Analysis of international publication trends in artificial intelligence in ophthalmology

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Key messages

- Artificial intelligence (AI) has entered the field of medicine, and ophthalmology is no exception
- Artificial intelligence (AI) in ophthalmology is a very attractive topic in science
- No journal has been found to specialize in AI in ophthalmology
- AI in ophthalmology research is focusing on retinal diseases and glaucoma

Abstract

Purpose: Artificial intelligence (AI) has entered the field of medicine, and ophthalmology is no exception. The objective of this study was to report on scientific production and publication trends, to identify journals, countries, international collaborations, and major MeSH terms involved in AI in ophthalmology research.

Methods: Scientometric methods were used to evaluate global scientific production and development trends in AI in ophthalmology using PubMed and the Web of Science Core Collection.

Results: A total of 1356 articles were retrieved over the period 1966-2019. The yearly growth of AI in ophthalmology publications has been 18.89% over the last ten years, indicating that AI in ophthalmology is a very attractive topic in science. Analysis of the most productive journals showed that most were specialized in computer and medical systems. No journal was found to specialize in AI in ophthalmology. The USA, China, and the United Kingdom were the three most productive countries. The study of international collaboration showed that, besides the USA, researchers tended to collaborate with peers from neighboring countries. Among the twenty most frequent MeSH terms retrieved, there were only four related to clinical topics, revealing the retina and glaucoma as the most frequently encountered subjects of interest in AI in ophthalmology. Analysis of the top ten Journal Citation Reports categories of journals and MeSH terms for articles confirmed that AI in ophthalmology research is mainly focused on engineering and computing and is mainly technical research related to computer methods.

Conclusions: This study provides a broad view of the current status and trends in AI in ophthalmology research and shows that AI in ophthalmology research is an attractive topic focusing on retinal diseases and glaucoma. This study may be useful for researchers in AI in ophthalmology such as clinicians, but also for scientists to better understand this research topic, know the main actors in this field (including journals and countries), and, have a general overview of this research theme.

Keywords

Artificial intelligence, ophthalmology, bibliometrics, journals, glaucoma, retinal diseases

Authors’ contributions

Christophe Boudry and Frederic Mouriaux designed the work; Christophe Boudry acquired data; Christophe Boudry Hassan Al Hajj, Louis Arnould and Frederic Mouriaux undertook analyses; Christophe Boudry, Hassan Al Hajj, Louis Arnould and Frederic Mouriaux drafted the work and contributed to its revision and have approved the submitted version.

Introduction

Artificial intelligence (AI) in healthcare consists of using complex algorithms and software, in order to emulate human cognition in the analysis, interpretation, and comprehension of complicated medical data. A number of research studies have previously suggested that AI can perform as well as or better than humans at key healthcare tasks, such as diagnosis [1]. AI has demonstrated promising results in medical fields, such as radiology, pathology, and dermatology. These medical fields have striking similarities to ophthalmology, as they are deeply rooted in diagnostic imaging, the most prominent application of AI in healthcare [2].

Bibliometrics refers to methods that use quantitative analysis and statistics to describe distribution patterns of publications, temporal evolution, and geographical distribution of research in a given field [3]. Bibliometrics is helpful in mapping the literature related to a research field and can provide useful data, leading to a better understanding of scientific fields. This can thus play a role in governing policymaking [4]. Bibliometric analyses are used in various research fields, including ophthalmology [5–7]. Some reviews of the literature have been done in AI in ophthalmology [8, 9]. A number of bibliometric analyses related to global research on AI [10, 11], AI in healthcare [12–14] and in some medical fields (e.g. radiology [15]) have also been performed. However, to the best of our knowledge, none were related to AI in ophthalmology. Consequently, there is a lack of knowledge about the research situation in this field. The present study used bibliometric tools to provide a retrospective and current view of mainstream research on AI in ophthalmology across the international scientific literature.

Materials and Methods

The search for papers to be included in this study was carried out on May 12th 2020 using the PubMed database (http://www.ncbi.nlm.nih.gov/pubmed) developed by the National Center for Biotechnology Information (NCBI) at the National Library of Medicine (NLM). PubMed was chosen because it is the most widely used in medicine [16], and allows a search using MeSH, the National Library of Medicine's controlled vocabulary thesaurus (http://www.nlm.nih.gov/pubs/factsheets/mesh.html).

The objective of the search strategy used was to exhaustively extract all articles related AI in ophthalmology indexed in the PubMed database. The search strategy was built by identifying the keywords listed in the medical subject headings (MeSH) thesaurus (words appearing in the MeSH field [Mesh]), i.e. the vocabulary of medical and scientific terms that are assigned to PubMed documents by a team of trained experts (indexers). The search strategy was : "Artificial Intelligence" [Mesh] AND ("Eye Diseases"[Mesh] OR "Ophthalmology"[Mesh] OR "Eye"[Mesh]) AND Journal Article [PT] AND 1966:2019 [DP]" where Mesh stands for "Medical Subject Headings," DP "Date of Publication," and PT "Publication Type."

The MeSH term "Eye Diseases" was chosen because it has been shown to have extensive coverage of eye diseases [5]. The MeSH term "Artificial Intelligence", whose definition in the NLM-controlled vocabulary thesaurus is "theory and development of computer systems which perform tasks that normally require human intelligence" was chosen because it covers all developed AI methods and is used in medicine (e.g. neural networks, or machine learning) (Fig. 1). "Journal Article" includes the following publication types: journal articles, introductory journal articles, and reviews. "Journal article" was used for the analysis because these document types include whole research ideas and results [17]. The year 1966 was chosen because it corresponds to the beginning of the Medline database. We did not impose any language restriction in the search, in order to analyze publication patterns of all publications related to AI in ophthalmology.

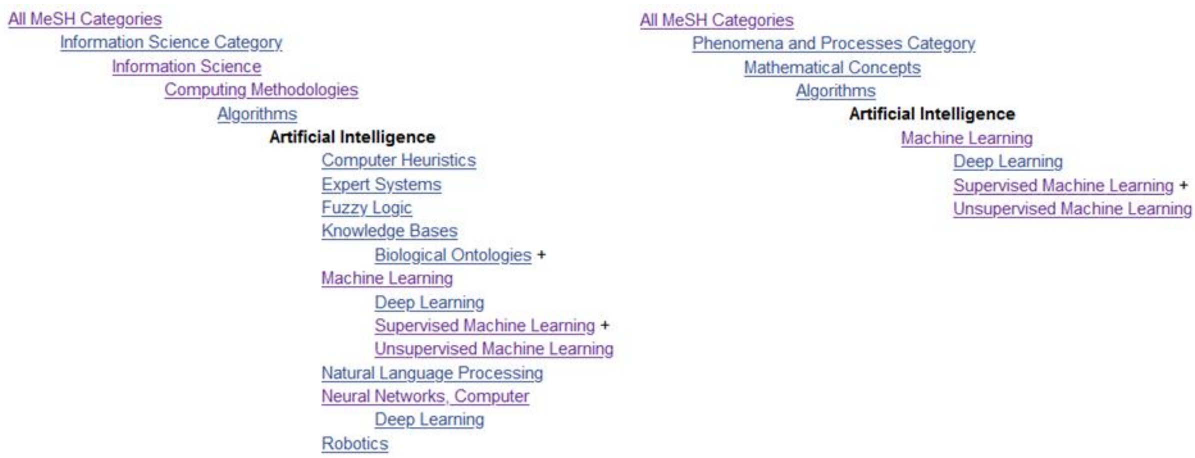

Fig 1. MeSH trees corresponding to the MeSH term “Artificial Intelligence”. This term is located in two different places in the National Library of Medicine-controlled vocabulary thesaurus

Data were downloaded from PubMed in Extensible Markup Language (XML) and were processed through developed hypertext preprocessor language (PHP) scripts, then imported to Microsoft Excel 2013 (Microsoft, Redmond, California, USA) for data processing as previously reported [18]. The total number of articles related to AI in ophthalmology per year was fitted to an exponential curve for our search strategy. The average yearly growth rate [19] of the literature related to AI in ophthalmology was calculated as the mean percentage of the annual growth rate for the period studied using the equation: annual growth rate = current year total number of articles – previous year’s total number of articles/previous year’s total number of articles. The average yearly growth rate was also calculated for the whole PubMed database. Languages of publication and journals were determined using the “Language” and “Journal” fields in PubMed data for all articles retrieved. An analysis of the MeSH terms used by PubMed indexers was done to classify the articles, calculated by their frequency in the retrieved articles and represented as a word cloud using https://www.wordclouds.com/. Check tags, i.e. MeSH terms obligatorily used by indexers to describe recurrent patterns in medical articles, were excluded from this frequency analysis because of their compulsory and recurrent aspects. They are shown in Supplementary Table 1. Co-occurrence, the simultaneous association of two MeSH terms in the same articles, was calculated for “clinical” MeSH terms retrieved.

In order to access article citations, PubMed’s unique identifiers of articles retrieved in the PubMed database were used to conduct searches in the Web of Science Core Collection (WoSCC). Data were downloaded from WoS in “Full record and cited references” and “Comma Separated Values” (CSV) formats. They were then imported to Microsoft Excel 2013 (Microsoft, Redmond, California, USA) for data processing. Citation counts reflect all the papers obtained on May 12th 2020 when the WoS database search process for this study was conducted. Countries, institutions, and subject categories were examined. Institutions were determined using the “Organizations-Enhanced” field. Articles originating from England, Scotland, Northern Ireland, and Wales were reclassified as originating from the United Kingdom (UK). Hong Kong was considered as part of the People’s Republic of China

(China). Year 2019 Impact Factors (IF) of journals were found on publisher websites. VOSviewer (Leiden University, Leiden, Netherlands) was used to generate the knowledge map of countries related to AI in ophthalmology.

Results

1. Global Publication Trends

Overall, 1356 references over the period 1966-2019 were found in PubMed. Among these 1356 references, 84 were reviews and two introductory journal articles. The first articles related to AI in ophthalmology were published in 1985 and the number of publications increased exponentially to 197 in 2019 (Fig. 2).

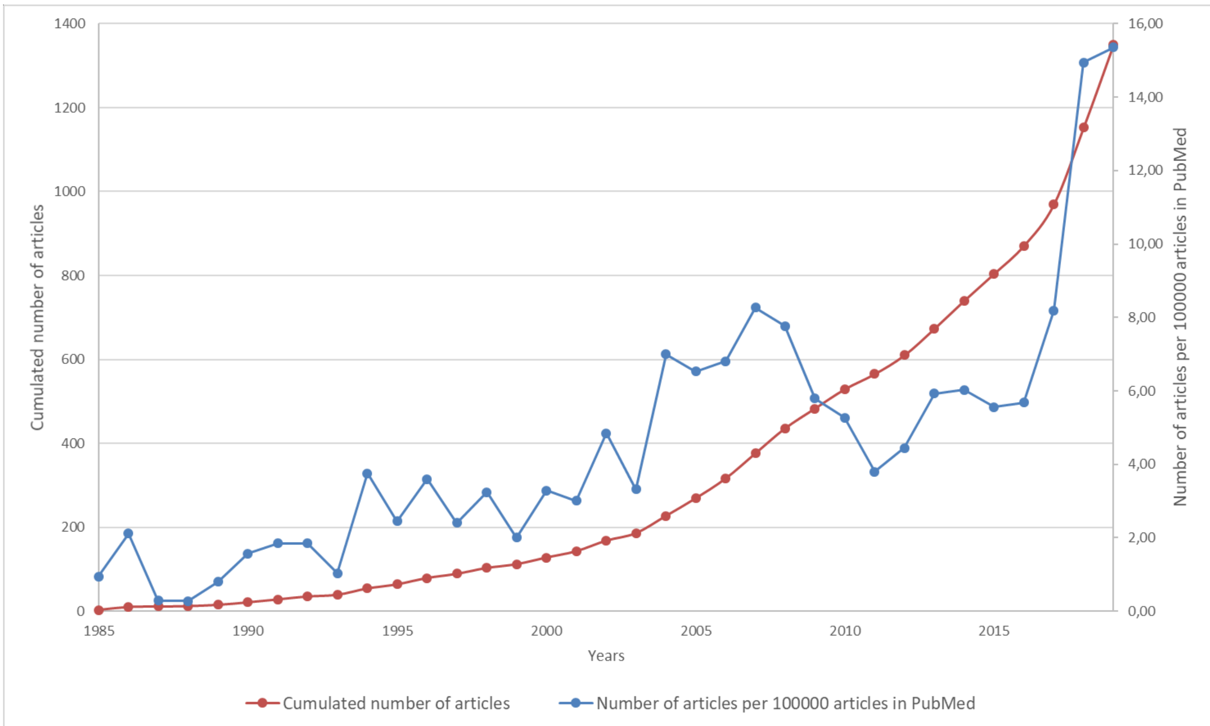

Fig. 2 Growth of literature related to AI in ophthalmology (annual number per 100000 articles in PubMed and total number)

Interestingly, the number of publications grew steadily until 2016, then grew sharply between 2016 and 2019. Using the cumulative number of publications, we calculated the exponential adjustment ($y = 6^{-132} * e^{0,1534x}$ with $r^2 = 0.96$). We calculated that the average yearly growth rate was 18.89% over the last ten years. In the entire PubMed database, it was 4.71% over the same period.

2. Language of Publication and Journals

Eleven different languages of publication were identified in PubMed. The seven most frequent languages were English (n = 1307; 96.4%), German (n =17; 1.25%), Chinese (n = 10; 0.74%), French (n = 7; 0.52%), and Russian (n = 7; 0.52%). All other languages amounted to less than 2 articles. Because the percentage of articles in English in the entire PubMed database for the same period was 87.01%, this shows that the number of papers on AI in ophthalmology published in English is higher than expected compared to the overall body of medical literature.

A total of 1215 articles were retrieved in the WoSCC. These articles were published in 355 journals, and were cited 36046 time with an average of 29.67 citations per article. Of these 355 journals, 198 (55.77%) published only one article. Only 31 (2.47%) journals published more than ten articles on AI in ophthalmology. Table 1 lists the 15 journals with the greatest number of papers published related to AI in ophthalmology.

Table 1: Top 15 most productive journals on AI in ophthalmology research.

Journal	Impact Factor	No. of articles related to AI in ophthalmology (%)	No of citations (%)	Total number of articles published by the journal (percentage of articles related to AI in ophthalmology)
IEEE Engineering in Medicine and Biology Society	N/A	62 (5.1)	444 (1.23)	27109 (0.23)
Investigative Ophthalmology & Visual Science	3.812	40 (3.3)	2155 (5.98)	22661 (0.18)
PLOS ONE	2.776	40 (3.3)	320 (0.89)	223296 (0.02)
Computer Methods and Programs in Biomedicine	3.424	39 (3.2)	906 (2.51)	4462 (0.87)
IEEE Transactions in Medical Imaging	6.79	38 (3.1)	4809 (13.34)	4821 (0.79)
Computers in Biology and Medicine	2.286	32 (2.6)	848 (2.35)	3813 (0.84)
IEEE Transactions on Biomedical Engineering	4.491	28 (2.3)	1063 (2.95)	8395 (0.33)
Journal of Medical Systems	2.415	25 (2.1)	453 (1.26)	3315 (0.75)
Scientific Reports	4.011	20 (1.6)	265 (0.74)	103226 (0.02)
Ophthalmology	7.732	19 (1.6)	653 (1.81)	16920 (0.11)
Neural Networks: the official journal of the International Neural Network Society	5.785	18 (1.5)	502 (1.39)	3259 (0.55)
American Journal of Ophthalmology	4.483	16 (1.3)	219 (0.61)	13721 (0.12)
Journal of Biomedical Optics	2.555	16 (1.3)	804 (2.23)	6363 (0.25)
Biological Cybernetics	1.305	14 (1.2)	239 (0.66)	2436 (0.57)
Computerized Medical Imaging and Graphics: the official journal of the Computerized Medical Imaging Society	3.298	14 (1.2)	476 (1.32)	1990 (0.7)

These top 15 journals of 355, which represent only 4.23% of all journals found in this study, published one-third of the articles on AI in ophthalmology (33.54%; n = 421). These 421 articles were cited 14156 times, corresponding to 39.27% of the overall citations. Therefore, these 15 journals are "core journals", and are of great interest for researchers because one-third of the articles on AI in ophthalmology could be found in this small fraction of journals. As usual, multidisciplinary megajournals such as PLOS ONE and Scientific Reports were well represented. All other journals specialized in computer methods and medical systems. Surprisingly, our results showed that articles related to AI in ophthalmology are rarely published in ophthalmology journals. Only three specialized in ophthalmology (Investigative Ophthalmology & Visual Science, Ophthalmology, and the American Journal of Ophthalmology) and the percentage of articles related to AI in ophthalmology published in each of the top 15 journals comprise less than one percent of the overall articles published. This clearly indicates that no one journal is specifically dedicated to publishing articles related to AI in ophthalmology. A total of 71 reviews were retrieved in the WoSCC. These reviews were published in 47 journals, and were cited 5151 times with an average of 72.55 citations per article.

3. Countries, International Collaborations, and Institutions

A total of 65 countries were found in author affiliations in the 1215 articles studied. Thirty three (2.72%) articles were entered without author information, so without countries of affiliation. Table 2 shows the ten most productive countries in AI in ophthalmology. As expected, the USA accounted for the largest number of articles published, far more than other countries. The ratio "percentage of articles divided by the percentage of citations" was equal to 1.43 for the USA, logically meaning that articles published by researchers located in the USA were cited 1.43 times more than expected. This shows the high scientific impact of research on AI in ophthalmology in the USA. To a lesser extent, this is also the case for Germany and the UK (ratios equal to 1.24 and 1.16, respectively). Conversely, articles from China, Japan, and Australia are less cited than expected, with ratios equal to 0.56, 0.62, and 0.65, respectively (almost half of the citations expected for China). All other countries, with ratios close to one, received the number of citations expected.

Table 2: Top 10 most productive countries for AI in ophthalmology research.

Country	No. of articles (%)	No. of citations (%)	Ratio "percentage of citations / percentage of articles"	Average citation per article	No. of articles with international collaboration (%)
USA	419 (34.5)	17785 (49.34)	1.43	42.44	147 (35.08)
China	169 (13.91)	2812 (7.8)	0.56	16.64	69 (40.83)
UK	113 (9.3)	3901 (10.82)	1.16	34.52	68 (61.06)
Germany	88 (7.24)	3231 (8.96)	1.24	36.71	41 (46.59)
Australia	66 (5.43)	1264 (3.51)	0.65	19.15	40 (60.61)
Singapore	59 (4.86)	1769 (4.91)	1.00	29.98	43 (72.88)
India	58 (4.77)	1816 (5.04)	1.05	31.31	21 (36.2)
Japan	57 (4.69)	1042 (2.89)	0.62	18.28	15 (26.31)
Spain	49 (4.03)	1496 (4.15)	1.04	30.53	19 (38.78)
France	48 (3.95)	1564 (4.34)	1.08	32.58	30 (62.5)

The number of articles with international collaboration was 316 (26.1%), with Singapore in the lead (72.88% of articles with international collaboration). The analysis of international collaboration (Fig. 3) shows that the USA, Germany, the United Kingdom, and China are hubs of the international collaborative network. Apart from these countries, researchers tended to collaborate with researchers from neighboring countries. For example, most of the countries situated in Europe (The Netherlands, Switzerland, Spain, Portugal, Poland, and Belgium, shown in red in Fig. 3) or in Asia (Singapore, India, and Malaysia (shown in purple in Fig. 3) are in this case.

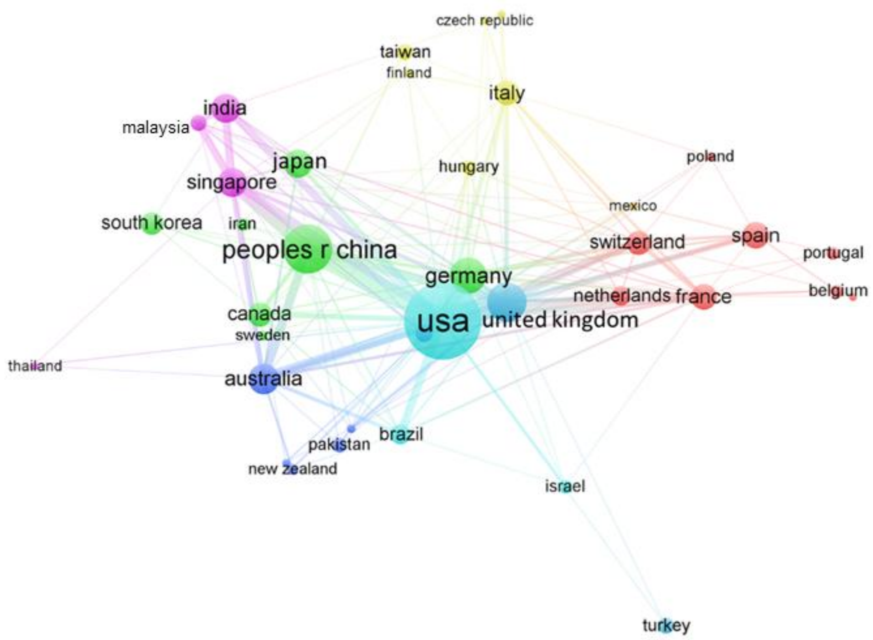

Fig. 3 Visual map of networks of country collaboration. A minimum of five documents per country was set as the threshold and 37 countries were included in the map. Dots represent countries and their size indicates the number of publications. Colors indicate different clusters with a high degree of collaboration. The thickness of the link between any two countries is indicative of the extent of co-authorship (i.e. collaboration)

Of the top 10 most productive institutions, four are located in the USA and three are in Singapore (Table 3). The articles published by most institutions located in the USA are cited more often than the average value obtained for articles overall. For example, the articles from the University of Iowa are cited four times more than the average value. This shows that these institutions are not only very productive quantitatively (number of articles), but also qualitatively (number of citations).

Table 3: Top 10 most productive institutions for AI in ophthalmology research.

Institution (country)	No. of articles (%)	No. of citations (%)	Ratio "percentage of citations / percentage of articles"	Average citations per article
University of California San Francisco (USA)	63 (5.19)	4073 (11.3)	2.18	64.65
Harvard University (USA)	36 (2.96)	2186 (6.06)	2.05	60.72
University of London (UK)	36 (2.96)	1066 (2.96)	1.00	29.61
National University of Singapore (Singapore)	36 (2.96)	1183 (3.28)	1.11	32.86
Johns Hopkins University (USA)	30 (2.47)	780 (2.16)	0.88	26
Agency for Science Technology Research (Singapore)	27 (2.22)	662 (1.84)	0.83	24.52
Chinese Academy of Sciences (China)	26 (2.14)	982 (2.72)	1.27	37.77
University of Iowa (USA)	26 (2.14)	2988 (8.29)	3.87	114.92
Nanyang Technological University (Singapore)	24 (1.98)	650 (1.8)	0.91	27.08
Eidgenossische Technische Hochschule Zurich (Switzerland)	22 (1.81)	741 (2.06)	1.14	33.68

4. Analysis of Subject Categories and MeSH Terms

Based on the Journal Citation Reports (JCR) categories, the AI in ophthalmology output data were distributed into subject categories. As shown Table 4, most focus on engineering and computing, and only two are related to medicine/clinical practice (Ophthalmology, n = 242; 19.81% and Neurosciences, n = 148; 12.18%).

Table 4: Top 10 JCR categories of journals on AI in ophthalmology research.

Web of Science Categories	No. of articles (%)
Engineering biomedical	337 (27.74)
Ophthalmology	242 (19.91)
Computer science interdisciplinary applications	177 (14.57)
Neurosciences	148 (12.18)
Radiology nuclear medicine medical imaging	145 (11.93)
Medical informatics	142 (11.69)
Engineering electrical electronic	134 (11.03)
Computer science artificial intelligence	125 (10.29)
Mathematical computational biology	101 (8.31)
Computer science theory methods	87 (7.16)

The number of MeSH terms found in PubMed was 15792 (average of 11.64 MeSH terms per article) among the 1356 articles. Among these 15792 MeSH terms, 1865 unique MeSH terms were identified. The 20 most frequent MeSH terms are presented Fig. 4. These MESH terms can be aggregated into four main categories: Artificial Intelligence, which is well represented (e.g. Neural Networks Computer, Machine Learning, Deep Learning), Image Analysis (e.g. Image Interpretation, Computer-Assisted, Image Enhancement), and Method Evaluations (e.g. Sensitivity and Specificity, Reproducibility of Results, ROC Curves). The fourth category (Ophthalmology) is represented by clinical MeSH terms related to the retina and glaucoma (Supplementary Table 2 shows complementary data for each of these four MeSH terms: the five most co-occurring MeSH terms in articles with these four MeSH terms).

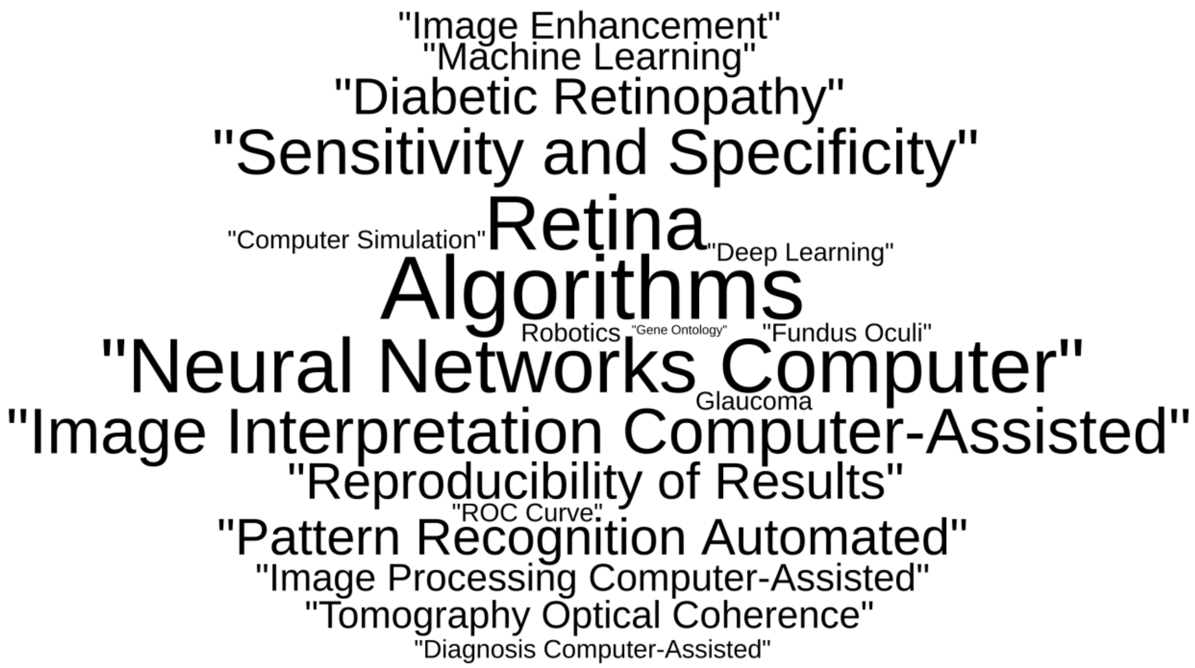

Fig. 4 Word cloud of the twenty most frequent MeSH terms for AI in ophthalmology research. The size of the words is proportional to their frequency. Terms used in the search query were excluded

The number of MeSH terms found in the 84 reviews was 782. Among these 782 MeSH terms, 266 unique MeSH terms were identified. Fig. 5 presents the word cloud of the twenty most frequent MeSH terms found in these 84 reviews.

Fig. 5 Word cloud of the twenty most frequent MeSH terms for AI in ophthalmology research limited to reviews. The size of the words is proportional to their frequency. Terms used in the search query were excluded

Discussion

The aim of this study was to perform a bibliometric analysis related to AI in ophthalmology. This is an original article and not a systematic review or a meta-analysis. To our knowledge, no similar studies have been conducted to date. This analysis was done using PubMed and WosCC databases, allowing the use of both MeSH terms in the query to obtain qualitative data (citations) as well as reliable determinations of authors' affiliations with countries in the articles studied [18]. The usefulness of using controlled thesaurus vocabulary as MeSH terms for indexing and retrieving documents is well known [20, 21]. In this study, the MeSH terms "Artificial Intelligence" allowed us to search 13 sub-categories [https://www.ncbi.nlm.nih.gov/mesh/68001185] related to AI (e.g. Machine Learning or Robotics) located beneath AI in the MeSH tree. Please note that these 13 sub-categories related to AI can be called by 128 different synonyms (e.g. Transfer Learning for Machine Learning or Telerobotics for Robotics). Therefore, using the "Artificial Intelligence" MeSH term as a query in PubMed can exhaustively retrieve, in one shot, articles related to these 13 sub-categories that can have 128 different synonyms. This great number of existing synonyms makes it difficult to build a search query for extracting articles related to AI in ophthalmology in a bibliographic database (e.g. WosCC) without using MeSH. However, only using PubMed did not allow us to determine the country affiliation of authors with precision. This is because before the year 2014, the country affiliation of the author, when present, indicated only one country per article, which fails to identify collaborative research needed to obtain a qualitative evaluation of research output (i.e. number of citations). Thus, for such a study we must use PubMed and WosCC. There are limitations in the present study. Although PubMed is the most widely used bibliographic database in medicine, it does not contain all biomedical journals and is biased in favor of English-language journals [22]. Using PubMed and WoSCC leads to losing some articles because PubMed and WoSCC databases do not have the same coverage. For example, 141 articles (10.4%) were not taken into account for country, institution, and citation analysis because they were not indexed in the WoSCC. Another potential limitation of this study should be mentioned, as the search was performed in May 2020. This scientific research field is very dynamic, and major publications might not have been included at the time of publication. Despite these limitations, we believe that this study provides a wide view of trends and scientific productivity related to AI in ophthalmology.

With an average yearly growth rate of 18.89% over the last ten years, the growth of AI in ophthalmology publications has been higher than that of the PubMed database as a whole and is exponential. As a comparison, ophthalmology research showed a yearly average growth rate of only 4.27% over the period 2010-2014 with stabilization of the publication rate [18]. This indicates great interest in AI in ophthalmology on the part of the scientific community, "an attractive topic in science" according to Michon et al and Fernandez-Cano et al [23, 24]. Our results are in accordance with former studies which have shown that AI is an attractive topic in other research fields (Global AI [15] and AI related to radiology [25]). One must note that the number of publications in AI in ophthalmology grew sharply between 2016 and 2019, concomitant with Microsoft's announcement that 2016 would be the year of AI, and that its new artificial intelligence and research group would consist of more than 5,000 employees [26]. This shows that the interest in artificial intelligence extends well beyond the academic world. The analysis of the top 15 most productive journals showed that most journals publishing articles related to AI in ophthalmology specialized in computer and medical systems. The percentage of articles related to AI in ophthalmology published in the top 15 was very low (less than one percent for each journal) compared with other subspecialties in ophthalmology (e.g. dry eye diseases [6]). This can result in difficulties for researchers trying to keep up to date with AI in ophthalmology. In contrast, other research fields have some specialized journals that publish a large part of the articles of interest [27].

When analyzing countries, Singapore was found among the top most productive countries in AI in ophthalmology, while it was mentioned among the most productive countries when considering global research in AI [10, 11] or in other medical sub-specialties (e.g. radiology [15]). This position can be explained by the presence of three institutions located in Singapore that were in the top 10 most productive institutions in AI in ophthalmology research and the large number of articles with international collaboration. International collaboration is necessary and is constantly growing [28], given the growth of accumulated knowledge, increased specialization, and the complexity of science [29]. The analysis of international collaboration showed that researchers in Europe and Asia tend to collaborate with researchers from neighboring countries, while the USA, Germany, the United Kingdom, and China, located in collaboration network hubs, tend to collaborate closely with each other [30]. One must note that, due to the multiple motives for international collaboration (i.e. culture, language, history, political and economic factors, or distance between countries [28, 31]), our results are difficult to interpret more precisely. At the country level, Singapore still attracts attention, having a very high percentage of articles with international collaboration. This country has already been singled out in AI in health/medicine by Tran et al. [13] as having one of the highest percentages of papers with international collaboration (66.2%). It is of note that international scientific collaboration has been shown to offer opportunities to small countries [32]. While uncertain, it is true that scientists in small countries have far more scientists outside of their country who can cooperate with others, and far fewer inside than scientists in much larger countries [28].

In order to provide details on article topics and offer additional information on AI in ophthalmology research trends, we analyzed the top 10 JCR categories of journals and MeSH terms for articles. This analysis confirmed that AI in ophthalmology research mainly focuses on engineering and computing and is mainly technical research related to computer methods, not clinical practice. The analysis also confirms that this research topic involves scientists far removed from medicine. In the future, AI could become a powerful tool for improving screening and triage of patients with chronic ocular diseases. It could also help ophthalmologists enhance their ability to diagnose common diseases and facilitate the decision-making process in the fields of retinal disease and glaucoma, for example. In summary, we are faced with a growing healthcare demand and a decreasing number of ophthalmologists, particularly in some rural areas. AI could help by enhancing medical care in this context.

Among the twenty most frequent MeSH terms retrieved, there were only four related to clinical topics, revealing the retina and glaucoma as the most frequent subjects of interest in AI in ophthalmology. Numerous imaging techniques are available for the diagnosis and treatment of retinal diseases, for instance fundus images and optical coherence tomography (OCT). In the literature, commonly explored topics are segmentation of regions of interest such lesions, diabetic retinopathy, and premature or age-related macular degeneration (AMD). Ultimately, some systems are approved by medical institutions, such as IDx [33], approved by the United States Food and Drug Administration and OphtAI, which is European

Conformity marked. There is no denial that AI and deep learning will continue to impact the way in which we screen, manage, and monitor the treatment of retinal diseases, resulting in numerous applications and advances that help us to improve public health. It is predicted that the prevalence of glaucoma will increase by almost 50% over the next twenty years [34]. Glaucoma care is thus currently suffering from a mismatch between capacity and demand. The burden of glaucoma care will continue to grow, and early diagnosis remains a much-needed strategy. AI could enhance access to large-scale screening and will improve medical support in low-resource countries through refined automated strategies for clinical diagnosis [35–37].

In conclusion, this study presents a current view of mainstream research on AI in ophthalmology across the world. This study may be useful for researchers in AI in ophthalmology such as clinicians, but also for scientists. They will better understand this research topic, know the main actors in this field (including journals and countries), and, have an informed overview of this research theme. Decision makers may also be interested in this study to help them guide future developments in this research topic. This analysis can also be useful for those who are less familiar with this field but interested in AI applications in ophthalmology.

Supplementary material

Supplementary Table 1: Check tags for AI in ophthalmology research. Check tags: MeSH terms obligatorily used by indexers to describe recurrent patterns in medical articles for type of material studied (e.g. human, animals, in vitro), gender (male/female), age, chronological elements, and type of study (e.g. comparative study).

Supplementary Table 2: "Medical" MeSH terms for AI in ophthalmology research; top five co-occurring MeSH tems; top five countries, institutions, and journals

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Conflict of interest/Competing interests

The authors have no conflicts of interest to declare that are relevant to the content of this article.

Financial or non-financial interests

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Check tag	Number of articles indexed with this MeSH term (%)
Humans	1148 (84.66)
Female	302 (22.27)
Male	300 (22.12)
Animals	242 (17.85)
Middle Aged	229 (16.89)
Aged	164 (12.09)
Adult	163 (12.02)
Aged 80 and over	57 (4.2)
Young Adult	44 (3.24)
Adolescent	38 (2.8)
Mice	29 (2.14)
Child	19 (1.4)
Rats	14 (1.03)
Child Preschool	14 (1.03)
Rabbits	13 (0.96)
Infant	10 (0.74)
Infant Newborn	8 (0.59)
Cats	6 (0.44)
Chick Embryo	4 (0.29)
Cattle	3 (0.22)
Dogs	2 (0.15)
Guinea Pigs	2 (0.15)
Pregnancy	1 (0.07)
History 20th Century	1 (0.07)

Supplementary Table 1: Check tags for AI in ophthalmology research

Check tags: MeSH terms obligatorily used by indexers to describe recurrent patterns in medical articles for type of material studied (e.g. human, animals, in vitro), gender (male/female), age, chronological elements, and type of study (e.g. comparative study).

MH terms	FIve most co-occurring MeSH terms in articles with the MeSH term in the first column (% of co-occurrence)
Retina	Neural_Networks_Computer (45.27) Algorithms (37.25) Artificial_Intelligence (26.65) Image_Interpretation_Computer-Assisted (22.64) Models_Neurological (17.19)
Diabetic_Retinopathy	Algorithms (69.21) Image_Interpretation_Computer-Assisted (45.02) Sensitivity_and_Specificity (37.7) Pattern_Recognition_Automated (31.94) Artificial_Intelligence (30.37)
Glaucoma	Algorithms (37.69) Neural_Networks_Computer (33.85) Optic_Disk (28.46) Artificial_Intelligence (28.46) Sensitivity_and_Specificity (27.69)
Fundus_Oculi	Algorithms (56.2) Neural_Networks_Computer (39.67) Diabetic_Retinopathy (36.36) Image_Interpretation_Computer-Assisted (33.88) Image_Processing_Computer-Assisted (33.06)

Supplementary Table 2: "Medical" MeSH terms for AI in ophthalmology research; top five co-occurring MeSH tems; top five countries, institutions, and journals.