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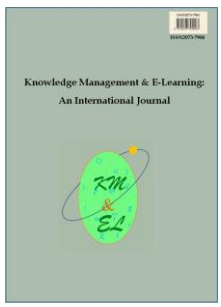

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Computerized provider order entry and patient safety: A scoping review

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Abstract: As health systems in Canada are being modernized with the use of technologies, digital health tools are now increasingly being used to improve patient safety. Computerized Provider Order Entry (CPOE) is now being used in Canada and the technology may have an important impact on patient safety. The objective of this scoping review is to explore the impact of CPOE on patient safety in health care settings. Four databases were searched for studies related to CPOE and patient safety. Following title, abstract and then full text review, twelve studies were selected for further analyses. Several key themes emerged from the literature. The findings revealed several important themes: (1) the implementation of CPOE is an important aspect of patient safety, (2) comparisons of CPOE implementations across multiple sites or facilities were made, (3) the end-user experience of using CPOE was important, and (4) the evaluation of CPOE is key to establishing risk frameworks. Risk mitigation strategies and lessons for academia and industry are discussed. Overall, the scoping review revealed that although patient safety can be improved using CPOE, there is a large difference in realized impacts among healthcare systems.

Keywords: Computerized provider order entry; ePrescribing; Patient safety; Safety; Factors; Risk mitigation

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1. Introduction

Health service delivery is being modernized in Canada. As a result, there is a need for evidence-based decision-making where technology is concerned. Electronic Health Records (EHRs) support clinicians' evidence-based decision-making efforts with the use of the software and its associated alerts and warnings (Coleman et al., 2013). New forms of clinical risk have been introduced through the use of EHRs, and there is a need to understand the impact of these risks. Such understanding allows one to avoid errors and to mitigate the occurrence of such errors (Borycki et al., 2013b; Mozaffar et al., 2017). A focus on patient safety should be a part of the CPOE design and implementation process, including the collection of information about patient care (Kirkendall et al., 2013).

Electronic Health Records are a key technology in a modern healthcare system. EHRs aid in direct patient care and clinical workflow (Li et al., 2013), as well as assisting with clinician decision-making, inventory management, reviewing the historical record of a patient's care and providing information about the interventions that have occurred for a patient. An EHR system is composed of various components, typically including electronic documentation, order management, and other functionality described in section 3 below. The digital functionality of an EHR can be added to, or built upon, in a sequential manner. Such activity requires investment in terms of human learning and has financial implications for healthcare organizations. There is a need to invest in the implementation (training, change management, etc. involving the technology) of EHRs (Maslove et al., 2011). Administrator investments in EHR systems are typically made with the goal of patient safety and modernization of healthcare in mind. However, research has shown that there are potential patient safety risks introduced with the implementation of an EHR system (Fortman et al., 2020; Tolley, Forde, et al., 2018). For those organizations investing in EHR technologies, a key goal of health systems everywhere is to maximize the potential safety benefits from the technology, while minimizing the potential harms that may result from its introduction (Maslove et al., 2011). This research will attempt to better understand what is known about the impact of

one key EHR function: the implementation of Computerized Provider Order Entry (CPOE). This work includes identifying potential patient safety benefits and addressing risks associated with clinical workflows that complement CPOE.

CPOE is defined by the Centers for Medicaid and Medicare as "the provider's use of computer assistance to directly enter medication orders from a computer or mobile device" (CMS.gov, 2010). The provider order is an input in a digital, structured, and computable format and is used for improving order routing (such as to a Pharmacy system, Diagnostic Imaging system etc.), for reporting, and improving patient safety (CMS.gov, 2010). In this way, the order is processed resulting in both primary usage (such as supporting direct patient care), and secondary usage including reporting and inventory management. The use of digital orders can impact patient safety positively whether by increasing legibility compared to handwritten orders, validation and checking for contraindications, as well as flagging if a medication dose is late to be administered to a patient (Carli et al., 2018; Tolley, Slight, et al., 2018). Conversely, the introduction of this technology is known to lead to new types of clinical risks, which may lead to patient harm (Borycki et al., 2012; Brown et al., 2017). This scoping review investigates the safety benefits and risks that are present in the implementation and operation of CPOE.

2. Purpose

The primary purpose of this scoping review was to evaluate the potential safety benefits and risks associated with the introduction of CPOE in a healthcare system. Given that many institutions in Canada that are implementing EHRs to improve patient care, which often include CPOE, ensuring a proper understanding of the expected outcomes of the technology is important when contemplating the associated investment in the technology. The secondary purpose of this study is to evaluate the potential patient safety risks associated with CPOE – both during the implementation when the potential for error is assumed to be higher, as well as after the CPOE system is operational.

3. Background

To quantify EHR usage across healthcare systems, the Healthcare Information and Management Systems Society (HIMMS) has published an Electronic Medical Record Adoption Model (EMRAM) scale which outlines a hierarchy based on common system functionality. The EMRAM is a seven-point scale that is hierarchical in nature and is used for evaluating EHR functionality within a health organization. It serves as a maturity model for EHR implementations in a hospital setting. For this study, CPOE implementations are placed in stage 4 of the model out of a possible 7 stage model. This model is a commonly used model for characterizing EHR implementations. The patient safety impacts of EHRs and their components is poorly understood. While it is known that some technologies may improve patient safety (by reducing the number of safety events), risks may also be introduced with the usage of electronic systems (Mattsson et al., 2015; Tolley, Forde, et al., 2018). These risks must be contextualized and where possible, quantified, to enable better implementation of new technologies while ensuring correct mitigation approaches are in place to guard against the potential for patient harm (Mattsson et al., 2015).

4. Research objectives

The first objective of this scoping review is to identify the safety benefits of introducing CPOE in healthcare systems. Given that many institutions in Canada are implementing EHRs to improve patient care, ensuring a proper understanding of the expected patient care outcomes is important when contemplating the associated investment in health technology. The second objective of this study is to evaluate potential patient safety risks associated with CPOE during the implementation phase, when the potential for new types of errors is introduced. In the next section of this paper, we describe how the scoping review was undertaken. We describe the extent and scope of the research concerning the patient safety impacts of implementing and operating CPOE. The paper will also touch on the major themes emerging from the literature identified during the scoping review, as well as discuss future research studies arising from the gaps identified in the available literature.

5. Methods

A scoping review was undertaken to identify and describe the factors that affect patient safety, such as the safety benefits, as well as any risks associated with CPOE implementation. This study followed the framework described by Arksey and O'Malley (2005) for conducting a scoping review of the literature (Arksey & O'Malley, 2005). These steps are outlined in Table 1 below:

Table 1
Methodological framework

Stage 1: identifying the research question
Stage 2: identifying relevant studies
Stage 3: study selection
State 4: charting the data
Stage 5: collating, summarizing, and reporting the results
Stage 6: optional consultation exercise

This methodological framework provided structure and an approach, and the optional stage 6 of the framework was excluded from the process of this scoping study.

5.1. Identifying the research question

The following research questions were addressed in this study:

1. What are the potential benefits to patient safety that emerge from using CPOE technology?
2. What is the patient safety risks that arise from implementing CPOE technology?
3. How can these risks be avoided or mitigated?

5.2. Identifying relevant studies

This study was primarily concerned with the interplay of two concepts: (1) CPOE and (2) patient safety. The study also investigated how the two concepts are described and evaluated in the literature. This study is primarily concerned with clinical outcomes and clinical risks to patients (thus excluding financial, reputational and other types of organizational risks), and medically focused research databases were used, as well as technical/engineering sources. The final list of databases that were searched included Medline, CINAHL, Web of Science and IEEE Xplore. Search terms were used to include alternate phrases with "OR" and "AND" as operators. "OR" and "AND" were used to separate the two study concepts described above (i.e., benefits to patient safety AND risks to patient safety). Proxy terms for patient safety, such as 'adverse events', 'errors' and other similar terms were not searched to limit the resolute to those papers that directly deal with patient safety considerations. The final search string consisted of "CPOE" or "computerized physician order entry" AND "patient safety" AND "factors" or "causes" or "influences". Further, the date range was set for 10 years prior to the study date (2010-2020 inclusive), and studies available in English-only on those databases that allowed such filtering. The initial search results are described in Table 2 below.

Table 2
Initial database search results

Research Database	Initial Search Results
Medline	99
CINAHL	59
Web of Science	72
iEEE Xplore	0

Results were found in three out of the four databases searched. Most of the published articles were indexed in Medline. Of note, no search results were returned in IEEE Xplore that met the search criteria.

6. Article selection

A detailed review of titles and abstracts was completed to screen the articles for relevancy using Covidence® (Covidence.Org, Melbourne Australia) by two researchers (RK, EB). Relevancy was determined using the below listed inclusion and exclusion criteria.

Inclusion Criteria:

- Those focusing on Computerized Provider Order Entry, Computerized Physician Order Entry, or ePrescribing
- Those with a patient safety focus or patient care focus
- Those that had an abstract available online

Exclusion Criteria:

- Those that were published in a language other than English

- Those that were available in hardcopy only
- Those that were not peer-reviewed, published studies
- A lack of focus on patient safety,
- and/or that the study did not include CPOE

7. Article screening, review, and data extraction

Following the abstract and title review, a full text review of the remaining studies was completed, with the above inclusion and exclusion criteria. Key data were charted for each of the articles (see Appendix I). Data were extracted from the articles according to the PRISMA-ScR methodology (Tricco et al., 2018). The data charting form can be viewed in the Table 3 below.

Table 3
Data charting table

Author(s)
Year of publication
Aims/purpose
Study population
Study Setting (ER, Ambulatory, IP etc.)
Origin/country of origin
Methodology/methods
Intervention Technologies
Indicators
Findings
Limitations

8. Summarizing and reporting results

Following the completion of the data extraction, the studies were grouped into four key themes that emerged through a detailed review and data extraction. Within each study, primary topics and study designs informed the logical groupings of studies, which led to the emergence of key themes and subthemes. These themes and subthemes are detailed in Fig. 1.

9. Ethics

The proposal for this research project was reviewed by the Research Ethics Facilitator from the Office of Research Services at the University of Victoria. As this research uses publicly available information, it was determined that this project was exempt from research ethics review.

10. Results

In this section, the results of the scoping review are presented.

10.1. Article screening, review, and data extraction results

Two-hundred and thirty studies were exported to a CSV file with full citations and abstracts, and imported into Covidence (Covidence.Org, Melbourne Australia). Upon import, 77 duplicate studies were removed, for a total of 152 studies that required a title and abstract review. Two researchers reviewed the titles and abstracts, and 128 studies were excluded, resulting in 24 studies being eligible for full text review. Of the 24 studies, one was unavailable, and 23 were reviewed in detail. Eleven studies were excluded, with the most common reason for exclusion being that the effects of CPOE could not be isolated in the study results. Many studies examined the effects of implementing CPOE in conjunction with other health technologies such as Clinical Decision Support Systems. Other reasons for exclusion of studies included: a lack of focus on methodologies, indicators, sample sizes, patient safety, the poor quality of the study, and/or that the study did not include CPOE. This resulted in 12 studies being part of the final group of papers selected for data extraction. For additional details, see Fig. 1below.

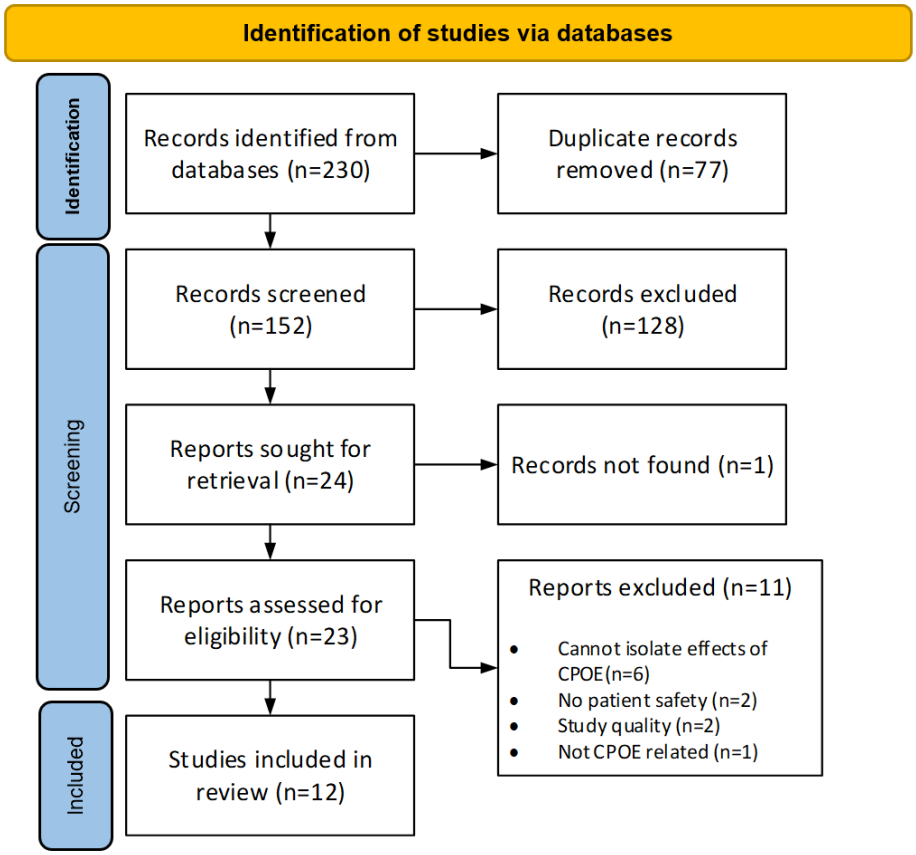

Fig. 1. PRISMA flow diagram

10.2. Thematic analysis

An analysis of study methodologies, indicators, sample sizes and research questions were conducted by the researchers. Four key themes and numerous subthemes emerged. The first theme to emerge from the articles was the focus (by the authors of the articles) upon a particular implementation of CPOE in an organization. The effects of implementing CPOE were examined using quasi-experimental designs (i.e., pre-, and post-implementation of a CPOE system). The studies examined the impact of implementing CPOE in an organization. They also evaluated the effects of the new technology upon meeting organizational or study-defined goals.

The second theme to emerge from the selected studies focused on comparing different implementations (i.e., comparative studies). Researchers looked at differences in CPOE experiences across a variety of CPOE technologies, facilities, and/or care settings, and examining the effects of CPOE on patient safety benefits and mitigating risks associated with the technology. These studies clarified a variety of outcomes of CPOE implementation at a health system level. In some cases, researchers identified contributing factors and/or other lessons that could be learned by examining variation among CPOE implementation experiences.

The third theme that emerged focused on illuminating system factors related to the experience of end users who utilize CPOE systems. Researchers investigated end-user devices required to operate CPOE systems to evaluate safety-related metrics or scenarios across different devices (Brown et al., 2017; Cooley et al., 2012). Other investigations studied system design by examining human-computer interaction. Other studies documented the voices and opinions of end-users of CPOE. This research provided valuable insights into the opinions of CPOE users regarding patient safety (as well as numerous other areas of users could provide feedback about safety). These studies collected data using questionnaires and semi-structured interviews that occurred prior to and following an implementation. These studies yielded insights into the operation of CPOE by end users, as well as the tools they use to do so.

The last theme to emerge in this scoping review was evaluating the focus on CPOE installation risk profiles. Risk was considered in the context of various care settings and even in the context of other industries (i.e., in the evaluation of relative risk) (Lichtner et al., 2020). A clinical risk classification was developed by Amalberti and Vincent for CPOE, to classify the safety of the technology, as well as the factors that increase and decrease risk (Amalberti & Vincent, 2020). This study was included in the scoping review and the focus of the research was unique (as it differed from the other research reviewed in this paper). This novel perspective on evaluating health information technology relative to risk profile across clinical care settings was both interesting and informative. A full listing of themes and subthemes are in Table 4.

10.3. Implementations of CPOE

A variety of themes emerged following a review of the CPOE studies, where CPOE was an intervention. Mattsson et al. (2015) found no statistically significant change in patient safety associated with implementing CPOE, as compared to prior paper ordering processes (Mattsson et al., 2015). This was a surprising finding. It must be noted that before CPOE was implemented the study setting had abnormally low rates of errors in both the pre- and post-study periods (as compared to other published works). The study authors attributed the low error rate to a focus on intercepted errors rather than those errors that were not caught (which could still be occurring within the sample).

Table 4
Themes and subthemes

Theme	Subtheme	Studies
Implementations of CPOE	Electronic/paper Order errors intercepted	Mattsson et al., 2015 Reinhardt et al., 2019 Rosa et al., 2019
Relative Comparison of CPOE Systems	Recreating common errors in various systems Comparing Commercial Systems	Coleman et al., 2012 Fortman et al., 2020
User Experience and Reflections	Usability studies and simulations End-user opinions	Brown et al., 2017 Elshayib & Pawola, 2020 Griffon et al., 2017 Mozaffar et al., 2017 Mumcu et al., 2013 Wu et al., 2016
Clinical Risk Framework	Classification of CPOE within an established risk framework	Lichtner et al., 2020

In a large single site study, Reinhardt and colleagues (2019) evaluated 18,823 chemotherapy orders for 2,436 patients. The researcher found that CPOE was responsible for capturing 2% of all orders that required further review (Reinhardt et al., 2019). Further, 1.5% of the orders were clinically relevant, including those with potentially reduced efficacy of treatment (0.44%), the need for increased patient monitoring (0.48%), increased length of stay (LOS) (0.55%), and fatalities (0.02%) were avoided as potential consequences for those orders that were intercepted by CPOE. Although the overall number of errors intercepted was small (2.00%), the efficacy of the CPOE system was a failsafe for ordering becoming meaningful when weighed against the possible harms introduced by the system. This is particularly important when CPOE is used in high-risk clinical treatment settings, such as chemotherapy units in cancer care organizations.

In a multi-hospital implementation of CPOE in Brazil, Rosa et al. (2019) isolated orders for two high risk medications (i.e., potassium chloride for injection concentrate, and heparin). In the first site implementation, there was a 25% increase in the frequency of errors in the post-intervention period, and a statistically significant decrease in errors occurred following a CPOE implementation at the second site (Rosa et al., 2019). While no explanation was offered as to the difference in outcomes, the pre-implementation study period was two years length (i.e., in the two years prior to the implementation of CPOE). This means that other confounding factors may have affected the results, such as changes in clinical practice or guidance. The mixed findings from the study are indicative of the wide variety of approaches and impacts of CPOE on patient safety as they arise from implementing this technology.

10.4. Comparing CPOE systems

Two studies examined similar outcome metrics across a variety of CPOE systems, to better understand the factors that influence CPOE implementation. Differences in vendors, configurations and settings, end-user training/familiarity, and other factors may influence CPOE patient safety related outcomes. Understanding how various implementations compare in the context of similar metrics and technologies would enhance our understanding regarding how CPOE can impact patient safety, both positively and negatively. Two subthemes emerged in this scoping review, when

considering the differences between CPOE implementations. The first theme that emerged from the literature focused on errors and/or problematic workflows. Here, researchers attempted to recreate errors and problematic workflows across a variety of CPOE instances and systems. The second theme identified the need for direct comparisons between systems on a particular metric or variable across multiple CPOE implementations. This research was done to directly compare vendors and/or configurations in the context of a particular process, and then error rates were analyzed. Slight et al. (2016) designed a study that tested a wide variety of CPOE systems, for various types of common medication errors. The researcher found that among the varying systems.

> *"electronic alert warnings varied widely…and depended on a number of factors, including how the order information was entered. Alerts were often confusing, with unrelated warnings appearing on the same screen as those more relevant to the current erroneous entry. Dangerous drug-drug interaction warnings were displayed only after the order was placed rather than at the time of ordering. Testers illustrated various workarounds that allowed them to enter these erroneous orders." (Slight et al., 2016)*

The lack of industry-wide standards for presenting warnings and alerts to clinicians. This lack of information leads to variability in system design (Coleman et al., 2013; Slight et al., 2016). Some designs have the potential to improve patient safety, while others may be neutral, or hinder activities that may result in a clinical safety event. There is a need for comparative design studies to inform best practice, where on-screen design is concerned. There is also a need to ensure that critical information is easily accessible and as the user performs activities that may introduce risk.

Fortman et al. (2020) examined patient verification in the ordering process by tracking eye movement in a simulated ordering environment against two commercially-available EHR systems – Cerner and Epic Systems (Fortman et al., 2020). Ensuring that orders are entered for the correct patient is critical to ensuring safe patient care and treatment. It was found that 62.4% of the study scenarios led to the prescriber verifying the correct patient before or after placing the order. There was also a difference between systems, with participants using vendor A verifying patient identity in 79.6% of scenarios, while participants using vendor B verifying patient identity in fewer scenarios (i.e., 47.6%). The identity of the vendors (i.e., vendor A and B) was not revealed in the paper; however, it is clear from the results that there is a great variation in steps required to enter a medication, which can easily impact overall patient safety.

10.5. User experience and reflections

Staff perceptions of a system itself, or of the implementation of that system, can yield valuable insights as to how well the change was implemented. In addition to this, patient safety considerations that are not otherwise detectable through other methods, such as chart reviews can be undertaken. Such anecdotal feedback from staff may be more variable and opinion-based, but with the use of evidence-based user engagement approaches end-users of systems can be participants in the system evaluation process, project design, and/or system (Kirkendall et al., 2013). To illustrate, end user change management, training, post-implementation support, and overall change readiness can also be evaluated using surveys, and semi-structured interviews with impacted clinician end users (Khanna & Yen, 2014). Key subthemes for the User Experience studies were the 'voice of the user' studies, including surveys and semi-structured interviews that

gather information about systems and implementations. The second key subtheme that emerged was usability studies – in particular examining the differences between type of device (i.e., keyboard, mouse, screen and display) and error rates (e.g., a mistyped order).

An implementation of CPOE at a large academic hospital system had to be rolled back to paper following a loss-of-information incident three years after implementation (Griffon et al., 2017). The incident compromised patient safety. The researchers identified that data was lost between the ordering process, and a key section of the care plan. The organization stopped using the system and paper-based ordering was reinstated. A cross-sectional web survey of end users who used both paper and electronic ordering systems found that users were understandably more frustrated with the computer-based system. (i.e., "analysis revealed frequent bugs, crashes or problems with computerization") (Griffon et al., 2017). As such, end-users were more positive about paper-based ordering systems. This conclusion was not surprising given the short timeframe of the implementation (6 months of CPOE or less, depending on the unit/clinic) coupled with the need to 'roll back' to paper processes. This example illustrates how learning from failed implementations is an important aspect of systems implementation. Organizational learning from past experiences can be incorporated into subsequent implementations as illustrated in the quote below:

> *"…all the information collected and analyzed during this survey was useful for re-implementation of the CPOE system at RUH and helped to prevent HIT fallacies [35]. As a consequence, the budget of the information systems department has been substantially raised to allow for complete reorganization, better documentation and purchase of new servers. Also, the information systems hotline has been reorganized to allow for better understanding and implementation of users' needs. There are now not only more computers, but also newer computers on RUH wards, sometimes with multiple screens, easing visualization of medical records. Discussion with CPOE suppliers has resulted in a slight improvement in the readability of CPOE prescription." (Griffon et al., 2017)*

Although regarded as a failure to implement and sustain CPOE, an implementation failure can provide important lessons learned for future projects, both within that site, as well as for other hospitals considering CPOE implementation. Mozaffar et al. (2017) studied CPOE implementations across 6 hospitals in England, and conducted semi structured interviews with 214 participants, as well as a review of project-related documentation (Mozaffar et al., 2017). A taxonomy of factors resulting in safety threats was developed along with themes arising from suboptimal system designs, inappropriate usage of systems, and suboptimal implementation strategies. For greater detail, see Table 5.

Mozaffar et al. (2017) found that system design issues, system usage issues, and implementation issues may lead to potential patient safety threats in an ePrescribing system. It is assumed that ePrescribing systems are similar to CPOE. CPOE is used in an acute care setting. ePrescribing is used in primary care and community pharmacy settings. By developing a taxonomy of common issues, including underlying factors, the researcher illustrated how common issues need to be examined and mitigated amongst those hospitals choosing to implement CPOE solutions.

Mumcu et al. (2013) sent a questionnaire to physicians and nurses in 24 private medical facilities in Istanbul Turkey. CPOE was already in place at these facilities. It was found that with experience comes comfort and trust in the system among those who had been using CPOE systems for greater than 1 year (i.e., only 4.2% of clinicians wished to revert to their prior ordering system after a year of using the new systems) (Mumcu et al.,

2013). Furthermore, the researchers found that CPOE users improved their prescribing, patient safety, reliability, and legibility of their orders. The end users reported that systems were rated favourably by users. The users reported no change in accessing medications, dosages, alerting, speed, reducing error, communication, usability, and effects on decision-making.

Table 5
Safety threats and underlying factors

Safety Threat	Underlying Factors
Inadequacies in system design	lack of access to accurate timely information
	poor system performance
	poorly designed user interfaces
	lack of support for complex medication administration regimens
	lack of effective integration between different systems
	lack of effective automated decision support tools
Inappropriate use of system	incorrect data entry
	alert fatigue
	too much reliance on the system
	introduction of workarounds
	changes in work organisation
Problems in implementation strategies and infrastructure	partial roll-out/dual systems
	lack of appropriate training

Elshayib and Pawola (2020) found nine categories of unintended consequences. Specifically: 1) more/new work for clinicians, 2) workflow issues, 3) never-ending system demands 4) the persistence of paper, 5) changes in communication practices and patterns, 6) the emergence of negative emotions, 7) the generation of new kinds of errors, 8) changes in the power structure, and 9) the development of overdependence on technology (Elshayib & Pawola, 2020). This study also found seven types of flaws in system design, namely: 1) poor CDS design, 2) order duplication, 3) alert fatigue, 4) poor system interface design, 5) poor user interface design leading to errors in selecting, editing, or performing new tasks, 6) limited CPOE functionality and 7) poor screen display. There were also two socio-technical factors examined by the investigators: 1) communication between providers, and 2) lack of organizational readiness for change. The above was also observed by several researchers as an issue associated with CPOE implementation (Cooley et al., 2012; Farre et al., 2019; Kirkendall et al., 2013).

Patient safety issues associated with CPOE may not arise solely from system design and/or workflow. Devices used to access CPOE may also lead to errors (e.g., keyboards, mice, screens, tablets etc.) (Brown et al., 2017). Wu et al. (2016) compared the entering of orders via keypads (typically on the right of keyboards) and number bars (typically along the top of keyboards) to ascertain the effectiveness of various devices and the impact on medication entry error rates. The researcher found that orders entered on the number bar led to an increase in errors, particularly in scenarios that represented urgency (Wu et al., 2016). The investigators concluded that the type of device that is used to enter orders via CPOE can have an impact on patient safety, and accurate ordering.

In a systematic review of prescribing errors, Brown et al. (2017) found that factors such as auto-population, on-screen instructions, intuitiveness of workflows, documentation processes (including double-documentation), and user work processes all impacted the accuracy of prescriptions. Such considerations are an important factor for those interested in implementing CPOE. Many of these features are enabled in CPOE to save clinicians time and effort (Li et al., 2013) while at the same time they may also lead to errors. This is an important aspect of CPOE that needs to be recognized.

10.6. Clinical risk framework

Lichtner et al. (2020) examined CPOE as a medical intervention and applied a classification system developed by Vincent and Amalberti (2016). This innovative approach to classifying health information technology using a safety model yielded insights into the relative risk of CPOE and has made analogous comparisons to clinical workflow variation in safety. An overview of this approach is in Table 6, below.

Table 6
Classifying CPOE among a safety framework

Characteristics and Strategies	Examples within Healthcare	Examples outside of Healthcare
	Ultra Safe – Avoid Risk	
Power to regulators and system supervisors Defined 'no-go' contexts for operations, Rigid operating procedures, optimization of work processes/automation	Radio Therapy Blood Transfusion	Civil Aviation Nuclear Power
	High Reliability – Managed Risk	
Power to the group to organize itself, adapt. Organizational learning, improving capacity for monitoring, adaption and response, learning from incidents	Scheduled Surgery Chronic Care	Firefighting Oil & Gas
	Ultra-Adaptive – Embracing Risk	
Power to experts relying on personal resilience, expertise and technology. Developing professional expertise, knowing own limitations, learning from success	Innovative/clinical trial medications & procedures Trauma Care	Mountaineering Competitive Sports

Using the above model, the researcher classified CPOE (in a pediatric oncology setting) as an ultra-safe technology, but also analyzed both supporting and confounding factors associated with using the technology (Lichtner et al., 2020).

> *"Implementation of CPOE in chemotherapy appears to be a move towards ultra-safe, but our findings suggest that CPOE design must be improved. In such a complex and high-risk setting, CPOE design should facilitate clinicians' decision-*

> *making processes, rather than add difficulties. Lessons can be learned for design of chemotherapy CPOE that better supports the management of interdependences in regimens and workflows. This might include affording a variety of visualization displays over different time horizons and capturing more accurate timestamps of activities, tracking protocol variation and cumulative effects over time. CPOE implementations also need to support learning processes for clinicians to gain the awareness needed to use CPOE systems safety." (Lichtner et al., 2020)*

This researcher examined CPOE in a pediatric oncology setting (i.e., an already ultra-safe area of practice). The investigators concluded CPOE was a supporting technology in an otherwise risk averse area of clinical practice. The researcher also noted that the implementation process must also be considered, when including learning and awareness. Similarly, factors affecting the implementation process and actions taken pre-implementation were seen as important by others (Farre et al., 2019), who have advocated for the need for gradual transitions.

The themes above show the variety of ways that the patient safety of CPOE may be evaluated.

11. Discussion

In this section of the paper, we discuss the scoping review findings, study limitations, implications for health informatics practice, implications for health informatics rea and future research directions.

11.1. Patient safety benefits of CPOE

The implementation of CPOE can have positive implications on end-users' clinical practice (Farre et al., 2019). This can include benefits such as improving the ordering process itself (i.e., the legality of orders, ease of access to orders, and currency of orders (Farre et al., 2019). Farre and colleagues (2019) also reported that time savings occurred through faster prescribing and ordering, as well as checking on supplies (Mumcu et al., 2013). These benefits extended to the clinical teams' dynamics, with improved care coordination and communication among the clinical team as an outcome (Farre et al., 2019). The implementation of CPOE can also have positive effects on organizations. CPOE was shown to reduce medication errors and adverse drug events (Khanna & Yen, 2014; Maslove et al., 2011). One study found that CPOE contributed to a 20% reduction in mortality in a pediatric setting. Functionality enabled by CPOE, such as flags and alerts can increase the patient safety effects of CPOE, potentially preventing patient harm due to errors and omissions in the ordering process (Reinhardt et al., 2019). As such, CPOE may be considered a supporting technology for other systems that impact patient safety.

In addition to patient safety impacts, non-safety related benefits of CPOE were found. These included expedited test results for pathology testing with Emergency Departments with CPOE (i.e., patient flow and care timeliness) (Li et al., 2013). Although this was not the focus of this scoping review, the benefits to the health system arising from CPOE (aside from patient safety) must also be considered when considering this technology.

11.2. CPOE and patient safety risks

The implementation of any new technology carries risk, and CPOE is no exception. Risks were found to originate from; inadequacies in system design, inappropriate use of the system and problems with the implementation strategy (Mozaffar et al., 2017). CPOE may also fail to intercept errors in the ordering process, including dosing errors (Kadmon et al., 2020). Workarounds due to difficult in-system workflows or incomplete training were also found to result in potential errors (Elshayib & Pawola, 2020; Slight et al., 2016). These errors may result from CPOE designs that increase the complexity of what was historically a simpler routine task (according to CPOE users) (Farre et al., 2019).

Medication errors were also found to increase at some facilities. Some studies reported that these correlations between medication errors and the implementation of CPOE emerged (Elshayib & Pawola, 2020). Factors that may contribute to medication errors include more/new work for clinicians, workflow issues (such as improper CPOE design), system demands such as re-training, paper persistence in the ordering process, changes to communication patterns, negative emotions, change resistance, the emergence of new kinds of errors (such as text-input errors), changes in the clinical power structures and overdependence on technology, were all found to contribute to medical errors as a result of CPOE (Elshayib & Pawola, 2020).

Implementation planning may also lead to CPOE-linked adverse outcomes. A failure to plan for technology and computer devices used to operate CPOE systems was also found to be an impediment to patient care (Farre et al., 2019). Organizational change readiness and change management were found to contribute to poor user experiences during CPOE implementations (Elshayib & Pawola, 2020). Inappropriate user training was found to contribute to errors in the post-implementation period (Farre et al., 2019).

As a supporting technology to other components of the EHR, CPOE may indirectly contribute to patient safety events. More specifically, alert fatigue was noted as a potential source of error (Coleman et al., 2013; Slight et al., 2016). Failure of the system to alert users to ordering errors may also contribute to patient safety incidents (Kadmon et al., 2020). Although not directly relevant to this scoping study, additional research is required to understand the risks associated with other technologies that are supported by CPOE.

11.3. Risk avoidance and mitigation strategies

When implementing CPOE, attention must be paid to the potential risks resulting from CPOE. There are numerous frameworks that can that address error and mitigation strategies. System improvement strategies include system design enhancement (i.e., short term fixes and bug removal) and extensions of the system (i.e., medium and long term planned system enhancements) (Mozaffar et al., 2017). Ongoing upgrades and improvements in technological (i.e., in-system) workflows may also increase CPOE effectiveness (Elshayib & Pawola, 2020). Additionally, system updates and upgrades to the most recent version of CPOE software and safety features may reduce clinical errors drastically (i.e., 61% of errors prevented, and 5% of errors less likely to occur) (Reinhardt et al., 2019).

User interface design and human factors considerations while using CPOE were also found to be important. User interface design decisions such as colour selection, bold fonts, and tall-man lettering, can also contribute to safe CPOE usage. The availability and usage of appropriate computer and peripheral devices was found to contribute to safe usage of CPOE (Brown et al., 2017; Cooley et al., 2012; Wu et al., 2016). Organizational

strategies included: appropriate alert management, assessing change in practice, assessments of workarounds, analysis of incident reporting tools, training, and user awareness (Mozaffar et al., 2017).

11.4. Study limitations

This scoping review was limited by the study inclusion criteria, and the databases that were searched. Relevant data and findings may exist in other databases or under different search criteria. Further, many studies were limited to examining safety issues or error rates with a particular drug or treatment specified, which may not be transferable to other orderable medications and/or procedures (Dequito et al., 2011). Other health information technologies are often interrelated in the context of CPOE, including Clinical Decision Support (CDS) and electronic clinical documentation. Most often, these technologies are be implemented in parallel. This may result in additional clinical risks (Tolley, Forde, et al., 2018) as well as potential clinical benefits to the organization (Maslove et al., 2011). This scoping review attempted to isolate the effects of CPOE only; however, if implementing a full suite of health information technology at once, a comprehensive review of each technology to be implemented would be beneficial to participants.

11.5. Implications for health informatics practice

Healthcare organizations and technology vendors regularly look to patient safety as a consideration for implementing CPOE. This scoping review highlights a variety of patient safety impacts associated with implementing CPOE, and in some cases, the findings associated with implementing the technology were mixed (Mattsson et al., 2015; Tolley, Forde, et al., 2018). There is a continuum of patient safety relationships arising from CPOE, not all of which are positive. Specific considerations must be paid to implementation decisions, such as the layout of key information displayed during the ordering process (Fortman et al., 2020), and the devices used to operate the system (Brown et al., 2017; Cooley et al., 2012; Wu et al., 2016), to reduce potential sources of error.

Those healthcare facilities considering implementing CPOE would be wise to consider the variety of sources of potential patient risk. Consideration must be applied to the layout of key information on each screen, the physical environment in which users interact with the system on the ward or clinic (Coleman et al., 2013; Tolley, Forde, et al., 2018), and interfaces between other components of the EHR (Mozaffar et al., 2017). These factors may be potential sources of patient harm and must be contemplated throughout a CPOE implementation. The intrinsic benefits of CPOE on patient safety is less than clear, but is impacted by the level of attention applied to the implementation.

11.6. Implications for health informatics education

This scoping review would suggest that there are opportunities within the health informatics field to better understand the impacts and causes of clinical risk with relation to technology, as well as strategies to measure and mitigate risks resulting from CPOE. The variety of ways used to measure risk found throughout this scoping review ranged in nature (i.e., from user surveys to chart reviews). This suggests a lack of consensus on how to best measure quality and risk in a clinical setting.

Numerous studies included in this scoping review also highlighted non-technical factors that may impact CPOE implementation, specifically organizational readiness and change management efforts (Cooley et al., 2012; Farre et al., 2019; Kirkendall et al., 2013). End user training was also found as a potential underlying risk factor for safety threats (Mozaffar et al., 2017). Training future leaders on adult education and appropriate curriculum design for EHRs or CPOE technologies would help to reduce concerns about end user training during new projects. Furthermore, enabling users to access medical guidance at the point of care and sharing information among the clinical team can also have important communication and patient safety benefits. (Mather & Cummings, 2015). These skills are important to the safe implementation of CPOE and EMRs in general, and to ensure that students are prepared with the relevant implementation skills. This is an important consideration for implementing systems.

11.7. Future research directions

Several studies in this scoping review highlighted differences in patient safety results, despite implementing similar technologies (Cooley et al., 2012; Kirkendall et al., 2013; Maslove et al., 2011). One possible cause of these differences may be their being limited research focusing on organizational readiness where health information technology implementations and operations are concerned (Cooley et al., 2012; Maslove et al., 2011). Implementation readiness concerns the various steps required to implement significant changes to clinical practice as a result of CPOE and other health information technology systems (Kirkendall et al., 2013). Organizational change management, end-user training, and end-user involvement in system design were rarely mentioned in the published research. Furthermore, many of these studies critically evaluated the successful adoption of CPOE and other health information technology tools (Kirkendall et al., 2013). There is a need for further research focusing on how organizational readiness factors influence implementations. Such research may yield valuable insights into best practices for that may better prepare users to be able to change practices and implement new technologies (Cooley et al., 2012).

There is also a need to study the impact of an ideal state of configuration of CPOE and other health information technologies (Borycki et al., 2013a; Dhillon-Chattha et al., 2018; Khanna & Yen, 2014). Commercial CPOE systems allow for an organization to customize the functions of the system to meet local needs or workflows. None of the studies selected for this paper examined the differences in local configurations of their systems as a potential source of error. Configurations may help in patient safety by enforcing best practice, providing alerts or reminders to clinicians, or providing 'default' treatment plans that are in accordance with the most recent medical literature (for example order sets may be configured with the latest medical evidence for treatment for a particular condition or disease) (Coleman et al., 2013). Understanding contextual factors and pressures in healthcare delivery to better integrate CPOE can be enhanced by experiential design, with potential impacts on access, delivery and receipt of healthcare (Campbell, 2020). There is also pressure for systems implementers to configure systems to closely match pre-implementation workflows to limit the need for change management interventions and staff training. However, mirroring previous workflows and practices may not be the most effective method for configuration, as historical workflows may not be in keeping with the most recent recommendations published in the health informatics or medical literatures. As such, the design of CPOE systems should be studied in greater depth and across CPOE implementations.

Future research should also establish the patient safety case for varying health information technologies to identify which technologies will have the greatest impact on patient safety, and those with the highest degree of risk. Such knowledge would support organizational decision making about which technologies to implement first. For organizations with a limited budget or capacity to implement new technological systems, understanding the impact of various options would help in the planning and deployment of these solutions.

12. Conclusion

The deployment of health information technology brings about many risks (Tolley, Forde, et al., 2018), as well as opportunities to modernize care. CPOE systems have a unique ability to aid in the process of clinical decision making by supporting clinician's decision-making, as well as monitoring of health-related patient interventions (e.g., medication regimens). By providing clear, legible medication orders that are routed directly to the other clinical team members (including a pharmacist for validation and dispensing and a nurse for administration), the possibility of mistakes can be reduced or eliminated (Imfeld et al., 2012). Additionally, alerts and flags can signify an incorrect or contraindicated order. Such an alert provides the prescriber with an opportunity to reconsider treatment. As such, alerts and flags can be a powerful support for ensuring safe, high-quality care for all patients.

In this scoping review, some studies examined safety from the perspective of a single facility that has implemented CPOE technology. Others have examined CPOE from a multiple facility experience using a single patient safety metric, or a group of patient safety metrics to identify the source of variation among differing CPOE technologies and local supporting workflows. Still other facilities look to end-users' opinions about CPOE with a focus on patient safety. Lastly, one study examined CPOE within a safety framework that contextualized the technology.

Careful deployment of CPOE technologies have the potential to improve patient safety, but they may also introduce new types of risks and errors into clinical practice (Borycki et al., 2013a). Errors may be introduced at the design (enterprise) level, with specific repeatable workflows, or at an individual order level (Borycki & Kushniruk, 2013a). The development of mitigation strategies and awareness of the potential risks associated with using a system is the first step in maximizing potential benefits while minimizing risk. Learning from other organizations' experiences' is key to ensuring successful deployments. End-users have new responsibilities as clinical practice becomes more digitized, including proper documentation, the prompt entering of orders, as well as care fulfillment. All these activities require that processes must be clearly articulated and constantly improved. The lack of industry-wide design standards leads to variability in technological solutions with some solutions being safer than others when performing particular clinical tasks and in preventing errors which may impact clinical care.

Author Statement

The authors declare that there is no conflict of interest.

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Appendix I

Data charting results

Authors	Year of publication	Aims/purpose	Sample	Study Setting (ER, Ambulatory, etc.)	Country	Methods	Intervention Technologies	Indicators	Findings	Limitations
Brown et al.	2017	Find types of, and causes of prescribing errors with CPOE, and recommended improvements.	n/a non experimental study	n/a - non experimental study	UK/USA	Systematic Review	CPOE	System-related error, user related error and system/user related error	Computer screen display, drop-down menus & auto population, Wording, Default settings, Non-intuitive ordering information (including interoperability), Repeat prescriptions and automated processes, Users work process, CDS systems.	Somewhat Dated - Search ended June 2015, so newer innovations in CPOE technology not included. This paper appears almost entirely considers the physician point of view, with little attention paid to med fulfillment (dispensing), administration functions (nursing), or other closed loop med admin activities, which may contribute to, or mitigate errors. Some findings are contradictory - for example recommendation #1 is that all medications should be displayed in one area, while recommendation #5 is to avoid long lists of medications.
Elshayib & Pawola	2020	To review and summarize evidence of CPOE-related MEs (Medication Errors) in hospitalized patients, and sociotechnical factors impacting safe usage of CPOE	n/a non experimental study	Acute care hospitals	USA	Systematic Review	CPOE	Rates and statistics on CPOE-related med errors, types of CPOE-related unintended consequences, factors related to CPOE-failure, recommendations addressing sociotechnical factors.	Unintended Consequences - More/new work for clinicians, Workflow issues, Never Ending System Demands (access device issues/upgrades), paper persistence, Changes in communication, Negative Emotions (change resistance), Generation of new errors (e-Iterogenisis), Changes in the power structure, dependence on tech. Flaws in System Design - Poor CDS, Order duplication, Alert fatigue, UI issues, Design issues, limited functions & display issues. Sociotechnical - Communication issues, Change Readiness/system usability.	Difficult to separate CPOE vs other technologies in findings. A structured approach to categorizing and presenting findings would be beneficial
Fortman et al.	2020	Determine rates of Patient Identity verification when using CPOE to order, using eye tracking technology.	n(study scenarios)=6 n(EHR systems)=2 n(participants)=55 n(excluded participants)=16 n(excluded scenarios)=6 n(included scenarios)=150	Study took place in an office environment. Participants were ER doctors.	USA	Cohort study	CPOE in two commercial systems (Cerner, Epic)	Pt verification rates, and non verification rates. Verification before signing order and after. Most frequent location for verifying pt. identify (i.e. banner bar).	Vendor A had higher pt. verification rates, and higher rates of pre-order signing verification. Only 62.4% of scenarios had any pt verification (both systems)	Small sample. Office environment to study ER physicians (fewer distractions, noise, cognitive load). No controlling for variations in end-user training/familiarity with the system.
Griffon et al.	2017	Evaluate users' (medical residents) satisfaction with CPOE and paper-based order entry, when their system experienced	n(residents)=51	Acute care hospital. Rouen University Hospital	France	Cross-sectional study (web survey)	CPOE, Paper Based Ordering	User satisfaction, usability, reliability, time consumption, communication with RNs, experience levels with both systems.	Reliability, usability and patient safety all increased with paper system.	Surveys measured users' opinions, not factual data (i.e. actual patient safety data). Did not consider qualitative analysis of issues (only perceptions of those who were surveyed). Did not differentiate by clinical population/setting.

		issues.								or by clinical speciality (surgeons, ER etc.) of participants. Occurred after the system had failed (i.e. not after a successful solution was found, which may have increased satisfaction)
Lichtner et al.	2020	Evaluates CPOE against other safety strategies in pediatric clinical oncology. Secondary focus was on CPOE's impact of interdependencies in pediatric oncology care.	post-CPOE implementation oncology incident reports: n(total)=827 semi-structured interviews: n(total)=19; n(doctors)=10, n(nurses)= 6, n(pharmacist)=1, n(IT clinicians)2	Pediatric oncology. 350 bed Pediatric facility in NSW	Australia	Mixed Methods study (Data Analysis & Semi Structured Interviews)	CPOE	Incident reports content analysis classified by Vincent and Amalberti's (2016) safety model (ultra-safe, high-reliability [manage risk], or ultra-adaptive[embracing risk]). Semi Structured transcript content analysis - same method as above.	CPOE is considered an 'ultra-safe' technology because of; automation, access to information, standardization of the semantic of protocols (disambiguation). 'Ultra-safe' was challenged based on; complexity of using the system, difficulty assessing patient's progress throughout protocol.	oncology only. Doesn't apply to clinical settings outside of the ultra safe (i.e. trauma care, experimental care etc.).
Mattsson et al.	2015	Determine error rates for orders in CPOE vs Paper environments	n(prescriptions)=5767	Inpatient Oncology	Denmark	prospective comparative cohort study	CPOE	Patient characteristics, Prescription-related info, Patient chart review, Correct anti-neoplastic dose is according to guidelines (y/n), episodes of neutropenia and fever prior to dose.	No statistically significant difference between CPOE & Paper	Possible Hawthorn effect of all prescribers, particularly paper cohort. Study error rate was abnormally low, and beyond the bounds of other studies n(error_rate)=1.73%, n(rates reported in authors citations)=2%-20%.
Mozaffar et al.	2017	A review of evidence to find root cause of unintended safety threats associated with introducing ePrescribing systems. Examined threats that emerge in system design, implementation, and usage & developed a taxonomy to develop risk mitigation strategy.	n(interviews)=214 n(observations)=24 n(documents)=18	Acute care hospitals	England	Longitudinal multi-site case study	health information technology systems	Inadequacy of system design, Inappropriate usage of system, implementation/infrastructure	Factors underlying unintended safety threats in: (1) suboptimal system design, including lack of support for complex medication administration regimens, lack of effective integration between different systems, and lack of effective automated decision support tools; (2) inappropriate use of systems--in particular, too much reliance on the system and introduction of workarounds; and (3) suboptimal implementation strategies resulting from partial roll-outs/dual systems and lack of appropriate training.	Qualitative study and entirely based on opinions of end users. No qualitative component. Only considered clinicians in interviews -
Mumcu et al.	2013	The aim of the study was to compare the effectiveness and outcomes of computerized provider order entry (CPOE) between physicians and nurses in emergency care (EC) services	n(physicians)=24 n(nurses)=24	Emergency Medicine	Istanbul, Turkey	in person questionnaires	CPOE	1) General information about study participants, 2) Efficiency of CPOE in Medications 3) Efficiency of CPOE in Clinical Practice 4) Outcomes of CPOE in Clinical Practice	No significant difference was found in score (OF) item effectiveness regarding 'accessing list of medication', 'dosages and prescriptions' 'alerting drug interaction', 'faster prescription' 'reducing prescribing error', 'providing effective communication with staffs', 'easy working' and 'easy managing', 'allowing decision making' and saving time' between physician and nurses ($p>0.05$). However,	asking nurses about prescribing (unless it is part of their role, such as an NP) is misleading. Comparing the two professions is questionable. No objective definition for "easy working" or "easy managing".

									significant difference was seen in score of 'being better approach for prescribing' between physician and nurses (p=0.038). Almost similar scores were seen in items of outcomes regarding 'achieving patient safety' and 'increasing reliability and legibility of data' (p>0.05).	
Reinhardt et al.	2019	1) Identify the relative frequency, root causes, and potential consequences of chemotherapy prescribing errors, 2) to determine whether errors identified could be prevented using an upgraded CPOE tool, and 3) to develop effective methods for error avoidance by combining software engineering with conventional safety measures	n(patients)=2,436 n(orders)=18,823	Chemotherapy	Germany	retrospective cohort study	CPOE + manual review	chemotherapy prescribing errors, total orders, clinically relevant errors, classification of errors (i.e. avoided harm): reduced therapeutic efficacy, the need for increased monitoring, prolonged hospital stay, and fatality	406 chemo orders were intercepted (2%). Clinically relevant in 375 (1.5%). reduced therapeutic efficacy (0.44%), the need for increased monitoring (0.48%), prolonged hospital stay (0.55%), and fatality (0.02%) were avoided as potential consequences. Of all the errors analyzed, 61% would be avoided through further software development.	only looked at chemotherapy orders (i.e. entered by a specialist, administered by a specialist - doesn't apply to broader clinical context (ER, Inpatient) where specialists are less likely to be found.
Rosa et al.	2019	To assess the frequency and severity of prescriptions errors with potentially dangerous drugs (heparin and potassium chloride for injection concentrate) before and after the introduction of an electronic prescribing system.	n(hospitals)=2 n(orders)=1028 quantity of orders in each cohort not specified.	Hospitals	Brazil	Retrospective cohort.	ePrescibing/CPOE	Used criteria from Dean, barber and Schacter (2000) to classify errors: a)errors in the decision process b) errors in the writing of the prescription Secondary criteria -Prescriptions with at least 1 error -Pharmaceutical form -Concentration -Administration route -Administration interval -Dose	An increase of 25% in the frequency of errors in Hospital 1 was observed after the intervention (p<0.001). In contrast, a decreased error frequency of 85% was observed in Hospital 2 (p<0.001). Regarding potassium chloride, the error rate remained unchanged in Hospital 1 (p>0.05). In Hospital 2, a significant decrease was recorded in Stage 2 (p<0.001). A reduced error severity with heparin (p<0.001) was noted, while potassium chloride-related prescription severity remain unchanged (p> 0.05).	Brazilian study - differences in practice from Canada? Didn't specify how or why one hospitals results were different - different patient catchment populations? Was training the same? Etc.? The pre- results were long before the post results so other factors could have influenced data. Study didn't specify the full sample of orders that were reviewed, nor how errors were identified as part of the sample.
Slight et al.	2016	test the vulnerabilities of a wide range of computerized physician order entry (CPOE) systems to different types of medication errors, and develop a more comprehensive qualitative understanding of how their design could be improved.;	The authors reviewed a random sample of 63,040 medication error reports from the US Pharmacopeia (USP) MEDMARX reporting system where CPOE systems were considered a "contributing factor" to errors and flagged test scenarios that could be tested in current CPOE systems.	Various (Community & academic hospitals + private practice in inpatient and outpatient settings)	USA	Mixed methods study -review and categorization of med errors found in MedMarx DB, and -simulating these errors within a variety of CPOE systems	CPOE + CDS	Alert warnings (Generation, wording, timing, level of severity), workarounds,	CPOE systems often failed to detect and prevent important medication errors. Generation of electronic alert warnings varied widely between systems, and depended on a number of factors, including how the order information was entered. Alerts were often confusing, with unrelated warnings appearing on the	Study used numerous systems to study, but failed to consider aspects like unique configuration/development that happens in these systems, end user training etc. Study focused primarily on how the system failed to alert when an error was entered, but didn't consider other factors that may have led to the error (insufficient training, unclear workflows, staff miscommunication or cognitive load). Study also

									same screen as those more relevant to the current erroneous entry. Dangerous drug-drug interaction warnings were displayed only after the order was placed rather than at the time of ordering. Testers illustrated various workarounds that allowed them to enter these erroneous orders.	had users recreate known errors, which introduced artificiality in the study participants.
Wu et al.	2016	This study aimed to examine the effects of numeric inputting methods (i.e. keypad vs top row numbers), daily prescription behaviour (i.e. transcribing written orders at EOD), and urgency levels on numeric inputting errors of prescription (cognitive load/stress).	n(residents)=30 n(scenarios)=4	Not specified but presumably a simulated (office) setting.	China	Simulation study	CPOE	Numeric inputting, Errors of each digit (inc numeric distribution, spatial incidence [delta], confusion	In urgent situations, error rates were higher, particularly with the number bar. Error rates didn't increase in control scenario. . Most errors were either omission or substitution types, but the proportion of transposition and intrusion error types were significantly higher than that of the previous research. Among numbers 3, 8, and 9, which were the less common digits used in prescription, the error rate was higher, which was a great risk to patient safety	simulated environment, limited study participants (residents). Didn’t factor out training/ experience with the system etc.