), with no difference between the two time points observed in the control group (Nguyen et al., 2014). Health system computerization decreased category C errors (considered to be of no harm to the patient) by 35% (Chapuis et al., 2010), but had no effect on errors causing harm to the patient (categories E–H). Nevertheless, no fatal error or life-threatening error occurred.

4. Discussion

4.1. Principal findings

We identified 26 studies evaluating interventions for decreasing administration error rates based on the direct observation and the total opportunity for error. Only seven of these 26 studies had an acceptable design for inclusion in this analysis: five were randomized controlled trials

studies and two were non-randomized controlled studies. Three studies focused on health system computerized prescribing system or automated dispensing systems and four studies focused on the training and education of nurses. We found a high heterogeneity between studies. All seven studies were susceptible to a potential high risk of bias. Overall administration error rates were not different in the intervention groups compared to the control groups. Two studies were in favor of the intervention group, two in favor of the control group and three (all technology-related) did not show any difference between groups. No fatal error was observed in the three studies evaluating the gravity of errors.

By contrast, in the before-and-after studies, we observed a decrease in error rates after the intervention, in the intervention group.

However, potential biases are likely to be greater for non-randomized studies compared with randomized trials (Reeves et al, 2008). Uncontrolled before and after studies are intrinsically weak evaluative designs because secular trends or sudden changes make it difficult to attribute observed changes to the intervention (Eccles et al., 2003). Lipsey and Wilson in an overview of meta-analyses of psychological, educational and behavioral interventions noted that the observed effects from uncontrolled studies were greater than those from controlled studies (Lipsey and Wilson, 1993). Therefore, results from before and after studies should be interpreted with caution. Such design could be an acceptable design when it is impossible to randomize groups (Reeves et al, 2008), but it is not the case in this review.

4.2. Comparison with other studies

Several systematic reviews of interventions for improving medication administration have been published. Keers et al. (2014) evaluated the impact of interventions designed to reduce administration errors. They included 13 studies in their analysis, seven of which were based on direct observation. Wrong-time errors were included in the reported error rates. The authors mentioned the results of individual studies but did not evaluate error types or the clinical impact of errors. They concluded that the evidence base for interventions designed to reduce medication administration errors in hospital is limited (many studies did not utilize optimal study designs or more suitable data collection techniques). As our results, evidence from strong design suggests that dedicated medication nurses (Greengold et al., 2003) and self-directed educational CD ROM packages (Schneider et al., 2006) may not reduce medication errors. Hassink et al. (2012) carried out a literature review focusing on the effect of barcode-assisted medication administration systems on error rates, types of errors and their clinical impact. They found that most studies reported a reduction of the rate of administration errors following the implementation of barcode systems, but the studies included in the analysis were heterogeneous in design (randomized controlled trials, before-and-after studies). Only one study with a controlled before-and-after design was included (Paoletti et al., 2007). Barcode-assisted medication administration was found to decrease the number of administration errors observed by 54% ($p = 0.045$). Double-checking has been recommended as an intervention to reduce medication administration errors and is standard practice in some countries. In a systematic review of the existing evidence base for the efficacy of this intervention, Alsulami et al. (2012) included 16 studies (three of which were quantitative), but only one of these studies was a crossover study. They concluded that the rate of medication administration errors was significantly lower if two nurses checked the medication before its administration to patients.

4.3. Strengths and limitations

Pooling data from studies with high heterogeneity may be questioned. We limited heterogeneity, by focusing on studies evaluating administration errors by direct observation, with the exclusion of wrong-time errors. It was not possible to take into account other causes of heterogeneity such as different in population and study site.

Unlike other systematic reviews, we considered only studies based on the direct observation, which is considered the gold standard for detecting administration errors.

The types of errors considered in many studies did not follow the American Society of Health-System Pharmacists classification, and these studies did not consider all possible types of error. As a consequence, the definition of error rates (numerator and denominator) differed between studies. We were unable to evaluate the effect of the types of units, medications, and direct observation (disguised or undisguised). In three studies, the intervention and control groups were compared before the intervention and shown to be similar. In the other four studies, no evaluations were carried out before the intervention, but we assumed that there was no difference between groups before the intervention and focused on differences between the two groups after the intervention.

It is now recommended that barriers to change be prospectively identified before planning an intervention. It has been suggested that tailored interventions to potential barriers are more effective than non-tailored interventions (Baker et al., 2010). In none of the 7 included studies, authors tried to identify potential barriers before designing their intervention. In addition, no statistical analysis was possible on errors types to analyze how different types of intervention affect different types of errors.

5. Conclusions and recommendations

This review did not find evidence that an intervention can effectively decrease administration errors. However, healthcare agencies have recommended the implementation of interventions such as barcode-assisted medication administration systems or nurse education. The balance between different types of intervention has changed over time, with an increase in the use of barcode-assisted medication administration systems over the last 10 years. Despite the recommendations of the American Society of Health-System Pharmacists in 2010, only 35% of American hospitals have invested in barcode-assisted medication administration systems (Pedersen et al., 2011). Very few

European hospitals have evaluated and invested in such systems to date. These interventions have been shown to be beneficial in before-and-after studies, which are known to be subject to a high risk of bias.

More studies are needed, including qualitative studies evaluating potential barriers to change before implementation of interventions. Interventions should be evaluated using experimental or quasi experimental designs and follow international requirements such as those provided by the Cochrane collaboration and/or the Equator network (http://www.equator-network.org/).

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Conflict of interest. None declared.

Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at http://dx.doi.org/10.1016/j.ijnurstu.2015.08.012.

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