Global trends and prospects in research of artificial cornea over past 20 years: a bibliometric and visualized analysis

Youran Cai · Jiaxin Zhou · Xuyang Xu · Bingbing He · Wenjin Zou

Received: 12 September 2022 / Accepted: 17 November 2022 / Published online: 27 November 2022
© The Author(s), under exclusive licence to Springer Nature B.V. 2022

Abstract

Background  Many studies have been focused on the area of the artificial cornea. In our study, a bibliometric analysis was performed on the artificial cornea to identify the global key research fields and trends over the past 20 years.

Methods  Publications about artificial cornea were retrieved and downloaded from the Web of Science Core Collection from 2002 to 2021. CiteSpace and VOSviewer were used to analyze countries, institutions, authors, and related research areas.

Results  A total of 829 eligible publications were analyzed. The USA was the most productive country for the artificial cornea, followed by China and Canada. Harvard University was the most prolific institution in this field. Cornea published most of the studies in this area and Dohlman CH was the most cited author.

Conclusions  Bibliometric analysis in our study first provides a general perspective on the artificial cornea, which can be helpful to further explore the issues in the rapidly developing area.

Keywords  Artificial cornea · Bibliometric analysis · Publication · CiteSpace · VOSviewer

Introduction

Corneal diseases contribute significantly to blindness worldwide, accounting for 12% of total global blindness [1, 2]. Primary corneal transplantation has high rates of graft survival in non-complex eyes [3]. Graft survival decreases in eyes requiring repeat transplantation and complex eyes despite advances in surgical techniques such as selective lamellar keratoplasty [3]. Cornea transplantation in eyes with recurrent and chronic inflammation of the ocular surface, glaucoma, and cornea vascularization is most likely to fail. The availability of cornea tissue varies globally dependent on donor supply and the need for adequate processing facilities [4]. Hence, the development of an “artificial cornea” (keratoprosthesis, KPro) can be considered for end-stage corneal diseases (multiple graft failures or inflammatory ocular surface disease) or as primary treatment to surmount these problems [5, 6].

A keratoprosthesis is an artificial or prosthetic cornea made of synthetic materials to restore the vision of patients with severe corneal diseases [7, 8]. Pellier de Quengsy first proposed the idea of keratoprosthesis in 1779 with a gradual introduction of various types of keratoprosthesis [9]. At present, there are three main types of corneal prosthesis widely used: the Boston Keratoprosthesis (B-KPro) [10, 11], the osteo-odontokeratoprosthesis (OOKP) [12, 13] and the MICOF (Moscow Eye Microsurgery Complex in Russia) [14].
Bibliometric analysis is a standard method that uses mathematical and statistical approaches to exploit bibliometric theory. It is widely used to analyze pertinent literature in various research areas [15]. For instance, a global bibliometric analysis of corneal transplants was performed by Pekel et al. to present the publication trends of the past decade [16]. However, a global bibliometric analysis of artificial cornea has not yet been conducted. Our study was designed to provide an overview of global artificial cornea research based on WoSCC data from 2002 to 2021. Bibliometric analysis was applied to generate the research focus, frontiers, and critical publications of artificial cornea combined with citation information to offer a comprehensive and promising reference for related researchers.

Materials and methods

Data source and search strategies

WoSCC provided by Thomson Reuters (Philadelphia, PA, USA) is the most extensive database available and is regarded as the best database for bibliometric analysis [17]. The literature was extracted from WoSCC for the period from 2002 to 2021. The following terms were searched as follows: TS = (“artificial cornea” OR “artificial corneas” OR keratoprosthesis OR kPro OR kPros OR “bioartificial cornea” OR “bioartificial corneas” OR “cornea, bioartificial” OR “corneas, bioartificial”). Only articles and reviews will be included. The language was not restricted as the English abstracts were available. Our study did not directly contact any individual participants, thus ethical approval was not necessary.

Data collection and extraction

Following the above-mentioned search strategies, all data including titles, authors, abstracts, keywords, journals, and cited references were downloaded in “plain text” format and stored in “download_txt” format. We retrieved 1181 publications. All searches were carried out within one day (on 18 August 17, 2022) to avoid prejudice related to database updates. Two investigators (Y.C. and J.Z.) independently performed the research and discussed the controversial publications. The discussion continued until the investigators reached 100% agreement [18]. The information on journal impact factor (IF) and disciplinary category quartiles (Q1-Q4) was obtained from the Journal Citation Report (JCR) (Clarivate Analytics, Philadelphia, United States). The h-index measures the citation impact of individual research results [19].

Bibliometric analysis

Microsoft Excel 2021 (Microsoft Corporation, Redmond, WA, USA) and the bibliometrix package in R 4.2.1 were used for the analysis of bibliometric indicators including annual counts of publications/citations, top-cited publications, countries/regions, institutions, journals, and authors, as well as keywords. CiteSpace V (version 5.8 R3) [20], VOSviewer (version 1.6.18) [21] and the online bibliometric website (https://bibliometric.com/app) were used for bibliometric analysis and data visualizations. Different colors in the network visualization represent various groupings, including nations, authors, and institutions, while connecting lines represent factors such as cooperation and citation. The diameter of the circle indicates how strong the association is. The degree of collaboration is shown by the coarseness of the connecting lines [22–24]. The network’s Q value indicated the network’s modularity. The network’s cluster performs better the higher the Q value. When Q>0.3, the network cluster structure was noteworthy. The homogeneity of a cluster network is gaged using the silhouette value. The homogeneity of the cluster network increased as the silhouette value approached 1. The results of the cluster analysis demonstrated good reliability when the silhouette value was greater than 0.7 [25].

Results

Flowchart for searching

Figure 1 shows the criteria for selecting publications for the collection, as follows: (1) a time interval of 2002 to 2021; (2) publication included in the WoSCC; (3) articles and reviews; (4) title and abstract available and related to the artificial cornea field.
Global trends of publications

Figure 2A shows the annual trends of publications and citations per publication about artificial cornea from 2002 to 2021. The period of papers published during the past 20 years could be divided into three periods: the initial period was from 2002 to 2007, with the growth rate being significantly low in this stage. The second stage was the development period from 2008 to 2014, with the growth rate remaining increased except from 2012 to 2013. And it showed a boom period from 2015 to 2021, accounting for 49.8% (426) of all publications. The most published year was 2016, with 70 publications. The number of published articles presented a stable pattern.

In total, 829 articles published in the past 20 years were included through our search strategy. Over 99% of these articles were published in English. Most of the publications were original research articles (732,

---

**Fig. 1** Search flowchart

**Fig. 2**  
(a) An annual number of publication trends for the past 20 years.  
(b) World map representing the scientific production by countries.  
(c) The cooperation of the country/region contributed to publications.  
(d) Country/region with a minimum of 8 articles co-authorship analysis map.
88.3%), and review articles accounted for 11.7% with 97 publications.

Countries and institute distribution

The articles we collected were from 64 different countries/regions (Fig. 2b). We ranked the top 10 most highly outputs countries/regions in Table 1. The USA had the most articles published (381, 46.0%), followed by China (84, 10.1%) and Canada (80, 9.7%). Figure 2a reveals the annual trends of publications of the five most high-cited countries/regions. Total citations of all the countries/regions were 17,812 times. Articles from the USA were cited by 8387 times, accounting for 47.1% of all the citations, followed by Canada (1768, 9.9%) and China (1339, 7.5%) (Fig. 3b). Among the collaboration between countries/regions (Fig. 2c) and the percentage of

| Ranking | Country/region | TP (%) | SCP (%) | MCP (%) |
|---------|----------------|--------|---------|---------|
| 1       | USA            | 340    | 243 (71.5) | 97 (28.5) |
| 2       | China          | 79     | 68 (86.1)  | 11 (13.9)  |
| 3       | Canada         | 61     | 49 (80.3)  | 12 (19.7)  |
| 4       | India          | 42     | 38 (90.5)  | 4 (9.5)    |
| 5       | Germany        | 40     | 32 (80.0)  | 8 (20.0)   |
| 6       | UK             | 39     | 21 (53.9)  | 18 (46.1)  |
| 7       | Spain          | 31     | 18 (58.1)  | 13 (41.9)  |
| 8       | Singapore      | 26     | 19 (73.1)  | 7 (26.9)   |
| 9       | Australia      | 25     | 9 (36.0)   | 16 (64.0)  |
| 10      | Japan          | 24     | 22 (91.7)  | 2 (8.3)    |

TP: number of articles; SCP: number of publications with intra-country collaboration; MCP: number of publications with inter-country collaboration

Fig. 3  a Top 20 countries/regions with the most publications. The bars show the number of documents divided into MCP and SCP produced by the country/region. b The citations of the top 10 most cited countries/regions. c Institution co-authorship analysis map. d Overlay visualization for the institution in the co-authorship network map. SCP, Number of publications with intra-country collaboration; MCP, Number of publications with inter-country collaboration
multiple country publications (Fig. 3a), we found many countries actively cooperating with other countries, including the USA, Canada and the UK. The most cooperation was between the USA and Canada. Researchers from China, Japan and India were lower active in collaboration with other countries. Figure 2d shows a country/region co-authorship produced by VOSviewer. Out of the 25 countries/regions with at least 8 articles used to generate the co-authorship network, the USA was the most influential country/region with a total link strength (TLS) is 189, followed by the UK (TLS = 61) and Brazil (TLS = 45).

In our study, 890 institutions contributed to the publications we included. The 69 institutions with a minimum of 5 documents were demonstrated in Fig. 3c. Harvard University in the USA holds the most publications, followed by University of Illinois in the USA and L V Prasad Eye Institute in India. We ranked in the top 10 most prolific institutions in this research field in Table 2. Seven institutions are from the USA, two in Singapore, and the other in India. From Fig. 3d, the most prolific institutions published main articles from 2012 to 2016. Figure 4b shows the institution collaboration network, the most collaborative organization is Singapore National Eye Center, followed by Singapore Eye Research Institution and Harvard University.

Journals and articles distribution

All the publications were from 189 different journals in the past 20 years. We have comprehensively ranked the features of the 10 most prolific journals collectively in Table 3. The journals published 378 articles, accounting for 45.6% of all the publications. Cornea was the most productive journal of all (164, 19.8%). This was followed by the American Journal of Ophthalmology (37, 4.5%) and the British Journal of Ophthalmology (36, 4.3%). All these journals were categorized into ophthalmology apart from the Biomaterials. Articles from Cornea were the most cited, with citations 3554 times, followed by Ophthalmology (1848) and American Journal of Ophthalmology (966). Ophthalmology ranked first in the number of citations per publication (61.6), followed by Biomaterials (54.1). The dual-map overlay of journals in Fig. 4c was performed by CiteSpace. The citing journal graphs are in the left cluster, while the cited journal graphs are in the right. The lines on the left and right are citation links [26]. We found that most articles were published in journals of neurology, sports and ophthalmology, and these journals mainly cited journals of chemistry/materials/physics, molecular/biology/genetics and ophthalmology.

The first 10 most cited articles are listed in Table 4. The citations of the paper written by Zebra BL in 2006 were 260 times, ranking the first. Of all the 10 articles, only one was a review article, as the others were all research articles. Eight of the articles were written by American scholars while the other authors were from Canada and China, respectively. Most of the articles were published in ophthalmologic journals with articles published in materials journals.

| Table 2 The top 10 productive institutions |
|-------------------------------------------|
| Ranking | Institution               | Articles | TC     | CPP 2021 | Country |
|---------|---------------------------|----------|--------|----------|---------|
| 1       | Harvard Univ              | 166      | 1902   | 11.5     | USA     |
| 2       | Univ Illinois             | 48       | 355    | 7.4      | USA     |
| 3       | LV Prasad Eye Inst        | 42       | 233    | 5.6      | India   |
| 4       | Univ Calif Los Angeles   | 36       | 668    | 18.6     | USA     |
| 5       | Singapore Natl Eye Ctr    | 32       | 471    | 14.7     | Singapore |
| 6       | Johns Hopkins Univ        | 31       | 359    | 11.6     | USA     |
| 7       | Stanford Univ             | 31       | 284    | 9.2      | USA     |
| 8       | Singapore Eye Res Inst    | 31       | 231    | 7.5      | Singapore |
| 9       | Massachusetts Eye & Ear Infirm | 29 | 614    | 21.2     | USA     |
| 10      | Sankara Nethralaya        | 29       | 224    | 7.7      | India   |

TC: number of citations; CPP: number of citations per publication
**Fig. 4**  
(a) The network of institutions.  
(b) The network of co-authors.  
(c) A dual-map overlay of the literature’s journals

### Table 3  
The top 10 most prolific journals

| Ranking | Journal                                                        | Counts (%) | TC    | h-index | IF\textsubscript{2021} | Web of Science category | CPP\textsubscript{2021} |
|---------|---------------------------------------------------------------|------------|-------|---------|-------------------------|-------------------------|------------------------|
| 1       | *Cornea*                                                      | 164 (19.8) | 3554  | 32      | 3.152                   | Ophthalmology            | 21.7                   |
| 2       | *American Journal of Ophthalmology*                          | 37 (4.5)   | 966   | 18      | 5.488                   | Ophthalmology            | 26.1                   |
| 3       | *British Journal of Ophthalmology*                           | 36 (4.3)   | 564   | 14      | 5.908                   | Ophthalmology            | 15.7                   |
| 4       | *Ophthalmology*                                               | 30 (3.6)   | 1848  | 22      | 14.277                  | Ophthalmology            | 61.6                   |
| 5       | *Ocular Surface*                                              | 23 (2.8)   | 484   | 16      | 6.268                   | Ophthalmology            | 21.0                   |
| 6       | *Investigative Ophthalmology & Visual Science*                | 23 (2.8)   | 589   | 12      | 4.925                   | Ophthalmology            | 25.6                   |
| 7       | *Graefe's Archive for Clinical and Experimental Ophthalmology* | 19 (2.3)   | 354   | 12      | 3.535                   | Ophthalmology            | 18.6                   |
| 8       | *Retina-The Journal of Retinal and Vitreous Disease*         | 17 (2.1)   | 171   | 8       | 3.975                   | Ophthalmology            | 10.1                   |
| 9       | *Current Opinion in Ophthalmology*                           | 15 (1.8)   | 449   | 11      | 4.299                   | Ophthalmology            | 29.9                   |
| 10      | *Biomaterials*                                                | 14 (1.7)   | 758   | 13      | 15.304                  | Engineering, biomedical  | 54.1                   |

TC: number of citations; IF: impact factor; CPP: number of citations per publication
| First author | Title                                                                 | Year | Journal                        | Quartile | IF   | TC  | Type                     | Countries/regions |
|--------------|----------------------------------------------------------------------|------|--------------------------------|----------|------|-----|--------------------------|-------------------|
| Zerbe BL     | Results from the multicenter Boston Type 1 Keratoprosthesis Study    | 2006 | Ophthalmology                  | Q1       | 14.277 | 260 | Research article         | USA               |
| Aldave AJ    | The Boston type I keratoprosthesis: improving outcomes and expanding indications | 2009 | Ophthalmology                  | Q1       | 14.277 | 222 | Research article         | USA               |
| Duan X       | Dendrimer crosslinked collagen as a corneal tissue engineering scaffold: Mechanical properties and corneal epithelial cell interactions | 2006 | Biomaterials                   | Q1       | 15.304 | 220 | Research article         | Canada            |
| Chew HF      | Boston keratoprosthesis outcomes and complications                   | 2009 | Cornea                         | Q2       | 3.152  | 182 | Research article         | USA               |
| Wang JH      | Preparation and in vitro characterization of BC/PVA hydrogel composite for its potential use as artificial cornea biomaterial | 2010 | Mat Sci Eng C-Mater            | Q2       | 7.328  | 151 | Research article         | China             |
| Ruberti JW   | Corneal biomechanics and biomaterials                                | 2011 | Annu Rev Biomed Eng            | Q1       | 11.324 | 141 | Review                   | USA               |
| Greiner MA   | Longer-term vision outcomes and complications with the Boston type 1 keratoprosthesis at the University of California, Davis | 2011 | Ophthalmology                  | Q1       | 14.277 | 138 | Research article         | USA               |
| Bradley JC   | Boston type 1 keratoprosthesis: the university of california davis experience | 2009 | Cornea                         | Q2       | 3.152  | 135 | Research article         | USA               |
| Falcinelli G | Modified osteo-odontokeratoprosthesis for treatment of corneal blindness: long-term anatomical and functional outcomes in 181 cases | 2005 | Arch Ophthalmol-Chic           | Q1       | 8.253  | 134 | Research article         | Italy             |
| Sayegh RR    | The Boston keratoprosthesis in Stevens-Johnson syndrome              | 2008 | Am J Ophthalmol                | Q1       | 5.488  | 121 | Research article         | USA               |

IF: impact factor; TC: number of citations
Authors and co-authors distribution

Over 2,900 authors made contributions to the publications included in our study. We identified the 10 most productive authors in the artificial cornea area including $h$-index, citations, countries and publications (Table 5). Scientists from the USA contribute an enormous of articles to this field. Dohlman CH was the most active author, with 70 articles, followed by Chodosh J (57) and Harissa-Dagher M (42). In terms of citations in this area, the first author was the same as the most productive. Dohlman CH ranked first with 1206 times and followed by Aldave AJ (608) and Harissa-Dagher M, with 529 times. The collaborations between authors are presented in Fig. 4b. The 5 authors with the highest TLS were Dohlman CH (TLS = 3344), Chodosh J (TLS = 2535), Harissi-Dagher M (TLS = 1890), Aldave AJ (TLS = 1581) and Yu F (TLS = 1050).

Table 5 The top 10 productive authors

| Ranking | Author          | TP  | TC   | TLS  | $h$-index | Country  |
|---------|-----------------|-----|------|------|-----------|----------|
| 1       | Dohlman CH      | 70  | 1924 | 3344 | 27        | USA      |
| 2       | Chodosh J       | 57  | 1045 | 2535 | 21        | USA      |
| 3       | Harissi-Dagher M| 42  | 851  | 1890 | 18        | Canada   |
| 4       | Akpek EK        | 25  | 706  | 1581 | 16        | USA      |
| 5       | Aldave AJ       | 24  | 865  | 726  | 15        | USA      |
| 6       | Aquavella JV     | 16  | 645  | 764  | 14        | USA      |
| 7       | Mehta JS        | 19  | 461  | 753  | 13        | Canada   |
| 8       | Robert MC       | 20  | 418  | 880  | 13        | Canada   |
| 9       | Cortina MS      | 27  | 397  | 1032 | 12        | USA      |
| 10      | De La Cruz J    | 21  | 386  | 584  | 12        | USA      |

TP: number of articles; TC: number of citations; TLS: total link strength

Fig. 5  
A Treemap of the top 20 most frequently used keywords.  
B Top 20 keywords with the strongest citation burst on the artificial cornea from 2002 to 2021.  
C Timeline map of the keywords from 2002 to 2021.  
D Keywords cluster analysis co-occurrence map.
Analysis of keywords

THE core word extractions provided by scholars in the studies are keywords. According to the treemap of the most frequent 20 author keywords (Fig. 5a), the top five keywords with a significant number of occurrences are outcomes that appear 147 times; complications 117 times; implantation 89 times; penetrating keratoplasty 88 times and surgery 85 times. The burst keywords through CiteSpace were explored and 20 keywords with the strongest strength of the last 20 years were identified (Fig. 5b). We used CiteSpace to perform a subject clustering map (Fig. 5d) and timeline (Fig. 5c). The articles on the artificial cornea field published from 2002 to 2021 could be categorized into 10 main research hotspots, each of different sizes and periods. The modularity Q value was 0.7394 and the average silhouette value was 0.8919, demonstrating that clustering quality was acceptable. The first 10 clusters were generalized and ordered from the largest to the smallest number of co-cited references. The first cluster was “#0 long-term outcome”, and this was followed by “#1 corneal epithelial cell migration” and “#2 anterior segment”. The top 20 keywords with the most vigorous citation burst are shown in Fig. 4b. The earliest and highest strength burst keyword in the past 20 years was “artificial cornea”, which was from 2002 to 2010. The keywords appeared at different time points and periods, with the highest intensity of the words being “retention” in recent years. As shown in the timeline view, a cluster called “#2 anterior segment” appeared in recent years. The cluster “#0 long-term outcome”, “#5 Boston keratoprosthesis type” and “#7 corneal regeneration” were present throughout.

Discussion

In this study, we conducted a bibliometric and visualized analysis of the last 20 years of WoSCC-based SCI artificial cornea. We provide insight into artificial cornea for SCI and some valuable information. The quantity of publications in each period can indicate the trends in an area of a study. In our analysis, the number of documents published has increased rapidly since 2008 and reached its peak in recent years. Although common artificial corneas such as B-kPro and OOKP had been developed before 2000, their original techniques were refined and standardized later [13, 27]. This might be related to the high increase rate of the number of publications since 2008. Currently, this research field remains a hot topic both in ophthalmology and the materials field.

Researchers and institutes from the USA were the core study strength with about 46.0% of all publications. In addition, publications from the USA were the highest cited as well. All of these results indicate that the USA leading the quality of articles, institutions, and journals in this field. This result follows a similar trend to many bibliometric studies in other areas, which confirms the USA as an international research leader in both quantity and quality [28–30]. China and Canada jointly contributed to the dominant number of publications. However, countries with higher economic rankings were reported to have more and higher qualitative biomedical publications [31]. Of the top prolific countries/regions in our study, countries from other developing areas such as China and India made both noticeable contributions to the artificial cornea field. The academic cooperation network shows that regions such as the USA, Germany and Australia were active in interactions with other regions. However, Asian countries like China, Japan and India were lower active in cooperating with others even though the production was high in these countries. These regions should actively cooperate with others in this field as a higher academic level can be approached by a collaboration of countries and institutions. In addition, the highest TLS was the USA, followed by the UK and Brazil. This demonstrates that contents, originality, usefulness and new contributions of the research may be more closely tied to the citations received than the number of publications.

Regarding institutions, Harvard University was the most prolific of all the institutions. The top 10 most productive institutions were from the USA, India and Singapore. Although most productive countries including China and Canada, their institutions could not get into the most prolific institutions. This might be related to the researchers and institutions that were quite scattered in these countries in the artificial field.

Analyzing journals could help scholars to choose appropriate journals for their paper submission. Journals in the ophthalmology field contributed the most to the artificial area. The journal “Cornea” ranked the first productive journal, with the highest h-index.
Authors generally tend to choose high IF journals for their research publication, and journals with high IF are also interested in publishing high quality papers [32]. All of the top 10 most productive journals had an IF > 3.0, and six of them had an IF > 5.0. The number of citations per article was significantly high in Ophthalmology and Biomaterials. The journals were the only two journals in which IF was over 10. This indicates that the articles in the high IF journals obtain, on average, a more significant number of citations.

Time has an essential effect on articles’ citations as the citations of articles accumulate depending on the publication time. While it may take 15 years or more for an article to reach its peak total citations [33], three articles have been published in less than 15 years among the top 5 highest cited articles [34–36]. The citations of these articles might continue to increase over the coming years. Of the top 10 cited articles, 60% of these were about the Boston type I keratoprosthesis [34, 35, 37–40], as the Boston type I keratoprosthesis is the most commonly used synthetic cornea worldwide [5, 34]. Three articles are found in research on biomaterials of cornea [36, 41, 42], which is an essential aspect in the artificial cornea field. The other was about OOKP [13], which is one of the most widely used keratoprosthesis worldwide [43]. However, of these articles only one article was review and the other articles were all research articles, which is different from that reported in the previous study [44]. The review written by Ruberti JW et al. was published in 2011 and is one of the top 10 most recently cited articles. The citations of it may increase in future years [42]. The reason for the few highly cited reviews in our study might be that most review articles were published in recent years. Old published papers are expected to have more citations than recent ones [45]. In addition, articles received more citations than reviews in ophthalmologic journals [46]. There is a lack of high-impact publications in this area, as the most cited article has only 226 citations.

Regarding authors, Dolhman CH from Harvard University was one of the leading research and development staff [47]. He ranked first in productivity, publication citations and h-index. Chodosh J was the second most productive author at the same institution as Dolhman CH. Of the most influential authors, seven authors were from the USA, and the other authors were from Canada and Singapore. This is consistent with the result for the most productive countries/regions. This may indicate that the number of active authors is usually higher in fertile countries/regions. In addition, the collaboration result illustrates close and comprehensive cooperation among scholars all over the world, which indicates have been extensive developments within this field.

Burst keywords can reveal a large amount of attention from experts in a particular area over an extended period of time [48]. They have always been considered another significant indicator of research frontiers. In our study, burst detection showed that “retention,” “tissue” and “intraocular pressure” were the new hotspots within the field of the artificial cornea. They were comparing the burst keywords “artificial cornea,” “keratoprosthesis” and “adhesion” the last time. The result suggests a shift in focus from the surgery of the artificial cornea to improve prognosis and reduce complications. From the cluster and timeline maps, we found that “long-term outcome,” “Boston keratoprosthesis type” and “corneal regeneration” remained all the time during the 20 years. Therefore, these topics might sustain over time, although new hotspots may arise. The cluster “anterior segment” did not emerge until 2007. This is related to increasing attention on permitting keratoprosthesis by using the anterior segment imaging [49, 50]. The conventional clinical examination techniques for implanted keratoprosthesis remained with several limitations. Anterior segment imaging, such as ultrasound biomicroscope (UBM) and anterior segment optical coherence tomography (AS-OCT), improves the assessment of anterior chamber structures with poor vision after implantation of artificial corneas [51]. In addition, the most frequently occurring keywords were “outcome” and “complications” in the treemap. This is consistent with the burst keywords and timeline map in recent years. All these observations demonstrate improved outcomes and decreased complications after implanting the artificial cornea is a critical hotspot in this field recently.

Limitations

Our study data only included the literature data in WoSCC without other databases like Scopus and Google Scholar. Additionally, the citation data were
only from the articles published from 2002 to 2021, rather than including all the publications in this research area. These issues probably contributed to a selection bias in this study.

Conclusions

In summary, we depicted the scientific output of artificial cornea overall by bibliometric analysis over the past 20 years. Our results reveal that the USA ranked first in terms of productivity, but Asian and European countries also made outstanding contributions. Among all the journals, Cornea has published the maximum number of articles and received the most citations in this field. It seems that the prospects for artificial corneas appear to be even brighter for corneal implantation surgery. We expect that future studies in this area will continue improving the outcomes and reducing complications after implanting the artificial cornea.

Author contributions YC, JZ and WZ contributed to the design of the study. YC and JZ collected and excluded the data. XX and BH performed the statistical analysis. YC wrote the draft of the manuscript. WZ revised the article. All authors critically reviewed the manuscript and approved the final version.

Funding This study was supported by the National Natural Science Foundation of China (81160119) and the Key Research and Development Program in Guangxi (AB20238003).

Data availability The data supporting the findings of this study are available from the corresponding author upon reasonable request.

Declarations

Competing interests The authors declare no competing interests.

Conflict of interest The authors declare no conflicts of interest with the publication of this article.

References

1. Whitcher JP, Srinivasan M, Upadhyay MP (2001) Corneal blindness: a global perspective. Bull World Health Organ 79(3):214–221
2. Pascolini D, Mariotti SP (2012) Global estimates of visual impairment: 2010. Br J Ophthalmol 96(5):614–618. https://doi.org/10.1136/bjophthalmol-2011-300539
3. Tan DT, Dart JK, Holland EJ, Kinoshita S (2012) Corneal transplantation. Lancet 379(9827):1749–1761. https://doi.org/10.1016/s0140-6736(12)60437-1
4. Ballouz D, Sawant OB, Hurlbert S, Titus MS, Majmundar PA, Kumar A, Zhou Y, Musch DC, Mian SI (2021) Impact of the COVID-19 pandemic on keratoplasty and corneal eye banking. Cornea 40(8):1018–1023. https://doi.org/10.1097/ICO.0000000000002748
5. Dohlman C (2022) The Boston keratoprosthesis—the first 50 years: some reminiscences. Annu Rev Vis Sci 8:1–32. https://doi.org/10.1146/annurev-vision-100820-021253
6. Fu L, Hollick EJ (2002) Artificial cornea transplantation. StatPearls Publishing, Treasure Island
7. Avadhanyan VS, Smith HE, Liu C (2015) Keratoprosthesis for corneal blindness: a review of contemporary devices. Clin Ophthalmol 9:697–720. https://doi.org/10.2147/ophth.S27083
8. Akpek EK, Alkharashi M, Hwang FS, Ng SM, Lindsley K (2014) Artificial corneas versus donor corneas for repeat corneal transplants. Cochrane Database Syst Rev 11(11):CD009561. https://doi.org/10.1002/14651858.CD009561.pub2
9. Salvador-Culla B, Kolovou PE (2016) Keratoprosthesis: A Review of Recent Advances in the Field. J Funct Biomater. https://doi.org/10.3390/jfb7020013
10. Dohlman CH, Schneider HA, Doane MG (1974) Prothokeratoplasty. Am J Ophthalmol 77(5):694–770. https://doi.org/10.1002/0002-9394(74)90534-0
11. Dohlman CH, Harissi-Dagher M, Khan BF, Sippel K, Aquavella JV, Graney JM (2006) Introduction to the use of the Boston keratoprosthesis. Expert Rev Ophthalmol 1(1):41–48. https://doi.org/10.1586/17469899.1.1.41
12. Marchi V, Ricci R, Pecorella I, Ciardi A, Di Tondo U (1994) Osteo-odonto-keratoprosthesis. Description of surgical technique with results in 85 patients. Cornea 13(2):125–130
13. Falcinelli G, Falsini B, Taloni M, Colliardo P, Falcinelli G (2005) Modified osteo-odonto-keratoprosthesis for treatment of corneal blindness: long-term anatomical and functional outcomes in 181 cases. Arch Ophthalmol 123(10):1319–1329. https://doi.org/10.1001/archophth.123.10.1319
14. Huang Y, Yu J, Liu D, Du G, Song J, Guo H (2011) Moscow eye microsurgery complex in Russia keratoprosthesis in Beijing. Ophthalmology 118(1):41–46. https://doi.org/10.1016/j.jfph.2010.05.019
15. Zou X, Yue WL, Yu HL (2018) Visualization and analysis of mapping knowledge domain of road safety studies. Accid Anal Prev 118:131–145. https://doi.org/10.1016/j.aap.2018.06.010
16. Pekel E, Pekel G (2016) Publication trends in corneal transplantation: a bibliometric analysis. BMC Ophthalmol 16(1):194. https://doi.org/10.1186/s12886-016-0379-x
17. Leydesdorff L, Carley S, Rafols I (2013) Global maps of science based on the new Web-of-Science categories. Scientometrics 94(2):589–593. https://doi.org/10.1007/s11192-012-0784-8
18. Kundel HL, Polansky M (2003) Measurement of observer agreement. Radiology 228(2):303–308. https://doi.org/10.1148/radiol.2282011860
19. Hirsch JE (2005) An index to quantify an individual’s scientific research output. Proc Natl Acad Sci USA 102(46):16569–16572. https://doi.org/10.1073/pnas.0507655102

20. Synnestvedt MB, Chen C, Holmes JH (2005) CiteSpace II: visualization and knowledge discovery in bibliographic databases. AMIA Annu Symp Proc 2005:724–728

21. van Eck NJ, Waltman L (2010) Software survey: VOSviewer, a computer program for bibliometric mapping. Scientometrics 84(2):523–538. https://doi.org/10.1007/s11192-009-0146-3

22. Lapin M, Tjensvoll K, Oltedal S, Javle M, Smaaland R, Gilje B, Nordgård O (2017) Single-cell mRNA profiling reveals transcriptional heterogeneity among pancreatic circulating tumour cells. BMC Cancer 17(1):390. https://doi.org/10.1186/s12885-017-3385-3

23. Fu J, Jiang Z, Hong Y, Liu S, Kong D, Zhong Z, Luo Y (2021) Global scientific research on social participation of older people from 2000 to 2019: a bibliometric analysis. Int J Older People Nurs 16(1):e12349. https://doi.org/10.1111/opn.12349

24. Liu T, Liu X, Li Y, Liu S, Cao C (2021) evolving trends and research hotspots in disaster epidemiology from 1985 to 2020: a bibliometric analysis. Front Public Health 9:720787. https://doi.org/10.3389/fpubh.2021.720787

25. Jie L, Chen C (2017) Citespace: text mining and visualization in scientific literature, 2nd edn. Capital University of Economics and Business Press, Beijing

26. Ke L, Lu C, Shen R, Lu T, Ma B, Hua Y (2020) Knowledge mapping of drug-induced liver injury: a scientometric investigation (2010–2019). Front Pharmacol 11:842. https://doi.org/10.3389/fphar.2020.00842

27. Dohlmman CHH-DM, Khan BF et al. (2006) Introduction to the use of the Boston keratoprosthesis. Expert Rev Ophthalmol 1:41–48

28. Ahmad T, Imran M, Ahmad K, Khan M, Baig M, Al-Rifai RH, Al-Omari B (2021) A bibliometric analysis and global trends in fascioliasis research: a neglected tropical disease. Animals (Basel). https://doi.org/10.3390/ani11123385

29. Yao RQ, Ren C, Wang JN, Wu GS, Zhu XM, Xia ZF, Yao YM (2020) Publication trends of research on sepsis and host immune response during 1999–2019: a 20-year bibliometric analysis. Int J Biol Sci 16(1):27–37. https://doi.org/10.7150/ijbs.37496

30. Sweileh WM, Al-Jabi SW, Sawalha AF, AbuTaha AS, Zyoud SH (2016) Bibliometric analysis of medicine-related publications on poverty (2005–2015). Springerplus 5(1):1888. https://doi.org/10.1186/s40064-016-3593-3

31. Qiu L, Binns CW, Zhao Y, Zhang K, Xie X (2010) Hepatitis B and breastfeeding in Hangzhou, Zhejiang Province, People’s Republic of China. Breastfeed Med 5(3):109–112. https://doi.org/10.1089/bfm.2009.0093

32. Gondivkar SM, Sarode SC, Gadbail AR, Gondivkar RS, Choudhary N, Patil S (2018) Citation classics in cone beam computed tomography: the 100 top-cited articles. Int J Dent 2018:9423281. https://doi.org/10.1155/2018/9423281

33. Loonen MPI, Hage JJ, Kon M (2008) Plastic Surgery Classics: characteristics of 50 top-cited articles in four Plastic Surgery Journals since 1946. Plast Reconstr Surg 121(5):320e-e327. https://doi.org/10.1097/PRS.0b013e31816b13a9

34. Aldave AJ, Kamal KM, Vo RC, Yu F (2009) The Boston type 1 keratoprosthesis: improving outcomes and expanding indications. Ophthalmology 116(4):640–651. https://doi.org/10.1016/j.ophtha.2008.12.058

35. Chew HF, Ayres BD, Hammersmith KM, Rapuano CJ, Laibson PR, Myers JS, Jin YP, Cohen EJ (2009) Boston keratoprosthesis outcomes and complications. Cornea 28(9):989–996. https://doi.org/10.1097/ICO.0b013e3181a186dc

36. Wang JH, Gao C, Zhang YS, Wan YZ (2010) Preparation and in vitro characterization of BC/PVA hydrogel composite for its potential use as artificial corneal biomaterial. Mater Sci Eng C Mater Biol Appl 30(1):214–218. https://doi.org/10.1016/j.msec.2009.10.006

37. Zerbe BL, Belin MW, Ciolino JB (2006) Results from the multicenter Boston type 1 Keratoprosthesis study. Ophthalmology 113(10):1779.e1–7. https://doi.org/10.1016/j.ophtha.2006.05.015

38. Bradley JC, Hernandez EG, Schwab IR, Mannis MJ (2009) Boston type 1 keratoprosthesis: the University of California Davis experience. Cornea 28(3):321–327. https://doi.org/10.1097/ICO.0b013e31818b6bfa

39. Greiner MA, Li JY, Mannis MJ (2011) Longer-term vision outcomes and complications with the Boston type 1 keratoprosthesis at the University of California. Davis Ophthalmology 118(8):1543–1550. https://doi.org/10.1016/j.ophtha.2010.12.032

40. Sayegh RR, Ang LP, Foster CS, Dohlmman CH (2008) The Boston keratoprosthesis in Stevens-Johnson syndrome. Am J Ophthalmol 145(3):438–444. https://doi.org/10.1016/j.ajo.2007.11.002

41. Duan X, Sheardown H (2006) Dendrimer crosslinked collagen as a corneal tissue engineering scaffold: mechanical properties and corneal epithelial cell interactions. Biomaterials 27(26):4608–4617. https://doi.org/10.1016/j.biomaterials.2006.04.022

42. Ruberti JW, Sinha Roy A, Roberts CJ (2011) Corneal biomechanics and biomaterials. Annu Rev Biomed Eng 13:269–295. https://doi.org/10.1146/annurev-bioeng-070909-105243

43. Liu C, Paul B, Tandon R, Lee E, Fong K, Makrikakis I, Herold J, Thorp S, Brittain P, Francis I, Ferrett C, Hutt C, Lloyd A, Green D, Franklin V, Tighe B, Fukuda M, Hamada S (2005) The osteo-odontokeratoprosthesis (OOKP). Semin Ophthalmol 20(2):113–128. https://doi.org/10.1016/j.semoph.2009.218.006

44. Usman MS, Siddiqui TJ, Khan MS, Fatima K, Butler J, Manning WJ, Khosa F (2017) A scientific analysis of the 100 citation classics of valvular heart disease. Am J Cardiol 120(8):1440–1449. https://doi.org/10.1016/j.amjcard.2017.07.035

45. Aksnes DW, Langfeldt L, Wouters P (2019) Citations, citation indicators, and research quality: an overview of basic concepts and theories. SAGE Open 9

46. Liu XL, Gai SS, Zhou J (2016) Journal impact factor: do we still trust it? https://doi.org/10.1097/PRS.0b013e3181a186dc

47. Springer
47. Khan B, Dudenhoefer EJ, Dohlman CH (2001) Keratoprosthesis: an update. Curr Opin Ophthalmol 12(4):282–287. https://doi.org/10.1097/00055735-200108000-00007
48. Kleinberg J (2003) Bursty and Hierarchical Structure in Streams. Data Min Knowl Disc 7(4):373–397. https://doi.org/10.1023/A:1024940629314
49. Fernandez AG, Radcliffe NM, Sippel KC, Rosenblatt MI, Sood P, Starr CE, Ciralsky JB, D'Amico DJ, Kiss S (2012) Boston type I keratoprosthesis-donor cornea interface evaluated by high-definition spectral-domain anterior segment optical coherence tomography. Clin Ophthalmol 6:1355–1359. https://doi.org/10.2147/opth.S34787
50. Kang JJ, Allemann N, Vajaranant TS, Vajaranant T, de la Cruz J, Cortina MS (2013) Anterior segment optical coherence tomography for the quantitative evaluation of the anterior segment following Boston keratoprosthesis. PLoS ONE 8(8):e70673. https://doi.org/10.1371/journal.pone.0070673
51. Garcia JP Jr, de la Cruz J, Rosen RB, Buxton DF (2008) Imaging implanted keratoprostheses with anterior-segment optical coherence tomography and ultrasound biomicroscopy. Cornea 27(2):180–188. https://doi.org/10.1097/ICO.0b013e318159bc7d

Publisher’s Note Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.