Effects of implementing Computerized Provider Order Entry with various levels of Clinical Decision Support System: a systematic review

Prosjektoppgave

av

Hallvard Solbø Hagen
kull: Høst -11
Effects of implementing Computerized Provider Order Entry with various levels of Clinical Decision Support Systems: a systematic review
Hallvard Solbø Hagen, stud. med.

Abstract
Context: Errors in the phases of medication ordering have been shown to pose a huge threat to patient safety in health care. One of the means to combat these errors have been the implementation of information technology in health care.
Objective: To analyze effects of implementation on medication errors (MEs) after stratifying trials based on the level of Clinical Decision Support System (CDSS).
Methods: Systematic search in Medline and Embase for papers describing the effect on implementation of Computerized Physician Order Entry (CPOE) with or without (CDSS) in an inpatient setting.
Results: An increase in the effect with the increasing level of complexity from 2/6=33% for “no CDSS”, 3/6=50% for “Basic CDSS” and 8/12=67% for “Complex CDSS” was found. The effect was found both in procedural errors and clinical errors.
Conclusion: An inverse relationship between the level of CDSS and medication errors can be found.

Introduction
Medication errors (MEs) have been repeatedly demonstrated to pose a huge threat to patient safety (1) for a long time. MEs can occur in all phases from prescribing, transcription, administration, dispensing and monitoring. One of the means to combat this challenge is the introduction of information technology in health care. This includes, but is not limited to, the introduction of Computerized Physician Order Entry (CPOE) systems replacing the handwritten prescriptions, with a varying levels of Clinical Decision Support System (CDSS) conveying an additional effect (2, 3).
The CDSSs are constantly being developed and can include features such as drug-drug interaction checks, drug-laboratory checks, order sets and predefined clinical pathways. These features can be adapted to the needs of the specific setting of the targeted institution. Several review articles have demonstrated the positive effect implementation can have on ME rates (3-5).
While initially gaining enthusiasm, several drawbacks have been highlighted in the recent years. Several of these concern the level of CDSS where examples such as alert fatigue, increased workload and overdependence on technology (6) have been reported. The aim of this paper is to try to shed a light on the effect on the medication errors at each level of CDSS. To my knowledge such a stratified approach has not previously been performed through a systematic way.

Methods
The search was initiated by formulating a PICO question creating the stem for a systematic search through Ovid Medline (In-Process & Other Non-indexed Citations, 1946 to September 2016) and Embase and Embase Classic (1947 to September 2016) using free-text with synonyms, MeSH-terms and Emtree-terms (listed in appendix 1 and 2) on 26 August 2016. Bibliographies of all relevant review articles were scanned for relevant articles.

Inclusion and exclusion criteria
The criteria for inclusion were: language (english or scandinavian), analytical (7) primary study, inpatient study population, implementation of CPOE with or without CDSS, effect on medication errors.

Abbreviations
ME: Medication Errors
ADE: Adverse Drug Effect
CPOE: Computerized Provider/Physician Order Entry System
CDSS: Clinical Decision Support System
PE: Prescribing Error
The criteria for exclusion were: no abstract, text not available text through university library, mixed population of inpatient and outpatient, theoretical implementation of CPOEs.

Articles with a main focus on the implementation of a CPOE with MEs as one of the main endpoints were included. Previous reviews have limited its scope to prescribing errors (PE) but several papers included used a wider definition and thus included errors committed in the phases of transcription, dispensing, administration and monitoring.

The selected articles were then classified according to a set of variables to identify the heterogeneous nature of software, study design, type of ward, length of data collection etc. As a consequence of the aforementioned heterogeneity it was found futile to perform a meta-analysis, but rather perform a qualitative assessment after classifying the articles using level of CDSS as independent variable to examine the effect on medication errors on each level.

CDSS was defined as ”Computer-based information systems used to integrate clinical and patient information and provide support for decision-making in patient care” as proposed by the National Library of Medicine (8). Three distinct groups were created based on the descriptions in the included articles; “No CDSS”, “basic level of CDSS” and “complex level of CDSS”. See table 1.

Where the functionality of the system to be implemented was described, but no indication of CDSS was given, the “No CDSS” was chosen.

Order sets were defined as being a part of the CDSS as these would be defined by the diagnosis given to the specific patient.

<table>
<thead>
<tr>
<th>Study design</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1) Randomized Controlled Trial</td>
<td>Includes quasi-randomized processes such as alternate allocation include intervention and control groups</td>
</tr>
<tr>
<td>2) Non-randomized controlled trial</td>
<td>Includes prospectively planned studies with predetermined eligibility criteria and outcome measures or prospective cohort studies that</td>
</tr>
<tr>
<td>3) Observational Study with control and</td>
<td>Includes retrospective, interrupted time series (a change in trend attributable to the intervention), case-control studies, cohort studies with controls, and health services research that includes adjustment for likely confounding variables</td>
</tr>
<tr>
<td>4) Observational study without control</td>
<td>Includes cohort studies without controls and case series</td>
</tr>
</tbody>
</table>

Classification of effect
The classification was based on a tabulation published in a previous review article by Eslami et al (10) indexing the outcomes into positive effect, no effect, negative effect and mixed effect. The positive and negative effects were subdivided into “demonstrated effect”, “statistically significant” and “mixed effect”. As weighting every single outcome would be extremely time-consuming (if not to say impossible due to the heterogeneity encountered) the summarized classification was based on the effects on overall error rate (when available) or a qualitatively assumed impact on patient safety (n=2).
Results

The systematic search resulted in 499 articles, 204 and 295 from Medline and Embase respectively. See figure 1. Fifty three of these were duplications and 48 did not contain an abstract. 18 review articles were found and a manual search through the review bibliographies was performed which resulted in the inclusion of 29 articles. A total of 409 articles were thereafter excluded on the basis of title and abstract. Four papers were excluded because they included data collection from outpatients or primary care patients. Some papers collected data from previously existing CPOEs with an additional upgrade (n=13). Papers that failed to relay information on the level of CDSS were excluded (n=6). Preliminary reports, research letters, letter to editor, commentaries, correspondence, short communications, editorials, clinical face-offs, “in reply”, roundup, case studies, poster presentations, supplements and conference abstracts were excluded (n=32).

Of the 77 articles requested, 17 were not available through the subscriptions of university library at the University of Oslo and 36 were excluded based on the aforementioned exclusion and inclusion criteria leaving a total number of 24 articles regarded as pertinent.

The bulk of articles were from the USA (11/24=46%) with the UK (4/24=17%) and Spain (3/24=13%) as runner-ups.

CPOE

A total of 19 different CPOEs were implemented, some commercial, some homegrown. In most cases a single system was being compared to the previous handwritten system. Some trials compared two different systems to baseline (11, 12). No clinical single system was tested in more than 2 trials.

Departments

9 trials were performed at pediatric wards, 1 trial at both pediatric and adult wards, while 14 were performed at adult wards.

The types of departments were very heterogeneous with a mix of medical and surgical wards where no type of department was represented in more than 3 papers. Some papers were limited to only one ward, whereas some trials performed a hospital-wide implementation.

Study design

As previously reviews have reported (10, 13), very few of the studies were of the RCT design (n=1) while the majority were crafted in a prospective before-after fashion and therefore categorized in group 1) (n=10). Four trials were purely retrospective and were classified in group 3). No studies fitted the criteria of group 4).

See table 2, table 3 and appendix 3.

Outcomes

A wide range of outcomes during all the phases of medication ordering were measured with the majority assessing several outcomes during the same trial. The ones concerning MEs can be placed in
two broad groups as suggested by Westbrook et al (11) in an attempt to classify errors committed during the prescription phase.

- **procedural error**: e.g. legal/procedural (local policy on the filling of prescriptions), unclear orders and incomplete orders. The group can be defined as all errors concerning the flow of information.

- **clinical errors**: e.g. duplication, wrong strength, wrong dose/volume, wrong rate/frequency, wrong route, wrong drug, drug not prescribed, drug-drug interaction, not indicated, wrong formulation, inadequate monitoring, allergy, wrong patient, Adverse Drug Events (ADEs) with the subdivisions such as potential ADEs, preventable ADEs. This group can be defined as all errors concerning the adherence to best practice for the specific patient.

Many of the papers also focused on the interceptability of the errors, defining the as either intercepted and non-intercepted error, meaning these could be placed in either of the above mentioned error groups depending on the nature of the error.

### Table 3

<table>
<thead>
<tr>
<th>Level of CDSS</th>
<th>Study design</th>
<th>Total</th>
<th>Positive</th>
<th>No effect</th>
<th>Negative</th>
<th>Mixed</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Demonstrated&lt;sup&gt;iii&lt;/sup&gt;</td>
<td>Stat. sig.</td>
<td>Mxd&lt;sup&gt;iv&lt;/sup&gt;</td>
</tr>
<tr>
<td>No CDSS</td>
<td>1&lt;sup&gt;iii&lt;/sup&gt;</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>2&lt;sup&gt;iii&lt;/sup&gt;</td>
<td>6</td>
<td>-</td>
<td>2</td>
<td>2</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>3&lt;sup&gt;iii&lt;/sup&gt;</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Basic level</td>
<td>1&lt;sup&gt;iii&lt;/sup&gt;</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>2&lt;sup&gt;iii&lt;/sup&gt;</td>
<td>4</td>
<td>-</td>
<td>2</td>
<td>1</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>3&lt;sup&gt;iii&lt;/sup&gt;</td>
<td>2</td>
<td>-</td>
<td>1</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Complex level</td>
<td>1&lt;sup&gt;iii&lt;/sup&gt;</td>
<td>1</td>
<td>-</td>
<td>1</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>2&lt;sup&gt;iii&lt;/sup&gt;</td>
<td>9</td>
<td>1</td>
<td>6</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>3&lt;sup&gt;iii&lt;/sup&gt;</td>
<td>2</td>
<td>1</td>
<td>-</td>
<td>-</td>
<td>1</td>
</tr>
</tbody>
</table>

<sup>1</sup> When reported as such by the authors, with or without statistical arguments

<sup>ii</sup> Mix of positive, absence of, and negative effects

<sup>iii</sup> When the authors report a predominantly positive effect but without reporting statistical significance.

<sup>iv</sup> Mix of statistically significant and demonstrated positive effects.

<sup>v</sup> When the authors report a predominantly negative effect but without reporting statistical significance.

<sup>vi</sup> Mix of statistically significant and demonstrated negative effects.

<sup>vii</sup> Randomized controlled trial

<sup>viii</sup> Non-randomized controlled trial

<sup>ix</sup> Observational study with control

### Effects

Although no certain conclusion can be drawn from this material a certain increase in the effect is suggested with the increasing level of complexity from 2/6=33% for “no CDSS”, 3/6=50% for “Basic CDSS” and 8/12=67% for “Complex CDSS”.

### No CDSS

In six of the papers a CPOE without CDSS was implemented (14-19) where all of them were classified as non-randomized trials with controls. Four trials showed a predominantly positive effect on
medication errors where the trials of Shawahna et al (17) and Shulman et al (17) showed a statistical significant level whereas the trials of Warrick et al (19) and Franklin et al (16) showed a mix of demonstrated and significant effect. The only trial to show a predominantly negative effect of all papers included was Evans et al (20) while the results King et al (21) were of a mixed nature.

**Basic level of CDSS**
Six trials implemented a basic level of CDSS (12, 22-26). Four of the study designs were classified as non-randomized trials with control and two classified as observational studies with controls. The studies of Bates et al, Bizovi et al, Holdsworth et al and Delgado Silveira et al (22-25) showed a predominantly positive effect, all statistically significant with the exception of Bates et al which was classified as mixed level of evidence. The studies of Upperman et al and van Doormal et al (12, 26) showed mixed results.

**Complex level of CDSS**
Twelve trials implemented a complex level of CDSS (2, 6, 11, 27-32). The only trail, of all the papers included, performed in a randomized controlled fashion was that of Colpaert et al (33). Nine of trials were rated non-randomized controlled trial and two as observational studies with controls. Eight papers showed a predominantly positive effect (2, 6, 11, 27-31, 33) where six of these were statistically significant. The papers of Zucker et al and Hernandez showed a mixed effect while that of Walsh et al showed no effect post-implementation.

**Discussion**

**Trends**
When classifying the outcomes as either procedural error or clinical error a trend of increased positive impact on both variables with increasing level of complexity is suggested. Especially interesting are the reports on positive impact on the level of ADEs as one study showed that clinical error rates in fact increased, though masked by a larger reduction of procedural errors (11), yielding the impression of an overall reduction. See appendix 3.

**Heterogeneity**
As shown in the descriptive part of the results the clinical situations analyzed constitute a high degree of complexity in terms of age group, type of CPOE and type of department. It should come as no surprise that the rate of errors vary from ward to ward (17). Another factor, controlled for by some of the papers, is the rate of errors made dependent on the experience of the prescriber (17, 34). For example, Shawahna et al classified physicians as either junior or senior and showed that the junior doctors committed more medication errors than their senior counterparts and that the difference in demographics at the wards under scrutiny were large.

The same level of complexity is found in the design of CDSS functionality where features such as the ability to override alerts and the timing (synchronous vs asynchronous alerts (35)) vary.

Most of the studies where before-after studies without a non-intervention control ward. While this may be considered a design weakness some trials including concomitant control wards did not experience any reduction in the control ward (11), although others did (21).

Bates et al (2) collected data through several periods and were therefore able to identify and correct system-related errors with a significant impact on error rates while other trials only collected data at two time-points and were thus unable to adjust the software based in initial audit.

Hopefully, by defining a clear research question, performing a systematic research and standardizing data extraction, some of jumbled nature of the question at hand has been counteracted throughout this paper.
Confounding factors
In some of the papers the implementation of the CPOE with or without CDSS was one of several concomitant measures intended to increase patient safety such as validation by clinical pharmacists (36) informational campaigns (17), lectures and pamphlets. One might assume that raised awareness might have contributed to a reduction in errors. (37) There were also major discrepancies in the time between implementation to data collection ranging from 1 week to 13 months (12, 19, 26, 32, 37) though some studies collected data at several time points showing a clear trend in decrease in overall error reduction (2). One of the few papers to control for the time of year was Walsh et al showing a clear correlation between error rate and month of the year (32) where rates were higher at the beginning of the academic year.

Other facets of information technology in health care
A lot of research has also been undertaken on the implementation of other mechanisms more concerned with administration phase of medication ordering. Some of the mechanisms encountered during this search includes Radio-frequency identification, bar-code medication administration, automatic dispensing, handheld devices to increase availability on ward-rounds.

Other outcomes
Other outcomes were being measured such as time from admission to dispensing of medication, level of reconciliation of medications, radiology procedure completion time and laboratory result turn-around time (30) must be assumed to make an impact. Some papers also measured length of stay and this could be interpreted as an indirect indicator of prescribing errors(30).

Systems-related unintended consequences
Several studies commented on systems-related errors including, but not limited to Evans et al (20), King et al (15) and Warrick et al(19). Even medication errors such as increase in duplication, overdosing, lack of prescription, the very phenomena that were being targeted, were reported (20). Other consequences such as alert fatigue, increased workload and overdependence on technology (6) were also reported. This perspective has been highlighted by Ash et al (38), but a systematic review of was beyond the scope of this paper.

Conclusion
The overwhelming majority of implementations proved to be predominantly positive on a range of outcomes, regardless of the level of CDSS. A certain inverse relationship between the level of CDSS and medication errors was found, though one should be careful in extrapolating. Digitalizing health information technology is likely to have consequences beyond the narrow perspective of this review.

References
1. Institute of Medicine Committee on Quality of Health Care in A. To Err is Human: Building a Safer Health System. In: Kohn LT, Corrigan JM, Donaldson MS, editors. To Err is Human: Building a Safer Health System. Washington (DC): National Academies Press (US) Copyright 2000 by the National Academy of Sciences. All rights reserved.; 2000.


