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Completed Research Paper

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Abstract

Evidence based medicine (EBM) refers to the conscientious, explicit, and judicious use of current best evidence in making decisions about the care of individual patients. This article presents systematic review of the use of information technology (IT) to support EBM with a particular emphasis on status and opportunities. Out of 2,490 papers initially scanned, 585 articles were included at the title level review. This was followed by an abstract review, which resulted in 196 articles. On full text scanning of the 196 articles, 69 articles met the inclusion criteria and were included in the final analyses. The key issues and potential for IT support for the practice of EBM are insufficient techniques to produce evidence in a computer interpretable format, insufficient research to combine the evidence from the multiple sources, inadequate techniques that automatically rate the literature and practice-based evidence, and integration of evidence at the clinician's workflow.

Keywords

Evidence Based Medicine, Health Information Technology, Systematic Review, Medical Informatics

Introduction

The United States spends more than $ 2.3 trillion per year in healthcare and is the second highest nation in healthcare spending as a percentage of GDP (The World Bank 2012). Nevertheless, this spending has not translated into quality of care. As much as 400,000 people die annually in hospitals because of medical errors (James 2013). More importantly, there is a large gap between the health care we could have and the health care that is currently available in the United States (Bates et al. 2001; Wells 2007). In response to this situation, the Institute of Medicine (IOM) proposed several recommendations to increase the quality of care. These include the usage of health information technology (IT) and the provision of medical care based on the best evidence available. Evidence based medicine is the conscientious, explicit, and judicious use of current best evidence in making decisions about the care of individual patients (Sackett et al. 1996). EBM means affirming the individual clinical expertise with the best available external clinical evidence. External clinical evidence may both invalidate previously accepted diagnostic tests and treatments and replace them with new ones that are more powerful, more efficacious, more accurate, and safer. There is a need for both external evidence and individual clinical expertise, and neither alone is adequate. Without clinical expertise, practice risks becoming tyrannized by evidence, for even excellent external evidence may be inapplicable to or inappropriate for an individual patient (Sackett et al. 1996). Without current best evidence, practice risks becoming rapidly obsolete.

This article presents an overview of the use of IT in the practice of EBM at the point-of-care. The objectives of this research are to determine via a systematic review (a) current status of the use of IT to support EBM (b) gaps in the literatures that hampers the practice of EBM (c) opportunities for IT to advance the practice of EBM (d) and provision of practical strategies for designers regarding the use of IT to support EBM. From the practical perspective, the research presents the current standing and future direction for adopting evidence based medicine at the point of care setting. From the theoretical

perspective, the research provides a distinctive contribution to personalized medicine, integration of health informatics in the clinician's workflow, and strategies to develop adoptable EBM systems. The paper is organized into four sections. The next section presents the methodology for conducting the research followed by the results that we obtained in our systematic review. After that, we present an analysis of the findings. In that section, we present the current status of computerized EBM, gaps identified in the literature, and practical strategies for the designers. Finally, the last section wraps up with the conclusion and directions for future research.

Methodology

We identified peer-reviewed scholarly articles by searching PubMed, Web of Science, IEEE, ACM, ABI/Inform and EBSCOhost using the keywords—(Evidence Based Medicine) AND (Computer OR Information Technology OR Information System) and conducted a citation analysis in Web of Science. We searched these keywords in the articles' Title, Keyword, and Abstract Sections. Next, we reviewed the title, abstract, and full text for inclusion if they meet the following criteria:

- IT is a primary tool for evidence generation, analysis, or presentation.

- EBM is generated at the point-of-care at the hospital setting.

- The primary contribution of included research is to discuss the methods to extract, generate, and presents the best available evidence.

- Guidelines and protocols for computerized EBM.

Articles are excluded from the search if they meet any of the following exclusion criteria:

- Articles not written in the English language.

- IT is not a key driver for EBM.

- IT is only used for web searching/retrieval of relevant articles.

Result

Out of 2,490 papers initially scanned, 585 articles were included at the title level review. This was followed by an abstract review, which resulted in 196 articles. On full text scanning of the 196 articles, 69 articles met the inclusion criteria and were included in the final analyses. Thirteen articles discussed the evidence generation using the organization's EHR (Electronic Health Record), Thirty six articles discussed the evidence generation using the literature (clinical trials, systematic review, and meta-analysis), six articles illustrated the evidence generation using a combination of pertinent literature and EHR, three articles discussed the creation of an evidence bank, and the remaining eleven articles discussed the guidelines, recommendation and protocols for designing computerized EBM.

Discussion and Finding

In this section, we first discuss the sources from which medical evidence can be generated. Next, we discuss the procedures of computerized evidence generation.

Evidence Sources

Source 1 — **Literature-Based Evidence:** The sources of evidence are randomized control trials (RCT), systematic reviews, clinical guidelines, cohort studies, quasi-experimental studies, descriptive studies, and expert opinions (West et al. 2002). As of Feb 2014, over 161 thousand clinical trials are registered in "clinicaltrial.gov" alone. The shear volume, variety and velocity of the data generated by the medical community present serious challenges to the timely translation and dissemination of research into practice as well as retrieving the 'right' knowledge, at the 'right' time, and at the 'right' place. In essence, "*we do not know what we know, what has been or is currently investigated, or which important research questions are not being investigated at all*" (Sim et al. 2002). Hence, one of the crucially sought areas is the use of IT to extract medical evidence, analyze it, and deliver the best care

protocols at the point of care. In a broad sense, IT can (a) help the research community to understand what is already known, (b) assist the clinicians in applying the best and latest available evidence to the individual patient (c) facilitate, monitor and encourage the practice change (Horn et al. 2007).

In our review, we found 36 out of 69 articles have employed literature as the only source of evidence. There are several techniques that facilitate the automated evidence generation from the literature (Cohen et al. 2010). Generally, IT has been used for (a) converting clinical guidelines into computer readable instructions (Essaihi et al. 2003) (b) article classification (Aphinyanaphongs et al. 2003) (c) creation of search/meta-search engine for efficient extraction of evidence (Schwartz et al. 2006), and (d) extraction of important sentences from the articles (Verbeke et al. 2012). For example, Kim et al. (2011) classify the key sentences in the population, intervention, comparison, and outcome (PICO) criteria whereas population, intervention, and comparison assess the quality of articles; and outcome assesses the result of conducting the interventions. The significance of this study is that it demonstrated the efficacy and viability of mining structured and unstructured abstracts of medical research.

Source 2 — Practice-Based Evidence: Practice-based evidence refers to the messy, real, and complicated medical world that cannot and is not subject to experimental controls. Instead, real world practice is documented and measured, just as it occurs (Swisher 2010). This means, evidence to treat a patient is generated from the day-to-day data collected in hospitals when treating patients. Westfall (Westfall et al. 2007) indicates that *"What is efficacious in randomized clinical trials is not always effective in the real world of day-to-day practice "*. Again, RCT are unlikely to discover a combination of interventions or practices that are efficient and effective in routine care. For example, treatment of heart failure is greatly affected by the patient-specific factors, and the reliance on a single measure and/or organizational factors limit the validity of heart failure treatments guidelines (Graham et al. 2000). Other major problems with RCT are long time frames, artificiality and standardization, selection criteria, patient recruitment, generalizability, blinding, and cost (Horn et al. 2007). One of the approaches to mitigate these problems is to generate evidence by studying the process of care and the manner in which diseases are diagnosed, treatments initiated, and chronic care managed at a 'real' hospital setting. Some of the merits of practice-based evidence are (a) practices that have been implemented in communities, have emerged locally, and are accepted with general consensus (b) practices that address circumstances, populations, cultures and conditions for the particular group of people (c) practice that is embedded in the culture and social conditions of the community, and (d) practices that address emergent issues or concerns that have not been addressed by traditional empirical science (University of South Florida 2011).

In our review, out of 69 articles, 13 articles relied on electronic health record as the only source of evidence. IT has been used to generate practice-based evidence to (a) collect treatment data from the different resources and produce evidence registries (Abernethy et al. 2010) (b) mine physician notes and extract important information (Chu et al. 2001) (c) mine health record and determine important association rules (Masuda 2002) (d) conduct intervention mining for highest clinical output (Pineau et al. 2007) (e) and create a federated database (Stolba et al. 2007). For example, a breast cancer treatment—system that mines Hospital Information Systems and matches the gene, demographic and disease conditions of a particular patient to other patients having similar gene, demographic, and disease conditions. A treating physician can then identify the type of therapy that delivered the best results to those patients and use it to treat that particular patient.

Source 3 — Evidence through multiple sources: It is evident that neither practice-based nor literature-based evidence alone are sufficient. Practice-based evidence is needed to overcome some of the limitation of Literature-Based Evidence (Horn et al. 2007). However, practice-based evidence also has its own limitations e.g., difficulty to draw statistical significance and non-uniformity among the providers. More importantly, RCT forms the foundation for evidence-based medicine, and it is also needed for determining the cause and effect of new treatment protocols. Therefore, a balance between the two sources of evidence is needed for optimum outcomes, given the limitations and strengths of each. Six out of 69 included research studies leveraged both sources in some form. Three articles proposed some form of an EBM architecture (Bakken et al. 2004; Bigus et al. 2011; Rodrigues 2000); one article discussed knowledge integration techniques (Best et al. 2008); and the remaining two articles matched the patient's conditions through health records, and identified relevant articles in the literature (Demner-Fushman et al. 2008; O'Sullivan et al. 2010). As an example, Bigus et al. (2011) proposed a framework where evidence

is collected from patient records, claims data, wellness data, and results from medical studies such as quasi-experimental, clinical trials, and community observation studies. The system compares the outcome among patients with similar disease progressions (i.e., cohorts). The curated evidence is stored in an evidence registry and is used at the point of care.

Source 4 — Evidence Banks: Recently, researchers and practitioners have shown interest in creating a databank or a set of coordinated databases that stores the treatment protocols. These treatments protocols may come from routinely collected data or set of clinical guidelines obtained from the literature. In our review, we found three articles that discussed the creation of evidence banks (Abernethy et al. 2010; McKinley et al. 2011; Yang et al. 2009). For an example, Abernethy et al. discussed the creation of rapid-learning systems for cancer care, where routinely generated data through the patient care and clinical research feed into an ever-growing databank. This databank can be queried to answer the clinical question at the point of care.

IT supported Evidence-Based Medicine

Task 1—Formulating Questions: The first step in evidence generation is to understand the patient's condition. In the existing literature, a physician formulates the clinical question by manually entering data into the system, or/and the system extracts the patient's condition through the electronic health record (Demner-Fushman et al. 2008; O'Sullivan et al. 2010). The questions that initiate evidence-based medicine can relate to diagnosis, prognosis, treatment, iatrogenic harm, quality of care, or health economics (Rosenberg et al. 1995). Moreover, clinicians can also manually set some questions relating to possible alternative interventions, side effects of alternatives, and the financial cost of an intervention. An example of a clinical question may be: In an adult male with diabetes, 40 years of age, overweight, having uncontrolled blood pressure, and severe glucose fluctuation; what are the possible courses of intervention? The system translates the clinical question into two search queries: one for searching the literature, and another for searching in the practice-based evidence, EHR.

Task 2—Evidence Analysis: Advanced analytics tools are used to transform the data collected from the heterogeneous sources into the consumable units (Best et al. 2008; Bigus et al. 2011). This is one of the most complicated and challenging steps for computerized evidence-based medicine. The raw data are collected from the dispersed literature and Hospital Information Systems, which may be structured or unstructured. Mining these diverse and unstructured data demands extensive pre-processing, and sophisticated analytics systems. Artificial Intelligence tools such as, Artificial Neural Networks, Support Vector Machine, Random Forest, Case Based Reasoning and Naïve Bayes may provide the backbone for the data analytics. Moreover, medical informatics specific tools and techniques such as UMLS (Unified Medical language Systems), SemRep, HL7, SNOMED, and ICD-10 are mandatory.

Some of the important applications of analytics in the existing research studies are (a) automation of the article selection procedure when conducting systematic reviews (Frunza et al. 2010) (b) automatically structuring the abstract of an article in according to the Population, Intervention, Comparison, and Outcome (PICO) criteria (Kim et al. 2011) (c) mine the free-text document of clinician notes (Chu et al. 2001) (d) mine the electronic health record and identify the patient's condition (Demner-Fushman et al. 2008) (e) convert the clinical guidelines into computer executable format (Essaihi et al. 2003) (f) grade the evidence and calculate the statistical significance(Lehmann et al. 2000) (g) Mine the health records and identify the optimum practice guidelines (Pineau et al. 2007), and (h) identify the association rules in the electronic health records (Masuda 2002).

Task 3—Evidence Grading and Calculation of Statistical Significance: With the plethora of knowledge production, practitioners are often confused whether to trust the evidence or not. Using standard instruments and procedures, formally grading the quality, and rating the overall strength of the evidence can produce confidence about the evidence suggested by computers. Moreover, the medical domain is an information critical domain. Therefore, the confidence level of the presented evidence hugely determines the adoption of new treatment protocols. Lohr et al. (Lohr 2004) illustrated the importance of grading as (a) illustrates the confidence in the research results and, thus, decisions, recommendation, or conclusion drawn from that research, and (b) helps to identify potential bias in the literature. In our literature review, we identified two articles that discussed grading and formulating the statistical significance of results in published articles (Lehmann et al. 2000; Lohr 2004). For example, Lehman et al. (Lehmann et al. 2000) proposed the "Bayesian Communication" specifications for

formulation of clinically significant electronic publications. They developed seventeen specifications, which included eight for readers, three for authors, three for publishers, and two for computers.

Task 4—Converting into Computer Interpretable Format: Next is to create a formal intervention plan (computer-interpretable procedure) representing the health care procedures to assist patients suffering from a particular disease, syndrome, or social issues. As an example, the Guideline Element Model is an XML, hierarchical model of guideline content, which has been accepted as an ASTM Standard (E2210-02). The model represents guidelines in the form of "IF (condition) THEN (actions)" statements (Essaihi et al. 2003; Shiffman et al. 2000). The key characteristics of computer interpretable guidelines are (Riano et al. 2012): (a) the capability of representing patient states (b) the availability of primitives to allow medical procedures to include concurrencies, sequences, alternatives, and loops, (c) the capacity of nesting as a means of describing medical procedures at various levels of abstraction and granularity, and (d) integration with electronic health records. There are numerous computer-oriented languages and systems to represent and execute these guidelines/plans—Asbru, Proforma, GLIF3, SDA, SAGE (Riano et al. 2012). Asbru language is one of the most common languages, which is a task-specific, time-oriented, and intention-based plan representing a language designed to embody clinical practice guidelines and protocols as skeletal plans (Miksch et al. 2000). Each of the skeletal plans corresponds to a possible step in the guidelines, and consists of a plan-body that may consist of sub-plans (set of steps performed sequentially or in parallel), or cyclical plan (repetition of several steps), or a user performed steps, or plan-activations (a call to another plan).

Task 5—Evidence Presentation: The final task in IT-based EBM systems is presentation of medical evidence in a manner that assures that the right information gets to the right person, at the right point in the clinician's workflow, at the right time, and in the right format (Bigus et al. 2011). It is crucial to understand that evidence and guidelines delivered should be accompanied by information about its provenance and reliability. Another important idea is that the information presented should be concise, and if possible, should fit in a single screen.

Issues

The following table (Table 1) highlights key issues identified in the literature.

Key findings	Illustration
Insufficient techniques that combine the evidence generated from the EHR and Literature	None of the studies have taken the fullest advantages of both literature and health records in their systems. For instance, O'Sullivan (2010) used health records only to identify a patient's condition and match that condition in the clinical trial of Cochrane Database
Insufficient mining methods to extract information from literature	We found no algorithm or procedures that automatically mine the published clinical trials (e.g. PubMed) and generate the evidence in the form of guidelines with adequate precision.
Evidence in the form of computer interpretable guidelines	There are studies that discuss the conversion of clinical guidelines into computer interpretable formats (Essaihi et al. 2003; Marshall et al. 2004; Sim et al. 2004). However, those studies have their limitations. As a result, future research should focus on developing techniques that allow the representation of systematic reviews and guidelines in a machine-readable format.
Automated Techniques for grading, and rating the quality of Evidence	Future researchers should devise techniques that allow the automatic grading of the literatures and evidence from the Hospital Information Systems. Also, researchers should focus on grading overall evidence like systematic reviews, guidelines etc.
Integration of EBM Systems in Workflow of Clinicians	Efforts to facilitate application of evidence into clinicians' practice are unlikely to be successful unless the EBM system is integrated into the workflow of clinicians.
Evidence Delivery in real	The majority of computerized EBM systems in literature studies are not able

time	to aggregate RCTs nor generate evidence in real time. Therefore, clinicians have found them inefficient at the point of care (Bigus et al. 2011).
Promotion of the Value Based care and Accountability of Care	The adoption of EBM systems will automatically increase as the providers are reimbursed for the quality they deliver (Bigus et al. 2011). Researchers can investigates how to promote value-based care through computerized EBM.
Recognition from Top Level Management	Support from the higher level management and integration of EBM systems into the healthcare practice should be included in the hospital's Business IT strategic plan (Wells 2007).

Table 1. Key Findings

Practical Strategies

The implementation of EBM in Hospital systems should change the existing workflow. Therefore, a system must provide added value and be technologically elegant. Otherwise, a system could be under-utilized and could fail. In this section we illustrate the practical strategies for developing Computerized EBM Systems (Table 2).

Practical Strategies	Illustrations
Respect the provider's workflow	Irrespective of the intervention methods, EBM systems should ideally fit and, more importantly, should improve the existing workflow. The new systems should allow a provider to "do the right thing" both easier and faster (Lester et al. 2008).
Make it real time (Bates et al. 2003)	Clinical practitioners are challenged by urgent treatment decisions that must be quickly and accurately made (Bigus et al. 2011). Therefore, it is not acceptable if the information needed is available someplace and sometime in the future.
Provide the latest Information	One of the key ideas to employ the IT for Evidence-Based Medicine is to deliver the latest information. If the designers are not able to deliver that, then the fullest benefit of IT may not be perceived and, more critically, the satisfaction may be diminished.
Employ the technology that can be adopted (Lester et al. 2008)	*Relative Advantages:* The systems should provide added value to the users. The added benefit may be the automation of some procedures in the workflow. It is the relative advantage that might increase the adoption rate of systems. Otherwise, users will resist the use of a new system *Make Compatible with User needs:* The mantra, "If you build what they need, they will come" may be appropriate. To address the users' need, designers must collaborate with users to identify their problems. *Non-Complex:* Only embed the complexity when there is an absolute need. Keep in mind that most of the physicians are not tech savvy. *Trial-ability:* Allow testing periods to physicians before actually deploying systems in their practice. - High-visibility: Starting the early phases of project development, a high degree of visibility can help stimulate peer discussion and user acceptance. Before a system's release, promotional and training material should be distributed and leaders should be involved in face-to-face discussions with users.

Preserve Physician Autonomy	When compliance with guidelines are strongly enforced, physicians may perceive that as undermining their authority. (Cabana et al. 1999).
Promote the transformation of clinical information into action(Bates et al. 2003)	Presenting clinical information without integration with actions has no or very little impact. For instance, if systems suggest the change in an intervention plan, then they should also automatically change the alert and notification prescription to the pharmacy accordingly.
Provide the simplest Information	Evidence suggests that if you cannot fit a guideline on a single screen, clinicians will not be pleased about using it.
Allow the systems to ask more information only when absolutely needed	Only require information, which is not already available in the systems and is absolutely needed for decision-making. For example, never ask clinicians to enter patients' age, race, laboratory results, etc. Instead, import such information from other hospital departments (administrative, laboratory and etc.)

Table 2. Practical Strategies for Designers

Conclusion

In this systematic review, we identified how IT has been used to support evidence-based medicine, presented gaps in current research, and generated practical strategies for system designers. Currently, IT has been used to mine the literature, personal health records, claims, and organizational records to generate pertinent medical evidence. The key issues and potential for IT support for the practice of EBM are insufficient techniques to produce evidence in a computer interpretable format, insufficient research to combine the evidence from the multiple sources, inadequate techniques that automatically rate the literature and practice-based evidence, and integration of evidence at the clinician's workflow. Nevertheless, advances in information technology continues to hold promise to further the practice of evidence based medicine particularly as healthcare shifts from volume-based reimbursements to value-based reimbursements.

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