

Grant Final Report

Grant ID: 5K01HS018352

Context-Aware Knowledge Delivery into Electronic Health Records

Inclusive Project Dates: 09/30/09 – 08/31/13

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Abstract

Purpose: The purpose of this study was to investigate clinicians' point-of-care information needs and to design, develop, and evaluate a knowledge delivery prototype to help clinicians meet their information needs.

Scope: Unaddressed knowledge gaps are among the main causes of errors in the health care system and are missed opportunities for just-in-time learning and practice improvement.

Methods: We 1) systematically reviewed studies on clinicians' information needs; 2) observed clinicians' information needs in the care of complex older adults; 3) led the development of the Health Level Seven (HL7) Infobutton Standard, which enables the delivery of context-specific knowledge into EHR systems; 4) assessed implementers' opinions about the Infobutton standard; 5) developed OpenInfobutton, a standards-compliant platform for delivering context-specific knowledge into EHR systems; and 6) developed and evaluated a prototype knowledge delivery intervention that automatically summarizes contextually relevant information from multiple online resources.

Results: Studies included in our systematic review found that out of 20 patients seen in a primary care practice, clinicians raise 12 information needs, pursue 6, and successfully meet 4 of these needs. In the care of complex aging patients, clinicians raised 2 information needs per patient seen and 60% of these needs were not met. The HL7 Infobutton Standard has received wide adoption and is required for EHR certification in the Meaningful Use Program. OpenInfobutton has been deployed at several health care organizations, including Intermountain Healthcare, the Veterans Health Administration (VHA), and the University of Utah, and Duke University.

Key Words: information needs; informatics; clinical decision support

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Final Report

Purpose

A seminal 1985 study by Covell et al. reported that internal medicine physicians raise two questions for every three patients they see in office practice.¹ In 70% of the cases, these questions were not answered. Since then numerous studies have examined the information needs of clinicians in the course of patient care. In general, these studies have confirmed that information needs arise frequently and often go unmet. Unmet information needs are seen as an important opportunity to improve patient outcomes by filling gaps in medical knowledge in the context of clinical decisions.²⁻⁴ In addition, providing just-in-time answers to clinical questions offers an opportunity for effective adult learning.⁵ The challenge of maintaining current knowledge and practices is likely to be aggravated by the expansion of medical knowledge, increasing complexity of health care delivery, and the growing aging population.⁶⁻⁸

Online health knowledge resources provide answers to most information needs, but significant barriers compromise their use at the point of decision-making.^{9,10} In essence, clinicians become overwhelmed with the vast amount of information available, raising the necessity for tools that help them identify relevant, high quality knowledge in a timely manner and in the context of need.

The goals of this study were 1) to investigate clinicians' point-of-care information needs; 2) to help disseminate existing interventions to help clinicians meet their information needs; and 3) design, develop, and evaluate a novel knowledge delivery prototype to help clinicians meet their information needs.

Specific Aims

Aim 1. Build a knowledge base of providers' knowledge needs.

Aim 1.A – Conduct a systematic review of clinicians' patient care information needs.

Aim 1.B – Observe clinicians' information needs in the care of older adults.

Aim 2. Design and develop a scalable, standards-based knowledge delivery service.

Aim 2.A – Development of the Health Level Seven (HL7) Context-Aware Knowledge Retrieval Standard

Aim 2.B – Evaluation of the challenges, strengths, limitations, and uptake of the HL7 Infobutton Standard

Aim 2.C - Design and development of a standards-based knowledge delivery service (OpenInfobutton)

Aim 3. Conduct a pilot evaluation of a prototype knowledge delivery tool that automatically summarizes contextually relevant information from multiple online resources.

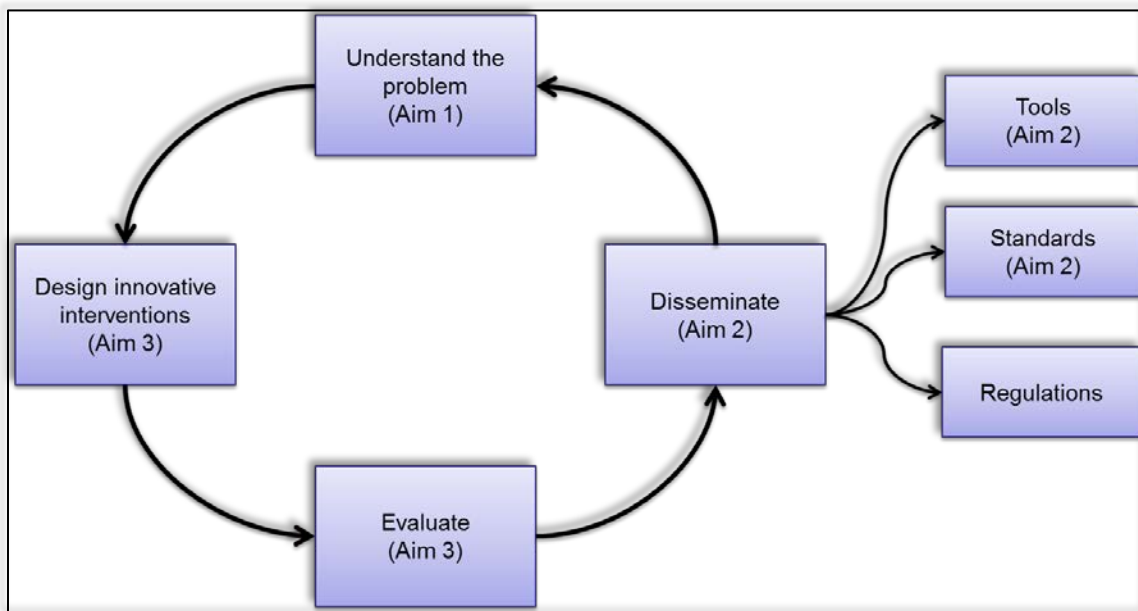
Aim 3.A – Design and intrinsic evaluation of a knowledge delivery tool (Knowledge Summary)

Aim 3.B - Extrinsic evaluation of the Knowledge Summary tool

Scope

This project touched on all aspects of a health information technology life cycle (Figure 1). In Aim 1, we investigated the information needs that clinicians raise in the care of their patients and the barriers clinicians face to meet these needs.^{11, 12} Guided by the findings of Aim 1, in Aim 3 we designed and evaluated a novel knowledge delivery tool to help clinicians meet their information needs.¹³⁻¹⁵ In Aim 2, we developed a set of standards, open source tools, and best practices to help foster the dissemination of knowledge delivery interventions integrated with EHR systems.¹⁶⁻²⁴ The work done in Aim 2 led to a set of Federal regulations that require EHR systems to adopt the standards developed in Aim 2.

Figure 1 – Health information technology innovation life cycle.



Methods

Aim 1: Clinicians' information needs

Aim 1.A - Systematic review of clinicians' information needs

We conducted a systematic review of the literature on clinicians' information needs. We focused on the need for general medical knowledge that might be obtained from books, journals, specialists, and online knowledge resources, as opposed to information about a specific patient, such as that obtained from the patient or their health record. The systematic review was guided

by four primary questions: 1) How often do clinicians raise information needs; 2) how often do clinicians pursue information needs they raise; 3) how often do clinicians succeed at meeting the information needs that they pursue; and 4) what types of questions are asked?

The methodology was based on the *Standards for Systematic Reviews* set by the *Institute of Medicine*.²⁵

Data Sources and Searches. We searched MEDLINE (1966 to May 26th 2011), CINAHL (1982 to May 26th 2011), and Scopus (1947 to May 26th 2011) using search strategies developed with the assistance of two medical librarians. In addition to searching databases, we also inspected the citations of included articles and previous relevant reviews; and requested reviews from experts on this topic.

Study Selection. We searched for original studies that examined clinicians' information needs as defined by Ely et al.²⁶: "questions about medical knowledge that could potentially be answered by general sources such as textbooks and journals, not questions about patient data that would be answered by the medical record." We used a broad definition for clinicians that included physicians, medical residents, physician assistants, nurse practitioners, nurses, dentists, and care managers. We included only studies that collected information needs that arose in the care of real patients.

We excluded studies that met any of the following criteria: 1) data collection outside the context of patient care, such as surveys and focus groups; 2) focus on the use, awareness, satisfaction, impact, or quality of information or educational resources without providing data on the frequency of information-seeking or the nature of the questions asked; 3) information needs of individuals not defined as clinicians in our study, such as health information consumers, medical students, administrators, pharmacists, dietitians, and psychologists; 4) needs for specific patient data (e.g., laboratory test results) that can be found in the patient's medical record; 5) no data on at least one of the systematic review primary questions; and 6) articles not written in English.

Abstract screening. One author independently reviewed the title and abstract of all retrieved citations. Two additional authors independently reviewed two samples of 100 citations randomly selected from the complete pool. In this phase, articles were labeled as "not relevant" or "potentially relevant."

Article selection. Two authors independently reviewed the full-text of all citations labeled as potentially relevant in the abstract screening. Included articles were classified into one of five categories based on the method used to collect information needs: 1) Interviews between patient visits or at the end of a clinic session (After-Visit Interviews); 2) clinicians asked to keep a record of information needs that arise in the care of their patients (Self-Report); 3) direct observation of clinicians in patient care activities by the researcher (Direct Observation); 4) analysis of inquiries submitted to information services, such as drug information services (Information Services); and 5) analysis of online information resource usage logs (Search Logs). Disagreements between the two reviewers were reconciled through consensus with a third reviewer.

Data Extraction. Two authors independently reviewed the included articles to extract the data into a data abstraction spreadsheet. Next, all the quantitative data (e.g., frequency of information needs) were verified by the two authors for accuracy. Disagreements and questions were reconciled with the assistance of a third reviewer.

Data Synthesis and Analysis. For quantitative measures, we aggregated data from published studies to determine a mean, standard deviation, median, and confidence interval across these studies. Due to large variation in study methods and measurements, a meta-analysis of methodological features and contextual factors associated with the frequency of information needs was not possible.

Aim 1.B - Clinicians' information needs in the care of older adults

Despite substantial previous research on providers' information needs, little was known about the specific characteristics of information needs in the care of aging and complex patients. Knowledge of information needs in this patient population may be used to guide the design of interventions that help providers meet their information needs. The overall aim of this study was to address this gap. Specifically, we aimed at answering the following study questions: 1) How frequently do providers raise, pursue, and meet their information needs? 2) How important, urgent, and difficult are these information needs? 3) What types of information needs are most commonly raised? 4) What and how aging factors contribute to the nature of information needs?

Study subjects and sites. We recruited 10 health care providers from outpatient settings at 3 study sites located in Utah: Geriatric clinic at the University of Utah, geriatric clinic at the Salt Lake City Veterans Administration Medical Center (VAMC), and a community clinic at Intermountain Healthcare (Intermountain). In a typical clinic day, we asked providers to identify complex patients who were scheduled for a visit. Complex patients were defined according to the Agency for Health Research and Quality (AHRQ) definition as those with two or more chronic conditions.

Observations. To elicit information needs, we conducted patient care observations according to cognitive work analysis. A researcher observed and audio-recorded providers in all activities related to a patient visit, including preparing for the visits (e.g., reviewing the patient's chart), interacting with the patient, and concluding the visit (e.g., documentation, medication prescription). Providers were asked to briefly summarize the case, listing the patient's problems, medications, and visit goals. At the end of each appointment, providers were briefly interviewed regarding the information needs that were raised in the visit. For each information need, we asked providers to rate its importance and urgency; the provider's level of confidence in the subject of the information need; and the level of difficulty to find an answer. These measures were obtained through a Likert scale questionnaire. We also noted whether the information need was pursued, the resources used, and whether the information need was met. Up to four weeks after the appointment, providers were contacted for a follow-up interview to inquiry about information needs that were not met in the visit.

Data analysis. Audio-recordings were transcribed and de-identified for analysis. Two investigators independently reviewed the transcripts to identify information needs, including

those that were explicitly stated by providers in the post-visit interview and those that were inferred from providers' verbalizations and observed information-seeking behavior. Next, annotations were compared assisted by the researcher who conducted the observations and discrepancies were resolved by consensus. The final set of information needs was coded independently by two investigators according to the Ely's taxonomy of clinical questions.²⁷ In this phase, disagreements were also resolved by consensus.

Information needs were also coded according to aging-related factors associated with an information need. An aging factor was defined as a patient characteristic that is exclusive to, or more common in, aging patients and that motivates, or modifies the nature of, an information need. Factors were created and assigned to information needs independently by the four study authors using the constant comparison method. In a first round, candidate factors were created independently for a subset of 20 information needs. Next, the factors proposed by each investigator were reconciled through group consensus. In a second round, investigators used the list of reconciled factors to code another set of 35 information needs. In this round, new factors were created and the definition of previous factors was refined through group consensus. In a third and final round, investigators coded the remaining information needs. No changes to the factors were necessary in this final round.

Aim 2: Design and development of a standards-based knowledge delivery service

Aim 2.A - Development of the Health Level Seven (HL7) Context-Aware Knowledge Retrieval Standard

As a co-chair of the HL7 Clinical Decision Support (CDS) Work Group (WG), the PI led the development of a set of standard specifications at HL7 named the *HL7 Context-Aware Knowledge Retrieval Standard*, also known as the *Infobutton Standard*. This standard enables the integration between online health knowledge resources and EHR systems. The standard was developed iteratively with broad stakeholder input. The development of the specifications was done through bi-weekly conference calls, offline review of draft specifications, and onsite HL7 meetings (three times per year). The process followed standard ANSI/ISO requirements for standards development organizations. All specifications were submitted through the HL7 standard balloting process and published as a part of the official HL7 normative standard.

Aim 2.B - Evaluation of the challenges, strengths, limitations, and uptake of the HL7 Infobutton Standard

The overall goal of this study was to examine the experience of organizations that implemented the HL7 Infobutton Standard, including health care organizations, health information technology (IT) developers, and knowledge publishers. More specifically, we assessed the following topics: 1) The challenges that organizations faced in the course of implementing the standard; 2) the perceived benefits from adopting the standard; 3) strengths, limitations, and future enhancements; 4) perceived likelihood of widespread adoption; and 5) measures to accelerate adoption.

To answer the study questions, we conducted a cross-sectional study that included an online survey followed by in-depth phone interviews with members of healthcare organizations, health IT developers, and online knowledge publishers.

Eligibility criteria and recruitment method. Eligible organizations were those that have implemented, or are in the process of implementing, the HL7 Infobutton Standard. A purposive sample of healthcare organizations, health IT vendors, and knowledge publishers was recruited through the following methods:

- 1) Two e-mails submitted to the HL7 Clinical Decision Support Working Group (CDS WG) official discussion list;
- 2) oral announcement made during one of the CDS WG work sessions at the May 2011 HL7 Working Group Meeting (WGM); and
- 3) direct e-mails to members of organizations that did not respond to the first two recruitment strategies, but were known by the co-authors to have implemented the Infobutton Standard.

Online survey and in-depth interview script. The survey contained questions about organization demographics, implementation status and timeline, implementation approach, and infobutton parameters supported. In addition, slightly different questions were presented depending on the kind of implementation.

The in-depth interviews explored the following topics: 1) overall experience with the standard implementation process; 2) sources of information used to understand and implement the standard; 3) challenges faced in the course of implementing the standard; 4) benefits realized by enabling infobutton functionality; 5) benefits realized by adopting the standard; 6) lessons learned from implementing the standard; 7) main strengths and limitations of the standard; 8) perceived level of standard adoption in the next five years; and 9) measures that could be taken to promote adoption. Interviewees were also encouraged to raise any additional topics that they wished to discuss.

All phone interviews were conducted by the PI. Phone interviews were recorded with a digital voice recorder. In addition, detailed notes were taken during and after the interviews.

Data analysis. Descriptive statistics were generated from the survey data. From the in-depth interviews, we reviewed the recordings and notes to identify common themes that participants raised in the interviews.

Aim 2.C - Design and development of a standards-based knowledge delivery service (OpenInfobutton)

In the last two decades, researchers have investigated solutions to enable seamless access to online resources within the context of electronic health record (EHR) systems. “Infobuttons” are among these solutions.²⁸ Based on contextual attributes that describe the EHR user, the patient, and the care setting, infobuttons anticipate clinicians’ information needs and provide automated links to a set of relevant knowledge resources that may help clinicians meet these needs.

Despite studies showing positive impact of infobuttons on decision-making, the adoption of infobutton capabilities has been limited to a small set of healthcare organizations with home-grown systems and a strong informatics culture.²⁹⁻³¹ Among potential reasons for slow dissemination include the lack of standards and tools that facilitate implementing infobuttons. The goal of this project was to help disseminate infobutton capabilities in healthcare organizations. To achieve this goal we developed *OpenInfobutton*^{*}: a standards-based, open source Web service. The OpenInfobutton architecture consists of the following components: 1) A knowledge base of knowledge resource profiles; 2) context processing logic; 3) integration with terminology services; 4) an XML transformation service; 5) a Web service layer; and 6) a tailoring environment. Details of the project and its architecture are available elsewhere.²³

Aim 3: Design and pilot evaluation of knowledge delivery tool

Aim 3.A - Design and intrinsic evaluation of a knowledge delivery tool (Knowledge Summary)

We conducted preliminary studies for the design of a knowledge delivery intervention called *Knowledge Summary* (KS). The KS automatically summarizes the literature relevant to the treatment of a patient's condition. Based on the clinicians' information needs, the KS extracts key and contextually relevant sentences from online resources such as PubMed and UpToDate and produces an interactive summary (Figure 2). The KS was iteratively designed and developed through a user-centered method based on high-fidelity prototypes and observations of user interactions while solving case vignettes.

The intrinsic evaluation assessed the performance of the algorithms used to extract sentences for the KS in terms of the relevance and clinical usefulness of the sentences retrieved. We conducted 3 separate studies that evaluated sentences extracted from: 1) randomized controlled trials in PubMed citations; 2) comparative-effectiveness studies in PubMed citations; and 3) UpToDate evidence topics. The methods for each of these studies was similar and consisted of:

- 1) Gold standard development: all sentences from a set of PubMed citations and UpToDate topics were extracted and rated by 3 reviewers according to relevancy to a specific clinical topic and the usefulness for decision-making.
- 2) Measurement of algorithm performance in comparison with the gold standards and according to standard information retrieval measures (i.e., precision and recall).

Aim 3.B - Extrinsic evaluation of the Knowledge Summary tool (to be completed in Q1 2014)

Method description. Clinician volunteers will be asked to find answers to case vignettes and make a clinical decision using the KS. This evaluation will serve as a pilot study for a randomized trial comparing the KS with usual search (already funded by an R01 from the National Library of Medicine).

* <http://www.openinfobutton.org>

Case vignettes. We developed 5 case vignettes based on observations in Aim 1 as well as vignettes published in the literature.

Sample. 15 clinicians. Each clinician will be assigned to 3 vignettes.

Measures. For each vignette, we will measure: 1) time-to-task completion; 2) decision accuracy; 3) perceived information-seeking effort; and 4) perceived impact on clinicians' decision, confidence, uncertainty, knowledge, and recall; and 5) satisfaction with each component of the KS.

Results

Aim 1: Clinicians' information needs

Aim 1.A - Systematic review of clinicians' information needs

Principal Findings. Of 21,710 unique citations retrieved, 811 were selected for full-text screening and 72 articles met the study criteria. Information needs were collected in After-Visit Interviews in 19 studies; through clinician Self-Report in 11 studies; by Direct Observation of patient care activities in 11 studies; by analysis of questions submitted to an Information Service in 26 studies; and by analysis of online information resource Search Logs in 8 studies.

In 20 studies that provided sufficient data, the frequency of information needs ranged from 0.2 to 1.9 questions per patient seen. Frequency of information needs varied according to study methods, with intermediate frequencies in 11 After-Visit Interview studies (median 0.6; range 0.2 – 1.3), lower frequency of needs in 4 Self-Report studies (median 0.2; range 0.16 – 0.23), and higher frequency of needs in 5 Direct Observation studies (median 0.9; range 0.2 – 1.9).

The proportion of information needs that were pursued was available in 16 studies, with a median of 81% (23% – 82%) in 3 Self-Report studies, 47% (28% - 85%) in 11 After Visit Interview studies, and 47% (22% - 71%) in 2 Direct Observation studies. Finally, most consistent were the reported rates of successfully meeting information needs: when clinicians decided to pursue an information need, they were successful approximately 80% of the time across all study types.

Five studies classified information needs according to a formal taxonomy of 64 question types developed by Ely et al. The information need types followed a Pareto distribution, with roughly 30% of the question types accounting for 80% of the questions clinicians asked. lists the 13 most frequent question types across these five studies. Overall, 34% of the questions asked were about drug treatment and 24% were related to the potential causes of a symptom, physical finding, or diagnostic test finding.

Table 1 – Information needs classified according to the Ely taxonomy. The data include the 13 most frequent question types across studies that accounted for 80% of the questions asked.

Question type	Gorman, 1995 ³²	Ely, 1999 ²⁶	Gonzalez, 2007 ³³	Graber, 2007 ³⁴	Ebell, 2011 ³⁵	Overall
What is the drug of choice for	13%	10%	7%	10%	13%	10%

Question type	Gorman, 1995 ³²	Ely, 1999 ²⁶	Gonzalez, 2007 ³³	Graber, 2007 ³⁴	Ebell, 2011 ³⁵	Overall
condition x?						
What is the cause of symptom x?	3%	10%	20%	3%	6%	10%
How should I treat condition x (not limited to drug treatment)?	10%	6%	2%	5%	15%	7%
What is the cause of physical finding x?	2%	6%	15%	3%	3%	7%
What test is indicated in situation x?	9%	8%	3%	8%	6%	6%
What is the dose of drug x?	3%	8%	3%	13%	2%	6%
Can drug x cause (adverse) finding y?	6%	4%	1%	7%	8%	5%
What is the cause of test finding x?	4%	5%	3%	2%	5%	4%
Could this patient have condition x?	1%	4%	6%	1%	2%	4%
How should I manage condition x (not specifying diagnostic or therapeutic)?	2%	5%	4%	0.4%	1%	4%
What is the prognosis of condition x?	NA	NA	0.2%	4%	6%	2%
What are the manifestations of condition x?	NA	NA	1%	8%	2%	2%
What conditions or risk factors are associated with condition y?	NA	NA	1%	6%	1%	2%

* NA=Not available

Table 2 summarizes other substantial findings, including barriers to pursuing information needs, impact on clinical decision-making, and time spent seeking information.

Table 2 – Other substantial and recurring findings.

Barriers to pursuing information need / reasons not to pursue information needs: <ul style="list-style-type: none"> • Lack of time ^{1, 5, 10, 33, 36-42} • Question is not urgent ^{5, 26, 32, 40, 43} • Question is not Important ^{10, 33, 38-40} • Doubt that a useful answer exists ^{10, 26, 32, 34, 38, 39, 43} • Forgetting question ^{5, 33} • Referral ^{10, 33, 40}
Information found produced impact on clinician and decision-making , confirming or changing decisions ^{5, 30, 44-52}
Most information needs are pursued when the patient is still in the practice ^{32, 43, 53}
Most questions are highly patient-specific and non-generalizable ^{1, 32, 43}
Clinicians used human and paper resources more often computer resources ^{1, 10, 26, 32, 36, 43, 53}
Clinicians spend less than 2-3 minutes on average seeking information ^{30, 31, 38, 40}
Observed frequency of information needs much higher than clinicians' own estimate (once per week versus two out of every three patients seen in Covell et al. ¹ ; once a week to once a month versus 10.5 questions per half-day period in Schaafsma et al. ⁴¹)

Significance. This is the first systematic review of clinicians' patient care information needs. In nearly three decades since Covell's seminal study, over 20 additional studies have addressed these issues, employing differing methods in a variety of settings. What has emerged from these efforts is a fairly stable picture: clinicians have many questions in practice, at least one for every two patients they see, and while they find answers to most (nearly 89%) of the questions they pursue, more than half of their questions are never pursued and thus remain unmet. These unmet information needs continue to represent a significant opportunity to improve patient care and to offer self-directed learning by providing needed information to clinicians in the context of care.

Implications for Practice. A relatively small percentage of question types accounted for a large percentage of the questions asked. This finding has important implications in the design of information retrieval interventions, in the priorities for information resource development, and for the optimal structure of information resources.

Despite encouraging results obtained by recent information retrieval technology and online information resources,⁵⁴⁻⁵⁶ the rate of unmet information needs has remained remarkably stable over time. It is possible that current solutions are helping clinicians answer simple questions more quickly, but this improvement is being offset by busier settings, a higher rate of complex patients, and increasingly complex medical knowledge.⁸ It is possible that clinicians self-select simpler and more urgent questions as a result of estimating the value of information in terms of its perceived benefits and cost, with a high threshold for engaging in information-seeking.⁵⁷ Hence, potential solutions need to focus on the kinds of information needs that are most often unmet, even though answers are available. In addition, information interventions should allow clinicians to easily estimate the benefits of the information available versus the cost of seeking and processing the information as early as possible.

The results of this study also raise implications in clinicians' training and lifelong learning. A systematic review has shown decreasing physician knowledge and performance with increasing years in practice.⁵⁸ Traditional approaches to address this issue include requiring physicians to complete continuing medical education (CME) credits. However, the typical CME program follows a passive learning approach and fails to improve physician performance and patient outcomes.^{59,60} Alternate learning interventions could promote just-in-time and self-directed learning in the context of care as information needs arise.⁶¹ In the United States, this kind of approach could be integrated as a part of the requirements for Maintenance of Certification (MOC), particularly the lifelong commitment to learning through ongoing knowledge self-assessment and practice performance improvement.⁶² Electronic health record (EHR) systems are being considered as critical enablers of MOC-driven practice improvement.^{61,63} Hence the EHR could be a natural environment for innovative tools that help clinicians identify knowledge gaps, address these gaps, and improve practice. An important accomplishment in this regard is the recent inclusion of the Health Level Seven (HL7) Context-Aware Knowledge Retrieval Standard²⁰ as a requirement for EHR certification in the United States.⁶⁴ This standard enables the just-in-time delivery of clinical evidence into EHR systems and may provide a foundation for innovations that can help transform EHR systems into practice improvement and learning environments.

Implications for Research. There are several gaps in the literature regarding clinicians' information needs that call for further research. Although studies were done in a wide variety of settings, subjects, and conditions, none of the included studies directly assessed the effect of

characteristics such as care setting, level of training, and years of experience on the frequency and nature of information needs and information-seeking behavior. In-depth knowledge about these effects can be used to personalize information retrieval solutions to the characteristics of the clinician. Our review identified only one study that systematically assessed the nature of questions that clinicians were unable to answer.⁶⁵ More research is needed on the kinds of information needs that are often unmet and on the reasons why they are not being met. Studies have shown a positive impact of information-seeking on clinicians' performance⁵⁴ and patient outcomes^{55,56}. However, this review found no studies that assessed the association between unmet information needs and inferior clinicians' performance or patient outcomes. Further investigation is needed to address this question.

Further research is also needed to investigate information needs in subpopulations of special interest, such as complex and aging patients. In particular, the study of patient complexity has gained recent traction, but the literature still lacks a better understanding of clinicians' information needs and information seeking behavior in the care of these patients.^{8,66} While several studies in this review were conducted in the post-Web age, it is still unclear whether we are facing a change in status quo given the new generation of clinicians, who may have incorporated the use of information resources as a natural component of their clinical practice.

Conclusions. This systematic review estimates that clinicians raise between 0.4 and 0.8 information needs per patient seen and that roughly two thirds of these questions are left unanswered. Despite the wide variety of information needs, a relatively small percentage of information need types account for most of clinicians' information needs. Interventions are needed to lower the barriers to accessing highly relevant, patient-specific information to help clinicians meet their information needs and support patient care decision-making.

Aim 1.B - Clinicians' information needs in the care of older adults

Principal Findings. A total of 36 patient visits and nine providers were observed at the 3 study sites. Providers raised 70 information needs in 36 patient appointments (1.9 information needs per patient seen), pursued 50 (71%) and successfully met 34 (68%) of the information needs they pursued. Most information needs were pursued during the appointment versus the follow-up period (48 versus 2 out of 50 information needs pursued). Overall, 36 (51%) of providers' information needs were not answered.

Most questions (2 out of 70) were motivated or mediated by one of 10 aging-specific factors (Table 3). The most frequent factors were related to treatment decisions, specifically *treatment choice* (18; 26%), *prescribing considerations* (13; 19%), and *managing side effects* (9; 13%).

Table 3 – Frequency of information needs per aging factor (5 most frequent)

Aging factor	Frequency	Definition	Examples
Treatment choice	18 (26%)	Selection of an optimal individualized treatment considering aging factors such as risk/benefit and co-morbidities. Successful treatment outcome is more difficult because of various underlying aging issues. Includes aggressiveness of treatment strategy and goals that need to be tailored in light of the patient's overall prognosis and preferences.	What is the preferred A1c goal in the aging population? How tightly should we control this patient's diabetes? What is the best treatment choice for diabetes when the patient also has heart failure?
Prescribing considerations	13 (19%)	Medication prescription needs to be adjusted to maximize compliance, and minimize side effects / organ damage (e.g., by adjusting medication dose, frequency, treatment length). Includes contraindication questions.	What is the geriatric dose of buspar for depression? What is the CrCl cutoff for alendronate?
Managing side effects	9 (13%)	Consideration of potential or actual side effects. Issues such as polypharmacy and lower medication tolerance contribute to higher incidence and more difficult management of side effects.	Is hallucination a side effect of rivastigmine? Is there adjunct treatment of depression that does not cause drowsiness?
Condition prevalence	8 (11%)	Condition related to the information needs is much more prevalent in the elderly. Information needs related to these conditions would be uncommon in non-aging patients.	What is the best treatment choice for cognitive dysfunction? Is there any literature about obstructive sleep apnea on cognitive performance?
Understanding other provider's rationale	6 (9%)	Unable to interpret rationale of other providers due to lack of enough information (e.g., prescription without reason, diagnosis without explanation)	What are these eye drops used for? What are the indications of concomitant use of aspirin and warfarin?

Significance. This is the first study that assessed clinicians' information needs in the care of complex older adults. Investigating information needs in the care of older adults is important because the aging population is rapidly increasing⁶⁷ and elderly patients with multiple co-morbidities are more difficult to manage with available clinical practice guidelines.⁶⁸ In addition, several aging-specific factors influence clinical decision-making in this population. Understanding these factors may contribute to designing interventions that help providers with information needs that are raised in the care of older adults.

Discussion. When compared to studies that employed similar methodology, but not focused on older adults, our observed rate of information needs was on average three times higher (1.9 versus 0.6 information needs per patient seen). Our findings are consistent with those by Norlin et al., who found a 1.7 times higher rate of information needs in the care of children with special health care needs versus well-child visits.³⁹ The higher rate observed in our study was likely due to the complexity of the patients observed as well as to aging factors.

Consistent with the findings of the systematic review conducted in Aim 1, providers did not pursue over half of their information needs, even though providers considered most of their information needs to be important for the patient's care. When providers decided to pursue their information needs they were successful most of the time. This might be an indication that

providers self-select questions that can be answered with little effort. Providers infrequently pursued information needs after a patient's visit.

Compared to previous studies, we found a higher frequency of information needs related to treatment alternatives and adverse effects. This finding could be explained by the presence of aging-specific factors that affect treatment choice, require additional prescribing considerations, and impose careful management of medication side effects.

Implications. Given a health care environment where providers spend on average 15 minutes per patient visit,^{69, 70} limiting information-seeking to the time frame of a patient encounter compromises clinicians' ability to find and apply external knowledge to their decisions. A potential solution is to design interventions that help providers to record their information needs and pursue these needs when they are not under time pressure. References that answer these questions could be automatically stored in the patient's EHR and shared with other providers through technologies like social media. In addition, automated analysis of recorded information needs could be integrated with providers' self-assessment for tailoring long-life learning as a component of Maintenance of Certification.^{61, 71} This form of self-directed learning could be more effective and compatible with the adult learning style than traditional forms of continuing medical education.^{61, 63}

Finally, there is a stronger need to trade-off the aggressiveness of treatment goals with other factors, such as treatment tolerability, patients' priorities, and patients' life expectancy. These factors could be considered in the design of information resources, which could directly contrast treatment alternatives in light of aging-specific constraints and priorities. Information retrieval interventions could provide dynamic displays that help providers quickly visualize the types and frequencies of adverse effects for the active medications of a particular patient. Last, alternate sources of evidence derived from just-in-time, large-scale population analytics may help providers by showing outcomes of different interventions in similar patients.

Studies are needed to design and assess interventions that help clinicians' decision-making in aging and complex patients. As suggested in the previous sections, our findings provide important insights for intervention design. Moreover, larger studies are needed to enable subgroup comparisons such as the ones described above.

Conclusions. We found that providers raised a large number of information needs in the care of complex older adults and half of these needs were not met. The rate of information needs in our study was three times higher than in previous studies with similar methodology, but not focused on aging and complex patients. Providers rated most of their information needs as important for patient care, but not urgent. We also found a relatively higher rate of information needs related to treatment alternatives and adverse effects than studies not focused on aging and complex patients. This difference may be attributed to aging-specific issues, such as co-morbidities, polypharmacy, and a stronger need to tailor treatment goals in light of factors such as patient priorities, contraindications, and life expectancy.

Aim 2: Design and development of knowledge delivery service

Aim 2.A - Development of the Health Level Seven (HL7) Context-Aware Knowledge Retrieval Standard

Principal findings. The PI led the development of six HL7 Infobutton specifications that were balloted and published in the course of this career development award.

Significance. In 2012, These specifications were selected by the Office of the National Coordinator for Health IT (ONC) as required for EHR certification in the *EHR Meaningful Use Program*, both for patient education information and provider reference information. Inclusion in the Meaningful Use certification criteria will stimulate fast adoption of the Infobutton Standard among EHR vendors in the United States. Outside the US, the Infobutton Standard has been adopted at organizations in Australia, United Kingdom, Germany, and Argentina.

Implications. Widespread adoption of the Infobutton standard has the potential to bring contextually relevant clinical decision support content into the healthcare provider workflow.

Aim 2.B - Evaluation of the challenges, strengths, limitations, and uptake of the HL7 Infobutton Standard

Principal findings. A total of 17 organizations agreed to participate in the study: 6 healthcare organizations, 3 health IT vendors, and 8 knowledge publishers. A total of 20 themes were identified in the theme analysis.

Implementers underscored the benefits, simplicity, and flexibility of the HL7 Infobutton Standard. Yet, participants voiced the need for easier access to standard specifications and improved guidance to beginners. Implementers predicted that the Infobutton Standard will be widely or at least fairly well adopted in the next five years, but uptake will depend largely on adoption among electronic health record (EHR) vendors.

Discussion. Interviewees represented a broad sample of industry stakeholders, including health care organizations, health IT developers, and knowledge publishers as well as for profit, non for profit, and governmental entities. Overall, the attitude of participants towards the HL7 Infobutton Standard and its future adoption was quite positive. Participants especially appreciated the simplicity of the standard and the ability to transition into a standard-compliant product by leveraging preexisting software infrastructure and tools. As a result, most implementations were done by a fairly small team with minimal software development effort. In addition, participants named several benefits realized by enabling HL7-compliant infobutton capabilities in their products. These findings suggest that the cost-benefit of infobuttons may justify a higher prioritization in the stakeholders' roadmap as "low hanging fruit."

The perceived simplicity of the Infobutton Standard seems to derive primarily from strategic principles that guided the development of the two Infobutton Standard Implementation Guides: 1) employ implementation technologies that are compatible with implementers' underlying software infrastructure; 2) leverage ubiquitous Web-based standards with which most software developers are familiar and for which extensive support is available in the form of tools and infrastructure; and 3) specify an approachable and developer-friendly layer over the highly abstract HL7 Version 3. As a result, software developers do not need to become HL7 Version 3 experts to implement the Infobutton Standard.

Significance. This study demonstrated strong adoption of the Infobutton Standard among knowledge publishers, including resources provided by the US Federal government, such as

MedlinePlus Connect (see list at <http://www.openinfobutton.org/hl7-enabled-knowledge-resources>). Except for one large EHR vendor, adoption among EHR systems and healthcare organizations was still limited to organizations with home grown EHR systems. This study provided key information that guided ONC's decision to require the Infobutton Standard for EHR certification in the *EHR Meaningful Use Program*.

Implications. Challenges related to the adoption of standard terminologies and access to standard documentation will help guide future developments of the Infobutton Standard. To accelerate EHR adoption of the Infobutton Standard, implementers recommended HL7-compliant infobutton capabilities to be included in the United States Meaningful Use Certification Criteria EHR systems (this happened a year after the publication of this study).

Conclusions. Overall, implementers reported a very positive experience with the HL7 Infobutton Standard. Despite indications of increasing uptake, measures should be taken to stimulate adoption of the Infobutton Standard among EHR vendors. Widespread adoption of the Infobutton standard has the potential to bring contextually relevant clinical decision support content into the healthcare provider workflow.

Aim 2.C - Design and development of a standards-based knowledge delivery service (OpenInfobutton)

Principal findings. Since OpenInfobutton's first release in August 2010, collaborators from several healthcare organizations have successfully integrated OpenInfobutton with over 40 knowledge resources. The list includes a wide variety of resources, including resources that offer information for health providers (e.g., PubMed, ClinicalTrials.gov, guidelines.gov) and/or patient education (e.g., Medline Plus, Healthwise); resources that are compliant with the HL7 Infobutton Standard and others that are not; resources that cover a broad range of health domains (e.g., UpToDate, Dynamed) versus those that specialize in a particular subdomain (e.g., Genetics Home Reference, PharmGKB); and both freely available and subscription-based resources.

OpenInfobutton has been implemented at the following healthcare organizations: VHA, Intermountain Healthcare, University of Utah, Duke University, New York University (NYU), and University of Washington. Implementation at other organizations are underway, including the Regenstrief Institute and the EMERGE network. Details on the OpenInfobutton project are available at www.openinfobutton.org

Significance. OpenInfobutton has been released as open source software by the Open Source EHR Agent (OSEHRA) framework (<http://code.osehra.org/journal/browse/publication/33>). Several healthcare organizations are using the software. The VHA is currently providing funding for continuous development of OpenInfobutton.

Aim 3: Pilot evaluation of knowledge delivery tool

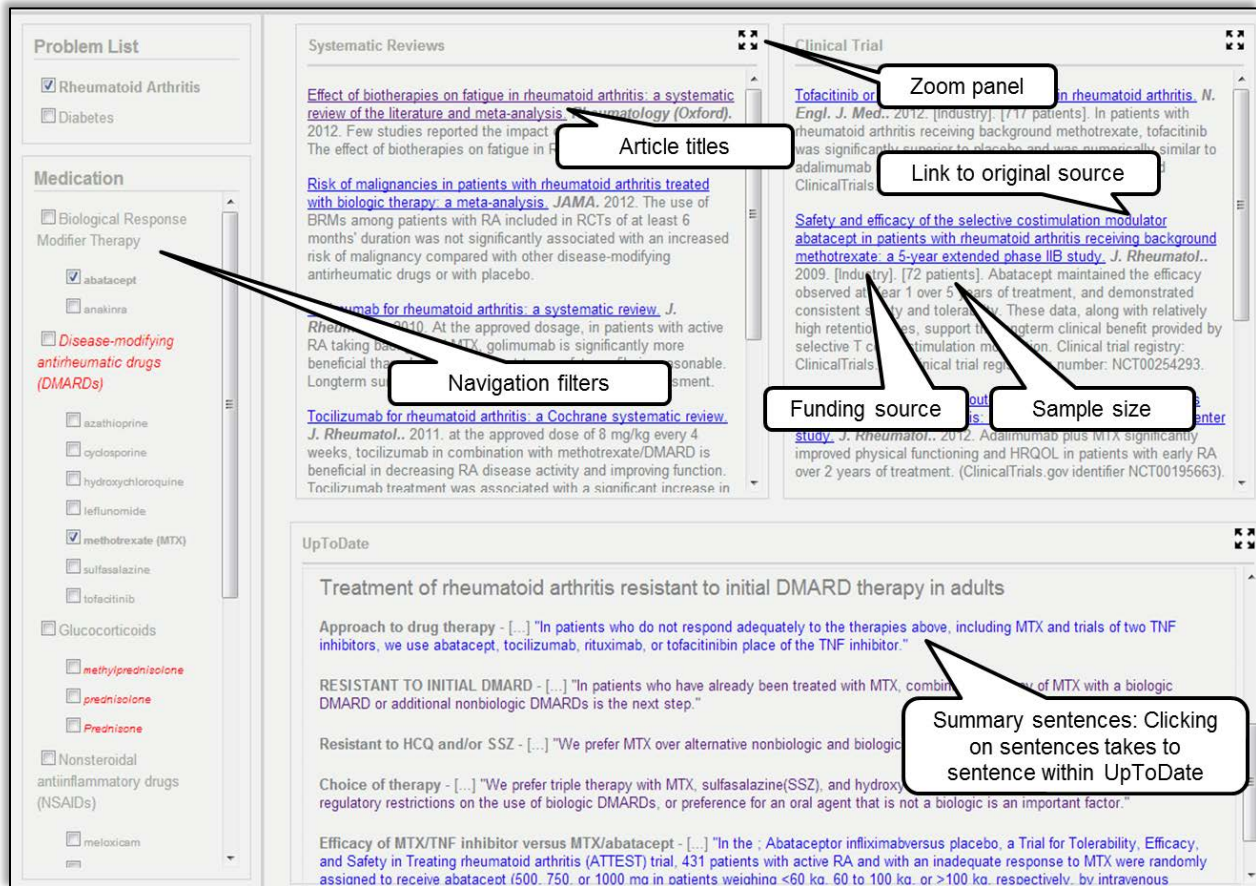
Aim 3.A - Design and intrinsic evaluation of a knowledge delivery tool (Knowledge Summary)

Principal findings. Figure 2 shows a screen shot of the knowledge summary prototype with its features. The patient's current problems and medications are received from the EHR via HL7 Infobutton Standard; and displayed on the left panel as navigation filters. A knowledge summary can be launched by clicking on one of the patient's problems. A combination of natural language processing and machine learning algorithms extract clinically useful sentences from systematic reviews, high impact randomized clinical trials, and UpToDate. The algorithms also extract information such as sample size and funding source from ClinicalTrials.gov when available. Hovering over a sentence expands the sentence to show its surrounding sentences. Clicking on a sentence takes the user to the source. The knowledge summary can be narrowed to a particular treatment option by clicking on one of the treatment filters displayed on the left menu.

We conducted 3 distinct evaluations that tested the relevancy and clinical usefulness of the sentences extracted from the 3 sources. Using treatment of depression and Alzheimer's disease as case studies, over 90% of the sentences extracted from clinical trials and systematic were rated as relevant. Using 12 documents on the treatment of coronary artery disease, hypertension, depression, and heart failure, 53% of the sentences retrieved from UpToDate were rated as clinically useful. All 3 studies identified alternatives and directions to improve the algorithms.

Discussion, significance, and future studies. The prototype demonstrated that it is feasible to produce a contextually relevant knowledge summary from multiple resources. We tested and integrated several natural language processing and machine learning tools and identified an adequate technical approach for the problem. Future studies include fine tuning the algorithms and rigorously evaluating their performance through larger studies. The PI has been awarded a 4-year R01 grant from the National Library of Medicine to fund this research.

Figure 2 – Screen shot of the knowledge summary tool.



Aim 3.B - Extrinsic evaluation of the Knowledge Summary (to be completed in Q1 2014)

Principal findings. We developed an evaluation procedure, 5 case vignettes, and a post-session questionnaire. These instruments were refined and tested with 5 physicians. The pilot study is planned to be completed in Q1 2014. The remainder of this pilot study will be funded by the PI's faculty development funds. In addition, a full-scale randomized controlled trial of the knowledge summary will be conducted, funded by a 4-year R01 grant from the National Library of Medicine.

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List of Publications and Products

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