Integrating computerized clinical decision support systems into clinical work: A meta-synthesis of qualitative research

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A B S T R A C T

Purpose: Computerized clinical decision support systems (CDSS) are an emerging means for improving healthcare safety, quality and efficiency, but meta-analyses findings are mixed. This meta-synthesis aggregates qualitative research findings as possible explanations for variable quantitative research outcomes.

Inclusion criteria: Qualitative studies published between 2000 and 2013 in English, involving physicians, registered and advanced practice nurses’ experience of CDSS use in clinical practice were included.

Search strategy: PubMed and CINAHL databases were searched. Study titles and abstracts were screened against inclusion criteria. Retained studies were appraised against quality criteria. Findings were extracted iteratively from studies in the 4th quartile of quality scores. Two reviewers constructed themes inductively. A third reviewer applied the defined themes deductively achieving 92% agreement.

Results: 3798 unique records were returned; 56 met inclusion criteria and were reviewed against quality criteria. 9 studies were of sufficiently high quality for synthetic analysis. Five major themes (clinician-patient-system integration; user interface usability; the need for better ‘algorithms’; system maturity; patient safety) were defined.

Conclusions: Despite ongoing development, CDSS remains an emerging technology. Lack of understanding about and lack of consideration for the interaction between human decision makers and CDSS is a major reason for poor system adoption and use. Further high-quality qualitative research is needed to better understand human—system interaction issues. These issues may continue to confound quantitative study results if not addressed.

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1. Introduction

The United States’ Health Information Technology and Clinical Health (HITECH) Act of 2009 was designed to increase the adoption of electronic health records (EHR). EHRs better integrate patients’ healthcare information, and provide a means for building regional and national databases that inform policy and evidence-based practices that improve patient safety, care delivery quality and efficiency [1–4]. Integrated into EHRs, computerized clinical decision support systems (CDSS) are intended to influence clinical decisions and improve the quality of care processes such as ensuring that the criteria for ordering medications (dose, route, absence of contra-indications, allergies or drug interactions) are met. For this reason CDSSs were included as part of the Office of the National Coordinator’s (ONCs) EHR certification requirements under the Meaningful Use 2 phase of HITECH implementation.

However, evidence for CDSS role in improving safety, quality and efficiency has been mixed. For example, Garg et al. [5] found that although a majority of systematically reviewed controlled trials showed improved practitioner performance with CDSS, only 13% improved patient outcomes. More recently, Nuckols et al. [6] systematically reviewed 16 pre-post and quasi-experimental studies of computerized physician order entry systems (CPOE, with and without CDSS), and found no differences in the incidence of preventable adverse medication events. Similarly, in an updated version of an earlier meta-analysis of computerized laboratory monitoring alerts [8], Bayoumi et al. [7] found no reductions in adverse drug events or lengths of hospital stay despite behavioral change in accordance with the alerts. Similar mixed results are evident in systematic reviews and/or meta-analyses addressing...
drug dosing, [9] diabetes management, [10] and comprehensive general reviews of CDSS effects [11]. Reviewers’ highlight methodological flaws in research protocols as a means for improving research outcomes, [5,12] but few alternative explanations or research directions are provided.

Mixed-methods research combines qualitative and quantitative methods [13]. In the early stages of new initiative development, qualitative methods build contextual knowledge that can suggest interventions, inform research directions and elucidate potentially confounding variables. Used during and following a research intervention, qualitative methods can provide possible explanations for intended and unintended effects that may not have been predictable prior to the intervention [13,14]. The purpose of this meta-synthesis was to conduct an interpretive synthesis of high-quality qualitative research to provide alternative explanations for the variation evident in quantitative CDSS research findings.

2. Meta-syntheses

Meta-synthesis is an emerging approach for interpreting the aggregate findings of qualitative research studies [15,16]. Major and Savin-Baden [15] propose that “synthesists seek to answer a specific research question through combining qualitative studies...that are located in broadly the same tradition, in order to make sense of themes and issues...” (p.10). In contrast to a comprehensive literature review, whose purpose is to critically locate a research study within a body of knowledge, a meta-synthesis interprets related findings within the synthesist’s research question using a structured and highly systematic approach [16,17].

Our guiding research question was: “What are the possible reasons and causes from healthcare clinicians’ perspectives, for difficulties in integrating CDSS into clinical work?” We also sought to better understand the contexts in which CDSS technology has been introduced, including the nature of affected decisions and the types of CDSS being implemented. We found no evidence in the Joanna Briggs Institute Library of Systematic Reviews, The Cochrane Library including the DARE database, MEDLINE or the PROSPERO databases that a meta-synthesis associated with CDSS integration in clinical work had been undertaken.

3. Method

The sections included in this method are those recommended for high quality meta-syntheses by the Joanna Briggs Institute (JBI) [18].

3.1. Inclusion criteria

3.1.1. Participants and context

The participants in the reviewed studies were clinicians who provided direct care to patients in in-patient or out-patient care settings. Thus, CDSS studies were selected for meta-synthesis review if the study participants included licensed physicians, board-registered nurses (RNs) and advanced practice nurses (NPs). CDSS studies involving only patients or allied health workers, such as pharmacists, were not included.

3.1.2. Phenomenon of interest

The phenomena of interest to this meta-synthesis were findings of participants’ experiences using CDSS in clinical practice. That is, we were most interested in the direct inspection of clinicians’ use of CDSS in clinical work.

Berner and Lande [19] define CDSS as computer modules, functions, features or systems designed to affect clinicians’ decision making about individual patients at the time these decisions are to be made. Osheroff et al. [20] propose that CDSS systems present knowledge and patient-related facts, relationships, best practices or new knowledge that has been filtered and presented at an appropriate time to enhance patient care. Table 1 lists the types of applications recognized as CDSS in this meta-synthesis. The CDSS types are based on definitions published by Osheroff et al. [20] and typically coexist with EHRs and CPOEs systems.

3.1.3. Types of studies

Phenomenological, grounded theory, ethnography, action research and studies that described the experience or effects of CDSS on participants’ practice in actual clinical settings were included in this meta-synthesis. Surveys without open-ended questions or a ‘free-text’ component and simulations including usability studies were excluded.

3.2. Search strategy

An experienced librarian (RW), in collaboration with the primary reviewer (AM) conducted a three-phase literature search. In Phase 1, keywords were generated from our research question constructs, (e.g., CDSS in health care; clinicians’ experience of CDSS adoption). The keywords were then extended using peer reviewed journal articles’ titles; abstracts; keywords and textbook subject indices. In Phase 2; PubMed and CINAHL databases were searched to eliminate the return of CDSS studies from non-healthcare industries. Our specific search strategy is given in Appendix A. Only studies published in English language journals were included. The literature searched was limited to the years 2000–2013 to cover the most contemporary CDSS implementations. In Phase 3; we reviewed the bibliographic reference lists of all studies included in the qualitative synthesis to determine whether additional relevant studies had been overlooked.

3.3. Method of review

Studies returned from the database search were reviewed in two iterations. Three reviewers (AM, BM, SA) conducted the first iteration independently. This iteration was limited to a title and abstract review to determine whether the study met inclusion criteria. Each reviewer provided a short reason for excluding a study. These reasons were collated inductively as a post-hoc analysis of excluded CDSS records. Studies meeting inclusion criteria were evaluated for methodological quality using the appraisal tool presented in Appendix B. This tool expands the JBI’s Qualitative Assessment and Review Instrument (QARI) [20] using more explicitly defined qualitative research dimensions (credibility, transferability, dependability and confirmability) and quality criteria [15,21]. Using these criteria, each study was given a score out of a total of 40. Studies with scores in the top 25% of study scores (i.e., the 4th quartile) were included for detailed analysis and results synthesis. We believed that this cut-off criterion achieved a sufficient number of studies for meaningful results while maintaining acceptable levels of quality.

3.3.1. Summarizing study methods and extracting findings

Two reviewers (BM, AM) independently read and systematically summarized each of the retained studies using the following JBI defined dimensions [20]:

1. Method—the way or ways the data was collected and how it was used;
2. Phenomena of interest—the primary focus of the study;
3. Setting—the specific location or context in which the study was conducted including its geographical and/or cultural context;
Table 1

Types of CDSS application included in this meta-synthesis.

<table>
<thead>
<tr>
<th>Type of CDSS application</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Smart documentation forms</td>
<td>Computerized forms that support the complete documentation of care.</td>
</tr>
<tr>
<td>Order sets and multi-step protocols</td>
<td>Computerized orders or protocols that promote adherence to agreed care policies, best practices and/or care pathways.</td>
</tr>
<tr>
<td>Parameter guidance</td>
<td>Proactive interventions that help to ensure parameters such as drug doses and frequencies, diagnostic (laboratory test results) and therapeutic constraints are complete and correct.</td>
</tr>
<tr>
<td>Critiques and warnings</td>
<td>Reactive immediate alert interventions that prompt clinician assessments of possible errors, hazards or quality improvement opportunities related to new data/orders entered into information systems.</td>
</tr>
<tr>
<td>Relevant data summaries</td>
<td>Concise presentations of important data about a patient's circumstances that ensure that all pertinent data are noted and considered. These summaries organize complex data and highlight needed actions.</td>
</tr>
<tr>
<td>Multi-patient monitors</td>
<td>Relevant patient summaries for groups, or lists of patients that highlight critical information that assists in decision making about urgency or priority in real time.</td>
</tr>
<tr>
<td>Predictive and retrospective analytics</td>
<td>The presentation of population data and application of models and algorithms to data over time that can be used to risk-stratify patients or raise awareness about clinical hazards or opportunities.</td>
</tr>
<tr>
<td>Filtered reference information and knowledge resources</td>
<td>Summaries of reference information from textbooks, consensus opinions and other references, or resources such as nomograms, tables, flow-charts or calculators.</td>
</tr>
<tr>
<td>Expert workup and management advisors</td>
<td>Applications that use patient data from the EHR to suggest diagnoses, tests or procedures that might clarify diagnoses or treatment options.</td>
</tr>
<tr>
<td>Event driven alerts and reminders</td>
<td>Provide active alerts to events that either have (e.g., test result is abnormal, a new admission has arrived) or have not occurred (e.g., preventative screening test has not occurred according to recommended schedule).</td>
</tr>
</tbody>
</table>

4. Participants—including their demographics and how they were recruited and selected;

5. Data analysis—the techniques used to analyze the data.

The two reviewers independently extracted each of the included study authors' main findings together with participant quotations, field observations or other supporting evidence. Findings were themes or conclusions supported by evidence presented in the included studies. The reviewers compared their respective lists of findings. Common findings were identified. Disagreements about whether a finding existed were resolved by re-reading the relevant study to verify that a finding and its evidence was present and not overlooked or misinterpreted. Once findings had been extracted they were rated as:

- Unequivocal—the finding is clearly supported by data (e.g., quotations, direct observations) and is not open to challenge;
- Credible—the finding and presented data lack a clear association and are thus open to challenge, or
- Unsupported—the finding is not supported by data [20].

3.3.2. Data synthesis

The reviewers (AM, BM) independently re-read the studies to ensure that they had captured the study authors' interpretative context. They then inductively grouped the findings based on 'conceptual similarity' to achieve the first synthetic iteration. Following this iteration, the reviewers compared their thematic groups and the content within each theme. A finding could be allocated to more than one thematic group. A second synthetic iteration focused on resolving dissimilarities. The reviewers independently regrouped dissimilarly grouped findings. They again compared their outcomes and met to resolve disagreements. Findings that had initially been allocated to multiple thematic groups were either divided to multiple separate constructs, or resolved to one theme based on 'best fit' consensus. Group themes and subcategories were defined and refined as part of this process.

The original list of ungrouped findings and the theme and category definitions were submitted to a third reviewer (SA), who was asked to group the findings deductively using the themes and categories defined by the first two reviewers. The third reviewer's groups were compared to the first reviewers' groups. Dissimilarities were discussed and the theme and category definitions were refined to better clarify their meaning. The overall findings were submitted to a forth reviewer (DM) for an assessment of their comprehensibility and congruence.

4. Results

4.1. Preliminary search and screening

Fig. 1 presents the search results using a PRISMA flow diagram [22] and shows that of 3798 unique records, 30% were excluded because they presented an aspect of CDSS under development, that is, a system not deployed in a clinical setting. Examples included, algorithm, feature or system developments. An additional 24% of excluded studies involved EHRs and CPOE systems that did not include a CDSS component; 12% were patient-centered CDSS, such as treatment adherence reminders, and 10% did not include qualitative data. The remaining 24% of records also failed to meet minimum inclusion criteria for the reasons presented in Fig. 1.

Table 2 shows that the number of records (N) returned increased across the study period, however, the proportions of records under each deletion category remain remarkably consistent. For example the records in rows 1 and 2 account for approximately 50% of records across all years and were related to CDSS and/or EHR/CPOE development. The number of records returned for patient-centered CDSS appears to decrease, while the number of quantitative research studies appears to increase.

4.2. Evaluation against quality criteria

In total, 56 full-text studies were assessed as eligible for evaluation against quality criteria (Appendix B). Of these, 59% of the CDSS applications were event driven alerts as defined in Table 1; 19.5% were order sets or multi-step protocols; 9% were expert workup; 3.5% of studies were smart-documentation; 3.5% were
filtered references; 3.5% involved parameter guidance and 1.7% included predictive analytics or practice guidelines. We note that there is evidence of historical development across the CDSS types; that earlier implementations may seem less sophisticated compared to more contemporary examples. Osheroff et al’s taxonomy is also more representative of current than past implementations. These percentages should therefore be considered as generally indicative rather than definitive.

The evaluation criteria assessed four dimensions of qualitative research quality (credibility, transferability, dependability and confirmability) that are broadly analogous to internal validity, external validity, reliability and concurrent validity, respectively. The combined sample (N=56) quality score statistics were: mean and standard deviation of 22 and 7.2, respectively; median of 21, range of 10–38 and interquartile range of 15.5–27. Studies with scores in the forth quartile (i.e., >27) were included in meta-synthesis. The forth quartile quality score cut-off for inclusions was considered an acceptable balance between a suitable number of studies for meta-synthesis at a sufficiently high level of quality. Table 3 shows the summary statistics and t-test results for the quality scores of included and excluded studies.

The included studies had higher mean quality scores compared to the excluded studies. The most significant differences were associated with dependability and confirmability scores. For dependability, excluded studies typically included none or only one of ‘information attesting to inter-coder reliability’, ‘coder independence’, ‘conflict resolution processes’ and ‘information about how data saturation was determined’. For confirmability, excluded studies did not show attempts to triangulate data collection, and researcher transparency, including researcher reflexivity processes, were not apparent.

4.3. Synthetic analysis

Table 4 summarizes the studies included in synthetic analysis. All but one (Dowding et al. [23]), were undertaken in the United States, and in all but one (Feldstein et al. [24]), data collection was undertaken between 2006 and 2010. All but two studies (Campion et al. [25,26]) were undertaken in outpatient care settings. Inpatient environments were under-represented. Six studies included prescribing clinicians (physicians, nurse practitioners) and three studies [23,25,26] included registered nurses. The studies reflect a diverse set of commercial [27–29], government [23,30,31], and in-house [24–26] developed products. The majority (6) of the CDSS applications are event-based alerts (see Table 1) supporting medication prescribing decisions and processes. Other CDSS applications include multi-step protocols involving dosing calculators [23,25,26].

Methodologically, ethnographic non-participant observation (usually accompanied by semi-structured key informant interviews) was the most common data collection approach. One study [29] included observations with focus groups, and a second study [24] included observations with an artifact analysis. The studies’ foci were consistent, with seven studies focused on
the objective use and effects of CDSS applications on medication ordering processes. Only one study focused specifically on clinicians’ decision-making [23] and only one [24] focused on social interactions and emotional responses to CDSS. All but three studies used inductive or grounded theory thematic content analysis. One study [30] used a theory-based deductive analytical framework and two used pre-determined coding frameworks based on the operationalization of primary research questions [28,29].

In total, 81 study findings were extracted. Of these, 54 (67%) findings were rated as unequivocal, 15 (18.5%) were rated as credible, and 12 (15%) were unsupported by evidence. Table 5 summarizes the themes and subthemes emerging from the meta-synthesis together with the number of rated findings in each subtheme.

Reviewers achieved 92% agreement about the allocation of findings to the five themes and subthemes that emerged from the synthesis. Each theme is discussed in more detail below.

4.3.1. Usability issues

Usability issues were associated with the presentation of information in a user interface, users’ needs for that information, and/or with the interaction between users and user interface elements. The findings were divided into three main subthemes. Nuisance issues included alerts that compelled documentation compliance [26]; poor fit between alerts and actual patient need (i.e., poor prioritization [24], inappropriate signal to noise [26]), repetitive and redundant alerts [25–27,31], inappropriate alert presentation within a process where alerts became distractions that predispose to missing or forgetting information [30,31]. User control and inefficiency issues involved users’ inability to actively manage alerts by delaying or receiving them at a later more opportune time [30,31], or by turning them off especially when redundant [24]. Data entry associated with alerts was found to be rigid and inflexible often using repetitive data entry modes that were thought to be over-engineered or ‘mouse-heavy’ [25,27,29–31]. Alerts also failed to adequately inform or were unintelligible. Some alerts were written in language more appropriate to specialists such as pharmacists than to prescribing providers [30]. Defaults were poorly selected [26]. Risk or priority levels were missing or unclear. Providers preferred the use of categories (high, moderate, low) or ‘traffic light’ indicators rather than statistical probabilities which some found difficult to interpret [31]. Alerts often did not identify the alerting trigger or the means for resolving it, [31] and presented scales or language that was inconsistent with clinical practice [23].

4.3.2. Clinician-patient-system integration

Poor clinician-patient-system integration issues involved CDSS integration within the socio-technical system beyond just the technological system. The ability to extract ‘meaning’ as an emergent outcome of integrating the CDSS advisories, the patient’s clinical situation and the clinician’s own knowledge and experience, was a core construct within this theme. The clinician-patient-system integration theme was composed of two subthemes: (1) clinician-system integration involved congruence between clinician cognition (judgment, problem solving) and CDSS logic in real-world contexts, and (2) patient-system integration involved the congruence between CDSS and other patient data including free text comments.

Examples of clinician-system integration issues included: reliance on clinicians to integrate CDSS and information across different EHR modules, such as medication prescription and laboratory test ordering; CDSS requirements for immediate action despite the need for further information or consultation [30]; and the interaction between clinician experience/expertise and CDSS effects, for example, on junior clinicians’ trust in system recommendations [27]. Dowding et al. [23] and Campion et al. [26] also found that nurses became highly familiar with CDSS algorithms and modified data entry in anticipation of system responses. Data entry modification may be based on the nurses’ knowledge of the patient, and thus had a customizing or tailoring effect, or may be based on concern that system recommendations were in some way inconsistent with the clinical situation. These nurses also attempted to calibrate their knowledge of algorithm relationships by attempting to predict algorithm outcomes [23,26].

Patient-system integration issues involved lack of processes for information gathering that would more completely represent the patient. For example, patients’ medication histories may be incomplete [28], or CDSS outputs may not be presented with or accommodate other patient-relevant information such as trends [23].

4.3.3. The need for ‘better algorithms’

CDSS algorithms themselves were found to be lacking in maturity. Algorithms, for example, may not fully accommodate a work task or problem. In one study, insulin/dextrose dose calculators did not appear to accommodate other clinical information that nurses believed to be important in managing emergent hypoglycemic events [26]. Algorithms may not accommodate more complex patient scenarios. Examples included: CDSS failed to recognize that patients can be appropriately prescribed more than one medication in the same class (e.g., asthma inhalers) resulting in confusing and/or multiple alerts [31]; the failure of alerts to distinguish between allergies and side-effects [31]; inadequate algorithm referencing and inadequate differentiation between actual and theoretical risk [31]. Researchers also found that alerts often lack or did not accommodate contextual information. Insurance algorithms, for example, may not accommodate a patient’s actual income or provide different cost options for similar medications [28]. Alerts may also make inappropriate assumptions about provider knowledge of the content domain or of the patient and often needed to be interpreted [23,25,31].

4.3.4. System immaturity

System immaturity issues were associated with broader platform interoperability (e.g., information flow between infusion pumps and EHRs) [26], and between different departments or healthcare agencies [29]. Other issues included system response times, the requirements for multiple logins, and general system ‘crashes’.

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**Table 3**

Summary statistics for excluded and included studies based on quality criteria (Appendix B).

<table>
<thead>
<tr>
<th>Criteria scores max score = 40</th>
<th>Credibility max score = 12</th>
<th>Transferability max score = 12</th>
<th>Dependability max score = 10</th>
<th>Confirmability max score = 6</th>
</tr>
</thead>
<tbody>
<tr>
<td>Excluded studies</td>
<td>N = 47</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mean (Std Dev)</td>
<td>8 (1.7)</td>
<td>7 (2.6)</td>
<td>2 (2.3)</td>
<td>2 (1.0)</td>
</tr>
<tr>
<td>Median (range)</td>
<td>8 (4–11)</td>
<td>7 (2–12)</td>
<td>2 (0–8)</td>
<td>2 (0–4)</td>
</tr>
<tr>
<td>Included studies</td>
<td>N = 9</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mean (Std Dev)</td>
<td>9 (1.6)</td>
<td>11 (1.6)</td>
<td>7 (2.0)</td>
<td>5 (1.6)</td>
</tr>
<tr>
<td>Median (range)</td>
<td>9 (8–12)</td>
<td>11.5 (2–12)</td>
<td>8 (4–10)</td>
<td>6 (2–6)</td>
</tr>
<tr>
<td>T-test</td>
<td>P &lt; 0.003</td>
<td>P &lt; 0.0002</td>
<td>P &lt; 0.0001</td>
<td>P &lt; 0.0001</td>
</tr>
</tbody>
</table>

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<table>
<thead>
<tr>
<th>Study</th>
<th>Sample</th>
<th>Setting</th>
<th>Context</th>
<th>Data collection</th>
<th>Data analysis</th>
</tr>
</thead>
<tbody>
<tr>
<td>Abramson et al. [27]</td>
<td>All 19 physicians working at least 75% and 2 days/week in the setting</td>
<td>United States. Academic, hospital-based ambulatory internal medicine practice. February–November 2009</td>
<td>9 months following replacement of in-house EHR with commercial EHR with CDSS support for drug–drug &amp; drug–allergy interactions during prescribing. CDSS = event-driven alerts</td>
<td>2–3 h observations of physician-patient interactions focused on work-flow &amp; physician efficiency when ordering. Semi-structured interviews focused on experiences with new system, struggles compared to old system, CDSS features, UI.</td>
<td>Inductive, grounded theory approach to thematic content analysis from electronic transcripts</td>
</tr>
<tr>
<td>Crosset et al. [28]</td>
<td>Purposive sampling. 8 practices that included: 18 physicians; 46 practice staff.</td>
<td>United States. Physician owned family medicine, internal medicine, obstetrics &amp; gynecology outpatient clinics. Prior to December 2010</td>
<td>Two commercial e-prescribing applications sponsored by BCBS; both included automated formulary-insurance benefit checks and medication history documentation with drug–drug and drug–allergy alerts. CDSS = event-driven alerts</td>
<td>Ethnographic field observations and semi-structured interviews 3-months pre- and post-system implementation Observation and interview guided focus: ambulatory meaningful use stage 1 e-prescribing: drug-drug, drug-allergy checks with maintained active medication &amp; allergy list and drug-formulary checks</td>
<td>Deductive coding using a before-after template focused on formulary and benefit and medication history. Electronic transcripts</td>
</tr>
<tr>
<td>Russ et al. [30]</td>
<td>Snowball sampling. 4 prescribers (MDs/NPs) each from 5 primary care clinics and 2 prescribers each from 8 specialty clinics (N= 16).</td>
<td>United States. VA Medical Center clinics: primary care, anticoagulation, infectious diseases, transplant, psychiatry, nephron, endocrine, gastro &amp; oncology. August 2008–2009</td>
<td>The VA’s EHR system includes CPOE with medication alerts for drug–drug and drug–allergy interactions. Alerts require a response from a prescriber, a rationale for some over-rides including free-text justifications, a 2-tiered severity rating and can present multiple alerts on one screen. CDSS = event-driven alerts</td>
<td>Half-day observations focused on prescribers’ interactions with alerts, understanding how alerts were integrated into patient care, and system factors that influence prescriber-alert interactions. Structured interviews focused on how medication alerts help and hinder clinical work and what changes should be made.</td>
<td>Deductive coding using Norman’s Mental Model Framework. Electronic transcripts</td>
</tr>
<tr>
<td>Campion et al. [25]</td>
<td>Convenient sample 25 RN volunteers</td>
<td>United States. Surgical and Trauma Intensive Care Units in an academic tertiary care facility February 2010 – March 2010</td>
<td>An Intensive insulin therapy protocol computerized and implemented in 2004–2005 involved nurses entering a patient’s blood sugar level, CSD calculates either an insulin dose or a dose of 10% dextrose. CDSS = multi-step protocol</td>
<td>Retrospective chart review for incidence of over-rides and subsequent effects on patients’ blood sugar levels 2.3-h ethnographic observations with unstructured interviews focused on the interactions between people, processes and technology related to insulin CDSS.</td>
<td>Inductive, grounded theory approach to thematic content analysis. Electronic transcripts</td>
</tr>
<tr>
<td>Campion et al. [26]</td>
<td>Convenient sample 37 RN volunteers</td>
<td>United States Surgical and Trauma Intensive Care Units in an academic tertiary care facility February 2010–March 2010</td>
<td>An Intensive insulin therapy protocol computerized and implemented in 2004–2005 involved nurses entering a patient’s blood sugar level, CSD calculates either an insulin dose or a dose of 10% dextrose. CDSS = multi-step protocol</td>
<td>Ethnography 2–3 h ethnographic observations with unstructured interviews focused on the interactions between people, processes and technology related to computerized intensive insulin therapy in critical care units.</td>
<td>Inductive, grounded theory approach to thematic content analysis. Electronic transcripts</td>
</tr>
<tr>
<td>Lapane et al. [29]</td>
<td>Purposive sample: 64 ambulatory care practices more than 25% Medicare patients. 177 physicians &amp; 99 office staff</td>
<td>45% of practices were internal medicine; 39% family medicine, and 25% of practices were single practitioners. April–August 2006</td>
<td>Commercial e-prescribing applications that included automated formulary–authorization checks. CDSS = event-based alerts</td>
<td>Preliminary site visit interviews and observations informed survey design focused on the effects of e-prescribing on work efficiency compared to other methods (e.g., paper, fax etc.). Group interviews focused on e-prescribing usability, implementation barriers, patient safety.</td>
<td>Deductive codes framed and defined by research foci. Electronic transcripts</td>
</tr>
</tbody>
</table>
4.3.5. Patient safety

Campion et al. [25,26] and Feldstein et al. [24] both found that alerts related to patient safety were perceived to be most helpful (and least annoying) when the domain represented by the alert was not the clinician’s area of expertise. Findings were, however, somewhat ambivalent. On the one hand, junior clinicians were thought to inappropriately accept CDSS recommendations without critical evaluation [29], but few providers recommended turning them off completely [24].

5. Discussion

The purpose of this meta-synthesis was to provide alternative explanations for the variation evident in quantitative CDSS research findings. Specifically, we sought to identify possible reasons and causes for differences in integrating CDSS into clinical work while also building a more integrated profile of the contexts into which CDSS has been applied and the nature of affected decisions.

Foremost, we found that high quality studies of clinicians’ experience using CDSS were relatively rare, especially when compared to the number of quantitative research studies (Table 2). Although qualitative studies appear to be increasing, they still represent a marginal portion of the overall research output. This is concerning, as it suggests that CDSS implementations are being developed and implemented based on limited understanding of actual clinical work or CDSS effects on actual clinical decision making. This may explain some of the workflow integration issues associated with CDSS. The overall quality of qualitative CDSS studies is also lacking. Even some of the studies selected for synthesis had weaker dependability and confirmability scores and no mixed-methods research studies were eligible for synthetic analysis. Thus, there is considerable room for improvement in the quality of qualitative research and its integration with mixed-method research approaches. Without more and better qualitative research that supports a richer understanding of clinical work contexts, the variations observed by meta-analysts [5–12] are likely to continue as contextual variables are omitted from consideration in CDSS development, and in quantitative research designs.

Most qualitative CDSS studies involved alerts and reminders associated with medication prescription and administration. These applications tend to ensure that well-defined, criterion-based or transactional processes are completed comprehensively (e.g., drug-allergy; drug–drug interactions are not omitted) and correctly (e.g., right dose range, right route). However these objectives often appear to be undermined by poor information and interaction design that affects the usability of alerts and reminders.

Few CDSS studies appear to accommodate naturalistic decision making, such as diagnostic pattern recognition [33] and situation awareness [34,35]. Additionally, most studies involved out-patient care settings; few studies involved in-patient environments. These findings are also concerning, because they suggest that major aspects of clinical decision making, and segments of the health-care environment that HITECH is intended to improve, are woefully understudied.

Our results suggest clear directions for future research. Most lacking is research related to the interaction between CDSS and clinical decision makers, both in terms of the decisions they make, and their adaptations to and unintended uses of CDSS. Especially intriguing are Dowding et al. [23] and Feldstein et al. [24] accounts of nurses’ adoptions to CDSS algorithms. It is likely that physicians engage in similar behaviors but there is little research to attest this. Research related to the extraction of clinical ‘meaning’ from
Table 5
Summary of emergent themes and sub-themes.

<table>
<thead>
<tr>
<th>Theme</th>
<th>Subtheme * = numbers of rated findings</th>
</tr>
</thead>
<tbody>
<tr>
<td>Usability: problems related specifically to the user interface design (its 'look') or interaction design (its behavior).</td>
<td>Nuisance: inappropriate or unnecessary interruption or distraction. Unequivocal = 5; credible = 4; unsupported = 0</td>
</tr>
<tr>
<td></td>
<td>User control/inefficiency: requires additional work that is only marginally related to the task at hand; inability to move forward at the desired pace or in the desired way. Unequivocal = 7; credible = 3; unsupported = 4</td>
</tr>
<tr>
<td>N = 35; 43% of total</td>
<td>Transparency/failure to inform: displays, processes or information presentations do not provide sufficient information upon which to make a decision, or complete a task. Unequivocal = 10; credible = 1; unsupported = 1</td>
</tr>
<tr>
<td>Clinician-patient-system Integration: the capacity for information to flow freely between providers, systems and patients in ways that support joint problem solving, decision making, and the construction of meaning.</td>
<td>Clinician-system integration: CDSS is not congruent with clinicians' expectations, problem solving strategies or workflow processes. Unequivocal = 17; credible = 2; unsupported = 2</td>
</tr>
<tr>
<td>N = 27; 33% of total</td>
<td>Patient-system integration: the CDSS fits congruently with other representations of the patient and the patient's condition. Unequivocal = 5; credible = 0; unsupported = 1</td>
</tr>
<tr>
<td>Algorithm immaturity: algorithms are incomplete, lack comprehensiveness, are not flexible or do not account for patient related contextual variables.</td>
<td>Algorithm maturity: Algorithm itself is not complete with respect to the variables included in total work tasks or relevant clinical problem. Unequivocal = 5; credible = 3; unsupported = 0</td>
</tr>
<tr>
<td>N = 12; 15% of total</td>
<td>Lack of context awareness: the algorithm does not take account of contextualizing or personalizing patient factors. Unequivocal = 3; credible = 1; unsupported = 0</td>
</tr>
<tr>
<td>System immaturity: basic network or platform problems, in particular interoperability.</td>
<td>Unequivocal = 2; credible = 0; unsupported = 2</td>
</tr>
<tr>
<td>N = 4; 5% of total</td>
<td>Unequivocal = 1; credible = 1; unsupported = 1</td>
</tr>
<tr>
<td>Patient safety threats: specific threats that may cause harm to patients. N = 3; 4% of total</td>
<td>Unequivocal = 1; credible = 1; unsupported = 1</td>
</tr>
</tbody>
</table>

Diverse information sources may also lead to fruitful insights about the presentation of CDSS related information.

As confirmed in Table 2, the technical knowledge needed to build and deliver CDSS-related technologies continues to evolve [19,20,32]. However, knowledge about the integration of CDSS into real-world, socio-technical environments is barely emerging. This conclusion should not be surprising. Despite that CDSS and other advanced computational capacities have developed since World War 2, the transition of these technologies into complex socio-technical systems is relatively recent, especially on scales as large as healthcare [19,32]. Thus knowledge about their effects in real-world environments is just beginning to emerge. The results of this synthesis together with the mixed results of many meta-analyses [5–12] suggest that research approaches that encompass human-system interactions in real-world care settings need to go hand-in-hand with basic development if the promises of CDSS are to be fully realized. We believe that the Office of the National Coordinator’s inclusion of CDSS and user-centered design in its EHR certification requirements is an important first step in this direction.

In conclusion, the results of this meta-synthesis suggest a need for high-quality research to better understand the interactions between computational and human reasoning and problem solving in real-world clinical settings, including how clinicians respond and adapt to computational interventions over time. Research is also needed to better understand how CDSS interventions could be presented to human decision makers (patients and clinicians) in user interfaces. Research programs that encompass these issues will require a far greater collaboration between social, behavioral, cognitive and computer scientists, not just in the design of better computer systems but also in the design of better human-computer interactions.

5.1. Limitations

This meta-synthesis is limited by our search criteria, which deliberately focused on problems and barriers to CDSS adoption. However, by clearly defining our search question we were better able to consolidate targeted studies in ways that more effectively support conclusions and future directions. Facilitators and enablers of CDSS adoption were not covered in this meta-synthesis and should be addressed in future meta-syntheses. Our findings are also limited by the databases we searched. It is possible that some studies, especially in the grey literature exist that were not included in this analysis and that if included would change our results and conclusions. Meta-synthesis processes are still emerging with few examples in the published literature especially related to health care informatics, and hence there may be flaws in our method or approach that we are as yet unaware of. It is hoped that this example provides an impetus for further qualitative syntheses in healthcare informatics.

Conflict of interest

The authors confirm that there is no conflict of interest.
Summary points

What was already known:

- Evidence for Clinical Decision Support (CDS) systems’ role in improving patient safety, quality and efficiency has been mixed.
- Other than improving research protocols, few alternative explanations or research directions have been provided that would explain the variability in CDS outcomes.
- Qualitative research can provide possible alternative explanations but qualitative CDS studies have not been systematically evaluated.

What this study has added:

- There are few high quality qualitative research studies, which is concerning as CDS may be implemented with incomplete contextual knowledge.
- Although CDS technological capabilities are advanced, knowledge about how to integrated CDS into clinical decision making is still emerging.
- Usability, human computer interaction design and poor human-systems integration issues may be confounding CDS randomized control trials.
- Mixed qualitative and quantitative research approaches may result more effective CDS implementations and outcomes.

Author contributions

Anne Miller led and coordinated the project. She participated in conceiving the research questions, developed the research design, coordinated other team members’ efforts, collated and analyzed the data, extracted findings, and drafted the manuscript.

Brian Moon and Shilo Anders analyzed the data, extracted findings, participated in thematic development and edited the drafted manuscript.

Rachel Walden developed the search strategy, undertook the manuscript search and contributed to the drafted manuscript.

Steven Brown participated in conceiving the research question and developing the research design. He reviewed the projects findings and edited the manuscript.

Diane Montella participated in conceiving, refining and focusing the project’s research question. She participated in developing the search strategy, reviewed the projects findings and participated in editing the manuscript.

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Appendix A.

Search strategy

PubMed search strategies (the same strategies were used to search CINAHL)
References