Original Article

Research progress of optic nerve imaging during 1991–2023: a bibliometric analysis

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Background: Optic nerve imaging is crucial for diagnosing and understanding optic neuropathies because it provides detailed visualization of the nerve's structure and pathologies through advanced modalities. This study conducted a bibliometric analysis within the field of optic nerve imaging, aiming to pinpoint the latest research trends and focal points in optic nerve imaging.

Methods: The core literature on optic nerve imaging published between January 1991 and August 2023 was retrieved from the Web of Science Core Collection. The analysis and visualization of scientific productivity and emerging trends were facilitated through the utilization of Bibliometrix software, CiteSpace, Gephi, VOSviewer, R software, and Python.

Results: In total, 15,247 publications on optic nerve imaging were included in the analysis. Notably, the top 3 journals contributing to this field were *Investigative Ophthalmology & Visual Science*, *Ophthalmology*, and the *British Journal of Ophthalmology*. This research on optic nerve imaging extended across 97 countries, with the USA leading in research endeavors. Noteworthy burst term analysis revealed that "Segmentation" and "Machine learning" are gaining attention. Additionally, the Latent Dirichlet Allocation model indicated that image processing has been a hotspot in recent years.

Conclusions: This study revealed the research trends, hotspots, and emerging topics in optic nerve imaging through bibliometric analysis and network visualization. At present, the research focus is directed towards employing artificial intelligence for image post-processing. The findings of this study offer valuable insights into future research direction and clinical applications.

Keywords: Optic nerve; medical imaging; bibliometric analysis; magnetic resonance imaging (MRI); optical coherence tomography (OCT)

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Introduction

Optic neuropathies are among the most prevalent causes of vision impairment (1). The optic nerve, known as the second cranial nerve, is one of the largest nerve bundles in the central nervous system (2). It acts as the essential link between the eye and the brain's visual processing (3). It can be divided into 4 segments: intraocular, intraorbital, intracanalicular, and intracranial. Each segment is characterized by unique anatomical and physiological features, and susceptible to common diseases specific to each segment.

Imaging of the optic nerve is crucial in clinical practice, providing valuable insights into its structure, status, and any underlying pathologies. Various imaging modalities, including optical coherence tomography (OCT), magnetic resonance imaging (MRI), ultrasound, computed tomography (CT), and fundus photography, have evolved to offer detailed visualization of the optic nerve. These techniques are essential for diagnosing optic neuropathies and identifying their causes (1,4). Although there have been multiple reviews in the ophthalmology field with different emphases (5-7), a comprehensive and visualized analysis of the evolution and trends of optic nerve imaging is still lacking. We conducted a bibliometric examination of studies on optic nerve imaging from January 1991 to August 2023 in terms of the distribution of annual publications, journals, countries, institutions, authors, keyword co-occurrence, and burst terms, aiming to identify research trends and hotspots of optic nerve imaging, offering references for future investigations.

Methods

Data was obtained from the Web of Science Core Collection on 4 August 2023. The following search terms were used: TS=("Diagnostic Imaging" OR "Imaging, Diagnostic" OR "Medical Imaging" OR "Imaging, Medical" OR "imaging" OR "display" OR "radiodiagnosis" OR "Tomography" OR "MRI" OR "Magnetic Resonance" OR "Tomography, NMR" OR "Diffusion Tensor Imaging" OR "Spin Echo Imaging" OR "CT Scan*" OR "Computed Tomography" OR "OCT" OR "Optical Coherence Tomography" OR "Rontgenolo*" OR "X ray" OR "Ultrasonography" OR "Ultrasound" OR "Ophthalmoscop*" OR "Retinoscopy" OR "Photography") AND TS=("Optic Nerve" OR "Cranial Nerve II" OR "Nervus Opticus" OR "Second Cranial Nerve*" OR "retina afferent" OR "retinal afferent" OR "retina afferent fiber" OR "retinal afferent fiber"). The literature search was performed for articles from 1991 to 2023 on 4 August 2023.

Bibliometrix software (version 4.1.3; https://www.bibliometrix.org/home/) was used to conduct the descriptive analysis of bibliometric indicators. Coauthorship analysis and keywords co-occurrence visualization were carried out using VOSviewer (version 1.6.20; https://www.vosviewer.com/) to identify popular research topics. CiteSpace (version 6.2.6; https://www.vosviewer.com/) was employed for burst-detection analysis, the key indicators of hotspots and cutting-edge developments within a particular field of study (8). Only names of independent institutions were selected for further analysis, and consortiums or alliances were excluded. Additionally, to address keyword repetition, we initially extracted the top 300 keywords and manually identified duplicates (Appendix 1). Python (https://www.python.org/) was employed subsequently to merge synonymous terms such as "optical coherence tomography" and "OCT", "optic disc" and "optic disk". To uncover hidden themes in textual data, text mining was conducted using Latent Dirichlet Allocation (LDA), a machine learning-based algorithm widely applied across various fields. LDA helps to discover and analyze relationships, trends, and the intellectual structure within text documents from a comprehensive set of publications, providing valuable insights (9). The modeling algorithm was trained in R (version 4.3.1; https://www.r-project.org/), and Gephi Software (version 0.10.1; https://gephi.org/) was used for visualizing the results. The 2022 journal impact factors and the quartile in the category of the journals were retrieved from the Journal Citation Reports on 6 September 2023.

Results

Selection of articles

Using the search queries, 19,335 publications were retrieved. Based on the selection criteria, 4,088 non-original articles were excluded, and 15,247 original articles related to optic nerve imaging were included in the analysis (*Figure 1*).

The quantity of published articles on optic nerve imaging showed an overall trend by year, which rose from 122 in 1991 to 1,252 in 2022. Until 4 August there were 604 publications in 2023 (*Figure 2*).

Distribution by journals

The 15,247 articles were published across 1,837 journals. The top 10 journals based on number of publications published 3,856 articles on optic nerve imaging and

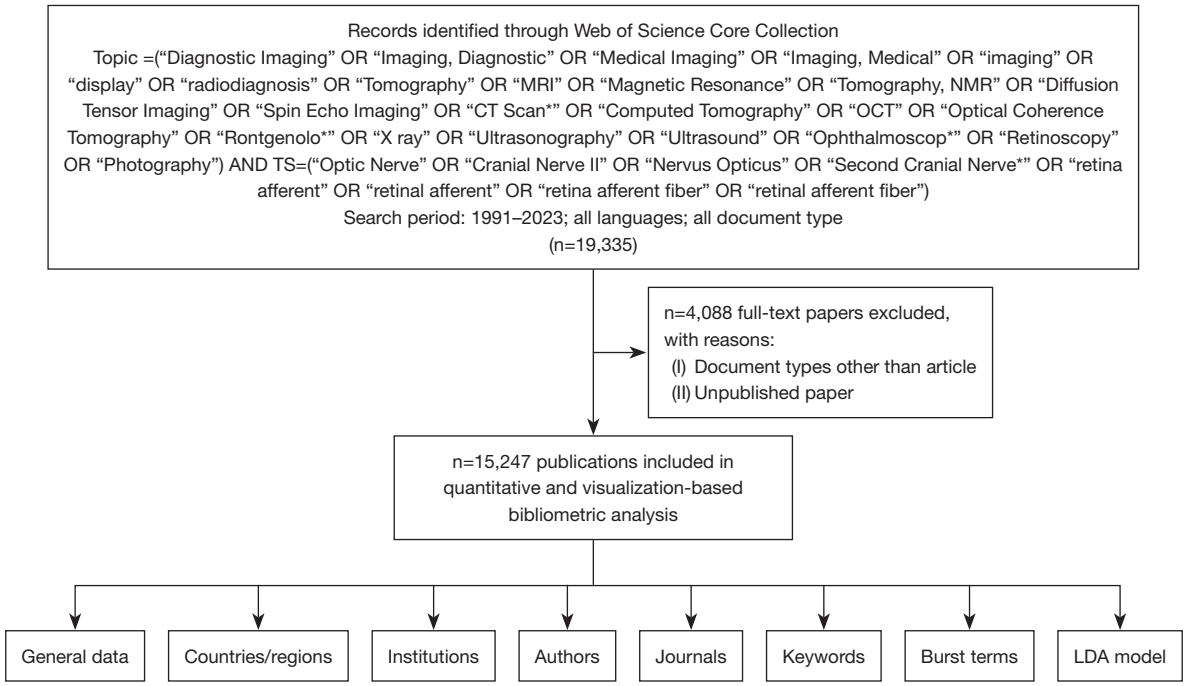

Figure 1 The data collection and retrieval strategy. The symbol "*" is a wildcard character used to represent any combination of characters that follow. MRI, magnetic resonance imaging; NMR, nuclear magnetic resonance; CT, computed tomography; OCT, optical coherence tomography; TS, topic; LDA, Latent Dirichlet Allocation.

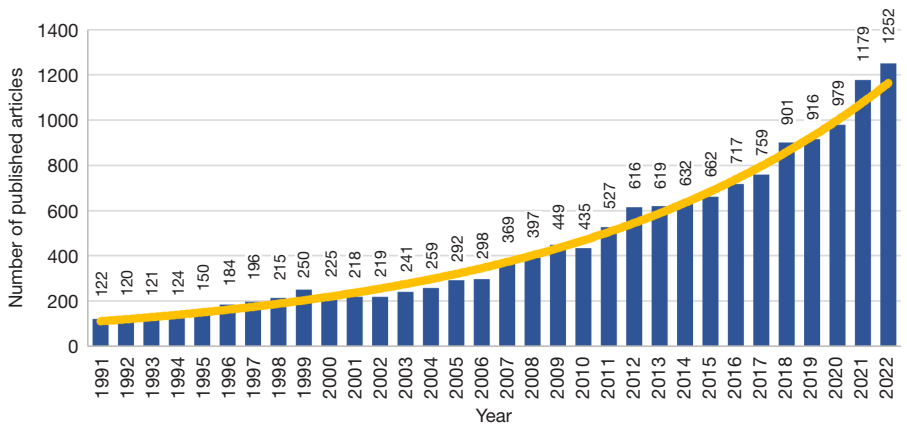

Figure 2 The number of articles on optic nerve imaging per year from 1991 to 2022.

accounted for 25.29% of all articles (*Table 1*). Among the top 10 journals, 8 were specialized in ophthalmology, whereas the remaining 2 were multidisciplinary. *Investigative Ophthalmology & Visual Science* was the most productive journal (976 publications) and the most highly cited journal (37,813 citations), followed by *Ophthalmology* with 438 publications and *British Journal of Ophthalmology* with 405 publications.

Distribution by countries/regions

The 15,247 articles originated from 97 countries and regions. The USA, China, Germany, Japan, and Korea were the most common locations for publishing articles on optic

Table 1 The top 10 journals ranked by publication number

Rank	Journal title	Category	Quartile in category (2022)	Impact factor (2022)	Publications	Citations	Average citation
1	*Investigative Ophthalmology & Visual Science*	Ophthalmology	Q1	4.4	976	37,813	38.7
2	*Ophthalmology*	Ophthalmology	Q1	13.7	438	27,866	63.6
3	*British Journal of Ophthalmology*	Ophthalmology	Q1	4.1	405	13,435	33.2
4	*Journal of Glaucoma*	Ophthalmology (Subspecialty)	Q3	2.0	399	7,664	19.2
5	*American Journal of Ophthalmology*	Ophthalmology	Q1	4.2	362	19,784	54.7
6	*PLoS One*	Multidisciplinary sciences	Q2	3.7	304	5,455	17.94
7	*Graefes Archive for Clinical and Experimental Ophthalmology*	Ophthalmology	Q2	2.7	303	5,667	18.7
8	*Journal of Neuro-Ophthalmology*	Clinical Neurology/ ophthalmology (subspecialty)	Q3/Q2	2.9	268	3,120	11.6
9	*Eye*	Ophthalmology	Q1	3.9	209	4,171	20.0
10	*Scientific Reports*	Multidisciplinary sciences	Q2	4.6	192	1,696	8.8

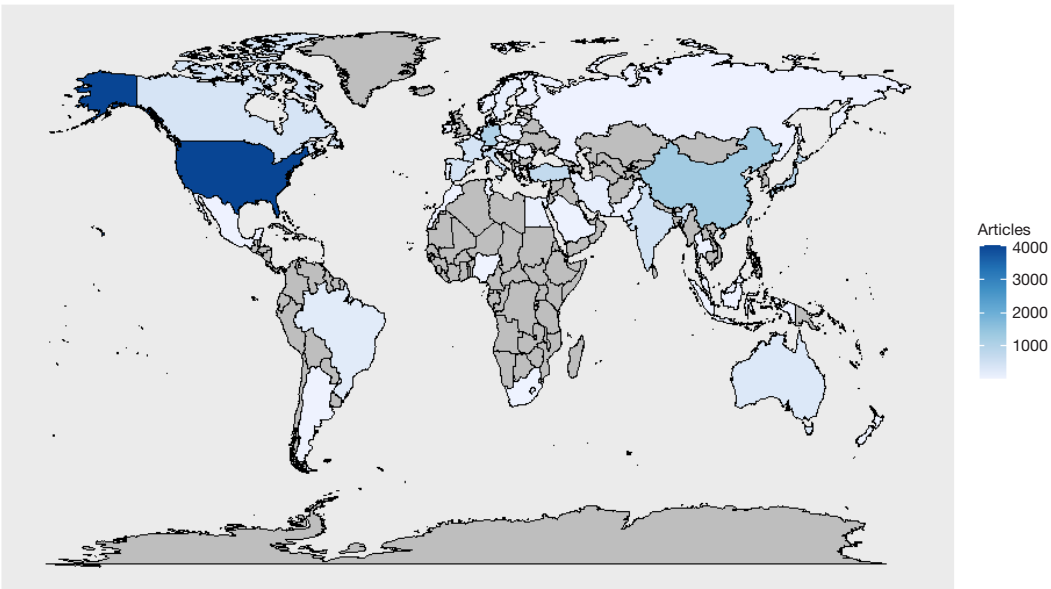

Figure 3 Distribution of countries/regions in optic nerve imaging research.

nerve imaging (*Figure 3*, Table S1). The co-authorship network visualization map of countries is shown in *Figure 4*. In total, 94 countries/regions and 855 cooperation instances were showcased. The USA had the strongest international cooperation network and cooperated most closely with China.

Distribution by institutions

The ranking of the top 10 most productive institutions is based on the frequency of institutional author affiliations. Among these, 5 were located in the USA, 1 in the United

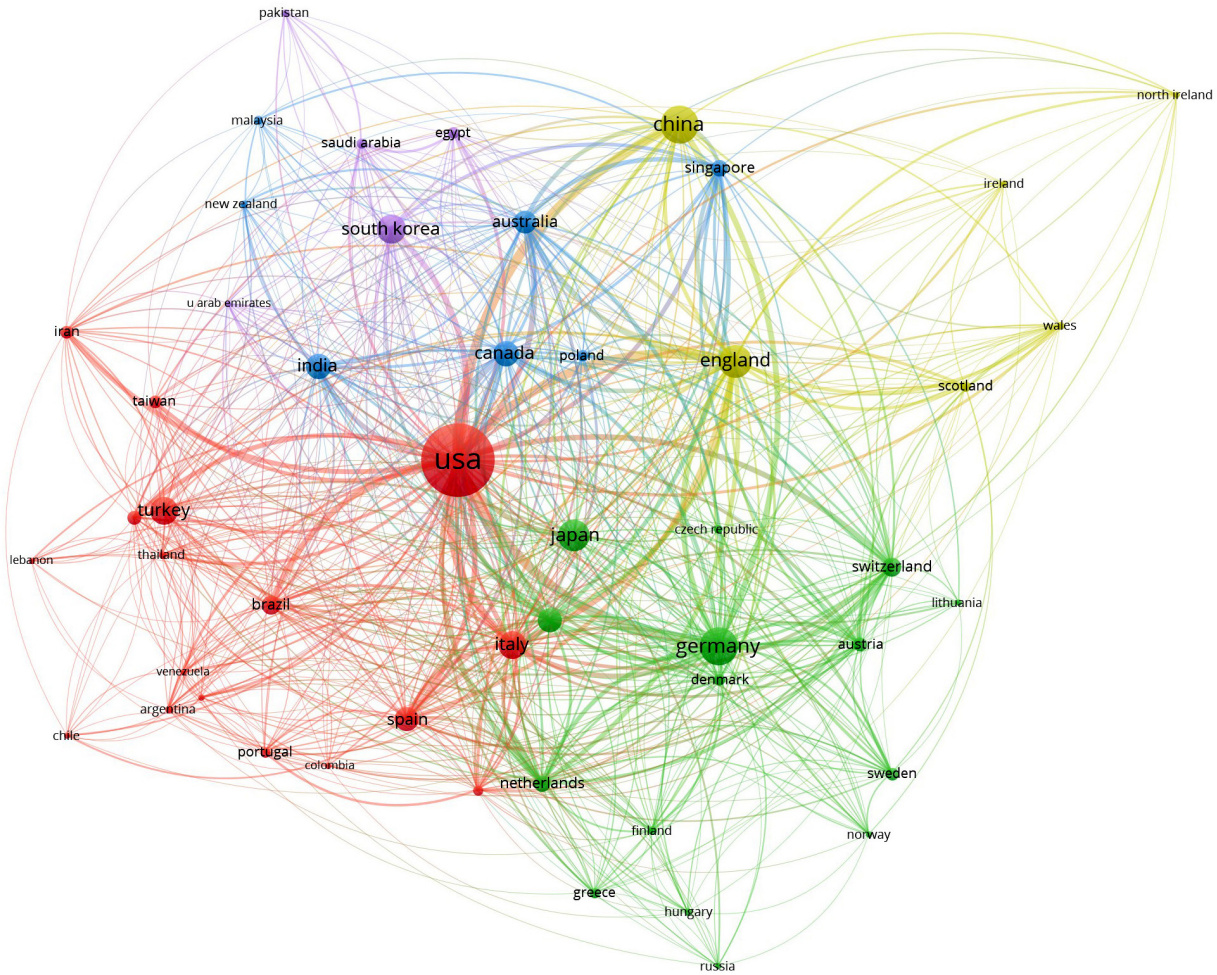

Figure 4 The co-authorship network of countries/regions.

Kingdom, 1 in Singapore, 1 in Korea, 1 in Germany, and 1 in Canada (Table S2). The University College London published 882 articles in this field, followed by the University Harvard University, National University of Singapore, University of California San Diego, and University of Pittsburgh (*Figure 5*).

Distribution by authors

The 15,247 articles were written by 49,488 authors in total. The top 10 authors publishing articles on optic nerve imaging are shown in *Table 2*. Weinreb RN from the University of California San Diego ranked first, followed by Zangwill LM from the University of California San Diego and Jonas JB from the Heidelberg University. In addition, Weinreb RN was the author with the highest number of total citations and the highest H-index.

Analysis of keywords co-occurrence

We identified the top 20 keywords (keywords with inherent alignment to our theme such as "optic nerve" was excluded) and classified them into 4 categories (*Figure 6*); the co-occurrence of the top 100 is shown in *Figure 7*. Apart from "optic nerve", "glaucoma", "optical coherence tomography", "magnetic resonance imaging", and "retinal nerve fiber layer" were the most frequent keywords.

Analysis of burst terms

The burst terms with occurrence bursts lasting until 2023 represented hot topics. The most recent burst

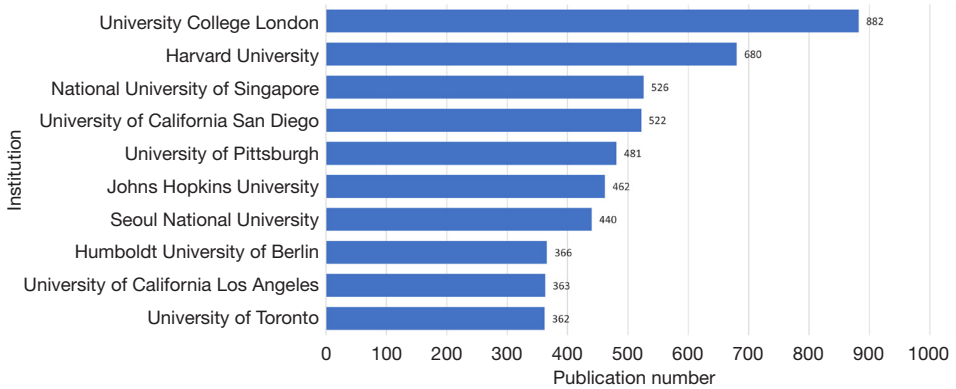

Figure 5 Top 10 institutions that produced the largest number of articles.

Table 2 The top 10 authors ranked by publication number

Rank	Author	Affiliation	Publications	Citations	H-index
1	Weinreb RN	University of California San Diego	236	5,381	70
2	Zangwill LM	University of California San Diego	138	3,076	54
3	Jonas JB	Heidelberg University	109	1,596	38
4	Schuman JS	New York University	99	2,523	39
5	Medeiros FA	Duke University	97	2,293	47
6	Burgoyne CF	Legacy Research Institute	86	3,280	40
7	Girard MJA	Singapore Eye Research Institute	84	1,174	28
8	Lee EJ	Seoul National University	84	1,140	25
9	Park KH	Seoul National University	81	679	25
10	Liebmann JM	Columbia University	80	1,666	38

keywords were "vessel density", "segmentation", "myelin oligodendrocyte glycoprotein", "machine learning", and "optical imaging", signifying heightened attention in specific study fields (*Figure 8*).

LDA model

LDA uses a Bayesian approach and assumes that the topics and the topic distribution within documents follow Dirichlet distributions (10). The model operates on 3 levels: words, topics, and documents. It assumes that each document is a mixture of a small number of topics and that each words' creation is attributable to 1 of the document's topics. A key assumption of LDA is that the probability of each word is dependent on the topic it was drawn from, and each document is a mixture of topics with different proportions. This allows for the interpretation of the topics and the analysis of the documents in terms of these topics (9,11).

By employing LDA topic modeling, our study generated the top 50 topics associated with optic nerve imaging (*Figure 9*). Moreover, a clustering network unveiled the interrelation among these topics, revealing the presence of 3 distinct clusters: structural and functional assessment, imaging techniques and disease evaluation, and neuro-ophthalmology and clinical research (*Figure 10*).

Discussion

General knowledge structure in optic nerve imaging research

Bibliometric analysis employs statistical techniques to systematically examine patterns and trends in published

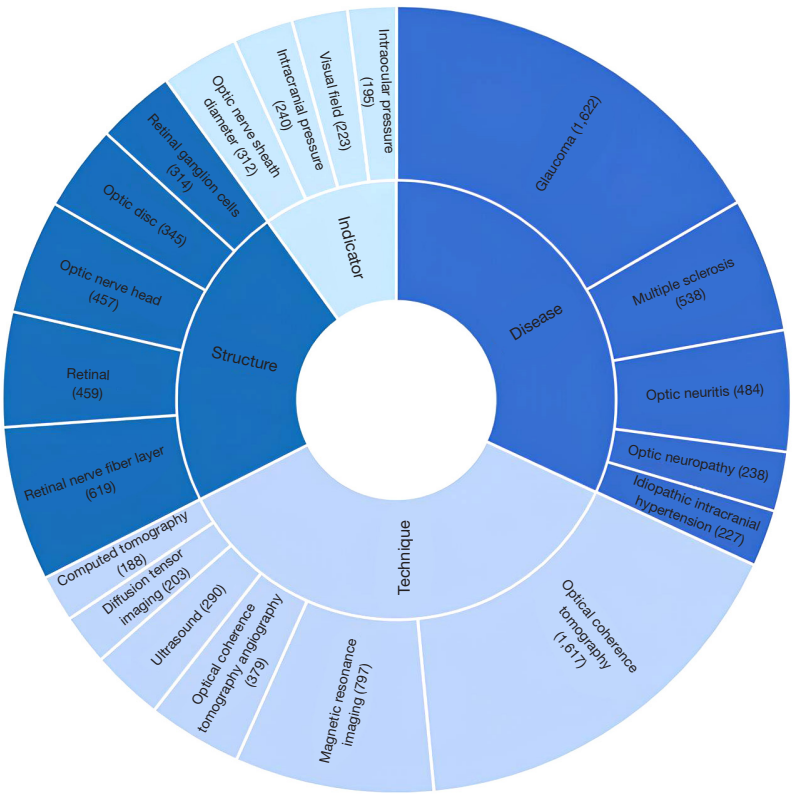

Figure 6 Top 20 keywords in 4 categories.

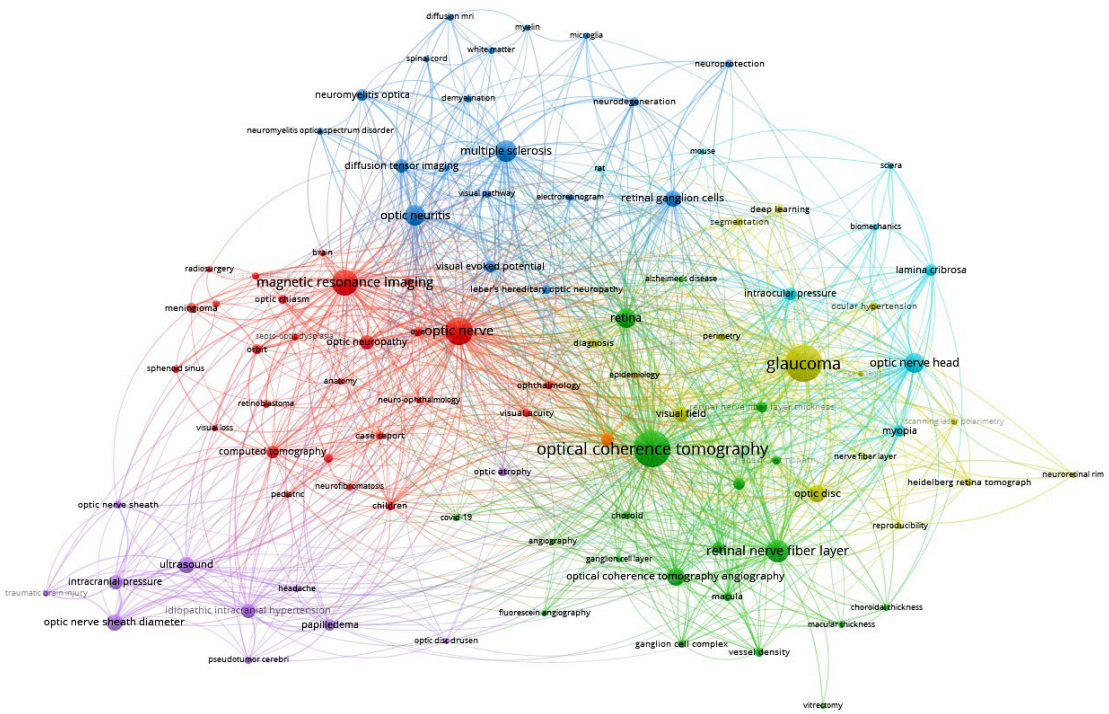

Figure 7 Co-occurrence network of author keywords.

Figure 8 Keywords with the strongest occurrence burst on optic nerve imaging. The color bar (lighter blue) represents the timeline from 2013 to 2022. The darker blue indicates the appearance of keywords, whereas red highlights the periods of strongest citation bursts for these keywords.

literature (12). This method identifies influential authors, institutions, and journals, as well as international collaborations and global interests in the field of optic nerve imaging. Consequently, it assists scientific readers in recognizing key contributors, tracking emerging trends, and locating high-quality sources and potential collaborators for their research.

In the realm of optic nerve imaging, a notable trend in research progression has emerged over the years. Starting modestly in 1991 with 122 publications, this field has experienced significant growth. In 2022, the number of publications surged to an impressive 1,252, reflecting a growing interest and substantial advancements. As we approached 4 August 2023, an additional 604 publications further emphasized the dynamic nature of optic nerve imaging. This robust growth highlighted the enduring significance of this field as a focal point of scientific inquiry and innovation, poised to expand our understanding and capabilities in ophthalmology. In the realm of high-impact research on optic nerve imaging, the USA held a dominant position, with the highest number of publications and citations and fostering strong international collaborations. Besides, a dramatic surge in the number of publications has been witnessed in China in recent years, suggesting a gradual expansion of China's influence in the field. Notably, the University College London stood out as a leading

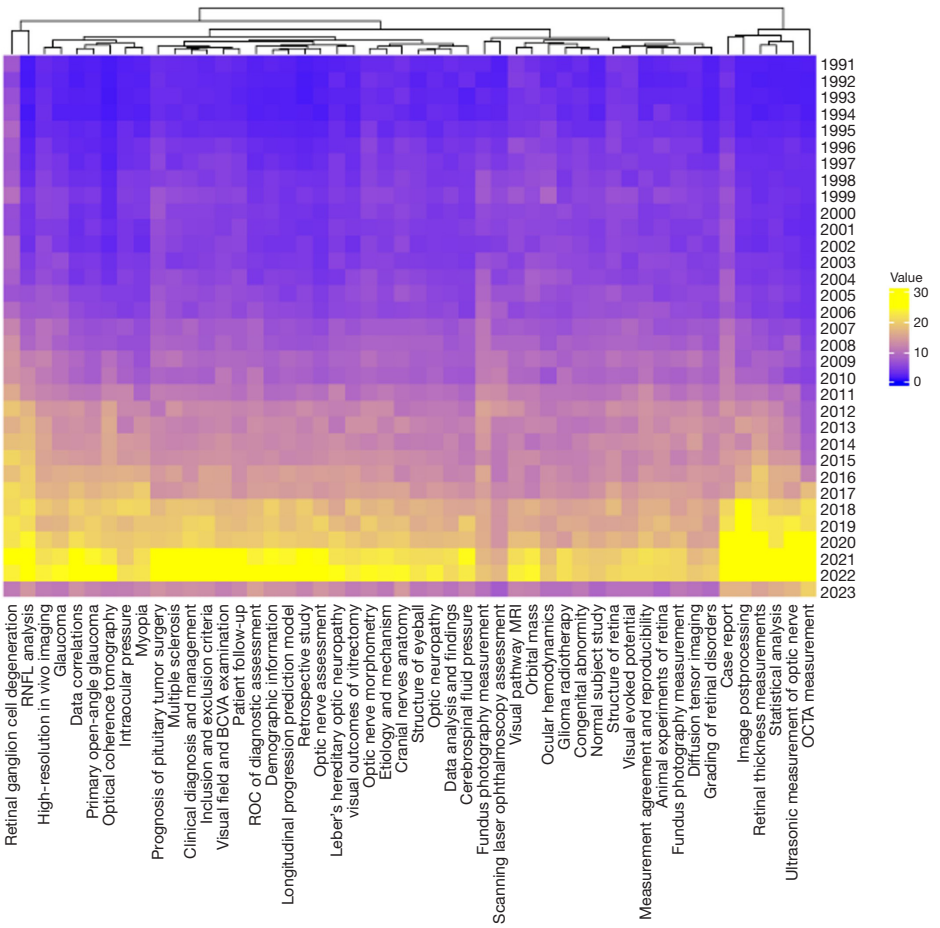

Figure 9 Distribution value of 50 topics determined by Latent Dirichlet Allocation model in the field of optic nerve imaging from 1991 to 2023. RNFL, retinal nerve fiber layer; BCVA, best-corrected visual acuity; ROC, receiver operating characteristic; MRI, magnetic resonance imaging; OCTA, optical coherence tomography angiography.

institution, contributing significantly to both publications and citations and actively collaborating with other research centers. It is noteworthy that the top 2 most productive authors, Weinreb RN and Zangwill LM, were affiliated with the University of California San Diego. Weinreb RN's research encompassed a broad spectrum, spanning from the anterior to the posterior of the eye, including optic disc (13) and retinal nerve fiber layer (RNFL) imaging (14). Meanwhile, Zangwill LM specialized in developing computational and statistical techniques to enhance the detection of glaucomatous changes (13,15). Among the top 10 journals in optic nerve imaging, although *Investigative Ophthalmology & Visual Science* boasted the highest number of publications and citations, *Ophthalmology* demonstrated the greatest average citation count. This correlation suggests that the journals' impact factor could influence citation rates.

Main research domains in optic nerve imaging research

Keywords play a crucial role in representing the central theme and content of a research paper, whereas co-occurrence relationships among keywords provide insights into hot topics and emerging trends within a research field. In the context of optic nerve imaging, keyword analysis revealed 4 primary categories: (I) imaging technique, (II) disease, (III) optic nerve structure, and (IV) indicator.

Imaging technique

The field of optic nerve imaging has witnessed substantial advancements in recent years. Current research primarily revolves around "Optical Coherence Tomography" for

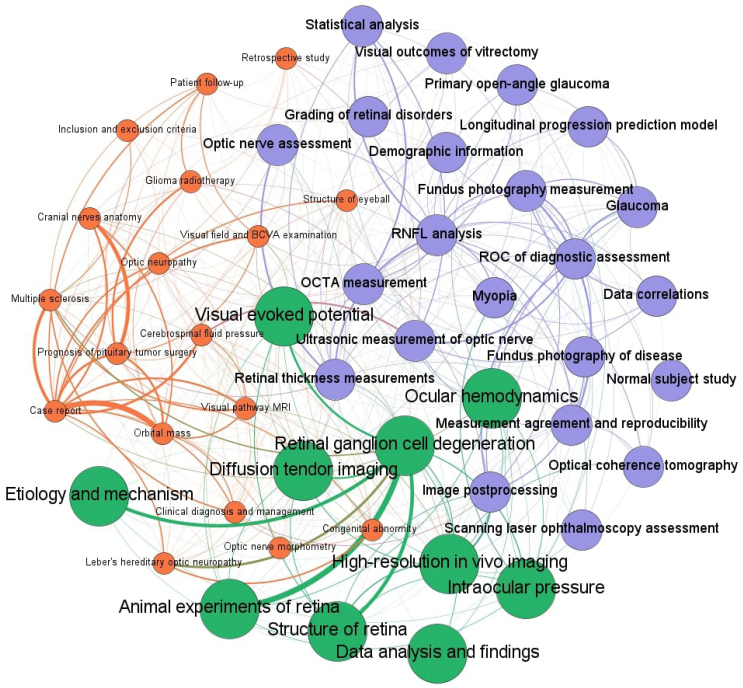

Figure 10 Topics network with clustering. Three clusters were identified, including structural and functional assessment (green), imaging techniques and disease evaluation (violet), neuro-ophthalmology and clinical research (red). RNFL, retinal nerve fiber layer; BCVA, best-corrected visual acuity; ROC, receiver operating characteristic; OCTA, optical coherence tomography angiography; MRI, magnetic resonance imaging.

detailed examination of retinal anatomy and "Magnetic Resonance Imaging" for a comprehensive evaluation of the optic nerve and the entire visual pathway. OCT is an infrared-based, non-invasive method that offers high-resolution cross-sectional images of the retina and optic nerve head (ONH). OCT enables the differentiation of retinal layers and provides quantitative measurements of their thickness. Additionally, OCT angiography has emerged as a technique for high-resolution retinal vasculature imaging without the need for fluorescein dye injection (16). Over the past decade, research has increasingly shown the diagnostic and prognostic potential of various OCT modalities for conditions such as multiple sclerosis (MS) (17), papilledema (18), and optic neuritis (ON) (19).

MRI encompasses structural magnetic resonance (MR), diffusion MR, and functional MR, each offering unique advantages in optic nerve imaging. Structural MRI provides superior contrast resolution and diverse image contrast mechanisms, making it the preferred choice for various optic nerve applications. Diffusion MRI maps the diffusion process of molecules, revealing microscopic details about tissue architecture in both normal and diseased states (20,21). Both structural and diffusion MRI play crucial roles in clinical imaging, particularly in the diagnosis of orbital diseases such as thyroid eye disease (22) and optic neuropathies (23). Additionally, functional MRI has gained popularity in recent years for optic nerve research, enabling the evaluation of optic neuropathy-related effects on the entire visual system (24-26). This may offer valuable differential diagnostic or prognostic insights in clinical settings (27).

Disease

Optic nerve imaging is one of the most reliable tools for diagnosing ophthalmic diseases. The majority of optic nerve imaging research focuses on 3 primary diseases: glaucoma, MS, and ON. Glaucoma is a widespread condition and has become the primary cause of irreversible blindness globally (28). Recent advancements in laser scanning imaging techniques, such as OCT, have greatly improved the early detection of the disease and the monitoring of progressive optic nerve fiber loss over time (29). ON is an acute inflammatory condition that causes demyelination

of the optic nerve and often results in varying degrees of permanent visual impairment. The specific contrast enhancement of the optic nerve on MRI has become an essential tool for the differential diagnosis of ON (30). As ON occurs during the disease course in approximately 70% of MS patients (31), some researchers suggest including symptomatic optic nerve involvement in the diagnostic criteria for MS (32). Notably, 3-dimensional (3D)-double inversion recovery MRI demonstrates significant sensitivity in detecting ON in MS (33). Moreover, post-processed MRI techniques offer valuable insights into the pathophysiology of ON associated with MS (34).

Optic nerve structure

Various imaging techniques can provide insights into different aspects of the optic nerve's anatomy. Commonly examined structures include the RNFL and ONH. RNFL offers an alternative to visually assessing the optic nerve neuroretina rim. It also provides a quantitative estimate of axonal loss in retinal ganglion cells. Measurements of RNFL thickness are particularly reliable, especially when obtained using spectral-domain OCT devices (35). Despite the nerve-fiber layer, analyzing the size and shape of the ONH enhances diagnostic capabilities and aids in monitoring conditions. For example, signal changes in the ONH shown in 3D T2-weighted MRI scans may be a neuroimaging marker of glaucomatous optic neuropathy (36).

Indicator

The most frequently mentioned indicators in optic nerve imaging include the optic nerve sheath diameter (ONSD) and intracranial pressure (ICP). ONSD is considered an indirect marker for ICP (37). Increased ICP can lead to optic nerve swelling and subsequent vision loss. Moreover, detecting and assessing reduced ICP may be useful in diagnosing glaucoma at earlier stage (38).

Future trends

Keyword burst analysis offers a valuable tool for forecasting research frontiers and predicting trends in both fundamental and clinical research (39). Utilizing the LDA model, image post-processing has garnered increasing attention over the past 6 years, which was also observed as 2 of the most recent hot keywords ("Machine learning" and "Segmentation") with the highest term frequency in the analysis of the strongest citation burst. The results indicate an increased focus on utilizing artificial intelligence techniques for segmentation algorithms used in image analysis to improve diagnostic accuracy or prognostic evaluation in retinal and optic nerve diseases.

Limitations

There are some limitations in our study. We solely relied on the Web of Science Core Collection database for screening, potentially missing relevant studies from other sources. Moreover, during the manual merging of the top 300 repeated keywords, there might be an impact on the outcome of co-occurrence and burst term analyses. Finally, our findings may be influenced by the ongoing updates in the literature as new research in optic nerve imaging might be published every month due to rapidly evolving imaging techniques.

Conclusions

This current study provides the first quantitative and comprehensive analysis of global research trends on optic nerve imaging through bibliometric and visualized methods. It indicates a growing interest in this field and identified key contributors, including prominent authors, countries, institutions, and influential journals.

Moreover, the research demonstrates that artificial intelligence will be a promising area of focus in the coming years. Consequently, this investigation provides a comprehensive overview of the research landscape, offering insights for prospective studies in the realm of optic nerve imaging.

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Footnote

Conflicts of Interest: All authors have completed the ICMJE

uniform disclosure form (available at https://qims.amegroups.com/article/view/10.21037/qims-24-870/coif). The authors have no conflicts of interest to declare.

Ethical Statement: The authors are accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved.

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