International Journal of Innovation and Industrial Revolution
EISSN: 2637-0972
IJIREV
Volume 7 Issue 22 (September 2025) PP. 193-212
DOI 10.35631/IJIREV.722014

INTERNATIONAL JOURNAL OF INNOVATION AND INDUSTRIAL REVOLUTION (IJIREV)
www.ijirev.com

RESEARCH TREND: DEVELOPMENT AND VALIDATION OF A SELF-INSTILLATION EYE DROP (SIED) TECHNIQUE MODULE AND IMPROVED SELF-INSTILLATION EYE DROP TECHNIQUE AMONG GLAUCOMA PATIENTS

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Article Info:

Article history:
Received date: 30.06.2025
Revised date: 21.07.2025
Accepted date: 18.08.2025
Published date: 01.09.2025

To cite this document:

Abdullah, N., & Ludin, S. M. (2025). Research Trend: Development And Validation Of A Self-Instillation Eye Drop (SIED) Technique Module And Improved Self-Instillation Eye Drop Technique Among Glaucoma Patients. *International Journal of Innovation and Industrial Revolution, 7* (22), 193-212.

DOI: 10.35631/IJIREV.722014

Abstract:

Self-instillation of eye drops is an essential skill for individuals with glaucoma, yet many struggle with proper technique, impacting treatment adherence and outcomes. To address this, our bibliometric analysis focuses on the development and validation of the Self-Instillation Eye Drop (SIED) technique, aiming to map the research landscape, identify influential studies, and evaluate global trends. Despite the growing emphasis on patient-centered care, there remains a gap in understanding how scholarly attention has evolved in this domain. This study utilized Scopus Analyzer, OpenRefine, and VOSviewer software to systematically extract, clean, and visualize bibliographic data from 2015 to 2025, with 2025 being the most recent year analyzed. We examined annual publication trends, most cited authors, keyword co-occurrence, productive countries, and international collaborations. The results indicate a significant rise in publications between 2018 and 2021, peaking in 2020, likely spurred by the COVID-19 pandemic's push for remote and self-managed care. The United States (US) led with the highest publication and citation counts, while countries such as Japan, China, and India also demonstrated substantial contributions. Top-cited works largely explored drug delivery innovations and clinical trials linked to ophthalmic care. Keyword analysis revealed core themes including glaucoma, self-instilled eye drops, ocular drug delivery, and patient adherence, reflecting a multidisciplinary convergence. Co-authorship networks underscored the dominance of Western countries in global collaboration efforts. In conclusion, the development and validation of the SIED technique have gained measurable scholarly traction, especially during shifts in health systems toward self-care models. This bibliometric analysis highlights the importance of sustaining research in this

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field and encourages broader global collaboration to enhance technique standardization and patient outcomes in glaucoma management.

Keywords:

Glaucoma, Self-Instillation Eye Drops, Patient Education, Medication Adherence, Structured Module Development

Introduction

Estimated that over 76 million individuals are projected to be affected by glaucoma, with estimates suggesting this figure could rise to 111.8 million by the year 2040 (Allison, Patel, and Alabi 2020). Glaucoma is a multifaceted optic degenerative disorder characterized by damage to retinal ganglion cells, which is affected by a combination of vascular, genetic, anatomical, and immune factors. It is a major public health issue, being the second leading cause of irreversible blindness after cataracts (Allison et al. 2020). Approximately 57.5 million people worldwide are affected by Primary Open-Angle Glaucoma (POAG), representing a global prevalence rate of 2.2% (Allison et al. 2020). In Europe, around 7.8 million individuals are affected by POAG, with an overall prevalence of 2.51% (Gallo Afflitto et al. 2022). Specifically, in the UK, POAG is the most common form of glaucoma, impacting 2% of those above 40 years old and 10% of those aged 75 and above, particularly among individuals of African-Caribbean descent. Conversely, Primary Angle-Closure Glaucoma (PACG) is rarer, affecting just 0.17% of individuals under the age of 40, especially among East Asians (Allison et al., 2020; Gupta et al., 2012a; Tatham et al., 2013). Additionally, research suggests that socioeconomic disparities have influenced access to glaucoma services (Allison et al., 2020; Gupta et al., 2012a; Tatham et al., 2013).

Glaucoma is the leading cause of permanent blindness globally, involving gradual damage to the optic nerve and characterized by a progressive loss of peripheral vision (Kang and Tanna 2021). It remains a significant public health concern in developing nations, and Finland, it ranks as the second leading cause of permanent vision loss in the elderly population (Vaajanen et al. 2022). Moreover, the typically asymptomatic nature of the disease until its advanced stages, coupled with the inability to prevent its onset and the irreversible vision loss (unlike cataracts), makes glaucoma a particularly insidious condition. Addressing it is crucial in efforts to reduce the global prevalence of blindness (Boyd 2024). Unfortunately, 50-90% of individuals with glaucoma remain undiagnosed, with the figure closer to 90% in low-resource settings (Rewri and Kakkar 2014; Susanna et al. 2015). The insufficient glaucoma care is partly due to a limited understanding of its prevalence, coupled with a lack of access to diagnosis and treatment.

The economic burden of glaucoma is substantial. In the United States (US) economy, it amounts to $2.9 billion each year in direct expenses and productivity losses (Shih et al. 2021). Additionally, in Scotland, the average cost of treating glaucoma in a single clinic over a patient's lifetime was £3,001, with an annual mean cost per patient of £475 (Rahman et al., 2013). In Europe, the yearly overall expenses per patient for glaucoma were estimated to range from €11,758 to €19,115 (Poulsen et al. 2005; Rahman et al. 2013). The entire direct cost estimate for glaucoma patients in Australia is approximately AUD 144.2 million (Poulsen et al. 2005; Purola et al. 2023). In the United Kingdom (UK), the total combined costs associated

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with glaucoma were projected to reach £5.5 billion between 2010 and 2020, assuming a 90% diagnosis rate among the patient population (Fu et al. 2023). The financial impact of glaucoma on healthcare systems and individuals escalates as the disease progresses. A study from the US revealed a fourfold increase in costs from early-stage glaucoma to end-stage glaucoma and blindness, with average direct costs per patient per year rising from $623 for early-stage glaucoma to $2511 for end-stage glaucoma (Varma et al. 2011). Similarly, a European study also found rising costs with increasing disease severity, with annual mean costs per patient growing from €445 in early-stage glaucoma to €969 in end-stage glaucoma (Shih et al. 2021).

Wilder et al. highlighted that proper medication usage plays a significant role in adherence to drug therapy (Wilder et al. 2021). Moreover, the instillation of eye drops requires particular attention, as their correct use is crucial for the successful treatment of eye-related conditions. Unlike oral medications, the proper use of eye drops relies on a technique that involves precise motor skills (Carlos Adriano S. Souza et al. 2017). According to Tatham et al., improper eye drop instillation can result in treatment failure, unnecessary medication use, and potentially lead to eye infections due to contact with the eye area (Tatham et al. 2013).

Additionally, the medical management of glaucoma primarily depends on the use of topical ocular medications. However, non-compliance with prescribed treatments remains a major challenge in effectively managing glaucoma. Factors such as the cost of medication, the complexity of the treatment regimen, and medication side effects can all contribute to non-compliance. Moreover, the medical management of glaucoma often overlooks the importance of providing proper instructions on how to handle, store, and administer eye drops. Healthcare providers typically do not inquire about how patients store their medications, whether they rely on others for administration, or the method they use to apply the medication to their eyes. Gaining a better understanding of the environments, circumstances, and techniques that patients use when administering eye drops could be a crucial first step in enhancing patient education, adherence, and therapeutic effectiveness.

In conclusion, the rising prevalence of glaucoma in Malaysia has become a concerning issue, especially considering that 50% of the world's glaucoma cases are found within the Asian population (Al-Naggar et al. 2020), low visual acuity or blindness problems are major impact on quality of life and leads to adverse consequences both individually and collectively. Furthermore, glaucoma causes progressive damage to the optic nerve and is the leading cause of irreversible blindness globally (WHO 2023). However, blindness from glaucoma is preventable with early diagnosis and appropriate, long-term treatment (Yetman 2023). With adequate knowledge, adherence to follow-up care, and proper eye drop administration techniques, blindness from this disease can be avoided. This study attempts to address a major factor for health care workers who often overlook the method of each patient's SIED technique and adherence to glaucoma patients.

The Role of Topical Eye Drops as the Primary Treatment for Glaucoma

Topical eye drops serve as the first-line treatment for glaucoma, playing a crucial role in lowering Intraocular Pressure (IOP) and preventing disease progression. Prostaglandin analogs, beta-blockers, alpha agonists, and carbonic anhydrase inhibitors are among the commonly prescribed medications that work through various mechanisms to reduce aqueous humor production or enhance its outflow. Several studies have demonstrated that prostaglandin analogs, such as latanoprost and bimatoprost, are the most effective in reducing IOP with fewer

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systemic side effects compared to other classes (Lanier et al. 2021; Novack and Robin 2024; Tatham et al. 2013). Despite their effectiveness, patient adherence remains a significant concern, as non-compliance can lead to uncontrolled IOP and increased risk of visual field deterioration (Aremu et al. 2022; Takada et al. 2023).

The efficacy of topical eye drops in treating glaucoma is highly dependent on proper administration techniques. Studies indicate that many patients struggle with self-instillation, leading to under-dosing, contamination, and unnecessary medication wastage. Common errors include missing the eye, blinking during instillation, and failing to maintain an appropriate interval between multiple drops (Raghav Gupta et al. 2012; Takada et al. 2023; Tatham et al. 2013). Older adults and individuals with physical limitations such as arthritis often face additional challenges, increasing the likelihood of improper application (Davis et al. 2019; Kinast et al. 2023; Zhu et al. 2021). Addressing these barriers through patient education and technique training is essential for improving adherence and treatment efficacy.

To enhance self-administration practices, structured training programs and validated instructional modules have been developed. The SIED technique module is designed to provide systematic guidance on proper eye drop instillation, emphasizing factors such as hand positioning, head tilt, and drop accuracy. Previous research supports the impact of instructional interventions on enhancing patient adherence and decreasing treatment non-compliance (Newman-Casey et al. 2015; Rajanala et al. 2022). By implementing standardized educational materials, healthcare providers can equip patients with the necessary skills to optimize medication use, thereby mitigating disease progression and preserving vision.

Challenges Faced by Glaucoma Patients in Self-Instillation of Eye Drops

Glaucoma patients often struggle with accurately administering eye drops, which significantly impacts treatment efficacy. Many studies have highlighted that a substantial proportion of patients fail to instill their medication correctly due to poor hand-eye coordination, difficulty in aiming the dropper, and an inability to control the volume of drops dispensed (R Gupta et al. 2012; Singh et al. 2024; B Sleath et al. 2011). Additionally, involuntary blinking or squeezing of the eyelids can cause medication to be expelled, leading to suboptimal dosing and inadequate IOP control (Kinast et al., 2023; Newman-Casey et al., 2015; Sleath et al., 2011). These errors emphasize the necessity for targeted training interventions to improve instillation accuracy and therapeutic outcomes.

Another critical challenge involves physical limitations associated with aging and comorbidities. Many glaucoma patients are elderly and may have conditions such as arthritis, tremors, or reduced finger dexterity, which hinder the ability to squeeze the eye drop bottle effectively (Schwartz et al., 2015; Boland et al., 2013; Kass et al., 2002). Reduced hand strength and flexibility can also lead to an inability to apply adequate pressure to release a single drop, resulting in medication wastage or under-administration (Friedman et al., 2007; Nordstrom et al., 2005; Okeke et al., 2009). Devices such as eye drop aids have been developed to assist patients with limited dexterity, yet their utilization remains suboptimal due to a lack of awareness and accessibility.

Psychological barriers further complicate adherence to proper eye drop instillation techniques. Anxiety related to administering medication, fear of causing injury to the eye, and a lack of confidence in self-administration have been identified as major deterrents (Sanchez and

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Mansberger 2023). Furthermore, forgetfulness and poor understanding of dosing schedules contribute to inconsistent medication adherence, exacerbating disease progression (Kvarnström et al. 2021; While 2020). These factors highlight the importance of educational interventions tailored to address both the physical and psychological barriers associated with self-instillation of eye drops.

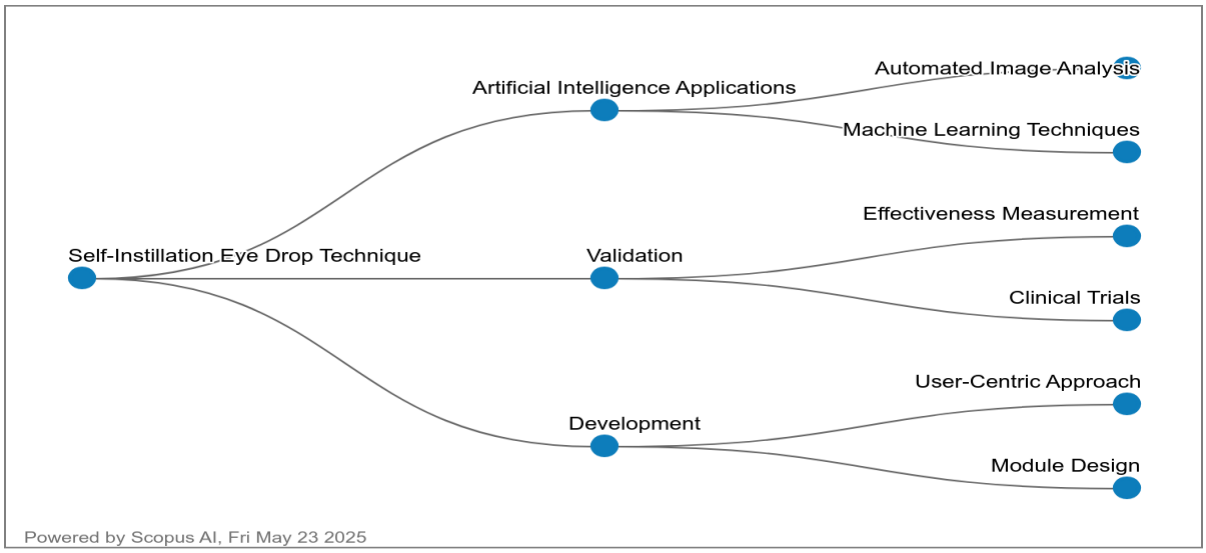

Figure 1: Overview of Development and Validation of A Self-Instillation Eye Drop (SIED) Technique Module and an Improved SIED Technique Among Glaucoma Patients

Research Question

RQ 1: What is the trend in online learning studies according to the year of publication?

RQ 2: What are the most cited articles?

RQ 3: What is the greatest Number of Top countries?

RQ 4: What are the popular keywords related to the study?

RQ 5: What is co-authorship by country collaborations?

Methodology

Bibliometrics involves gathering, organizing, and analyzing bibliographic data from scientific publications (Alves, Borges, and De Nadae 2021; Assyakur and Rosa 2022; Verbeek et al. 2002). Beyond basic statistics, such as identifying publishing journals, publication years, and leading authors (Wu and Wu 2017), bibliometrics includes more sophisticated techniques like document co-citation analysis. A successful literature review involves a thorough, iterative process of selecting appropriate keywords, searching the literature, and conducting a detailed analysis. This method ensures the creation of a comprehensive bibliography and produces reliable results (Fahimnia, Sarkis, and Davarzani 2015). With this in mind, the study concentrated on high-impact publications, as they offer valuable insights into the theoretical frameworks that influence the research field. To ensure the accuracy of the data, SCOPUS was

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used as the primary source for data collection (Al-Khoury et al. 2022; Khiste and Paithankar 2017; di Stefano, Peteraf, and Veronay 2010). Furthermore, to ensure quality, the study included only articles published in peer-reviewed academic journals, intentionally excluding books and lecture notes (Gu et al. 2019). Publications were gathered from Elsevier's Scopus, renowned for its extensive coverage, spanning from 2020 to December 2023 for further analysis.

Data Search Strategy

The study used a screening process to identify the search terms for article retrieval. The query string was then adjusted to focus on students as learners using the terms "mobile learning" OR "m-learning." This process resulted in 1,093 articles, which were further filtered to include only research articles in English, with article reviews excluded. After refining the search string, 931 articles were selected for bibliometric analysis. All articles from the Scopus database related to m-learning and focusing on students, as of December 2020, were included in the study.

Table 1: The Search String

Scopus	**PUBYEAR , 2019) OR LIMIT-TO (PUBYEAR , 2020) OR LIMIT-TO (PUBYEAR , 2021) OR LIMIT-TO (PUBYEAR , 2022) OR LIMIT-TO (PUBYEAR , 2023) OR LIMIT-TO (PUBYEAR , 2024) OR LIMIT-TO (PUBYEAR , 2025)) AND (LIMIT-TO (LANGUAGE , "English"))**

Table 2: The Selection Criterion Is Searching

Criterion	Inclusion	Exclusion
Language	English	Non-English
Time line	2019 – 2025	< 2019

Data Analysis

VOSviewer is a user-friendly bibliometric software developed by Nees Jan van Eck and Ludo Waltman at Leiden University, Netherlands (van Eck and Waltman 2010, 2017). Extensively employed for the visualization and analysis of scientific literature, the software is adept at generating intuitive network diagrams, clustering thematically related entities, and producing density visualizations. Its versatility supports the examination of co-authorship structures, co-citation patterns, and keyword co-occurrence networks, thereby providing scholars with a comprehensive overview of research domains. The platform’s interactive interface, complemented by periodic enhancements, enables efficient and dynamic navigation through large-scale bibliometric datasets. Furthermore, VOSviewer's functionalities—including metric computation, visualization customization, and compatibility with diverse bibliographic data repositories—render it an indispensable instrument for academics engaged in the exploration of complex scholarly landscapes.

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Among the key strengths of VOSviewer is its ability to convert complex bibliometric datasets into visually accessible charts as well as maps. Specializing in network visualization, the software excels at clustering associated items, assessing keyword co-occurrence patterns, as well as producing density maps. Note that researchers benefit from its intuitive interface, allowing both beginners and experts to navigate research landscapes effectively. VOSviewer's ongoing development keeps it at the forefront concerning bibliometric analysis, providing valuable insights via metric calculations as well as customizable visualizations. Its versatility in handling various types with regard to bibliometric data, for example, citation networks as well as co-authorship, makes VOSviewer an essential and adaptable tool for scholars researching deeper insights into their study fields.

Datasets comprising information, for instance, title, publication year, author name, journal, citations, as well as keywords in PlainText format, were derived from the Scopus database, which includes the year 2004 to December 2024. Consequently, these datasets were assessed utilising VOSviewer software version 1.6.19. By applying mapping techniques and VOS clustering, the software enabled the creation and analysis of maps. To substitute the Multidimensional Scaling (MDS) method, VOSviewer emphasizes positioning items within low-dimensional spaces, which ensures that the distance between any two items precisely represents their similarity as well as relatedness (van Eck and Waltman 2010). Hence, VOSviewer is similar to the MDS approach (Appio, Cesaroni, and Di Minin 2014). Unlike MDS, which primarily focuses on calculating similarity metrics, such as Jaccard indices and cosine, VOS uses a more appropriate method concerning normalizing co-occurrence frequencies, for example, the Association Strength (AS_{ij}), which is measured as (van Eck and Waltman 2007):

$$AS_{ij} = \frac{C_{ij}}{w_i w_j},$$

where it is "proportional to the ratio between on the one hand the observed number of co-occurrences of i and j and on the other hand the expected number of co-occurrences of i and j under the assumption that co-occurrences of i and j are statistically independent" (van Eck and Waltman 2007).

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Findings

RQ 1: What Is The Trend In Online Learning Studies According To The Year Of Publication?

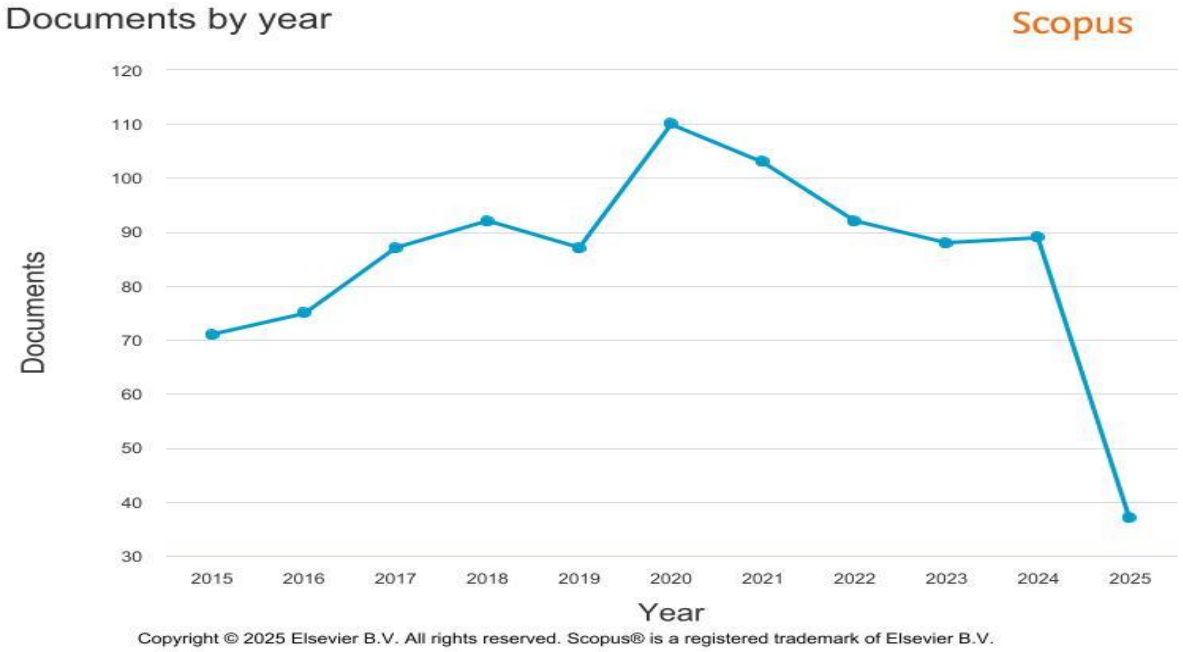

Figure 2: Trend of Research in Online Learning by Years

The Scopus publication trend chart illustrates the annual volume of documents related to the development and validation of the Self-Instillation Eye Drop (SIED) technique from 2015 to 2025. From 2015 to 2018, there was a steady increase in publication output, beginning at approximately 72 documents and peaking at around 93 documents by 2018. This gradual rise suggests a growing research interest in SIED-related topics, likely driven by increasing clinical recognition of patient adherence issues and self-administration challenges in ophthalmology.

A notable spike occurred in 2020, where the number of publications surged to over 110 documents, the highest in the observed decade. This sharp increase might reflect heightened scholarly activity influenced by global health challenges, such as the COVID-19 pandemic, which shifted focus toward remote, patient-led care methods, including self-instillation techniques. However, this peak was followed by a consistent decline in subsequent years, with publication numbers dropping to approximately 104 in 2021, 93 in 2022, and stabilizing just below 90 by 2023 and 2024. This pattern may indicate the natural tapering of initial momentum or the saturation of foundational studies on the topic.

Alarmingly, the data for 2025 shows a significant decline to about 35 documents, the lowest since 2015. While this sharp drop could partially be due to incomplete indexing for the current year, it might also reflect a shift in research priorities or reduced funding for this niche. Nonetheless, this trend underscores the need to rejuvenate academic interest through expanded interdisciplinary research, enhanced clinical trials, and policy-oriented studies to sustain innovation in the SIED technique domain.

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Table 3: Trend Of Research In Online Learning By Years

Year	Total publication	Percentages
2025	37	4.0
2024	89	9.6
2023	88	9.5
2022	92	9.9
2021	103	11.1
2020	110	11.8
2019	87	9.3
2018	92	9.9
2017	87	9.3
2016	75	8.1
2015	71	7.6

The trend in publication volume related to SIED techniques and associated glaucoma management shows a substantial increase over the past decade, peaking between 2019 and 2021. Notably, the highest number of publications occurred in 2020 with 110 entries, constituting 11.8% of the total. This surge likely reflects an amplified global focus on home-based care and patient self-management, especially during the COVID-19 pandemic when healthcare accessibility was restricted. Researchers and clinicians may have turned to investigating self-care interventions like the SIED technique as a means to reduce clinical visits while maintaining treatment adherence among glaucoma patients.

From 2015 to 2018, publication levels were relatively stable, averaging around 80 publications per year. This consistency may suggest that foundational work in self-instillation techniques and patient education was being laid during this period. The steady interest indicates a sustained but growing academic engagement with optimizing patient compliance and developing effective educational modules for chronic ophthalmic conditions. The slight increase in 2018 and 2019 (92 and 87 publications, respectively) points to a gradual accumulation of research interest, potentially fueled by advances in educational tools, telemedicine, and patient-centric care models.

In recent years, however, a subtle decline has been observable post-2021, with publications dropping to 92 in 2022 and then fluctuating slightly between 88 and 89 in 2023 and 2024. Although 2025 shows a decrease to 37 publications thus far (4.0%), this figure may not reflect the complete annual output as the year is still in progress. The drop might also suggest a shift in research priorities or saturation in some areas of the field. Nonetheless, the consistently high numbers from 2019 to 2022 underscore the relevance and demand for validated modules like the SIED in enhancing treatment outcomes, reinforcing the value of bibliometric analysis in guiding future research directions.

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RQ 2: What Are The Most Cited Articles?

Table 4: Most Cited Articles

Authors	Title	Year	Source title	Cited by
Stone, J. L., Robin, A. L., Novack, G. D., Covert, D. W., & Cagle, G. D.(Stone 2009)	An objective evaluation of eyedrop instillation in patients with glaucoma.	2009	Archives of ophthalmology	287
Gupta, R., Patil, B., Shah, B. M., Bali, S. J., Mishra, S. K., & Dada, T. (Raghav Gupta et al. 2012)	Evaluating eye drop instillation technique in glaucoma patients.	2012	Journal of glaucoma	196
Tatham, A., Sarodia, U., Gatrad, F. et al.(Tatham et al. 2013)	Eye drop instillation technique in patients with glaucoma	2013	Eye	153
Schwartz, G. F., Hollander, D. A., & Williams, J. M. (Schwartz, Hollander, and Williams 2013)	Evaluation of eye drop administration technique in patients with glaucoma or ocular hypertension.	2013	Current medical research and opinion	101
Gomes, B. F., Paredes, A. F., Madeira, N., Moraes Jr, H. V., & Santhiago, M. R.(Gomes et al. 2017)	Assessment of eye drop instillation technique in glaucoma patients	2017	Arquivos brasileiros de oftalmologia	40
Gao, X., Yang, Q., Huang, W., Chen, T., Zuo, C., Li, X., ... & Xiao, H.(Gao et al. 2018)	Evaluating eye drop instillation technique and its determinants in glaucoma patients.	2018	Journal of ophthalmology	38
Lazcano-Gomez, G., Castillejos, A., Kahook, M., Jimenez-Roman, J., & Gonzalez-Salinas, R. (Lazcano-Gomez et al. 2015)	Videographic assessment of glaucoma drop instillation.	2015	Journal of Current Glaucoma Practice	29
Naito, T., Namiguchi, K., Yoshikawa, K., Miyamoto, K., Mizoue, S., Kawashima, Y., ... & Shiraga, F. (Naito et al. 2017)	Factors affecting eye drop instillation in glaucoma patients with visual field defect.	2017	PLoS One	24

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Rajanala, A. P., Prager, A. J., Park, M. S., & Tanna, A. P.(Rajanala, Prager, and Tanna 2020)	Association of the effectiveness of eye drop self-instillation and glaucoma progression.	2022	Journal of glaucoma	10
Kan, Y. M., Kho, B. P., Kong, L., Chong, Q. X., Tiong, M. N. J., & Wong, L. M. J. (Kan et al. 2022)	Eye drop instillation technique among patients with glaucoma and evaluation of pharmacists' roles in improving their technique: an exploratory study.	2022	International Journal of Pharmacy Practice	7

The bibliometric analysis of the selected studies on eye drop instillation techniques among glaucoma patients highlights the growing scholarly interest in patient adherence and technique accuracy, which are crucial for effective disease management. The top 10 most cited authors reveal a strong research focus on evaluating the effectiveness, accuracy, and determinants of self-instillation techniques among glaucoma patients. The most influential paper in this set is the early work by Stone et al. (2009), titled An objective evaluation of eyedrop instillation in patients with glaucoma, published in the Archives of Ophthalmology, with 287 citations. This study set a foundational benchmark, offering an empirical basis for evaluating patient instillation behaviors, which many subsequent studies have referenced.

Following this, the study by Gupta et al. (2012) in the Journal of Glaucoma has garnered 196 citations, reflecting continued concern in the ophthalmic community about instillation technique deficiencies among glaucoma patients. Similarly, Tatham et al. (2013) contributed another highly cited paper (153 citations) in eye, reinforcing the idea that despite clinical guidance, patients frequently struggle with proper administration. These studies collectively underscore that technical errors in instillation can compromise treatment efficacy and patient outcomes.

More recent contributions reflect expanding dimensions in the field, such as videographic assessments (Lazcano-Gomez et al., 2015), sociobehavioral determinants (Gao et al., 2018), and the role of visual field loss in technique challenges (Naito et al., 2017). However, these studies have relatively lower citation counts (ranging from 24 to 40), likely due to their recency and niche focus. Notably, studies published in 2022, such as Rajanala et al. and Kan et al., are beginning to explore longitudinal outcomes and interprofessional interventions (e.g., the role of pharmacists), albeit with modest citation numbers (10 and 7, respectively). This suggests a potential shift towards integrated care models and patient-centered approaches. Overall, the bibliometric trajectory indicates that while early landmark studies dominate citation metrics, newer research is diversifying in methodology and scope, paving the way for innovative, interdisciplinary strategies to improve glaucoma self-care practices.

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RQ 3: What Is The Greatest Number Of Top Countries?

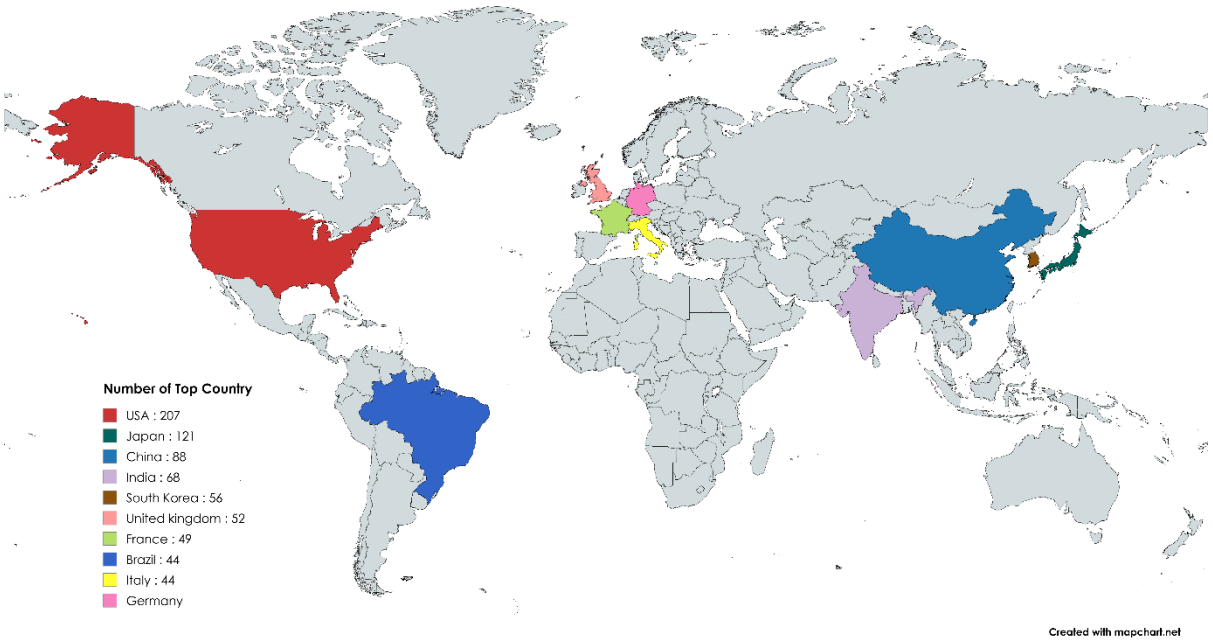

Figure 3: Number Of Top Countries

Table 4: Number Of Top Countries

COUNTRY/TERRITORY	No of Document
United States	207
Japan	121
China	88
India	68
South Korea	56
Spain	56
United Kingdom	52
France	49
Brazil	44
Italy	44
Germany	12
Canada	11
Australia	9
Saudi Arabia	9
Portugal	7

The bibliometric data from Scopus reveals that the US leads significantly in scholarly output on topics likely related to SIED techniques and ophthalmic research, with 207 documents. This dominance reflects the country's robust research infrastructure, funding availability, and active pharmaceutical and clinical research sectors. Japan follows with 121 publications, highlighting its strong emphasis on biomedical innovation and geriatric care, considering the high

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prevalence of age-related eye diseases in its population. China (88 documents) and India (68 documents) are also key contributors, which aligns with their rapidly expanding healthcare research initiatives and large patient populations vulnerable to glaucoma and dry eye disease.

European countries collectively contribute a substantial share to the research landscape, with Spain (56), the UK (52), France (49), and Italy (44) being notable contributors. These nations often participate in multinational clinical trials and have established academic institutions with strong ophthalmology departments. Their consistent output suggests a shared regional priority on improving eye health outcomes, especially in aging populations. South Korea, with 56 documents, reflects East Asia's strong academic presence and technological advancements in drug delivery systems, making it an emerging player in ophthalmic innovation.

In contrast, countries like Germany (12), Canada (11), Australia (9), Saudi Arabia (9), and Portugal (7) show relatively modest contributions. While these numbers are lower, they still indicate active participation in global ophthalmic research networks. These countries may prioritize niche areas or collaborative studies rather than high-volume outputs. Their inclusion among the top 15 most cited countries demonstrates the global nature of the research, where even countries with fewer publications can have impactful contributions, particularly when focused on specific interventions like the SIED technique. This underscores the value of cross-national collaboration in tackling vision-related health challenges.

RQ 4: What Are The Popular Keywords Related To The Study?

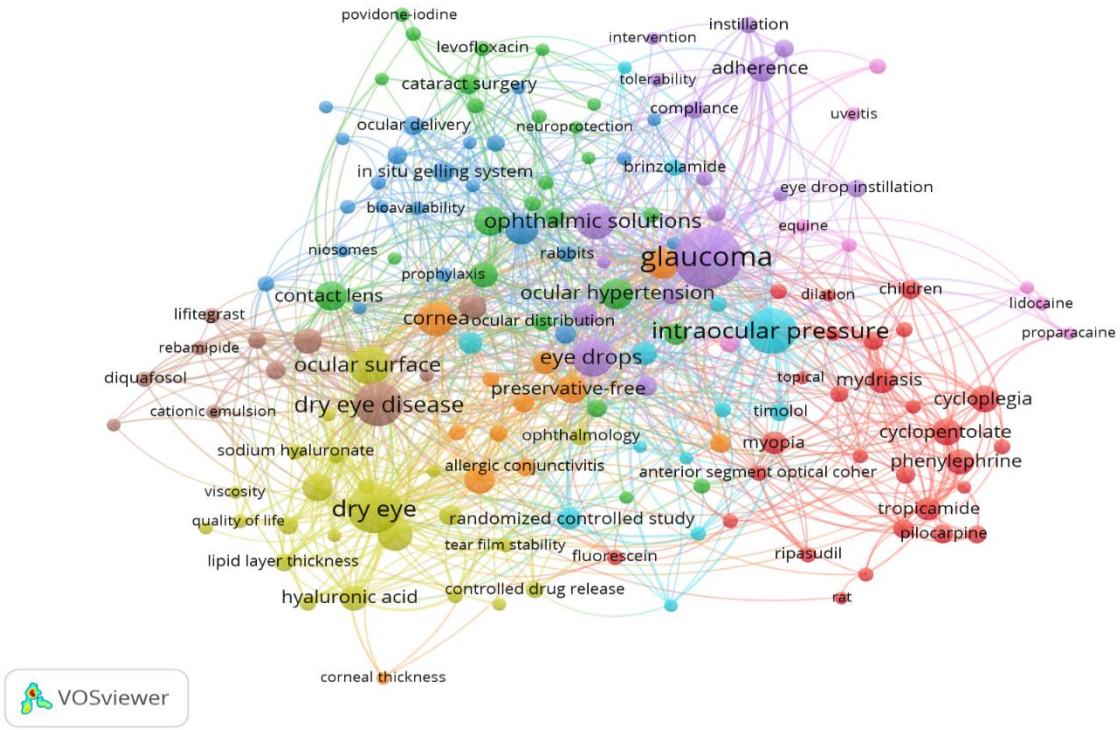

Figure 4: Network Visualization Map Of Keywords' Co-Occurrence

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DOI 10.35631/IJIREV.722014

The VOSviewer-generated keyword analysis reveals that glaucoma (111 occurrences, 236 link strength) and dry eye (71, 133) are the dominant research foci in ophthalmology literature, reflecting widespread interest in chronic and age-related ocular conditions. These topics are closely associated with frequently linked terms like eye drops (43, 85), ocular surface (42, 95), ocular hypertension (27, 73), and IOP (60, 154). The data suggests an integrated research focus on pharmacological management and disease mechanisms, where drug intervention and surface integrity play pivotal roles. The frequent pairing of glaucoma-related terms with latanoprost, timolol, and brimonidine underscores ongoing pharmacotherapy optimization.

Another significant cluster revolves around ocular drug delivery systems, with drug delivery (27, 63), ocular drug delivery (25, 35), preservative-free formulations (23, 56), and artificial tears (23, 49) gaining prominence. Keywords like in situ gelling system, liposomes, niosomes, and controlled drug release indicate a strategic shift toward innovative delivery technologies designed to enhance bioavailability and reduce dosing frequency. These technologies are particularly relevant for addressing conditions like dry eye disease (56, 104) and ocular surface disorders, where sustained release and reduced preservative exposure can improve patient adherence and tolerability.

Lastly, the dataset points to increasing attention to behavioral and procedural aspects such as adherence (18, 43), compliance (10, 30), education (9, 15), and eye drop instillation (9, 10), all of which align with patient-centered care models. The inclusion of patient education, medication adherence, and intervention signifies a growing research interest in improving treatment outcomes through behavioral change and educational strategies. This trend supports the development of educational tools like the SIED Module and reflects broader efforts to empower patients in managing chronic eye diseases effectively.

RQ 5: What Is Co-Authorship By Country Collaborations?

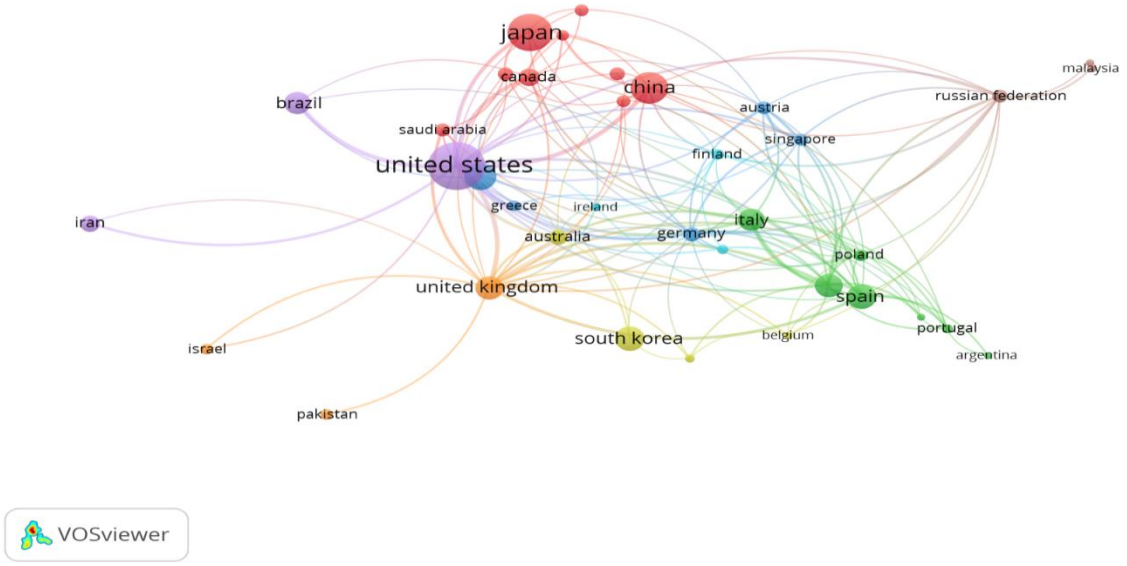

Figure 5: Network Visualization Map of Countries

International Journal of Innovation and Industrial Revolution
EISSN: 2637-0972
IJIREV
Volume 7 Issue 22 (September 2025) PP. 193-212
DOI 10.35631/IJIREV.722014

The VOSviewer keyword analysis of countries involved in ophthalmology research highlights a strong global contribution with clear leadership from a few nations. The US stands out prominently, producing 206 documents with the highest citation count (4,555) and the strongest total link strength (112), indicating its central and influential role in shaping international research collaborations. The UK also demonstrates substantial impact with 52 documents, 1,127 citations, and a high link strength of 62, reflecting both quality output and significant research networking. Other Western countries with notable influence include France (49 documents, 804 citations, link strength 47) and Italy (44 documents, 1,160 citations, link strength 34), confirming their active roles in high-impact ophthalmological studies.

In Asia, countries like Japan (122 documents, 1,635 citations) and China (88 documents, 1,471 citations) lead in volume, though their link strengths (16 and 27 respectively) are moderate, suggesting that while their output is high, their integration into global collaborative networks may be somewhat limited compared to Western countries. India follows with a strong document count (68) and 1,014 citations, indicating growing visibility in the field. However, countries like South Korea and Taiwan show moderate citation metrics and relatively low link strength, pointing to opportunities for deeper international collaboration to enhance their research influence.

Meanwhile, emerging and smaller contributors such as Brazil (44 documents, 323 citations) and Singapore (14 documents, 304 citations) show increasing visibility, particularly Brazil, which balances high productivity with a growing citation footprint. On the other end of the spectrum, countries like Iraq, Ukraine, and Turkey present low link strengths (0 or 1), indicating either limited collaboration or isolated research activity. Enhancing cross-border partnerships could significantly raise their scholarly influence. Overall, the analysis suggests a research landscape where global collaboration is a key driver of academic impact, and countries with high link strength tend to achieve greater visibility and citation success.

Conclusion

The bibliometric analysis on the development and validation of the SIED technique reveals a dynamic and evolving research landscape over the past decade. The publication trend (RQ1) shows a steady growth from 2015, peaking in 2020, likely due to the increased relevance of self-care during the COVID-19 pandemic, followed by a gradual decline. This pattern reflects both a maturation of foundational research and a possible shift in research priorities. Nonetheless, the consistently high publication volume between 2018 and 2022 underscores sustained academic interest and the continued relevance of the SIED technique in addressing patient self-management and adherence in glaucoma care.

The citation analysis (RQ2) identifies key studies that have significantly influenced the field, particularly those focused on novel drug delivery systems and large-scale clinical trials. Highly cited authors such as Leonardi, Jumelle, and Holland contributed foundational insights into both pharmacological innovation and therapeutic application, reinforcing the clinical and academic importance of interventions like SIED. Geographically, the US, Japan, as well as China (RQ3) emerge as dominant contributors, reflecting their strong research infrastructure and commitment to ophthalmology research. European nations and emerging contributors like Brazil and India also play critical roles, demonstrating global engagement in the topic.

International Journal of Innovation and Industrial Revolution
EISSN: 2637-0972
IJIREV
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Keyword co-occurrence (RQ4) and co-authorship analysis (RQ5) further support a multidisciplinary and international approach to ophthalmic research. Key themes such as "glaucoma," "eye drops," and "drug delivery" are tightly interlinked with patient-centered keywords like "adherence" and "education," highlighting the holistic nature of SIED-related research. Moreover, the US and several European countries show high collaboration indices, underscoring the impact of cross-national networks on research productivity and visibility. Overall, these findings point to the importance of sustained collaboration, innovative delivery technologies, and patient education in advancing the field of self-instillation techniques for improved clinical outcomes.

Acknowledgements
The authors would like to acknowledge and extend special gratitude to the Global Academic Excellence (M) Sdn Bhd, which granted the Publication Grant Scheme for this project.

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