Automatically Extracting Clinically Useful Sentences from UpToDate to Support Clinicians' Information Needs

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Abstract

Clinicians raise several information needs in the course of care. Most of these needs can be met by online health knowledge resources such as UpToDate. However, finding relevant information in these resources often requires significant time and cognitive effort.

Objective: To design and assess algorithms for extracting from UpToDate the sentences that represent the most clinically useful information for patient care decision making.

Methods: We developed algorithms based on semantic predications extracted with SemRep, a semantic natural language processing parser. Two algorithms were compared against a gold standard composed of UpToDate sentences rated in terms of clinical usefulness.

Results: Clinically useful sentences were strongly correlated with predication frequency (correlation= 0.95). The two algorithms did not differ in terms of top ten precision (53% vs. 49%; p=0.06).

Conclusions: Semantic predications may serve as the basis for extracting clinically useful sentences. Future research is needed to improve the algorithms.

Introduction

Clinicians' patient care information needs are common and frequently unmet [1]. Most of these information needs can be met by online health knowledge resources like Medline and UpToDate [2]. However, clinically useful information is not always easy to find [3]. The most useful information for the care of a specific patient may be buried within long documents or fragmented across multiple documents and resources. Therefore, methods are needed to help clinicians identify clinically useful information efficiently and effectively.

Research on information extraction and summarization has been done in the biomedical text-mining domain, but most previous studies have been restricted to titles, abstracts, and metadata from Medline records [4-7]. More recently, the focus has shifted to extracting and summarizing information from the full-text of biomedical journals [8]. Although biomedical journals are sometimes useful for clinical decision making, they are not designed to directly answer clinicians' information needs [3]. On the other hand, resources such as UpToDate provide expert reviews on clinical topics with the goal of helping clinicians meet their patient care information needs. Although UpToDate documents provide summary recommendations on specific topics, these documents are still relatively long, often with over 200 sentences.

The overall goal of our research is to generate automatically knowledge summaries to support patient care decision making. Our approach consists of extracting clinically useful sentences from relevant documents using semantic natural language processing (NLP) methods. Specifically, in the present study we aimed at designing and assessing an algorithm that extracts clinically useful sentences on treatment recommendations for specific conditions from UpToDate documents.

Background

Clinicians' information needs. A seminal study by Covell et al. found that clinicians raise two questions out of every three patients seen and that 70% of these information needs go unmet [9]. A recent systematic review identified several studies that confirmed Covell's findings [1]. The review also identified significant barriers that limit clinicians' ability to meet their information needs, especially clinicians' lack of time and perception that an answer cannot be easily found in the available resources. In our research, we aim to address these barriers by reducing the time and cognitive effort that clinicians need to devote seeking for information.

Information extraction and summarization. Overall, text summarization can be classified into two types: 1) extractive summarization; and 2) abstractive summarization. In extractive summarization, the sentences are selected based on their relevance and key words. In abstractive summarization, novel sentences based on important concepts are created [8]. However, this method has many underlying challenges and is less popular than the extractive method.

Researchers have investigated both extractive and abstractive text summarization of the biomedical literature. Fiszman et al. designed a method that generates graphical abstractive summarization based on semantic interpretation of biomedical text [5]. Reeve et al. used the Unified Medical Language System (UMLS) to extract semantically related sentences for summaries [10]. Another method was proposed by Jin et al. to generate gene summaries from Medline abstracts based on the selection of information rich sentences [11]. Agarwal and Yu presented a method to extract figures in the biomedical literature based on a sentence classification system for selection of sentences from the full text [12]. Despite providing a foundation for our research, most prior studies have focused on assisting biomedical researchers, such as in generating new hypothesis. Unlike these studies, our goal is to summarize clinically useful recommendations to assist patient care decision making.

Previous Related Work. In a previous study, we assessed the feasibility of generating knowledge summaries composed of relevant sentences extracted from Medline citations [7]. The system consists of a pipeline that integrates multiple NLP tools and information retrieval resources, including the UMLS Metathesaurus [13] for concept extraction and SemRep for semantic predication extraction [14]. The system achieved a high precision in extracting sentences related to the topic of interest. In the present study, we apply similar methods to extract clinically useful sentences from UpToDate documents.

SemRep. SemRep is a semantic NLP parser that uses underspecified syntactic analysis and structured domain knowledge from the UMLS [14]. SemRep extracts a set of semantic predications that consist of a subject (e.g., a medication), an object (e.g., a condition), and a predicate (e.g., 'TREATS'). Predications extracted by SemRep can be loaded into a relational database for further processing according to the needs of specific applications [15]. An example of a sentence and its SemRep output is listed below in Table 1. Our underlying assumption is that clinically useful treatment sentences generate a higher density of treatment-related predications than other sentences. This assumption served as the basis for designing our algorithm.

Method

The study method consisted of: 1) developing a gold standard composed of UpToDate sentences that were manually annotated regarding their clinical usefulness; 2) processing UpToDate documents with SemRep to generate sentence predications; 3) designing candidate algorithms to identify clinically useful sentences and selecting best candidate algorithms for the evaluation phase; and 4) comparing the performance of the selected algorithms.

Gold Standard. The gold standard consisted of a training set with 5 UpToDate treatment documents and a test set with 12 documents on the treatment of four conditions: coronary artery disease (CAD), hypertension (HT), depression, and heart failure (HF). The 12 documents consisted of the 3 most frequently accessed documents on the treatment of each of the 4 conditions according to UpToDate's usage log. In the gold standard, sentences were annotated according to a 5-point scale that rated the clinical usefulness of sentences. The scale was designed according to previous studies that showed clinician's preferences for patient-specific, objective, and actionable

Table 1. Example of a sentence on the treatment of atrial fibrillation and its SemRep output.

Sentence: "Dronedarone and amiodarone are the only two drugs that can be initiated in outpatients while in atrial fibrillation."

SemRep Output:

Dronedarone TREATS Atrial fibrilation

Amiodarone TREATS Atrial fibrilation

Dronedarone TREATS Outpatients

Amiodarone TREATS Outpatients

recommendations as opposed to study results and background information. Table 2 describes the rating instrument with examples.

Table 2: Clinical usefulness scale and examples of sentences rated in the gold standard.

Level 1: Sentences that are not relevant to the treatment of the condition of interest. Examples include introductory sentences about a document or section. Sentences in this category are very unlikely to be useful and should not be included in a knowledge summary.

Example: "*The initial treatment of patients with moderately to severely active RA [Rheumatoid Arthritis], regardless of duration, will be reviewed here.*"

Level 2: Sentences that provide background information on the treatment of interest. Although these sentences are topically relevant, they do not provide any actionable information. Examples include descriptions of the mechanism of action of a specific treatment and the descriptions of research studies without providing an interpretation or conclusion. Also in this category were sentences describing the results of placebo trials without specifying the characteristics of the trial population. Sentences in this category are unlikely to be useful and should not be included in a knowledge summary, unless a clinician would like to review specific details surrounding a more useful sentence.

Examples*: "The treatment of rheumatoid arthritis (RA) is directed toward the control of synovitis and the prevention of joint injury."*

"For patients with multivessel coronary artery disease (CAD) and proximal LAD disease, most of the randomized trial data evaluating survival come from surgical trials comparing CABG to medical therapy that were performed more than 25 years ago."

Level 3: Sentences that describe potentially useful information, but that is not necessarily actionable. Examples include sentences with treatment alternatives without specifying the specific target population. This category also includes information that may be useful when implementing a specific treatment, such as adverse effects, precautions, and monitoring. Typically these sentences provide support for implementing actionable recommendations that are described in other more clinically useful sentences. Level 3 sentences are not likely to be useful upfront, but may become important once the clinician decides to pursue a specific treatment alternative.

Example*: "We take a number of important precautions before using DMARDs, including laboratory assessment (complete blood count, serum creatinine, aminotransferases, and other studies as indicated), evaluation of comorbidities, vaccinations, and screening for hepatitis C, hepatitis B, and latent tuberculosis infection."*

Level 4: Sentences that describe an objective and actionable recommendation for the treatment of a given condition of interest for a specific target population. Level 4 sentences are clinically useful and should be included in a knowledge summary.

Example*: "We suggest that patients who fail to achieve remission or low disease activity within three to six months of initiating therapy or who require more than approximately 5 to 7.5 mg/day of prednisone or equivalent glucocorticoid chronically to maintain a state of remission or low disease activity receive a more potent DMARD or combination of DMARDs."*

Level 5: Same as Level 4, but explicitly supported by scientific evidence (e.g., evidence grading, reference to treatment guideline).

Examples*: "In patients who fail to achieve remission within three to six months of initiating therapy or who require more than approximately 5 to 7.5 mg/day of prednisone or equivalent glucocorticoid on a chronic basis to maintain a state of remission or low disease activity, we suggest using a more potent DMARD or combination of DMARDs rather than continuing the same treatment regimen for a longer period of time (Grade 2C)"*

"We agree with the 2012 ACCF/AHA/ACP/AATS/PCNA/SCAI/STS guideline for the diagnosis and management of patients with stable ischemic heart disease, which recommends beta blockers as first line therapy to reduce anginal episodes and improve exercise tolerance."

The gold standard and the rating instrument were iteratively developed by three clinicians. First, one document was independently rated by two clinicians (RM, GDF), yielding an inter-rater agreement (linear weighted kappa) of 0.52. Disagreements were reconciled through consensus and the instrument was refined. In the next step a second document was rated independently by the same two clinicians (linear weighted kappa= 0.74) and was further refined. Next, another document was rated by RM and a third clinician who had not been previously exposed to the annotation instrument (linear weighted kappa=0.82). Given the high inter-rater reliability of the instrument, only one clinician (RM) rated the remaining documents.

Processing documents with SemRep. UpToDate documents in the training and test sets were obtained in XML format and then transformed by a script into SemRep's input format. The documents were then submitted to SemRep for batch processing. Last, the SemRep output was loaded into a relational database that was designed in previous research on Medline citations [15].

Designing candidate algorithms and selecting algorithms for final evaluation. Informed by documents in the training set, we designed several algorithm variations for preliminary analysis. The design was guided by manually inspecting sentences and their predications as well as by analyzing the frequency and types of predications generated by useful vs. not useful sentences. Candidate algorithms were then evaluated using the training set. Two algorithms that appeared to perform best were selected for the final evaluation: a *baseline algorithm* and an *alternate algorithm*. Both algorithms were implemented as SQL statements that queried the predication database.

The *baseline algorithm* simply based on the density of predications in a sentence. The higher the number of predications generated by the sentence, the higher the sentence ranking. When two or more sentences had the same number of predications, the sentence that appeared later in the document received preference, since earlier sentences tended to be background sentences.

The *alternate algorithm* was similar to the *baseline algorithm*, except that it excluded from the final output sentences and predications that were less useful for clinical decision making. For this, the algorithm applied the following steps:

1) select predications with a predicate type of 'TREATS', 'ADMINISTERED', 'AFFECTS', 'PREVENTS', 'PROCESS_OF', 'compared_with', 'higher_than', 'lower_than', or 'same_as';

2) exclude sentences that contain one or more of the following predicate types: 'METHOD_OF', 'OCCURS_IN', 'COEXISTS_WITH', 'DISRUPTS', 'AUGMENTS', 'STIMULATES', 'INHIBITS', 'ASSOCIATED_WITH', 'CAUSES', 'LOCATION_OF', 'CAUSES', 'PART_OF', 'COMPLICATES', 'ISA', 'PRODUCES', 'PRECEDES', 'USES';

3) exclude sentences with predications whose subject is "placebo".

Evaluation. The two algorithms selected in the previous step were compared in terms of three outcome measures 1) top 10 precision (primary outcome); 2) average rating of the top 10 sentences; and 3) top 10 recall. Top 10 precision was obtained as the percentage of sentences among the top 10 ranked ones that were rated as Level 4 or 5 sentences in the gold standard. Average rating was obtained by calculating the average of the gold standard ratings for the top 10 sentences. Statistical significance was tested with Student's paired t-test for top 10 precision and recall, and Wilcoxon ranked sum test for the average rating.

Results

Documents in the training set had a total of 1293 sentences. Out of these, 743 (57.5%) sentences generated no predications. The average number of predications for sentences rated as Level 4 and 5 was 1.38 and 1.58 respectively. Other sentences had less than 1 predication on average.

Table 3 provides descriptive statistics for the test set. The 12 documents in the test set had 2833 sentences. Of these, 1623 (57.3%) sentences did not generate any predications. The correlation coefficient between sentence rating and average number of predications was 0.95. Sentences rated as Levels 4 and 5 generated 1.19 and 1.23 predications per sentence respectively, while other sentences generated less than 1 predication on average.

Table 3. Descriptive statistics of sentences in the test set.

Rating	Number of sentences	Sentences with no predication	Average number of predications
1	203 (7%)	173 (85%)	0.21
2	549 (19%)	314 (57%)	0.71
3	1343 (47%)	800 (60%)	0.71
4	654 (23%)	301 (46%)	1.19
5	84 (3%)	35 (42%)	1.23
Overall	2833 (100%)	1623 (57%)	0.8

Table 4 presents the top 10 precision, top 10 recall, and average rating of the top 10 documents for both algorithms. No difference was found between the baseline and alternate algorithms in terms of top 10 precision (53% vs. 49%; p=0.06) and average rating (3.5 vs. 3.4; p=0.4). The alternate algorithm was significantly better than the baseline in terms of top 10 recall (p=0.0002).

*CAD = Coronary artery disease; HT = Hypertension; HF = Heart Failure; †Statistically significant

Discussion

In this study we aimed to develop and assess an algorithm that extracts clinically useful sentences from UpToDate. The ultimate goal is to automatically summarize treatment recommendations to help clinicians meet their patient care information needs. Both algorithms performed reasonably well but further studies are needed to improve the precision of extracted sentences. Using the algorithms designed in our study, about half of the sentences extracted by the algorithms in a knowledge summary would not be clinically useful. The two algorithms had equivalent performance in terms of the primary outcome (top 10 precision). Although the alternate algorithm had better top 10 recall, the absolute difference was only 7%. In addition, clinicians may favor precision over recall given the time constraints in busy clinical settings. Therefore the baseline algorithm may be a better option because it is simpler than the alternate algorithm. Perhaps most important is the finding that clinical usefulness is highly correlated with the number of predications in a sentence.

Although predication density seems to be a strong predictor for identifying clinically useful sentences, other approaches are needed to improve algorithm performance. We conducted an analysis of UpToDate sentences classified as useful vs. not useful in order to better understand their linguistic characteristics and to identify possible future directions. One characteristic that is significantly more prevalent in useful sentences is the use of *deontic modality* [16], particularly, of *obligative* type. This modality type is generally expressed by verbs such as *suggest* and *recommend*. In particular, when such verbs take as subject the first-person plural pronoun ("we"), the sentences that they appear in are generally useful sentences that indicate actionable statements, such as the following: "For patients with heart failure, we suggest amiodarone in preference to dofetilide."

Table 4. Performance of the algorithms on each document of the test set.

	Baseline algorithm			Alternate algorithm		
Document*	Top 10 precision	Average rating	Top 10 recall	Top 10 precision	Average rating	Top 10 recall
CAD1	50%	3.4	23%	30%	2.8	21%
CAD2	90%	3.9	21%	80%	3.9	31%
CAD3	20%	3.2	08%	20%	2.7	20%
Depression1	50%	3.4	11%	40%	3.4	12%
Depression2	40%	3.4	20%	30%	3.1	38%
Depression3	30%	3.1	23%	30%	3.1	33%
HF1	90%	3.9	15%	70%	4.0	19%
HF2	60%	3.7	08%	70%	3.8	14%
HF3	50%	3.5	09%	50%	3.2	17%
HT1	50%	3.4	19%	50%	3.4	31%
HT2	50%	3.4	41%	50%	3.4	50%
HT3	60%	3.5	42%	60%	3.5	46%
Average	53%	3.5	16%	49%	3.4	23%†

Another characteristic of useful sentences seems to be the high level of certainty, or lack of hedging. Hedging is often indicated by modal auxiliaries, such as *may* and *can*. In UpToDate, the use of hedging seems to be correlated with non-useful sentences. A highly speculative statement like the following would not be considered useful in clinical care. “For example, although the atrial myocardium may not be capable of sustaining AF in this setting, it may be able to generate and sustain atrial flutter.”

Statements supported by specific, quantitative evidence are generally characterized as useful. In particular, it is noteworthy that all statements mentioning statistical significance with respect to some finding were deemed useful. On the other hand, statements indicating unspecific evidence are generally considered not useful. For example, in the following sentence hedging expressed with *may* also contributes to characterization of the sentence as not useful “Compared with MTX, there is less information available regarding the long-term safety of biologic DMARDs, and there is some evidence that the risk may be greater with these agents.”

We also analyzed documents that yielded extreme precisions (high and low) to identify characteristics that may have contributed to creating these outliers. For example, the second document on coronary artery disease (90% top 10 precision) contained several evidence-based sentences such as “Angiotensin converting enzyme (ACE) inhibitors and angiotensin receptor blockers (ARBs) decrease cardiovascular mortality in post MI patients with systolic dysfunction and ACE inhibitors in most patients with an acute anterior MI.” On the other hand, the third document on coronary artery disease focused primarily on describing the latest research on the treatment of this condition. For example, the document contained sentences like “A randomized trial comparing PCI with DES to minimally invasive direct coronary artery bypass surgery (MIDCAB) evaluated outcomes in 130 patients with isolated proximal LAD disease.”

Limitations. This study had several limitations. First, although reliable the sentence usefulness scale was not clinically validated. For example, it is unknown whether sentences rated as more useful actually help clinicians’ meet information needs. Second, the evaluation was limited to four conditions and treatment topics, and the study was limited to UpToDate. Thus, it is unknown whether the method can be generalized to other conditions, areas (e.g., diagnosis), and knowledge resources. Our algorithms used no information that is specific to UpToDate. Therefore, the algorithms are likely to generalize to other resources. Third, we did not test whether the retrieved sentences when combined produce a readable summary. Future studies are needed to design and assess summary presentation and readability.

Conclusion and Future work

Our study found that clinically useful sentences were strongly correlated with a higher number of predications. The two algorithms performed equally in terms of top 10 precision, achieving a reasonable top 10 precision (53% and 49%). Although usable, future research is needed to improve algorithm performance. Identifying deontic modality constructions and hedging seem to be promising approaches. Although SemRep is currently unable to identify these meta-predication constructions, work to implement this capability is underway. These topics have also been garnering much interest from the clinical and biomedical NLP communities recently [17, 18], and we plan to enhance our system based on insights from such research. Another potential approach is to employ machine learning sentence classification with SemRep predications as predictors.

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