In search of the right literature search engine(s)

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Abstract

Background

Collecting scientific publications related to a specific topic is crucial for different phases of research, health care and 'effective text mining'. Available bio-literature search engines vary in their ability to scan different sections of articles, for the user-provided search terms and/or phrases. Since a thorough scientific analysis of all major bibliographic tools has not been done, their selection has often remained subjective. We have considered most of the existing bio-literature search engines (http://www.shodhaka.com/startbioinfo/LitSearch.html) and performed an extensive analysis of 18 literature search engines, over a period of about 3 years. Eight different topics were taken and about 50 searches were performed using the selected search engines. The relevance of retrieved citations was carefully assessed after every search, to estimate the citation retrieval efficiency. Different other features of the search tools were also compared using a semi-quantitative method.

Results

The study provides the first tangible comparative account of relative retrieval efficiency, input and output features, resource coverage and a few other utilities of the bio-literature search tools. The results show that using a single search tool can lead to loss of up to 75% relevant citations in some cases. Hence, use of multiple search tools is recommended. But, it would also not be practical to use all or too many search engines. The detailed observations made in the study can assist researchers and health professionals in making a more objective selection among the search engines. A corollary study revealed relative advantages and disadvantages of the full-text scanning tools.

Conclusion

While many studies have attempted to compare literature search engines, important questions remained unanswered till date. Following are some of those questions, along with answers provided by the current study:

a) Which tools should be used to get the maximum number of relevant citations with a reasonable effort? ANSWER: *Using PubMed, Scopus, Google Scholar and HighWire Press individually, and then compiling the hits into a union list is the best option. Citation-Compiler (http://www.shodhaka.com/compiler) can help to compile the results from each of the recommended tool.*

b) What is the approximate percentage of relevant citations expected to be lost if only one search engine is used? ANSWER: *About 39% of the total relevant citations were lost in searches across 4 topics; 49% hits were lost while using PubMed or HighWire Press, while 37% and 20% loss was noticed while using Google Scholar and Scopus, respectively.*

c) Which full text search engines can be recommended in general? ANSWER: *HighWire Press and Google Scholar.*

d) Among the mostly used search engines, which one can be recommended for best precision? ANSWER: *EBIMed.*

e) Among the mostly used search engines, which one can be recommended for best recall? ANSWER: *Depending on the type of query used, best recall could be obtained by HighWire Press or Scopus.*

The current study was initiated in 2007. The responses of some peer-reviewers of different journals have been disappointing and even surprising. We thank the readers of nature precedings whose votes have been a motivation for our continued study of the topic across the recent years.

Introduction and Background

The search for published scientific literature is a very basic, yet crucial component of hypothesis generation, protocol selection, experimental design and interpretation of observations in biology. Even though the significance of literature search has been realised by scientists and health professionals [1-3], comparison of the search engines has not received enough attention. Literature search also has an important role in clinical activities.

In fact, in the current era of '-omics', the identification and collection of all relevant citations is critical to any type of meaningful data mining. For example, one could use information extractors such as iHOP [4] and ARBITER [5] to mine PubMed-citations for obtaining the details of molecular interactions in the context of a specific biological event. But, it is not possible to comment on the extensiveness of the information derived by such programs. This is mainly because we do not know if PubMed can actually retrieve all (or most of) the relevant citations. In fact, a relative account of the retrieval efficiencies has not been established for most of the search engines.

It is not easy to compare all the search engines. The literature search tools vary in multiple aspects, including the databases or other sources used for scanning the published literature, search algorithms employed, query features permitted, display of the output page and the ability to further process/analyze the citations. The current search engines can be broadly categorized into 3 main types: (a) simple summary-scanners, which search for the key words only in the fields of citations (i.e., title, details of the author(s) and journal, and the abstract, if available); (b) full-text scanners, which search the entire main-text of articles for the query terms/phrases; and (c) summary-scanners with information processing capacity, which can automatically process the retrieved citations, organize them in a useful way and/or extract further information. The variations in the users' search objectives also add to the complications in comparing the search programs.

Nevertheless, there is an urgent need to systematically compare these tools. With the increasing number of bio-literature search engines [6-8], scientists and medical professionals often make an arbitrary choice among these search tools. The only other option they have is to deviate from their main research objective, and spend time and effort to multiple features of a plethora of such tools. In this regard, a thorough application-based assessment, preferably a quantitative one, of all bio-literature search engines would help many scientists and physicians. While some studies have compared the search tools from the user's perspective, they have considered very few tools, and often in context to a specific domain [9-17]. Two recent studies [18, 19] have been remarkable in considering a large number of search engines. But no study has still provided data that can help researchers to systematically compare multiple search engines from various perspectives. This also means, the questions which are listed above in the abstract have not been answered:

To find answers to these questions and provide the first time semi-quantitative comparison of most of the tools, we have performed the comparative analyses as described below:

1. Most search engines were considered [8] initially, some of them were excluded for various reasons (details in supplementary notes 1, http://www.shodhaka.com/LitSearch2011), and finally 18 were selected for detailed comparative study.
2. The search programs have been systematically compared under different parameters such as the quality of query, output features, and citation retrieval efficiency.
3. The usefulness of full-text scanners was compared by searching for a specific component in the research-method, which is usually present in the 'methods' section of research reports.

Supplementary notes 1, http://www.shodhaka.com/LitSearch2011 provides URLs of the bibliographic tools considered in this study.

Methods

A. Semi-quantitative comparison of literature search engines:

The features of literature search tools were compared under the following major categories:

i. Query quality: features provided by the tools for designing an effective query.
ii. Output quality: features associated with the display of the results.

iii. Resource coverage: sources, such as databases and web pages that can be scanned by the search engine.

iv. Miscellaneous: other attributes, like the duration for which results can be stored.

v. Search efficiency: the ability of the tool to retrieve the relevant citations.

Specific parameters were identified in each of the first 4 categories (i-iv). A 'relative potential impact' of every parameter on the quality of user's search process and the output, was estimated. Based on this assessment, a 'maximum possible score' for each of the parameters was decided. As an example, a maximum score of 10 was assigned to the 'number of query terms or characters allowed', while the feature allowing 'phrase search' had an upper limit of 3 and 'truncation of key-word' feature was given a maximum score of 1.5. Similarly, the 'history' option such as in PubMed, which could significantly affect the overall search efficiency, was given an upper limit a highest score (12 points) than the feature of enabling the search in natural language (1 point) as in askMEDLINE. Several preliminary searches were performed before arriving at the final 'maximum possible score'.

Search efficiencies (v) or retrieval efficiency of the tools was evaluated in two rounds, based on their precision and recall abilities. The exclusive citations contributed by the tools were also estimated.

Round I.

This round of analysis was performed to assess the basic search features of the tools. Multiple searches were performed using 3 simple sets of query terms corresponding to the following topics: a) RNA binding proteins in the context of transcription initiation; b) Alternative promoters in mice; c) cell death in the context of liver toxicity. Seven of the 18 tools considered interface with PubMed and provide similar results as that of PubMed. Hence, the retrieval efficiencies of these tools were not separately assessed. The query sets were used uniformly across 11 tools, irrespective of their input-page features.

The results of each search were analyzed and the relevance of every citation was assessed (see Supplementary notes 2, http://www.shodhaka.com/LitSearch2011 for details on relevance assessment). The retrieval efficiency of the tools was assessed by two important parameters:

a) Recall, which reflects the number of relevant articles retrieved from the database. A 'Relative Recall Score' (RRS) was calculated by using the ratio of the relevant hits obtained by each tool, to an estimated maximum possible number of relevant citations across the tools.

b) Precision, which indicates the concentration or dilution of relevant articles among the hits obtained. An 'Indicative Precision Score' (IPS), was calculated for each tool by considering the number of relevant hits among the total number of citations retrieved.

Round II.

About 7 tools that performed better (IPS+RRS = 9 or more) in round I were considered for the second round. In this round, we tried to obtain the maximum possible relevant citations, for each topic, from each selected tool. The available query features of the tools were used optimally for designing the best possible query set (examples mentioned below) for every objective. The searches were restricted to recent years. The number of resulting citations was thus minimized in all tools, which in turn facilitated uniform and easy comparisons.

Among many currently active research areas, a few diverse topics were chosen. The familiarity of the authors with different topics also influenced the selection. Following were the topics chosen: a) microRNAs (miRNAs) involved in translational repression that may serve as markers for breast cancer; b) NMR studies on the quadruplex nucleic acid (qDNA) structures in the context of HIV; c) Piwi-interacting RNA (piRNA) occurrence in non-testicular cells/tissues; d) transcription regulation in the context of apoptosis and prostate cancer; e) Chikungunya outbreaks.

One of the 7 tools was not studied further (see results section). Using the above mentioned 5 topics, and 6 tools, a total of 47 individual searches were performed. The ratio of relevant hits to that of the total hits was noted for each search. The relevance determination can vary between individuals, despite the pre-defined criteria. Hence, we repeated many searches to estimate the variations due to individual perceptions as well as the differences in the time of search. The percentage difference was calculated across repetitions for every topic (the average variation was 3.4%; please see Supplementary notes 3, http://www.shodhaka.com/LitSearch2011 Table 1 for details).

In tools like PubMed and Scopus, there is no limitation to the number of query terms that can be employed. Hence, the best query-set was designed after several trial searches, using several key words and phrases in combination with Boolean operators and parentheses. The 'history' option (provided by both the tools) was extremely useful in deriving the optimal query set. However, in case of Google Scholar and HighWire Press, which allow a limited number of query terms, the query had to be split. Hence, multiple searches were carried out, each search with different combinations of synonyms.

The results obtained from multiple searches in such cases were compiled into a non-redundant union list, manually or using Citation-Compiler [20]. This program was also used to create the union list across search tools and extract the citations retrieved exclusively by any tool. The relative contribution of exclusive citations by the search engines was calculated and represented by an 'Indicative Exclusive Contribution Score' (IECS). The details of IPS, RRS and IECS calculations included in the study are given in Supplementary notes 4 (http://www.shodhaka.com/LitSearch2011).

B. Assessing the efficiencies of full-text scanners:

Some of the full-text search engines were compared for their ability to retrieve,

i. protocols of RNA isolation from human testis for microarray experiments, and

ii. some of the most frequently used primer designing software.

In the process, a highly customized query for each of the objective was used. First 100 citations from every tool were analyzed, except for PubMed (see Supplementary notes 5, http://www.shodhaka.com/LitSearch2011 for details).

Majority of the studies were conducted between late 2006 to mid-2008. Periodic evaluations were done to ensure that the results are valid even now (see Supplementary notes 6, http://www.shodhaka.com/LitSearch2011 for details).

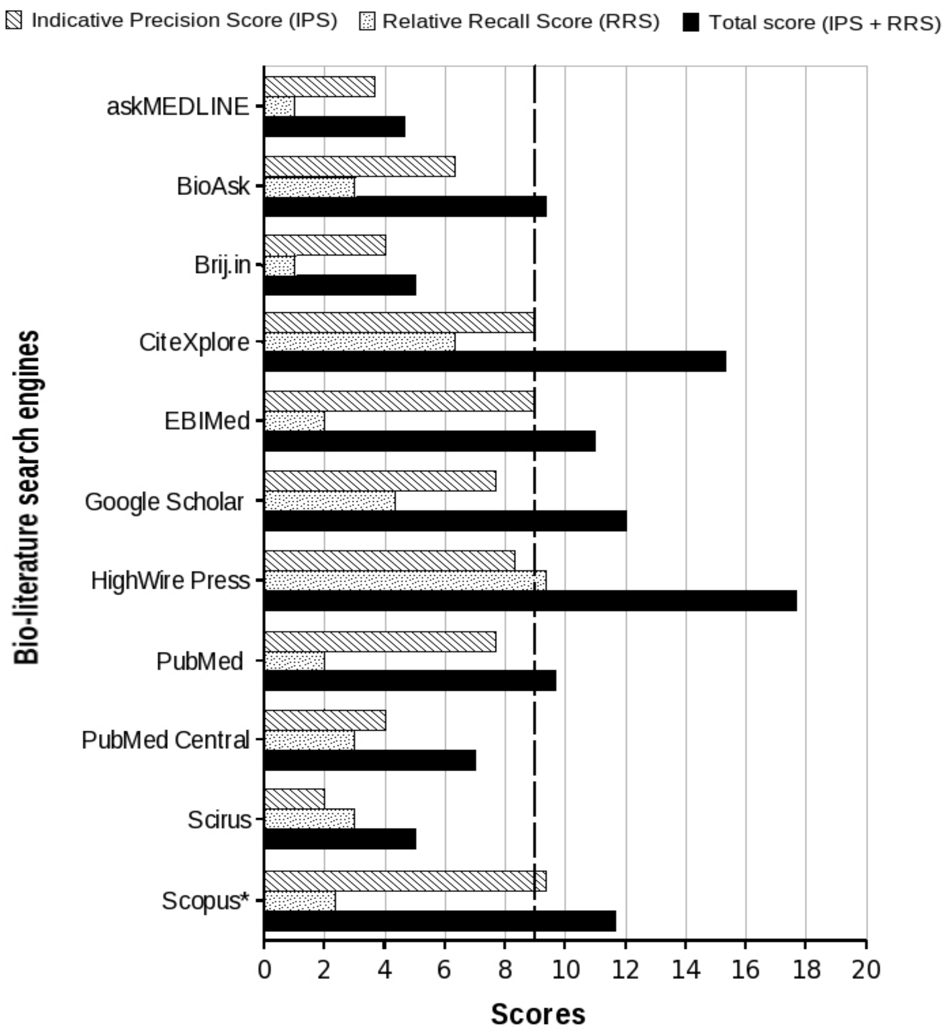
Results

A. Comparison of citation retrieval efficiencies:

Of the 7 better performing tools (see Figure 1), BioAsk could not be analyzed in detail as it was frequently non-functional. The remaining top performers in round I, viz., Google Scholar, PubMed, Scopus, HighWire Press, CiteXplore and EBIMed were taken up for further analysis in round II.

A better precision of a tool can certainly save time for the user while browsing through the results. We could achieve the best precision, in round II, using EBIMed. PubMed was the next best. The other top performers showed significantly lower precision in their results. However, both PubMed and EBIMed showed only moderate recall ability. A better precision with poor recall could mean loss of important citations in the results. Scopus exhibited a relatively higher recall compared to others.

Figure 1



Comparison of indicative precision and relative recall scores of search engines (round I). Most of the tools interfacing directly with PubMed were not separately analyzed as they are very likely to have similar scoring as that of PubMed. A cut-off of 9 was applied for the total scores, which yielded the top seven tools considered in the second round analysis. BioAsk however, was not further analyzed because of its inconsistency in functioning. *A trial version of the paid tool Scopus was used. Supplementary notes 1, http://www.shodhaka.com/LitSearch2011 provides URLs of the bibliographic tools considered.

CiteXplore and EBIMed, despite showing high precision and/or recall efficiency in round I, did not contribute any exclusive hits in round II. Similarly, HighWire Press showed a good balance of precision and recall in both the rounds (Figure 1 and Table 1), but provided less number of exclusive hits. On the contrary, Scopus and Google Scholar retrieved high number of exclusive citations (Table 1).

The detailed results of citation retrieval efficiencies are provided in Supplementary notes 7 http://www.shodhaka.com/LitSearch2011.

Table 1. Results of round II citation retrieval analysis.

Literature search engine →	**PubMed**	**Scopus**	**HighWire Press**	**Google Scholar**
Total number of hits	863	1431	2450	1168
Relevant hits	616	663	1373	256
"May be relevant" hits	122	301	356	223
IPS	**9.2***	**4**	**5**	**3.2**
RRS	**3.8**	**6.4**	**3.8**	**4.2**
Total exclusive hits[1]	17	512	60	601
Exclusive relevant hits	2	37	2	35
Exclusive "may be relevant" hits	10	189	41	125
IECS	**4.5**	**7.8**	**5.3**	**7**

[1]Four of the 5 searches (miRNA, qDNA, piRNA and Chikungunya) were considered to identify the exclusive citations.

IPS: Indicative Precision Score (details in Supplementary notes 7, http://www.shodhaka.com/LitSearch2011 Table 3).

RRS: Relative Recall Score (details in Supplementary notes 7, http://www.shodhaka.com/LitSearch2011 Table 4).

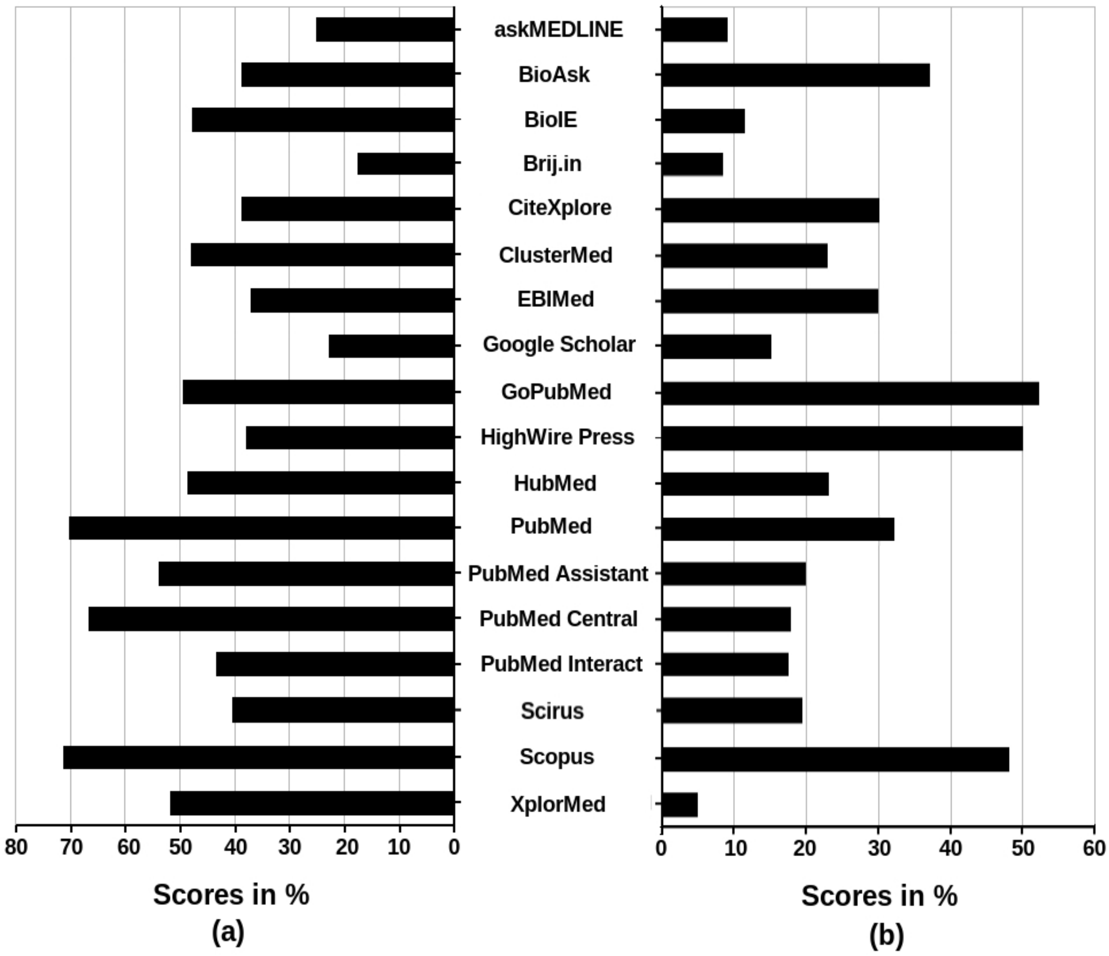
IECS: Indicative Exclusive Contribution Score (details in Supplementary notes 7, http://www.shodhaka.com/LitSearch2011 Table 5).

*The mean IPS of PubMed was significantly ($P < 0.05$) higher than that of Google Scholar, HighWire Press and Scopus respectively. There were no other statistically significant differences in the values of IPS, RRS and IECS across the tools.

B. Comparison of other qualities:

The semi-quantitative procedure used allowed us to make broad comparative assessments. While the summary of results (Figure 2) from such procedures can provide good starting points for further analysis, the details (Supplementary notes 8, http://www.shodhaka.com/LitSearch2011) can provide more useful comparative account of specific features. Since each sub-parameter has been compared on a similar scale and perspectives, the feature comparison can be useful while choosing the tools for various purposes.

Figure 2



Results of the semi-quantitative comparisons of search engines for their query (a), and output (b) qualities. Supplementary notes 1, http://www.shodhaka.com/LitSearch2011 provides URLs of the bibliographic tools considered.

Scopus and PubMed allow the user to create ‘intelligent query sets’ by permitting unlimited query terms/characters, field restrictions etc. PubMed Central can boast of an equivalent query system as well as the full-text scanning ability, but is limited in its coverage of documents. The ‘query-limiting’ categories provided in the output page of Scopus, helps the user to effectively narrow the search, thereby making it one of the best tools in the output analysis section as well. It also provides good ‘citation-tracking’ and ‘journal-analyzing’ options. Scopus, however, showed significant deficiencies in scanning the ‘affiliation’ field of citations.

GoPubMed, HighWire Press and Scopus have more useful 'overall output quality' than the other tools studied. They ranked high due to contributions from different features, which are not necessarily common between them. For example, the visualization features of HighWire Press contributed to its higher scores. On the contrary, GoPubMed's ability to display bio-entities and categorize the results based on MeSH (Medical Subject Headings) and GO (Gene Ontology) [21], as well as its ability to provide the statistical analysis of the results, helped it to score high. Furthermore, the number of hits processed (up to 1,00,000) by this tool, and its speed, are much better compared to other citation-categorizing tools.

Comparison of the coverage feature indicated that Google Scholar and Scopus provide the best coverage of research citations. However, Google Scholar could have a better coverage than Scopus as indicated by our analysis of the journals from which the citations were retrieved exclusively (results not shown) by various tools. PubMed and PubMed Central provided the best options to store the results.

Since many tools have been developed with specific objectives, it is not easy to compare all of them under the 5 broad parameters.

C. Findings of the study on full-text scanners:

The full-text scanning ability (present in Scirus, Google Scholar, HighWire Press and PubMed Central) might boost the retrieval efficiency of the tools. A search for RNA isolation protocols, in a specific context, showed that Google Scholar, HighWire Press and Scirus retrieved 1700, 554 and 2695 hits respectively. Analysis of the first 100 articles of all the three results showed that only 9 in Google Scholar, 8 in HighWire Press and none in Scirus were useful. However, Google Scholar was much more effective than any other tool, when a more specific search was conducted, i.e., to find protocols that used trizol to extract RNA from testis in the context of microarray.

When searching for the most frequently used primer designing software in the recent years, HighWire Press and Google Scholar provided better results than Scirus and PubMed Central. HighWire Press and Google Scholar provided 84% and 64% relevant hits respectively, when searched for citations published during 2007 – 2009. Scirus yielded 60% while PubMed Central retrieved only 22% of relevant hits.

The details of full text search engine comparison are provided in Supplementary notes 9, http://www.shodhaka.com/LitSearch2011.

Discussion

A researcher or a health professional specialized in a specific topic is likely to be in touch with the related literature over several years. In such cases, a choice of only one search engine might seem sufficient. This is because most of them perform literature searches using relevant key words, or with familiar author or journal names. They also extensively scan the articles cited in most relevant reports and reviews, over a long period of time. Such periodic back-reference checks from related articles might compensate for any loss of information during the use of a single search engine. However, researchers have to frequently perform searches in the areas less familiar to them. This is particularly true in the current era of information explosion and systems biology. In such cases, the researchers have to depend heavily on search engines, rather than relying on the back-reference collections, for obtaining relevant citations in a short time.

When limited time is available for searches, the users may like to use only one search engine. For a quick collection of maximum number of relevant citations, HighWire Press may seem to be a good option. It provided best results in the round I of our studies. But, one has to eventually put in time for filtering out the unrelated hits. Hence, it might be difficult to use this tool when the number of hits is very high. In such cases, spending more time for designing the query set and using PubMed can be a better choice as it provides more precise results. Even though EBIMed offers a better precision, it lacks a robust query system, and is often slow. Scopus can be a good choice due to its overall good performance. This commercial tool, however, did not provide reliable results when using certain field restrictions (affiliation and author name) in some cases.

For obtaining hits categorized based on the type of bio-entities within the citations, we recommend GoPubMed, particularly when a user prefers to use only one tool. Similarly, for full-text scanning, Google Scholar and HighWire Press can be preferred over Scirus and PubMed Central, in general.

Scopus and Google Scholar made remarkable contributions to the set of exclusive relevant articles. The coverage and/or full-text scanning ability (in case of Google Scholar) might have been an added advantage [22]. Around 1/5th of the exclusive (relevant) contributions from Google Scholar were non-journal resources (i.e., books, news-articles etc.). Interestingly, PubMed had the potential to retrieve about 50% of the exclusive citations covered by Google Scholar or Scopus, as detected by a retrospective analysis of the results.

But, PubMed failed to retrieve these citations during the intended initial searches. This indicates that Scopus and Google Scholar use a different method to scan the citations for the query terms and/or their equivalents, compared to PubMed. All the exclusive citations retrieved by Scopus could also be retrieved by specific searches in Google Scholar. Google Scholar may not have displayed such citations (as it displays only the first 1000) during the main study.

Our results strongly suggest that no single bibliographic tool can be relied upon for a thorough search of all relevant citations, particularly when searching for information in a novel domain. In fact, the citation retrieval efficiencies of the top-performers in this study varied across topics. For example, in case of ‘transcriptional regulation in the context of apoptosis and prostate cancer’, HighWire Press showed the best recall ability while Google Scholar was lower in the ranked list of tools. However, the scenario was exactly opposite in case of the search conducted on ‘chikungunya’. Hence, the use of multiple search engines would be necessary.

Every user would desire a system that can integrate searches across multiple bibliographic tools. Unfortunately, such a system does not exist as of now. A probable reason for the lack of such a system could be the intellectual property rights associated with the search engines and citations.

Thus, currently, use of multiple search engines might be inevitable. But, as the number of tools used and/or the resulting citations increase, compiling all the citations into one non-redundant union list becomes more laborious. Currently, it is tedious to derive a comprehensive non-redundant list from all the relevant citations from multiple search engines. The main reason for such a setback is that the citations of Google Scholar and HighWire Press cannot be exported at a stretch for further processing. One has to download the hits in instalments of 150 (HighWire Press) or 100 (Google Scholar). Such steps make it extremely difficult to compile results from multiple tools. To some extent, suites such as Citation-Compiler can reduce the efforts in compiling the citations across search engines.

Conclusions

Every tool has different coverage and/or offers certain unique feature(s). In the absence of an ideal search engine, periodic comparative studies are necessary. The first tangible account of the relative strengths and weaknesses of most of the available search engines is provided by the current analysis. This can be used by researchers and health professionals to make a more objective selection of the search engine(s).

Based on the citation retrieval efficiency, particularly the presence of exclusive hits among the results and other general features, four tools can be identified as the overall top-performers in the current study. These tools included two of the full-text scanners (HighWire Press and Google Scholar) and two citation scanners (PubMed and Scopus). Hence, we recommend a search using these four tools, to ensure a collection of maximum number of potentially relevant citations. A few commercial tools or other search engines that could not be included in the current study can also be tried. If time is a constraint (and the goal is to gather maximum relevant citations), HighWire Press, and even PubMed, can be avoided during combinatorial searches, as they contribute significantly less number of exclusive hits (see Supplementary notes 7, http://www.shodhaka.com/LitSearch2011 Table 6). Frequent changes in the features of the existing tools and development of new tools will continue to pose challenges for anyone, trying to compare them. However, majority of search engines have been analyzed here, and it would assist the users in selecting the right tool(s) for a specific purpose. The findings of this study might also make it easier to perform similar studies with the inclusion of the currently excluded search programs and/or topics.

Summary

Despite the vital nature of the literature search process, many scientists are compelled to make a subjective selection among the search engines. This is mainly because a thorough scientific analysis of all the major bibliographic tools has not been done so far.

After surveying all search tools we selected 18 of them for a first round of comparison. Our semi-quantitative comparison of these bio-literature search engines includes 8 different topics and about 50 searches. After every search, the relevance of retrieved citations was carefully assessed to estimate the citation retrieval efficiency of the tools. Our study includes a special analysis of the full-text scanning tools as well. The results show that, use of a single search tool can lead to a loss of up to 70% of the relevant citations in some cases. Hence, use of multiple search tools is recommended. Our results strongly suggest that no single bibliographic tool can be relied upon for a thorough search of all relevant citations, particularly when searching for information in a novel domain. Based on the overall citation retrieval efficiency and contribution of exclusive relevant hits, we recommend the

combinatorial use of Scopus, Google Scholar, HighWire Press and PubMed for a ‘reasonable net retrieval efficiency’. The detailed observations made in the current study, about the relative retrieval efficiency, input and output features, resource coverage and a few other utilities, can assist researchers and healthcare professionals in making a more objective selection among the search engines.

Currently there is no alternative to the semi-quantitative method we employed. The method employed by us, as well as the results of the first large scale comparison, can be useful for many such future studies.

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