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Optimization of infobutton design and Implementation: A systematic review

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A B S T R A C T

Objective: Infobuttons are clinical decision tools embedded in the electronic health record that attempt to link clinical data with context sensitive knowledge resources. We systematically reviewed technical approaches that contribute to improved infobutton design, implementation and functionality.
Methods: We searched databases including MEDLINE, EMBASE, and the Cochrane Library database from inception to March 1, 2016 for studies describing the use of infobuttons. We selected full review comparative studies, usability studies, and qualitative studies examining infobutton design and implementation. We abstracted usability measures such as user satisfaction, impact, and efficiency, as well as prediction accuracy of infobutton content retrieval algorithms and infobutton adoption/interoperability.
Results: We found 82 original research studies on infobuttons. Twelve studies met criteria for detailed abstraction. These studies investigated infobutton interoperability (1 study); tools to help tailor infobutton functionality (1 study); interventions to improve user experience (7 studies); and interventions to improve content retrieval by improving prediction of relevant knowledge resources and information needs (3 studies). In-depth interviews with implementers showed the Health Level Seven (HL7) Infobutton standard to be simple and easy to implement. A usability study demonstrated the feasibility of a tool to help medical librarians tailor infobutton functionality. User experience studies showed that access to resources with which users are familiar increased user satisfaction ratings; and that links to specific subsections of drug monographs increased information seeking efficiency. However, none of the user experience improvements led to increased usage uptake. Recommender systems based on machine learning algorithms outperformed hand-crafted rules in the prediction of relevant resources and clinicians' information needs in a laboratory setting, but no studies were found using these techniques in clinical settings. Improved content indexing in one study led to improved content retrieval across three health care organizations.
Conclusion: Best practice technical approaches to ensure optimal infobutton functionality, design and implementation remain understudied. The HL7 Infobutton standard has supported wide adoption of infobutton functionality among clinical information systems and knowledge resources. Limited evidence supports infobutton enhancements such as links to specific subtopics, configuration of optimal resources for specific tasks and users, and improved indexing and content coverage. Further research is needed to investigate user experience improvements to increase infobutton use and effectiveness.

Contents

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1. Introduction

Clinicians and patients routinely encounter multiple information needs which, if answered, improve quality of care [1–6]. Unfortunately, the majority of these needs are not met [6]. Online health knowledge resources can help meet these information needs, but their impact is limited by barriers including accessibility, rigor, relevance, time needed to find pertinent information, cognitive effort to judge applicability, and user preference for local hospital-based approved practices guidelines [6].

Context-sensitive decision support tools or "infobuttons" have been developed in an effort to overcome such barriers [7]. These tools integrate online knowledge resources within electronic health record (EHR) and personal health record (PHR) systems. Based on the EHR task and clinical context (e.g. patient and provider characteristics, care setting), infobuttons anticipate the users' information needs and automatically retrieve relevant information from selected knowledge resources. The typical infobutton consists of a small icon adjacent to EHR data such as a medication, diagnosis, or laboratory test result (see Fig. 1). When clicked, the infobutton opens a web page with dynamic links to online knowledge resources relevant to the EHR task (e.g., review of laboratory results or medication order entry). This information can be further tailored to the clinical context using characteristics of the patient (e.g. age, gender, comorbid conditions), provider (e.g. specialty), or care setting (e.g. outpatient, inpatient).

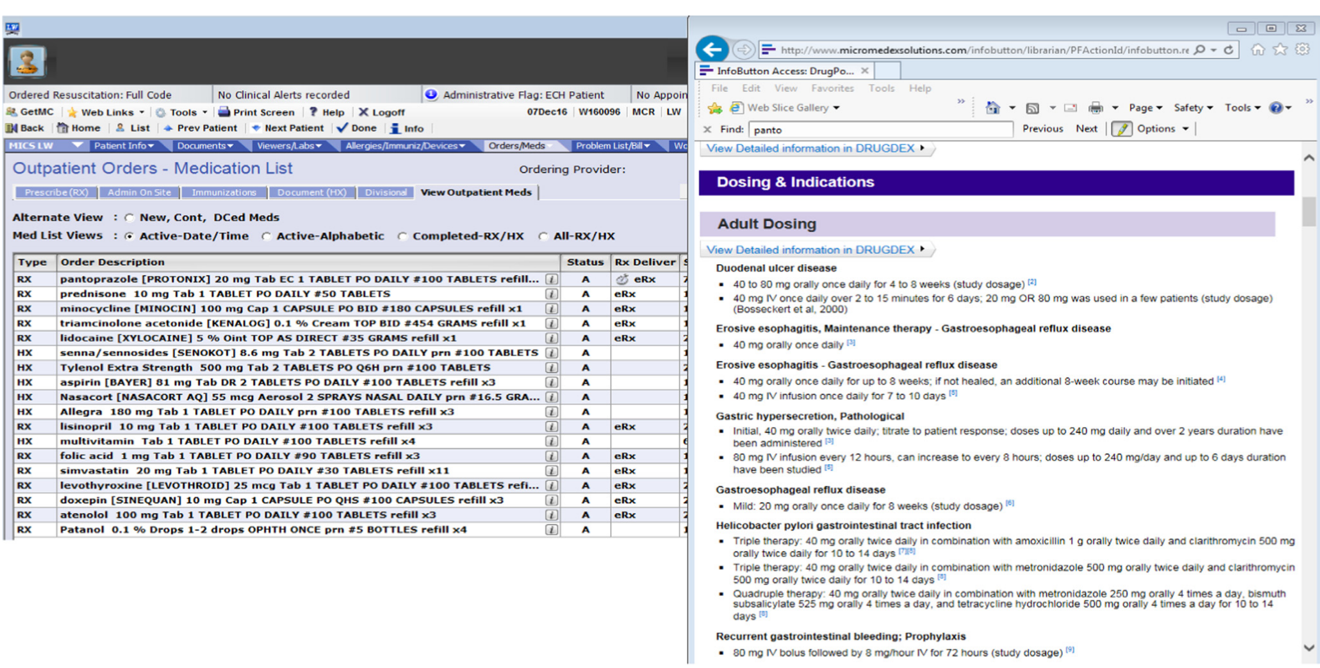

Fig. 1. Infobutton example with a patient's medication list (left) and the retrieved knowledge resource content for a specific medication (right).

In the United States, contemporary EHRs must be compliant with the *Health Level Seven (HL7) Infobutton Standard* [8] in order to meet government incentive "meaningful use" certification [9]. The adoption of the Infobutton Standard parallels the wide adoption of health information technology in general. As of June 29th 2017, 1728 EHR products from 535 EHR vendors/developers had certified against the Clinical Decision Support criterion [10], which includes a requirement to provide infobutton functionality compliant with the HL7 Infobutton Standard [9]. While compliance with "meaningful use" certification has resulted in widespread EHR adoption and perceived enhancement in patient care overall, a systematic review of the effect of health IT on patient care found mixed results and suggested the need for further research to identify approaches that ensure optimal implementation [11].

In a previous systematic review focused on the *health care impacts* of infobuttons, we found overall positive effects on perceived decision making, learning, and workflow efficiency; but also found slow usage uptake both in absolute terms (average use is less than eight times per month per user) and in comparison with traditional searching of online knowledge resources [12]. The purpose of the present review is to study *technical approaches* that may contribute to improved infobutton functionality. Specifically, we attempted to identify evidence-based strategies to improve the interoperability, tailoring, user experience, and content retrieval of infobuttons in order to optimize their impact on patient care quality, efficiency, and cost.

2. Methods

We used a protocol based on PRISMA standards to plan, conduct and report this systematic review [13].

2.1. Study questions

We sought to determine which infobutton technical approaches would improve each of the following:

1. large-scale interoperability;
2. infobutton tailoring
3. infobutton user experience, and
4. the retrieval of relevant content.

2.2. Data sources and searches

The first author and an experienced research librarian developed a strategy to search MEDLINE, EMBASE, CINAHL, the Cochrane Registry, Scopus, Web of Science, and ProQuest Dissertations for original research studies examining infobutton use, as previously defined [12]. We searched each database from its inception to March 1, 2016. We also identified potential studies from the reference lists of included studies and from a review by an expert panel (see online supplement for the full search strategy).

2.3. Study selection

We defined an infobutton as "a knowledge retrieval tool embedded in an EHR that automatically links to knowledge resources tailored to the specific EHR context" [12]. Study selection was done in two stages. The first stage included all original research studies describing infobuttons for any consumer of medical content including administrators, health care providers, researchers, and patients. From this broad inclusion selection process a historical timeline was developed.

In the second stage, we selected for detailed abstraction the subset of studies from the first stage that investigated approaches to improve infobutton design and functionality. We specifically included studies that met one of the following criteria; (a) direct comparison of *technical implementation* approaches; (b) rigorous *usability* research (defined as a study using an explicit usability method that involved more than user satisfaction surveys alone); or (c) rigorous *qualitative research* (defined as a study reflecting goals consistent with a qualitative approach and employing explicit methods of qualitative data analysis). Criterion (a) required a comparison group; criteria (b) and (c) did not.

Two authors independently and in duplicate screened potential articles for inclusion, looking first at the titles and abstracts of all retrieved citations (MT and BH raw inter-rater agreement 84%; kappa 0.6) and then reviewing the full text of potentially relevant citations (MT and GDF raw agreement 90%; kappa 0.7). Conflicts were resolved by consensus with assistance of an additional reviewer (GDF or DAC) when needed.

2.4. Data extraction and quality assessment

We included any outcomes measuring different technical approaches to infobutton design and implementation including user satisfaction, impact, and efficiency in the clinical environment or in the laboratory. Data on content retrieval and the evaluation of infobutton interoperability were also extracted.

Using an iteratively designed data abstraction form, two authors (MT and GDF) independently abstracted information on study type (direct comparison of *technical implementation* approaches, *usability* study or *qualitative research)*, study design, sample size, study location, study duration, and a descriptive summary of findings. We also extracted information on the methodological quality of quantit/ative studies, using an adaptation of the Newcastle-Ottawa Scale for cohort studies [14,15] to evaluate the representativeness of the intervention group, selection of the comparison group and comparability of the cohorts, blinding of outcome assessment, and completeness of follow up in both comparative and usability studies. Disagreements on data abstraction points were again resolved through consensus by discussion with a third author (DAC).

2.5. Data synthesis

We used narrative synthesis to integrate the findings into descriptive summaries regarding infobutton design, implementation and functionality. Lack of common quantitative outcomes among studies and variation in implementation or reporting prevented synthesis using meta-analysis.

3. Results

3.1. Trial flow

The search strategy identified 638 potentially eligible articles. Database searches yielded 637 articles with one additional study added from reference review and author contact lists. Eighty-two studies met the broad inclusion criteria, and were integrated into a historical timeline. A subset of 12 of the 82 studies (13%) met the criteria for full review (see Fig. 2).

3.2. Historical timeline and overview

A timeline outlining the history of infobuttons and other context sensitive clinical decision tools is found in Fig. 3. The earliest infobutton-like tools relied solely on Medline search terms [16,17]. One of these integrated systems, known as the Medline Button, allowed the clinician to select patient diagnoses coded in

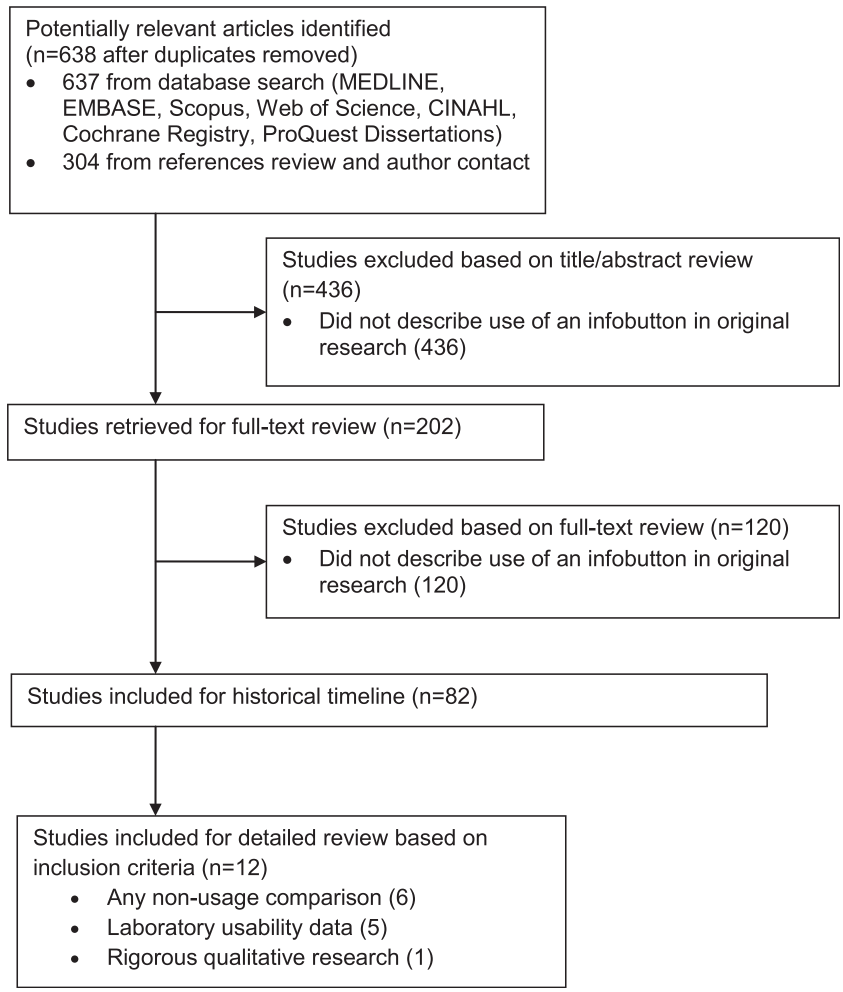

Fig. 2. Trial flow.

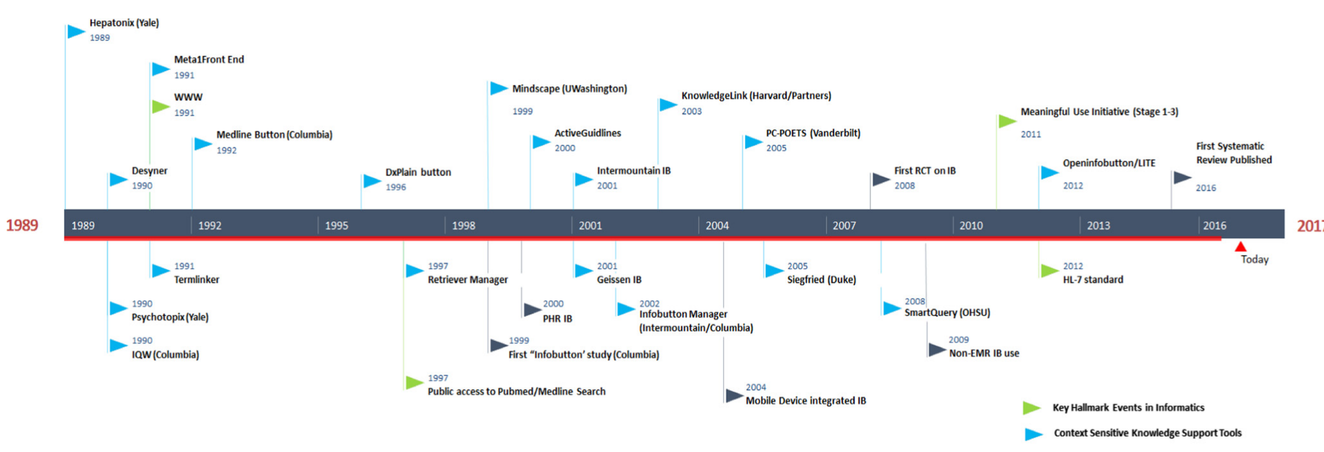

Fig. 3. Historical timeline.

ICD-9-CM (International Classification of Diseases, Ninth Revision, Clinical Modification) in a mainframe-based EHR and automatically used the ICD terms to search a Medline database hosted on the same mainframe server. With the advent of the World Wide Web, other non-Medline online databases were developed and linked to infobuttons [18–23].

Eventually, the Medline button was capable of linking to other resources and Zeng and Cimino coined the term "information button" or "infobutton" in 1997 [24]. In 2002, Cimino proposed an architecture based on an EHR-independent software component called "infobutton manager." Based on the clinical context within the EHR and a knowledge base, infobutton managers anticipate

Table 1
Characteristics of studies reviewed in detail (N = 12).

Study category	Author, year	Sample No.: type	Site	Duration (mo.)	Technical topic	Comparison	Outcome	Summary of results
Inter-operability (N = 1)	Del Fiol, 2012 [8]	17: IT experts	Multisite	NA	HL7 Infobutton standard	None	20 themes related to adoption of the Infobutton standard	• Factors favoring adoption: simplicity, ease of implementation, and development over a stack of widely adopted standards • Challenges: accessibility of documentation, learning curve especially for novices, and need for education/promotion among implementers
Infobutton tailoring (N = 1)	Jing, 2015 [47]	14: mixed/ medical librarians	Multisite	NA	Infobutton Manager configuration (LITE)	None	Success rate/task completion	• 70% of participants reported overall positive impression; 36% ease of use; 62% usefulness; 64% recommended use/planned to use in the future; 83% felt infobutton met their needs • All tasks successfully completed. System Usability Scale = 72 (average) in short time (<10 min)
User experience (N = 7)	Price, 2002[44]	11: Residents	OHSU	NA	Usefulness/ Ease of use	Infobutton vs unspecified 'usual' search	Satisfaction, Usefulness, Learning potential	• Overall useful (91%), but not better than usual methods • Ability to search multiple sources most useful with preference for automatic queries to guidelines and textbooks over Medline
	Maviglia, 2006 [27]	590: MD, RN,NP	Partners	12	Resource features and content	Infobutton linking two knowledge resources	Usage, Impact Satisfaction, Session duration	• Resources linked to infobutton had an effect on user satisfaction and frequency of use. Micromedex used 3× more frequently and led to 1.6× higher satisfaction than SkolarMD • No difference in success rate (84% vs 85%) and in changes to medical decision (15% vs 14%) • Average overall session time was 25 s
	Cimino, 2007 [48]	12: Mixed	Columbia	14	Premature termination of infobutton session	Infobutton w/enhanced navigation vs original Infobutton; Infobutton vs resources page	Usage, Session duration, Success rate	• Reduction of time to select a link (from 11 s to 6 s) with redesigned Infobutton page in a laboratory setting • No changes in usage, selection rate (~47%), or time to select a link (~14 s) with redesigned Infobutton page in clinical settings • Resources page with static links had 3.5× higher usage than infobuttons
	Del Fiol, 2008 [49]	104: Mixed	IHC	6	Navigation efficiency	Infobutton w/topic-specific links vs Infobutton w/ non-specific links	Usage, Impact Session duration, Success rate	• Topic-specific sessions are 17% shorter than non-topic specific links (36 s vs 43 s) • No difference in frequency of use, success rate, or clinician impact • Infobutton's success rate and impact on clinicians was positive in both study arms
	Collins, 2009 [50]	14: MD, NP/PA,RN	Columbia	NA	Infobutton effectiveness	Infobutton vs. non-infobutton by user type	Success rate, Info need, Usability themes	• Infobuttons increase chance of successful searches (50% vs 38%) compared to non-infobutton searches • In 9% of the cases, infobutton searches did not retrieve any content • Content preferences are dependent on clinician type • Users recommended access to institutional protocols, improved awareness through a more visible infobutton icon, and fewer required mouse clicks
	Schnall, 2012 [37]	9: Case Managers	Columbia	NA	Usefulness/ Ease of use	NA	Usefulness, Information Quality, Interface	• Positive: Infobutton manager provides high usability (including satisfaction, usefulness, information quality, and interface quality) according to survey • Negative: Difficulty understanding resource labels; too many mouse clicks to find information
	Dragan, 2015 [51]	48: Dental Students	Tufts	NA	Navigation efficiency/ infobutton effectiveness	Medication infobutton vs. 'usual' search	Session duration, Success rate/accuracy Satisfaction	• Overall positive satisfaction with infobuttons, with 69% of users reporting they would use it again • No difference in search time between infobutton vs. non-infobutton searches (286 s vs. 265 s) • No difference in examination scores (about half found an answer to their question) • Participants reported infobutton to be easy to use (63%) and fast (50%)

Infobutton content retrieval (N = 3)	Del Fiol, 2008 [52]	4829: Sessions	IHC	12	Prediction of user behavior	Computer algorithms (±concept drift); vs human crafted rules among different users/tasks	Accuracy, Agreement between models and clinicians	• Classification models performed better than baseline (Kappa agreement between predicted and actual choice = 0.58 vs.0.39) • Predictors of use: user, specialty, frequency of infobutton sessions, concept class, EHR Task. Removal of user identifier predictor made classifier equal to baseline • Classification performance degraded over time, but concept drift handling resolved issue
	Del Fiol, 2009 [53]	3078 Sessions	IHC	6.8	Prediction of user behavior	Computer algorithms, predictors and learning methods	Accuracy, Agreement between models and clinicians	• Classification models help predict content topics • High prediction performance for pediatric dose, patient education, pregnancy category, and adult dose (AUC = 0.85–0.99) and low prediction for adverse effects, how supplied, precautions, drug interactions (AUC = 0.75–0.79). • Best predictors were reads/writes to EHR /orders entered, drug class, and age of patient
	Del Fiol, 2010 [54]	N not specified/ mixed users	Multisite	24	Content coverage	Newly revised content indexing vs no revision to content	Session coverage (proportion of infobutton uses retrieving relevant content)	• Infobutton resources analysis can improve knowledge resource indexing and prioritize new content development • Resource with improved indexing and expanded content (Clineguide) showed 2.4–6.6% increase in coverage (average 4%) compared to unchanged resource (ARUP; 2% drop in coverage)

Abbreviations: *Users*: IT expert = information technology expert; MD = practicing/resident physician; ML = machine learning; NP = nurse practitioner; PA = physician assistant; RN = nurse; *Site*: Columbia = Columbia University (New York Presbyterian Hospital); IHC = Intermountain Healthcare; OHSU = Oregon Health Science University; Partners = Partners HealthCare System (Harvard); Tufts = Tufts Medical Center; Multisite = data collected from multiple (≥3) hospitals or academic centers.
Results: AUC = area under the ROC curve; ARUP = Associated Regional and University Pathologists (University of Utah's clinical and anatomic pathology reference laboratory); EHR = Electronic Health record; LITE = Librarian Infobutton Tailoring Environment; SVM = support vector machine.

clinicians' information needs and automatically retrieve relevant information from target knowledge resources [25]. Subsequently, infobutton manager implementations became available at other institutions [26,27] and as an open source software suite [28].

Infobutton technology has been integrated into patient-accessible medical record systems [29–33] and enabled in EHRs within mobile devices [34,35] and commercial EHRs such as ClinRefLink [36]. Implementations in other clinical information systems also became available, including Hazard and Near-Miss Reporting Systems [37,38].

Infobutton-like research grew in the late 1990s in the US [27,39–45] and soon expanded internationally [33,46] although adoption remained limited to a few early-adopting institutions. Following the requirement in 2011 for EHR products to adopt the Health Level Seven (HL7) "Infobutton Standard" for "Meaningful Use" certification [9], infobutton-capable EHR systems and knowledge resources have proliferated [10] (see Fig. 3).

3.3. Characteristics of studies included in detailed review

Table 1 contains key information from the 12 studies selected for detailed review. Of these, one (8%) study investigated infobutton interoperability [8], one (8%) assessed tools to assist in tailoring infobutton managers [47], seven (58%) explored alternatives to improve user experience and increase infobutton use [27,37,44,48–51] and three (25%) investigated approaches to improve the relevance of content retrieved by infobuttons [52–54]. Ten (83%) of the included studies originated from one of three institutions with locally-developed EHR systems, namely Columbia University, Intermountain Healthcare, or Partners HealthCare [8,27,37,47–50,52–54]. There were three (25%) multisite studies [8,47,54].

3.4. Quality of studies included in detailed review

We were able to evaluate 11 of the 12 studies for quality (Table 2) [27,37,44,47–54]. All of the user experience studies enrolled participants who were deliberately selected based on participant characteristics (purposeful sampling) and thus were not representative of all potential users. Two studies enrolled a representative sample [52,53]. Seven studies (58%) used a comparison group [27,48,49,51–54], including three (25%) with randomized assignment [27,49,51] and two with non-random assignment using historical controls [48,54]. Among the comparative studies, three studies took measures to ensure comparability of cohorts [51–53]. In eight (67%) studies, $\geq$75% of enrolled participants provided data for at least one objective outcome (see Table 2) [27,47–49,51–54].

3.5. Infobutton interoperability

One study specifically investigated interoperability of the infobutton [8]. The authors of this multisite qualitative study investigated HL7 infobutton implementations through in-depth interviews with implementers from 17 organizations including EHR vendors, healthcare networks, and knowledge publishers. Overall, interviewees reported a positive experience with the HL7 infobutton standard, finding it to be simple and easy to implement. They identified salient needs for wide adoption of the standard, including accessibility of technical specifications and educational materials, promotion and awareness, clarity in user guide documentation, and conformance testing criteria.

Table 2
Study quality (N = 12).

Study category	Author, year	Study design[#]	Representativeness (sampling)	Selection of comparison group	Randomized	Comparability of cohorts[*]	Outcome follow-up[†]	Outcome assessment[$]
Interoperability (N = 1)	Del Fiol, 2012 [8]	Qualitative	NA	NA	NA	NA	NA	NA
Infobutton tailoring (N = 1)	Jing, 2015 [47]	Cross-sectional	0	NA	NA	NA	0	Obj-U, Sub
User experience (N = 7)	Price, 2002 [44]	Cross-sectional	0	NA	NA	NA	1	Sub
	Maviglia, 2006 [27]	RCT, 2-group	0	1	1	NA	0	Obj-B, Sub
	Cimino, 2007 [48]	Historical control	0	1	0	0	1	Obj-B
	Del Fiol, 2008 [49]	RCT, 2 group	0	1	1	NA	1	Obj-B, Sub
	Collins, 2009 [50]	Cross-sectional	0	0	NA	NA	1	Sub
	Schnall, 2012 [37]	Cross-sectional	0	NA	NA	NA	1	Sub
	Dragan, 2015 [51]	RCT, 2 group cross-over	0	1	1	1	1	Obj-B, Sub
Infobutton content retrieval (N = 3)	Del Fiol, 2008 [52]	Diagnostic accuracy study	1	1	NA	1	1	Obj-B
	Del Fiol, 2009 [53]	Diagnostic accuracy study	1	1	NA	1	1	Obj-B
	Del Fiol, 2010 [54]	Historical control	0	1	0	0	NA	Obj-B

NA = not applicable (no separate comparison group, no follow-up period defined, or qualitative design).
[*] Comparability of cohorts could be demonstrated through randomized group assignment or by statistical adjustment for baseline characteristics.
[†] Outcome followup: 1 = high ($\geq$75% of enrolled participants provided data for ANY outcome).
[$] Sub = Subjective; Obj = Objective. B = Blinded; U = unblinded.
[#] Newcasttle criteria was not applicable to qualitative studies as a purposive sample being considered more useful than a random sample in this case.

3.6. Infobutton tailoring

The OpenInfobutton project developed the Librarian Infobutton Tailoring Environment (LITE), a tool that allows multiple institutions to collaborate and share infobutton manager configuration [47]. One study investigated the feasibility and usability of LITE to assist non-IT personnel (e.g. medical librarians) in tailoring an infobutton manager to the needs of a specific institution. The study found that non-IT personnel were successfully able to perform infobutton manager configuration tasks in less than 6 min. Users rated LITE according to the System Usability Scale survey (SUS) and reported a positive overall impression, perceived usefulness and utility, although only half of the study participants thought LITE to be easy to use [47].

3.7. Infobutton user experience

We found five laboratory setting studies with a total of 94 users [37,44,48,50,51] and three real clinical setting studies [27,48,49]; (Cimino et al. [48] included both a laboratory and a clinical setting study) with 694 users that aimed to improve the user experience (e.g., usability, usefulness) or increase the use of infobuttons. Studies included comparisons with alternate user interface designs [27,48,49], comparisons with non-infobutton searching [48,51], and studies without a comparison [37,44]. All seven studies evaluated at least one outcome related to infobutton effectiveness such as clinician impact, success rate of finding answers to questions, or overall usefulness [27,37,44,48–51]. Three studies assessed user satisfaction and all three had overall positive outcomes [27,44,51].

Four studies shed light on how to improve infobutton user efficiency, as measured by a user's time seeking information to answer a clinical question [27,48,49,51]. Two studies found that alternative designs of the infobutton user interface significantly reduced information-seeking time [48,49]. First, a randomized trial comparing infobuttons links to specific subtopics (e.g., drug dosing, adverse reactions, contraindications) within drug monographs versus non-specific infobutton links showed an improvement in clinicians' information-seeking efficiency by reducing infobutton search time by 17% (topic specific sessions lasting 35.5 vs 43 s), but did not increase usage uptake, information-seeking success rate, or information-seeking impact on clinicians [49]. Second, a historical control study looked at a multilevel redesigned infobutton page with links displayed according to topics and resources as opposed to full-prose questions [48]. The study showed reduced time choosing a link in the redesigned infobutton page from 11.13 s to 5.92 s in the laboratory with increased overall satisfaction. However, these improvements did not carry over when the new design was implemented in the clinical setting, as indicated by the lack of significant changes in either the infobutton usage rates (1937[±250]/month vs. 1789 [±154]/month) or the average search time (14.8 s[±1.4] vs 14.5 s[±1.5]) [48]. Another crossover randomized study among dental students in a laboratory setting compared medication infobutton links to UpToDate® with manual search of UpToDate. The study found no significant difference in search time (286 s vs 265 s respectively; p = 0.429) or examination scores (average 42.2% vs 42.6% correct answers respectively) [51].

Three studies evaluated approaches to infobutton resource selection [27,44,49]. Users preferred access to resources with which they were more familiar; and automatic queries to guidelines and online textbooks over Medline [44]. Though participants in a laboratory study indicated that they would like the ability to automatically search multiple resources [44], a different study found that in clinical care settings clinicians rarely sought information in more than one resource in a given infobutton session, suggesting that computer-recommended prioritization of resources may be preferable to providing multiple options to users [49]. When studied in a randomized controlled trial comparing medication infobuttons linking to one of two commercial medication

Table 3
Key findings and implications for implementation and research.

Category	Finding	Currently supported best practices	Suggestions for future research
Interoperability	• Implementers of the HL7 Infobutton Standard valued its usefulness and simplicity [8] • The infobutton Standard has been widely adopted by EHR system vendors and knowledge publishers [8,10]	• Supporting ongoing evolution of the Infobutton Standard • Promote adoption via continued implementation of Meaningful Use requirements	• Investigate the implementation of the Infobutton Standard by various commercial EHR systems
Infobutton tailoring	• Non-IT personnel with expertise in knowledge resources (e.g., medical librarians) were able to tailor infobutton functionality to the needs of health professionals and patients [47]	• Enable infobutton tailoring tools that can be used by experts in knowledge resources • Engage content experts with training in knowledge delivery (e.g., medical librarians) to assist in tailoring infobutton functionality	• Investigate the tailoring of infobuttons by knowledge resource experts in clinical settings
User experience	• Linking users directly to content subsections that specifically address their information needs increased user efficiency [49]	• Structure and index knowledge resource content in granular "chunks" according to users' anticipated information needs • Enable HL7-compliant APIs to directly access granular "chunks"	• Investigate the user experience and health care impact of infobutton implementations in commercial EHR systems
Infobutton content retrieval	• Better indexing and increased content coverage for high priority areas improved relevance of infobutton responses [54] • Recommender systems outperformed hand-crafted rules in the prediction of relevant resources and clinicians' information needs [52,53]	• Leverage infobutton log data from multiple institutions to systematically and continuously improve content indexing and coverage	• Investigate coupling of infobuttons with recommender systems in clinical settings

Abbreviations: IT = information technology; EHR = electronic health record; API = application program interface; HL7 = Health Level Seven.

knowledge resources, there were no differences in information-seeking time, success, and changes to medical decisions based on the information found [27]. Yet, users reported a 1.6 times higher satisfaction and 3 times higher frequency of use when infobuttons provided links to a resource with which users were more familiar [27].

3.8. Infobutton content retrieval

We identified three studies that collectively analyzed nearly 8000 infobutton sessions to evaluate approaches aimed at better predicting information needs, selecting relevant resources, and retrieving content relevant to a particular clinical context [52–54].

Two studies suggested that machine learning "recommender" algorithms aimed at predicting users' optimal behavior have a promising role in enhancing infobutton functionality [52,53]. One study compared human-crafted rules with machine learning algorithms in predicting users' knowledge resource choice based on clinical context and user characteristics. The machine learning algorithm achieved a higher agreement between predicted and actual users' choice than human-crafted rules [52]. Of the predictors studied (e.g., user, user clinical specialty, number of previous infobutton sessions, concept class, EHR task) the best predictors of future behavior were the user type (e.g., physician, physician assistant, nurse) and the EHR task (e.g., medication order entry, laboratory results review). Although users' resource preferences changed over time (i.e., *concept drift*), use of machine learning algorithms that accounted for concept drift ensured that the prediction performance remained stable over time [52].

A second machine learning study produced several classification models based on medication infobutton usage data to predict the medication-related content topics that a clinician is most likely to choose while entering medication orders in a particular clinical context [53]. The authors found differences among classification models in their ability to guide the selection of relevant information. Specifically, stacking, support vector machines, and Bayesian Networks were the most accurate prediction models, with the Area Under the Curve (AUC) for the best model ranging from 0.72 to 0.99 depending on the predicted topic [53].

Another study analyzed the infobutton usage log of laboratory test results at three institutions to identify unsuccessful searches, and used this information to improve knowledge resource indexing and, help prioritize new content development. A pre-post comparison with a historical control showed an increase of 4% ($p < 0.0001$) in the proportion of infobutton searches that retrieved relevant content from the intervention resource, while the historical control had a decrease of 2% ($p < 0.0001$) [54].

4. Discussion

In the present systematic review, we investigated technical features to improve infobutton design and implementation that were evaluated according to usage rates, efficiency, clinician impact, user experience, interoperability, and relevance of the content retrieved. The key findings are summarized in Table 3. In summary, the HL7 Infobutton Standard was well-accepted and considered to be easy to implement [8]; and a tool within the OpenInfobutton project (LITE) enabled medical librarians to tailor the behavior of infobutton managers to meet the needs of health professionals and patients at their institutions [47]. Studies attempting to improve the infobutton design and user interface generally led to enhanced user experience, satisfaction, and efficiency [27,37,44,48,49]. However, these interventions failed to increase clinical infobutton use and information-seeking success [48,49,27,50]. Lastly, better indexing and increased content coverage appeared to improve the relevance of infobutton responses [54]; and machine learning algorithms outperformed human-crafted rules in the prediction of user behavior [52,53].

Our historical timeline shows that attempts to improve infobutton parallel attempts by the informatics community to overcome barriers to infobutton implementation and use by optimizing user interfaces, understanding and predicting clinical information needs, and optimizing resource content and indexing. Overall, the studied approaches focus on ensuring clinicians have access to the most relevant information by optimizing both "front end" user interfaces and "back end" processes involved in the prediction of clinicians' questions and the retrieval of relevant information.

4.1. Strengths and limitations

Our conclusions are limited by the number, quality, and research focus of the published work in this field. From the 82 studies identified as original infobutton research, only 12 studies met the full review inclusion criteria. These included studies generally lacked representativeness and generalizability including only one study using a commercial EHR [36] and none outside academic institutions. Furthermore, despite infobuttons becoming a more global and widely adopted clinical decision tool [10], all but two studies originated from three institutions, which may limit the generalizability of our findings. One of the co-authors (GDF) was involved in most of the included studies; this raises the possibility of bias, but we attempted to mitigate this limitation by having other authors (MT and DAC) independently abstract and synthesize results.

Strengths of our systematic review include a rigorous search of multiple databases conducted in conjunction with an expert research librarian, inclusion decisions and data abstraction conducted in duplicate with acceptable agreement, and involvement of experts in the field in identifying studies and selecting data for abstraction.

4.2. Integration with prior work

Previous systematic reviews attempted to identify features of clinical decision support tools and EHR systems that could be associated with positive effects [11,55]. Five features were associated with improved clinical practice in randomized controlled trials of clinical decision support tools: integration with clinician workflow, provision of recommendations rather than just assessments, provision of decision support at the time and location of decision making, and computer based decision support [55]. The various infobutton tools studied in the present review comply with those features. Another systematic review of 236 studies on the impact of health IT functionalities on key aspects of health care, such as quality, safety, or efficiency also found evidence supporting the use of clinical decision support tools [11]. Yet, limitations in study design and lack of reporting of contextual and implementation details precluded identification of features related to successful interventions. The studies included in the present review suffer from similar limitations. Improved and standardized reporting of health IT interventions is needed for better understanding of the effects of system features, implementation, and context on the success of those interventions.

4.3. Implications for infobutton implementation and research

Studies in this review indicate that usability improvements, particularly attempts to link users directly to subsections that specifically address their information needs, may increase user efficiency and should be further investigated. To enable this kind of functionality, knowledge resources need to have their content tagged and indexed according to clinicians' information needs; and the HL7 Infobutton standard needs to evolve over time to support different kinds of information needs. In addition, we found some evidence suggesting the importance of systematic usage log analysis to guide knowledge resource publishers in prioritizing content development and improving content indexing.

With the wide adoption of the HL7 Infobutton standard by certified EHR products in the US [37], infobutton functionality is available to care settings that use one of these certified EHR systems. According to implementers, factors such as simplicity, ease of implementation, and regulatory incentives were considered as the main drivers for such an adoption. Other emerging health IT standards, such as the HL7 Fast Health Interoperability Resources (FHIR) are following a similar path [56].

We also found that machine learning based on infobutton usage logs appears to be a promising approach to predict infobutton users' information needs and information-seeking behavior. Yet, further research is needed to investigate the integration of such tools in care settings. The availability of usage log data from the multiple institutions that use OpenInfobutton provides an opportunity to significantly scale up such efforts.

Further research is needed to determine best practice technical approaches in order to ensure optimal user experience that increases infobutton use, efficiency, and effectiveness. Since most infobutton studies have been carried out at settings with home grown systems, particular attention should be dedicated to studies in clinical settings with commercial EHR systems.

5. Conclusion

Despite wide availability within EHR products, infobuttons remain a promising and understudied clinical decision support tool. Available evidence confirms their potential to favorably influence practice-relevant outcomes, but further research is needed to investigate approaches to improve infobutton user experience in laboratory and clinical settings.

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Competing interests

We are not aware of any competing interests.

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Appendix A. Supplementary materials

Supplementary data associated with this article can be found, in the online version, at http://dx.doi.org/10.1016/j.jbi.2017.08.010.

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