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Review

The role of standardized data and terminological systems in computerized clinical decision support systems: Literature review and survey

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ABSTRACT

Introduction: Clinical decision support systems (CDSSs) should be seamlessly integrated with existing clinical information systems to enable automatic provision of advice at the time and place where decisions are made. It has been suggested that a lack of agreed data standards frequently hampers this integration. We performed a literature review to investigate whether CDSSs used standardized (i.e. coded or numerical) data and which terminological systems have been used to code data. We also investigated whether a lack of standardized data was considered an impediment for CDSS implementation.

Methods: Articles reporting an evaluation of a CDSS that provided a computerized advice based on patient-specific data items were identified based on a former literature review on CDSS and on CDSS studies identified in AMIA's 'Year in Review'. Authors of these articles were contacted to check and complete the extracted data. A questionnaire among the authors of included studies was used to determine the obstacles in CDSS implementation.

Results: We identified 77 articles published between 1995 and 2008. Twenty-two percent of the evaluated CDSSs used only numerical data. Fifty one percent of the CDSSs that used coded data applied an international terminology. The most frequently used international terminology were the ICD (International Classification of Diseases), used in 68% of the cases and LOINC (Logical Observation Identifiers Names and Codes) in 12% of the cases. More than half of the authors experienced barriers in CDSS implementation. In most cases these barriers were related to the lack of electronically available standardized data required to invoke or activate the CDSS.

Conclusion: Many CDSSs applied different terminological systems to code data. This diversity hampers the possibility of sharing and reasoning with data within different systems. The results of the survey confirm the hypothesis that data standardization is a critical success factor for CDSS development.

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1. Introduction

It has been demonstrated that clinical guidelines provided by real-time clinical decision support systems (CDSSs) significantly improve patient care [1] and reduce practice variability [2,3]. The success of CDSSs requires that they are seamlessly integrated with clinical workflow and with existing patient information systems [4,5] to enable the automatic provision of advice at the time and place where decisions are made. CDSSs that are designed as part of or in parallel with patient information systems are more or less naturally integrated. However, integrating CDSSs with independent information systems has been shown difficult [6]. It has been suggested that this is due to lack of agreed standards for semantic interoperability [7-11].

Semantic interoperability is the ability of computer systems to exchange information and have that information properly interpreted by the receiving system in the way as intended by the transmitting system [12,13]. Achieving semantic interoperability requires not only the use of communication standards such as HL7 with its underlying models and specifications, but also common concepts and their interpretation, including concept grammar and terminological systems [14]. In practice, standards and their implementations are usually gradations toward true semantic interoperability [15]. A terminological system relates concepts of a particular domain among themselves and provides their terms and possibly their definitions and codes [16]. Terminological systems facilitate the integration of CDSSs with the patient information system by binding the patient data in the patient information system with the concepts in the decision rules of a CDSS. They smooth the progress of CDSS development by enabling terminological reasoning. For example, without a terminological system the CDSS rule "If a patient already suffered from a renal disease, then a urine analysis test should be done before surgery" would have to

be repeated for each type of renal disease, i.e. polycystic kidney disease, pyelonephritis, renal acidosis, etc. When a terminological system is used all these subtypes would be recognized as types of renal disease and only one rule will be sufficient to represent this preoperative assessment recommendation. In this way the readability of the knowledge base and its maintenance are simplified [17]. Although in theory the benefits of terminological systems for facilitating CDSS implementation are clear, there is a lack of knowledge on the actual role of terminological systems in CDSSs in clinical practice.

In this study we analyzed the literature regarding CDSSs and performed a survey to answer the following questions: (1) Do CDSSs use standardized (numerical and/or coded) data? (2) Do authors of CDSS studies consider a lack of standardized data an impediment in CDSSs implementation? and (3) If coded data were used, e.g. for diagnoses or procedures, which terminological systems have been used to represent this data type?

2. Methods

2.1. Materials

Our starting point was the set of included articles from the systematic review of Garg et al. on effects of computerized clinical decision support systems on practitioner performance and patient outcomes. This systematic review was based on literature retrieved from MEDLINE, EMBASE, Evidence-Based Reviews databases (Cochrane Database of Systematic Reviews, ACP Journal Club, Database of Abstracts of Reviews of Effects, and Cochrane Central Register of Controlled Trials), and INSPEC bibliographic databases [18]. It covers 88 randomized controlled trials (RCTs) and 12 non-randomized trials from 1974 till September 2004. In our study, we included all RCTs from 1995 referenced by Garg et al. One option to extend

this set of articles with articles published after 2004 was to use Garg's search strategy for the more recent time period. Due to time and resource limitations we decided to use CDSS studies identified by the American Medical Informatics Association (AMIA)'s "Year in Review" from October 2004 till October 2008. During each "Year in Review" session of the Annual AMIA Fall Symposium the previous year's publications of RCTs in the medical informatics field are discussed. They identify RCTs examining more than 100 patients or providers by extensive literature review and a poll of American College of Medical Informatics (ACMI) fellows. The strategy used can be found in [19]. As AMIA's 'Year in Review' was restricted to RCTs we decided to also restrict ourselves to RCTs from Garg's review. Based on full-text review, only studies evaluating a CDSS that provided a computerized advice based on patient-specific data items were included.

2.2. Data extraction

To systematically capture the information that was relevant for answering the research questions, an extraction form based on reviews of the literature [1,9,18] and expert consensus was designed. The form has 3 parts: general information about the study, CDSS characteristics, and knowledge representation. The first part includes data items regarding publication year; study design; clinical setting, and arena; and findings on the effect of the CDSS on patient or practitioner performance outcomes. For each study we collected up to three primary outcomes mentioned in the article. The second part consists of data items regarding activation of the CDSS, the systems integration within its surrounding information infrastructure and the system's style of communication. The last part consists of items such as the data types used in decision rules, i.e. numerical data, coded data or free text that invoked the system or generated the advice, and the use of terminological systems for coding the data (see Appendix A for data extraction form). In this study a terminological system varies from a simple predefined list of terms referring to concepts in a specific domain (local terminology) to a more comprehensive list of concepts which are hierarchically structured and related to each other including definitions, such as SNOMED CT (vocabulary and nomenclature) [16].

The extraction form was examined for coverage, clarity, and content validity in several consensus meetings. Four randomly selected articles were reviewed by all six authors of this study, and extracted data were discussed to refine the extraction form and solve ambiguities in the form. To have the same interpretation of the identified data items during the data extraction the definition of each data item was described (see Appendix B). In addition, the data extraction form was circulated for external review. Two authors of recently published articles on CDSSs [20,21] checked whether the data items were sufficiently clear.

For each included study the extraction form was completed by two independent reviewers. Disagreements were resolved through discussion between the two reviewers. If reviewers could not reach an agreement, disagreements were discussed with other authors. The filled-in extraction form was sent to the corresponding author of the included studies to check the data extracted from their article and to complete any missing

data. A document including the definitions of the concepts that we used in our data extraction form was accompanied (see Appendix B). In addition we asked the authors five questions: four of these questions were about data types used in the system and the application of terminological systems; the fifth question was whether authors had ever decided not to start or to abandon developing a CDSS because of problems regarding required data or other types (e.g. financial or organizational) of problems (see Appendix A, section II).

Authors were sent one email message and, if necessary, up to two reminders. When primary authors did not respond or could not be reached we contacted the second author or the last author.

To test differences between the use of standardized data versus non standardized data regarding features of CDSSs and practitioner performance or patient outcomes we used chi square statistics. In this study we considered coded data and numerical data as standardized data. We interpreted $p \leq 0.05$ as statistically significant.

3. Results

3.1. Study selection

Garg's review and AMIA's 'Year in review' resulted in 112 potentially relevant articles. Of these, 77 articles [6,22–97] were included (Fig. 1). Most of the excluded studies ($n = 31$) described a system that did not provide computerized advice based on patient-specific data items. Authors of 48 (62%) studies [6,22,23,25,26,30,33–35,37–39,42,43,45,49,53–55,58,61,62,64,65,67,68,70,73,76–80,82–86,88–97] confirmed the extracted data and provided answers to the additional questions.

3.2. Description of studies

Part one of Table 1 describes the characteristics of the included studies. Fifty one percent of the studies have been performed in a multicenter setting, 33% of them were managed by a single health maintenance organization. Most studies described systems which were developed for disease management (35%) and treatment (23%), followed by drug dosing and prescribing (10%), prevention (12%), patient education (5%), screening (5%), diagnosis (4%), risk assessment (4%), and clinical documentation (1%). The unit of analysis in 19 studies was patients, in 33 studies clinicians and in the other studies both patients and clinicians.

3.3. Description of clinical decision support systems and users

Part 2 of Table 1 shows features about the way the CDSSs were implemented and integrated into the workflow. None of the 77 included studies reported a negative effect of CDSS on patient outcome or practitioner outcome. In 82% ($n = 45$) of 55 integrated CDSSs (second row of part 2 in Table 1), systems prompted the user automatically and did not need to be initiated manually to get advice. In 44% ($n = 24$ out of 55) of the integrated CDSSs additional input from users was required to get the advice. CDSSs which used a consulting

Table 1 – Characteristics of the included studies and features of decision support systems (n = 77). See Appendix B for the definitions of the characteristics presented in the table.

	Number of studies (%)
<i>Characteristics of the included studies</i>	
Publication year	
1995–1999	23 (30)
2000–2004	23 (30)
2005–2008	31 (40)
Country of study	
United states	53 (69)
United kingdom	9 (11)
Canada	3 (4)
Norway	3 (4)
Italy	2 (3)
The Netherlands	2 (3)
France	1 (1)
Lithuania	1 (1)
Multiple countries	3 (4)
Study setting ^a	
Single center	37 (48)
Multiple center, single HMO ^b	13 (17)
Multiple center	26 (34)
Clinical setting ^{a,c}	
Primary care	34 (44)
Secondary or tertiary outpatient care	19 (25)
Secondary or tertiary inpatient care	22 (29)
Clinical arena addressed by CDSS	
Family medicine or general practice	20 (26)
Internal medicine	18 (23)
Cardiology	8 (10)
Supporting specialties	6 (8)
Hospital wide	6 (8)
Hematology	3 (4)
Home Care or nursing care	3 (4)
Intensive care medicine	3 (4)
Psychiatry	2 (3)
Other specialties	8 (10)
System features	
System activation ^d	
System automatically prompts the user	49 (64)
System should be initiated manually	27 (35)
System integration	
Integrated (linked system)	55 (71)
Independent (stand-alone system)	22 (29)
Style of communication ^{d,e}	
Consulting model (system gives advice about what user should do)	38 (49)
Critiquing model (system criticizes user about his/her action)	12 (16)
Reminder system (system reminds user of something that (s)he has not done)	25 (32)
System requires data entry	
System requires user input to give the advice	43 (56)
System does not require user input to give the advice	34 (44)
Users of the system ^f	
Physicians	66 (86)
Nurses	21 (27)
Paramedics	4 (5)
Patients	5 (6)

^a One study evaluated a web-based clinical decision support systems which was used by patient at home.

^b Health maintenance organization.

^c One study was carried out in both primary care and secondary or tertiary outpatient care.

^d There were one missing data item regarding system activation, and one regarding style of communication.

^e One system applied two modes of communication consulting and reminder.

^f One system could have different users.

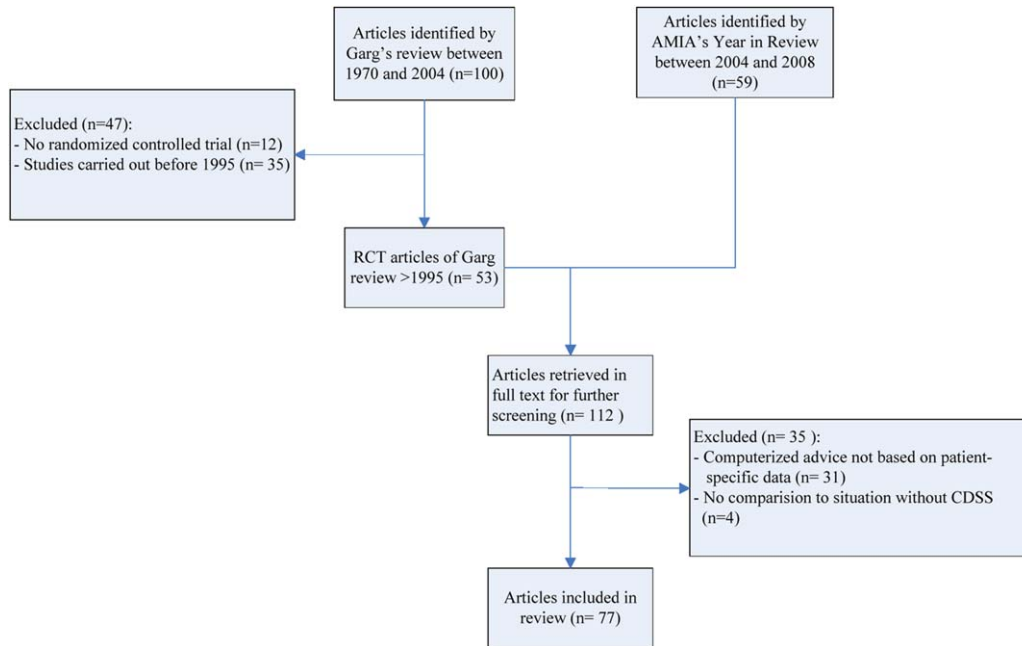


Fig. 1 – Selection process of studies on clinical decision support systems.

style of communication (systems that give users advice about what they should do) required additional data entry in 74% ($n=28$ out of 38) of the cases; while critiquing systems (systems that provide feedback on the actions that users perform or intend) required additional data entry in 50% ($n=6$ out of 12) of the cases, and reminder systems (the systems that remind users of something that they have not done) in 32% ($n=8$ out of 25) of the cases. System developers mostly used the consulting model (49%) as communication style of CDSSs. Systems which needed to be initiated manually to get advice required additional data entry in 81% ($n=22$ out of 27) of the cases.

Authors of 48 studies who responded to our questionnaire reported the following ways of invocation of their CDSS; the CDSS automatically selected the relevant cases in 44% ($n=21$), cases were selected automatically by another computer application in 15% ($n=7$), the system was invoked manually by the end-user in 25% ($n=12$), and the system was invoked by another person (e.g. a research assistant) in 12% ($n=6$). In 4% ($n=2$) of the studies the CDSS invocation was changed during the study from automatic invocation to manual invocation.

3.4. Data types used in clinical decision support systems

Table 2 indicates different data types that were used in CDSSs. Of the 77 evaluated CDSSs, 17 (22%) systems used only numerical data items, 11 (14%) of them used only coded data items, 31 (40%) system used combination of numerical and coded data items, and the other 9 (12%) systems used free text with or without numerical and/or coded data items to invoke the CDSS or generate an advice. In 9 studies the used data types by CDSSs were not described and authors of these studies did

not provide the required information. Authors who responded to our questionnaire reported that the numerical data items were mostly used for demographic and health data ($n=20$) (e.g. age, weight and BMI), in which the data item age ($n=18$) was the most frequent one, followed by laboratory test results ($n=16$) (e.g. hemoglobin), and physiological parameters ($n=10$) (e.g. vital signs). Other numerical data items were medication parameters ($n=6$) (e.g. medication dosage), results of diagnostic tests ($n=6$) (e.g. ejection fraction), disease risk factors ($n=3$) (e.g. cardiac risk score) and other numerical data items ($n=5$) (such as number of visits and days in the hospital). CDSSs that used free text ($n=9$), extracted patient diagnosis, medications or other clinical data from the free text records. Extraction of the data from free text was done, for example, by using a natural language processing method or by personal reviewing of the patient records. For instance, a pharmacist reviewed the patient prescriptions and determined if a prescription should be discontinued based on existing guidelines and then an automated message was sent to the physician via the patient information system. More information about coded data can be found in Section 3.6.

The percentage of positive practitioner performance outcomes of the systems that used standardized data was higher (79% versus 50%, p -value = 0.038). The percentage of positive patient outcome of the systems that used standardized data seems to be higher than those that used free text but this difference was not statistically significant (45% versus 33%, p -value = 0.51).

Table 3 presents the frequency of using standardized data (numerical and/or coded) and free text data based on different system features. Standardized data were used more often in systems that automatically prompted the user (p -value = 0.038).

Table 2 – Outcome of clinical decision support systems based on data types used into the system.

Data type	Number of studies (%) ^a	Number of positive outcomes/total number of outcomes (%) ^b			
		Practitioner performance outcome		Patient outcome	
Numerical data	57 (74)	44/57 (77)	45/57	27/60 (45)	27/60
Coded data	49 (63)	40/56 (71)	(79)	17/41 (41)	(45)
Free text	9 (12)	5/10 (50)		3/9 (33)	

^a The categories in this table are non-exclusive as one study could use different data types. The presented result is based on all 77 included studies. In 9 studies the used data types were not described.

^b For each study up to three outcomes were considered. Hence the number of outcome measures is larger than the number of studies.

3.5. Obstacles in clinical decision support systems implementation

We asked authors whether they have ever decided not to start or to discontinue developing a CDSS. In 58% of cases, the authors had experienced problems with developing a CDSS (Fig. 2). Ninety-two percent of these problems were related to data (standardization) required to develop the CDSS. Eight percent of the experienced problems were non-data related problems including financial or organizational problems.

3.6. Terminological systems used in clinical decision support systems

CDSSs most frequently used an international terminological system ($n=25$) compared to national ($n=15$) or local terminological systems ($n=23$), where a terminological system is

considered international when it is in wide use in multiple countries. Authors who responded to our questionnaire used terminological systems for representing 93 coded data items. Fig. 3 presents the terminological systems that were used to code these data items. One CDSS could use several coded data items. International terminological systems were used mostly for representing diagnoses (68%), whereas national terminological systems for representing medications (50%). The international terminological systems that were used were ICD (International Classification of Diseases) $n=23$ (68%), LOINC (Logical Observation Identifiers Names and Codes) $n=4$ (12%), and other terminological systems $n=7$ (20%). Nearly all CDSSs that used international terminological systems were evaluated in the USA ($n=24$), except one CDSS that was evaluated in The Netherlands. National terminological systems were applied in the USA ($n=12$), United Kingdom ($n=2$) and in The Netherlands ($n=1$). The national terminological systems

Table 3 – Frequency of using standardized data and free text based on system features. See Appendix B for the definition of the concepts presented in the table.

System features	Data type ^a		p-Value
	Standardized data (numerical and/or coded)	Free text	
System activation ^a			
System automatically prompts the user	40	3	0.038
System should be initiated manually	18	6	
System integration			
Integrated (linked system)	42	7	0.681
Independent (stand-alone system)	17	2	
Style of communication ^{a,b}			
Consulting model (system gives advice about what user should do)	31	3	0.279
Critiquing model (system criticizes user about his/her action)	11	1	
Reminder system (system reminds user of something that (s)he has not done)	17	5	
System requires data entry			
System requires user input to give the advice	31	5	0.866
System does not require user input to give the advice	28	4	

^a Data was missing regarding data types ($n=9$), system activation ($n=1$), and style of communication ($n=1$).

^b One system applied two modes of communication consulting and reminder.

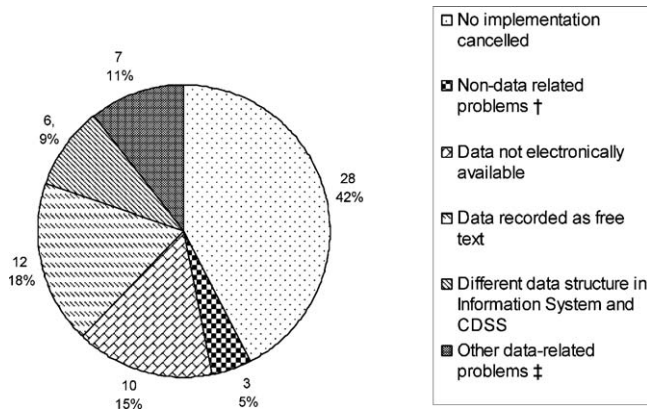


Fig. 2 – Authors' responses regarding obstacles in clinical decision support systems implementation (authors could choose more than one answer). †Non data related problems including financial or organizational problems. ‡Authors mentioned low data quality and incomplete data as other data related problems.

included NDC (National Drug Code), CPT (Current Procedural Terminology), Read codes, FDA drug list (Food and Drug Administration), and NDF (National Drug File). Other countries used local terminological systems to represent the coded data (e.g. a predefined list of medications). Recently evaluated CDSSs used international terminological systems more frequently: 72% ($n = 18$ out of 25) of the CDSSs that utilized international terminological systems were evaluated after 2003.

In general, terminological systems were more frequently utilized in integrated CDSSs. Eighty eight percent ($n = 22$ out of

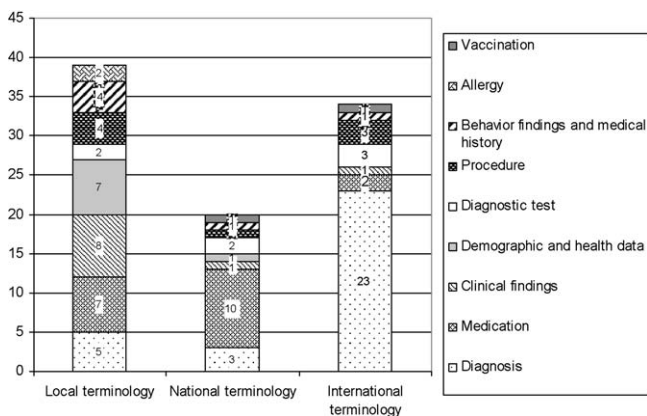


Fig. 3 – Terminological systems used in clinical decision support systems (the presented results in this figure are based on the studies that used coded data and their authors responded to our questionnaire). The international terminological systems were ICD: The International Classification of Diseases ($n = 23$), LOINC: Logical Observation Identifiers Names and Codes ($n = 4$), DRG: Diagnosis-Related Group ($n = 3$), ATC codes: Anatomical Therapeutic Chemical Classification System ($n = 1$), GPI: Generic Product Identifier ($n = 1$), ICPC: International Classification of Primary Care ($n = 1$), and DSM IV Diagnostic and Statistical Manual of Mental Disorders ($n = 1$).

25) of the CDSSs that used international terminological systems were integrated systems. Moreover, 93% ($n = 14$ out of 15) of the CDSSs that used national terminological systems and 70% ($n = 16$ out of 23) of CDSSs that used local terminological systems were integrated systems. While CDSSs that used local terminologies required additional input from user in 57% ($n = 13$ out of 23) of the cases, those CDSSs that applied international terminological systems and national terminological systems required additional input in only 32% ($n = 8$ out of 25) and 40% ($n = 6$ out of 15) of the cases, respectively. There was no association between the type of terminological systems and patient outcome and practitioner performance (p -value = 0.22 and 0.5).

4. Discussion

This literature review showed that 22% of the evaluated CDSSs used only numerical data items, 14% of the systems used only coded data, and 40% of the systems combined numerical data with coded data to invoke the CDSS or generate an advice. The lack of standardized data is mentioned by a majority of responders of our questionnaire as a major obstacle in CDSS development and implementation. The most frequently used terminological system was one of the ICD family, but still 42% of the studies used a local terminological system to standardize data.

The specificity of the CDSS advice varied considerably, which can be explained by the number of data items that were used by the CDSS to trigger relevant recommendations. Some systems simply checked a numerical data item, e.g. patient's age, to discern appropriate interventions, whereas others used multiple factors (e.g. diagnoses, laboratory results, and medications) in generating recommendations. Numerical data are an easy way of standardization as numerical values are unambiguous, and interpretable by both human and computer. Consequently, such values are easy to use for reasoning in CDSSs. They require a standardized measurement method and unit to be exchanged in a standardized format among different systems.

The CDSSs studied in this review used different terminological systems to present coded data to be used for decision making. The diversity of these terminological systems is an obstacle for the CDSS shareability. This diversity even existed within country borders. The most frequently used terminological system, ICD, groups together similar diseases and procedures and organizes related entities for easy retrieval [98].

Currently there is widespread enthusiasm for introducing CDSSs in healthcare. However, uptake has been slow, and multiple challenges have arisen at every phase of development and implementation. The majority of these challenges, as indicated by the authors of the included studies in this review, were related to semantic interoperability. If developers of CDSSs could pass the first challenge "availability of required data", they may face other data related challenges such as different style of data documentation (free text) or different information models, which are used for presentation of data in existing patient information systems.

To our knowledge this study is the first literature review focusing on the role of data standardization and terminological systems in CDSS implementation. Other literature reviews [1,4,9,11] on CDSS features did not report these features of the CDSS. Real improvement in the success of CDSSs will not come with only solving technical issues, but also with the more accurate capture of data items required for decision support, obtained through the maintenance of large medical databases in standardized format [99-102] by using international terminologies such as SNOMED CT.

Wright and Sittig [103] developed a four-phased framework for evaluating architectures for CDSS that consist of: feature determination, existence and use, utility, and coverage. They pointed among other features of CDSS the following success features: "Avoids vocabulary issues", "Shareability", and "content integrated into workflows". An important step in creating interoperable CDSSs is the binding of terminology used in patient information system to terminology used in the decision rules. In some knowledge representation languages like the older version of the Arden syntax a term used in a patient information system had to be mapped to the specific terms used in the decision rules to activate a logical statement [104]. As this kind of language can not support using different but synonymous terms, any encoding of clinical knowledge in the decision rules must be adapted to the local institution in order to use the local vocabulary. In the Arden syntax this problem has become known as the "curly braces problem", because Arden syntax contains non-standardized names and expressions in curly braces. This problem affects the shareability of the defined decision rules. To overcome this problem some knowledge representation languages defined domain ontologies and used them in their decision rules [105,106]. Recent knowledge representations such as GLIF (Guideline Interchange Format) and SAGE (Standards-Based Active Guideline Environment) deal with vocabulary issues by specifying a clinical information model which includes vocabulary standards. Using standard terminological systems in guideline formalization and in patient information systems will facilitate the interoperability and reusability of the formalized guidelines and thereby ease implementation of the guideline into a CDSS [107,108]. Application of the unified medical language system (UMLS) which integrates over 100 key terminological systems provides a possibility to integrate CDSSs with diverse patient information systems [107,109].

The results of our study show that international terminological systems were used mostly in integrated systems, providing the possibility of sharing decision support content. It has been described that systems that are provided as an integrated component of health information systems are significantly more likely to succeed than stand-alone systems [1]. Stand-alone systems avoid vocabulary issues entirely since they do not interface with other patient information systems and they can simply be copied from one computer to another. However, this kind of system is not recommended as they request more time and effort from the users as this kind of systems does not have the desirable feature "content integrated into workflows". Integrated systems reduce the need for additional data entry by the healthcare provider, enable the display of the most up-to-date data and patient information, and max-

imize healthcare provider exposure to the recommendations. However, 44% of the integrated systems that were evaluated in the included studies of this literature review still required additional data entry by the healthcare provider for example, because the data is not recorded in the source system and hence additional data is required to get proper advice from the CDSS. Arduous data entry was suggested as a reason for poor system acceptance in other studies [110,70], as physicians are not willing and do not have time to interact with a system that requires them to do more work.

Our study covers the situation of CDSSs over the last 15 years concerning the use of data standardization and terminological systems. It is perceived that some specific features of CDSS improve patient outcome and practitioner performance. In this study we also found that the practitioner performance was significantly improved in studies that did avoid using free text compared to those systems that used free text (Table 2). However, due to the limited amount of studies, the lack of reported information on data standardization in the included studies, and the heterogeneity of systems and sites included we are not able to provide strong evidence on this subject. Future reports of CDSS evaluations should provide as much detail as possible when describing the systems including the use of terminological systems and information models in a structural way. The trend toward using international terminological systems may be consolidated with the world-wide uptake of SNOMED CT, a terminological system that provides formal representation which can facilitate defining decision rules. SNOMED CT is considered to be a reference terminological system which is designed to document the information during the course of patient care and due to its formal representation of concepts and their characteristics. As such, it is one of the most promising terminological systems to bind CDSS to electronic patient records [98,111]. However, no mention was made of the application of this terminological system in CDSSs described by any of the included articles. This result is in line with findings of a literature review on SNOMED CT [112]. However, recent studies on guideline formalization applied SNOMED CT to encode guidelines which provides steps toward application of this terminology in CDSSs [5,108,113,114]. As we expect the implementation of SNOMED CT, to increase rapidly in many settings in coming years [115] (e.g. as it is aligned with ICD-11 and is promoted within the US "Health Information Technology for Economic and Clinical Health" act) we recommend specific evaluation studies in these settings.

4.1. Limitations

Some limitations of this study need to be mentioned. First, we did not run a new search strategy as we relied on articles identified by Garg's search strategy [18] and updated it by studies identified by AMIA's "Year in Review". Garg's search strategy was a comprehensive search that was run in several databases and Masys et al. applied a broad search string and a poll of experts in the field to identify the relevant studies for the "Year in Review". Second, as we restricted our inclusion to RCTs, some relevant studies might be missed. Moreover, some CDSSs may not be evaluated or their evaluation results were not reported as a scientific study. For instance, we know that

Kaiser Permanente Health Connect is an information management system including CDSS which uses SNOMED CT [116] but we did not find any RCT on CDSS using SNOMED CT. Nevertheless, we believe that our results are not influenced by these choices, as one cannot say the included systems were developed in a fundamentally different manner than those that were not included. This is very unlikely given the diversity of systems and settings (academic versus non-academic, commercial versus non-commercial) that were included in our review. On the other hand, in the RCTs investigators generally evaluate systems that have the potential of being used in practice and applied at a larger scale. A third limitation is that many studies did not clearly report on data items that are used for CDSS invocation or advice generation, and on any terminological systems used for presenting coded data. To overcome this limitation, we contacted the authors of the included studies. However, not all contacted authors may have had sufficient information about the evaluated CDSS, its implementation process and the degree of integration with a patient information system. Our response rate was 62% which is comparable to Garg's study [18]. Some bias might be introduced in the question regarding abandoning the development of a CDSS, because of the suggestive formulation of this question and its answer categories. However, we started the answer categories with two answers describing the absence of any problem and any non-data related problem. Therefore, we expect that the overall conclusion that a majority of authors observed some obstacles in CDSS implementation due to a lack of data standardization is still valid.

5. Conclusion

Still a lot of work needs to be done to come to fully integrated and interoperable CDSSs. This can be explained by the fact that CDSSs applied different terminological systems to code data items. This diversity hampers the possibility of sharing and reasoning with data within different systems. Using local terminological systems, which were the case in presentation of about half of the coded data, will negatively affect the shareability of the data and decision rules. A survey among authors of articles included in this study revealed that the lack of standardized data is a major obstacle for CDSS implementation. To adequately use a CDSS, quality, availability and standardization of data are essential.

Author's contributions

All authors qualify for authorship by substantial contributions to the research and production of the manuscript. All authors contributed in designing the extraction form and acquisition of the data. L. Ahmadian completed the analysis and interpretation of the data, and drafted the article. M. van Engen-Verheul and F. Bakhshi-Raiez reviewed and revised the article. N. de Keizer, R. Cornet and N. Peek provided substantial input in the conception and design of the study. N. de Keizer and R. Cornet were the chief designers of the study, and critically revised the manuscript. All authors gave final approval of the manuscript.

Summary points

Already known

- CDSSs significantly improve patient care and reduce practice variability.
- Using standard terminological systems in guideline formalization and in patient information systems will facilitate the interoperability and reusability of the formalized guidelines and thereby ease implementation of the guideline into a CDSS.
- Some barriers of clinical decision support systems implementation including organizational issues, clinician disagreement and suboptimal use of the electronic medical record are already discussed.

Knowledge added by this study

- Lack of semantic interoperability is the most important obstacle in clinical decision support system implementation.
- Standardized data is used more frequently in CDSSs that automatically prompt users, compared to those that are manually initiated.
- The use of local terminological systems in clinical decision support systems is commonly hampering the shareability and reusability of the systems.
- The ICD family is the most frequently used international terminological system in CDSSs.

Conflict of interest

The authors have no conflicts of interest to declare.

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Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at [doi:10.1016/j.ijmedinf.2010.11.006](https://doi.org/10.1016/j.ijmedinf.2010.11.006).

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