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Review

The impact of computerized physician medication order entry in hospitalized patients—A systematic review

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ABSTRACT

Objective: To identify all published studies evaluating computerized physician order entry (CPOE) in the inpatient setting and uniformly classify these studies on outcome measure and study design.

Data sources: All studies that evaluated the effect of CPOE on outcomes pertaining to the medication process in inpatients were electronically searched in MEDLINE® (1966 to August 2006), EMBASE® (1980 to August 2006) and the Cochrane library. In addition, the bibliographies of retrieved articles were manually searched. Articles were selected if one of their main objectives was CPOE evaluation in an inpatient setting.

Review method: Identified titles and abstracts were independently screened by three reviewers to determine eligibility for further review.

Results: We found 67 articles, which included articles on CPOE evaluation on some outcome at the time of ordering. Most papers evaluated multiple outcome measures. The outcome measures were clustered in the following categories: adherence ($n = 22$); alerts and appropriateness of alerts ($n = 7$); safety ($n = 21$); time ($n = 7$); costs and (organizational) efficiency ($n = 23$); and satisfaction, usage and usability ($n = 10$). Most studies used a before–after design ($n = 35$) followed by observational studies ($n = 24$) and randomized controlled trials ($n = 8$).

Conclusion: The impact of CPOE systems was especially positive in the category adherence to guidelines, but also to some extent in alerts and appropriateness of alerts; costs and organizational efficiency; and satisfaction and usability. Although on average, there seems to be a positive effect of CPOE on safety, studies tended to be non-randomized and were focused on medication error rates, not powered to detect a difference in adverse drug event rates. Some recent studies suggested that errors, adverse drug events (ADEs) and even mortality increased after CPOE implementation. Only in the category time the impact has been shown to be negative, but this only refers to the physician's time, not the net time. Except for safety, on the whole spectrum of outcomes, results of RCT studies were in line with non-RCT study results.

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Contents

1. Introduction

Medication prescription plays a central role in health care. It concerns 65% of the US population and it annually accounts for 13% of health care expenditures [1]. Various studies show that adverse drug events (ADEs), many of which are preventable, form a major problem in the US [2–5]. In the early 1990s, it was estimated that there are 3.7 adverse events per 100 admissions in the US [6]. Of these, 28% are medication related, half of which preventable. From an economic point of view, hospital costs of adverse drug events were estimated at $2 billion per year. Similar reports in other countries show that medication errors indeed have important impact on mortality, morbidity and cost of care [7].

Medication errors are usually the result of failures during the medication process. Errors can occur in any step of this process: taking history, ordering, pharmacy management, administration management or surveillance [8]. A medication error may or may not result in patient harm, but almost all medication errors are considered to be preventable. adverse drug events (ADEs) are usually considered to include both medication errors that result in harm (preventable ADEs), and adverse drug reactions (ADRs), which are considered unpreventable [9]. Although high workload [10] and failures in monitoring patients [11] have been reported as a possible causes of medication errors, most medication errors and preventable ADEs are related to the medication process and mainly occur during the ordering step [3,12]. In addition to the inability of the average physician to memorize the ever increasing number of drugs, treatment regiments and side effects, prescribing the old fashioned way with pen and pad is prone to slips which are sometimes errors of inattention [13].

The institute of medicine and other important stakeholders have identified computerized physician order entry (CPOE) or electronic prescription (EP) as the main opportunity to reduce medication errors and thereby improve safety [2,14] especially when decision support is provided. CPOE systems promise to have also effects on outcomes other than safety, such as medication and process costs. A CPOE system refers to a variety of computer-based systems that share the common features of automating the medication ordering process and that ensure standardized, legible, and complete orders [15]. Electronic medical record systems which merely document medication orders and medication administration, after the time of ordering, are beyond the scope of this paper and are therefore excluded. In addition, we defined a decision support system (DSS) in this context as any system designed to aid a health professional in decision-making at the moment of ordering medication. A DSS can be an inherent part of CPOE or a separate system communicating with the CPOE system. The main objective of this review is to identify, uniformly characterize, and assess the reported CPOE impact in all published studies evaluating any aspect, safety and otherwise, associated with the use of a CPOE system in the inpatient setting. We excluded all studies in the outpatient setting since this is a completely different context with different challenges and a review on CPOE in the outpatient setting is published elsewhere [16]. The measured effects are summarized and associated with an evidence level. One should, however, realize that the assessment of effects of information technology in health care is inherently hard because the technology is only part of a much larger and complex social system [17]. Nevertheless, by presenting and assessing the state-of-the-art in CPOE evaluation studies, this review contributes to a better

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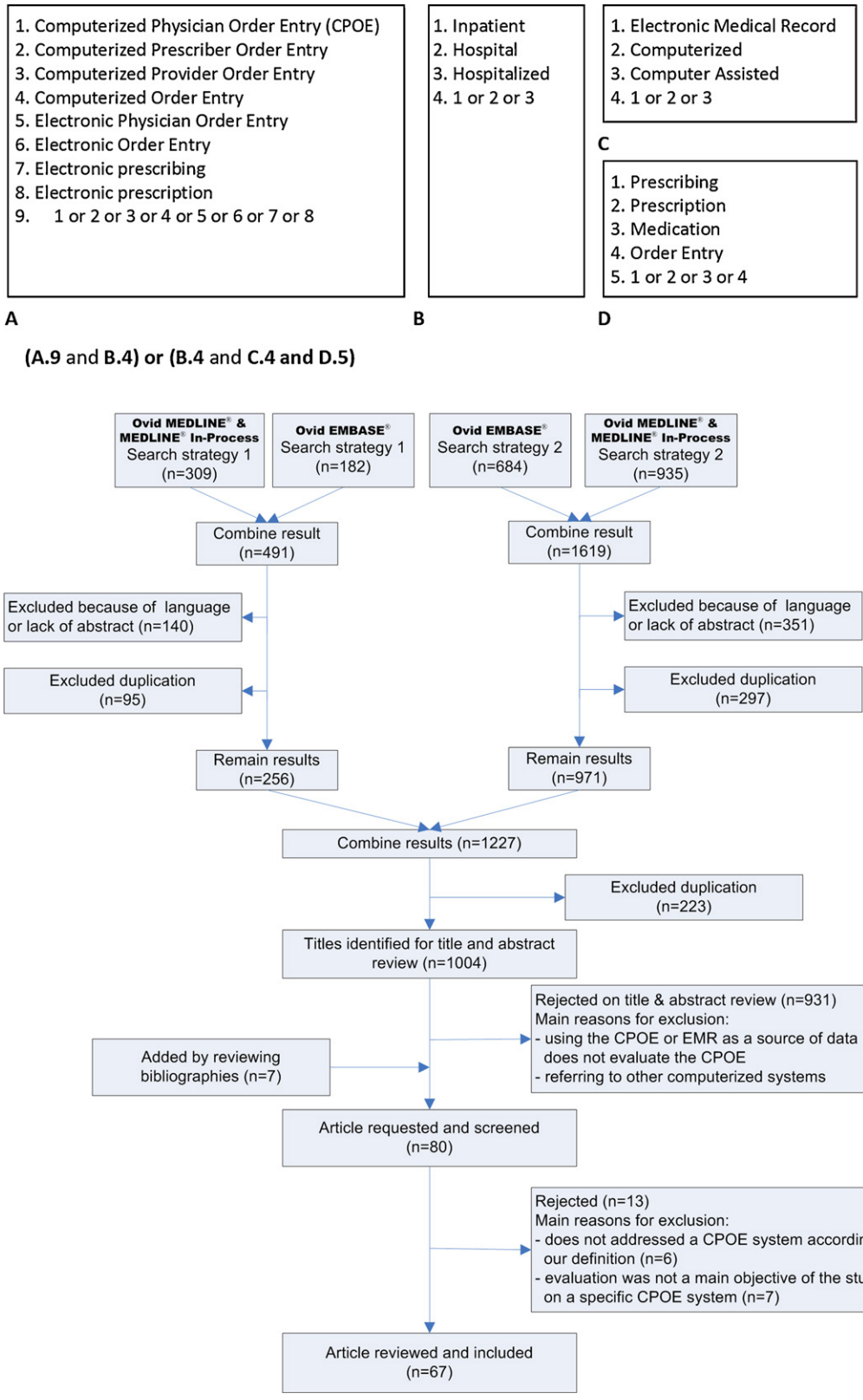

Fig. 1 – Keywords used in the two search strategies and the search flow. In strategy 1, keywords and MeSH terms that are currently in use for referring to a CPOE system (part A) are combined with terms related to inpatient care (part B). In strategy 2, computer (C) and medication (D) related terms are combined to identify studies that address prescribing with computerized systems in an inpatient setting (B), for especially uncovering older studies. The results of these two strategies are combined by using the boolean operator "or".

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understanding of the merits of CPOE systems in the inpatient setting, and identifies lacunas in current research on CPOE evaluation.

2. Methods

We searched for relevant english language articles, based on keywords in title, abstract and MeSH terms, using Ovid MEDLINE® & MEDLINE® in-process (1966 to August 2006), Embase® (1980 to August 2006), and Cochrane library. Fig. 1 shows the two applied search strategies and the corresponding search flowchart. In strategy 1, keywords and MeSH terms that are currently in use for referring to a CPOE system (part A) are combined with terms related to inpatient care (part B). In strategy 2, computer (C) and medication (D) related terms are combined to identify studies that address prescribing with computerized systems in an inpatient setting (B), for especially uncovering older studies. The results of these two strategies are combined by using the boolean operator "or".

Searching was supplemented by scanning bibliographies from identified review articles. The literature search was performed in August 2006.

Identified titles and abstracts were screened by three reviewers to determine eligibility for further review. Articles were selected if they reported original data from a study in which one of the main focuses was on evaluation of a CPOE system for medication ordering in an inpatient setting. All studies reporting on alerts, reminders, and DSS which are not part of or related to a CPOE system and which are not triggered during the medication order entry were excluded. Opinion papers, reviews, and letters were excluded.

From the selected papers, the same three reviewers extracted data on the materials, study design, outcome measures, and results. Discrepancies between reviewers were resolved by consensus. For the included papers all reported outcome measures have been extracted and clustered into homogeneous outcome groups.

To obtain insight into the heterogeneous nature of these evaluation studies, we classified them according to the hierarchy of study designs developed by the University of California San Francisco Stanford evidence-based practice Center and implemented by Kaushal et al. [15] in their review (Table 1).

3. Results

Searching the online databases resulted in 1,004 articles from Ovid MEDLINE®, Ovid MEDLINE® In-process, Ovid EMBASE®, and the Cochrane library. After initial screening of titles and abstracts, 74 articles were considered for full text review. Six additional articles were identified by reviewing bibliographies, yielding a total of 80 articles. Based on the full text review, six articles were excluded because they turned out not to address a CPOE system according to our definition, and seven articles have been excluded because evaluation was not a main objective of the study or evaluation was not performed on a specific CPOE system, leaving 67 articles for detailed analysis (see Fig. 2). A summary of the study design, outcome measures and main results of the 67 studies is available as supplementary material. It is noteworthy to mention that the number of articles on CPOE evaluation has sharply increased in recent years (Fig. 2).

Most of evaluation studies on CPOE were done in USA (83%, 56 out of 67), only 11% (7 out of 67) in the European Union and the rest (6%, 4 out 67) in Brazil, Canada and Australia.

Table 1 – Hierarchy of study designs [15]

Level	Study design	Description
I	Randomized controlled rrial (RCT)	A study in which people are allocated at random (by chance alone) to receive one of several clinical interventions. One of these interventions is the standard of comparison or control. The investigator controls the exposure to the intervention.
II	Non-randomized controlled trial	A study in which people are allocated to receive one of several clinical interventions. One of these interventions is the standard of comparison or control. The investigator controls the exposure to the intervention but allocation of people is not based on chance. It includes interrupted time series and before–after studies.
III	Observational study with control	A study in which individuals are observed or certain outcomes are measured without a specific attempt to affect the outcome (the investigator does not control the exposure to the intervention e.g. the use of a CPOE). The intent is to observe how exposure to risk factors (implemented CPOE) influences the outcome of interest. Includes cross-sectional studies to estimate the prevalence of the outcome of interest or the prevalence of exposure to intervention or both; cohort (longitudinal) studies with control in which individuals who are exposed to the intervention are followed for a defined length of time and the effects of the intervention on the exposed group is compared to a group that was not exposed; and case control studies in which a comparison of exposure to the CPOE in a group of individuals with the outcome of interest (cases) is compared to those without the outcome of interest (controls).
IV	Observational study without control	Includes cohort studies without controls or case series.

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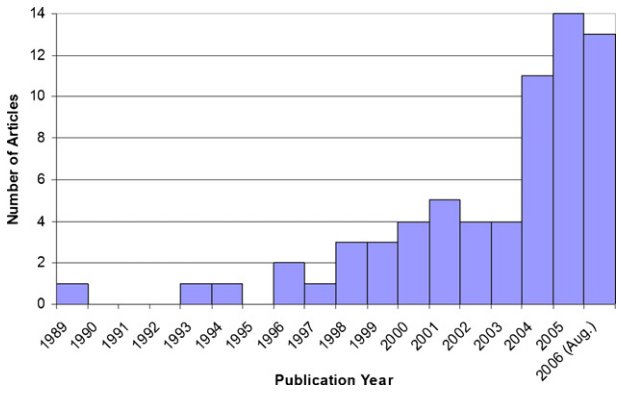

Fig. 2 – Distribution of the number of published articles on CPOE evaluation over the years.

Benchmark leaders in CPOE evaluation are Brigham Women's Hospital and Partners Heath Care in Boston (19%, 13 out of 67), Vanderbilt University Medical Center in Nashville (9%, 6 out of 67) and Regenstrief Institute (6%, 4 out of 67).

In all these studies, we categorized the main outcome measures in six main groups: adherence to guidelines; medication safety; cost and (organizational) efficiency; alerts and appropriateness of alerts; time; and satisfaction, usage and usability. Most papers evaluated multiple outcome measures.

Table 2 shows a summary of all reported measured effects of CPOE evaluation studies where results are reported separately by study design and by outcome group. The column on the right summarizes the effect of CPOE accompanied by the level of evidence.

Below, we describe the effects per outcome group for all included studies. Details about materials and results of each study are shown in the supplementary material.

3.1. *CPOE and adherence to guidelines*

Twenty-two articles were classified in this group. Two articles in this group described adherence to system alerts without using a control group [18,19]. One randomized clinical trial [20] (RCT) and one non-RCT [21] did not find a significant difference between the control and the intervention group with regard to adherence to the guideline. Seventeen other studies, four RCTs and thirteen non-RCTs, showed positive effects on adherence to guidelines [22–38]. Among these, four non-RCTs, showed positive effects on the adherence to order sets, which are predefined prescriptions [32,36–38]. McAlearney et al. [39] showed that order set utilization and utilization trend varied by condition. Dexter et al. [40] in an RCT, showed that adherence to standing orders was significantly better than adherence to reminders during order entry.

3.2. *CPOE and medication safety*

In 21 controlled studies, medication errors, ADEs, and/or mortality were compared between an intervention group using the CPOE and a control group not using the CPOE. In all of these trials the controls were not randomly selected. In addition, ten articles described the effect of CPOE on safety in an observational study [19,41–49]. Next to ADEs, various combinations of parameters were measured to indicate medication errors including wrong dose adjustment, route and interval errors, drug–drug interaction, drug allergy, wrong therapy and contraindications, formulary errors, illegibility, transcription errors, administration errors, and dispensing errors. There were 24 studies that mentioned the medication error type. These included 18 studies (75%) reporting on dosing errors especially excessive dosage, 7 (29%) on wrong therapy/contraindication, 5 (21%) on drug interaction, 5 (21%) on illegibility, and 4 (17%) on drug allergy.

In 1998, Bates et al. [50] performed a prospective non-RCT and showed for the first time that CPOE reduced serious medication error rate by 55%. Despite a positive trend the study was not powered to detect a significant difference in the preventable ADE rate. To evaluate safety, ADE rate is more relevant than medication errors because errors do not necessarily result in adverse events. All 19 non-RCT studies that evaluated the effect of a CPOE on the number of errors showed positive effects on the reduction of the number of errors [22,34,50–66]. Shulman et al. [64] showed a significant reduction of medical errors in a non-RCT but they also reported two serious errors—those of definite clinical significance with the potential to cause harm to the patient—caused by CPOE leading to adverse events and increase in length of stay, and another three potential ADEs attributed to CPOE. In the same year, another observational study showed that the number of medication errors remained at a high-level after CPOE implementation [48] and three other recent observational studies described how new medication errors have been associated with CPOE systems [47,49,67].

Ten studies, all non-RCTs, assessed the effect of DS on the number of ADEs [23,50–54,57,58,62,65]. Among them, seven studies showed a reduction in the number of ADEs, while the remaining three studies did not show an effect [23,54,62]. Two studies which showed reduction in the number of errors could not show a reduction in the number of ADEs [54,62]. Nebeker et al. [68] reported in an observational study that the number of ADEs remained at a high-level after CPOE implementation.

In 2005, a non-RCT, showed that after CPOE implementation mortality increased significantly in pediatric ICU [69]. In 2006, another non-RCT showed a non-significant reduction in mortality rate after CPOE implementation in pediatric ICU [70]. One observational study reported 55 incidents which were related to CPOE. However, few incidents resulted in patient harm varying between 12% for physiologic harm and 2% for psychological distress [46].

3.3. *CPOE, cost and (organizational) efficiency*

Twenty-three studies, four RCTs, fifteen non-RCTs and four observational studies fell in this group [23–29,32–34,36,45,51,53,54,57,59,61,71–75]. The main outcome measures were hospital cost, medication cost, cost of process time, and proxies for efficiency and costs such as length of stay (LOS) and defined daily dose. Organizational efficiency was measured by changes in the distribution of workflow processes.

One RCT showed that a CPOE system did not change any related aspects to cost and efficiency [25]. One non-RCT study showed mixed effects, some positive and some negative, on

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Table 2 – Effects of CPOE on outcome categories subdivided by quantitative study designs

Outcome category	Study design	Total	Positive effect			No effect[a]	Negative effect			Mixed effect[b]	Overall conclusion based on level of evidence
			Demonstrated[c]	Statistically sig.	Mix[d]		Demonstrated[e]	Statistically sig.	Mix[f]		
Adherence to guideline	RCT	5	1	3	–	1	–	–	–	–	Adherence to guideline or to computerized recommendation increase due to CPOE systems.
	Non-RCT	14	3	8	1	1	–	–	–	1	
	Obs. ctrl.	–	–	–	–	–	–	–	–	–	
Safety	RCT	–	–	–	–	–	–	–	–	–	Prescribing errors decrease although there are some negative (observational) studies recently. There is no evidence on the effect of CPOE systems on ADEs.
	Non-RCT	21	7	10	–	1	–	1	–	2	
	Obs. ctrl.	1	1	–	–	–	–	–	–	–	
Cost and efficiency	RCT	4	–	2	1	1	–	–	–	–	Studies on cost and effectiveness showed mixed results. In addition, some important costs may not be accounted for.
	Non-RCT	16	6	2	4	2	–	1	–	1	
	Obs. ctrl.	–	–	–	–	–	–	–	–	–	
Alert	RCT	1	–	1	–	–	–	–	–	–	Quantitative studies show high adherence to alerts. However qualitative studies show many overridden alerts. Acceptance rate increase with the clinical importance of the alerts.
	Non-RCT	2	–	2	–	–	–	–	–	–	
	Obs. ctrl.	2	1	–	–	1	–	–	–	–	
Time	RCT	1	–	–	–	–	–	1	–	–	Direct order entry time increase. When indirect time is also measured the overall time did not change, or even decreased.
	Non-RCT	5	1	2	–	–	–	2	–	–	
	Obs. ctrl.	–	–	–	–	–	–	–	–	–	
Satisfaction, usage and usability	RCT	–	–	–	–	–	–	–	–	–	No conclusion due to lack of quantitative studies.
	Non-RCT	–	–	–	–	–	–	–	–	–	
	Obs. ctrl.	–	–	–	–	–	–	–	–	–	
Total	RCT		1	6	1	2	–	1	–	–	
	Non-RCT		17	24	5	4	–	4	–	4	
	Obs. ctrl.		2	–	–	–	–	–	–	–	

Outcome categories are ordered in decreasing level of evidence of the overall conclusion.

[a] When reported as such by the authors, with or without statistical arguments.

[b] Mix of positive, absence of, and negative effects.

[c] When the authors report a positive effect but without reporting statistical significance.

[d] Mix of statistically significant and demonstrated positive effects.

[e] When the authors report a negative effect but without reporting statistical significance.

[f] Mix of statistically significant and demonstrated negative effects.

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cost and efficiency [27]. Fifteen studies, three RCTs and twelve non-RCTs, showed that CPOE had a positive effect on at least one relevant aspect of cost and/or efficiency. While nine studies showed that CPOE decreased the hospital or pharmacy costs [26,28,29,51,53,54,57,59,71], four articles showed that there was no statistically significant effect on hospital or pharmacy costs [23,25,36,61]. Mekhjian et al. [61] showed that CPOE did not change cost significantly although the total cost per admission decreased significantly in some selected services. The outcome measure LOS gave mixed results as five studies, two RCTs and three non-RCT, showed that CPOE has no statistically significant effect on LOS [25,27,33,36,71] and even increase it, and three other studies, non-RCTs, showed a significant reduction of LOS [23,51,61].

Kaushal et al. [74] considered in an observational study various kinds of CPOE costs and benefits and showed that over 10 years, 80% of CPOE implementation cost was reimbursed.

Finally, Cheng et al. [72] evaluated the effect of CPOE on disruption in the workflow process in an observational qualitative study. They showed that policies designed to increase flexibility and safety led to an increased coordination load on the health care team, and created new sources of errors. A recent observational study showed that after CPOE implementation, physicians and nurses worked in asynchronous mode, and left the coordination of their actions to the system. The study also showed that orders were exhaustively documented but that some data may be misinterpreted forming new sources of errors [75].

3.4. *CPOE, alerts and appropriateness of alerts*

Three observational studies assessed the impact of CPOE on generated, accepted and ignored alerts [42,43,76]. Most of the alerts were ignored by the physicians. One study showed that when the alerts were classified in high-level and low-level groups, the high-level alerts were more often accepted than the low-level alerts (57% versus 8%) [42].

Three studies, one RCT, one non-RCT and one observational study, showed that alerts given by pharmacists for solving prescription problems, and efforts for helping clinicians decreased significantly after the implementation of CPOE [25,54,60]. Another non-RCT showed that the rate of alerts given by pharmacists was not different in the clinical areas with electronic prescription system compared to the clinical areas using hand-written prescription [44].

3.5. *CPOE and time*

Seven articles focused on the effect of CPOE on time [56,59,61,71,77–79]. We considered ordering time and turnaround time and have not attempted to distinguish between patient care time and teaching time. Three studies, one RCT and two non-RCTs, showed that CPOE increased the ordering time [71,77,78]. These studies focused on physicians, and time savings for pharmacy and nursing have not been addressed. Only a recent observational study showed that direct patient care time did not change significantly [79].

Another outcome measure in this group was medication turn-around time, the total time from writing the medication order to the delivery of the medication to the ward. Three non-RCTs showed that a CPOE system decreased medication turnaround time significantly [56,59,61].

3.6. *CPOE, user satisfaction and usability*

Ten observational studies [42,44,45,54,57,79–83] focused on user satisfaction and usability. Eight studies showed that after the introduction of the CPOE system, the majority of users were satisfied with the system and they believed that the system is usable. Although the environment, questionnaire, and target groups (nurses or physicians) were different in these studies, the majority of users believe that CPOE improved drug management and quality of care. One additional observational study compared two CPOE systems, one commercial and one self-developed, and showed that users were more satisfied with the self-developed system [82]. Only one (recent) paper found that electronic prescribing with DS was not feasible at the hospital studied [84]. Although feasibility forms a different concept than usability and satisfaction, it was taken here as a crude proxy for this category.

4. Discussion

We identified and described the results of 67 papers on evaluation of CPOE systems in hospitalized patients. The number of such evaluation studies shows a strong increase in recent years.

Our findings suggest that the impact of CPOE systems has been shown to be positive especially in Adherence to guidelines, but also in Alerts and Appropriateness of alerts; costs and organizational efficiency, and satisfaction and usability. A major goal for the implementation of CPOE is safety improvement. Despite the generally positive effect of CPOE on safety shown in generally non-randomized studies, they were focused on medication error rates, not powered to detect a difference in adverse drug event rates or mortality. In addition, in light to recently published case studies showing a negative effect on safety one should conclude that, by itself, the introduction of a CPOE system does not necessarily lead to better safety and that there are other factors at play [47,49,67,69]. Implementing information technology applications such as CPOE is a socio-technical activity, which often depends more on organizational context than on a specific technology [92]. Although in the category Time, the impact has been negative for physicians' time, there was a positive effect on turnaround-time. Except for Safety, on the whole spectrum of outcomes, results of RCT studies were in line with non-RCT study results.

The influence of publication bias was not investigated in this review but one should be aware of its possible existence while interpreting the generally positive findings of the impact of CPOE systems. Ammenwerth et al. [92] showed in their analysis of the contradictory results concerning the effect of CPOE systems on mortality rates in two pediatric intensive care units that implementing a CPOE system primarily concerns a socio-technical activity and that each setting is unique in its combination of sociological, technical, organizational and human factors. Because of this, it is hard to make absolute

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conclusions about the effect of CPOE on an outcome category, especially when there is a negative study.

Our literature search has been extensive in the sense that our search criteria were meant to capture different ways a CPOE system is referred to while covering search criteria used by other reviews. However, our review is restricted to CPOE systems i.e. a system that allows clinicians to enter medication prescriptions for inpatients into a computer prospectively and not general EMR systems in which medication orders and medication administration are merely documented after paper-based prescription.

4.1. *Former reviews*

To our knowledge five other reviews have been published on the evaluation of CPOE systems in inpatients [15,85–88]. The scope of these reviews includes CPOE systems that are sometimes embedded in a larger whole, and CPOE systems that may or may not focus on medication. Kaushal et al. [15] focused on medication safety and the review was restricted to studies evaluating the effect of CPOE on errors and ADEs. In 2003, Oren et al. [85] published a second review article focusing on the impact of CPOE, bar-coding and computerized medication administration records on medication errors and ADEs. However, eight out of the eleven studies in their review did not concern medication errors or ADEs. In 2003, Kuperman et al. [86] also published a review article on CPOE but it did not focus on medication. In early 2005, another broad review article on the impact of health information technology on quality, efficiency, and cost of medical care has been published [87]. This review captured fewer studies than ours in the field of CPOE evaluation. Another recent review article focused on overriding drug safety alerts in CPOE which forms only one aspect of CPOE system evaluation [88]. Grag et al. [89] recently published a review article about DS systems but, assumingly because it did not specifically focus on CPOE, it did not include any paper about CPOE. Compared to these five reviews, we have uncovered more studies in the same time frame; this is due to the more comprehensive strategy we adopted which included old and new CPOE related terms. Furthermore we extended the review time frame to also include the most recent studies. We also provided a more extensive characterization of the selected studies including description of a studies evidence level, study design, methods, materials, and results. Our study focuses on medication but the evaluation aspects are not limited to only safety although this is one of the most important outcome measures. We will now summarize and discuss the effects of CPOE on six categories of outcome measures.

4.2. *CPOE and adherence to guidelines*

Almost all studies in our review that evaluated the effect of CPOE systems on adherence to guidelines showed a positive effect. This shows that clinicians generally accept the system's suggestions. However, if the guidelines are not correctly implemented in the system or when patient information is not correctly recorded in the system, any problem in matching the guidelines with patient information can lead to serious errors and to ADEs as some recent papers [49,67] have indeed reported.

4.3. *CPOE and medication safety*

Our review shows that the rates of the proximal outcomes, medication errors, fell due to CPOE introduction although the effect on ADEs, which is a more relevant clinical outcome, did not merit enough attention. One study even showed a negative effect of CPOE on mortality. All of the reviewed studies on safety turned out to be non-RCTs although most are controlled ones. The great majority of studies have employed relatively little DS.

4.4. *CPOE, cost and (organizational) efficiency*

There is some evidence about the positive effects of CPOE on hospital and pharmacy costs. But we believe that it would be beneficial to include also the cost of software and its maintenance, of personnel's time utilization, of adherence to guidelines, and of errors and ADEs, e.g. in terms of additional treatment, and logistic and nursing cost, but we admit this is difficult to operationalize. Only a recent single-center study assessed some of these aspects and showed that developing, implementing and operating a CPOE system is costly ($11.8 million over 10 years) but considering the money saved due to the CPOE system the net effect was positive [74]. Because adherence to computerized suggestions based on guidelines is high, costs are expected to be affected accordingly: costs will tend to decrease when the guideline is geared towards cost reduction, and costs will tend to increase when the guideline entails more expensive treatment as, e.g. Hulgan et al. [29] reported on decreasing medication costs after the implementation of an intravenous/oral conversion DSS.

4.5. *CPOE, alerts and appropriateness of alerts*

All three articles concerning the acceptance of alerts showed that physicians did not accept most of the alerts. This should be considered from two points of view: system weakness and user response. We believe that a major system weakness is the provision of too many alerts leading to low user compliance. They also include patient non-specific advice and use incomplete patient information. Overloading physicians with irrelevant alerts may result in inattention. Alert systems should be redesigned to only show important patient-specific alerts [42,88].

4.6. *CPOE and time*

All three studies which consider ordering time as an outcome measure, from 1993 until the most recent one in 2001, showed that CPOE increased ordering time for physicians. In addition this increase in time might lead to an increase in the clinician's workload which can introduce new medical errors [11]. However there were no studies in our review which assessed the effect of a CPOE system on workload. CPOE time reduction for pharmacy and nursing was not studied. Recently, a study showed that direct-patient-care time did not change signifi-

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cantly [79]. As this study is an observational one, and the only one found on direct-patient-care, it is premature to arrive at strong conclusions.

4.7. *CPOE, user satisfaction and usability*

Almost all studies which evaluated the effect of CPOE on user satisfaction and usability were observational studies and showed positive results. However, more studies with better evidence level are necessary especially for studying the impact on usability, usage and feasibility.

4.8. *Other evaluation measures*

Interestingly, none of the studies in our review evaluated technical facets [90] such as user interface, data management, data security, technical functionality of a checking mechanism for dangerous drug dosage, flexibility in changing the knowledge and rules etc. Also the following medical facets were mainly missing: knowledge base completeness and accuracy; the extent of adverse drug reaction reporting and consistency with dealing with different medication trade names.

4.9. *Study designs*

On the whole, the studies we found were heterogeneous in terms of their study design and most of them produced level-two evidence, non-RCTs such as before–after studies. Twenty-six out of the 35 non-RCTs (74%) reported at least one statistically significant positive difference, which is comparable to six out of eight RCTs (75%) reporting on at least one statistically significant positive difference. The comparability among studies in this review is hard at least due to the lack of standardization methodology for CPOE evaluation. Moreover, the scope of the studies varies from a narrow domain such as specific drugs to a hospital-wide setting; studies also differ in the implementation environment of the CPOE, the approach to DS, and the nature and types of medication and treatment. This heterogeneity may explain at least some differences in results such as effects on cost or LOS.

5. Conclusion

In conclusion, CPOE evaluation studies vary in scope, aims and results, and one should not expect unequivocal judgment about their effects. One could perhaps argue for more RCT studies in the evaluation of CPOEs but they do have prohibitive costs. One fruitful way to proceed with is the use of controlled trials focusing on CPOE systems with more decision support for specific patient groups, high risk drugs, typical ADEs, using more powerful designs like interrupted time-series. Another fruitful direction is to recognize that while the standard RCT methodology is excellent for studying system or clinical performance, it is not well suited to answering questions concerning whether systems will be used or how they will be used [91]. This calls upon a complementary evaluation methodology that considers the social context in which CPOE systems operate.

Summary points

What is already known:

- CPOE systems have been identified as key for improving patient's safety.
- CPOE systems can influence both positively and negatively physicians' behavior and outcomes

What this study added to our knowledge:

- The impact of CPOE systems was especially positive in adherence to guidelines, but also to some extent in alerts and appropriateness of alerts; costs and organizational efficiency; and satisfaction and usability.
- Studies on safety showed some positive effect of CPOE but tended to be non-randomized and were focused on medication error rates, not powered to detect a difference in adverse drug event rates.
- CPOE had negative impact on the prescribing physician's time, however, there was a positive effect on the net turn-around-time.
- Except for safety, on the whole spectrum of outcomes, results of RCT studies were in line with non-RCT study results.

Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at doi:10.1016/j.ijmedinf.2007.10.001.

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