Research Article

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The Application of Artificial Intelligence to Ophthalmology: A Bibliometric Study (2000-2021)

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Abstract

Artificial Intelligence (AI) is an advanced technology for the latest 20 years. Machine learning (ML) and deep learning (DL) are the major innovations for AI, which has been applied for multiple fields. This study utilizes methods of text mining and bibliometric analysis to explore applications of AI to ophthalmology. 179 related articles from Web of Science (WOS) and 96 papers from China National Knowledge Infrastructure (CNKI) are explored from 2000 to 2021. A descriptive analysis of major trends, journal releasing, topic mapping and quotation relationships is implemented in this paper. Leading authors, journals, institutions, nations and references in the related research are identified. Findings show that the application of AI technologies in ophthalmologic diagnosis with optical coherence tomography (OCT) fundus images is the most hot topic for this area's studies, especially for diabetic retinopathy (DR), aged macular degeneration (AMD) and glaucoma. It is also be predicted as the core direction over the recent years. Besides, The USA, England and China is the most competitive countries in this scientific filed. Journals of Ophthalmology, Investigative Ophthalmology and Visual Science, Eye, Acta Ophthalmologica and Scientific Reports are the top five journal related to the research area. There is a significant difference between WOS and CNKI databases pertaining to the application of Artificial Intelligence (AI) to ophthalmology, especially for the historic development, topic mapping and discipline category. Finally, the potential academic value of interdisciplinary of "AI in Ophthalmology" and tradition Chinese medicine (TRM) is discussed, and suggestions for the future research is indicated.

Keywords: Artificial Intelligence, Ophthalmology, Bibliometric Study, Citespace, Machine Learning, Deep Learning.

Introduction

Eye disease is regarded as one of the most significant healthcare problems, such as diabetic retinopathy (DR), age-related macular degeneration (AMD), glaucoma, retinal vein occlusion (RVO), retinal artery occlusion (RAO), retinal detachment (RD), epimacular membrane (EM), fundus tumors (FT), papilledema and diabetic macular edema (DME) [1-3]. Fundus diseases are the major cause for vision loss. For instance, DR is estimated as the most cause for blindness of adults [4]. The shortage of ophthalmologists and diagnose services are the major issue for lesion detection [1]. Thus, a computer aided diagnose solution plays a vital role for ophthalmology.

The enhancement of Artificial Intelligence (AI) presents a significant value for human healthcare, which exhibits a vital advantage in ophthalmology in clinical level [5]. Optical coherence tomography (OCT) technology is regarded as the breakthrough for choroidal fundus images acquirement technology, which is a

foundation of AI diagnose based on fundus images [6]. Machine learning (ML) and deep learning (DL) algorithms are wildly applied for fundus diseases detection [7]. Studies related to AI-based ophthalmology applications are constantly emerging and developing in the latest 20 years.

Scient metrics is a research method based on field-oriented scientific literatures. This method has been considered as one of the most significant approaches for literature analyzing research in multiple areas [8]. Cite Space is one of the most popular tools for the bibliometric study. It is functioned by analyzing and measuring the topic, author, institution, journal, develop trend, etc. A systematic literature analysis contributes a reference for related researchers to understand the present state and predict the future direction [9].

This article delivered a bibliometric study on applications of Artificial Intelligence (AI) technologies on ophthalmology, where the machine learning (ML) and deep learning (DL) technologies are included. The structure of this paper is concluded as the following. The second section introduces the method of this study, where data sources and analysis methods are included. Results and the discussion are delivered in the third and fourth section respectively. The conclusion is presented in the final section.

Methodology

Data Sources

Scientific articles in English are obtained from Web of Science (WOS), and Chinese literatures from China National Knowledge Infrastructure (CNKI). Search string is defined as: TS= ("AI" OR "artificial intelligent*" OR "deep learning" OR "machine learning") AND TS=("Ophthalmolog*"). Time span is set as 1st January 2000 to 10th October 2021.

Analysis Methods

TXT results from WOS and CNKI are input into the software of Cite Space. The version of this software is 5.7.R3,64bit for Windows operation system. Analysis of authors, institution, countries, keywords, categories and journals are conducted on the data. A process of visualization and comparable analysis is implemented on the results.

Results

With 179 literatures from WOS and 96 literatures from CNKI, the development trends of the application of ML and DL in ophthalmology research are explored from 2000 to 2021. Authors, institutions, journals, countries and hotspots are descriptively analyzed in this section.

Analysis of the Trends in the Literature

The \ref{Figure:1} shows the developing history on "AI applicated to Ophthalmology" from 2000 to 2020. Numbers of publications grew significantly in the period of 2014 to 2020 for WOS, and 2017 to 2020 for CNKI. From 2014 to 2020, 144 articles are recoded in WOS database, which is approximately 4 times more than the period of 2000 to 2014. It presents a similar increase trend for CNKI. In 2017, 9 papers were published in CNKI, it is increased to 72 publications in 2020, which is 8 times of 2017. The amount is predicted to be continuously increasing in the recent years.

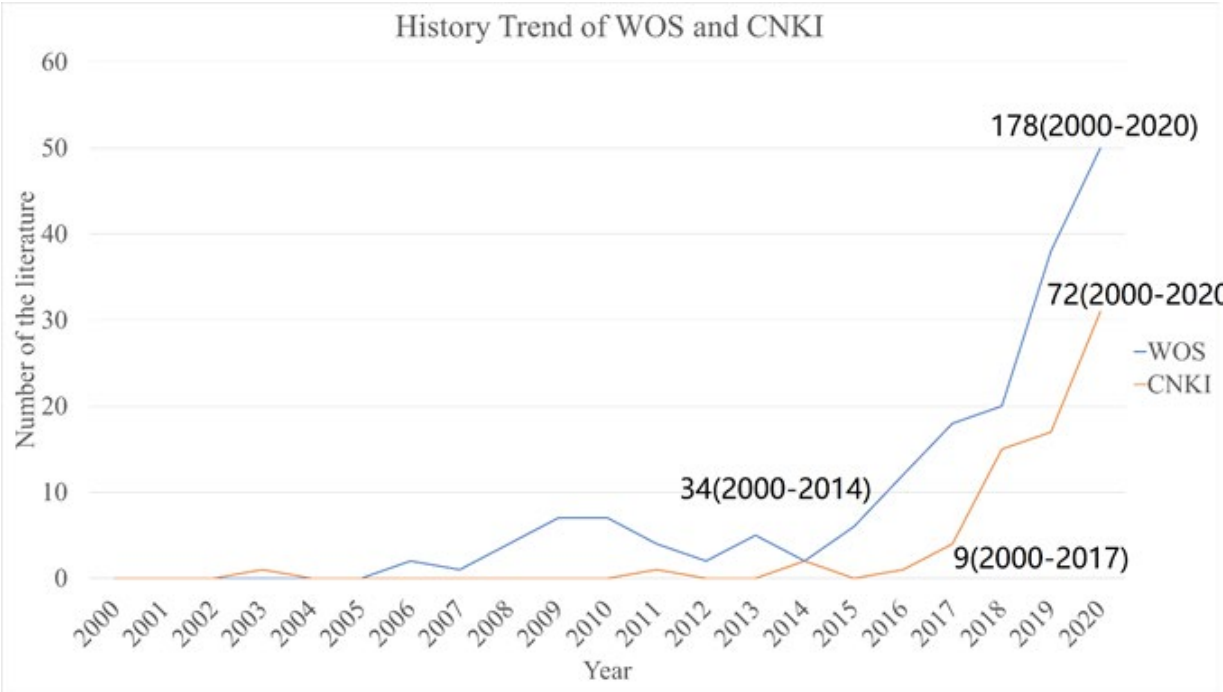


Figure 1: History trend analysis of WOS and CNKI

Analysis of the Countries, Authors, Institutions, Journals and Cited References

A country distribution Figure (\ref{Figure:2}) is generated based on WOS database in Cite Space. 19 notes and 25 links (\ref{Figure:2}.) are given in this map, which represents 52 countries and 25 collaboration are involved. Top 14 countries are listed in \ref{table:1} based on the amounts of the publications, where USA (centrality=0.63, count=38), England (centrality=0.28, count=14) and China (centrality=0.24, count=11) are regarded as the top 3 countries based on centrality and co-occurrence. \ref{Figure:2}. indicates that the strongest cooperation is between Germany and Netherlands.

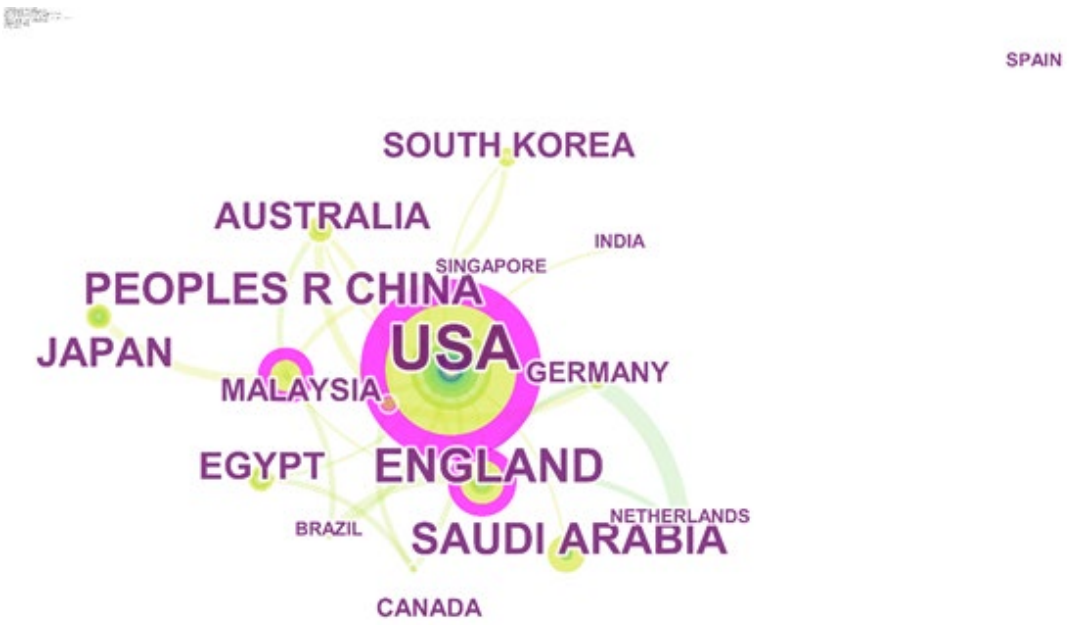


Figure 2: The distribution of countries

Table 1: Top 14 countries according to the number of publications in WOS

Ranking	Country	Count	Centrality
1	USA	38	0.63
2	England	14	0.28
3	China	11	0.24
4	Saudi Arabia	11	0
5	Japan	9	0
6	Australia	8	0.07
7	Egypt	8	0
8	South Korea	6	0.02
9	Malaysia	5	0.05
10	Turkey	5	0
11	Greece	5	0
12	Germany	4	0.05
13	Canada	3	0.05
14	Singapore	2	0.03

The social networks of authors from WOS (a) and CNKI(b) display in \ref{Figure:3}. 21 nodes and 19 links for WOS, and 239 nodes and 613 for CNKI are presented on the map. Cooperation networks between scholars are given from the map. For instance, there are collaborations between Dawn A. Sim, Ahmed Abder and Aliem Mohamed Amr (from WOS), and Zhao Xin and Yang Zhiwen (from CNKI). \ref{Figure:3} shows that there are more collaborations in CNKI than WOS.

Figure 3: The distribution of authors of WOS (a) and CNKI(b)

As the \ref{table:2} shown, the academic influence is measured by the amount of authors' publications. The top 2 authors are Aihong Chen (count=3) and Michael F. Chiang (count=3) from WOS, and Lin Haotian (count=5, centrality=0.03) and Chen Jingjing (count=4, centrality=0.03).

Table 2: Top 10 authors according to the number of publications

Ranking	WOS			CNKI		
	Count	Centrality	Author	Count	Centrality	Author
1	3	0	Aihong Chen	5	0.03	Lin Haotian
2	3	0	Michael F. Chiang	4	0.03	Chen Jingjing
3	2	0	Athanasios I. Kotsolis	3	0	Chen Nan
4	2	0	Ilias Georgalas	3	0	Liu Hanruo
5	2	0	Ioannis D. Ladas	3	0	Du Yifan
6	2	0	Ahmed Abdel Aliem Mohamed	3	0	Wang Ningli
7	2	0	Asmaa Ismail Ahmed	3	0	Yang Weihua
8	2	0	Mohammad Ahmad Rashad	3	0	Zack Zhang
9	2	0	Anneke I. Den hollander	2	0	Zhang Xiao
10	2	0	Carel B. Hoyng	2	0	Pang Ruiqi

The \ref{fig:4} shows the collaboration network among institutions. 22 nodes and 20 links for WOS, and 30 nodes and 0 links for CNKI. It indicated that there are slight collaborations between institutions in WOS and no cooperation in CNKI. Collaborations between Johns Hopkins University and Kin Khalid Eye Specialist Hospital are relatively significant.

Figure 4: The distribution of institutions of WOS (a) and CNKI (b)

The academic influence of institutions is ranked by their publication numbers. As the tab. 4 shown, top 5 institutions in WOS are Ain Shams University (count=6, centrality=0), Sun Yat-sen University (count=6, centrality=0), Johns Hopkins University (count=6, centrality=0.22), Oregon Health & Science University (count=6, centrality=0) and King Khaled Eye Specialist Hospital (count=6, centrality=0.13), two of which are in the U.S. Top 5 institutions in CNKI are Zhongshan Ophthalmology Center of Sun Yat-sen University (count=6, centrality=0), Beijing Tongren Hospital (count=6, centrality=0), the Afflated

Eye Hospital of Nanjing Medical University (count=6, centrality=0), Beihang University (count=6, centrality=0), the company of Airdoc (count=6, centrality=0), three of which are in Beijing city of China.

Table 3: Top 5 institutions according to the number of publications

Ranking	WOS				CNKI			
	Institution	Country	Count	Centrality	Institution	City of China	Count	Centrality
1	Ain Shams University	Egyptian	6	0	Zhongshan Ophthalmology Center of Sun Yat-sen University	Guangzhou	7	0
2	Sun Yat-sen University	China	5	0	Beijing Tongren Hospital	Beijing	7	0
3	Johns Hopkins University	The U.S.	4	0.22	The Afflated Eye Hospital of Nanjing Medical University	Nanjing	5	0
4	Oregon Health & Science University	The U.S.	3	0	Beihang University	Beijing	3	0
5	King Khaled Eye Specialist Hospital	Saudi Arabia	3	0.13	The company of Airdoc	Beijing	2	0

The core journal is identified by the numbers of publications. 129 nodes and 731 links are displays in \ref{Figure:5}Top 10 co-cited journals of WOS are listed in tab. 4 according to centrality. The real-time impact factor is searched from website of Academic Accelerator, in 24th October, 2021. It indicated that publications in the top 10 journals are in a high quality. Journal of Ophthalmology is the core journal with the highest number of publications (108) and centrality (0.16).

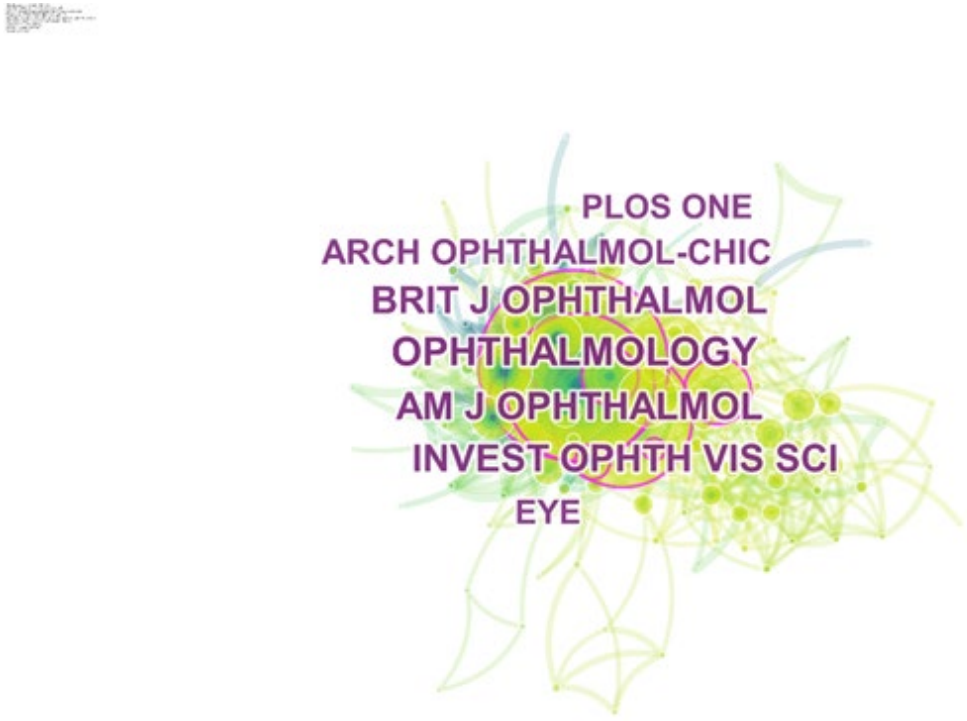


Figure 5: The distribution of cited journal of WOS

Table 4: The top 10 co-cited journals of WOS according to centrality

Ranking	Count	Centrality	Journal	Real-time Impact factor
1	108	0.16	Ophthalmology	14.8
2	80	0.16	Investigative Ophthalmology and Visual Science	6.6
3	46	0.15	Eye	5
4	20	0.15	Acta Ophthalmologica	5.2
5	14	0.15	Scientific Reports	7.1
6	29	0.13	Survey of Ophthalmology	8.5
7	88	0.12	American Journal of Ophthalmology	7.1
8	33	0.12	Acta Ophthalmologica	5.2
9	37	0.1	Journal of the American Medical Association	56.272
10	18	0.1	New England Journal of Medicine	74.699

\ref{fig:6}displays the distribution of cited reference in WOS, 116 nodes and 380 links are given from the map. Top 5 references are recognized in \ref{tab:5} according to the number of being cited. With 20 times cited in other studies, a study from Gulshan et al. (Gulshan et al., 2016) is defined as the most influential article.

Figure 6: The distribution of cited reference of WOS

Table 5: Top 5 cited references of WOS according to times of being cited

Ranking	Count	Centrality	Year	Cited Reference	Author
1	20	0.12	2016	Development and Validation of a Deep Learning Algorithm for Detection of Diabetic Retinopathy in Retinal Fundus Photographs	Gulshan et al.(Gulshan et al., 2016)
2	13	0.04	2017	Development and Validation of a Deep Learning System for Diabetic Retinopathy and Related Eye Diseases Using Retinal Images from Multiethnic Populations with Diabetes	Ting et al.(Ting et al., 2017)
3	11	0.27	2018	Clinically Applicable Deep Learning for Diagnosis and Referral in Retinal Disease	De Fauw et al. (De Fauw et al., 2018)
4	8	0.05	2012	ImageNet Classification with Deep Convolutional Neural Networks	Krizhevsky, Sutskever, & Hinton (Krizhevsky, Sutskever, & Hinton, 2012)
5	8	0.04	2018	Efficacy of a Deep Learning System for Detecting Glaucomatous Optic Neuropathy Based on Color Fundus Photographs	Li et al. (Li et al., 2018)

Analysis of the Hotspots

The hotspot map is illustrated in \ref{Figure:7}, 64 nodes and 198 links for WOS and 181 nodes and 562 links for CNKI are displayed. According to the \ref{Figure:7}, keywords of Artificial Intelligence, diabetic retinopathy, optical coherence tomography, deep learning, machine learning, ophthalmology, glaucoma, aged macular degeneration (AMD) and diagnosis are the most significant topics.

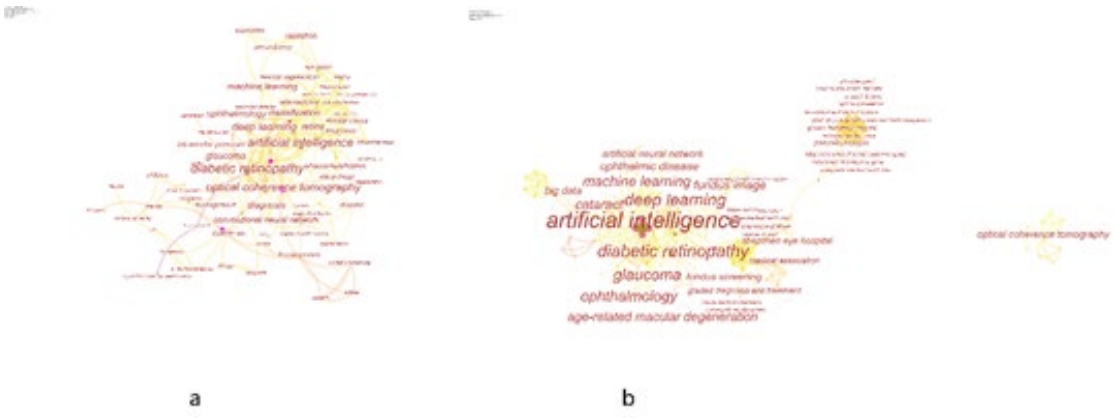


Figure 7: The topic mapping visualization of WOS (a) and CNKI (b)

The time zone view and the history trend of "AI in Ophthalmology" are revealed in \ref{Figure:8} (a and c) and \ref{Figure:9}. As far as WOS database is concerned, topics of DR and AMD emerged in 2009, the keyword of OCT appeared in 2016, hotspots of glaucoma, ML, DL and fundus image turns up in 2017 and 2018, the topic of AI arose in 2019. Regarding to the database of CNKI, the keyword of AI appeared in 2017, topics of DL, glaucoma, DR and ophthalmology emerges in 2018, AMD, ML, fundus screening and OCT-related keywords burst after 2019.

\ref{Figure:8} (b and d) presents top 12 hotspots with strongest citation bursts of WOS and CNKI during the developing history. As for WOS database, the keyword of glaucoma draws a high attention during 2009 to 2013, the topic of OCT gains much focus during the period of 2016 to 2017, the hotspot of AI holds the interests from 2019 to 2021. When it comes to CNKI database, keywords of fundus screening and convolution neural network burst after 2020.

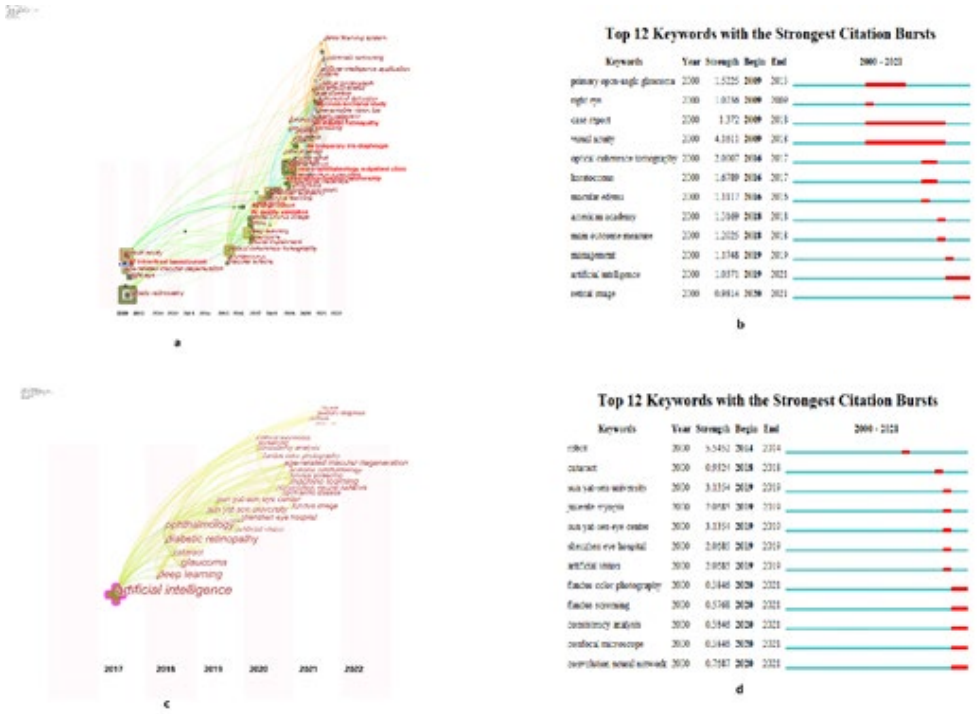


Figure 9: The time zone and the citation bursts of keywords of WOS (a and b) and CNKI (c and d)

According to the \ref{Figure:9}, topics from WOS are classified into 6 clusters, which are partial deepithelization, retinal photography, transfer learning, neuro-ophthalmology outpatient clinic, AI and age factor. It is implemented as 12 clusters for keywords of CNKI, which are AI, Digital medical technology, medical reform, hospital information security, information platform, ophthalmology, fundus image, consistency analysis, classical hierarchical model and internet hospital.

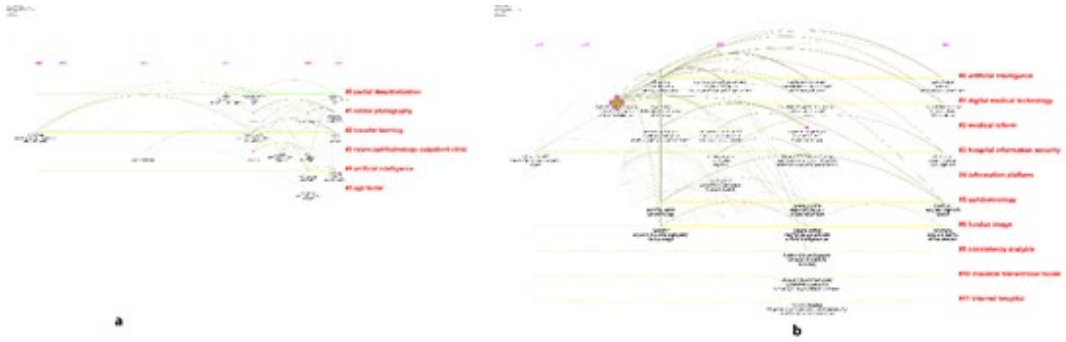
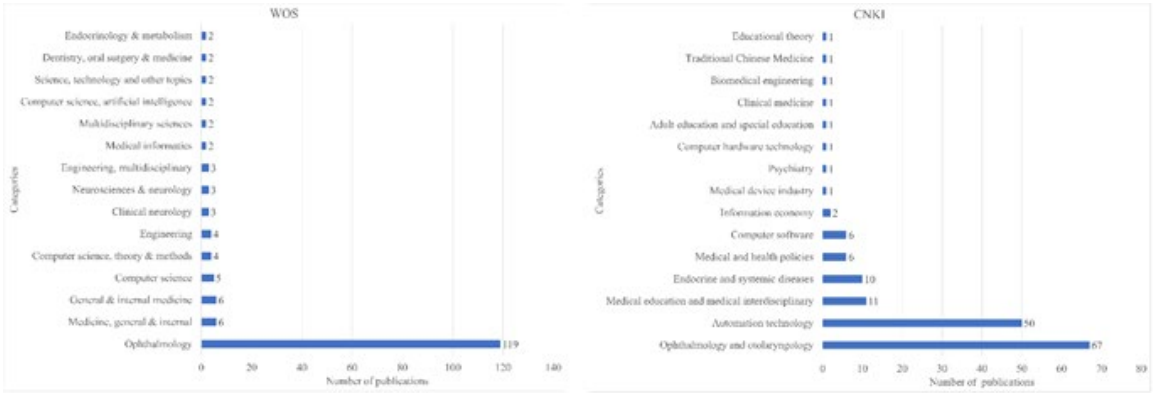


Figure 10: Developing history of keywords and clusters visualization of WOS (a) and CNKI (b)

Analysis of the Categories

Based on the number of publications, the top 15 categories are listed in Figure. 10. The core disciplinary is defined as Ophthalmology, which is with 119 publications in WOS and 67 publications in CNKI. AI-related category emerges in the fourth place of WOS and second place if CNKI. Comparing the two database, multidisciplinary-related category is creatively listed as a cluster for WOS. Some of papers related to "AI in Ophthalmology" in CNKI uniquely publishes in the fields of education and traditional Chinese medicine (TCM).



a b

Figure 11: Top 15 categories according to the number of publications of WOS (a) and CNKI (b)

The distribution of categories of WOS database is visualized in \ ref{Figure:11}. 15 nodes and 9 links are involved in this Figure. It reveals that corporations between computer science based, ophthalmology based and engineering-based disciplinaries are week, which should be pard more attention in the future.

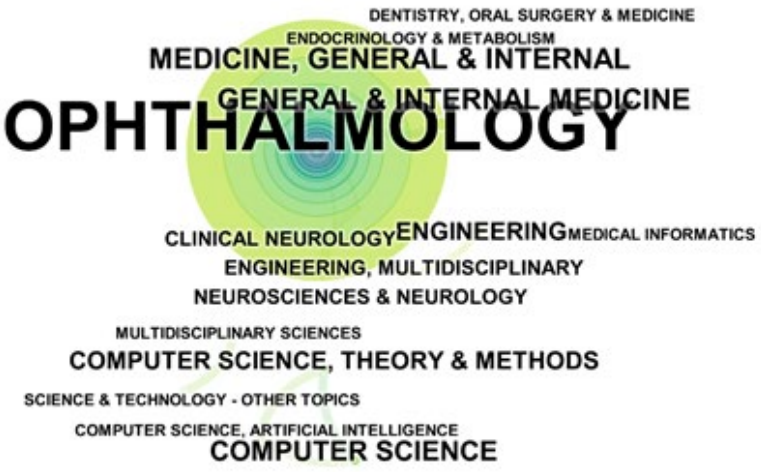


Figure 12: The distribution of categories of WOS database

Discussion

AL technology increasingly becomes a popular focus in the ophthalmology research, especially in the latest 5 years, which is predicted to be continually increasing in the next few years. This study utilizes the tool of Cite Space to scientifically explore and exhibit the knowledge structure and developing trend of the specific research field of "AI in Ophthalmology".

Data Analysis

Topic mapping and its time distribution are displayed in this article. As the Figure. 7 shown, DR, AMD, glaucoma, AI, OCT, fundus image, DL, ML, diagnosis are the major topics in both databases of the WOS and CNKI. Thus, this study indicates that the application of AI in Ophthalmologic diagnosis with OCT fundus images plays a significant role in the "AI + Ophthalmology" studies, especially for DR, AMD and glaucoma. It is also a vital direction in following years.

Furthermore, scientific publications are identified as one indicator of core competitiveness of a country [11]. As the \ref{table:1}. and \ref{Figure:2}. shown, according to the country distribution result of WOS, the USA shows an advantage in this research field, followed by England and China. According to the \ref{table:3} and \ref{Figure:4}, with the greatest number of publications, institutions of Ain Shams University (Egyptian), Sun Yat-sen University (in China) and Johns Hopkins University (in the U.S.) are regarded as the top-three institutions in this research area. However, measured by the centrality result (>0.1), Johns Hopkins University (the U.S.) and King Khalid Eye Specialist Hospital (Saudi Arabia) are the most essential institutions. When it comes to CHKI, most of institutions involved are from China, where Zhongshan Ophthalmology center of Sun Yat-sen University and Beijing Tongren Hospital presents a significant contribution academically.

Besides, the academic influence of articles and authors and journals can be determined by the cited frequency and the centrality result (>0.1) [12]. As the \ref{table:5} and \ref{Figure:6} shown, regarding to WOS database, the article of "Development and validation of a deep learning algorithm for detection of diabetic retinopathy in retinal fundus photographs" exhibits the greatest advantage in WOS database, it possesses the highest cited amount (20) and a relatively high centrality value(0.12) [10]. As the Figure. 3, Figure. 5, Table. 2 and \ref{table:4} shown, Aihong Chen is the most influential author, who is involved to the research of comparing the vision screening programs within 18 countries [13]. Journal of Ophthalmology is the core journal with the highest cited record (108) and a centrality value (0.16). As far as CNKI is concerned, Haotian Lin presents the most advantage in publication frequency and centrality value, he is involved in the paper named as "Establishment of ophthalmic data center and intelligent service cloud platform", which is a research related to the applications of AI to intelligent ophthalmologic center constructions [14].

The number of nodes and links in cooperative network indicates the cooperative relationships, where higher the number of links, stronger the relation is [11, 12, 15]. According to the social network of WOS exhibited in \ref{Figure:3}. (note=19, link=25 for WOS; note=239, link=619 for CNKI), \ref{Figure:4}. (note=22, link=20 for WOS; note=30, link=0 for CNKI) and Figure. 2. (note=19, line=25 for WOS), the cooperation between authors, institutions and countries are insufficient. Moreover, as the \ref{Figure:11} (node=15, link=9) shown, the research of Interdisciplinary theories and applications should be paid more attention.

The strength of bursting citation of keywords represents the degree of retrieving focuses in the specific period [14]. By analyzing the \ref{Figure:8} and \ref{Figure:9}, it is indicated that AI-diagnose-related keywords are not significant enough in the developing history line before 2019, it presents a huge burst during 2019 to 2021. The topic of OCT fundus image exhibits a great burst in 2016 (from WOS) and 2020 (from CNKI).

Comparing the database of WOS and CNKI, there is a significant difference in the aspects of developing histories and discipline categories. As \ref{Figure:1}, \ref{Figure:8} and \ref{Figure:9} shown, this study concludes that the development of the AI in Ophthalmology research of WOS database is slightly advanced than the CNKI. CNKI's developing history starts with the bursting topic of "robot" (2014), which brings "AI" (2017) two years early than WOS (2019). Hot-topic of "diabetic retinopathy" (2009) is the beginning in WOS's developing history, which emerges in 2018 for CNKI. The keyword of "optical coherence tomography "bursts in 2016 for WOS, which is three years early than CNKI (2019). Thus, considering bursting topics and time series, this study divides the developing history of the two databases into three phases. As far as WOS studies are concerned, the first, second and the last phase is defined as "fundus disease" (2009)," OCT" (2016) and "AI" (2019) respectively. As for the CNKI database, three phases are recognized as "AI" (2014), "fundus disease" (2018) and "OCT" (2019). The \ref{Figure:7}indicates that the cross degree of WOS's interdisciplinary research is more significant than CNKI, especially for AI and OCT studies. Furthermore, as the \ref{Figure:10} shown, ophthalmology-based, engineering-based and computer-based disciplines are involved in both of the databases. Category of traditional Chinese medicine (TCM) is a novel discipline of CNKI for AI applicated in ophthalmology [16]. In their research, they classified the AI-based TCM studies into four categories, which are TCM diagnosis, TCM syndrome differentiation, health management and ophthalmology. When it comes to the aspects of ophthalmology, the paper highlights two studies from Wen and Li for their contributions of TCM eye observation [17, 18]. Wen performs a research on iris diagnosis with computer vision algorithms [17, 16]. Li proposes DL algorithms of eye edge extraction, pupil center location, analysis of the white of the eye and inheritance on Skin Color [18-22].

Strengths and Limitations

This research is the first study to systematically explore the literature from 2000 to 2021 on applications of AI (ML and DL) to ophthalmology. Papers of WOS and CNKI in Chinese and English languages are analyzed in this paper. The information of leading authors, journals, institutions, nations and references is identified. Insights of potential cooperative relationship among authors, institutions and countries are provided. Findings of the hotspot-mapping, developing history and future research direc-

tion are contributed. Finally, a comparation between WOS and CNKI datasets is discussed. The potential academic value of interdisciplinary of "AI in Ophthalmology" and TRM is discussed, and suggestions for the future research is indicated.

However, limitations are inevitable. This study is performed based on papers retrieved from WOS and CNKI on the specific keyword searching. It should be considered to applying more related searching strings in multiple databases for more literatures. Besides, this study only considered Chinese and English articles, it is suggested to perform bibliographic research on papers in more than two languages.

Conclusions

AI-based technologies exhibit a great potential value for Ophthalmological applications. Although there is a difference in developing history between WOS and CNKI, the future direction extracted from the two databases is as the same as the application of AI in DR with OCT fundus images. Furthermore, results indicates that the traditional Chinese medicine applicated to this area could be another future direction. Moreover, deeper cooperation between authors, institutions and countries of interdisciplinary studies should be enhanced to promote the research of "AI in Ophthalmology".

Acknowledgments

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