

Grand challenges in clinical decision support

Dean F. Sittig^{a,b,*}, Adam Wright^{b,h}, Jerome A. Osheroff^{c,d}, Blackford Middleton^e,
Jonathan M. Teich^{f,g}, Joan S. Ash^b, Emily Campbell^b, David W. Bates^h

^a Department of Medical Informatics, Northwest Permanente, PC, Portland, OR, USA

^b Department of Medical Informatics and Clinical Epidemiology, Oregon Health and Science University, USA

^c Thomson Healthcare, Denver, CO, USA

^d University of Pennsylvania Health System, Philadelphia, PA, USA

^e Clinical Informatics Research and Development, Partners HealthCare System, Boston, MA, USA

^f Elsevier Health Sciences, Philadelphia, PA, USA

^g Department of Medicine (Emergency Medicine), Brigham & Women's Hospital, Harvard Medical School, Boston, MA, USA

^h Department of General Internal Medicine and Primary Care, Brigham & Women's Hospital, Harvard Medical School, Boston, MA, USA

Received 13 August 2007

Available online 21 September 2007

Abstract

There is a pressing need for high-quality, effective means of designing, developing, presenting, implementing, evaluating, and maintaining all types of clinical decision support capabilities for clinicians, patients and consumers. Using an iterative, consensus-building process we identified a rank-ordered list of the top 10 grand challenges in clinical decision support. This list was created to educate and inspire researchers, developers, funders, and policy-makers. The list of challenges in order of importance that they be solved if patients and organizations are to begin realizing the fullest benefits possible of these systems consists of: improve the human–computer interface; disseminate best practices in CDS design, development, and implementation; summarize patient-level information; prioritize and filter recommendations to the user; create an architecture for sharing executable CDS modules and services; combine recommendations for patients with co-morbidities; prioritize CDS content development and implementation; create internet-accessible clinical decision support repositories; use freetext information to drive clinical decision support; mine large clinical databases to create new CDS. Identification of solutions to these challenges is critical if clinical decision support is to achieve its potential and improve the quality, safety and efficiency of healthcare.

© 2007 Elsevier Inc. All rights reserved.

Keywords: Clinical decision support; Clinical information systems

1. Introduction

Multiple local, regional, and national initiatives [1] have encouraged health care providers to implement state of the art clinical information systems, targeting practice groups ranging from single physician practices [2] to large integrated delivery networks [3]. The efforts have aimed to create interoperable, longitudinal electronic health records (EHRs) for all patients to improve the quality of care

and reduce waste. However, whether these efforts will achieve these aims is uncertain. Models and pioneering deployment efforts suggest that a high level of clinical decision support (CDS) is central to achieving these goals [4,8], yet many EHRs do not currently include robust clinical decision support features or functions. Furthermore, if the goal of gathering “complex genomic profiling data toward the goal of personalized medicine” [5] is to be achieved, the amount and complexity of data available—and decision support required to appropriately interpret and respond to that data—will grow exponentially. The net result is that there is a pressing need for high-quality clinical decision support capabilities for clinicians, patients

* Corresponding author. Address: Center for Health Research, 3800 N. Interstate Ave., Portland, OR 97227, USA. Fax: +1 503 335 6311.

E-mail address: dean.f.sittig@kp.org (D.F. Sittig).

and consumers. In this paper, we will use a definition from a widely used guidebook [6] of the term “clinical decision support” to “refer broadly to providing clinicians or patients with computer-generated clinical knowledge and patient-related information, intelligently filtered or presented at appropriate times, to enhance patient care”.

Many recognize the potential value of providing advanced clinical decision support to participants in care delivery [7]. Nonetheless, there are few CDS implementations to date in routine clinical use that have substantially delivered on the promise to improve healthcare processes and outcomes, though there have been an array of successes at specific sites in individual domains [8]. Yet even these successes have generally not been widely replicated. There are many reasons for the lack of diffusion of these systems. Some include “...the complexity that arises from the nature of decision making, the intellectual challenge of creating knowledge, technical dimensions of delivering CDS, and social aspects of incorporating changes into clinical care” [3]. In an attempt to identify and describe the key challenges that must be overcome if we are to achieve these anticipated benefits, we (the authors along with several clinicians) used an iterative, consensus-building process to generate a list of the top 10 “grand challenges” in clinical decision support. We then circulated this list via email so that each person could rank the challenges from 1 (most important) to 10 (least important). Ties were not allowed.

The goal of this exercise was to further elucidate an as yet unresolved challenge briefly described in 1994 [9] and to help re-stimulate and focus efforts toward addressing the most critical barriers to unlocking the full potential of CDS. We ranked the challenges according to the importance that they be solved if patients and organizations are to begin realizing the fullest benefits possible of these systems. Our hope is that this list may help educate and inspire stakeholders in a position to advance the state of CDS technology and practice—particularly informaticians world-wide and those who fund them—and as a result, accelerate fruitful explorations. These challenges resonate with the strategic objectives recently outlined by an expert panel in a roadmap for national action on CDS [3].

2. The top 10 clinical decision support grand challenges

We placed the grand challenges into three large categories:

1. Improve the effectiveness of CDS interventions
2. Create new CDS interventions
3. Disseminate existing CDS knowledge and interventions

Within each of these broad categories, we identified several grand challenges, which we briefly describe below.

2.1. Improve the effectiveness of CDS interventions

2.1.1. Improve the human–computer interface

We need a new or greatly improved human/computer interface (HCI) paradigm for the presentation of clinical decision support recommendations (both solicited and unsolicited), one that supports and does not interrupt the clinical workflow. Rather, the CDS should unobtrusively, but effectively, remind clinicians of things they have truly overlooked and support corrections, or better yet, put key pieces of data and knowledge seamlessly into the context of the workflow or clinical decision-making process, so the right decisions are made in the first place [10,11]. Currently, unsolicited CDS alerts and reminders are often overridden [12] for a multitude of reasons, one of which is the poor human/computer interfaces that are currently in use. We need new HCIs that will facilitate the process by which CDS is made available to clinicians to help them prevent both errors of omission and commission. Improved HCI design may include increased sensitivity to the needs of the current clinical scenario; provide clearer information displays, with intrusiveness proportional to the importance of the information; and make it easier for the clinician to take action on the information provided.

2.1.2. Summarize patient-level information

No one can retain and process the entire content of a complicated patient’s data; clinicians need to recall the most important facts and conclusions pertinent to the current situation. The CDS challenge is to intelligently and automatically summarize all of a patient’s electronically available clinical data, both freetext and coded, and to create one or more brief (e.g., 1–2 page) synopses of the patient’s pertinent past medical history, current condition(s), physiologic parameters, and current treatment(s). These synopses should be sufficiently detailed to enable a clinician to understand the patient’s current condition as if she had spoken with all of the patient’s healthcare providers. The purpose of these summaries is to make all key data needed for optimal decision-making available to each decision maker; different summaries may be needed, particularly for patients with complicated data, to address the perspectives of different clinicians and workflows [13,14]. In addition, these summaries should supply needed data automatically to CDS applications that support such decisions.

This summarization engine should be able to derive the patient’s physiological state from a wide variety of data sources and codify it as an “intermediate variable” which could then be used as a trusted data item in another portion of the logic, for example, “patient is on anticoagulation therapy” or “patient is pregnant”. As the amount of electronically available, patient-specific, clinical information increases, the need for clinicians to be able to understand the patient’s pertinent medical history quickly and accurately will become even more difficult and important. Ultimately, vast amounts of data may be reduced to a sum-

mary set of indicators allowing ‘at a glance’ assessment of patient status. In addition, with better data-driven derivation and statement of a patient’s condition and related data, automatic triggering of more extensive and more specific CDS becomes possible.

2.1.3. Prioritize and filter recommendations to the user

A robust, reliable, evidence-based CDS value model is needed, particularly for intrusive CDS interventions. Such a system could automatically prioritize recommendations according to a multi-attribute utility model by combining patient- and provider-specific data to take into account expected mortality or morbidity reduction, patient preferences and life style, cost to the individual or organization, effectiveness of the test or therapy, how the patient might tolerate the recommended intervention, location in the clinician’s workflow, insurance coverage, genetic and genomic considerations, clinician’s past performance, and other factors. The main challenge here is to appropriately account for competing influences and values impacting clinical decision making, and thus clinical decision support. The second challenge here is to rank in priority order, and reduce the number of computer-generated recommendations that a clinician or patient has to deal with to a manageable number based upon an explicit value model, thus reducing the “alert fatigue” that is a frequent cause of user dissatisfaction. This challenge results from both the clinician’s limited time and attention, as well as the patient’s limited ability to accurately administer a large number of medications or make multiple, difficult, life-style changes at one time, for example.

2.1.4. Combine recommendations for patients with co-morbidities

Current clinical care guidelines for condition or medication management, for the most part, ignore the fact that the majority of elderly patients have multiple co-morbidities and medications that must be addressed by their patient care team [15]. The challenge is to create mechanisms to identify and eliminate redundant, contraindicated, potentially discordant, or mutually exclusive guideline-based recommendations for patients presenting with co-morbid conditions or multiple medications. Instead, a CDS system should present a synthesized version of the recommendations from two or more guidelines to the clinician. One of several reasons why clinical guidelines are underutilized in practice is because they do not adequately address these co-morbidity or polypharmacy issues [16]. For example, a clinician may wish to follow a diabetes mellitus guideline, but the guideline likely will not address the fact that the patient may not only have diabetes, but also, chronic obstructive pulmonary disease (COPD), and congestive heart failure, as well. These co-morbid conditions and existing medications may alter considerably the best-practice management of diabetes [17]. Addressing this challenge may require new combinatorial, logical, or semantic

approaches to combining and cross-checking recommendations from two or more guidelines.

2.1.5. Use freetext information to drive clinical decision support

We need methods of extracting the clinical information contained in the freetext portions of our electronic health record systems into a form that would allow clinical decision support systems to access and utilize this information. For such a system to work, it must be able to accurately identify and classify the freetext information [18]. Automated text processing would enable more specific CDS interventions to be presented (i.e., highly-tailored alerts and reminders or even condition- or patient-specific order sets) and could be used to satisfy existing clinical decision support logic (e.g., by asserting that the patient is pregnant, even though pregnancy is not specifically listed in the problem/condition list). This is especially important because, according to some reports, at least 50% of the clinical information describing a patient’s current condition and stage of therapy resides in the freetext portions of the EHR [19].

2.2. Create new CDS interventions

2.2.1. Prioritize CDS content development and implementation

Development and implementation of clinical decision support content required to help clinicians and organizations deliver the highest quality, yet still reasonably priced health care, will take many years. Deciding which content to develop or implement first (e.g., interventions to improve patient safety, chronic disease management, or preventive health interventions), must be based on a multitude of factors including value to patients, cost to the health care system, availability of reliable data, difficulty of implementation, and acceptability to clinicians and patients, among others. While prioritization by national interest and overall healthcare value may lead to longer and more difficult discussions prior to some future CDS deployment, in the long run this prioritization should greatly facilitate the widespread use of the most valuable CDS and lead to a much greater overall impact in the cost, safety, and quality of healthcare. Over time, the current ad hoc approach to local implementations might be supplanted by a more concerted, systematically prioritized and executed approach.

2.2.2. Mine large clinical databases to create new CDS

There are undoubtedly many new, valuable guidelines and CDS interventions that are waiting to be developed and put into service, based on clinical knowledge that has not yet been fully synthesized. We need to develop and test new algorithms and techniques to allow researchers to mine large clinical data repositories to expand the global fund of clinical knowledge, which in turn underpins CDS interventions that help promote improved outcomes. In addition to the technical challenges associated with the cre-

ation, testing, and execution of these algorithms, we must begin to address the myriad social and political challenges facing researchers as they struggle to create or gain access to these large clinical databases. For example, as these clinical data resources begin to cross institutional and organizational boundaries, much effort will be required to insure that patient-identifiable information will remain private and secure [20]. Similarly, a system that could “parse and mine” the currently available scientific literature and identify potential clinical decision support interventions would be quite useful. In other words, we should be able to program our computers to “learn” from large aggregate databases [21].

2.3. Disseminate existing CDS knowledge and interventions

2.3.1. Disseminate best practices in CDS design, development, and implementation

As noted earlier, some healthcare organizations have had successful and enduring experience with CDS [8]. When these organizations are studied, common success factors emerge, from design to communication to clinical practice style to management; yet, this knowledge is frequently not readily available to other organizations seeking to develop CDS programs [22,23]. We need to build on initial efforts [6,24] in developing more robust methods to identify, describe, evaluate, collect, catalog, synthesize and disseminate best practices for CDS design, development, implementation, maintenance, and evaluation. Specifically, we need measurement tools to help us identify the most usable, economical and effective methods of implementing these CDS-related initiatives. This is primarily a matter of identification, communication and education; the CDS implementation process needs to be expressed and catalogued in a way that allows information from successful sites to be easily found by others. Additionally, best-practice information also applies at the level of the individual CDS intervention. For example, should we use an interruptive alert to remind clinicians to order a pneumococcal vaccine, or would a standing order for nurses be more effective [24]?

The establishment of such methods for sharing our collective experiences are essential for research and development purposes—to refine and accelerate new intervention development, and to highlight gaps and opportunities for improvement in the knowledge-base itself. Identification of CDS best practices implies the need for reliable measurements and feedback mechanisms to assess CDS performance [25,26], and comparisons across different implementations of the same CDS tools and services, see for example [27]. To accomplish this, we need to achieve consensus on a standard taxonomy of clinical decision support interventions and outcomes that would allow us accurately describe the best practices as well as compare outcomes between implementations of different systems and across organizations.

2.3.2. Create an architecture for sharing executable CDS modules and services

The goal is to create a set of standards-based interfaces to externally maintained clinical decision support services that any EHR could “subscribe to”, in such a way that healthcare organizations and practices can implement new state of the art clinical decision support interventions with little or no extra effort on their part [3,28]. These knowledge modules might be designed so that they can be loaded into a clinical information system [29], or they might be designed to execute as a remote service, with the local clinical system invoking them over a network according to a standardized interface [30]. A key component of this challenge would be to identify and standardize the definitions of and interfaces to the data required by the various CDS modules. In addition this architecture should not require a specific knowledge representation scheme, but rather encapsulate the clinical knowledge in such a way that many different inference mechanisms could be used. Similarly, the architecture should describe the general intervention device used (e.g., alert, order set, intelligent form) and its key parameters, while still allowing for experimentation and commercial competition on the human/computer interface within these broad guidelines. The vast majority of EHR implementations across the USA have currently implemented little if any clinical decision support [31]. We hypothesize more ‘plug and play’ CDS applications will help overcome several of the key implementation barriers that are currently limiting more widespread use of CDS. Another benefit of such an architecture is the potential to greatly speed the transition from research finding to widespread practice, a process that is estimated to take as much as 17 years [32]. In the future, research articles and consensus statements that have direct CDS implications could be accompanied by a sharable CDS module in standard format.

2.3.3. Create internet-accessible clinical decision support repositories

The challenge is to build one or more internet-accessible repositories of high quality, evidence-based, tested, clinical decision support knowledge modules. These interventions and services could be easily downloaded, maintained, locally modified, installed, and used on any Certification Commission for Healthcare Information Technology (CCHIT)-certified EHR product [33], using the architecture described in Challenge 2.3.2, for example [34]. Such a collection should have standards for accessibility, sponsorship, and trust levels, and appropriate business models to ensure sustainability. The central repositories should support local deployment of selected content in various healthcare organizations and allow local customizations, yet retain the ability to respond to on-going upgrades. Formalized knowledge management processes and procedures must be developed and made available to users of such a system. These tools and techniques are essential for effective curation of knowledge assets of diverse types for differ-

Table 1

Summary of the grand challenges of clinical decision support along with their mean rank and the standard deviation of that ranking ($n = 9$)

Grand challenge description	Mean ranking	Standard deviation
Improve the human–computer interface	2.89	2.71
Disseminate best practices in CDS design, development, and implementation	3.33	1.87
Summarize patient-level information	3.67	2.06
Prioritize and filter recommendations to the user	4.56	2.96
Create an architecture for sharing executable CDS modules and services	5.44	2.30
Combine recommendations for patients with co-morbidities	5.89	2.20
Prioritize CDS content development and implementation	6.00	2.96
Create internet-accessible clinical decision support repositories	6.89	1.69
Use freetext information to drive clinical decision support	7.89	1.27
Mine large clinical databases to create new CDS	8.44	3.00

ent stakeholders within an organization (e.g., to ensure consistency of information for different care delivery settings across rules, order sets, documentation tools, reference information, etc.) [e.g., Ref. 6, Fig. 6-3].

A related issue for managing the quality and integrity of individual rules or other CDS interventions deployed in a specific organization is to assure that in the aggregate the content set performs inference and offers guidance appropriately, and that when new knowledge is added to the local CDS implementation, or local customizations introduced, errors do not arise from myopic knowledge engineering, or conflicts between disparate knowledge elements. Establishment of such a repository is vital so each healthcare practice and organization does not have to reinvent its own rules and interventions, a painstaking and error-prone process. Some material in such repositories may come from national sources (e.g., like AHRQ's USPSTF guidelines [35]), some may come from commercial vendors, and some may be based on interventions developed and uploaded by local care delivery organizations.

3. Discussion

We have presented a set of challenges around clinical decision support, which we believe if addressed can unlock its substantial potential. Undoubtedly there are other challenges which are important, but these clearly represent a pivotal set. It will take some time to address these and the answers will likely vary somewhat, but proceeding down this path will move things forward.

In our attempt to rank the challenges according to the importance that they be solved in the near future if patients and organizations are to begin realizing the fullest benefits possible from these systems, we asked several of our colleagues to rank them in order from most to least important. While the following ranked list (see Table 1) represents an aggregate of these rankings, there was not a clear consensus. This lack of consensus is best illustrated by the relatively large standard deviations of the ranking scores.

This study has limitations. Only a small group of informaticians were surveyed, though all are expert in clinical decision support. Other challenges certainly exist and we may not have considered all of them.

4. Summary

Using an iterative, consensus-building process, we have identified a set of grand challenges in clinical decision support. This list was created to educate and inspire an array of stakeholders, including researchers and funders among others, with the hope of stimulating further dialog and effort in this important area. Solving these challenges is critical if we are to achieve the full benefits of clinical decision support.

Acknowledgments

This research was supported by a Grant LM06942 from the National Library of Medicine, National Institutes of Health, titled Overcoming the Unintended Consequences of Computerized Physician Order Entry Implementation. Emily Campbell and Adam Wright were also supported by National Library of Medicine training Grant ASMMI0031.

References

- [1] Bush GW: Transforming Health Care: The President's Health Information Technology Plan, <http://www.whitehouse.gov/info-cus/technology/economic_policy200404/chap3.html>; 2007 [accessed 04.06.07].
- [2] Doctor's Office Quality—Information Technology (DOQ-IT) Program. Available from: <http://www.joindoqit.com/>.
- [3] Osheroff JA, Teich JM, Middleton B, Steen EB, Wright A, Detmer DE. A roadmap for national action on clinical decision support. *J Am Med Inform Assoc* 2007;14(2):141–5.
- [4] Johnston D, Pan E, Walker J, Bates DW, Middleton B. The value of computerized provider order entry in ambulatory settings. Boston (MA): Center for Information Technology Leadership; 2003.
- [5] West M, Ginsburg GS, Huang AT, Nevins JR. Embracing the complexity of genomic data for personalized medicine. *Genome Res* 2006;16(5):559–66.
- [6] Osheroff JA, Pifer EA, Teich JM, Sittig DF, Jenders RA. Improving outcomes with clinical decision support: an implementer's guide. - Health Information Management and Systems Society; 2005.
- [7] American Health Information Community Quality Workgroup Vision Summary January 31, 2007, <http://www.hhs.gov/healthit/ahic/materials/qual_vision_summary.pdf>; 2007 [accessed 04.05.07].
- [8] Chaudhry B, Wang J, Wu S, Maglione M, Mojica W, Roth E, et al. Systematic review: impact of health information technology on quality, efficiency, and costs of medical care. *Ann Intern Med* 2006;144(10):742–52.

- [9] Sittig DF. Grand challenges in medical informatics? *J Am Med Inform Assoc* 1994;1(5):412–3.
- [10] Berner ES, Moss J. Informatics challenges for the impending patient information explosion. *J Am Med Inform Assoc* 2005;12(6):614–7.
- [11] Miller RA, Waitman LR, Chen S, Rosenbloom ST. The anatomy of decision support during inpatient care provider order entry (CPOE): empirical observations from a decade of CPOE experience at Vanderbilt. *J Biomed Inform* 2005;38(6):469–85.
- [12] Weingart SN, Toth M, Sands DZ, Aronson MD, Davis RB, Phillips RS. Physicians' decisions to override computerized drug alerts in primary care. *Arch Intern Med* 2003;163(21):2625–31.
- [13] Zeng Q, Cimino JJ. A knowledge-based, concept-oriented view generation system for clinical data. *J Biomed Inform* 2001;34(2):112–28.
- [14] Petersen LA, Orav EJ, Teich JM, O'Neil AC, Brennan TA. Using a computerized sign-out to improve continuity of inpatient care and prevent adverse events. *Jt Comm J Qual Improv* 1998;24(2):77–87.
- [15] Boyd CM, Darer J, Boulton C, Fried LP, Boulton L, Wu AW. Clinical practice guidelines and quality of care for older patients with multiple comorbid diseases: implications for pay for performance. *JAMA* 2005;294(6):716–24.
- [16] McDonald CJ, Overhage JM, Tierney WM, Abernathy GR, Dexter PR. The promise of computerized feedback systems for diabetes care. *Ann Intern Med* 1996;124(1 Pt 2):170–4.
- [17] Durso SC. Using clinical guidelines designed for older adults with diabetes mellitus and complex health status. *JAMA* 2006;295(16):1935–40.
- [18] Hripcsak G, Friedman C, Alderson PO, DuMouchel W, Johnson SB, Clayton PD. Unlocking clinical data from narrative reports: a study of natural language processing. *Ann Intern Med* 1995;122(9):681–8.
- [19] Hicks J. The potential of claims data to support the measurement of health care quality. Ph.D. dissertation. RAND Graduate School, 2003. Available as of December 20, 2004, at: <http://www.rand.org/cgi-bin/Abstracts/ordi/getabbydoc.pl?doc=RGSD-171>.
- [20] Safran C, Bloomrosen M, Hammond WE, Labkoff S, Markel-Fox S, Tang PC, et al. Toward a national framework for the secondary use of health data: an American Medical Informatics Association White Paper. *J Am Med Inform Assoc* 2007;14(1):1–9.
- [21] Warner Jr HR. Iliad: moving medical decision-making into new frontiers. *Methods Inf Med* 1989;28(4):370–2.
- [22] Improving Quality and Reducing Cost with Electronic Health Records: Case Studies from the Nicholas E. Davies Awards. Healthcare Information and Management Systems Society (HIMSS); 2007.
- [23] Ash JS, Sittig DF, Campbell E, Guappone K, Dykstra R. Some unintended consequences of clinical decision support systems. *AMIA Annu Symp Proc* 2007; in press.
- [24] Dexter PR, Perkins SM, Maharry KS, Jones K, McDonald CJ. Inpatient computer-based standing orders vs physician reminders to increase influenza and pneumococcal vaccination rates: a randomized trial. *JAMA* 2004;292(19):2366–71.
- [25] Leonard KJ, Sittig DF. Improving information technology adoption and implementation through the identification of appropriate benefits: creating IMPROVE-IT. *J Med Internet Res* 2007;9(2):e9.
- [26] Thompson DI, Osheroff J, Classen D, Sittig DF. A review of methods to estimate the benefits of electronic medical records in hospitals and the need for a national benefits database. *J Healthc Inf Manag* 2007;21(1):62–8.
- [27] Bates DW, Kuperman GJ, Wang S, Gandhi T, Kittler A, Volk L, et al. Ten commandments for effective clinical decision support: making the practice of evidence-based medicine a reality. *J Am Med Inform Assoc* 2003;10(6):523–30.
- [28] Kawamoto K, Lobach DF. Proposal for fulfilling strategic objectives of the U.S. Roadmap for national action on clinical decision support through a service-oriented architecture leveraging HL7 services. *J Am Med Inform Assoc* 2007;14(2):146–55.
- [29] Hripcsak G, Wigertz OB, Kahn MG, Clayton PD, Pryor TA. ASTM E31.15 on health knowledge representation: the Arden Syntax. *Stud Health Technol Inform* 1993;6:105–12.
- [30] Wright A. SANDS: a service-oriented architecture for clinical decision support in a national health information network. Ph.D. dissertation, Oregon Health & Science University, Portland, OR; 2007.
- [31] Simon SR, Kaushal R, Cleary PD, Jenter CA, Volk LA, Orav EJ, et al. Physicians and electronic health records: a statewide survey. *Arch Intern Med* 2007;167(5):507–12.
- [32] Balas EA, Boren SA. Managing Clinical Knowledge for Health Care Improvement. Yearbook of Medical Informatics 2000: patient-centered systems. Stuttgart, Germany: Schattauer; 2000. p. 65–70.
- [33] Certification Commission for Healthcare Information Technology Certified Ambulatory Electronic Health Record (EHR) Products. Available from: <http://www.cchit.org/certified/products.htm>.
- [34] Ohno-Machado L, Boxwala AA, Ehresman J, Smith DN, Greenes RA. A virtual repository approach to clinical and utilization studies: application in mammography as alternative to a national database. *Proc AMIA Annu Fall Symp* 1997:369–73.
- [35] Agency for Healthcare Research and Quality—U.S. Preventive Services Task Force USPSTF. Available from: <http://www.ahrq.gov/clinic/prevenix.htm>.