Visualizing the Intellectual Structure of Electronic Health Research: A Bibliometric Analysis

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Abstract. The aim of this study is to detect the evolutionary track of the electronic health from its birth to the present, and then analyze its foundational knowledge and research hotspots. We conducted a bibliometric analysis on the 3085 literatures data collected from the Web of Science core data collection in 1992–2017. We used several bibliometric tools such as CiteSpace and Netdraw to complete time-and-space analysis and keywords co-occurrence network analysis. This research can provide important academic reference for international electronic health and medical informatics researchers.

Keywords: Electronic health · Medical informatics · Information technology Bibliometrics

1 Introduction

Based on information technologies and the fields of biomedical engineering and healthcare, e-health aims at providing collaborative healthcare services, integrating regional health resources, sharing and delivering medical information [1]. In the past 20 years, due to the significant breakthroughs in medical information construction around the world, electronic health represented by HIS, PACIS, and telemedicine has prospered. The widespread use of HIS, PACIS, etc. in hospitals has produced health big data represented by *EHR* (Electronic Health Records) and *EMR* (Electronic Medical Records) [2], which provide an important basis for disease diagnosis, health care and disease decision-making.

In recent years, the research and application of emerging information technologies such as artificial intelligence, cloud computing, Internet of things and wearable devices in the field of healthcare has expanded the content of electronic health. Mobile platforms use artificial intelligence, deep learning, advanced statistics and other technologies to dig up health changes in complex health big data, analyze the relationship between health changes and behavior, monitor outliers, and propose health promotion programmes. In this context, mobile health and smart health emerge as the important

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part of constructing smart city. Electronic health has ushered in an unprecedented historical development opportunity, attracting more and more researchers around the world to carry out related research. For example, Heidi et al. conducted an 8-week telebehavioral therapy program on 466 diabetic patients. The results showed that telehealth intervention elevated patients' depression, anxiety, and improved the frequency of blood glucose self-test [3]. Kathryn et al. studied existing mobile applications targeted toward reproductive endocrinology and infertility service providers [4]. Wang et al. systematically analyzed 16 studies about long-term health interventions for chronic diseases use smartphone. These studies found that the smartphone intervention was a completely effective tool to assist in managing some chronic diseases [5]. Yang et al. used bibliometrics to analyze the telemedicine articles published in the SCI–Expanded database from 1993 to 2012 [6].

Above studies have studied some hot issues in e-health from different perspectives, however it is difficult to meet the expectations of researchers in this field. In order to show the evolution process and identify the research hot spots of global knowledge in e-health, we conducted a series of bibliometric analyses on the retrieved 3085 literatures in 1992–2017 from the Web of Science database. The future research trends of e-health are discussed using visual analysis combined with systematic analysis. It will provide knowledge support for domestic and foreign research scholars to carry out research in related fields.

2 Methodology

2.1 Data Source

This article used SCI-E, SSCI, A&HCI, CPCI-S, CPCI-SSH, ESCI, CCR-E, and IC in Web of Science as data sources. We used advanced search methods, search #1 AND #2 AND #3, where #1 is TS = (health* OR "health management" OR "health service*" OR "medic*" OR #) (# represents 6 related keywords in the field of health), #2 is TS = ("Internet of things" OR "cloud computing" OR "information technology*" OR "information system*" OR ##) (## represents 7 related keywords about emerging technologies) and #3 is TS = ("electronic health" OR "e-health" OR "digital healthcare" OR "telemedic*" OR ###) (### represents 6 keywords that emerged after new information technologies applied to the healthcare field). The literature type was selected as "Article", search period was 1992–2017, and the retrieval time was January 18, 2018. A total of 3085 literature data were collected.

2.2 Method and Data Analysis Tools

Bibliometrics is an interdisciplinary that utilizes mathematics, statistics, and bibliography to analyze academic literature quantitatively [7]. Scientific literature is one of the manifestations of scientific research achievements, which can reveal related research in a comprehensive and concrete way. For data statistics and visualization analysis, we comprehensively used CiteSpace, SATI3.2, UCINET and NETDRAW.

CiteSpace is a visualization software based on JAVA language and developed by Chen Chaomei, a Chinese scholar at Drexel University in the United States. CiteSpace is mainly based on co-citation analysis and path finding network algorithm (PFNET) to calculate specific domain literature to explore the critical evolution path and knowledge turning point of subject [8].

SATI was jointly developed by Liu Qiyuan and Ye Ying of Zhejiang University. It has four major functions: title format conversion, information extraction, word frequency statistics, and knowledge matrix construction [9]. After obtain the high-frequency keyword co-occurrence matrix, we used UCINET and NetDraw to draw the keyword co-occurrence network. Then the relationship among individual keywords can be visualized, which is convenient for analysis.

3 E-Health Knowledge Map of Time-and-Space Analysis

3.1 Time Distribution Map of the Published Literature Number

In order to examine the research outcomes in the health and medical fields under emerging information technology, this paper used CiteSpace to count literature amount from 1992 to 2017 and obtains the literature's quantity change yearly, as shown in Fig. 1.

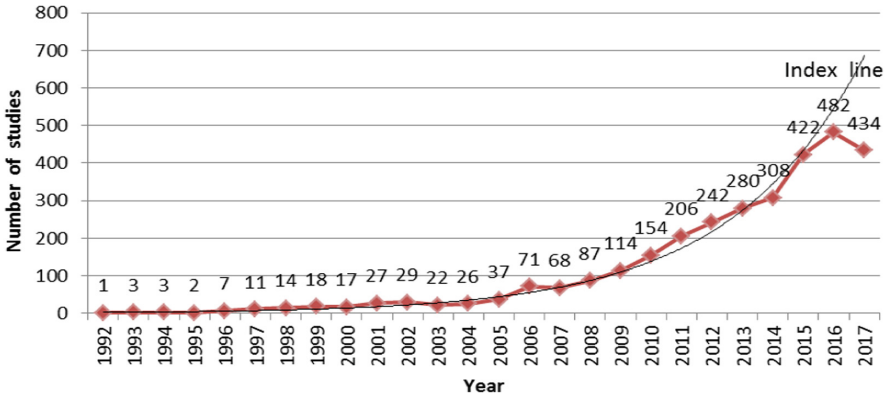

Fig. 1. Annual number of published articles.

The first article about e-health first began in 1992. The article titled "Current Status of Image Save and Carry (IS-AND-C) Standardization" was published in the journal named COMPUTER METHODS AND PROGRAMS IN BIOMEDICINE. It was also the first paper referring to electronic health and medical records. It was mainly about the image preservation and carrying plans for the transmission and exchange of medical information from different medical devices or medical institutions [10]. Since 2001, the number of scientific literature in the field of electronic health has increased significantly, and the number of relevant research scholars has also increased to 71.

The European commission's proposal for the "Electronic European Action Plan 2002" draft, which emphasized the importance of online medical, has effectively promoted scholars' research on telemedicine and electronic medical records at that time. With the introduction of cloud computing in 2006, the development of big data processing technologies and the improvement of residents' living quality, people have new pursuits for their own health management, and relevant scientific literature also shows an increasing trend year by year. For 2017, which has just ended, some documents may still be reviewed and not included in the Web of Science database. Thus the literature amount of 2017 is relatively less. According to the index trend line, the literature number after 2017 will still maintain a high growth rate. It can be seen that since the beginning of this century, internationally electronic health research has been developing vigorously.

In general, the annual input amount trend of authors in the field of electronic health is consistent with the change trend of the scientific literature number, which is roughly an exponential increase. The number of relevant authors in 2006 was 216. By the year 2016, the number of authors has grown to 2166, and the number of authors has turned 10 times in ten years. With the widely application of emerging technologies in telemedicine and mobile health as well as economic development and improvement of living standards in the past decade, the government is paying more attention to the national healthcare. Residents' demands for health have also shifted from being "disease-seeking" to full-life-cycle health. It can be seen that under the attention of all walks of life, the authors of e-health management research have become more and more involved. Corresponding e-health research achievements have also appeared one after another.

3.2 Spatial Distribution of Electronic Health Research

We used CiteSpace to visually analyze the spatial distribution of electronic health literature, and then obtained the knowledge distribution and cooperation networks among different authors, different countries/regions, and different institutions. Research cooperation is an important way to enhance the overall research strength, share knowledge, and complement research resources advantages [11].

3.2.1 Authors' Cooperative Relationship Network

The core authors group refers to the cluster of authors who have a large number of publications and a large influence in the subject area. According to the Price's law which uses to measure the literature authors distribution in specific subject area, $M = 0.749(NMax)/2$, where NMax refers to the papers number of the author who has the most publications, and the scholars with published papers number above M are the core authors in this field [12]. Based on the literature statistical analysis tool Hiscite, it shows that the author with the most publications is Sittig DF (with 50 articles) i.e. $NMax = 50$. According to Price law, $M = 18.7$, indicating that the authors with over 19 articles are the core authors in electronic health field, a total of 7 scholars. Table 1 reports the core authors and their cited information in the field of electronic health. The distribution of core authors is relatively concentrated, and they are mainly divided into two cooperation networks with Sittig DF as the core and Menachemi N as the core.

Most links of the authors' cooperation relationship are in warm colors, indicating that the core authors are closely collaborating.

Table 1. Core authors with high production of published papers

Author	Recs	TLCS	TGCS
Sittig DF	50	141	616
Bates DW	42	218	1123
Kaushal R	34	139	511
Singh H	33	97	445
Wright A	29	108	528
Jha AK	23	457	1779
Menachemi N	23	116	323

3.2.2 National/Regional Distribution and Cooperation Network

The distribution of knowledge possession and cooperation network for e-health research in different countries/regions is shown in Fig. 2. The size of the circles indicates the literature amount, and the different colors of circles and lines represent different years of publication. There are a total of 90 countries/regions in the map, and there are a total of 285 cooperative links between countries/regions. In general, in the field of electronic health, cooperation between countries/regions is very close.

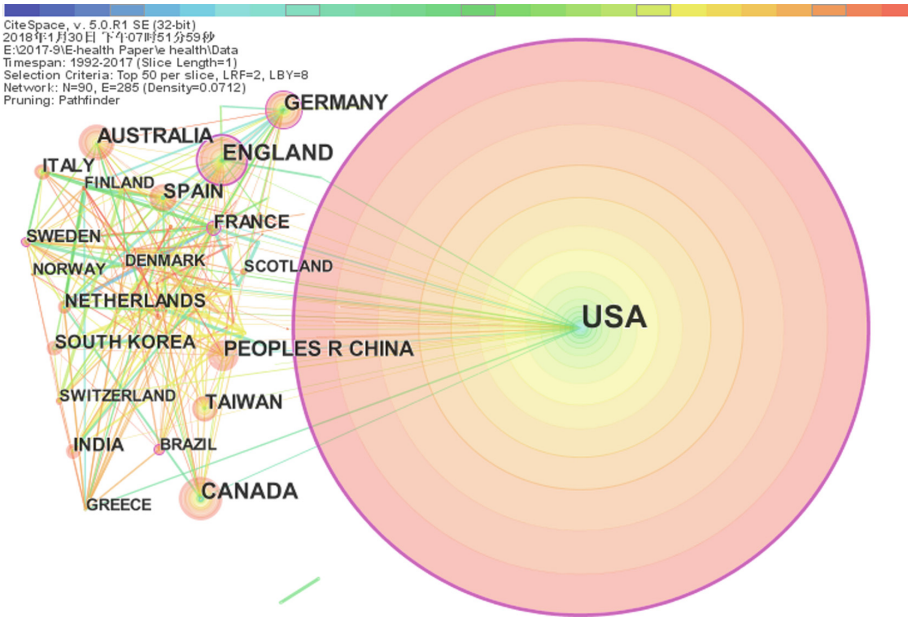

Fig. 2. National/regional distribution and cooperation network (Color figure online)

In terms of the number of published scientific and technical literature, the United States ranked first with 1,680 documents, and accounted for 54.4% of the total number of electronic health documents worldwide, far exceeding that of other countries/regions. China (including Taiwan) ranked second with 198 articles, but China started e-health research relatively late—began to produce literature in 1999. Taiwan began e-health research in 2007, but Taiwan has published 90 articles in a short period of ten years, surpassing Italy and France, which began research at the end of last century. China should follow the trend of the times, pay attention to health management, and emphasize cross-strait academic exchanges and cooperation in the future. Subsequent countries are Canada, Germany, and Australia, with 140, 134, and 132 articles respectively. The centrality describes the importance degree of the nodes, which is reflected in the purple circle of the nodes' outer edge on the cooperation network map. The highest centrality is the United States, which is 0.57, followed by the United Kingdom's 0.21 and France's 0.18. It can be seen that both the U.S. and U.K. have an advantage in terms of volume and importance. When it comes to the time of various countries began investing in e-health research, the earliest was still the United States, followed by Germany, which launched e-health research in 1994. Most countries began investing in this field in 1999. In the top ten countries/regions, from cooperation network it can be seen that the cooperation among European countries is the closest. At the same time these European countries all have an intimate cooperative relationship with the United States. Among them, the United States and Germany have the most cooperation. In contrast, cooperation between Asian countries is relatively small.

3.2.3 Institutional Distribution and Cooperation Network

CiteSpace was used to obtain an institutional cooperation network, as shown in Fig. 3. In the field of e-health, Harvard University and Brigham & Women's Hospital are the cores to form a complex cooperative network. Harvard University took first place with

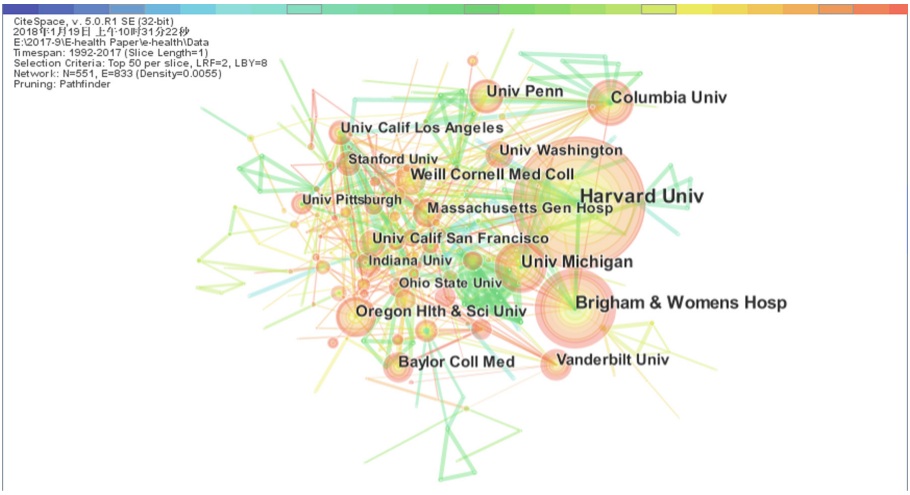

Fig. 3. Major institutional cooperation network

167 articles. The second-ranked Brigham & Women's Hospital is a well-known teaching branch of Harvard Medical School and has the most advanced resources for clinical care, medical research, doctor training and education. Most organizations that published more than 30 scientific articles are the world's top universities or affiliates in the United States. Since 2000, these authoritative academic institutions mainly from the U.S. cooperated very closely. This explains why U.S. has such a high output of e-health literature.

4 The Electronic Health Research Focus Analysis

One of the most important content of bibliometric analysis is the keywords analysis, which extracts the research hotspots in the field to summarize development trends and predict the future development direction. The research hotspot refers to the problems that are discussing and solving by a large number of related documents in a time period. By analyzing the keywords, it is easy to determine research hotspots in a certain field. The co-word analysis method holds that if two terms appear in a single document simultaneously, there is a certain co-occurrence relationship between these two. These two-two appearing keywords are constructed as a co-word network.

This paper uses the three-step method of co-word analysis: extraction keywords, constructing co-word matrix, and data analysis [13]. In order to construct a keyword co-occurrence network more rationally, the statistical analysis tool SATI 3.2 was used to perform statistics on documents. After the pre-processing such as synonym merging and irrelevant punctuation, we finally obtained a 65 * 65 co-occurrence matrix. Based on the co-word matrix, we used Ucinet 6.0 and Netdraw to generate a keyword co-occurrence network, as shown in Fig. 4.

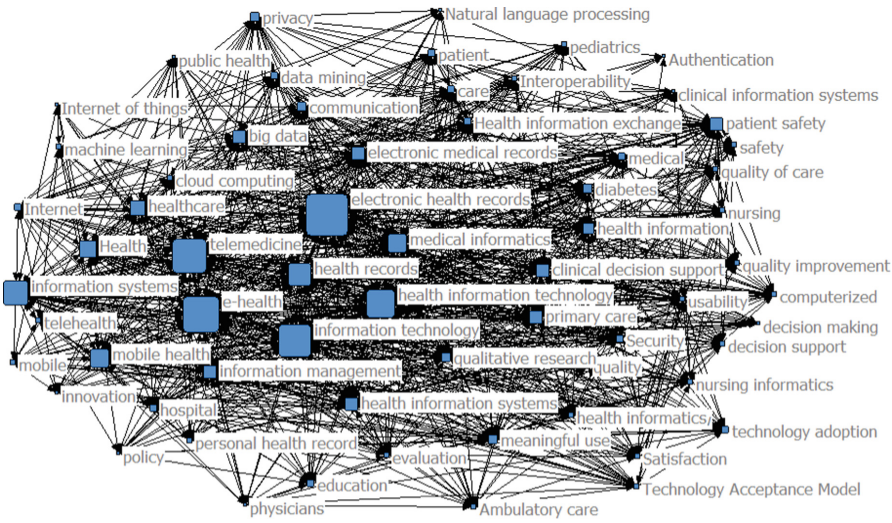

Fig. 4. Keywords co-occurrence network

Among all keywords, high-frequency keywords can best reflect research hotspots and research trends in specific areas [14]. Electronic health records, telemedicine, and e-health have become hot applications in electronic health research; Data mining, health information technology, and cloud computing have become hot technology topics in this area. Meanwhile, scholars have also paid close attention to hot issues such as privacy, security, and quality improvement.

Electronic Health Records (EHR) is the largest key node. Studies have shown that at least 80.5% of hospitals adopted a basic electronic health records system by 2015, an increase of 5.3% points compared to 2014; however, only 37.5% of hospitals used 8 or more EHR data for performance measurement, and 41.7% of hospitals used 8 or more EHR data for patient participation. The performance measurement and patient participation function of electronic health records are key factors in improving hospital performance. Although the "Economic and Clinical Health Information Technology Act" promotes the widespread adoption of EHR in hospitals, the application of advanced EHR functions has lagged behind. This situation is particularly present in some important hospitals [15]. In the current actual situation, there are still some limitations in the use of electronic health records. For example, because the lack of standards and regulations for electronic health records, different hospitals, mobile health companies issue various electronic health records or medical examination reports. Even the criteria for judging whether the index is normal are not the same, which is undoubtedly a significant impediment to integrate EHRs from different institutions and extract useful information from physical health changes. If there is no unified industry standard for electronic health records, it is difficult to achieve data interconnection and interoperability thoroughly.

5 Conclusion

In this study, we searched the core data of WOS, obtained 3,085 literature data of e-health research from 1992 to 2017. Bibliometric analysis was conducted to clarify the spatial and temporal distribution and research hotspots of electronic health. The results show that: First, during the period from 1992 to 2005, the annual output of scientific literature in the field of e-health was small; after 2005, the number of documents has been increasing year by year, and it has generally grown in an exponential manner. It is expected that the electronic health-related literature will continue to grow exponentially in the future. Secondly, the countries/regions that have issued documents in electronic health have relatively close cooperation and the cooperation between EU countries is the closest. In terms of the number of documents issued, the United States ranked first. Thirdly, the academic research studies in e-health have a strong co-citation relationship. Fourth, electronic health records, telemedicine, e-health, etc. have become hot applications in e-health research. Meanwhile, scholars have also paid close attention to such hot issues as privacy, security, and health quality improvement. Based on the bibliometric analysis and a systematic review, we summarized the following trends in the development of e-health research.

First, mobile healthcare based on the Internet of Things and smart wearable devices. With the development of the mobile Internet and wearable devices, mobile

health management services are flourishing. Mobile health services quickly penetrate people's daily lives because of their convenience, economy, and personalization. Mobile health has a positive impact on the treatment of chronic diseases and daily care [16].

Second, smart health combined medical and health care. Smart health is an era product based on the concepts of e-Health and Smart City. For smart health, "smart" is just a form of expression, the core is still "health." Under the big data environment, only to build a smart community, a smart health care platform for the aged, and data interconnection can solve the problem of increasing global aging population and improving the quality of elderly care services [17].

Third, the deep integration of electronic health information in cloud environment and the dynamic knowledge service for the entire life cycle. Most traditional medical information integration systems mainly deal with basic patient information, diagnosis and treatment information in hospitals, and rarely involve external health information resources. The enlightenment from the development of big data and cloud computing platforms is that health information resources are very complicated, and medical health management is also facing the challenge of integrating information resources. It is very important to study the information fusion and service collaboration of the supply side of the health care service, and the mutual benefit mechanism of various service units in the pension industry.

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