• Bibliometric Research •

Tracing global progress: two decades of age-related macular degeneration research

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Abstract

● **AIM:** To conduct a comprehensive bibliometric analysis of age-related macular degeneration (AMD) research from 2002 to 2022, identifying key contributing countries, institutions, authors, journals, and research hotspots to inform future research directions.

● **METHODS:** Publications related to AMD were retrieved from the Web of Science Core Collection (WoSCC) database for the period January 1, 2002, to December 31, 2022. The search was limited to English-language articles and reviews. Bibliometric analysis was performed using Microsoft Excel 2021 for data management and annual publication analysis. Visualization and network analyses were conducted using VOSviewer, CiteSpace, and the Bibliometrix package in R. Collaboration networks among countries, institutions, authors, and journals were mapped. Keywords were analyzed for co-occurrence to identify research hotspots. Metrics such as H-index, total link strength (TLS), and citation counts were used to assess impact.

● **RESULTS:** A total of 16 715 publications were analyzed, showing a consistent increase in AMD research output over the past 20y, peaking at 1445 publications in 2021. The United States was the leading contributor with 31.8% of total publications, followed by China and the United Kingdom. The University of Melbourne emerged as the most productive institution with the highest TLS, indicating strong international collaborations. Professor Frank G. Holz was identified as the most influential author based on H-index and publication count. *Investigative Ophthalmology & Visual Science* was the most prolific journal and had the highest citation impact. Keyword co-occurrence analysis revealed four main research clusters: pathogenesis, therapy, epidemiology, and diagnosis. Emerging research hotspots included anti-vascular endothelial growth factor (VEGF) therapies, optical coherence tomography angiography, and artificial intelligence (AI) applications in diagnosis.

● **CONCLUSION:** The bibliometric analysis highlights significant growth and collaborative efforts in AMD research globally. Key contributors have advanced understanding in pathogenesis, therapeutic strategies, epidemiology, and diagnostic technologies. Future research should focus on interdisciplinary collaborations, novel therapeutic targets, personalized medicine, and technological innovations such as AI to effectively address the challenges posed by AMD.

● **KEYWORDS:** age-related macular degeneration; bibliometric analysis; research trends; collaboration networks; research hotspots

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INTRODUCTION

Age-related macular degeneration (AMD) is a debilitating eye disease that progressively impairs central vision as the macula deteriorates over time[1]. AMD is categorized into two main types: nonneovascular and neovascular[1]. It is the leading cause of irreversible blindness in individuals over 60 in developed nations[2]. The global population with AMD is projected to reach 196 million by 2020 and 288 million by 2040, driven by population growth and increased life expectancy, underscoring the significant worldwide burden of this condition[3-4].

Despite advancements, AMD research faces substantial challenges. The disease's complex pathogenesis involves multiple genetic, environmental, and lifestyle factors, hindering the identification of precise therapeutic targets[5]. Moreover, the distinct treatment approaches required for dry and wet AMD further complicate research efforts. While anti-

vascular endothelial growth factor (anti-VEGF) therapies have transformed wet AMD management, effective treatments for dry AMD remain elusive. Another major challenge is the development and validation of reliable biomarkers for early detection and disease progression monitoring[6]. The heterogeneity of AMD phenotypes and its multifactorial nature impede the discovery of universally applicable biomarkers, and the need for non-invasive diagnostic tools remains a significant research focus[7-8].

The exponential increase in AMD-related research has led to a vast and growing body of literature, presenting challenges for researchers, especially newcomers, in navigating and synthesizing the available data. Bibliometric analysis, which employs mathematical and statistical methods to quantify and analyze publication volumes and impacts, has become an invaluable tool for assessing research trends and identifying key contributors[9].

Through bibliometric analysis, the evolution of AMD research, emerging hotspots, and collaborative networks among countries, institutions, authors, and journals can be elucidated. This approach provides a comprehensive overview of the current state of AMD research and offers insights into future directions and potential research gaps. This paper presents a comprehensive bibliometric analysis of AMD literature from 2002 to 2022, aiming to summarize the current state of AMD research, identify predominant focus areas, and highlight emerging research hotspots. The findings serve as a valuable reference for guiding future research directions and assisting new researchers in navigating the field.

MATERIALS AND METHODS

Ethical Approval This study is a bibliometric analysis of publicly available data and does not involve human or animal subjects. Therefore, ethical approval from an institutional review board or ethics committee was not required. However, all data used were sourced ethically from the Web of Science Core Collection (WoSCC).

Data Collection and Bibliometric Analysis In this study, we used the WoSCC because it is one of the most authoritative and comprehensive databases for the bibliometric analysis of scientific publications. The WoSCC database covers over 12 000 high-quality influential journals from around the world, providing a wide range of bibliometric indicators. Our literature search strategy involved the following search parameters: TI=("age related macular degeneration"*) OR AB=("age related macular degeneration"*) OR TI=("age-related macular degeneration"*) OR AB=("age-related macular degeneration"*) OR TI=("senile disciform macular degeneration"*) OR AB=("senile disciform macular degeneration"*) OR TI=("disciform macular degeneration"*) OR AB=("disciform macular degeneration"*) OR TI=("senile macular degeneration"*) OR AB=("senile macular degeneration"*) OR TI=("age-related maculopathy"*) OR AB=("age-related maculopathy"*) OR TI=("age related maculopathy"*) OR AB=("age related maculopathy"*) OR TI=("macular neovascularization"*) OR AB=("macular neovascularization"*) OR TI=("polypoidal choroidal vasculopathy") OR AB=("polypoidal choroidal vasculopathy") OR TI=("wet AMD") OR AB=("wet AMD") OR TI=("dry AMD") OR AB=("dry AMD") ORTI=("geographic atrophy") OR AB=("geographic atrophy") AND DT=(Article OR Review). The language was limited to English. The time frame of publications was set from January 1, 2002, to December 31, 2022. All records for the retrieved papers, including titles, authors, abstracts, and references, were compiled into a plain text exported filed and used as the dataset for this study. The data were then saved using the download text file.

First, Microsoft Office Excel 2021 was used for data management and annual publication analysis, followed by visual analysis using VOSviewer (version 1.6.18), CiteSpace (version 6.1.R3), and BiblioShiny. VOSviewer is a program used for building and viewing bibliometric maps. VOSviewer can be utilized to analyze collaboration networks among countries, institutions, journals, and authors, as well as cocitation of keyword clusters. As a measure of academic productivity, the H-index of an article indicates that the author/country has published at least H papers, each of which has received at least H citations[10]. Using CiteSpace, we examined research progress, explored the current research status and hotspots, generated a dual-map overlay for journals, and analyzed the development trends of the field[11]. The R package "Bibliometrix" was used for the visualization of publications across nations and the mapping of international collaborations[12].

RESULTS

Trend of Publication Outputs The literature search yielded a total of 17 252 records from the WoSCC database for the period between January 1, 2002, and December 31, 2022. Limiting the results to publications in the English language resulted in the exclusion of 537 non-English articles, leaving 16 715 records for analysis.

The analysis of global literature on AMD from 2002 to 2022 reveals a consistent increase in publication output over the study period (Figure 1). In 2002, there were 228 publications, which grew to a peak of 1445 publications in 2021. Between 2002 and 2004, the annual publication output remained relatively stable, averaging around 270 publications per year. A notable increase began in 2005, initiating a steady upward trend that continued through 2022. The annual number of publications rose significantly between 2019 and 2021, increasing from 977 to 1445. The cumulative number of

publications over the 20-year period reached 16 715 by the end of 2022, illustrating the overall growth in AMD research output during these years.

Distribution of Countries/Regions The analysis reveals that a total of 106 countries or regions contributed to the published literature on AMD from 2002 to 2022. As depicted in Figure 2, the United States emerged as the global leader, accounting for 31.8% of the total output with 5323 publications. China, the United Kingdom, Germany, and Japan followed, with 1729, 1041, 1017, and 957 articles, respectively.

Furthermore, the global collaboration network in AMD research, as illustrated in Figure 3, demonstrates a highly interconnected landscape. The analysis identified 1560 collaborative pairs worldwide, with the most frequent partnerships occurring between the United States and China, the United States and the United Kingdom, the United States and Germany, the United States and Australia, as well as the United Kingdom and Germany.

Contributions of Institutions A total of 9542 organizations contributed to the literature on AMD, with 121 institutions meeting the threshold of at least 60 publications. Figure 4 showcases the collaborative network of these institutions using VOSviewer, revealing a highly interconnected community of 121 nodes and 2868 links—a research ecosystem thriving on shared knowledge and resources. The network's structure shows distinct clusters, indicating that while institutions specialize in certain subfields of AMD research, they remain linked, creating a productive synergy across the field. Notably, institutions like the University of Melbourne (total link strength, TLS=791), National University of Singapore (TLS=702), and University of Sydney (TLS=689) form the backbone of a prominent Asia-Pacific cluster with strong international connections, particularly to North America and Europe.

Distribution of Authors The data reveals that 41 053 authors have contributed to research in the field of AMD. Figure 5 showcases the top ten most productive authors based on publication count. Leading this group is Professor Tien Y. Wong with 217 publications, affiliated with the Singapore Eye Research Institute and Singapore National Eye Centre. Following are Professor Frank G. Holz with 214 publications from the Department of Ophthalmology at the University of Bonn in Germany, and Professor Paul Mitchell with 196 publications from the Centre for Vision Research at the Westmead Institute for Medical Research and the Department of Ophthalmology at the University of Sydney in Australia.

The H-index was used to assess the impact of authors by accounting for both the quantity and citation frequency of their publications. As illustrated in Figure 6, the top three authors based on their H-index are Professor Frank G. Holz (69), Professor Paul Mitchell (66), and Professor Ronald Klein (65).

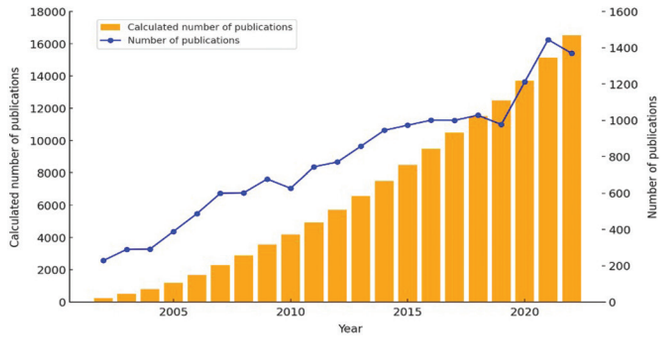

Figure 1 Annual number of publications in AMD research (2002–2022) AMD: Age-related macular degeneration.

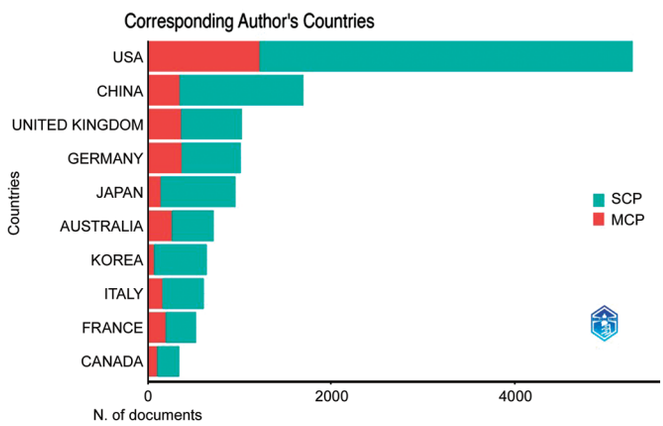

Figure 2 Top 10 countries/regions by publication output in the field of AMD AMD: Age-related macular degeneration; SCP: Single country publications; MCP: Multiple country publications.

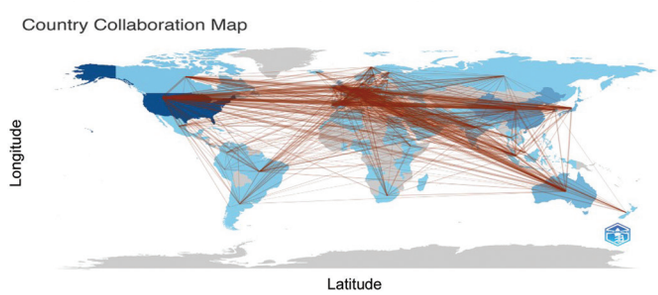

Figure 3 Geographic distribution map based on the total publications of different countries/regions.

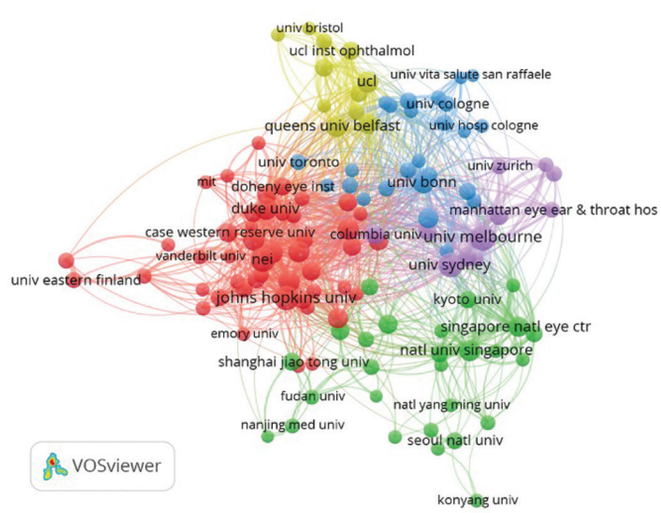

Figure 4 Collaborative network of institutions in AMD research AMD: Age-related macular degeneration.

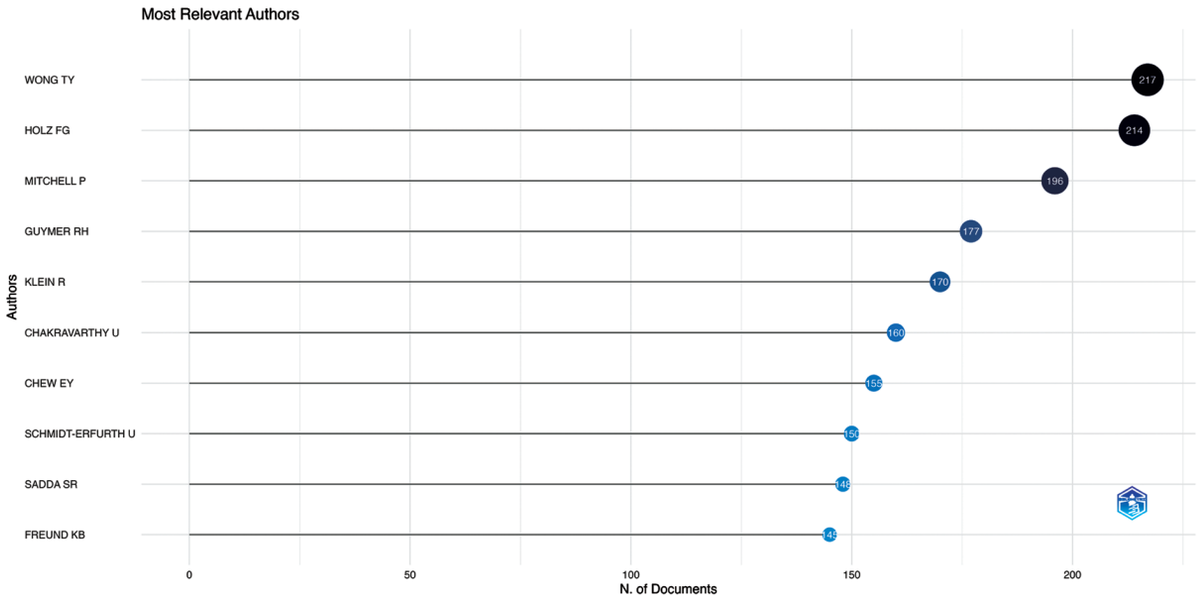

Figure 5 Top 10 most productive authors in AMD research AMD: Age-related macular degeneration.

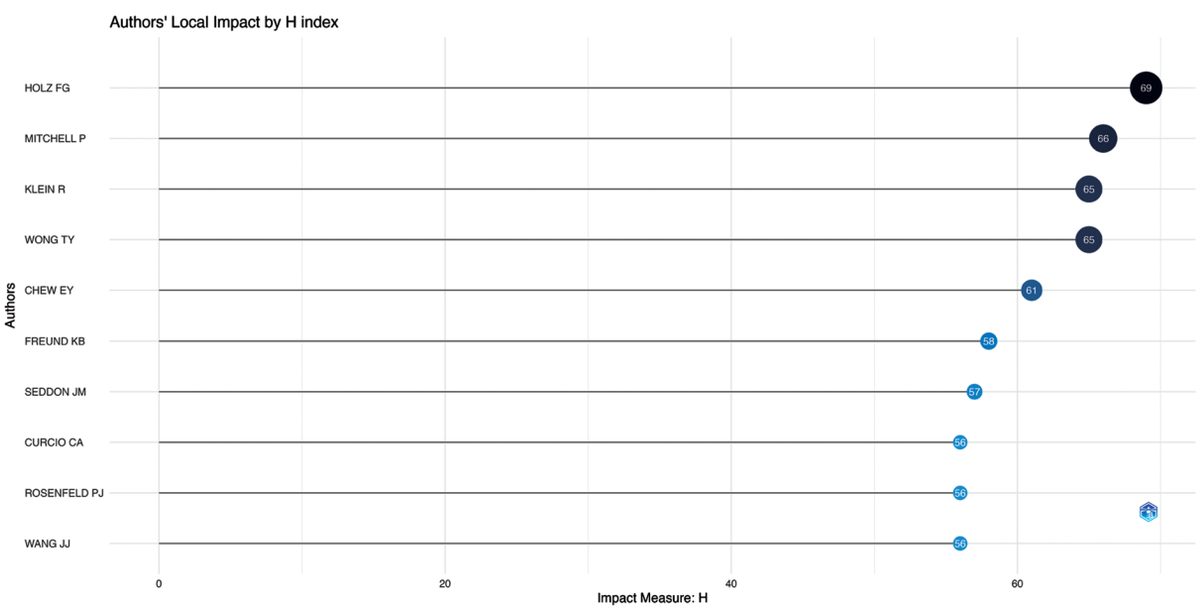

Figure 6 Top 10 authors in AMD research by H-index AMD: Age-related macular degeneration.

Professor Ronald Klein, although not among the top three in publication count, has a high H-index due to the significant citations of his work.

Distribution of Journals Our analysis revealed that research on AMD has been published in 1563 different journals. Figure 7 illustrates the top ten most relevant journals that have published articles on AMD. Among these, seven journals are based in the United States, while three originate from the United Kingdom. The top three journals, ranked by the number of published articles, are *Investigative Ophthalmology & Visual Science* (with 999 articles), *Retina*, *The Journal of Retinal and Vitreous Diseases* (691 articles), and *Ophthalmology* (684 articles). Figure 8 highlights that *Investigative Ophthalmology & Visual Science* and *Ophthalmology* rank first and second in terms of citations, demonstrating their pivotal role in disseminating AMD research. Additionally, *American Journal of Ophthalmology* ranks third in local citations, further reinforcing its influence in the field.

The dual map overlay of journals exhibits the distribution of connections among journals, where the journals that cite other journals appear on the left and the journals that are cited appear on the right. The relationships between the journals are indicated by colored paths. Figure 9 depicts the relationships between various fields, where the orange path illustrates that Molecular/Biology/Genetics journals are commonly cited by Molecular/Biology/Immunology journals, while the pink path shows that Neurology/Sports/Ophthalmology journals frequently cite Molecular/Biology/Genetics journals.

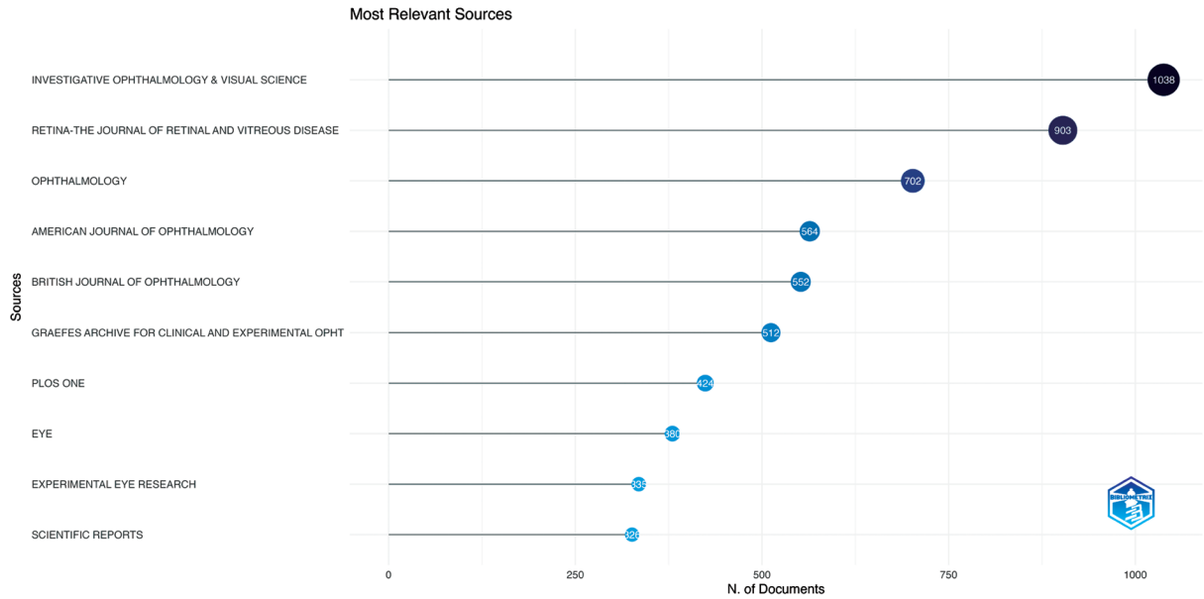

Figure 7 Top 10 journals in AMD research by publication output AMD: Age-related macular degeneration.

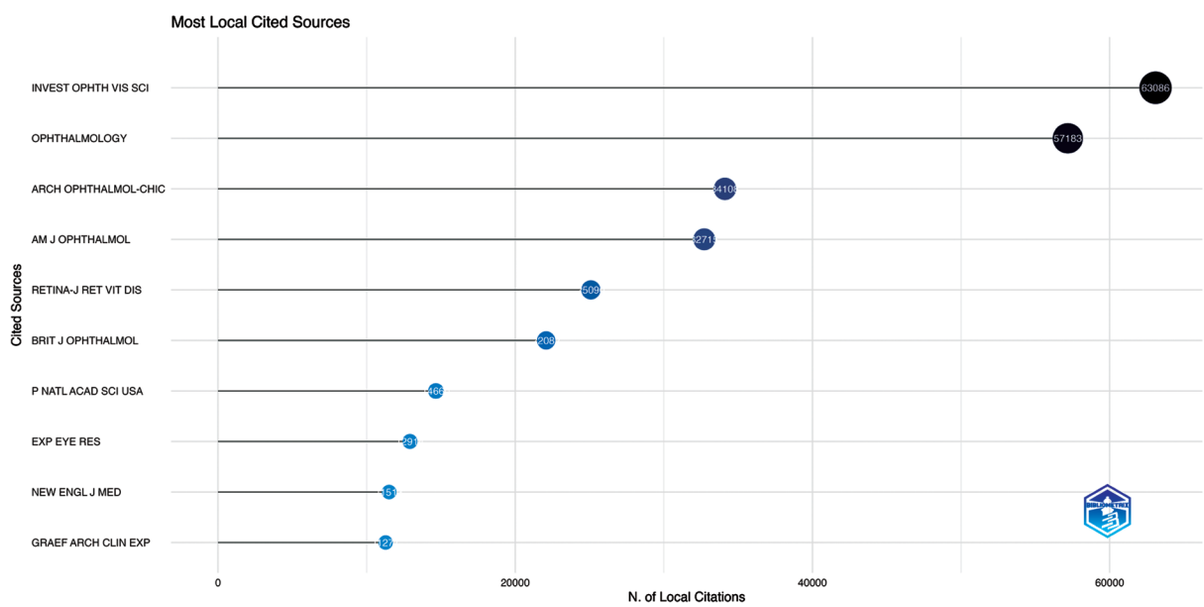

Figure 8 Top 10 journals in AMD research by local citations AMD: Age-related macular degeneration.

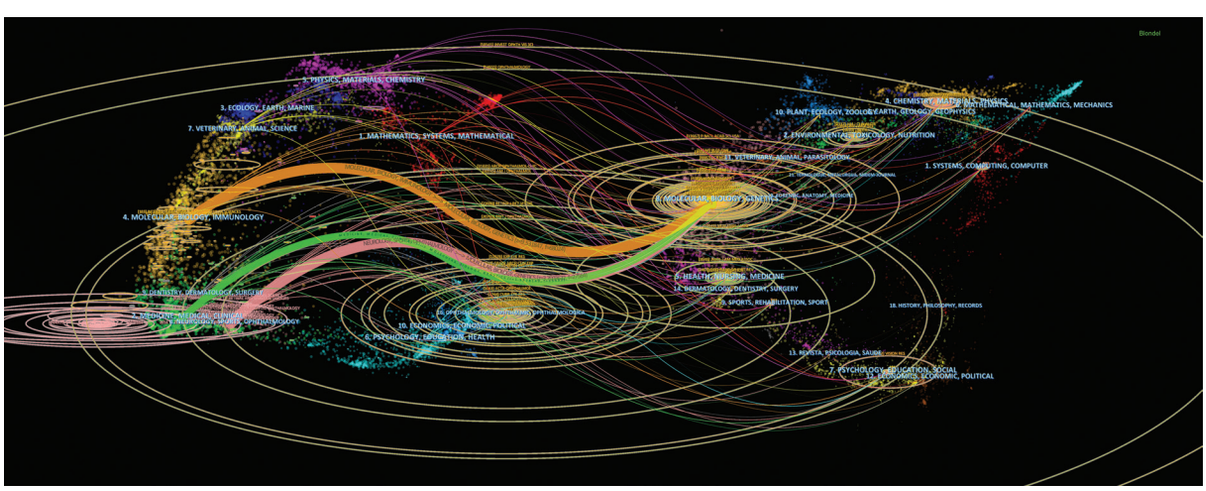

Figure 9 Dual-map overlay of journals in AMD research AMD: Age-related macular degeneration.

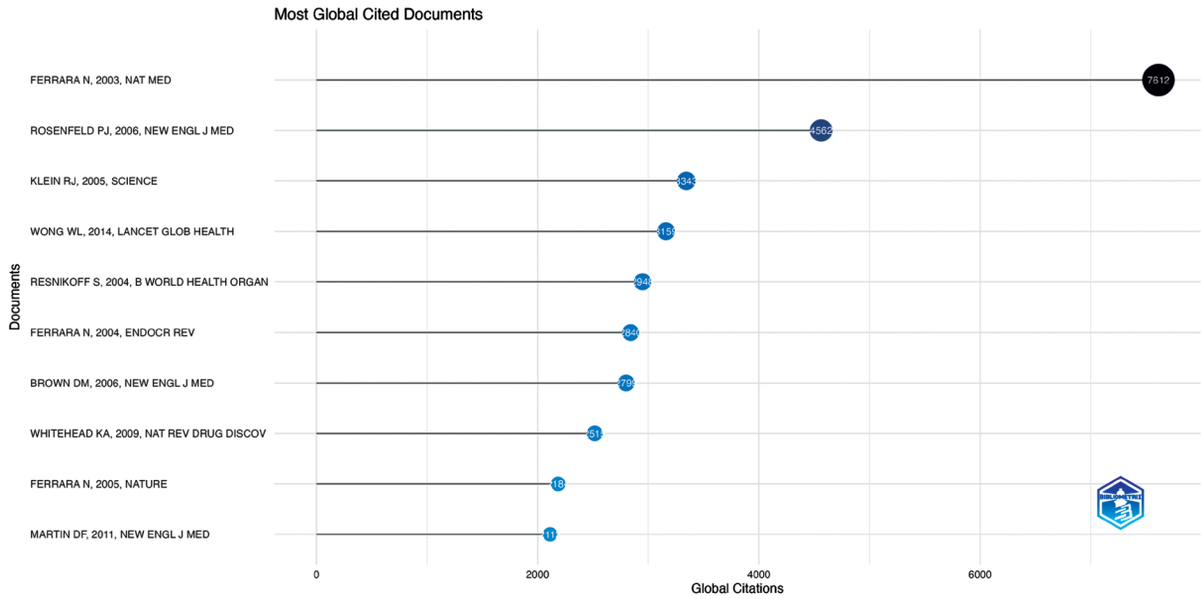

Figure 10 Top 10 most cited publications in AMD research AMD: Age-related macular degeneration.

Additionally, Medicine/Medical/Clinical journals often cite articles published in Molecular/Biology/Genetics journals, as indicated by the green path.

Top-ranked Cited Publications An analysis of influential publications on AMD from 2002 to 2022 highlights significant advancements in understanding and treating the disease. The top 10 most cited AMD research papers, summarized in Figure 10, collectively amassed over 30 000 citations, underscoring their substantial impact on the field. These key references primarily focus on the prevalence, genetic factors, and treatment modalities of AMD. The most frequently cited publication is a 2003 review article by Ferrara *et al*[13], titled "The Biology of VEGF and its Receptors", which has received 7612 citations and has a normalized citation count of 68.01. The second most cited paper is a 2006 multicenter clinical trial by Rosenfeld *et al*[14], which reported on the efficacy of intravitreal ranibizumab in patients with neovascular AMD (nAMD). This study has garnered 4562 citations and a normalized citation count of 46.16, reflecting its pivotal role in establishing ranibizumab as a standard treatment for nAMD. The third most highly cited publication is a 2005 genome-wide association study by Klein *et al*[15], which identified the association between complement factor H (CFH) polymorphism and AMD. This study received 3343 citations and a normalized citation count of 33.76.

Distribution of Keywords Using VOSviewer, we analyzed 16 715 publications related to AMD and identified a total of 15 998 unique keywords. Among these, 120 keywords met the inclusion criterion of appearing at least 50 times. Through co-occurrence analysis, these high-frequency keywords were classified into four distinct clusters, as illustrated in Figure 11. Cluster 1, represented in red, focuses on the pathogenesis of AMD, including key terms such as "oxidative stress", "apoptosis", "antioxidants", and "retinal pigment epithelium". Cluster 2, depicted in green, centers on therapeutic approaches for AMD, featuring keywords like "ranibizumab", "photodynamic therapy", "anti-VEGF", "aflibercept", and "brolucizumab". Cluster 3, shown in blue, pertains to the study of AMD's distribution and determinants, encompassing terms such as "geographic atrophy", "choroidal neovascularization", "prevalence", "risk factors", and "genetics". Lastly, Cluster 4, illustrated in yellow, focuses on diagnostic imaging and evaluation techniques for AMD, including keywords like "optical coherence tomography", "fluorescein angiography", "indocyanine green angiography", "fundus autofluorescence", and "imaging".

Figure 12 highlights the temporal evolution of these keywords, with a specific focus on the yellow-highlighted terms that indicate current research trends. The analysis identified emerging keywords that signify active areas of interest in AMD research. Notable among these are "ranibizumab", "aflibercept", "brolucizumab", "optical coherence tomography", "fluorescein angiography", "oxidative stress", "inflammation", "retinal pigment epithelium", "glaucoma", "diabetic retinopathy", and "artificial intelligence". These keywords represent significant trends and hotspots in the field of AMD research, reflecting ongoing advancements and interdisciplinary connections that are shaping the future of understanding and managing this condition.

DISCUSSION

General Information AMD has been the focus of extensive scholarly investigation, as evidenced by a consistent upward trend in publication output over the past two decades, culminating in a peak in 2021. This surge in research activity

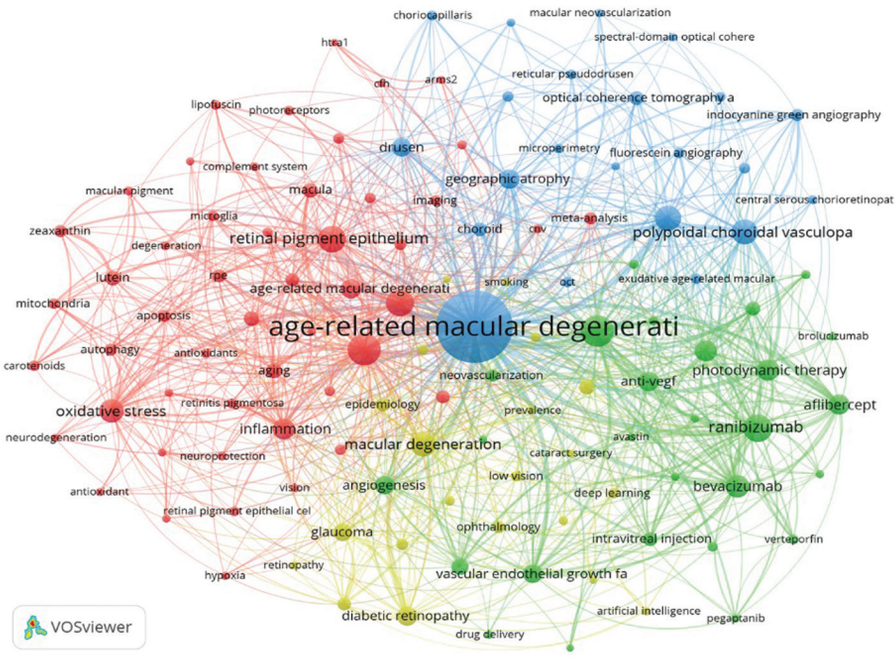

Figure 11 Co-occurrence analysis of keywords in AMD research AMD: Age-related macular degeneration.

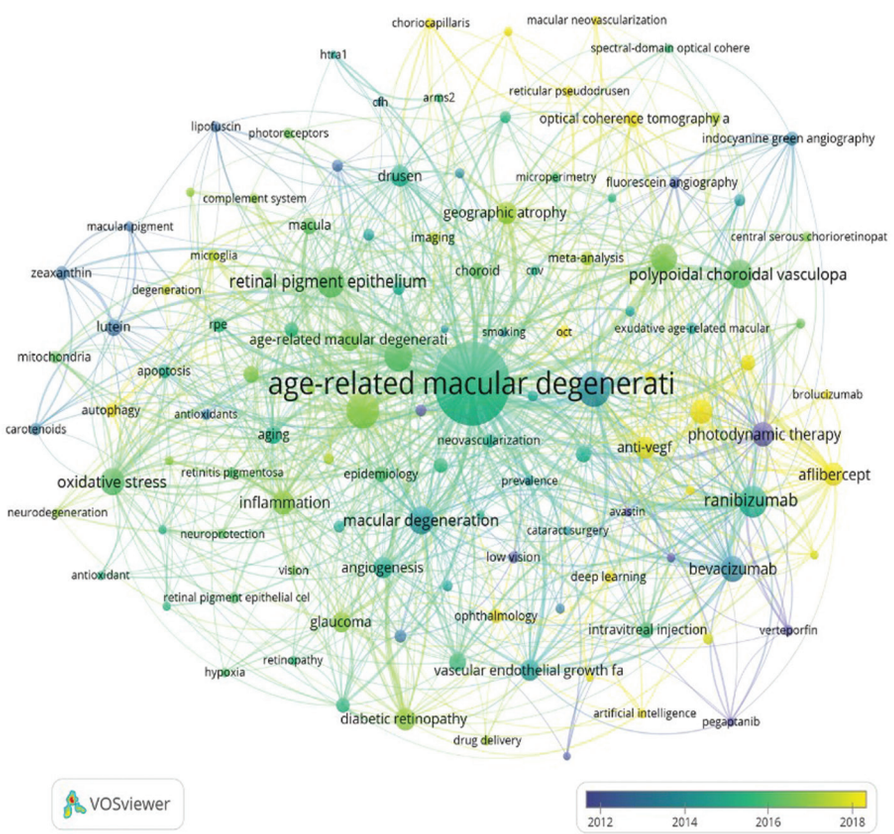

Figure 12 Keywords co-occurrence and temporal trends in AMD research AMD: Age-related macular degeneration.

coincides with significant advancements in AMD treatment, particularly the FDA approvals of anti-VEGF therapies in 2005 and 2020. Additionally, the approval of the anti-VEGF agent brolucizumab for the treatment of wet AMD in 2019 may have contributed to the spike in annual publications observed in 2020[16]. These milestones have not only transformed clinical practice but have also generated increased research interest and funding, further driving the upward trajectory in scholarly output on this condition.

The bibliometric analysis highlights the United States as the leading contributor to AMD research, accounting for approximately 37.74% of total publications. This dominance is

attributable to substantial investments in biomedical research, advanced research infrastructure, and a strong emphasis on innovation and collaboration. The extensive network connections between U.S. institutions and international collaborators underscore the country's commitment to fostering intellectual exchanges and global cooperation. Among the top contributing institutions, the University of Melbourne stands out with the highest number of publications and TLS, indicating robust collaborations with international partners. This emphasizes the importance of establishing world-class research institutions and enhancing collaborative efforts to amplify a country's academic impact.

In terms of author influence, individuals such as Frank G. Holz have emerged as key figures in AMD research, evidenced by high publication counts and significant H-index scores. These metrics reflect not only the productivity of these researchers but also the profound impact of their work on the field. Similarly, journals like *Investigative Ophthalmology & Visual Science* have been identified as core platforms for disseminating AMD research, further shaping the academic discourse. The dual map overlay of journals reveals interdisciplinary connections, particularly the frequent citation of molecular biology and genetics journals by ophthalmology journals, highlighting a trend towards integrating molecular insights into clinical practice.

Research Frontiers Keyword analysis serves as a critical tool in identifying research trends and emerging areas of interest within AMD studies. The top keywords extracted from the literature encompass a range of diagnostic, therapeutic, and pathogenic terms, with recent citation bursts in areas such as aflibercept, nAMD, optical coherence tomography angiography (OCTA), and deep learning. These emerging keywords indicate burgeoning research hotspots poised to drive future advancements in AMD understanding and management.

The co-occurrence of keywords has been categorized into four primary clusters: pathogenesis (red), therapy (green), epidemiology (blue), and diagnosis (yellow). This clustering provides a structured framework for comprehending the multifaceted nature of AMD research and identifying areas ripe for further exploration.

Pathogenesis The pathogenesis of AMD is inherently complex and multifactorial, involving a confluence of genetic predispositions, environmental factors, and cellular aging processes[17-18]. Central to AMD pathogenesis is the aging of retinal pigment epithelium (RPE) cells, which are crucial for maintaining photoreceptor function and retinal health[19]. The impairment of RPE cell function leads to the accumulation of cellular waste products, such as lipofuscin, which exerts toxic effects on RPE cells and contributes to cellular senescence and apoptosis[20].

Oxidative stress is a predominant factor in AMD pathophysiology, exacerbated by the retina's high oxygen consumption, exposure to visible light, and rich content of polyunsaturated fatty acids[21]. Reactive oxygen species (ROS) generated under oxidative stress conditions damage cellular components, leading to RPE and photoreceptor cell death[22]. Antioxidant defenses, therefore, play a protective role, with studies demonstrating that dietary supplementation with antioxidants can slow AMD progression[23].

Inflammation and the complement system have also been implicated in AMD pathogenesis[24-26]. Chronic inflammation, mediated by immune cells and inflammatory cytokines, contributes to tissue damage and disease progression[27]. Genetic studies have identified polymorphisms in *CFH*, *CFB*, *C3*, and *C2* genes, which regulate the complement cascade, as significant risk factors for AMD[28]. These genetic variants lead to uncontrolled complement activation, promoting inflammation and subsequent retinal damage[29].

Moreover, the ARMS2/HTRA1 locus on chromosome 10q26 has been strongly associated with AMD[30-31]. Variants in this region are believed to influence extracellular matrix remodeling and angiogenesis, thereby facilitating disease progression and the development of choroidal neovascularization (CNV). Understanding these genetic factors has paved the way for personalized medicine approaches and the development of gene-targeted therapies[32].

Therapy Therapeutic strategies for AMD have evolved significantly since the 1980s. Initially, laser photocoagulation was the primary treatment for classic extrafoveal CNV, albeit with limitations such as the risk of inducing scotoma[33-34]. The late 1990s saw the introduction of photodynamic therapy (PDT) with verteporfin, which offered improved outcomes for subfoveal CNV[35]. However, the advent of anti-VEGF therapies in the early 2000s marked a paradigm shift in AMD management[36].

Anti-VEGF agents, including ranibizumab, bevacizumab, aflibercept, and the more recent brolucizumab, have significantly enhanced clinical outcomes for patients with nAMD. These agents function by inhibiting VEGF activity, thereby reducing angiogenesis and vascular permeability[37]. Clinical trials have consistently demonstrated the efficacy of anti-VEGF treatments in stabilizing or improving vision in a substantial proportion of patient[38].

Despite their success, anti-VEGF therapies present challenges such as treatment resistance, incomplete responses, and the burden of frequent intravitreal injections[39-40]. To address these issues, ongoing research is exploring alternative angiogenic pathways, combination therapies, and extended-release formulations[41]. Additionally, emerging therapies targeting inflammation and the complement system offer promising

avenues for treating geographic atrophy in dry AMD[42].

Personalized treatment protocols, such as the "treat and extend" and "*pro re nata*" strategies, aim to optimize therapeutic efficacy while minimizing treatment burden. Long-term studies, however, indicate that sustaining the benefits of anti-VEGF treatments requires addressing factors like undertreatment, patient adherence, and the development of atrophy and fibrosis[43-44].

Epidemiology AMD is a leading cause of blindness, affecting millions globally. Projections indicate a substantial increase in AMD prevalence, with estimates suggesting a rise from 32.4 million blind individuals in 2010 to 288 million by 2040[4]. In the European Union alone, the number of individuals with late-stage AMD is expected to grow from 67 million to 77 million by 2050[45]. This demographic shift underscores the urgent need for enhanced healthcare resources and strategic planning to manage the burgeoning AMD burden.

Several risk factors have been identified for AMD, including advanced age, smoking, previous cataract surgery, and family history. Additional factors such as high body mass index, cardiovascular disease, hypertension, and elevated plasma fibrinogen levels have also been linked to an increased risk of late-stage AMD. Lifestyle modifications, including dietary changes, smoking cessation, and supplementation with vitamins C, E, beta-carotene, zinc, lutein, and zeaxanthin, have been shown to delay AMD progression[46].

Diagnosis Accurate and timely diagnosis of AMD is pivotal for effective disease management and treatment efficacy. Retinal imaging technologies have undergone significant advancements, enhancing the ability to detect and monitor AMD. Color fundus photography (CFP) remains a cornerstone for AMD screening, providing detailed images of the retina, optic disc, and macula[47]. Fundus autofluorescence (FAF) imaging offers functional insights by highlighting areas of RPE dysfunction through the detection of lipofuscin[48].

Fluorescein angiography (FA) and indocyanine green angiography (ICGA) are invasive techniques that visualize retinal and choroidal circulation, respectively[49-50]. While FA is instrumental in identifying vascular leakage and guiding anti-VEGF therapy decisions, ICGA provides deeper insights into choroidal vasculature abnormalities. Despite their diagnostic utility, both FA and ICGA carry risks of adverse reactions and are time-consuming[51].

Optical coherence tomography (OCT) has revolutionized AMD diagnosis by offering high-resolution, cross-sectional images of retinal structures. Enhanced depth imaging OCT (EDI-OCT) and swept-source OCT (SS-OCT) provide deeper penetration into retinal tissues, facilitating the assessment of choroidal thickness and vascular changes associated with AMD[52]. OCTA further advances diagnostic capabilities by non-invasively visualizing retinal and choroidal vasculature, enabling the detection of subclinical CNV and monitoring treatment responses[53].

The integration of artificial intelligence (AI) and machine learning (ML) into AMD diagnostic processes represents a significant innovation[54]. AI algorithms, particularly deep learning models, have demonstrated high accuracy in identifying AMD features from retinal images, automating image analysis, and enhancing diagnostic precision These technologies facilitate early detection, predict disease progression, and enable personalized treatment plans[55]. Furthermore, AI-powered teleophthalmology tools expand access to AMD care, especially in underserved or remote regions[56].

Emerging imaging technologies, such as adaptive optics (AO) and hyperspectral imaging, offer unprecedented resolution and biochemical insights into retinal structures. AO compensates for ocular optical aberrations, allowing for the visualization of individual photoreceptors and detailed assessment of retinal microstructures[55]. Hyperspectral imaging captures spectral information across different wavelengths, providing insights into the biochemical composition of retinal tissues and enabling the detection of metabolic changes associated with AMD[57].

Implications for Future Research The future of AMD research offers exciting opportunities for advancing our understanding and treatment of this complex disease. Multidisciplinary collaboration is essential, as combining insights from genetics, molecular biology, and clinical sciences will help uncover the underlying mechanisms of AMD and identify new therapeutic targets. Future research should also focus on personalized medicine by discovering biomarkers and applying pharmacogenomics to tailor treatments based on individual patient profiles. Additionally, exploring novel therapeutic approaches, such as targeting alternative angiogenic pathways, modulating the complement system, and advancing gene therapy and stem cell-based treatments, will be critical in overcoming the limitations of current therapies like anti-VEGF.

Technological innovations will play a pivotal role in improving diagnosis, monitoring, and treatment of AMD. AI and ML hold promise for early detection and personalized care, while telemedicine and wearable devices can improve access to care, particularly in underserved areas. At the same time, research should focus on modifiable risk factors, including lifestyle changes and environmental exposures, to develop effective preventive strategies. Ethical considerations, such as ensuring data privacy and reducing bias in AI systems, must also be addressed to ensure responsible advancements. Increased funding and global collaborations will be crucial in supporting

these efforts and reducing the growing global burden of AMD.

Limitations While this bibliometric analysis provides valuable insights into AMD research trends and patterns, it is not without limitations. The exclusion of non-English publications may result in an underrepresentation of research from non-English-speaking countries, potentially overlooking important Contributions. Additionally, bibliometric data can be influenced by factors such as publication practices, citation behaviors, and database coverage, which may affect the interpretation of the research landscape. Lastly, the influence of recently published studies may not be fully captured due to the time required for citations to accumulate[58].

In conclusion, this comprehensive bibliometric analysis of AMD research over the past two decades highlights significant growth in publication output, driven by advancements in understanding the disease's pathogenesis and improvements in diagnostic technologies. The collaborative efforts of leading countries, institutions, and researchers have substantially contributed to progress in this field. Emphasizing the importance of international collaboration and multidisciplinary approaches will continue to be vital in addressing the multifaceted challenges posed by AMD. Future research should build upon these findings, focusing on innovative diagnostic methods, uncovering new therapeutic targets, and ultimately improving outcomes for patients affected by this sight-threatening condition.

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