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ORIGINAL PAPER

Publication trends in the field of the cornea in the last 4 decades: a bibliometric study

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Abstract
Purpose The objective of this bibliometric study was to identify the top 100 most-cited articles on the cornea published in the English language between 1980 and 2021 using multidimensional citation analysis.
Methods The data were obtained from the Thomson Reuters Web of Science Core Collection and the PubMed databases. The top 100 articles in terms of citation number were identified and analyzed.
Results A total of 40,792 articles related to the cornea were retrieved. The 100 most-cited articles were published between 1995 and 2000. The average time since publication was 19.64 ± 5.75 years. The mean impact factor of the journals was 10.27 ± 17.14 and the Q category of most journals was Q1. *Ophthalmology* was the journal with the most published articles ($n = 10$), which represented level 3 evidence. The three most common topics among the top 100 articles were treatment modality, histopathology, and diagnostic imaging. The most frequently mentioned treatments were related to limbal stem cell failure, crosslinking, and lamellar keratoplasty. We observed a negative correlation between the average number of citations per year and the time passed since publication ($r = -0.629$; $p = 0.001$).
Conclusion Our analysis of the top 100 most-cited articles on the cornea revealed scientific contributions, vital current data related to clinical implementations, and valuable insights into the current developments in ophthalmology. To our knowledge, this is the first study to evaluate the most influential papers on the cornea, and our findings highlight the research quality and latest discoveries and trends in the management cornea diseases.

Keywords Bibliometric · Citation · Cornea · Trend analysis

Introduction

Corneal diseases span a wide range of disorders that threaten vision quality to varying degrees. Many studies have been conducted on improving vision quality and preventing blindness related to corneal diseases [1, 2].

The process of professional scientific publication has undergone a drastic evolution in the last decade [3]. Bibliometric sciences (citation-based metrics) involve statistical and quantitative analyses of published articles that measure their impact on a

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particular field of research. Bibliometric methods facilitate exploration of various factors, including citation counts and detailed scientific output statistics reported by single authors, as well as special topics, institutions, or countries [4]. The scientific citation index seems to be a readily the only accessible and historically quantifiable measure of a journal's scientific contributions and can be used to determine the "impact" that a journal has had on research [5]. The citation of a study indicates its relevance to its field of interest [6]. Garfield was the first to introduce the concept of "Citation Classics" in 1987 for the most-cited articles in *Journal of the American Medical Association* (JAMA) [7]. Bibliometric analyses are performed in most medical fields.

The mapping knowledge domain method introduces a novel approach to searching the literature that combines data mining and analysis [8]. The VOSviewer is a software program that uses the MKD approach to analyze visual network data. It enables researchers to create and explore a bibliometric map of co-citation or co-occurrence of data [9], and aids authors in research planning and predicting research trends by allowing them to consider a range of research subjects and identify novel topics [10].

Several bibliometric studies have been published that provide a general analysis of the field of ophthalmology [11, 12] corneal transplantation [13], dry eye [14], pterygium [15] and cataract [16]. To the best of our knowledge, this is the first study to quantify and analyze the most-cited papers on the cornea.

In our study, we conducted a systematic analysis of the 100 most frequently cited articles in corneal research from 1975 to 2021 to provide new insights and enlighten ophthalmologists as well as the academic community. This analysis will provide researchers and clinicians with a detailed overview of the most-cited papers on the cornea in the past decades.

Materials and methods

Study design

This retrospective clinical study has level 3 evidence of three or Group B according to the Scottish Intercollegiate Guidelines Network (SIGN) [17].

Ethical considerations

This study was conducted in accordance with the tenants of the Declaration of Helsinki. This study did not require ethics committee approval because it involved a bibliometric analysis of previously published studies for which ethics approval was already acquired. Moreover, patient data were not used in this study and therefore informed consent was not required.

Data collection

The authors (SZ and EB) independently scanned articles with titles, abstracts, and full texts. A total of 26,764 full-text articles were obtained and ranked according to the number of citations they have received using the technique described by Paladugu et al. [18]. According to the data obtained from Thomson Reuters Web of Science Core Collection (WoS) database (Clarivate, London, England) and PubMed (National Institutes of Health, Bethesda, MD, USA), the top 100 cornea-related articles published between 1975 and 2021 were ranked from the most-cited to the least-cited (accessed date: December 2, 2018). The WoS database was searched using the keyword "cornea." The keywords that emerged from the resulting articles were grouped into clusters according to their semantic integrity (Fig. 1). Data were collected on the journal name, citation rate per article, publication year, total number of citations (TC) for the article, country of origin, institution or organization, the most common subjects, funding status, article type, and level of evidence according to the SIGN [17]. The 100 most-cited articles (T100) list was generated by ranking according to the number of citations. In 2013, the *Archives of Ophthalmology* became *JAMA Ophthalmology*, a medical journal published by the American Medical Association. The *Australian and New Zealand Journal of Ophthalmology* was renamed to *Clinical and Experimental Ophthalmology* during our literature review. Two authors (SZ and EB) independently reviewed the top 100 most-cited publications independently and reached a consensus. All publications identified throughout the search process were meticulously evaluated before inclusion in the study. Articles not related to the "human cornea" were excluded from the study.

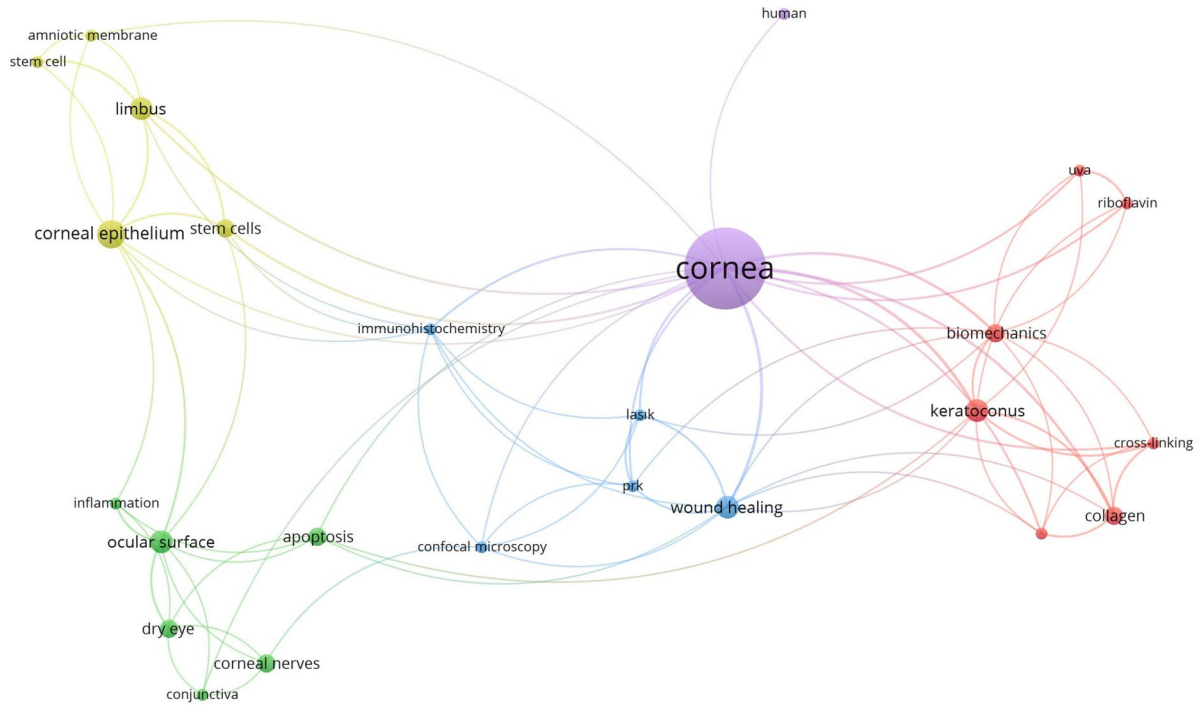

Fig. 1 Keyword analysis using VOSviewer

Statistical analysis

Descriptive statistics were performed using mean ± standard deviation or median (quartiles 1 and 3), where appropriate. The Shapiro–Wilk test was used to examine the normality of numeric variables. The mean differences between the groups with normally distributed data were compared using Student's t-test or one-way analysis of variance (post hoc Duncan test), whereas non-normally distributed data were compared by the Mann–Whitney *U* or Kruskal–Wallis tests (post hoc Dunn test). Spearman's or Pearson's correlation coefficients were calculated to identify linear links between numerical variables. Beta coefficients were calculated using univariate linear regression. SPSS version 24. 0 (IBM Corp., Armonk, NY, USA) was used for all statistical analyses. Two-tailed p values < 0.05 were considered statistically significant.

Results

A total of 40,792 articles were retrieved. Although we did not restrict the publication language, every article was published in English. The most-cited article was written by Pellegrini titled, "Long-term restoration of damaged corneal surfaces with autologous cultivated corneal epithelium" and was published in the *Lancet* in 1997.

Mean total citation, citation per year, journal impact factor, journal H index and time elapsed since publication were 415.51 ± 138.77, 22.04 ± 11.00, 10.27 ± 17.14, 251.47 ± 239.72 and 19.64 ± 5.75, respectively. The number of articles published over the years is shown in Fig. 2.

Journal perspective

Table 1 summarizes the T100 list involving 17 journals, with the number of papers per journal ranging from 2 to 10. The most represented journal was *Ophthalmology* ($n = 10$), followed by the *Journal of Cataract and Refractive Surgery* ($n = 9$), and *Cornea* ($n = 9$). The *Journal of Cataract and Refractive Surgery* received the most citations, followed by *Cornea* and *Ophthalmology*.

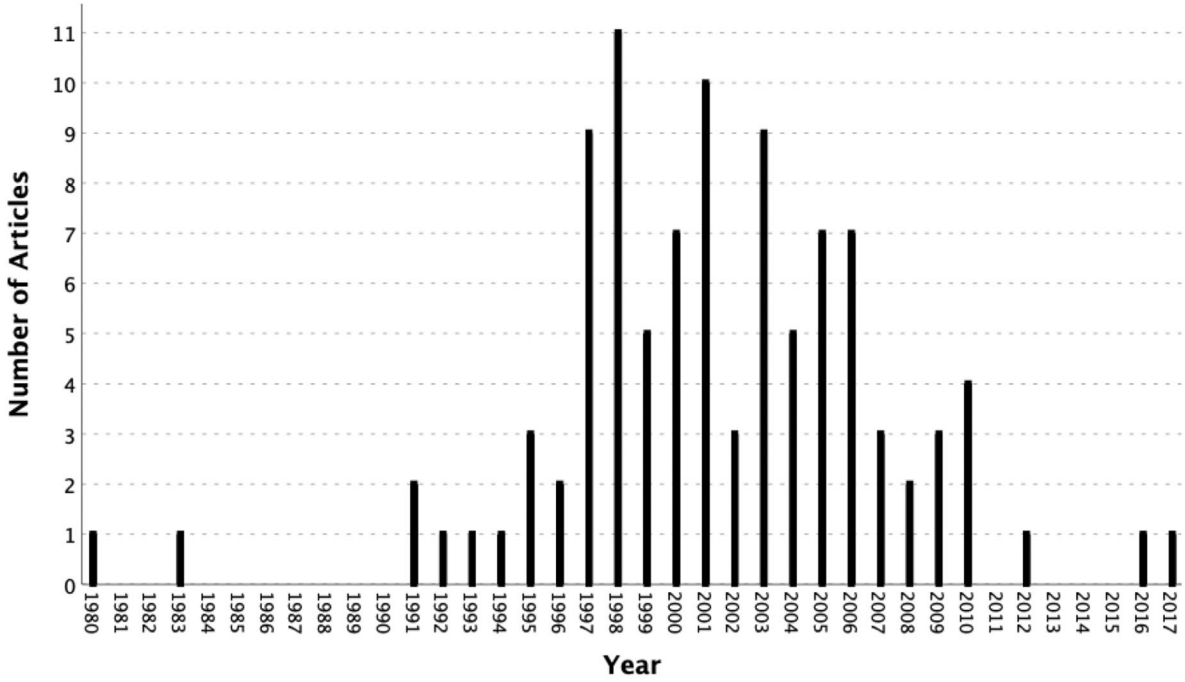

Fig. 2 The number of articles published over the years

Table 1 Journal names, number of articles and citation per journal

Journal	Number of articles in the T100	Citation per journal	Impact factor of the journal	Q category of the journal	H index of the journal
Ophthalmology	10	3731	8.47	Q1	229
Journal of Cataract and Refractive Surgery	9	4269	2.69	Q1	137
Cornea	9	3830	2.21	Q1	113
Investigative Ophthalmology & Visual Science	8	3123	3.47	Q1	209
Experimental Eye Research	8	3180	3.01	Q1	119
Progress in Retinal and Eye Research	5	1943	14.86	Q1	141
Survey of Ophthalmology	4	1965	4.19	Q1	129
New England Journal of Medicine	4	2033	74.70	Q1	987
American Journal of Ophthalmology	4	1741	4.01	Q1	179
Journal of Refractive surgery	3	1203	2.71	Q1	94
British Journal of Ophthalmology	3	992	3.61	Q1	146
Lancet	2	1288	60	Q1	747
Journal of Clinical Investigation	2	777	11.84	Q1	471
Journal of Cell Science	2	635	4.57	Q1	268
Current Opinion in Ophthalmology	2	895	2.98	Q1	83
Current Eye Research	2	823	1.75	Q2	77
Biomaterials	2	759	1.98	Q1	360

Publication year

Table 2 shows the articles categorized by the average number of TC per year, journal H index, and journal impact factor (IF) according to publication year. Eighty-seven articles in the T100 list in the field of the cornea were published between 1995 and 2010. The majority of papers were published between 1995 and 2000 ($n=34$), followed by 2000–2005 ($n=27$) and 2005–2010 ($n=26$). (Fig. 2). While there was no significant difference among time periods in terms of TC, we determined that the greatest number of citations occurred before to 1995. Journal IF values were significantly higher from 2010 to 2020 compared with that in other years, except for 1995–2000 ($p=0.014$).

Notably, we discovered a statistically significant decrease in the average number of TC per year as time passed from the publication year ($r=0.629$; $p=0.001$) (Fig. 3). According to univariate linear regression analysis, 40% of the variation in average per year was explained by time passed over article

Table 2 Total citation, average number of citations per year, journal H index and journal impact according to the publication year, level of evidence, Q category and main topics of journals

	Total cite	Average number of citations per year	H index	Impact factor
	M (Q1–Q3)	M (Q1–Q3)	M (Q1–Q3)	M (Q1–Q3)
Year				
Before 1995 ($n=10$)	480 (342–580)	^{A}16.01 (11.03–18.33)	184.5 (129–209)	^{A}3.75 (3.47–4.2)
1995–2000 ($n=34$)	363 (306–449)	^{A}15.57 (13.31–18.59)	157.5 (129–268)	^{AB}4.2 (3.01–14.86)
2000–2005 ($n=27$)	372 (303–453)	^{AB}19 (16.33–22.57)	146 (113–229)	^{A}3.14 (2.22–8.47)
2005–2010 ($n=26$)	395.5 (300–488)	^{B}26.28 (19.8–30.44)	173 (119–256)	^{A}3.01 (2.69–6.96)
2010–2020 ($n=3$)	364 (359–370)	^{C}59.83 (36.4–74)	190 (61–747)	^{B}12.34 (6.2–60)
p	0.692	**0.007**	0.937	**0.014**
Q category				
Q1 ($n=94$)	368 (306–471)	18.71 (15.32–24.5)	179 (129–229)	3.61 (2.98–8.41)
Q2 ($n=3$)	409 (324–414)	18.59 (16.2–23)	77 (77–150)	1.75 (1.75–2.18)
p	0.894	0.992	**0.047**	**0.001**
Level of evidence				
1 ($n=8$)	395.5 (372–572)	31.37 (16.94–35.8)	^{AB}149 (124–204)	4.10 (3–6.33)
2 ($n=17$)	348 (297–406)	18.33 (15.21–23)	^{AB}209 (119–229)	3.47 (2.71–7.52)
3 ($n=43$)	372 (311–487)	17.45 (14.14–21.5)	^{B}209 (146–360)	4.01 (2.69–8.47)
4 ($n=32$)	369 (304.5–457)	20.18 (16.65–26.28)	^{A}137 (113–143.5)	3.14 (2.7–6.96)
p	0.222	0.415	**0.018**	0.539
Main category				
Complication on treatment. surgery and drug ($n=2$)	407 (365–449)	18.48 (18.25–18.71)	120 (94–146)	3.16 (2.71–3.61)
Diagnosis and image ($n=11$)	303 (297–471)	16.24 (14.43–20.71)	179 (137–209)	3.67 (2.22–6.2)
Epidemiology ($n=2$)	595 (387–803)	29.31 (20.37–38.24)	193.5 (158–229)	7.72 (6.96–8.47)
Histopathology ($n=25$)	380 (312–453)	17.56 (15.83–21.5)	169 (129–268)	4.2 (3.01–14.81)
Molecular mechanism ($n=3$)	346 (330–586)	13.31 (11–21.7)	209 (209–268)	3.47 (3.47–3.49)
Pathophysiology ($n=8$)	304 (300–478.5)	16.96 (12.41–20.8)	124 (110–246)	3.44 (2.61–4.38)
Prognostic prediction ($n=2$)	416.5 (397–436)	17.75 (17.44–18.05)	169 (129–209)	3.83 (3.47–4.2)
Treatment ($n=38$)	383 (336–487)	19 (15.65–30.31)	162.5 (119–229)	3.31 (2.69–8.47)
Other ($n=9$)	370 (339–458)	21.92 (17.12–31.32)	137 (113–190)	3.61 (2.69–6.2)
p	0.831	0.741	0.338	0.877

M (Q1–Q3). M: Median, Q1: Quartile 1 (p25), Q3: Quartile 3 (p75). *p* value was obtained from Kruskal Wallis. ANOVA or Mann Whitney *U* test. Statistically significant *p* values are written in bold. Each different letter in superscripts in the columns indicates Dunn or Duncan test significance ($p<0.05$)

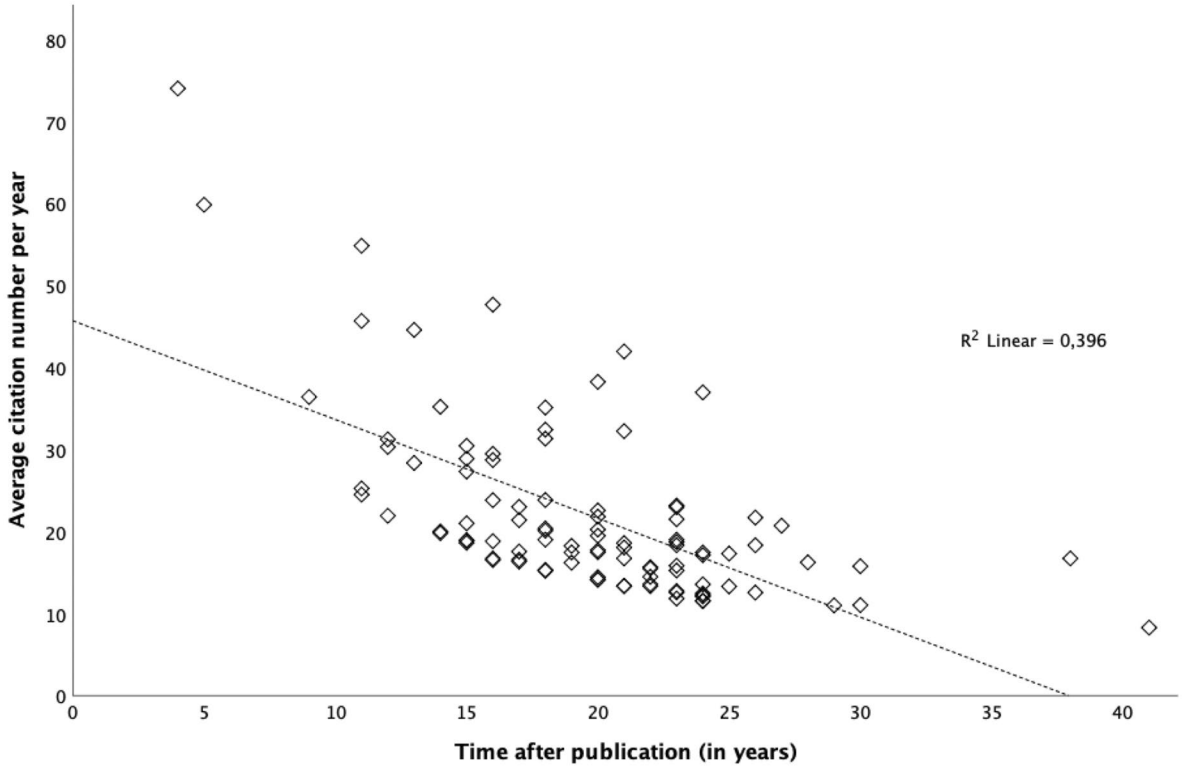

Fig. 3 Scatter plot between average of per year citation and time past over article

($f=64.25$; $p=0.001$). One unit increase in average per year resulted in a 1.21 unit decrease per year citation. We observed that articles published between 2010 and 2020 were cited significantly more in terms of average per year than in the previous years.

Furthermore, we discovered a slightly positive correlation between TC and IF ($r=0.222$; $p=0.026$).

Level of evidence and Q category

We found that 95 of the T100 were published in journals with an IF ≥ 2.00 (range 2.145–60.000) (according to Clarivate Analytics, 2020). Moreover, according to the Scimago Journal & Country Rank 2020, the Q categories of these journals were Q1, except for *Current Eye Research* and the *Journal of the Optical Society of America A-Optics, Image, Science, and Vision*, which were Q2 (Table 2).

Journals that contained level 3 evidence (non-analytic studies such as case series) had the most articles cited according to the SIGN criteria. However, articles with level 1 evidence had the highest total citation count, although this difference was not statistically significant (Table 2).

The H-indexes of the journals in which evidence level 2 and 3 studies were published were more significant than the H-indexes of the journals with publications of other evidence levels.

Research topic

When we sorted clinical research according to the main topic, the most-cited articles focused on treatment, histopathology, and diagnostic imaging. The most-cited main topics were epidemiology, prognostic prediction, and complications related to treatment, surgery, and drugs (Table 2). These main topics were also divided into sub-topics, as described in Table 3. Stem cells ($n=8$), cross-link ($n=7$), and lamellar keratoplasty ($n=7$) are mentioned accordingly under the topic of treatment. Corneal biomechanics ($n=3$), confocal ($n=3$), and central corneal thickness characteristics ($n=3$) are mentioned the most in articles on diagnostic imaging

Table 3 Subheadings of the most-cited topics

Main topic	Subheading	*n*
Treatment	Limbal stem cell deficiency	8
	Lamellar keratoplasty	7
	Cross-linking	7
	LASIK	5
	Artificial cornea	2
	Medical treatment	2
	Penetrating keratoplasty	2
	Corneal ring	1
Diagnosis and image analyze	Central corneal thickness	3
	Cornea biomechanics	3
	Confocal microscopy	3
	Anterior segment OCT	2
	Wavefront aberrometer	2
Histopathology and molecular mechanisms	Corneal wound healing	3
	Limbal stem cells	3
	Immune privilege mechanism	2
	Comparison of keratoconic and regular cornea	2
Pathophysiology and treatment	Corneal wound healing	3
	Corneal ulcer risk factors	2

analysis, while corneal wound healing ($n=3$) and limbal stem cells ($n=3$) are mentioned in articles on histopathology and molecular mechanisms and corneal wound healing ($n=3$) are mentioned in articles focused on pathophysiology and treatment.

Mapping the knowledge domain

Country analysis

Twenty-three countries were identified by analyzing the articles on the T100 list by country. The United States supplied the most significant number of publications ($n=57$), followed by England ($n=19$), and Germany ($n=13$). With 23,772 citations, the United States was the most productive nation.

Distribution of research organizations

When we sorted the articles in the T100 list by primary research organization, we discovered a total of 25 organizations with two or more articles (Table 1). The organization with the most articles (eight articles) in the T100 list was the *Technische Universitat Dresden*. This is followed by Harvard University and University of California System with six articles, and Tufts University with five articles.

Distribution of keywords

According to the keyword co-occurrence analysis of the T100 list, we identified five distinct clusters, each of which is represented by a different colour in Fig. 1. "Cornea," "corneal epithelium," "limbus," "stem cells," "ocular surface," "apoptosis," "wound healing," "keratoconus," "biomechanics," and "cross-linking" were the keywords with the highest co-occurrence and total link strength.

Discussion

A wide range of studies have been conducted on corneal diseases. In our bibliometric analysis, we searched for cornea-related articles using the WoS from 1975 to 2021 to determine the T100 in corneal research. Our most important finding is that research on limbal stem cell deficiency has been the trending topic for the last 46 years. Furthermore, most articles focused on treatment options. Our findings enable

specialists and new researchers in the field of the cornea to focus on the most important articles and identify gaps in the research.

The topics listed in the top 100 papers were wide-ranging and covered almost every aspect of the cornea; however, several themes were commonly observed in many papers and fall into three subject areas: treatment, histopathological features, and diagnostic imaging. We discovered a significant interest and curiosity regarding the treatment of limbal stem cell deficiency. If limbal stem cell insufficiency is present in both eyes or there is a limited number of stem cells in the eye from which stem cells were collected, the harvested cells must be multiplied. The importance of healing limbal stem cells and corneal epithelial cells has been highlighted by research on limbal stem cells and corneal wound healing under the theme of histopathology following therapy. Similarly, the subject of the most-cited article published in the *Lancet* is the cultivation of cells used for the treatment of limbal stem cell insufficiency.

The second most frequently cited subject is the cross-link procedure, which is a critical topic. The need for keratoplasty is reduced with this treatment since it halts keratoconus development.

The third most frequently cited issue is lamellar keratoplasty. The importance of lamellar keratoplasty is that it is gradually replacing penetrating keratoplasty in certain cases, which has been accepted as the gold standard for years. When researching the literature, Perry [19] examined the most-referenced publications in the *Cornea* journal in the previous 36 years. The paper titled, "Descemet-Stripping Automated Endothelial Keratoplasty" by Gorovoy [20] had the most citations. He attributed this to lamellar keratoplasty replacing penetrating keratoplasty. This issue is also related to the third most frequently mentioned topic in our study.

According to our data, journals were most often cited between 1995 and 2010. We believe that the articles published during this time period received more citations because the topics before 1995 were not trending, and articles published after 2010 have not yet reached citation saturation. To prevent this, the most-cited articles in the last 10 years should be reviewed separately. In addition, the fact that there are more average citations per year between 2010 and 2020 indicates the level of interest in current issues. Moreover, the average number of total citations in articles tends to decrease as time passes from the publication year. This phenomenon is commonly referred to as citation decay or citation aging. As new research articles are published, older research articles become less relevant or are superseded by more recent findings.

Most articles in the T100 list were clinical outcome studies with evidence levels of 3, demonstrating that small case series or cohort studies presenting an original concept can attract the interest of researchers and readers within the field. Although the number of publications with level 1 evidence was lower than that of papers with level 3 evidence, they received more citations per publication.

Although we know that citation frequency affects the impact factor, we found that the TC has only a minor effect on the IF. A modest impact occurs as papers reach citation saturation over a longer period of time, despite the IF assessment being based on the journal's citation frequency over the previous two years. The decreased average citation frequency over the years indicates that the articles in archived issues are outdated.

A high IF is an important scientometric criterion for determining the journal quality. However, IF has some limitations. For example, it tends to favour journals in certain fields, measures citations within a specific period, can be influenced by citation practices like self-citation or citation cartels, and neglect interdisciplinary or less-popular research areas [21]. Accordingly, in recent years, Q categories have gained more prominence in the determination of the scientific value of a journal [22]. Originally intended for an individual scientist or researcher, the H-index is an author-level indicator that assesses both the productivity and citation effect of a publication [23]. We considered that articles with evidence levels 2 and 3 published in journals with a higher H index were trending publications compared with those of other levels of evidence, probably because they are faster to feasibility. Although articles with evidence level 1 are more challenging to produce and thus relatively few, the high number of citations per article indicates that they are much more valuable.

Articles on the cornea published in general ophthalmology journals tend to receive more citations. The most-cited article in the field of the cornea was published in the *Lancet*, indicating that even the most prestigious general medical journals

are influential in the field of ophthalmology. In addition, the *Ophthalmology Journal,* a general ophthalmology journal, published the majority of the articles in our T100 list. Notably, the *Journal of Cataract and Refractive Surgery* and *Cornea* play an important role in the topic of the anterior segment in corneal research, and placed second in the T100 list after the *Ophthalmology Journal*. Although the first three journals listed above were ranked according to the total number of citations, the leader based on the mean number of citations per article is the *Journal of Cataract and Refractive Surgery.*

The present study revealed that institutions or organizations located in the United States are more prominent in terms of both the number of institutions producing publications and the number of publications per institution. Moreover, the United States has the highest number of scientific publications in many medical research areas [24, 25]. An explanation for the large research output coming out of the United States is likely thanks to its relatively large allocation of gross domestic product research and development compared with Europe [14]. The United Kingdom and Germany, respectively, follow the United States as the most-cited countries in our study, likely because they are also large economies of the Western World. These countries have allocated large sums of money to research and development, contributing to their high performance on the rank list.

Most authors of high-quality studies desire their work to be published in English-language journals from the United Kingdom and the United States as these journals have the highest rank and status in the field of ophthalmology Interestingly, although *Technische Universitat Dresden* originated in Germany, it produces the most publications which are published in English, indicating that English is the most frequently used publication language.

Exact quantification of how important any one scientific paper is to ophthalmologists is difficult; therefore, we used "the number of citations" as a surrogate for determining the influence of a paper. Citation analysis can be used to determine the relative importance of a medical journal using the IF [26, 27]. The most frequently used source is the WoS database, which includesimportant information on the number of citations and research on other relevant academic impacts [28]. Examining the most-cited articles helps researchers identify gaps in research and can reveal patterns in corneal research that can guide future investigations.

Although the current analysis yielded useful information on corneal research trends, our study had some limitations. First, bibliometric analysis evaluates articles based on the number of times it is cited. Therefore, our analyses included time-cited bias. Finally, the choice of keywords used in our searches can be considered as a limitation. Other relevant articles that did not include the specific search term may have been missed during our search. Beyond the bibliometric analysis, a strength of this study is that we determined the average number of citations per journal in addition to the average number of citations by level of evidence and combined with the journal's Q categorization.

In conclusion, our bibliometric analysis provides a comprehensive summary of seminal corneal articles published over the past 4 decades. This is the first research study to identify and assess the most influential articles on the cornea with the most valuable evidence and insights. These findings might help researchers to easily obtain and compare the most critical information in corneal research.

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Author contributions All authors contributed to the study conception and design. Material preparation, data collection and analysis were performed by SZ and EB. The first draft of the manuscript was written by SZ and all authors commented on previous versions of the manuscript. All authors read and approved the final manuscript.

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

Declarations

Conflict of interest The authors report there are no competing interests to declare.

Ethics approval This study was conducted in accordance with the tenants of the Declaration of Helsinki. This study did not require ethics committee approval because it involved a

bibliometric analysis of previously published studies for which ethics approval was already acquired.

Consent to participate Patient data were not used in this study and therefore informed consent was not required.

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