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The Intersection of Clinical Decision Support and Electronic Health Record: A Literature Review

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***Abstract*—It is observed that clinical decision support (CDS) and electronic health records (EHR) should be integrated so that their contribution to improving the quality of health care is enhanced. In this paper, we present results from a review on the related literature. The aim of this review was to find out to what extent CDS developers have actually considered EHR integration in developing CDS. We have also investigated how various clinical standards are taken into account by CDS developers.**

We observed that there are few CDS development projects where EHR integration is taken into account. Also, the number of studies where various clinical standards are taken into consideration in developing CDS is surprisingly low especially for *open*EHR, the EHR standard we aimed for. The reasons for low adoption of *open*EHR are issues such as complex and huge specifications, shortcomings in educational aspects, low empirical focus and low support for developers. It is concluded that there is a need for further investigation to discover the reasons why the rate of integration of EHRs and CDS is not at an optimum level and mostly to discover why CDS developers are not keen to adopt clinical standards.

I. Introduction

EVEN though more than 50 years of research have been put into the clinical decision support (CDS) field, the adoption rate of these systems is still low [1], [2], [3], [4], [5], [6]. Various researchers have investigated the factors that should be considered by developers of such systems in order to result in higher adoption. One of these factors is the integration of CDS into the electronic health record (EHR) systems. Different benefits are associated with the integration of CDS into EHRs. For instance, integration facilitates real time access to the knowledge provided by CDS at point of care, it also eliminates tedious duplicate patient data entry since the pre-existing digital patient data in the EHR system can be utilized for the purpose of providing decision support [1], [7], [8].

The aim of this study is to answer this research question: *is integration of clinical decision support into electronic health record taken into consideration by developers of clinical decision support?* The related literature was reviewed not only to explore CDS developers' attitude towards integration of EHR and CDS, but also to discover the status of EHR standards in this field.

The structure of the paper is as follows. We start with the background information including the motivation for integration of CDS and EHRs in Section II. In Section III the literature review search strategy is given. The results of the review are presented in Section IV. Section V includes the discussion of the findings along with our reflection on the low adoption rate of the *open*EHR EHR standardization approach. Finally, we end with a conclusion and future directions of the study in Section VI.

II. Background

The idea of computerized medical records has been around as one of the key research areas in medical informatics for more than 20 years. Iakovidis defines EHR as "digitally stored health care information about an individual's lifetime with the purpose of supporting continuity of care, education and research, and ensuring confidentiality at all times" [9]. EHRs include the whole range of patient-related data such as demographic information, medical history, medication, and allergies [10].

The main aim of EHRs is to make distributed and cooperating health information system and health networks a reality [10].

Several reasons have been identified for the low adoption rate of EHRs in small hospitals and office practices. This includes high implementation and maintenance costs, additional time and effort and finally the difficulty in choosing among available systems on the market due to a lack of standardization [1].

Improving the quality of health care is the ultimate goal of the EHR research domain, but it is in doubt whether EHRs have the ability to fulfill this goal [5]. EHRs need to be supported by other services in order to improve the quality of care [5], [11], [12], [13]. To reach the goal of improved health care quality, it is central to have CDS [5], [14], [3], [2], [6], [12], [15].

It has been observed that if there is no decision support service, the clinical knowledge needed for making a decision is not always available or applied [16]. Therefore, it is recommended that clinicians be automatically supported by

timely access to clinical decision support tools [7], [8]. The emphasize in the current application of EHRs is on timely access to patient data, patient tracking and providing decision support with the aim of improving quality of care [13]. In spite of this fact, the usage of decision support among EHR users is still quite low and there are still many EHR systems that do not include any CDS features [5]. Nonetheless, interest in applying CDS in various health care organizations to improve quality of health care has recently shown an increase [17], [18]. The CDS these organizations are looking for should provide support in patient specific assessments [17], [1].

A. Low Adoption of Clinical Decision Support

Results from several studies that deal with the question: *which factors should be considered in the design and development of CDS to result in an acceptable and effective CDS?* are summarized in[19]. These studies focus on developing such systems that lead to wider adoption of CDS and consequent improvement in quality of health care. According to these studies and those reviewed in this section, three of the main challenges in design and development of CDS are:

- human-related factors that are related to the way CDS systems are designed, evaluated and introduced to the users
- technical factors that are mainly related to knowledge representation and reasoning in CDS systems
- Integration to the EHR systems available in health organizations

B. Integration of Clinical Decision Support into Electronic Health Records

It is recommended that CDS be integrated into other information systems in the clinical domain and it has been demonstrated that an integrated system has better effects on the care process [20]. Different clinical applications such as computerized physician order entry (CPOE), electronic prescribing, e-prescribing (eRX) and personal health records (PHR) are valuable underlying platforms for CDS [16], [1]. Several studies discuss how delivery of decision support through EHRs can improve the quality of care [4], [3], [21], [22]. Moreover, integration of CDS into EHR systems has been advocated in several studies as being helpful to the wider adoption of CDS [2], [1], [5], [4], [23], [16], [24]. Overall, EHR is considered as leverage for CDS [6], [1].

Several studies have observed that manual data entry into CDS acts as a barrier for broad adoption of CDS. It is recommended that the CDS be provided at the point of care and without any additional effort to invoke it or utilize it [1], [17]. One sample scenario for an integrated CDS feature would be prompts or alerts that appear on the screen in order to inform the clinician about a drug-drug or drug-allergy interaction for one specific patient while reviewing/editing the patient's health record.

Manual data entry which is a time consuming task and a burden for clinicians can be removed by integrating CDS into EHR systems and utilizing the data which is already in an electronic, computer-readable format. In this case, there is no need for duplicate data entry and the system can query related information from the EHR system [2], [1], [23], [25], [6]. Therefore, implementation of CDS is facilitated by EHRs. If there is no integration, data must be extracted from EHRs to be applied in the CDS. Moreover, if CDS is not integrated into EHRs, that part of the domain knowledge which is included in EHR is not applied properly [1].

C. Interoperability of EHR systems

EHR systems are being developed by various vendors, so they might be stored in different formats. This results in systems that are not interoperable, and makes sharing EHRs among different health organizations difficult. To overcome this problem, and to support secure and timely access to EHRs, national and international EHR standards are developed [26], [27]. open*EHR* [28] and *health level 7* (HL7) [29] are two of the well-known interoperability standards. A description of these two standards follows:

1) open*EHR:* *open*EHR is an open standard specification. The *open*EHR specification describes how health data, i.e. EHRs, are managed, stored, retrieved and exchanged [30]. Three main concepts defined in *open*EHR are (i) the two-level software architecture (ii) archetypes (iii) templates. The two-level architecture for clinical applications deals with separation of knowledge and information levels in order to overcome the problems caused by the ever-changing nature of clinical knowledge. This is realized by using *open*EHR archetypes. Archetypes and templates are used for data validation and sharing [28]. Beale et al. in [31] define archetype and template as follows:

- Archetype is "a computable expression of a domain content model in the form of structured constraint statements, based on a reference (information) model. openEHR archetypes are based on the openEHR reference model. Archetypes are all expressed in the same formalism. In general, they are defined for wide re-use, however, they can be specialized to include local particularities. They can accommodate any number of natural languages and terminologies."
- Template is "a directly locally usable definition which composes archetypes into a larger structures often corresponding to a screen form, document, report or message. A template may add further local constraints on the archetypes it mentions, including removing or mandating optional sections, and may define default values."

2) Health Level 7: HL7 is an EHR standard that focuses on communicating health data, i.e. EHRs, [10]. According to HL7 website[1]: "Health Level Seven International (HL7) is a not-for-profit, ANSI-accredited standards developing organization dedicated to providing a comprehensive framework and related standards for the exchange, integration, sharing, and retrieval of electronic health information that supports

[1] http://www.hl7.org/

clinical practice and the management, delivery and evaluation of health services". In HL7 version 3 a comprehensive Reference Information Model (RIM) is introduced [10]. HL7 clinical document architecture (CDA) templates are analogous to *open*EHR archetypes [32].

3) Other Standards in the Clinical Domain: There are different approaches to support the interoperability among heterogeneous clinical systems. Other than EHR interoperability standards that concentrate on standardizing the clinical information model, the initiative has been taken to standardize other concepts in the clinical domain such as clinical guidelines and clinical terminologies to improve shareability and reusability of them among health institutions.

- Communicating the Clinical Terminology The language is not uniform in the clinical domain and clinicians may use different terms to refer to the same concepts. Therefore, there is a need to standardize the clinical terminology to enable communicating it [33]. SNOMED CT (Systematized Nomenclature of Medicine – Clinical Terms) is and advanced clinical terminology and coding system [33]. SNOMED CT concepts are usually referred to by an information model such as *open*EHR and HL7 [34].
  ICD (International Classification of Diseases) is a coding system that is designed to "promote international comparability in the collection, processing, classification, and presentation of mortality statistics" [35]. This classification standard is suitable for statistical reporting rather than clinical documentation as is supported by SNOMED CT. There is a map between SNOMED CT terms and the equivalent ICD codes [34].
- Sharing Clinical Guidelines Developing clinical guidelines involves a lot of effort. Therefore, there have been initiatives to enable reusability and shareability of clinical guidelines among various health organizations. The first step to support reusability and shareability of clinical guidelines is to define a common format for representing them [36]. One well-known language for this purpose is the one developed by the InterMed Collaboratory named GLIF (the GuideLine Interchange Format) [36].

III. Methods and Materials

The search was conducted in the Sciencedirect[2] database that includes the major journals in medical informatics. The search strategy is depicted in Figure 1 and explained in more details in the following.

- searching the combination of phrases "clinical decision support" and "electronic health record" returned 48 articles where 37 of them were selected for further studies.
- searching the combination of phrases "clinical decision support" and "medical health record" (excluding the papers that had the phrase "electronic health record") returned 50 articles where 37 of them were selected for further studies.

[2]http://sciencedirect.com

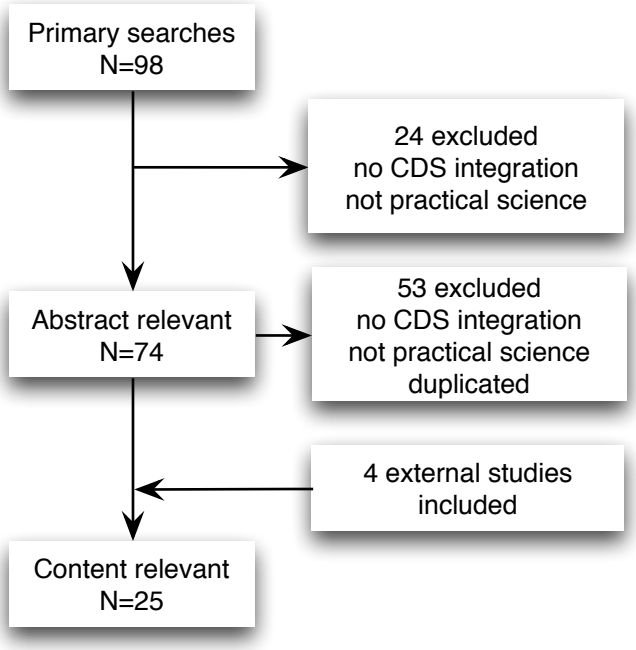

Fig. 1. Search process.

Of these 74 studies, only 21 turned out to be relevant to the review. In addition to these 21 studies, 4 more studies that the author had found were included in the review.

Inclusion criteria for the papers were positive answers to these questions based on their titles and abstracts:

- Is the study discussing development and/or evaluation of an EHR or a CDS system (i.e. practical science)?
- If Have the authors considered integration of CDS into EHRs or a related application (i.e. integration)?

Since, we were particularly interested in *open*EHR, further searches were carried out in ScienceDirect and PubMed[3] specifically on *open*EHR to find out if any development of an *open*EHR-based CDSS is documented in the literature:

- In ScienceDirect, searching the combination of phrases "clinical decision support" and *open*EHRresulted in 1 article that was reviewed before (the study by Greenes [1]).
- In PubMed, searching the combination of phrases "clinical decision support" and *open*EHR resulted in 2 articles by the author of this paper [37], [38] (these papers are not included in the review).

IV. Results

This section includes the preliminary findings from the literature review. Analysis of the findings are given in the next section.

The 25 selected articles were reviewed in order to find out whether they consider any of the clinical standards (i.e. EHR standards, guideline representation standards, and terminology

[3]http://pubmed.org

TABLE I
THE SUMMARY OF THE FINDINGS.

Who	Year	Integr-ation	Standards		
			EHR	Guideline	Terminology
Stair [39]	1998	✓	✗	✗	✗
Gadd et al. [40]	1998	✓	✗	✗	✗
Panzarasa et al. [41]	2002	✓	✗	✗	✓
Young et al. [42]	2004	✓	✗	✗	✗
Shiffman et al. [43]	2004	✓	HL7	✓	✗
Rosenbloom et al. [44]	2004	✓	✗	✗	✗
Galanter et al. [45]	2005	✓	✗	✗	✗
Haller et al. [46]	2007	✓	✗	✗	✗
Stutman et al. [47]	2007	✓	✗	✗	✗
Wilson et al. [24]	2007	✓	✗	✗	✗
Lobach et al. [48]	2007	-	HL7	✗	✗
Graham et al. [49]	2008	-	HL7	✗	✗
Marcy et al. [50]	2008	✓	✗	✗	✗
Wright et al. [51]	2008	✓	HL7	✗	SNOMED CT,ICD
Gerard et al. [52]	2008	✓	✗	✗	✗
Field et al. [53]	2008	✓	✗	✗	✗
Schnipper et al. [54]	2008	✓	✗	✗	✗
Peleg et al. [55]	2009	✓	✗	GLIF	✗
Saleem et al. [56]	2009	✓	✗	✗	✗
Field et al. [57]	2009	✓	✗	✗	✗
Chen et al. [58]	2010	✓	✗	✓	✗
Galanter et al. [59]	2010	✓	✗	✗	SNOMED CT,ICD
Noormohammad et al. [60]	2010	✓	HL7	✗	✓
Trafton et al. [61]	2010	✓	✗	✗	✗
Were et al. [62]	2010	✓	HL7	✗	✗

or vocabulary standards). The summary of the results is shown in Table I. The Integration column indicates if the integration of EHRs and CDS is taken into consideration in the study (✓) or not (✗), there are cases where the authors did not reveal any information in this regard (-). If any sorts of standards is applied in the study, the corresponding column is marked with ✓, and in cases where an international standard is used with the name of the standard e.g. HL7 for EHR, SNOMED CT for terminology.

As evident from Table I, there are various studies that have applied EHR standards (not including *open*EHR) in developing EHRs with CDS functionalities. HL7 is used in 7 studies, GLIF in 1, and SNOMED CT/ICT in 2 studies. There are also studies in which local representations or terminologies were used for representing clinical guidelines or clinical terms [60], [41]. Most of the CDS services were documented to be integrated into a CPOE system. The summary of findings is presented in Figure 2.

A. *HL7 versus* open*EHR*

While searching the combination of phrases "clinical decision support" and HL7 resulted in 41 papers[4], we did not find any study that reports on implementation of a CDS applying *open*EHR[5].

V. DISCUSSION

Theory supports the benefits offered by integrating CDS into EHR, but this concept is still appreciated more in theory than in practice. Only 25 related studies were discovered in this database while around 100 studies are documented in the literature that, based on their titles and abstracts, are about developing a CDSS. Nonetheless, the publication years of these 25 studies are an indication that in recent years, there has been an increase in consideration of EHR integration in development of CDS.

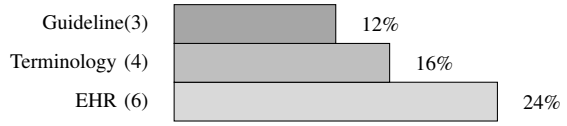

Fig. 2. Various standards reported in the reviewed studies. All of the EHR standards that were applied in studies were HL7. *open*EHR was not adopted in any of the studies.

Moreover, it is observed that taking standards into consideration in any clinical application (and generally any information system) is very important [11]. In case of CDSSs, since such systems operate by utilizing both patient/organizational-specific data and clinical knowledge, it is important to consider the standards that support each of these areas [11]. This however is observed to still be in need of further improvements. Of these 25 studies, only 6 had considered EHR standardization, and 3 had considered terminology standards which are both surprisingly small numbers.

Finally, one can conclude that based on the literature, HL7 has a higher level of adoption than *open*EHR and that applying *open*EHR in development of clinical applications specially CDS is yet rare. This brings the question that regardless of the advances in theory why *open*EHR is suffering from a low adoption rate in practice. This issue is discussed more in the following section.

A. *Low Adoption of* open*EHR*

Below is a list of problems that we or others have faced using *open*EHR[6]. These issues are considered as barriers to higher adoption of *open*EHR[7]:

1) Being huge and complex: open*EHR is naturally complex, and this complexity is not unexpected since *open*EHR is considered to be a solution for a complicated problem (i.e. interoperable future-proof EHR) in a complex domain (i.e. the clinical domain). For instance the powerful archetype model allows expressing complex clinical concepts, therefore, an inexperienced archetype developer should expect to spend some time on learning the *open*EHR concepts. Additionally, getting a grip on the current specifications (more than 1000 pages), UML diagrams and code documentation is challenging. At the same time, it is notable that this complexity is intensified by

[4]Not all of these studies are included in the review.

[5]The search was done in mid 2010. However, in a new search in 2011, we found more new studies related to *open*EHR. These studies are discussed more in the discussion section.

[6]In November 2010, there was a discussion on *open*EHR mailing list with the same topic. This shows that even people in the *open*EHR community have noticed that the adoption rate is low and some actions should be taken in order to improve it. Especially, it is noticeable that the amount of attention to *open*EHR is much less than HL7 in various domains i.e. government, academy and industry.

[7]Some of the issues presented here are the result of investigating the discussions in the *open*EHR mailing list, even though some others had been experienced in this study. Those issues are marked with an asterisk.

some other aspects such as improper educational support and limited internationalization.

2) Shortcoming in educational aspects:* Understanding a concept is the first step to be able to adopt it and this is even more valid for such complex concepts like those in *open*EHR. Unfortunately, no formal tutorial document exists for *open*EHR, formal training sessions are rare and even worse, not so many *open*EHR trainers exist around the world. Easy to understand tutorials are needed to help novice developers get a grip on *open*EHR.

3) Low government and industry penetration: Many of those who are interested in *open*EHR, in spending time on learning it or adopting it, are from the academic world (the main of which is University College London[8]). So far, there are very few companies that are adopting *open*EHR and to our knowledge these companies are considered to be a part of the core *open*EHR community. The main companies are Oceaninformatics[9], Cambio[10], and Zilics[11]. But what about "ordinary audience"? On the other hand, low support from the governmental agencies lead to low industry penetration. Considering the complication and the cost imposed by the *open*EHR approach, and also limited documentations and guidelines, applying *open*EHR is not still cost-efficient and yet commercial companies show a lot of hesitation to accept risks imposed by adopting this immature standard.

4) Shortcoming in internationalization aspects: In order to reach an international-wide adoption, it is suggested that establishing regional communities would be helpful; nevertheless, there are other concerns in this regard. *open*EHR community should consider issues such as supporting and providing guidelines for regional communities all around the world. It is also beneficial to publish *open*EHR specifications in various languages in order to speed up the process of learning for various people. Regional events such as educational sessions, gatherings and so on are also valuable to influence collaboration. As an example, in Sweden, there are around 4 groups of people[12] doing research on or adopting *open*EHR, but collaboration among them is at a very low level.

5) Low empirical focus: open*EHR should not just be about complex theoretical specifications and reference models, but also about implementation and practice. Semantic interoperability, two-level modeling and involving clinicians are interesting concepts, but so far these have been far from the practice. Currently, there are just a few empirical efforts on *open*EHR. Most of the focus of *open*EHR community has been on representation of domain concepts and theoretical aspects of the approach. Still, there is a huge need for supporting developers to make *open*EHR more practical.

6) Limited tools and implementations:* As mentioned above, developers needed to be supported in order to improve adoption of *open*EHR. One way of delivering this support is by providing frameworks and application programming interfaces (API). At this time, the *open*EHR reference model implementation is still immature and lacks important parts like templates, persistence, and services.

[8]http://ucl.ac.uk

[9]http://www.oceaninformatics.com

[10]http://cambio.se

[11]http://www.zilics.com.br

[12]Chalmers university of technology, Linköping university, Cambio company and The Swedish NHS.

B. Recent Advances in The openEHR-based CDS

When it comes to CDS, there are a few studies that deal with how *open*EHR offers opportunities for CDS. Most of these efforts however, seem to be more focused on integrating clinical guidelines into *open*EHR archetypes or utilizing archetypes for representing clinical guidelines [63], [25], [64] or to integrate reasoning and clinical archetypes (enhance archetypes by including knowledge representation capabilities to them) [65]. To our knowledge there is almost no study that has been focused on benefiting from the well-structured *open*EHR-based patient data for adopting data intensive reasoning methods in CDSSs or methods that rely on previous cases to carry out the reasoning process.

C. Why Are Clinical Standards Important for CDS?

According to the discussion in Section II, enough motivation exists to integrate CDS into EHRs. There is still a question whether integration of CDS into EHRs can be done without taking EHR related standards into account. If EHR standards are not considered in CDS development, all clinical data should be translated to a format understandable for the CDS system. This is not an efficient way for CDS and the EHR system to communicate. Moreover, there is an increasing interest in the medical informatics community to share clinical knowledge. This can also be supported if CDS is developed based on EHR standards. For instance, by enriching standard compatible EHRs with the reasoning knowledge, EHR sharing will also result in sharing and reusing the embedded knowledge. In cases where general domain knowledge including clinical guidelines are integrated into EHRs, the reusability and sharing of knowledge can be achieved as well.

VI. Conclusion

Researchers in the area of CDS and also EHR have argued that by integrating CDS into EHRs, the improvement in the quality of health care would be higher than when the systems operate separately. The integration will be more efficient if the standards related to EHRs are considered in developing CDS. The possibility to share the domain knowledge, especially the reasoning knowledge, in decision making is another motivation for taking standards into account in developing CDS.

Nevertheless, a review of the related literature indicates that not all of CDS developers take integration into account, also there are very few of them who consider standards in developing CDS. Discovering the reasons for this however needs further investigation and has not been in the scope of this review.

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REFERENCES

[1] R. Greenes, *Clinical decision support: the road ahead*. Academic Press, 2007.

[2] T. Wendt, P. Knaup-Gregori, and A, "Decision Support in Medicine: A Survey of Problems of User Acceptance," *Stud Health Technol Inform*, vol. 77, pp. 852–856, 2000.

[3] B. Chaudhry, J. Wang, S. Wu, and M. Maglione, "Systematic review: impact of health information technology on quality, efficiency, and costs of medical care," *Annals of Internal Med*, vol. 144, no. 10, pp. 742–752, 2006.

[4] A. Garg, N. Adhikari, H. McDonald, and M. Rosas, "Effects of computerized clinical decision support systems on practitioner performance and patient outcomes: a systematic review," *Journal of the American Medical Association*, vol. 293, no. 10, pp. 1223–1238, 2005.

[5] D. F. Sittig, A. Wright, J. a. Osheroff, B. Middleton, J. M. Teich, J. S. Ash, E. Campbell, and D. W. Bates, "Grand challenges in clinical decision support." *Journal of Biomedical Informatics*, vol. 41, no. 2, pp. 387–92, Apr. 2008.

[6] J. Osheroff, J. Teich, B. Middleton, E. Steen, A. Wright, and D. Detmer, "A roadmap for national action on clinical decision support," *Journal of the American Medical Informatics Association*, vol. 14, no. 2, p. 141, 2007.

[7] "Patient Safety: Achieving a New Standard of Care," Washington DC, 2003.

[8] "Crossing the Quality Chasm: A New Health System for the 21st Century," Website, Washington DC, 2001, http://journals.lww.com/qmhcjournal/Citation/2002/10040/Crossing_the_Quality_Chasm__A_New_Health_System.10.aspx.

[9] I. Iakovidis, "Towards personal health record: current situation, obstacles and trends in implementation of electronic healthcare record in Europe." *International Journal of Medical Informatics*, vol. 52, no. 1-3, pp. 105–15, 1998.

[10] B. Blobel, "Advanced and secure architectural EHR approaches." *International Journal of Medical Informatics*, vol. 75, no. 3-4, pp. 185–90, 2006.

[11] J. Osheroff, E. Pifer, J. Teich, D. Sittig, and R. Jenders, *Improving outcomes with clinical decision support: An implementer's guide*. HIMSS, 2005.

[12] R. Greenes, M. Sordo, D. Zaccagnini, M. Meyer, and GJ, "Design of a standards-based external rules engine for decision support in a variety of application contexts: report of a feasibility study at Partners HealthCare System," *Medinfo*, 2004.

[13] L. Zhou, C. S. Soran, C. a. Jenter, L. a. Volk, E. J. Orav, D. W. Bates, and S. R. Simon, "The relationship between electronic health record use and quality of care over time." *Journal of the American Medical Informatics Association*, vol. 16, no. 4, pp. 457–64, 2009.

[14] J. Anderson, "Increasing the acceptance of clinical Information," *MD computing: Computers in Medical Practice*, vol. 16, no. 1, p. 62, 1999.

[15] K. Kawamoto and D. Lobach, "Proposal for fulfilling strategic objectives of the US roadmap for national action on decision support through a service-oriented architecture leveraging HL7 services," *Journal of the American Medical Informatics Association*, pp. 146–155, 2007.

[16] I. Cho, J. Kim, J. H. Kim, H. Y. Kim, and Y. Kim, "Design and implementation of a standards-based interoperable clinical decision support architecture in the context of the Korean EHR." *International Journal of Medical Informatics*, vol. 9, pp. 611–622, Jul. 2010.

[17] K. Kawamoto, C. A. Houlihan, E. A. Balas, and D. F. Lobach, "Improving clinical practice using clinical decision support systems: a systematic review of trials to identify features critical to success." *BMJ (Clinical research ed.)*, vol. 330, no. 7494, p. 765, 2005.

[18] M. Trivedi, J. Kern, A. Marcee, B. Grannemann, B. Kleiber, T. Bettinger, K. Altshuler, and A. McClelland, "Development and Implementation of Computerized Clinical Guidelines : Barriers and Solutions," *Methods of Information in Medicine*, vol. 41, no. 5, pp. 435–442, 2002.

[19] H. Kashfi, "Towards Interaction Design in Clinical Decision Support Development: A Literature Review," *International Journal of Medical Informatics*, 2011, in review article.

[20] R. A. K. Horasani, M. I. T. Anasijevic, B. L. M. Iddleton, and M. S. C, "Ten Commandments for Effective Clinical Decision Support: Making the Practice of Evidence-based Medicine a Reality," *Journal of the American Medical Informatics Association*, vol. 10, pp. 523–530, 2003.

[21] D. Hunt, R. Haynes, S. Hanna, and K. Smith, "Effects of computer-based clinical decision support systems on physician performance and patient outcomes: a systematic review," *Journal of the American Medical Association*, vol. 280, no. 15, p. 1339, Oct. 1998.

[22] M. Johnston, K. Langton, and R. Haynes, "Effects of computer-based clinical decision support systems on clinician performance and patient outcome. A critical appraisal of reserach," *Ann Intern Med*, vol. 120, no. 2, pp. 135–142, 1994.

[23] E. Berner, *Clinical Decision Support Systems: Theory and Practice (Health Informatics)*. New York, NY 10013, USA: Springer, 2007.

[24] A. Wilson, A. Duszynski, D. Turnbull, and J, "Investigating patients' and general practitioners' views of computerised decision support software for the assessment and management of cardiovascular risk," *Informatics in Primary Care*, vol. 15, pp. 33–44, 2007.

[25] R. Chen, P. Georgii-Hemming, and H. Ahlfeldt, "Representing a chemotherapy guideline using openEHR and rules." *Studies in Health Technology and Informatics*, vol. 150, pp. 653–7, Jan. 2009.

[26] V. Stroetmann, D. Kalra, P. Lewalle, J. Rodrigues, and KA, "Semantic Interoperability for Better Health and Safer Health Care," *Deployment and Research*, no. January, 2009.

[27] P. Schloeffel, T. Beale, G. Hayworth, S. Heard, and H. Leslie, "The relationship between CEN 13606, HL7, and openEHR," in *In Health Informatics Conference*, vol. 7. Health Informatics Society of Australia, 2006, p. 24.

[28] T. Beale and S. Heard, "openehr architecture overview," Website, 2008, http://www.openehr.org/releases/1.0.2/architecture/overview.pdf.

[29] "HL7," Website, 2010, http://hl7.org.

[30] "openEHR," Website, 2010, http://en.wikipedia.org/wiki/openehr.

[31] T. Beale and S. Heard, "Archetype Definitions and Principles," Website, 2007, http://www.openehr.org/releases/1.0.2/architecture/am/archetype_principles.pdf.

[32] M. Eichelberg, T. Aden, J. Riesmeier, A. Dogac, and G. B. Laleci, "A survey and analysis of Electronic Healthcare Record standards," *ACM Computing Surveys*, vol. 37, no. 4, pp. 277–315, Dec. 2005.

[33] K. Donnelly, "SNOMED-CT: The advanced terminology and coding system for eHealth." *Studies in Health Technology and Informatics*, vol. 121, pp. 279–90, Jan. 2006.

[34] "SNOMED CT," Website, 2010, http://en.wikipedia.org/wiki/SNOMED_CT.

[35] "ICD," Website, 2010, http://www.cdc.gov/nchs/icd.htm.

[36] L. Ohno-Machado, J. H. Gennari, S. N. Murphy, N. L. Jain, S. W. Tu, D. E. Oliver, E. Pattison-Gordon, R. a. Greenes, E. H. Shortliffe, and G. O. Barnett, "The guideline interchange format: a model for representing guidelines." *Journal of the American Medical Informatics Association*, vol. 5, no. 4, pp. 357–72, 1998.

[37] H. Kashfi, "An openEHR-based clinical decision support system: a case study." in *Studies in health technology and informatics*, vol. 150, Jan. 2009, p. 348.

[38] ——, "Applying a user centered design methodology in a clinical context," in *Studies in health technology and informatics*, vol. 160, no. Pt 2, Jan. 2010, pp. 927–31.

[39] T. Stair, "Reduction of Redundant Laboratory Orders by Access to Computerized Patient Records," *The Journal of Emergency Medicine*, vol. 16, no. 6, pp. 895– 897, 1998.

[40] C. Gadd, P. Baskaran, and D. Lobach, "Identification of design features to enhance utilization and acceptance of systems for Internet-based decision support at the point of care." in *Proceedings of the AMIA*, Jan. 1998, pp. 91–5.

[41] S. Panzarasa, S. Maddč, and S. Quaglini, "Evidence-based careflow management systems: the case of post-stroke rehabilitation," *Journal of Biomedical*, vol. 35, no. 2, pp. 123–139, Apr. 2002.

[42] A. S. Young, J. Mintz, A. N. Cohen, and M. J. Chinman, "A network-based system to improve care for schizophrenia: the Medical Informatics Network Tool (MINT)." *Journal of the American Medical Informatics Association*, vol. 11, no. 5, pp. 358–67, 2004.

[43] R. N. Shiffman, G. Michel, A. Essaihi, and E. Thornquist, "Bridging the guideline implementation gap: a systematic, document-centered approach to guideline implementation." *Journal of the American Medical Informatics Association*, vol. 11, no. 5, pp. 418–26, 2004.

[44] S. T. Rosenbloom, D. Talbert, and D. Aronsky, "Clinicians' perceptions of clinical decision support integrated into computerized provider order entry." *International Journal of Medical Informatics*, vol. 73, no. 5, pp. 433–41, Jun. 2004.

[45] W. L. Galanter, R. J. Didomenico, and A. Polikaitis, "A trial of automated decision support alerts for contraindicated medications using computerized physician order entry." *Journal of the American Medical Informatics Association*, vol. 12, no. 3, pp. 269–74, 2005.

[46] G. Haller, P. S. Myles, J. Stoelwinder, M. Langley, H. Anderson, and J. McNeil, "Integrating incident reporting into an electronic patient record system." *Journal of the American Medical Informatics Association*, vol. 14, no. 2, pp. 175–81, 2007.

[47] H. Stutman, R. Fineman, and K. Meyer, "Optimizing the acceptance of medication-based alerts by physicians during CPOE implementation in a community hospital environment," in *AMIA Annual Symposium*, 2007, pp. 701–705.

[48] D. F. Lobach, K. Kawamoto, K. J. Anstrom, M. L. Russell, P. Woods, and D. Smith, "Development, deployment and usability of a point-of-care decision support system for chronic disease management using the recently-approved HL7 decision support service standard." *Studies in Health Technology and Informatics*, vol. 129, no. Pt 2, pp. 861–5, Jan. 2007.

[49] T. Graham, A. Kushniruk, M. Bullard, B. Holroyd, D. Meurer, and B. Rowe, "How usability of a web-based clinical decision support system has the potential to contribute to adverse medical events," in *AMIA Annual Symposium Proceedings*, vol. 2008. American Medical Informatics Association, Jan. 2008, p. 257.

[50] T. W. Marcy, B. Kaplan, S. W. Connolly, G. Michel, R. N. Shiffman, and B. S. Flynn, "Developing a decision support system for tobacco use counselling using primary care physicians." *Informatics in Primary Care*, vol. 16, no. 2, pp. 101–9, Jan. 2008.

[51] A. Wright and D. F. Sittig, "SANDS: a service-oriented architecture for clinical decision support in a National Health Information Network." *Journal of Biomedical Informatics*, vol. 41, no. 6, pp. 962–81, 2008.

[52] M. N. Gerard, W. E. Trick, K. Das, M. Charles-Damte, G. A. Murphy, and I. M. Benson, "Use of clinical decision support to increase influenza vaccination: multi-year evolution of the system." *Journal of the American Medical Informatics Association*, vol. 15, no. 6, pp. 776–9, 2008.

[53] T. S. Field, P. Rochon, M. Lee, L. Gavendo, S. Subramanian, S. Hoover, J. Baril, and J. Gurwitz, "Costs associated with developing and implementing a computerized clinical decision support system for medication dosing for patients with renal insufficiency in the long-term care setting." *Journal of the American Medical Informatics Association*, vol. 15, no. 4, pp. 466–72, 2008.

[54] J. L. Schnipper, J. A. Linder, M. B. Palchuk, J. S. Einbinder, Q. Li, A. Postilnik, and B. Middleton, ""Smart Forms" in an Electronic Medical Record: documentation-based clinical decision support to improve disease management." *Journal of the American Medical Informatics Association*, vol. 15, no. 4, pp. 513–23, 2008.

[55] M. Peleg, A. Shachak, D. Wang, and E. Karnieli, "Using multi-perspective methodologies to study users' interactions with the prototype front end of a guideline-based decision support system for diabetic foot care." *International Journal of Medical Informatics*, vol. 78, no. 7, pp. 482–93, Jul. 2009.

[56] J. Saleem, L. Militello, N. Arbuckle, and M. Flanagan, "Provider Perceptions of Colorectal Cancer Screening Clinical Decision Support at Three Benchmark Institutions," in *AIMIA Symposium Proceedings*, 2009, pp. 558–562.

[57] T. S. Field, P. Rochon, M. Lee, L. Gavendo, J. L. Baril, and J. H. Gurwitz, "Computerized clinical decision support during medication ordering for long-term care residents with renal insufficiency." *Journal of the American Medical Informatics Association*, vol. 16, no. 4, pp. 480–5, 2009.

[58] C. C. Chen, K. Chen, C.-y. Hsu, and Y.-c. J. Li, "Developing guideline-based decision support systems using protégé and jess." *Computer Methods and Programs in Biomedicine*, vol. in print, pp. 1–7, Jun. 2010.

[59] W. L. Galanter, D. B. Hier, C. Jao, and D. Sarne, "Computerized physician order entry of medications and clinical decision support can improve problem list documentation compliance." *International Journal of Medical Informatics*, vol. 79, no. 5, pp. 332–8, May 2010.

[60] S. F. Noormohammad, B. W. Mamlin, P. G. Biondich, B. McKown, S. N. Kimaiyo, and M. C. Were, "Changing course to make clinical decision support work in an HIV clinic in Kenya." *International Journal of Medical Informatics*, vol. 79, no. 3, pp. 204–10, Mar. 2010.

[61] J. Trafton, S. Martins, M. Michel, and E. Lewis, "Evaluation of the Acceptability and Usability of a Decision Support System to Encourage Safe and Effective Use of Opioid Therapy for Chronic , Noncancer Pain by Primary Care Providers," *Pain Medicine*, vol. 11, pp. 575–585, 2010.

[62] M. C. Were, C. Shen, M. Bwana, N. Emenyonu, N. Musinguzi, F. Nkuyahaga, A. Kembabazi, and W. M. Tierney, "Creation and evaluation of EMR-based paper clinical summaries to support HIV-care in Uganda, Africa." *International Journal of Medical Informatics*, vol. 79, no. 2, pp. 90–6, Mar. 2010.

[63] M. Marcos and B. n. Martínez-Salvador, "Towards the interoperability of computerized guidelines and electronic health records: an experiment with openEHR archetypes and a chronic heart failure guideline," in *Proceedings of the ECAI 2010 conference on Knowledge representation for health-care*, ser. KR4HC'10. Berlin, Heidelberg: Springer-Verlag, 2011, pp. 101–113.

[64] L. Xiao, G. Cousins, L. Hederman, T. Fahey, and B. Dimitrov, *The design of an EHR for clinical decision support*. IEEE, Oct. 2010, no. Bmei.

[65] L. Lezcano, M.-A. Sicilia, and C. Rodríguez-Solano, "Integrating reasoning and clinical archetypes using OWL ontologies and SWRL rules." *Journal of Biomedical Informatics*, vol. 44, no. 2, pp. 343–53, Apr. 2011.