The Canadian Journal of Information and Library Science
La Revue canadienne des sciences de l'information et de bibliothéconomie

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La réponse rapide du Canada en matière de recherche à la pandémie COVID-19 : une analyse bibliométrique

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Volume 44, numéro 2-3, 2021

URI : https://id.erudit.org/iderudit/1085236ar
DOI : https://doi.org/10.5206/cjilsrcsib.v44i2.13572

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Éditeur(s)

Canadian Association for Information Science - Association canadienne des sciences de l'information

ISSN

1195-096X (imprimé)
1920-7239 (numérique)

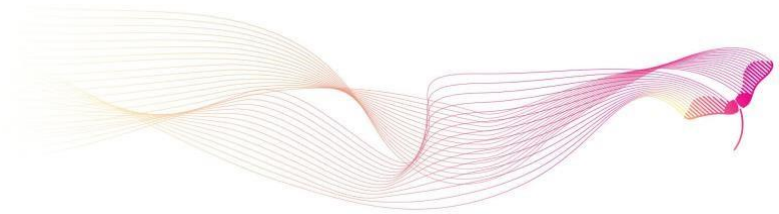
Découvrir la revue

Citer cet article

Stojanovic, V. (2021). Canada's rapid research response to the COVID-19 pandemic: A bibliometric analysis. *The Canadian Journal of Information and Library Science / La Revue canadienne des sciences de l'information et de bibliothéconomie*, *44*(2-3), 50–67. https://doi.org/10.5206/cjilsrcsib.v44i2.13572

Résumé de l'article

Cette étude évalue la nature de la réponse rapide du Canada en matière de recherche par le biais d'une analyse bibliométrique des termes et des mots clés. Elle pose les questions suivantes : Quels sont les principaux domaines de résultats de la recherche rapide menée au Canada au cours des cinq et demi premiers mois de 2020, et comment les résultats de cette analyse peuvent-ils éclairer les prochains efforts de recherche accélérée en vue d'une réponse efficace aux urgences en matière de maladies infectieuses ? Les résultats suggèrent que la prévention des infections, l'épidémiologie, le traitement et les stratégies de santé publique étaient parmi les domaines de recherche les plus actifs au Canada au début de la pandémie. De plus, l'analyse met en relief les lacunes existantes au sein de la littérature concernant le diagnostic et le développement de vaccins.



Canada's rapid research response to the COVID-19 pandemic: A bibliometric analysis

La réponse rapide du Canada en matière de recherche à la pandémie COVID-19 : Une analyse bibliométrique

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Abstract: This study assesses the nature of Canada's rapid research response through term and keyword bibliometric analysis. The following asks: What are the major areas of COVID-19 rapid research output conducted in Canada during the first five and half months of 2020, and how can the results of this analysis inform future accelerated research efforts toward an effective response to infectious disease emergencies? The results suggest that infection prevention, epidemiology, therapeutics, and public health strategies were among the top-producing research areas in Canada during the onset of the pandemic. Moreover, the analysis reflects gaps in the literature addressing diagnostics and vaccine development.

Keywords: Canada, COVID-19, bibliometrics, research output, keyword analysis

Résumé : Cette étude évalue la nature de la réponse rapide du Canada en matière de recherche par le biais d'une analyse bibliométrique des termes et des mots clés. Elle pose les questions suivantes : Quels sont les principaux domaines de résultats de la recherche rapide menée au Canada au cours des cinq et demi premiers mois de 2020, et comment les résultats de cette analyse peuvent-ils éclairer les prochains efforts de recherche accélérée en vue d'une réponse efficace aux urgences en matière de maladies infectieuses ? Les résultats suggèrent que la prévention des infections, l'épidémiologie, le traitement et les stratégies de santé publique étaient parmi les domaines de recherche les plus actifs au Canada au début de la pandémie. De plus, l'analyse met en relief les lacunes existantes au sein de la littérature concernant le diagnostic et le développement de vaccins.

Mots clés : Canada, COVID-19, bibliométrie, production de la recherche, analyse des mots-clés

La Revue canadienne des sciences de l'information et de bibliothéconomie, Vol. 44 (2021), No. 2/3
https://doi.org/10.5206/cjilsrcsib.v44i2.13572

Introduction

When infectious diseases overwhelm healthcare systems, stymie economic sustainability, and create global fear and anxiety, we turn to scientists for answers. Governments and healthcare organizations all over the world have relied on rapid research efforts to quickly understand disease transmission, prevention, diagnostics, and therapies. This reliance has been the case with Ebola, SARS, and the Zika Virus, and now researchers in both academic and private sectors are addressing the COVID-19 pandemic. Although government funding for global health research has declined worldwide over the last decade, the provision of timely resources in support of rapid clinical and public health research remains essential in implementing effective strategies toward the resolution of the current emergency (Hoffman et al. 2020).

The following study assesses the nature of Canada's rapid research response through bibliometric analysis. Bibliometrics are a series of quantitative measures used by universities, funders, and others to assess research outputs in tandem with other tools (such as altmetrics) toward understanding research impact. Common metrics include information such as the number of publications by an individual, citation counts, the h-index, and journal impact factors. Bibliometric analysis typically refers to the exploration, mapping, and visualization of published research landscapes to identify relationships between subject matter, authors, organizations, and citation networks. The methods used in this study and the results obtained only reflect the nature of the research published through traditional scholarly channels such as subscription-based and open access journals. It is important to underscore that bibliometrics as information are valuable for—and limited to—their ability to provide a snapshot of traditionally published research at any given time, providing a quantitative method for understanding research landscapes.

Undoubtedly, there are limitations to collecting data at the onset of the pandemic in relation to the analysis that is performed. However, the following analysis has the potential to provide helpful insights into the research priorities that are producing the quickest results. In this context, rapid research is defined as any COVID-19 related research that was accelerated through the editorial and review processes, thus appearing sooner in publication as a response to the increased needs for evidence in managing the virus and pandemic (Karakose and Demirkol 2021). As such, this study asks: What are the major areas of COVID-19 rapid research conducted in Canada during the first five and a half months of the COVID-19 pandemic, and how can the results of this analysis be used to inform future accelerated research efforts toward an effective response to infectious disease emergencies?

Literature review

There are several bibliometric studies addressing viral infectious diseases on both national and international scales. For example, a broad fifty-year study of worldwide research on the coronavirus by Ram (2020) found that scholarly publications on

coronaviruses had modest growth from the 1960s until 2002. Significant spikes in research activity followed in 2003 and again in 2013 in response to the outbreaks of SARS-CoV and MERS-CoV respectively. The study found that the overall nature of research on coronavirus is associated with virology, the study of viruses themselves. Similar bibliometric analyses on coronavirus have been conducted more recently (Laksham et al. 2020; Mao et al. 2020; Zhai et al. 2020) which, unsurprisingly, show that articles in virology, infectious disease, microbiology, and immunology are most prominent. Internationally, between 2003 and 2020 the highest-occurring article keywords (after "Sever Acute Respiratory Syndrome" and "Coronavirus") include "infection," "protein," and "identification" (Zhai et al. 2020, 9). Moreover, it has been noted that increasing research on spike protein-based vaccines between 2003 and 2020 is a positive indicator toward the creation of effective countermeasures against COVID-19 (Jia et al. 2020; Mao et al. 2020). The results of these studies suggested that collaboration among research institutions and countries—especially the US and China—are critical toward a timely resolution of the pandemic (Jia et al. 2020, 10).

Beyond coronaviruses, bibliometric studies have been conducted on other infectious diseases. For example, Delwiche (2018) provides a focused attention on research output associated with the Zika virus (ZIKV) between 1952 and 2016. Drawing on data extracted from PubMed, the findings of the study indicate that the top subject areas of research included medicine, communicable diseases, public health, epidemiology, science, virology, and microbiology. Delwiche (2018) highlights that 97 percent of the research was conducted between 2012 and 2016, across 80 countries, contending that ZIKV research was a highly collaborative endeavour (125). Similarly, de Oliveira et al. (2020) analyze the global research response to ZIKV during the 2015-2016 outbreak. Based on a total of 6,209 articles extracted from the Web of Science, Scopus, and PubMed, de Oliveira et al. (2020) found that the main research clusters included clinical aspects, diagnosis, epidemiology, entomology (as a mosquito-borne flavivirus), cellular biology, and microbiology (7). One of the most interesting conclusions of this study suggests that research focus and output are dependent upon the level of viral exposure within individual countries and the available funding to support global rapid research efforts (13).

In addition to ZIKV, bibliometric analyses have also been conducted on the Ebola virus (EBOV). For example, Ballabeni and Boggio (2015) evaluated the publications produced in 2014 to explore the scientific response to the Ebola outbreak and, further, how the scientific community might respond to "global threats with massive media coverages" in the future (7). The findings of this study showed that the majority of research published in 2014 on Ebola virus either addressed the West African epidemic or general preparedness (5). With regard to the research output of specific countries during this period, this study also ascertained that the top research foci for Canada included pathophysiology/epidemiology/ecology, followed by drugs/antibodies/vaccines, cell/molecular biology, preparedness, and society/policy/ethics (24, Figure S34).

At the time of the present study's data extraction, a limited number of bibliometric studies have analyzed the scientific research output associated with COVID-19 specifically. Tran et al. (2020) reviewed global trends, corroborating with de Oliveira

et al. that research variations across individual countries are dependent upon funding and the extent of transmission and exposure. By conducting a term and keyword analysis, Tran et al. (2020) discovered three main clusters consisting of themes associated with diagnostics, prevention/medicine/response, and virology. The authors of this study also highlight smaller clusters, noting that "high-income countries (HICs) showed less attention on research in epidemiological characteristics and interventions of psychological disorders" while low to middle level income countries were less interested in diagnostics (9). Overall, the global focus of published research has been on virology, clinical aspects, and epidemiology, with little attention on psychological health and stigmatization research (10-11). The study further suggests that the low quantity of published research on vaccines is likely due to the ongoing clinical development of this work during the early period of response.

A study by Pathak (2020) analyzes the coverage of publications on COVID-19 in India on a national scale to identify key authors, institutes, international collaborations, keywords, and journals. The findings suggest that India is among the top ten countries engaging in COVID-19 collaborative research across 70 countries worldwide. Although the term and keyword analysis in this study does not offer specific insights into key research areas, it does note 22 thematic clusters, suggesting a wide distribution of research undertaken by Indian scientists. As far as it can be discovered, the following bibliometric study is the first of its kind to address the COVID-19 research response in Canada.

Methods

Objectives

The aim of this study was to conduct a bibliometric analysis of scholarly research (i.e., published literature) produced during the first five and half months of 2020 that addresses COVID-19 in any capacity (virus, pandemic, etc.) by Canadian researchers and their global partners funded or hosted by Canadian research organizations. This was achieved by identifying and extracting bibliographic data, visualizing the data to determine thematic research foci, and contextualizing the data within the early pandemic response environment. Additionally, the methods outlined below are intended to provide transparency and reproducibility with the associated data. The analysis itself sought to determine which terms and selected keywords occur with the highest frequency. The results of this study provide insights into rapid research response in Canada which may be of interest to researchers, librarians, and academic institutions. The general Canadian public may also find the results of this study insightful.

Data collection

The data were collected on June 15, 2020 from the Scopus database through searching the default subject fields (Documents, Article title, Abstract, and Keywords). Scopus is a citation index by Elsevier that provides a comprehensive and worldwide coverage of published research in science, technology, medicine, and other related disciplines (Burnham 2006). It is a common source for bibliometric data used among

researchers studying the landscapes of scientific literature. The following search string was constructed based on the most common COVID-19 keywords appearing in the media and in scholarly publications as of June 15; it was used to search Scopus: (covid-19 OR covid19 OR 2019-nCoV OR "novel coronavirus" OR "wuhan virus" OR "china virus"). Additionally, several delimiters were used to narrow the search results. The retrieved records were filtered to include only those published in 2020 and affiliated with a Canadian institution or author. The document type was limited to articles, letters, reviews, notes, and editorials. As is common in bibliometric studies, short surveys, conference papers, and errata were excluded to limit the duplication of records because these record types often appear as, or part of, peer-reviewed articles as well (Tran et al. 2020; Machado-Silva et al. 2019). The language of the search results was not restricted to English only. The resulting records were then exported as a CSV file to capture citation and bibliographical information, as well as abstract, keyword, funding, and other details.

Data analysis

Once exported, the data was analyzed using VOSviewer (version 1.6.15, Centre for Science and Technology Studies, Leiden University, the Netherlands). VOSviewer is a commonly used open-source tool for bibliometric visualization and analysis of scholarly research, largely due to its ease-of-use, powerful computational functionality, and visualization capabilities (de Oliveira et al. 2020; Karakose and Demirkol 2021; Sweileh 2019; Zyoud and Al-Jabi 2020). As a result, VOSviewer excels at mapping bibliometric networks of terms, keywords, journals, authors, organizations, and countries. An abbreviation for 'visualization of similarities,' VOS is a computational method built into the viewer by which "concepts…are located in such a way that the distance between any pair of concepts…reflects their association strength… as accurately as possible" (van Eck et al. 2006, 7). The method and software draw on citations, bibliographic coupling, co-citation, and co-authorship relationships to construct and visualize these networks.

In the present study, co-occurrence networks were created and visualized to identify major thematic research clusters based on term and keyword frequency. The characterization and description of the clusters was conducted manually by reviewing the full text of random samples of the literature to extrapolate overarching clinical and research topics and/or areas. No predetermined criteria were set for reviewing the samples. For the VOSviewer analysis, the thresholds for both term and keyword co-occurrences were set to a minimum of eight occurrences across all documents, with no manual exclusions. VOSviewer automatically filtered and excluded common terms found in titles and abstracts. All keywords meeting the minimum co-occurrence frequency were included. In addition to VOSviewer, Microsoft Excel was used to analyze the data to determine thematic areas of research, for example, by randomly selecting publications for review and to sort through keywords and terms by occurrence frequencies.

Results

Globally, 15,476 documents were published by the top ten most productive countries. Table 1 illustrates that the USA, China, and Italy are positioned as the top three contributors followed by the United Kingdom, India, France, Canada, Germany, Australia, and Spain before any document exclusions. Overall, Canada contributed 4.6% of the published research on COVID-19 during the first five and a half months of 2020 among these countries. This timeline includes two months of research conducted prior to the WHO declaration of a global pandemic (Cucinotta and Vanelli 2020). A total of 699 documents affiliated with Canada were published between January 1 and June 15, 2020 and retrieved based on the selection criteria above, including 345 articles (49.3%), 133 letters (19%), 79 notes (11.3%), 72 (10.3%) reviews, and 70 editorials (10%).

Country	Number of publications	Percentage of contribution
United States of America	4124	26.6
People's Republic of China	3084	19.9
Italy	2079	13.4
United Kingdom	1813	11.7
India	1005	6.4
France	788	5.1
Canada	713	4.6
Germany	648	4.1
Australia	632	4.0
Spain	590	3.8
Total	**15,476**	**99.6**

Table 1: Number of publications and distribution among the top ten most productive countries

Analysis of terms and keywords

Co-occurrence analysis demonstrates "the relatedness of items based on the number of documents in which they occur together" (Mao et al. 2020, 6). Both terms and keywords were analyzed respectively to identifying the major research areas in Canada while also providing an opportunity to highlight where gaps exist. The difference between terms and keywords is the location from which they are extracted from the metadata. Terms are extracted from the titles and abstracts of the retrieved documents, allowing for an analysis of the research content of the published documents themselves. Keywords, on the other hand, are specific tags selected by the author, publisher, or index database (sometimes based on a controlled vocabulary) that aim to describe the general subject matter of each published document. It is necessary to conduct two separate analyses of terms and keywords due to the manner in which the data is organized and extracted, as well as due to the way in which VOSviewer processes this data.

Figure 1 shows the co-occurrence network of *terms* with a minimum of 8 occurrences within each of the analyzed publication titles and abstracts. A total of 143 unique terms were discovered, consisting of 99 links between terms, distributed among 3 main clusters. The terms with the overall highest occurrences include "case" (93),

"care" (94), "outbreak" (91), "coronavirus" (78), and "evidence" (75). The distribution of terms and broad research areas is shown in Table 2. Cluster 1 (yellow) consists of 52 terms largely dealing with patient care, clinical best practices, and prevention strategies. With 49 terms, cluster 2 (red) appears to address the spread of pandemic cases and death rates, detection, and geographic analyses. Cluster 3 (blue) consists of 42 terms mainly about public health strategies (e.g., social distancing, self-isolation), mental health, and forecasting. Figure 2 shows the density of occurring terms and co-occurring links.

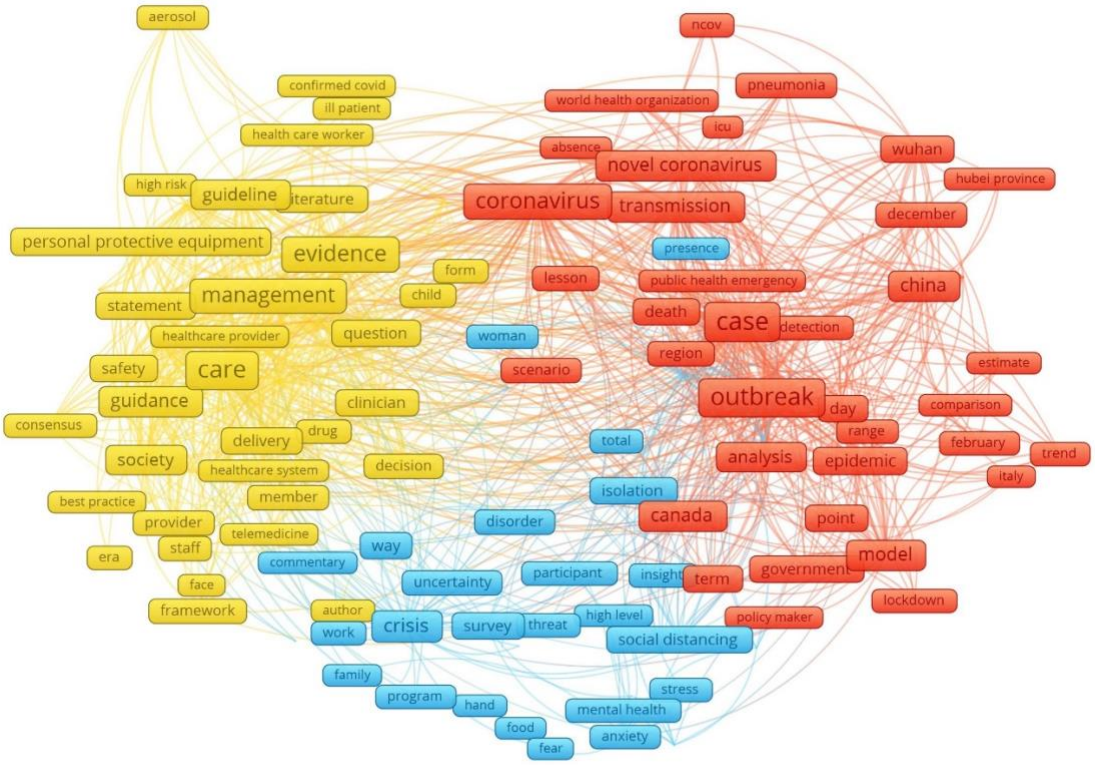

Figure 1: Network visualization of term co-occurrences and links. The network is divided into 3 distinct clusters. The size of each term corresponds to the number of occurrences of the term; the larger words occur more, the smaller, less. The proximity of a term to another term corresponds to the extent of co-occurrences of terms; the closer the terms are to each other, the more they occur together in the published record.

Cluster	Number of terms	Top 10 occurring terms	Approximate research areas
1	52	Care; evidence; management; recommendation; therapy; consideration; guidance; guideline; practice; society.	Patient care; mitigation and prevention strategies.
2	49	Case; outbreak; coronavirus; rate; Canada; China; transmission; model; novel coronavirus; analysis.	Pandemic spread; detection; country and regional analyses.

3	42	Crisis; symptom; way; social distancing; isolation; survey; difference; disorder; home; action.	Public health strategies; mental health.

Table 2: Summary of term cluster characteristics

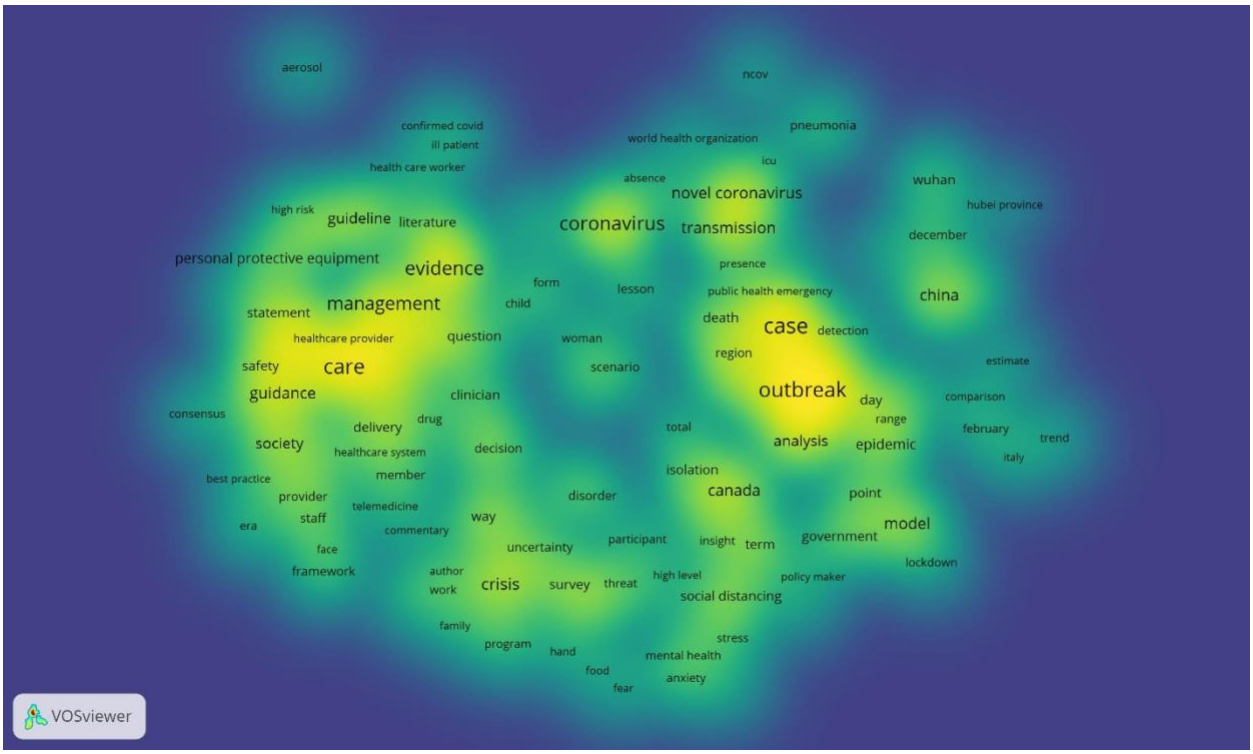

Figure 2: Density visualization of term co-occurrence concentrations. Bright yellow areas indicate a high density of occurring terms and co-occurring links.

Following the term analysis, a *keyword* analysis identified 157 assigned words or short phrases with a minimum of 8 occurrences from the obtained published literature. Figure 3 illustrates the co-occurrence network of these keywords consisting of 7,414 links, generating four main and one minor cluster. Unsurprisingly, the overall most frequent keywords are "covid-19" (266 times), "human" (258 times), "pandemic" (222 times), "coronavirus disease 2019" (211 times), and "coronavirus infection" (168 times). Table 3 shows the distribution of keywords and possible associated research areas for the clusters. Keywords describing document type (e.g., review, note, etc.) appear in the data and co-occurrence network, but were excluded in the table to highlight major research foci. Cluster 1 (yellow) consists of 45 keywords that largely address clinical practices and management, therapeutics, and prevention. Cluster 2 (red) presents 42 keywords with themes reflecting public health strategies, social dynamics, and government policy. The third cluster (blue) consists of 40 keywords largely describing research in epidemiology, virology, veterinary science, and global health. Cluster 4 (green) shows 25 keywords but is somewhat difficult to categorize because of its central position amid the clusters, reflecting a possible strong intersection of research in this area. Broadly, cluster 4 describes research dealing with infection control, patient care, and protection which are closely related to the previous three clusters. Finally, with only 5 associated keywords, cluster 5 (purple) may point to emerging research in

diagnostics, however there is a lack of data to effectively characterize this area of research.

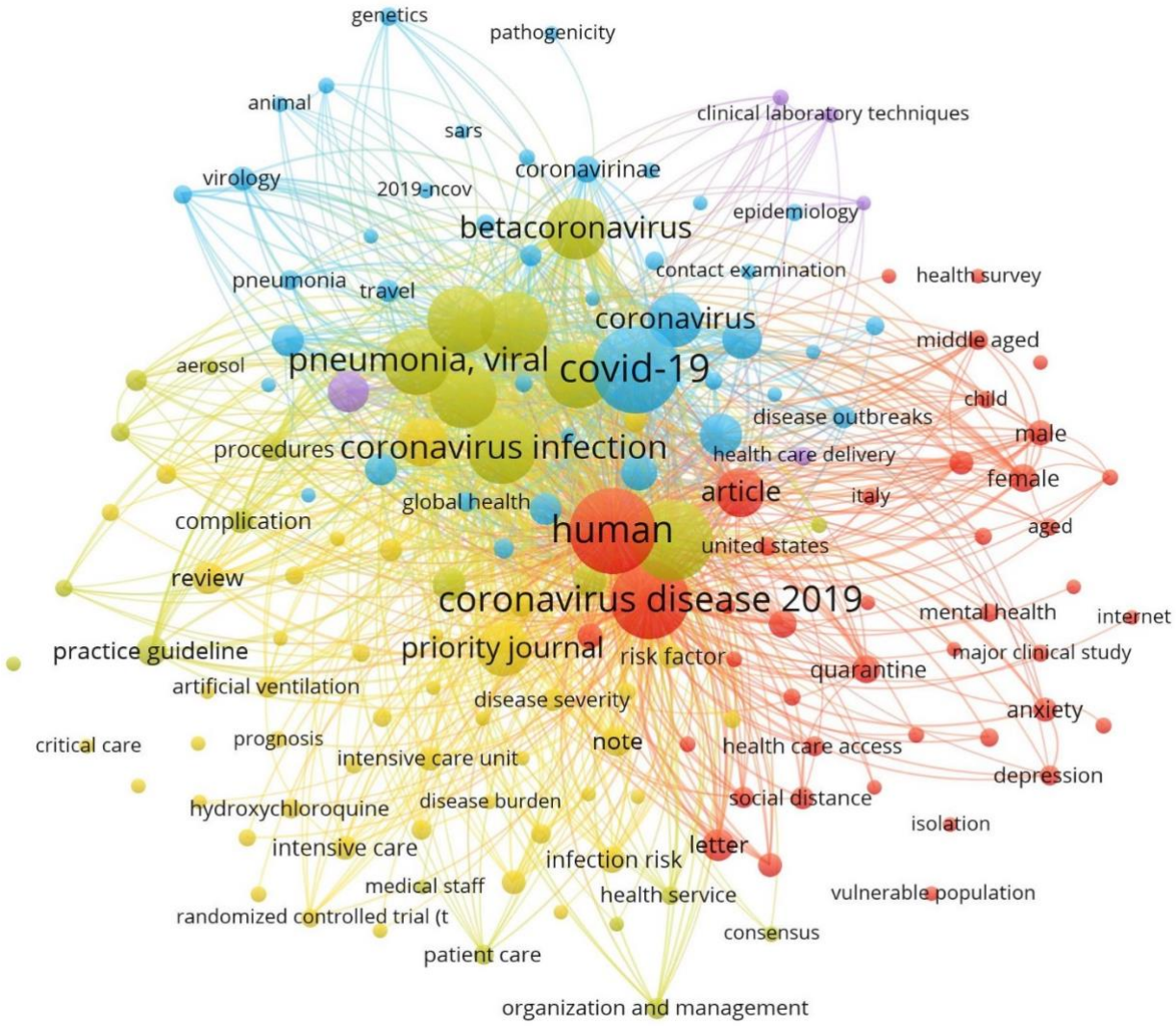

Figure 3: Network visualization of keyword co-occurrences and links. The network is divided into 5 clusters. The size of each keyword corresponds to the number of occurrences of the keyword; the larger words occur more, the smaller, less. The proximity of a keyword to another keyword corresponds to the extent of co-occurrences of keywords; the closer the keywords are to each other, the more they occur together in the published record.

Cluster	Number of terms	Top occurring keywords	Approximate research areas
1	45	Severe acute respiratory syndrome coronavirus 2; infection risk; risk factor; health care system; intensive care; intensive care unit; disease severity; mortality; severe acute respiratory syndrome; artificial ventilation.	Clinical practices and management; therapeutics; prevention

2	42	Human; coronavirus disease 2019; Canada; quarantine; female; infection prevention; male; anxiety; adult; telemedicine.	Public health strategies; social dynamics; policy
3	40	Covid-19; coronavirus; epidemic; public health; China; nonhuman; disease transmission; virus transmission; coronavirinae; virology.	Epidemiology; virology; veterinary sciences
4	25	Pandemic; coronavirus infection; virus pneumonia; coronavirus infections; pneumonia, viral; pandemics; humans; betacoronavirus; health care personnel; infection control.	Infection control; patient care; protection
5	5	Sars-cov-2; health care delivery; clinical laboratory techniques; laboratory techniques; immunology.	Limited data. Potentially referring to diagnostics

Table 3: Summary of keyword cluster characteristics

Discussion

This study highlights the major research areas that have been supported by Canada in its response to the COVID-19 virus and pandemic during the first five and a half months of 2020. Through visualized bibliometric analyses, the data suggests that research in patient care, clinical management, mitigation, prevention, and therapeutics have been the top-producing areas of scholarly output. In addition, research on public health strategies, epidemiology, virology, and infection control have also been produced. Contrary to Tran et al. (2020) who concluded that mental/behavioural health research has been stagnant worldwide between December 2019 and April 2020, this study shows that it has been an important focus of Canadian rapid research efforts. Moreover, the results also reveal gaps in the published literature, including research in diagnostics and vaccine development. The following discussion contextualizes the findings and the gaps, exploring how these results might inform future rapid research efforts toward an effective response to international infectious disease emergencies.

Canadian research output

On March 11, 2020, the World Health Organization (WHO) officially declared COVID-19 a global pandemic. On the same day, the Federal Government of Canada announced that $275 million would be dedicated to rapid research. Funding competitions resulted in 99 successful grants with an initial investment of $54.2 million as of March 31, 2020 (Government of Canada 2020b). As a major funder of COVID-19 rapid research, the Federal Government prioritized two broad research categories aligned with WHO priorities (Government of Canada 2020b; World Health Organization 2020). The first category included medical countermeasures and consists of diagnostics, vaccines, therapeutics, clinical management, transmission dynamics, and animal host modeling. The second category covered social and policy countermeasures, including the study of the public health response and its impact, social dynamics, communication, trust, as well as coordination, governance, and logistics. Although the federal government is not the only funder of COVID-19 scientific research in Canada, the results of this study are closely aligned with the number of studies funded by the government for each of these areas of research. For example, the top three funded

categories were therapeutics (17 studies), diagnostics (13), and transmission/modelling (epidemiology) (11).

The results of this bibliometric analysis demonstrate that mental health research was a key area of concern during the first five and a half months of 2020 leading into the COVID-19 pandemic. Although international efforts have accelerated in this area of research, Canada has demonstrated very active efforts in addressing mental health issues. For example, upon the official declaration of the pandemic, the Institute of Neurosciences, Mental Health and Addiction (INMHA) struck the COVID-19 and Mental Health (CMH) Initiative which was granted approximately $10 million in support of a knowledge synthesis for anticipated research (Canadian Institutes of Health Research 2020). This study's findings stand in contrast to other studies that have highlighted a lack of international research overall during past and current infectious disease events on sleep, anxiety, depression, distress, and trauma, just to name a few (Mukhtar 2020; Tran et al. 2020). The implementation of extraordinary measures such as physical distancing, self-isolation, quarantine, and increasing social and political tensions worldwide have undoubtedly prompted increased research on mental health by Canadian researchers (Brooks et al. 2020; Cameron et al. 2020; Dalexis and Cénat 2020).

Diagnostics research

Despite significant funding from the Canadian federal government, this study indicates that published research in diagnostics did not emerge as a significant cluster of output during the first five and a half months of 2020. This is not to say that no research has been conducted on diagnostics, rather, during the initial months of 2020 (or two and a half months since grants were awarded) there was a paucity of published scholarly output. There are several reasons as to why this might be the case. For example, there can be operational challenges to collecting samples of the virus in point-of-care settings, including the timely establishment of protective and collection protocols deployed by front line workers. In addition, a lack of time, human resources, appropriate and cost-effective shipping of samples, as well as privacy and permission protocols for sharing samples and their associated data only add to the difficulty of conducting diagnostics research within the first months of an outbreak (Koopmans et al. 2019).

There are also significant logistical difficulties in accessing and recruiting laboratory support to process the samples once they are collected, not to mention the importance of establishing effective quality control points, sometimes consisting of panels of clinical professionals (Koopmans et al. 2019). Moreover, within the context of the 2014-2016 Ebola outbreak, Pollock and Wonderly (2017) pointed to the lack of clarity regarding which authorities (either governmental or non-governmental) which were responsible for overseeing the different stages of diagnostics development. Additionally, questions about the ownership of diagnostic data are a key consideration and obstacle to conducting clinical research and publishing the results quickly (Pollock and Wonderly 2017). In previous infectious disease events, the cumulation of these challenges has led to delays in effective diagnostics deployment, inaccuracies in

reporting, and redundancies due to missed opportunities to collaborate on both national and international scales. Pollock and Wonderly (2017) suggest that in an effort to increase diagnostics research and streamline the process during outbreaks, the international community should develop shared evaluative templates and pre-determined standards for formal and informal approval processes (e.g., regarding ethics, data sharing, data ownership, etc.). Additionally, rapid research and diagnostics development for a global event is an international responsibility and as such it is also recommended that collaborations between global leaders (e.g., WHO, CDC/FDA) be strengthened and transparency of processes and data be increased (Pollock and Wonderly 2017). The results of the bibliometric study at hand potentially indicate that these recommendations have not yet been implemented to their fullest extent toward truly rapid research results in diagnostics. As more information has developed about COVID-19, publications addressing diagnostics have followed, especially after the initial periods of testing were completed.

Vaccine research

In addition to diagnostics, there is also a gap with regard to publications dealing with vaccine development during the first five and a half months of 2020. This gap is clearly reflected in the initial round of grants awarded by the Canadian government which total 6 grants out of 99, thus representing one of the least-funded areas of research by the Canadian government during the onset of the pandemic. The modest investment of $5,062,762 out of $54,232,128 in vaccine development may reflect federal policy issues around a reluctance to collaborate with pharmaceutical and biotechnology companies, instead opting to work with other research sectors such as universities and healthcare institutions with limited capacities (Blanchfield 2020). In addition to the funding, there have also been some political tensions between Canada and international collaborators such as China around the imprisonment of nationals (on both sides) and as such may have resulted in delays in the shipment of vaccine-related technologies and samples (Blanchfield 2020).

Moreover, a recent study found that vaccine research for COVID-19 has been strong in countries which were worst affected during the initial global outbreak, including China, the United Kingdom, and the United States (Radanliev, De Roure, and Walton 2020). This relationship between research output and highly affected countries suggests that the lack of vaccine-related research in Canada during the first five and a half months of 2020 is—at least in part—due to the low-impact of the virus in Canada until confirmed cases began to steadily increase in April 2020 and significantly spike in May ("Canada: WHO Coronavirus Disease (COVID-19) Dashboard" 2020). Subsequently, however, Canadian Prime Minister Justin Trudeau announced an additional allocation of $23 million toward the Vaccine and Infectious Disease Organization-International Vaccine Centre (VIDO-InterVac) "to accelerate development of a vaccine against COVID-19" (Federal Government of Canada 2020). While there has been some progress toward Canadian-based vaccine research, this study provides bibliometric evidence demonstrating that the Canadian response in this area of research was slow at the beginning of the pandemic. This evidence can be used to support the planning and

mobilization of national response strategies during future pandemics or other infectious disease events effecting Canada. More specifically, the results of this study may prove useful in demonstrating the importance of establishing stronger relationships with national pharmaceutical companies to better accelerate vaccine development to mitigate the impact of consecutive waves of transmission.

The global context

When it comes to global health research in general, Hoffman et al. (2020) have shown that Canada is focused on two main areas: public health and infectious diseases. Unsurprisingly, these priorities are aligned with the World Health Organization (WHO) and its increased effort in developing a global network of laboratories to better support rapid research during outbreaks (Singh 2004). For example, Singh (2004) addresses the mechanisms that were developed in response to SARS in 2003, highlighting that the Canadian research response displayed a "brand of teamwork [that] must also be taken up internationally, as only a cohesive international response will have an impact against newly emerging disease" (169). This international response and level of preparedness has been supported by the development of research assessment methods, such as the Rapid Research Needs Appraisal (RRNA) which was designed and piloted by Sigfrid (2019) and an international team of scientists. The RRNA pilot showed that an accelerated research appraisal could be achieved in 5 days with the appropriate training and expertise. The rapid research response and ensuing federal funding during the COVID-19 pandemic is a result of similar assessment protocols deployed to determine key areas of research focus for Canada within five days (Government of Canada 2020a).

Similar to diagnostics and vaccine research, there are a number of challenges to effective collaborative rapid research strategies. Recently, Sigrid et al. (2020) conducted a scoping review of specific challenges for clinical research responses to emerging epidemics and pandemics. The study explored the political, economic, administrative, regulatory, logistical, ethical, and social aspects that pose the greatest obstacles to timely and effective research outputs during the early stages of emerging diseases (Sigfrid et al. 2020). The results of the scoping review suggest that lessons learned from past responses such as the H1N1 influenza pandemic in 2009 and Ebola in 2014-2016 have not been fully implemented by the global community (Sigfrid et al. 2020). Furthermore, one of the biggest challenges is designated protocols for redirecting funding during rapid response periods. Singh (2004) also points to funding challenges, specifically, agile mechanisms that efficiently mobilize both availability and allocation. To this last point Hoffman et al. (2020) have noted that "Canada has not been immune to funding challenges," but that historically—and unsurprisingly—funding does increase during significant global outbreaks (82).

There are many other national and international challenges toward effect rapid response. For example, Brett-Major et al. (2020) highlight the importance of striking ethics and investigative committees in an effort to provide opportunities to identify challenges posed against risk management beyond the development of a vaccine. Moreover, as it has been mentioned regarding diagnostics above, rapid research initiatives also face operational challenges that include the collection of standardized

data from participating organizations worldwide, identifying scholarly journals that could published results in a timely manner, and managing pre-existing research efforts that could delay authors' ability to finalize manuscripts (Hurtado et al. 2018). Such challenges could be alleviated by extending collaborative efforts to industry partners. For example, Veletanlić and Sá (2020) have recently discussed the effectiveness of government programs for university-industry partnerships and their impact on national research efforts, while the aforementioned Sigfrid et al. (2004) echo the recommendations by Pollock and Wonderly (2017) who suggest the implementation of pre-determined protocols for assessing and disseminating research with global partners. Ultimately, this study highlights the major research areas that produced published results by Canadian scholars, institutions, and organizations as members of a global team of scientists and researchers working toward the effective resolution of the COVID-19 pandemic.

Limitations

This study possesses some limitations. First, the data were drawn from a single database (Scopus) and therefore does not present a comprehensive analysis of all published literature addressing COVID-19 affiliated with Canada. However, the results are intended to be generally representative of the nature of the rapid research response by identifying broad areas of focus, rather than determining the full extent of the published literature. Second, although VOSviewer is an effective visualization tool to represent relationships within a research landscape, the tool is limited in its ability to represent nuances, details, and complexities of the research literature. It is important to emphasize that though VOSviewer is commonly used in bibliometric studies, the results should be considered in tandem with other studies that engage in varied forms of data extraction and analysis to faithfully understand the extent and impact of research in any given field. Third, authors, organizations, journals, co-authorship networks, and co-citation networks were not analyzed and their inclusion may offer additional insight beyond the terms and keywords analyzed in this study. Finally, further research should address the global context of Canada's rapid response efforts as a member of the international scientific community. Ultimately, the data and results of this study capture a short window of time from the beginning of 2020.

Conclusion

This study aimed to identify the key areas of rapid research response in Canada to the COVID-19 pandemic. The mapping of terms and keywords suggests that prevention, the spread of infection, therapeutics, and public health strategies are among the most productive areas of research. The data has also shown significant knowledge production in virology, epidemiology, and mental health research. Furthermore, the findings highlight potential gaps that exist in the literature during this period, specifically diagnostics and vaccine development. In this light, the full implications of analyzing Canada's rapid research response to the COVID-19 pandemic are still in flux. From assessing research priorities, determining funding availability and

allocation, and mobilizing collaborative research efforts, the results of this study could aid to identify future strategies toward a global resolution of infectious diseases events. Recommended strategies include internationally established templates and protocols for diagnostics and testing processes, greater collaboration between the Canadian federal government and national pharmaceutical companies and strengthened capacities for international collaboration with clear funding and approval guidelines. This study relied on bibliometric and visual analyses methods to determine Canada's research output during the first five and a half months of 2020. It is hoped that the results can help not only the research community but also the general public to better understand how Canada has responded during the initial months of the COVID-19 pandemic.

Acknowledgements

This study had its origins in Dr. Heather Hill's MLIS course "Information in Disasters and Pandemics." I am grateful for the invaluable feedback and encouragement of Dr. Hill, Sam Vander Kooy, and my classmates.

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