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A bibliometric analysis of amniotic membrane transplantation research in ophthalmology

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Abstract

Purpose: Amniotic membrane transplantation (AMT) has become a widely used therapeutic approach in ophthalmology, particularly for managing ocular surface disorders. Despite its clinical significance, no comprehensive bibliometric analysis has been conducted to evaluate the research landscape of AMT in ophthalmology. This study aims to analyze publication trends, identify influential contributors, and highlight emerging research directions.

Methods: A bibliometric analysis was conducted using the Web of Science (WoS) Core Collection. A comprehensive search was performed on February 1, 2025, using the keywords “amniotic membrane” in the title or “amniotic membrane” OR “AMT” in the author keywords. Data were extracted from the “Analyze Results” and “Citation Reports” sections of WoS to assess publication trends, author productivity, institutional and country contributions, highly cited publications, and journal-level output. Bibliometric mapping was performed using VOSviewer to examine research focus areas, as well as co-authorship and country collaboration networks.

Results: A total of 1012 AMT-related publications in ophthalmology were identified, spanning 1995–2025. The United States emerged as the most productive country. Tseng SCG was identified as the most prolific author, with 102 publications and an H-index of 54. Highly cited publications primarily focused on ocular surface reconstruction, limbal stem cell deficiency, and pterygium surgery, whereas emerging research areas included glaucoma surgery, retinal disorders, and bioengineering applications.

Conclusion: AMT research in ophthalmology has evolved over time, with shifts in focus from anterior segment applications to emerging uses in glaucoma and retinal disorders. The increasing attention to bioengineering approaches, regenerative medicine, and minimally invasive techniques suggests promising directions for future investigations.

Keywords: Amniotic membrane transplantation; bibliometric analysis; ophthalmology; research trends; Web of Science.

Amniotic membrane transplantation (AMT) has become a well-established therapeutic modality in ophthalmology, particularly for the treatment of ocular surface diseases, due to its anti-inflammatory, anti-scarring, and regenerative effects.^[1–3] The medical use of the amniotic membrane, however, dates back to 1910,

when John Staige Davis first reported its application in skin grafting to support epithelial repair and reduce fibrosis.^[4] Its favorable biological properties soon led to broader adoption across fields such as oral and maxillofacial procedures, urology, and gynecology – particularly for managing non-healing wounds and tissue loss – thereby

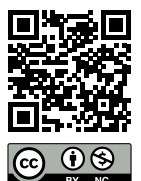


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reinforcing its role as a regenerative tool across surgical specialties.^[5]

The first documented ophthalmic use of the amniotic membrane was described by De Rötth in 1940 for conjunctival surface reconstruction.^[6] Since then, AMT has been increasingly employed in various ophthalmic indications, including persistent epithelial defects, corneal ulcers, chemical injuries, pterygium surgery, and limbal stem cell deficiency.^[7–11] These clinical applications are supported by its unique biological composition, including extracellular matrix components, growth factors, and anti-inflammatory cytokines, which together promote epithelialization, modulate local immune responses, and limit fibrosis.^[12]

Despite its extensive clinical use, challenges remain regarding the standardization of preparation techniques, preservation protocols, and long-term outcome assessment.^[13,14] To address these issues, research efforts have focused on optimizing its clinical applications, improving preservation techniques, and understanding its biological mechanisms of action.^[15,16]

Although numerous clinical and experimental studies have explored AMT in ophthalmology, no bibliometric analysis to date has systematically examined its evolution, structure, and current research landscape. As publication activity continues to expand, such an analysis is necessary to identify influential contributions, thematic trends, and future research directions.

This study aims to provide the first bibliometric overview of AMT in ophthalmology. Through a comprehensive analysis of publication output, citation metrics, authorship networks, geographic distribution, and keyword co-occurrence, we aim to map the intellectual structure of the field, highlight prominent research areas, and identify emerging focus topics.

Materials and Methods

This bibliometric analysis was conducted using the Web of Science (WoS) Core Collection database (Clarivate Analytics, Philadelphia, PA, USA). Since the study relies on publicly available data, ethical approval was not required. A comprehensive search was performed on February 1, 2025, using the keywords “amniotic membrane” in the title or “amniotic membrane” OR “AMT” in the author keywords. To refine the search strategy, a sensitivity analysis was conducted, testing various keyword combinations and filters. This process ensured that the final search method was the most sensitive and specific approach for identifying

relevant studies in AMT-related ophthalmology research.

To maintain relevance to the field, the search was restricted to studies classified under the ophthalmology research area in WoS. Only articles indexed in the Science Citation Index Expanded and Emerging Sources Citation Index were included. To ensure data quality, only original research articles and review articles were considered, whereas other document types, such as meeting abstracts, letters, and conference proceedings, were excluded. No language restrictions were applied, as all retrieved articles had English titles and abstracts.

The retrieved records were exported from the WoS Core Collection in plain text format (.txt) for processing. Bibliometric mapping and keyword analysis were performed using VOSviewer software (version 1.6.20; Centre for Science and Technology Studies, Leiden University, The Netherlands). Overlay and density visualization maps were generated to assess the evolution of research themes, whereas co-authorship and country collaboration network maps were created to evaluate collaborative relationships among authors and countries. The “Analyze Results” and “Citation Reports” tools in WoS were used to identify the most productive and influential authors, institutions, countries, and journals. Only citations excluding self-citations were considered for all citation analyses. H-index values of countries, institutions, and authors were also extracted from the database.

Results

Publication Trends

A total of 1012 AMT-related publications in ophthalmology were retrieved from the WoS database, covering the period from 1995 to 2025. Of these, 865 were indexed in the Science Citation Index Expanded and 147 in the Emerging Sources Citation Index. The annual publication output on AMT in ophthalmology has shown a steady increase since 1995 (Fig. 1). In the initial years (1995–2000), publication counts remained relatively low. However, after 2000, there was a marked increase in the number of studies, and a notable surge occurred around 2006. In recent years, the trend appears to have stabilized or fluctuated.

Countries and Institutional Contributions

The United States leads AMT-related ophthalmology research, contributing 263 publications (25.99%) of the total dataset. It also holds the highest citation count (12,385) and an H-index of 64. With 47.11 citations per publication, the U.S. demonstrates both productivity and influence. Germany (109 publications, 10.77%), India (88 publications,

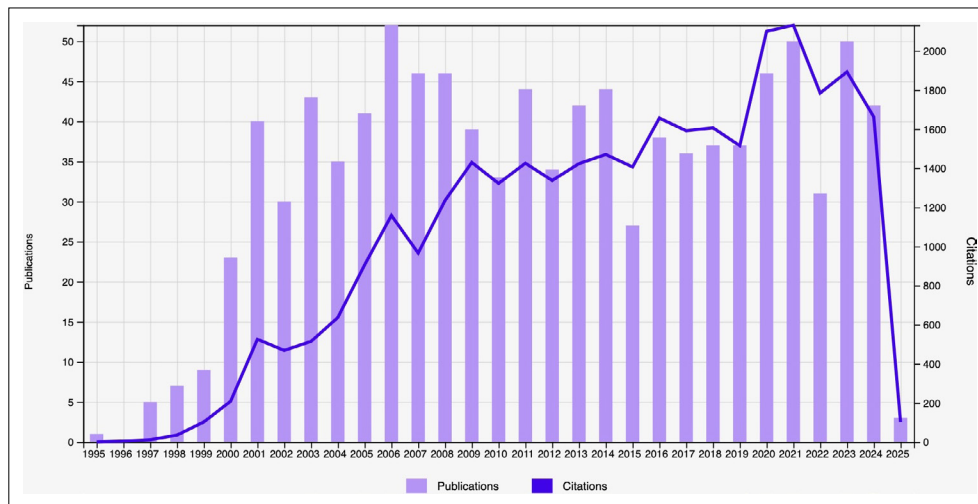


Fig. 1. Annual publication and citation trends in amniotic membrane transplantation research (1995–2025). The bar graph represents the annual number of publications on amniotic membranes in ophthalmology, while the line graph indicates the annual citation count of these publications.

8.70%), and Japan (83 publications, 8.20%) are also key contributors. While Japan has accumulated a high number of citations (5042) and the highest citation-per-publication ratio among these countries (60.75), Germany and India have comparatively lower total citations (3149 and 2147, respectively). England (70 publications) and South Korea (60 publications) also demonstrate notable impact, with identical citation counts (4606) and H-indices of 33. South Korea, in particular, exhibits the highest citation-per-publication value (76.77) among the top 10 countries.

When clinical and pre-clinical study outputs are considered, substantial differences emerge among countries. Egypt, for instance, exhibits the highest clinical-to-pre-clinical publication ratio (11.67). Similarly, Italy (4.80), Türkiye (4.23), and India (4.12) also demonstrate high clinical orientation. In contrast, Germany (1.06), Japan (1.25), and China (1.44) show relatively balanced or pre-clinical-leaning research profiles. These findings are summarized in Table 1. Furthermore, international collaboration patterns are illustrated in Figure 2, which demonstrates strong global research connectivity, particularly among countries such as the USA, Germany, Japan, and the UK. The central positioning of the USA is remarkable.

The contribution of research institutions to AMT studies varies, with certain institutions emerging as leading research centers. The University of Miami ranks as the most productive institution, with 50 publications (4.94%), followed by Essen University (25 publications, 2.47%) and Kanazawa University (17 publications, 1.68%). Notably, institutions such as the University of Nottingham (H-index: 10) and Kyoto Prefectural

University (H-index: 11) have demonstrated strong research impact despite their relatively lower publication counts. A detailed breakdown of the top ten institutions by publication count, citation count, and H-index is presented in Table 2.

Leading Authors and Highly Cited Publications

Among individual contributors, Tseng SCG stands out as the most prolific author, with 102 publications (10.08%), 8409 citations, and an H-index of 54. Other notable researchers include Meller D (34 publications, H-index: 20), Steuhl KP (29 publications, H-index: 16), and Kinoshita S (20 publications, H-index: 19). In addition, several other authors – Sangwan VS, Seitz B, Gomes JAP, Caporossi T, Kobayashi A, and Rizzo S – have made significant contributions to AMT research. A detailed summary of the most productive authors is provided in Table 3. In addition, co-authorship patterns among researchers are visualized in Figure 3, which clearly shows Tseng SCG as the central node in AMT research collaboration networks, with multiple interconnected authors such as Li W, He H, and Meller D.

The most cited study, “Amniotic membrane transplantation with or without limbal allografts for corneal surface reconstruction in patients with limbal stem cell deficiency” by Tseng SCG et al.^[17] published in *Archives of Ophthalmology* (1998), has accumulated 550 citations. Other high-impact works include Lee et al.^[18] (1997, 543 citations) on AMT for persistent epithelial defects and Kim et al.^[19] (1995, 543 citations) on corneal surface reconstruction. In addition, studies by Dua et al.^[20] (2004, 530 citations) on the amniotic membrane’s role in ophthalmology and Hao et al.^[21] (2000, 519 citations) on

Table 1. Top 10 most productive countries in amniotic membrane transplantation research in ophthalmology

Country	Record count	% of 1,012	Citation count	H-index	Citations per publication	Clinical/pre-clinical ratio
United States	263	25.99	12.385	64	47.11	2.30
Germany	109	10.77	3.149	31	28.89	1.06
India	88	8.70	2.147	26	24.40	4.12
Japan	83	8.20	5.042	35	60.75	1.25
China	78	7.71	1.685	24	21.60	1.44
England	70	6.92	4.606	33	65.80	2.00
Türkiye	68	6.72	828	18	12.18	4.23
South Korea	60	5.93	4.606	33	76.77	2.53
Italy	58	5.73	835	17	14.40	4.80
Egypt	38	3.76	1.026	18	27.00	11.67

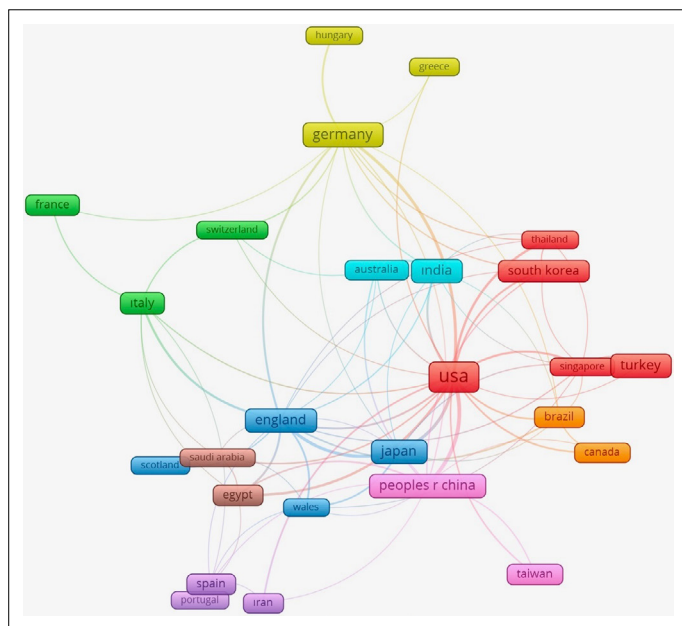


Fig. 2. Country collaboration network in amniotic membrane transplantation research in ophthalmology. The size of each node represents the number of publications from the corresponding country. Lines between nodes indicate co-authorship links, while colours denote distinct collaborative clusters.

its antiangiogenic properties have significantly shaped the field. A comprehensive overview of the top 10 most cited papers is presented in Table 4.

Journals Publishing AMT-Related Research

The distribution of AMT-related publications across journals provides insight into the main venues where AMT research is disseminated. Among the 1012 included studies, Cornea was the leading journal, publishing 154 articles (15.22%), followed by Investigative Ophthalmology and Visual Science (48 articles, 4.74%) and American Journal of Ophthalmology (39 articles, 3.85%). A complete list of the top 10 journals, along with their respective publication counts and percentages, is presented in Table 5.

Research Trends and Hot Topics

The combined analysis of the density visualization map (Fig. 4) and the overlay visualization map (Fig. 5) provides a comprehensive perspective on research trends in AMT for ophthalmology. While the density map highlights highly studied topics, the overlay map illustrates how research interests have evolved.

Well-Established Research Domains

The density visualization map reveals a strong concentration of research on AMT applications in ocular surface diseases, with prominent clusters in:

- Corneal ulcer, keratitis, and chemical burns.
- Limbal stem cell deficiency and transplantation, particularly in severe conditions such as Stevens–Johnson syndrome and toxic epidermal necrolysis.
- Pterygium surgery, wound healing, and fibrosis.

Emerging and Evolving Research Areas

The overlay visualization map highlights shifts in research priorities, with newer topics appearing in red hues, suggesting increasing attention in recent years. Key emerging research areas include:

- Trabeculectomy and glaucoma surgery.
- Macular hole and retinal detachment.
- Stem cells, growth factors, and ex vivo expansion.
- Fibrin glue applications.

These newer research areas, which appear green in the density map but red in the overlay map, indicate expanding clinical applications and growing scientific focus on novel AMT strategies.

Discussion

Another factor potentially contributing to the stabilization of publication trends in recent years is the emergence of

Table 2. Top 10 most productive institutions in amniotic membrane transplantation research in ophthalmology

Institution	Record count	% of 1,012	Citation count	H-Index
University of Miami	50	4.94	4.059	34
Essen University	25	2.47	1.390	18
Kanazawa University	17	1.68	228	9
University of Nottingham	15	1.48	1.388	10
Florida International University	13	1.29	191	8
Kyoto Prefectural University	12	1.19	793	11
Zhongshan Ophthalmic Center	10	0.99	480	10
Chang Gung University	9	0.89	395	7
Johns Hopkins Medicine	9	0.89	282	6
Queens Medical Centre	9	0.89	1.364	9

Table 3. Top 10 most productive authors in amniotic membrane transplantation research in ophthalmology

Author	Record count	% of 1,012	Citation count	H-index
Tseng SCG	102	10.079	8.409	54
Meller D	34	3.360	2.340	20
Steuhl KP	29	2.866	1.150	16
Kinoshita S	20	1.976	2.396	19
Sangwan VS	19	1.877	1.094	16
Seitz B	19	1.877	331	13
Gomes JAP	18	1.779	1.102	10
Caporossi T	17	1.680	371	10
Kobayashi A	17	1.680	228	9
Rizzo S	17	1.680	371	10

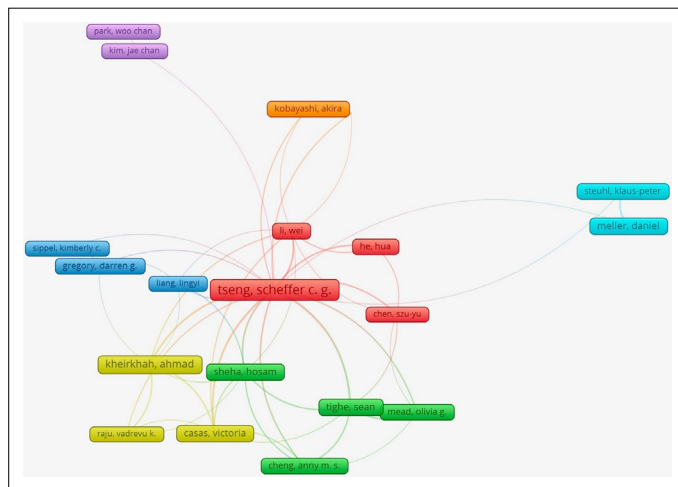


Fig. 3. Co-authorship network of the most prolific researchers in ophthalmic amniotic membrane transplantation research. Each node represents an individual author, with connecting lines indicating co-authored publications. Node colours correspond to collaboration clusters identified through network analysis.

alternative amniotic-derived products, particularly amniotic membrane extract (AME). Unlike the conventional membrane grafts used in AMT, AME can be administered in eye drop formulations and offers a non-surgical approach for delivering

the biological benefits of amniotic tissues.^[25] This shift reflects a growing interest in minimally invasive, regenerative therapies that preserve the key anti-inflammatory and pro-healing properties of AMT while improving accessibility and patient compliance. As such, the rise of AME and similar biologic products may have diverted some research attention away from traditional AMT applications, contributing to the observed plateau in publication volume.

The commercialization of AMT products – particularly FDA-approved devices such as Prokera® – has likely played a role in shaping research trends by facilitating the wider clinical adoption of AMT. These ready-to-use, sutureless AMT applications have made it easier for clinicians to incorporate AMT into routine ophthalmic practice.^[26] As the availability and standardization of such products increased, research focus may have partially shifted from foundational studies toward real-world clinical outcomes, comparative effectiveness, and product-specific investigations.

The high citation counts in later years further indicate that AMT remains a relevant and impactful research area, with key studies serving as foundational references in the field. The indexing distribution, with most publications appearing in the Science Citation Index Expanded and a smaller portion in the Emerging Sources Citation Index, suggests that AMT

Table 4. Top 10 most cited papers in amniotic membrane transplantation research in ophthalmology

Rank	Title	First author	Year	Journal	Citations
1	Amniotic membrane transplantation with or without limbal allografts for corneal surface reconstruction in patients with limbal stem cell deficiency	Tseng SCG	1998	Archives of Ophthalmology	550
2	Amniotic membrane transplantation for persistent epithelial defects with ulceration	Lee SH	1997	American Journal of Ophthalmology	543
3	Transplantation of preserved human amniotic membrane for surface reconstruction in severely damaged rabbit corneas	Kim JC	1995	Cornea	543
4	The amniotic membrane in ophthalmology	Dua HS	2004	Survey of Ophthalmology	530
5	Identification of antiangiogenic and anti-inflammatory proteins in human amniotic membrane	Hao YX	2000	Cornea	519
6	Growth factor mRNA and protein in preserved human amniotic membrane	Koizumi N	2000	Current Eye Research	512
7	Comparison of conjunctival autografts, amniotic membrane grafts, and primary closure for pterygium excision	Prabhasawat P	1997	Ophthalmology	430
8	Amniotic membrane transplantation for conjunctival surface reconstruction	Tseng SCG	1997	American Journal of Ophthalmology	349
9	Successful transplantation of bioengineered tissue replacements in patients with ocular surface disease	Schwab IR	2000	Cornea	322
10	Amniotic membrane transplantation for ocular surface reconstruction in patients with chemical and thermal burns	Shimazaki J	1997	Ophthalmology	319

research is predominantly published in well-established, high-impact journals, reinforcing its scientific credibility. In line with this, journals such as *Cornea*, *Investigative Ophthalmology & Visual Science*, and *American Journal of Ophthalmology* appear as leading publication venues, suggesting a strong clinical orientation in AMT research. Identifying these core journals not only informs future

researchers of suitable submission targets but also reflects the field's alignment with top-tier ophthalmology platforms. The geographic distribution of AMT research reflects both established leadership and growing international engagement. The United States ranks highest in publication volume, citation count, and H-index, likely driven by its strong research infrastructure, funding

Table 5. Top 10 journals publishing amniotic membrane transplantation-related articles in ophthalmology (n=1012)

Rank	Journal title	Number of publications	% of total
1	Cornea	154	15.22
2	Investigative Ophthalmology & Visual Science	48	4.74
3	American Journal of Ophthalmology	39	3.85
4	Der Ophthalmologe	36	3.56
5	British Journal of Ophthalmology	35	3.46
6	European Journal of Ophthalmology	34	3.36
7	Ophthalmology	31	3.06
8	Clinical Ophthalmology	30	2.96
9	International Journal of Ophthalmology	27	2.67
10	Current Eye Research	26	2.57

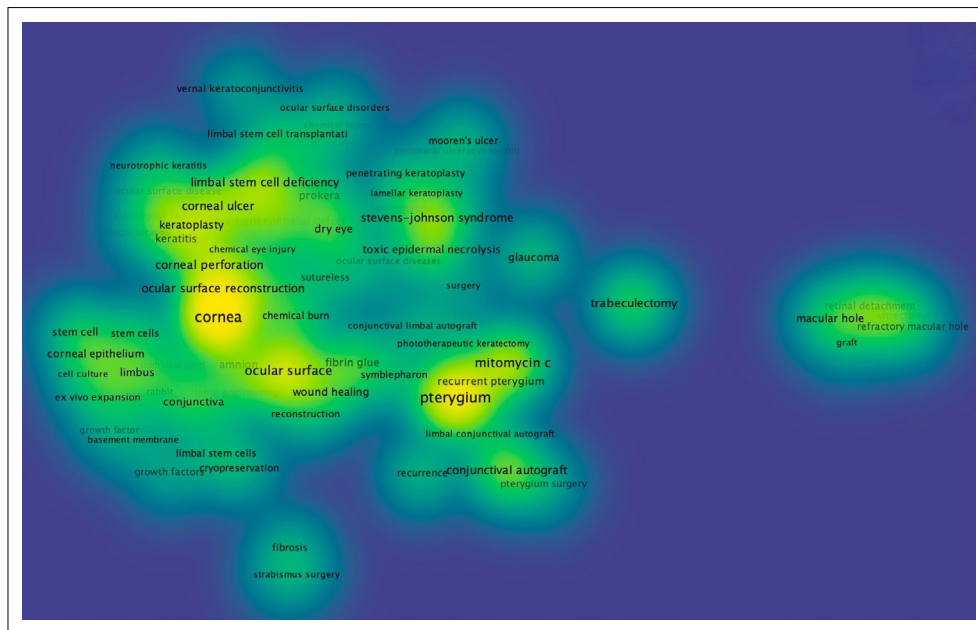


Fig. 4. Density visualization map of amniotic membrane transplantation research topics. This VOS-viewer-generated density visualization map illustrates the co-occurrence of keywords in amniotic membrane transplantation-related ophthalmology studies. Nodes represent keywords, with larger and brighter nodes indicating a higher frequency of occurrence. The color gradient (from blue to yellow) reflects the density of research focus, with yellow areas representing highly studied topics and blue areas indicating less explored domains. Core areas appear in bright yellow, while newer or less frequently studied areas appear in green, suggesting growing interest in these applications.

availability, and well-established institutions.^[27,28] Japan, South Korea, and England exhibit high citation-per-publication and H-index values, indicating strong research quality despite relatively lower output. Countries such as China, Türkiye, and Italy also feature among the top contributors, highlighting the expanding global interest in AMT. In addition, variations in clinical/pre-clinical publication ratios across countries suggest differing regulatory frameworks and research priorities. The variation in AMT-related publication output across countries may be partially explained by legal, logistical, and infrastructural differences. In some regions, the

medical use of human-derived biological materials such as amniotic membranes is subject to stringent ethical and regulatory oversight, which can limit accessibility and clinical utilization. In addition, logistical challenges in tissue procurement and preservation may further constrain research activity. Conversely, countries with higher publication volumes may benefit from more permissive regulatory environments, well-established tissue banks, and greater access to research funding. These systemic factors likely play a critical role in shaping both the volume and nature of AMT research output globally.

The country collaboration network (Fig. 2) highlights

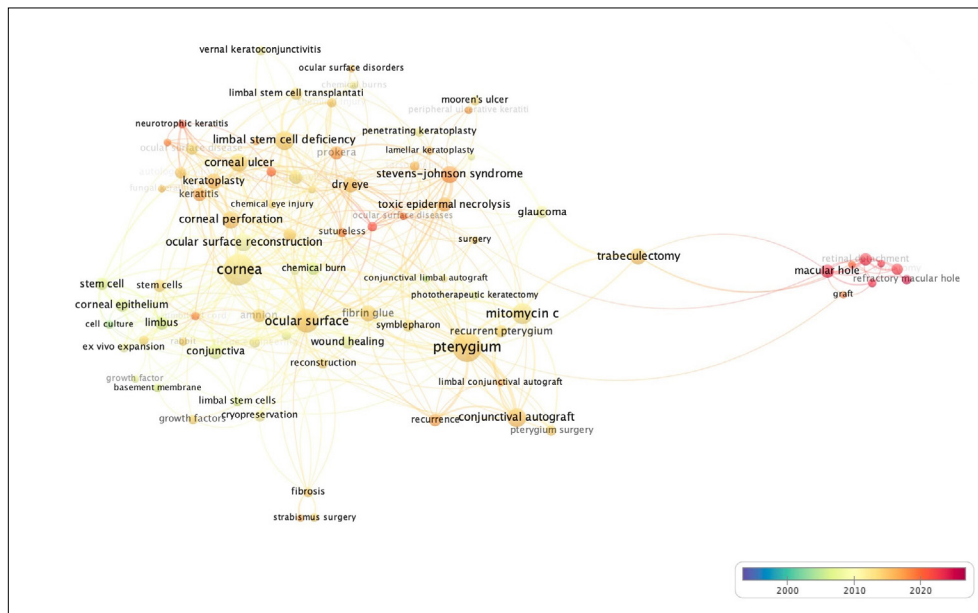


Fig. 5. Overlay visualization map of amniotic membrane transplantation research trends. This VOS-viewer-generated overlay visualization map illustrates the co-occurrence of keywords in amniotic membrane transplantation-related ophthalmology studies. Nodes represent keywords, with larger nodes indicating higher frequency. Connections between nodes represent co-occurrence relationships. The color gradient (from blue to red) reflects the chronological progression of research, with blue indicating earlier studies and red representing more recent trends.

strong international cooperation, with the United States, Germany, and Japan occupying central positions in global AMT research clusters. These connections suggest that international partnerships may have played a critical role in accelerating research and clinical translation. Similarly, the author co-authorship network (Fig. 3) reveals distinct collaboration clusters, with researchers such as Tseng SCG, Meller D, and Kinoshita S serving as central figures. These collaborative patterns likely enhance the consistency and innovation of research outputs across the field.

Institutional productivity follows a similar pattern, with the University of Miami leading due to its expertise in ocular surface disease and regenerative medicine.^[29,30] Meanwhile, institutions such as Essen University, Kanazawa University, the University of Nottingham, and Kyoto Prefectural University maintain high research influence despite lower publication volumes.

The analysis of individual contributors in AMT research highlights a concentration of expertise among a select group of prolific researchers. Tseng SCG stands out as the most influential author, with the highest number of publications, citations, and an H-index of 54, underscoring his pioneering role in AMT research, particularly in ocular surface reconstruction. Alongside Kim, he was the first to describe the use of cryopreserved amniotic membrane for ocular surface reconstruction in 1995 – a formulation that

laid the foundation for its widespread clinical adoption and remains the predominant form in use today.^[22] Other highly productive authors, including Meller D, Steuhl KP, and Kinoshita S, have also made significant contributions, reflecting international research efforts in AMT advancements. The diverse backgrounds of these researchers suggest a multidisciplinary approach, integrating expertise in corneal disease, regenerative medicine, and ophthalmic surgery.

The most cited publications reinforce the clinical importance and scientific impact of AMT in ophthalmology. The leading study by Tseng et al.^[17] with 550 citations has served as a foundational reference for AMT applications in limbal stem cell deficiency, a condition associated with significant clinical challenges. Similarly, highly cited works by Lee et al. (1997)^[18] and Kim et al. (1995)^[19] have helped establish AMT's role in treating persistent epithelial defects and corneal surface reconstruction. The presence of studies exploring AMT's antiangiogenic properties and broader ophthalmic applications suggests that its therapeutic potential extends beyond traditional uses. The high citation counts of these studies reflect their continued relevance in shaping clinical guidelines and future research directions in AMT.

Bibliometric analyses, such as this study, provide critical insights into the development and impact of AMT research by identifying the most productive countries, institutions, authors, and influential studies. Understanding which

countries and institutions lead AMT research can help foster collaborations, allocate funding efficiently, and track regional contributions to scientific advancements. Identifying the most prolific authors allows researchers to recognize key opinion leaders, facilitating potential collaborations and mentorship opportunities. In addition, highlighting the most cited publications helps clinicians and researchers prioritize influential studies, ensuring that clinical practice and future investigations are guided by high-impact, evidence-based research. Ultimately, these bibliometric insights contribute to a more structured and strategic approach to advancing AMT applications in ophthalmology.

The bibliometric analysis presents a dynamic picture of AMT research in ophthalmology. Over the years, AMT has become firmly established as a crucial therapeutic approach for corneal diseases, particularly in ocular surface reconstruction, pterygium, and limbal stem cell deficiency. This foundation remains strong, as reflected in the density visualization map, where these topics appear in yellow hues, signifying intense research focus.

However, what is particularly striking is the shifting landscape revealed by the overlay visualization map. Research that was once centered almost exclusively on anterior segment applications is now expanding into newer domains. The growing prominence of trabeculectomy and glaucoma surgery suggests that AMT's potential for modulating fibrosis is gaining traction beyond corneal applications. Similarly, the emergence of macular hole and retinal detachment as newer clusters in the overlay map points toward a broader exploration of AMT's regenerative properties in the posterior segment, an area that has historically received little attention in this context.

This transition aligns with a broader trend in ophthalmology toward regenerative and minimally invasive techniques. The increasing focus on sutureless AMT procedures, including fibrin glue applications, reflects ongoing efforts to refine surgical methodologies. As the field progresses, bioengineering approaches incorporating growth factors, stem cells, and tissue modifications could further optimize AMT's therapeutic potential.^[31] While the overlay map suggests that these advancements are still in their early stages, their growing presence indicates a promising direction for future studies.

Ultimately, the integration of density and overlay visualizations provides a compelling narrative: AMT research is expanding not only in volume but in scope. While anterior segment applications remain dominant, emerging investigations into glaucoma and retinal

applications suggest a field that is evolving in response to clinical needs and technological advancements. Moving forward, continued research into optimizing AMT for posterior segment disorders, refining surgical techniques, and integrating bioengineering solutions will be key to further broadening its applications in ophthalmology.

While this bibliometric analysis provides a comprehensive overview of AMT research in ophthalmology, certain limitations should be acknowledged. First, the study was restricted to publications indexed in the WoS Core Collection, potentially excluding relevant research from other databases such as PubMed and Scopus. In addition, although citation-based metrics such as total citations and the H-index offer valuable insights into research impact, they may not fully reflect the clinical significance of individual studies. A common challenge in bibliometric studies is that recently published articles tend to have lower citation counts, which may not accurately represent their potential long-term impact. Furthermore, while efforts were made to exclude self-citations, the citation landscape may still be influenced by factors such as the preferential citation of landmark studies and variations in citation practices across different regions and institutions. Despite these limitations, this study provides valuable insights into AMT research trends, influential contributors, and emerging directions, offering a framework to help guide future investigations in the field.

Conclusion

This bibliometric analysis highlights the growth and evolving focus of AMT research in ophthalmology, with its well-established role in ocular surface reconstruction now expanding into new applications, including glaucoma surgery and retinal disorders. The increasing number of publications and high citation impact of key studies underscore its continued relevance, while emerging trends indicate a shift toward regenerative approaches, bioengineering advancements, and minimally invasive techniques to enhance its therapeutic potential.

Publications and high citation impact of key studies underscore its continued relevance, while emerging trends indicate a shift toward regenerative approaches, bioengineering advancements, and minimally invasive techniques to enhance its therapeutic potential.

Ethics Committee Approval: Since the study relies on publicly available data, ethical approval was not required

Peer-review: Externally peer-reviewed.

Authorship Contributions: Concept: S.I.K., B.K.; Design: S.I.K.,

B.K.; Supervision: S.I.K., B.K.; Resource: S.I.K., B.K.; Materials: S.I.K., B.K.; Data Collection and/or Processing: S.I.K., B.K.; Analysis and/or Interpretation: S.I.K., B.K.; Literature Search: S.I.K., B.K.; Writing: S.I.K., B.K.; Critical Reviews: S.I.K., B.K.

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