

# Scientometric analysis and mapping of 20 years of glaucoma research

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## Abstract

• **AIM:** To provide a scientometric analysis in the field of glaucoma.

• **METHODS:** A bibliometric method was used to obtain a view of the scientific production in field of glaucoma by data extracted from the Institute for Scientific Information (ISI) from 1993 to 2013. Specific parameters were retrieved from the ISI. Articles about glaucoma were analyzed regarding the topics' structure, history, and document relationships using HistCite software. Also, the trends in the most influential publications and authors were analyzed.

• **RESULTS:** The number of articles was constantly increasing, and most highly cited articles addressed clinical and epidemiologic topics in this field. During the past three years, there has been a trend towards genomic research studies and also more molecular translational research.

• **CONCLUSION:** This was the first scientometric report on glaucoma, analyzing the characteristics of papers and the trends in scientific production. A constant increase was observed in the number of papers, while the subject of papers had a shift in the past three years towards genomic research studies.

• **KEYWORDS:** glaucoma; bibliometrics; historiography; scientometric analysis; citation analysis

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## INTRODUCTION

According to the data published by the World Health Organization, glaucoma is the second leading cause of

global blindness; by 2020, nearly 80 million persons worldwide will be affected with the disease<sup>[1]</sup>. Glaucoma affects one in 200 people aged 50 or younger, and one in 10 people aged 80 or older. It is a progressive optic neuropathy and if untreated leads to permanent impairment of the optic nerve and resultant visual field loss, and can progress to blindness<sup>[2]</sup>.

Nicknamed as the "sneak thief of sight" because of its often asymptomatic nature and gradual loss of vision. Primary open angle glaucoma (POAG) can be a devastating disease as treatment does not always slow disease progression in patients<sup>[3]</sup>. Primary congenital glaucoma (PCG) is also another catastrophic condition<sup>[4]</sup> as the unfortunate combination of delayed presentation and limited management options contribute to the disproportionately high percentage of glaucoma induced blindness in children; it is roughly responsible for 18% of children in institutions for the blind and 5% of overall pediatric blindness worldwide. It is estimated from population studies that 50% of patients with glaucoma in the developed world and up to 95% of the cases in the developing world are undiagnosed<sup>[5]</sup>.

Adult onset glaucoma is categorized into three main groups: open angle glaucoma (OAG), closed-angle glaucoma, and secondary glaucoma. The first category, OAG, is by itself subdivided into high-pressure glaucoma (POAG) and low-pressure glaucoma (normal tension glaucoma, NTG)<sup>[6]</sup>. Increased intraocular pressure (IOP) is central in the pathogenesis of OAG and even in NTG, the Collaborative Normal Tension Glaucoma Study (CNGTS) has shown that IOP lowering is essential to decrease the rate of worsening and damage<sup>[7]</sup>.

Patients with isolated elevated ocular pressure, the so-called ocular hypertension (OHT), do not suffer from glaucoma<sup>[8]</sup>. The progression of optic neuropathy, the hallmark of glaucoma, is characterized by cupping of the optic nerve head, and thinning of the nerve fiber layer resulting in retinal ganglion cell (RGC) death and loss of visual function. The largest single risk factor for glaucoma is age, and increased IOP is the most established clinical measures<sup>[9]</sup>.

Considering the impact of this disease, glaucoma research is attempting to reduce this burden through focusing on the methodologies for earlier diagnosis, elucidating modifiable risk factors and developing better IOP-dependent and non IOP-dependent treatments<sup>[10]</sup>.

Scientometric analysis is carried out for studying growth, development and spread of any area of research, and also for identifying centers of excellence, influential authors etc.<sup>[11-12]</sup>, which is frequently used by the heads of departments/institutions, research planners, policy makers and individual scientists. Although there have been few studies addressing the scientometric analysis of ophthalmology research, most of these studies have been restricted to certain geographical regions and none of them have been specifically focused on glaucoma<sup>[13-17]</sup>. We here represent the first scientometric analysis in the field of glaucoma.

### **MATERIALS AND METHODS**

The current descriptive study targeted a schematic view of scientific map in the field of glaucoma. We used ISI web of science (<http://www.isiknowledge.com>) as our database to carry out our analysis in March 2014. All three resources available in the ISI web of science were used for this purpose [Science Citation Index Expanded, Social Sciences Citation Index, and The Arts & Humanities Citation Index (A&HCI)]. Terms used for the searches were chosen in accordance with Medical Subject Heading (Mesh) which is used to index PubMed<sup>®</sup> contents. Only one parent term (glaucom\*) was used. The "\*" is a wildcard that can take any value.

The query was done using all the variations of this term for the intended period of 1993 to 2013. The study merely includes research articles among all other retrieved documents such as reviews, proceeding papers, letters, editorial material, meeting abstracts, notes, reprints, corrections, news items, book reviews, and additions. All statistical analyses were performed using Microsoft Excel 2003 computer spreadsheet software.

Articles about glaucoma were analyzed to obtain a view of the topic's structure, history, and document relationships using HistCite software. The bibliography retrieved from the Web of Science database was imported to HistCite. A historiography of the field between 1993 and 2013 was created by including articles that had been cited 100 or more times. For the citation analysis, two parameters were calculated: local citation score (LCS) and global citation score (GCS). LCS lists all papers sorted by citation frequency within the local (the starting bibliography). On the other hand, GCS would count citations in the whole collection. For the citation burst analysis, first, hundred keywords, which generated the citation bursts, were extracted, and then, non-specific and general keywords were omitted.

Overall number of related publications besides further aspects like annual publications, annual citations per paper, language, leading countries, first authors, most contributing journals, highly cited per paper, institutional affiliations, and collaboration were retrieved from ISI Web of Sciences. The Journal's impact factor reflects journals' scientific merits and standing in a specific field.

### **RESULTS**

**Annual Publication Number During 1993 –2013** There were a total of 9483 research articles on glaucoma in the ISI Web of Science during 1993-2013. These papers were drafted by 19 787 authors, 4644 institutions and 97 countries and were published in 744 journals in 12 languages. The growth rate of publications in this field was totally 6.38%. Two hundred and twenty-nine records were published in 1993, 179 records in 1994, 198 records in 1995, 250 records in 1996, 372 records in 1997, 326 records in 1998, 378 records in 1999, 392 records in 2000, 396 records in 2001, 394 records in 2002, 431 records in 2003, 427 records in 2004, 461 records in 2005, 554 records in 2006, 565 records in 2007, 593 records in 2008, 575 records in 2009, 616 records in 2010, 704 records in 2011, 713 records in 2012 and 730 records in 2013.

**Citation Profile of Articles** Total LCS of citations were 72 990 times and GCS of citations were 174 098 times. About 76 709 citations were self-citation. The average citations per paper (C/P) was 18.36. The average citations to articles in 1993 were 3.8, in 1994 were 3.2, in 1995 were 4.6, in 1996 were 5.2, in 1997 were 6.3, in 1998 were 6.5, in 1999 were 5.9, in 2000 were 7.2, in 2001 were 6.3, in 2002 were 7.2, in 2003 were 6.4, in 2004 were 5.6, in 2005 were 5.8, in 2006 were 6, in 2007 were 5.4, in 2008 were 4.4, in 2009 were 3.1, in 2010 were 2.6, in 2011 were 2.3, in 2012 were 1.1 and in 2013 were 0.1.

Table 1 shows the highly cited articles in this field. Table 2 shows the most active authors and the authors with highest number of citation.

Figure 1 shows the 20y research in this field. Total H-index of this category of research was 139. The keywords which generated most citation bursts were: low-tension glaucoma, 5-fluorouracil, filtering surgery, phxa41, perimetry, optic-nerve fibers, neuroretinal rim area, neodymium, pilocarpine, mitomycin, open angle glaucoma, hypotony, refractory glaucoma, single-plate, linkage, topographic measurements, automated perimetry, normal- pressure glaucoma, apoptosis, dorzolamide, timolol, brimonidine, bimatoprost, latanoprost, scanning laser polarimetry, ocular hypertension treatment, oxidative stress, central corneal thickness, aqueous-humor, optical coherence tomography (OCT), quality-of-life, nerve-fiber layer.

**Subject Analysis and Publisher of Documents** The most common topics of top ten highly cited papers were clinical research (60%) focusing on the treatment and prevention of progression, and epidemiologic studies (20%) and basic science research regarding the pathogenesis and genetics (20%, among the top ten articles). Table 3 shows the top journals with the largest number of documents on glaucoma research.

**Table 1 Articles with highest number of glaucoma-related citations (LCS)**

No.	Author(s)	Title	Source	Citation
1	Kass MA, Heuer Dk, Higginbotham EJ, Johnson CA, Keltner JL, Miller JP, Parrish RK 2nd, Wilson MR, Gordon MO	The Ocular Hypertension Treatment Study - A Randomized Trial Determines That Topical Ocular Hypotensive Medication Delays or Prevents the Onset of Primary Open-angle glaucoma	Archives of Ophthalmology. 2002; 120 (6): 701-713	1171
2	Quigley HA, Broman AT	Number of People with Glaucoma Worldwide	British Journal of Ophthalmology. 1996; 80 (5): 389-393	1141
3	Quigley Ha, Broman AT	The Number of People with Glaucoma Worldwide in 2010 and 2020	British Journal of Ophthalmology. 2006; 90 (3): 262-267	1067
4	Gordon MO, BeiserJA, Brandt JD, Heuer Dk, Higginbotham EJ, Johnson CA, Keltner JL, Miller JP, Parrish RK 2nd, Wilson MR, Kass MA	The Ocular Hypertension Treatment Study – Baseline Factors That Predict the Onset of Primary Open-angle Glaucoma	Archives of Ophthalmology. 2002; 120 (6): 714-720	933
5	No author listed	The Advanced Glaucoma Intervention Study (Agis): 7. The Relationship Between Control of Intraocular Pressure and Visual Field Deterioration	American Journal of Ophthalmology. 2000; 130 (4): 429-440	905
6	Heijl A, LeskeMc, Bengtsson B, Hyman L, Bengtsson B, Hussein M; Early Manifest Glaucoma Trial Group	Reduction of Intraocular Pressure and Glaucoma Progression - Results from the Early Manifest Glaucoma Trial	Archives of Ophthalmology. 2002; 120 (10): 1268-1279	858
7	Stone Em, Fingert JH, Alward WL, Nguyen TD, Polansky JR, Sundin SL, Nishimura D, Clark AF, Nystuen A, Nichols BE, Mackey DA, Ritch R, Kalenak JW, Craven ER, Sheffield VC	Identification of a Gene That Causes Primary Open Angle Glaucoma	Science. 1997; 275 (5300): 668-670	771
8	LeskeMc, Heijl A, Hussein M, Bengtsson B, Hyman L, Komaroff E; Early Manifest Glaucoma Trial Group	Factors for Glaucoma Progression and the Effect of Treatment - The Early Manifest Glaucoma Trial	Archives of Ophthalmology. 2003; 121 (1): 48-56	607
9	No Author listed	Comparison of Glaucomatous Progression Between Untreated Patients with Normal-Tension Glaucoma and Patients with Therapeutically Reduced Intraocular Pressures	American Journal of Ophthalmology. 1998; 126 (4): 487-497	565
10	Quigley Ha, Nickells Rw, Kerrigan LA, Pease ME, Thibault DJ, Zack DJ	Retinal Ganglion-cell Death in Experimental Glaucoma and After Axotomy Occurs by Apoptosis	Investigative Ophthalmology & Visual Science. 1995; 36 (5): 774-786	547

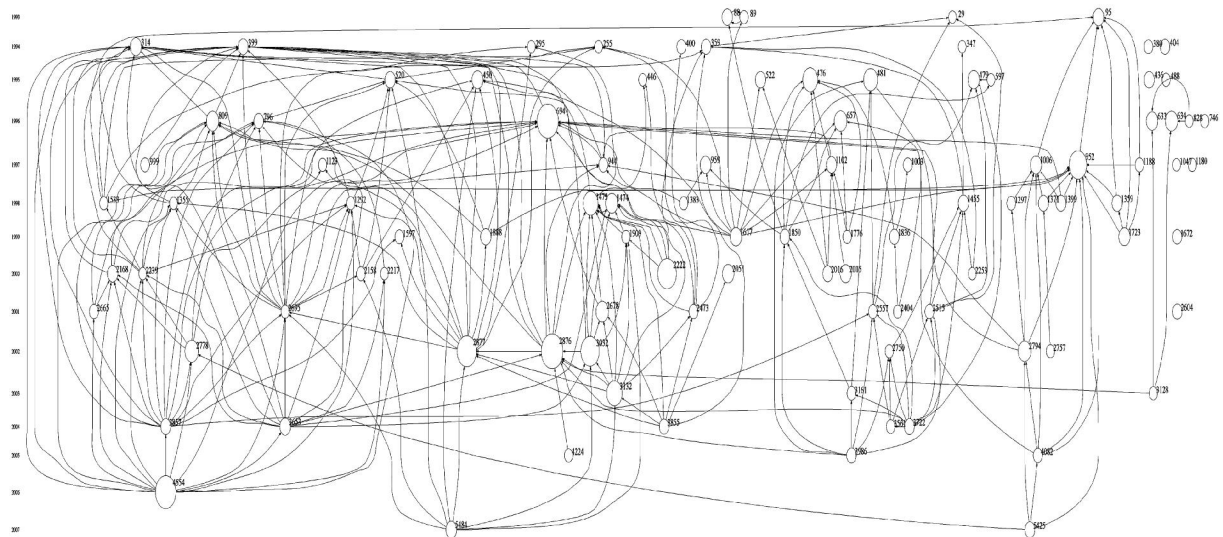
**Table 2 Most active and highly cited authors in the field of glaucoma-related research**

Most active authors				Highly cited authors			
No.	Author	Records	Citations	No.	Author	Records	Citations
1	Weinreb RN	209	7424	1	Quigley HA	105	9411
2	Ritch R	144	6558	2	Weinreb RN	209	7424
3	Liebmann JM	114	2414	3	Ritch R	144	6558
4	Zangwill LM	106	3608	4	Bengtsson B	53	4362
5	Quigley HA	105	9411	5	Leske MC	34	4006
6	Jonas JB	101	2058	6	Johnson CA	48	3919
7	Caprioli J	93	3566	7	Heijl A	61	3875
8	Sample PA	91	3271	8	Higginbotham EJ	25	3664
9	Stewart WC	90	2116	9	Zangwill LM	106	3608
10	Medeiros FA	89	2458	10	Caprioli J	93	3566

**Language and Author Profiles of Publications** The predominant language of most glaucoma articles was in English with 8831 records followed by German (341 records), French (232 records), and Portuguese (39 records). In total, the articles were written in twelve languages. Dr Weinreb with 209 articles had the largest number of publications in the field of glaucoma research (Table 2). Most of the top ten universities and institutions in the list are from the United States and UK. The first two of them are the University of California at San Diego and University of Erlangen Nurnberg in terms of number of documents and Johns Hopkins University and University of California at San Diego in terms of frequency of citations (Table 4).

**Geographical Distribution** In general, 97 countries contributed to the promotion of the field of glaucoma by publishing articles. The United States, Germany and UK had the highest number of documents but US, UK and Canada had the highest number of citations to their research papers in the field of glaucoma (Table 5). Figure 2 represents a visual presentation of collaboration between countries for producing original articles on glaucoma.

**Types of Journals** When analyzed based on the number of papers in glaucoma, all of the top twenty journals were ophthalmology journals and few general journals (such as *PLoS One*) ranked between 20 and 30. However, when the same calculation was made based on the citation number



**Figure 1 Historiography of the glaucoma literature regarding articles that had been cited 100 times or more** The circles represent papers. The size of the circle is relative to that paper's citations. The numbers outside the circle is the article number. An arrow pointing from one article to the next, usually to an older paper, indicates the citational relationship between papers, that is, the arrowhead points to the article that was cited. At the top of the histogram, the oldest articles (1993) appeared and at the bottom of the graph the newest ones (2007) with more than 100 citations are seen. The most highly cited articles can see in 2002.

**Table 3 Journals with highest number of glaucoma-related papers**

No.	Journal	Records	Citations	2-year IF	5-year IF
1	Journal of Glaucoma	846	11 559	1.865	2.046
2	Investigative Ophthalmology & Visual Science	766	23 037	3.441	3.730
3	Ophthalmology	693	27 723	5.563	5.777
4	American Journal of Ophthalmology	512	18 278	3.631	4.292
5	British Journal of Ophthalmology	449	11 462	2.725	3.023
6	Archives of Ophthalmology	375	19 847	3.826	4.160
7	Eye	293	2990	1.818	1.883
8	Graefes Archive for Clinical and Experimental Ophthalmology	285	3672	1.932	2.037
9	Acta Ophthalmologica Scandinavica	266	2432	-	-
10	Molecular Vision	238	2414	1.987	2.311

**Table 4 Institutions and universities with highest number of glaucoma-related papers and citations**

Institutions and universities with highest number of papers					Institutions and universities with highest number of citations			
No.	Institution	Country	Records	Citations	No.	Institution	Records	Citations
1	Univ Calif San Diego	USA	232	7760	1	Johns Hopkins Univ	217	12 696
2	Univ Erlangen Nurnberg	Germany	229	4166	2	Univ Calif San Diego	232	7760
3	Johns Hopkins Univ	USA	217	12 696	3	Moorfields Eye Hosp	212	6313
4	Moorfields Eye Hosp	United Kingdom	212	6313	4	Univ Miami	176	5923
5	Harvard Univ	USA	190	5339	5	New York Eye & Ear Infirm	173	5380
6	Univ Miami	Univ Miami	176	5923	6	Harvard Univ	190	5339
7	New York Eye & Ear Infirm	USA	173	5380	7	Washington Univ	98	5294
8	Duke Univ		153	3470	8	Univ Erlangen Nurnberg	229	4166
9	Univ Melbourne	Australia	130	4057	9	Univ Melbourne	130	4057
10	Univ Calif Los Angeles	USA	120	3531	10	Univ Calif Davis	47	3871

(LCS), 17 journals were ophthalmology journals; one general medicine journal (Lancet) and two were medical genetics journals. When analyzed based on GCS, highly cited papers were published in ophthalmology journals.

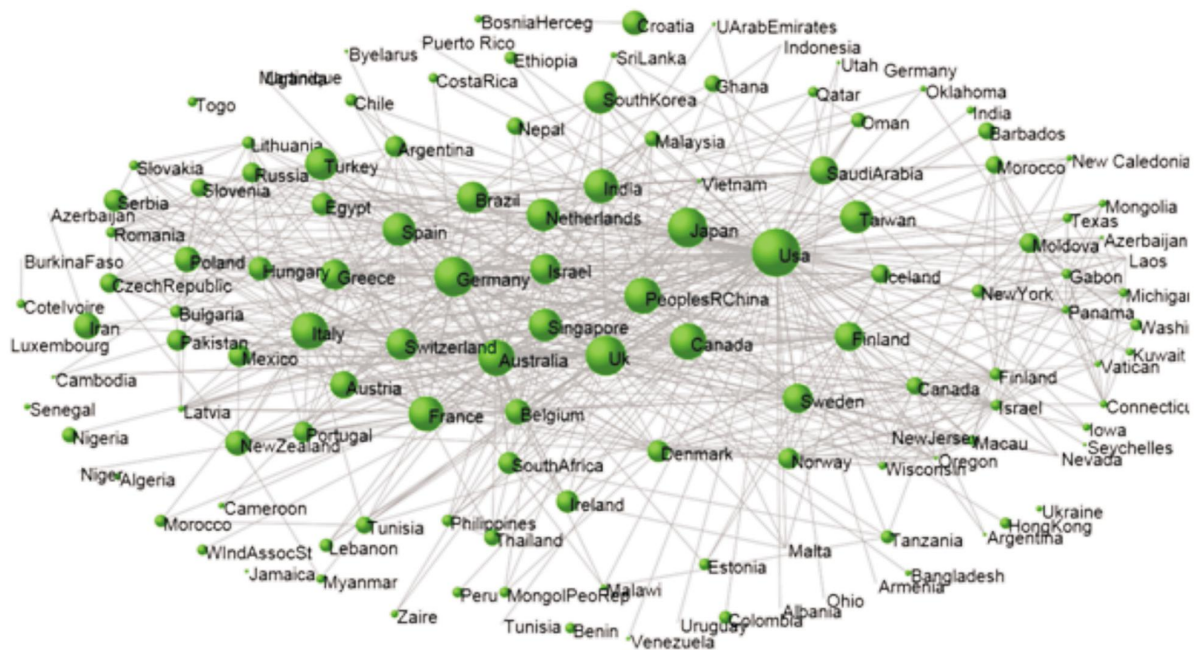
**DISCUSSION**

We analyzed the subject of highly cited papers, dividing them

to broad categories of clinical/translational versus genetic epidemiology versus basic science research. Most of the highly cited papers are clinical or genetic epidemiology studies. Subject of the most prominent clinical studies was focused on the control of IOP. Considering the importance of the quality of life and emotional status of subjects, a citation

**Table 5 Countries with highest number of glaucoma-related articles and citations**

Countries with highest number articles				Countries with highest number citations			
No.	Country	Records	Citations	No.	Country	Records	Citations
1	USA	3229	92 251	1	USA	3229	92 251
2	Germany	837	10 122	2	UK	822	16 655
3	UK	822	16 655	3	Canada	411	12 503
4	Japan	644	9266	4	Germany	837	10 122
5	Italy	443	5787	5	Japan	644	9266
6	Canada	411	12 503	6	Australia	364	8341
7	China	401	3753	7	Sweden	147	5792
8	Australia	364	8341	8	Italy	443	5787
9	India	310	3529	9	China	401	3753
10	France	279	3010	10	Netherlands	159	3694



**Figure 2 Collaboration network between the countries** The size of the nodes indicates the amount of collaboration. As it can see in the network, USA, UK, Japan, Germany and Italy have most scientific collaboration with other countries in this field of the study.

burst was observed recently regarding this subject. Recently, there has been a trend towards more applicable translational research such as the measurement of choroidal plexus thickness and molecular basis of the retinal damage. As citation burst analysis in the Table 6 shows, recently a trend towards basic science aspects of glaucoma has emerged, especially regarding the role of oxidative stress and nerve fiber layer in the pathogenesis of this disease.

According to our study, most highly cited articles were clinical studies focusing on control of IOP, which is consistent with the general picture in the field of ophthalmology as a whole; as in an analytical study of the ophthalmology research papers, case-control or cohort studies comprised most study designs used (40.1%), followed by nonanalytic studies (28.7%), basic science (24.6%), randomized clinical trials (3.3%), review articles (2.6%), and Meta-analyses (0.3%)<sup>[18]</sup>.

It is tempting to consider that most highly cited articles are

published in higher impact factor journals. This is based on the assumption that authors who are frequently cited, can target more prestigious journals. This can be due several factors: one is that the ophthalmology journals represent a very specialized field and papers in this field are not necessarily cited very frequently, and factors other than the quality of papers might affect the citation frequency of a paper. So most active authors might prefer to publish their work in sub-specialized journals to be better appreciated by their colleagues in the field<sup>[19]</sup>.

In a recent survey of nearly all ophthalmology journals to identify the most frequently cited articles using the Science Citation Index Expanded (1975 to 2006), the 100 most-cited articles were published in 13 journals, including the Archives of Ophthalmology, followed by Ophthalmology and the American Journal of Ophthalmology<sup>[20]</sup>. Use of OCT and hypotensive medications in glaucoma were among the major topics of 100 most cited articles<sup>[20]</sup>. Also we found that the

**Table 6 Glaucoma-related citation burst analysis**

Keywords	Strength	Begin	End
Low-tension glaucoma	44.5359	1992	2000
5-fluorouracil	24.4875	1992	1999
Filtering surgery	19.4215	1992	1998
Phxa41	14.0364	1992	2001
Perimetry	13.7976	1992	1997
Optic-nerve fibers	11.0279	1992	2001
Neuroretinal rim area	10.807	1992	2001
Neodymium	10.3907	1992	1998
Pilocarpine	9.1425	1992	2002
Mitomycin	5.3301	1992	2002
Open angle glaucoma	4.6875	1992	1997
Encircling band	3.7938	1992	2000
Hypotony	8.5724	1994	1998
Refractory glaucoma	6.8523	1994	1997
Single-plate	6.2367	1994	2002
Linkage	16.5857	1995	2000
Topographic measurements	12.3312	1995	2003
Automated perimetry	11.6398	1997	2000
Normal-pressure glaucoma	5.2103	1998	2002
Apoptosis	6.1021	1999	2002
Tension glaucoma	5.0368	1999	2003
Dorzolamide	9.5515	2000	2006
Timolol	8.133	2000	2004
Brimonidine	7.5546	2000	2003
Bimatoprost	6.7583	2004	2010
Latanoprost	5.7212	2004	2006
Scanning laser polarimetry	6.4903	2005	2006
Ocular hypertension treatment	10.5241	2006	2009
Oxidative stress	12.6385	2007	2014
Central corneal thickness	7.2242	2007	2009
Aqueous-humor central corneal thickness	3.3562	2010	2011
Optical coherence tomography	37.5132	2011	2014
Quality-of-life	9.9091	2011	2014
Nerve-fiber layer	8.4599	2012	2014

Burst-detection algorithm can be adapted for detecting sharp increases of interest in a specialty. In CiteSpace II, a current research front is identified based on such burst terms extracted from titles, abstracts, descriptors, and identifiers of bibliographic records. Burst-detection algorithms can identify emergent terms.

H-index of glaucoma research to be 139, which points to the importance of glaucoma research in the field. Dr Weinreb from University of California, San Diego, who was the most active author in the field of glaucoma research, is not among the top 100 most cited authors in the field of ophthalmology. The citation analysis performed in our study is consistent with the trends already present regarding the hot topics in the glaucoma research, as it is noted that there is a need to develop a better understanding of the natural history of the disease and the relationship between structural and functional measurements, and to identify new risk factors and biomarkers of glaucoma progression. It is very important to

identify the influence of genes on glaucoma remains to be determined and gene-environmental interaction studies should be performed<sup>[21]</sup>. Also, National Eye Institute, a branch of National Institute of Health (USA) has recently published the results of their assessment of progress in the glaucoma research in the past ten years. According to this report, the topics representing the most important development in this field include: the development of new diagnostic and imaging methods, better estimates of the prevalence of glaucoma, new drugs to lower IOP, the use of anti-metabolites to improve filtration surgery outcomes, characterization of the signaling mechanisms in the diverse tissues of the anterior segment, identification and characterization of glaucoma-associated genes, conceptualization of retinal ganglion cell loss in glaucoma as an active cellular process amenable to mechanistic study and the development of novel therapeutics<sup>[22]</sup>. Our results are mostly consistent with this report regarding the topic of most cited articles.

In conclusion, considering the importance of the field glaucoma, our study provides the first analysis of the progress in this field, which provides a framework for the weaknesses and strengths of the glaucoma research.

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