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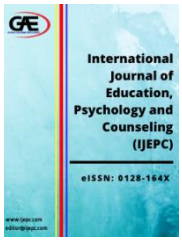

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A SELF-INSTILLATION EYE DROP (SIED) TECHNIQUE AMONG GLAUCOMA PATIENT: A RECENT COMPREHENSIVE STRUCTURED REVIEW

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Abstract:

This Systematic Literature Review (SLR) explores the effectiveness of the Self-Instillation Eye Drop (SIED) technique among glaucoma patients, a critical component in managing Intraocular Pressure (IOP) and preventing disease progression. Despite the widespread prescription of eye drops for glaucoma management, improper instillation techniques remain a significant barrier to effective treatment, leading to poor medication adherence and suboptimal clinical outcomes. This review systematically examines recent studies on SIED, focusing on the impact of patient education, technique optimization, and adherence interventions. A comprehensive search of three major databases—Scopus, PubMed, and ScienceDirect—yielded 74 studies published between 2020 and 2024, of which 31 met the inclusion criteria. These studies collectively involve over 12,000 glaucoma patients across various settings. The analysis reveals that proper instillation technique, reinforced through patient education and feedback mechanisms such as self-video monitoring, can improve medication adherence by up to 30% and reduce IOP levels by an average of 2.5 mm Hg compared to traditional methods. The findings also highlight those interventions tailored to individual patient needs, including personalized education and continuous monitoring, are crucial in enhancing the effectiveness of the SIED technique. The review concludes that while SIED offers significant potential in improving glaucoma management outcomes, ongoing research and the development of standardized training protocols are essential for broader implementation. These findings provide a foundation for future studies and clinical practices to optimize glaucoma treatment through better self-administration techniques.

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Keywords:

Eye Drop; Eye Instillation; Eye Drop Technique; Glaucoma; Self-Instillation

Introduction

Glaucoma is a leading cause of irreversible blindness worldwide, affecting over 76 million people as of 2020, a number projected to rise significantly by 2040 (Adornetto et al., 2020; Onyia et al., 2022). Characterized by progressive optic neuropathy and associated visual field loss, glaucoma necessitates meticulous long-term management to preserve visual function. Central to this management is the effective reduction of Intraocular Pressure (IOP) (Jansook & Loftsson, 2022), most commonly achieved through regular topical ocular hypotensive medications. However, the efficacy of these medications is heavily dependent on patient adherence to the prescribed regimen and their ability to correctly self-administer the eye drops. Despite the availability of effective medications, non-adherence and improper administration of eye drops are prevalent issues among glaucoma patients. Studies indicate that up to 59% of patients demonstrate poor adherence, while incorrect self-instillation techniques are observed in nearly half of all patients. These challenges are often compounded by factors such as age-related physical limitations, a lack of patient education, and the complexity of the medication regimen. Consequently, inadequate drug delivery leads to suboptimal IOP control (Fan et al., 2021), accelerating the progression of glaucoma and increasing the risk of vision loss.

Recognizing these challenges, there is an urgent need for interventions that can enhance patients' ability to correctly self-administer their eye drops and maintain adherence to their treatment regimen. The development of a Self-Instillation Eye Drop (SIED) Technique Module represents a proactive approach to addressing these issues(Biran et al., 2023; Noori et al., 2023). This module aims to equip patients with the necessary skills and knowledge to effectively manage their condition independently, thereby improving both treatment outcomes and overall quality of life. The SIED technique module is designed to address the multifaceted barriers to proper eye drop instillation (Biran et al., 2023). It includes comprehensive educational content, hands-on training, and personalized feedback to ensure that patients can confidently and accurately perform the self-instillation technique (Mehuys et al., 2020; Sam-Oyerinde et al., 2022; Tanito et al., 2023). The module also incorporates strategies to improve adherence, such as the use of reminders and the simplification of the instillation process.

This article presents the development and evaluation of the SIED technique module, focusing on its impact on self-instillation accuracy and adherence among glaucoma patients. By enhancing patients' self-efficacy and competence in managing their treatment, the SIED technique module has the potential to significantly improve clinical outcomes and reduce the burden of glaucoma-related vision loss (Jumelle et al., 2020; Lanier et al., 2021; Page et al., 2023). Furthermore, this study aims to provide valuable insights into the practical implementation of the SIED module within the context of government hospitals in Malaysia, highlighting its relevance and applicability in real-world clinical settings.

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Literature Review

The self-administration of eye drops is critical in managing glaucoma, a chronic eye disease requiring lifelong treatment to prevent vision loss (Ritch et al., 2003). Notably, effective self-instillation of eye drops is essential for maintaining IOP within a safe range. However, numerous studies have highlighted the challenges patients face in properly administering eye drops, which can compromise the efficacy of the treatment. According to Lee, Cho, and Yoo (Lee et al., 2024), a significant improvement in the technique of eye drop instillation was observed in glaucoma patients who received education using self-video feedback. This randomized controlled trial demonstrated that patients who could observe their own instillation technique through video feedback performed significantly better, particularly in critical steps. This includes avoiding contact between the dropper and the eyelid or eyelashes (Davis et al., 2019). Thus, this study underscores the significance of visual feedback in enhancing patients' ability to self-administer eye drops correctly. Further exploring the factors affecting proper eye drop instillation, Tripathi et al. (2023) examined patient awareness and adherence to antiglaucoma medication regimens (Tripathi et al., 2023). Their study revealed that while most patients had a reasonable level of awareness regarding their medication, a substantial proportion still lacked the necessary knowledge to perform the instillation correctly (Sakata et al., 2024; Schwartz et al., 2013; Tanito et al., 2023). The findings highlighted that approximately 25% of patients scored below 50% in drug treatment awareness, which correlates with the observed deficiencies in their self-instillation techniques (Mohindroo et al., 2015). The study concluded that reinforcing education programs focusing on the correct method of eye drop instillation could significantly improve patient adherence and treatment outcomes.

The introduction of technological aids in eye drop administration has also been studied. Quiroz-Mercado et al. (2020) evaluated a novel electromechanical drug delivery device designed to improve the precision and comfort of topical ophthalmic therapy (Quiroz-Mercado et al., 2020). This device, which delivers a microfluid stream rather than a conventional drop, was demonstrated to increase patient comfort and reduce drug exposure while maintaining the effectiveness of IOP reduction. Their study suggested that integrating such technology with educational programs could offer a dual approach to addressing the challenges glaucoma patients face in self-administering eye drops, combining improved technique with enhanced comfort and ease of use. The role of healthcare professionals, particularly pharmacists, in improving eye drop instillation techniques has also been investigated. Kan et al. (2022) conducted a study that explored the effectiveness of pharmacist-led counselling sessions in enhancing the eye drop instillation techniques of glaucoma patients (Kan et al., 2022). Their findings indicated a significant improvement in patients' ability to perform the instillation correctly after receiving personalized counselling from pharmacists. This study suggested that pharmacists can be crucial in-patient education, particularly in settings where direct interaction with ophthalmologists may be limited.

In addition to the practical challenges of eye drop instillation, psychological factors also play a critical role. Newman-Casey et al. (2020) explored the impact of Motivational Interviewing (MI) training for ophthalmic para-professionals on patient satisfaction and self-efficacy in eye drop instillation (Newman-Casey et al., 2020). While the training did not directly improve patients' self-efficacy in instillation, it did enhance their satisfaction with staff communication and support. This highlights the significance of patient-centered communication in managing chronic conditions like glaucoma. Furthermore, assistive devices have been studied as a

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potential solution for patients struggling with self-administration. Sakiyalak and Kobwanthanakun (2020) assessed the use of an Eye Drop Guide (EDG) device (Sakiyalak & Kobwanthanakun, 2020), which was discovered to be beneficial for certain patients, particularly those administering drops in a standing or sitting position. However, the study also noted that many patients did not regularly use the device, indicating that its utility may be limited to specific patient groups. In addition, the importance of regular and reinforced education on eye drop instillation techniques is further supported by Saif et al. (2024). The authors discovered that structured education significantly improved various parameters of eye drop administration among glaucoma patients (Saif et al., 2024). Their interventional study demonstrated that education could lead to better outcomes regarding the number of drops reaching the conjunctival sac, hand hygiene, and overall technique, thereby enhancing the effectiveness of glaucoma treatment.

Lastly, the factors associated with failure in eye drop instillation have been comprehensively examined by Tanito et al. (2023) (Tanito et al., 2023). Their study identified that older age, decreased cognitive function, and reduced visual acuity were significant predictors of instillation failure among glaucoma patients. These findings suggested that targeted interventions should be developed for these high-risk groups to ensure they receive the necessary support and training to manage their condition effectively.

Research Question

Research questions are crucial in a Systematic Literature Review (SLR) since they provide the foundation and direction for the entire review process. They guide the scope and focus of the SLR, helping to determine which studies to include or exclude, ensuring that the review remains relevant and specific to the topic of interest. A well-defined research question ensures that the literature search is exhaustive and systematic, covering all relevant studies that address key aspects of the topic. This minimizes the risk of bias and ensures a complete overview of the existing evidence. Additionally, research questions facilitate the categorization and organization of data from included studies, providing a framework for analyzing findings and synthesizing results to draw meaningful conclusions. They also enhance clarity and focus, avoiding ambiguity and keeping the review concentrated on specific issues, making the findings more actionable and relevant. Furthermore, well-formulated research questions contribute to the transparency and reprehensibility of the review, allowing other researchers to follow the same process to verify findings or extend the review to related areas. Ultimately, research questions ensure that the review aligns with the overall objectives of the study, whether it is to identify gaps in the literature, evaluate the effectiveness of interventions, or explore trends in a specific field, making them the backbone of a rigorous, focused, and relevant SLR.

Based on an advanced searching strategy on the Scopus database for the title “A Self-Instillation Eye Drop (SIED) Technique among Glaucoma Patients,” we discovered and developed three themes, which is Medication Adherence and Patient Behavior, Medication Adherence and Patient Behavior, and Preservatives, Drug Delivery Systems, and Adverse Effects. Based on themes and using the mnemonics style by PICo (population, Interest, and Context), we develop three research questions.

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1. How does the implementation of an SIED technique influence medication adherence among glaucoma patients?

2. What is the effect of preservative-free eye drops combined with a SIED technique on the reduction of ocular surface adverse effects in glaucoma patients?

Methodology

The Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) approach is a widely recognized standard for conducting SLRs, ensuring transparency, completeness, and consistency. By following PRISMA guidelines, researchers are guided to systematically identify, screen, and include studies in their review, which enhances the accuracy and rigor of the analysis. The approach also emphasizes the importance of randomized studies, recognizing their value in reducing bias and contributing robust evidence to the review.

Multiple databases, including Scopus, ScienceDirect, and PubMed, provide a comprehensive approach to literature review in biomedical research, particularly in glaucoma management. Each database brings unique strengths to the analysis: Scopus, with its broad index of peer-reviewed literature across disciplines, ScienceDirect offers in-depth access to scientific and technical research, and PubMed provides focused coverage in biomedical and life sciences. Despite their strengths, it is essential to recognize and address the inherent limitations, such as gaps in coverage or differences in the depth of information provided by each source, to ensure a balanced and thorough review. This multi-database approach allows for a more nuanced understanding of the complex issues surrounding medication adherence, patient behavior, and the impact of preservatives and drug delivery systems on glaucoma treatment outcomes.

The PRISMA approach is further structured into four significant sub-sections: identification, screening, eligibility, and data abstraction. Identification involves searching databases to find all relevant studies, followed by screening, where studies are assessed against predefined criteria to exclude irrelevant or low-quality research (refer to figure 1). The eligibility phase further evaluates the remaining studies to ensure they meet the criteria for inclusion. Finally, data abstraction involves extracting and synthesizing data from the included studies, which is crucial for drawing meaningful and reliable conclusions. This structured approach ensures that the systematic review is conducted with high rigor, producing reliable results that can inform further research and practice.

Identification

This study utilized key steps of the systematic review process to gather a substantial amount of relevant literature. The process began with selecting keywords and searching for related terms using dictionaries, thesauri, encyclopedias, and prior research. All relevant terms were identified, and search strings were created for the Scopus, PubMed, and ScienceDirect databases (refer to Table 1). This initial phase of the systematic review yielded 1,109 publications from the three databases pertinent to the study topic.

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Table 1 : The Search String

Scopus	**TITLE-ABS-KEY ((“Eye Drop”) AND (“Glaucoma Patient”) AND (LIMIT-TO (SUBJAREA, “MEDI”) OR LIMIT-TO (SUBJAREA, “PHAR”) OR LIMIT-TO (SUBJAREA, “HEAL”)) AND (LIMIT-TO (DOCTYPE, “ar”)) AND (LIMIT-TO (LANGUAGE, “English”))** Date of Access: August 2024
PubMed	“Eye Drop” AND “Glaucoma Patient” **Date of Access: August 2024**
ScienceDirect	“Eye Drop” AND “Glaucoma Patient” **Date of Access: August 2024**

Screening

During the screening step, potentially relevant research items are evaluated to ensure they align with the predefined research question(s). This phase often involves selecting research items based on the SIED Technique among Glaucoma Patients. Duplicate papers are removed at this stage. Initially, 601 publications were excluded, leaving 508 papers for further examination based on specific inclusion and exclusion criteria as shown in table 2. The first criterion was literature, as it is the main source of practical recommendations, including reviews, meta-syntheses, meta-analyses, books, book series, chapters, and conference proceedings not covered in the most recent study. The review was limited to English-language publications from 2020 to 2024. Overall, eight publications were rejected due to duplication.

Table 2 : The Selection Criterion is Searching

Criterion	Inclusion	Exclusion
Language	English	Non-English
Timeline	2020 – 2024	< 2020
Literature type	Journal (Article)	Conference, Book, Review
Publication Stage	Final	In Press
Subject	Medicine, Pharmacology, Toxicology and Pharmaceutics Health Professions	Besides Medicine, Pharmacology, Toxicology and Pharmaceutics Health Professions

Eligibility

In the third step, known as the eligibility phase, 74 articles were prepared for review. During this stage, the titles and key content of all articles were carefully examined to ensure they met the inclusion criteria and aligned with the current research objectives. Consequently, 41 articles

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were excluded as they did not qualify due to the out-of-field, title not significantly, abstract not related to the study's objective, and no full-text access founded on empirical evidence. As a result, 31 articles remain for the upcoming review.

Data Abstraction and Analysis

An integrative analysis was used as one of the assessment strategies in this study to examine and synthesize a variety of research designs (quantitative methods). The goal of the competent study was to identify relevant topics and subtopics. The data collection stage was the first step in developing the theme. Figure 1 displays how the authors meticulously analyzed a compilation of 31 publications for assertions or material relevant to the topics of the current study. The authors then evaluated the current significant studies related to titlepped classrooms. The methodology used in all studies, as well as the research results, are being investigated. Next, the author collaborated with other co-authors to develop themes based on the evidence in this study's context. In addition, a log was kept throughout the data analysis process to record any analyses, viewpoints, riddles, or other thoughts relevant to the data interpretation. Finally, the authors compared the results to observe any inconsistencies in the theme design process. It is worth noting that if there are any disagreements between the concepts, the authors discuss them amongst themselves.

The produced themes were eventually tweaked to ensure consistency. The analysis was selected by three experts: 1 = Ophthalmologist, 1 = Optometrist, and 1 HCW (sister or medical assistant with a post-basic Certificate in Ophthalmology). The expert review phase ensures the clarity, importance, and suitability of each subtheme by establishing the domain validity. Adjustments based on feedback and comments by experts have been made at the discretion of the author. The questions are as follows below:

1. How effective are different instructional methods (such as hands-on training and visual feedback) in improving the accuracy and consistency of the SIED technique among glaucoma patients?
2. How do patients perceive the ease and effectiveness of the SIED technique compared to assisted administration by healthcare professionals?
3. How does the use of assistive devices and educational interventions impact patient adherence and clinical outcomes in the SIED technique?

Quality of Appraisal

According to the guidelines proposed by Kitchenham and Charters (2007) (Kitchenham, 2007), once we have selected PSs, we have to assess the quality of the research they present and quantitatively compare them. In this study, we apply the Quality Assessment (QA) from Anas Abouzahra et al. (2020), which consists of five QAs for our SLR (Abouzahra et al., 2020). The scoring procedure for evaluating each criterion involves three possible ratings: "Yes" (Y) with a score of 1 if the criterion is fully met, "Partly" (P) with a score of 0.5 if the criterion is somewhat met but contains some gaps or shortcomings, and "No" (N) with a score of 0 if the criterion is not met at all (refer Table 3).

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Table 3: Quality Assessment by Expert

Quality Assessment	Expert 1	Expert 2	Expert 3	Total Mark
Is the purpose of the study clearly stated?	Y	Y	Y	3
Is the interest and the usefulness of the work clearly presented?	Y	Y	Y	3
Is the study methodology clearly established?	Y	Y	Y	3
Are the concepts of the approach clearly defined?	Y	Y	Y	3
Is the work compared and measured with other similar work?	Y	Y	Y	3

The table outlines a QA process used to evaluate a study based on specific criteria. Three experts assess the study using the criteria listed, and each criterion is scored as "Yes" (Y), "Partly" (P), or "No" (N). Here is a detailed explanation:

1. Is the purpose of the study clearly stated?
   - This criterion checks whether the study's objectives are clearly defined and articulated. A clear purpose helps set the direction and scope of the research.
2. Is the interest and usefulness of the work clearly presented?
   - This criterion evaluates whether the study's significance and potential contributions are well-explained. It measures the relevance and impact of the research.
3. Is the study methodology clearly established?
   - This assesses whether the research methodology is well-defined and appropriate for achieving the study's objectives. Clarity in methodology is crucial for the study's validity and reproducibility.
4. Are the concepts of the approach clearly defined?
   - This criterion examines whether the theoretical framework and key concepts are clearly articulated. Clear definitions are essential for understanding the study's approach.
5. Is the work compared and measured with other similar work?
   - This evaluates whether the study has been benchmarked against existing research. Comparing with other studies helps position the work within the broader academic context and highlights its contributions.

Each expert independently assesses the study according to these criteria, and the scores are then totaled across all experts to determine the overall mark. For a study to be accepted for the next process, the total mark, derived from summing the scores from all three experts, must exceed 2.5. This threshold ensures that only studies meeting a certain quality standard proceed further.

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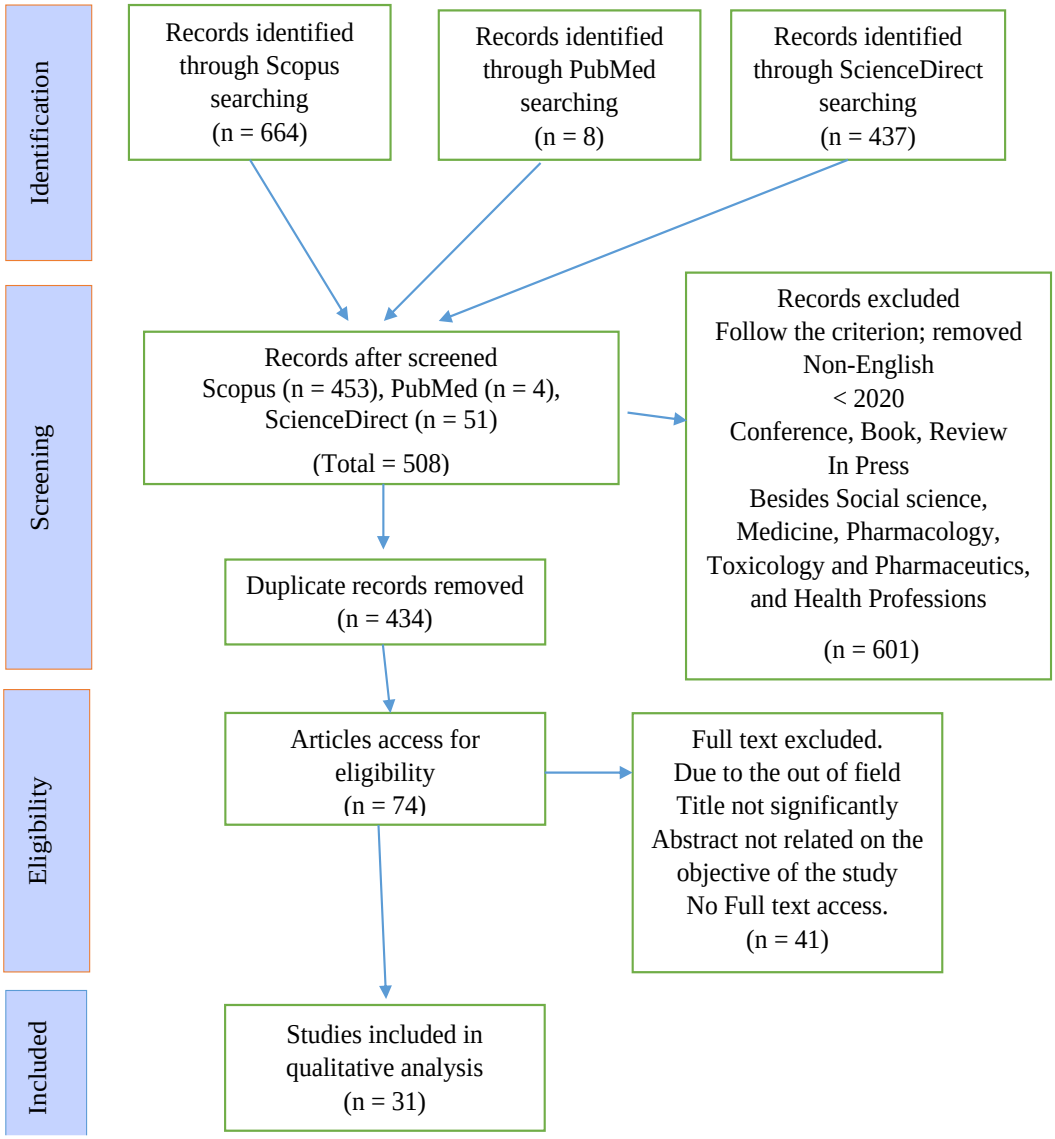

Figure 1: Flow Diagram Of The Proposed Search Study

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Table 4 : Summary of Study of Self-Instillation Eye Drop Technique for Glaucoma Patient

NO	AUTHORS	TITLE	YEAR	SOURCE TITLE	SCOPUS	PUB MED	SCIENCE DIRECT
1	Abid A.; Baxter S.L. (Abid & Baxter, 2024)	Breaking Barriers in Behavioral Change: The Potential of Artificial Intelligence-Driven Motivational Interviewing	2024	Journal of Glaucoma	√	√	
2	AlQahtani G.M.S.; Al Zahrani A.T.; Ahmad K.; Albalawi A.N.; Obeid D.A.; Al Shahwan S. (AlQahtani et al., 2024)	Knowledge, attitude, and practice (KAP) towards glaucoma among new glaucoma patients and their first-degree relatives: A cross-sectional study in a tertiary eye care center in Riyadh, Saudi Arabia	2024	European Journal of Ophthalmology	√	√	
3	Ayaki M.; Hanyuda A.; Negishi K. (Ayaki et al., 2024)	Symptomatic Presbyopia may Develop Earlier in Patients With Glaucoma—A Cross-Sectional Retrospective Cohort Study	2024	Translational Vision Science and Technology	√		√
4	Barakat N.A.; AlGhanem R.; Abdulrazeq B.; AlKhatib H.S.; AlRyalat S.A.; Muhsen S.; AlMuhaissen S. (Barakat et al., 2024)	Improving medication adherence in glaucoma patients: a randomized controlled interventional study	2024	Journal of Pharmaceutical Health Services Research	√		
5	Ekici Gok Z.; Gunduz A.; Bozgül P.G. (Ekici Gok et al., 2024)	Evaluation of the effects of mono or combined use of topical antiglaucomatous drops on conjunctival flora and antibiotic susceptibility	2024	European Journal of Ophthalmology	√	√	
6	Eraslan N.; Celikay O. (Eraslan & Celikay, 2023)	Effects of topical prostaglandin therapy on corneal layers thickness in primary open-angle glaucoma patients using anterior segment optical coherence tomography	2023	International Ophthalmology	√		
7	Hedengran A.; Freiberg J.; May Hansen P.; Boix-Lemonche G.; Utheim T.P.; Dartt D.A.; Petrovski G.; Heegaard S.; Kolko M. (Hedengran et al., 2024)	Comparing the effect of benzalkonium chloride-preserved, polyquad-preserved, and preservative-free prostaglandin analogue eye drops on cultured human conjunctival goblet cells	2024	Journal of Optometry	√	√	
8	Hirawat R.S.; Aron N.; Mahalingam K.; Gupta V.; Angmo D.; Dada T.; Titiyal J.S.; Sharma N.; Sihota R. (Hirawat et al., 2024)	Changes in confocal microscopy in glaucoma patients after intraocular pressure reduction with medical therapy	2024	Indian Journal of Ophthalmology	√	√	√
9	Kiyota N.; Shiga Y.; Ninomiya T.; Tsuda S.; Omodaka K.; Himori N.; Yokoyama Y.; Pak K.; Nakazawa T. (Kiyota et al., 2024)	The Effect of β-Blocker Eye Drops on Pulse Rate, Ocular Blood Flow, and Glaucoma Progression: A Retrospective Longitudinal Study	2024	Advances in Therapy	√	√	
10	Kolko M.; Hansen R.F.; Dal L.G.; Sabelström E.; Brandel M.; Bentsen A.H.; Falch-Joergensen A.C. (Kiyota et al., 2024)	Predictors and long-term patterns of medication adherence to glaucoma treatment in Denmark—an observational registry study of 30100 Danish patients with glaucoma	2024	BMJ Open Ophthalmology	√	√	√

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NO	AUTHORS	TITLE	YEAR	SOURCE TITLE	SCOPUS	PUB MED	SCIENCE DIRECT
11	Kyei S.; Kwao E.; Mashige P.K.; Listowell Abu S.; Racette L. (Kyei et al., 2023)	Adherence to Ocular Hypotensive Medication in Patients With Primary Open Angle Glaucoma in Ghana	2023	Journal of Glaucoma	√	√	
12	Lee T.-E.; Cho Y.; Yoo H.H. (Lee et al., 2024)	The effects of self-video feedback on the eyedrop instillation techniques of glaucoma patients: a prospective randomized controlled trial	2024	International Ophthalmology	√	√	
13	Martini K.; Baillif S.; Nahon-Esteve S.; Denis P.; Martel A. (Martini et al., 2024)	Intraoperative iStent versus postoperative selective laser trabeculoplasty in early glaucoma patients undergoing cataract surgery: A retrospective comparative study; [Injection d'un iStent peropératoire versus trabéculoplastie sélective au laser postopératoire chez des patients glaucomateux légers bénéficiant d'une chirurgie de la cataracte : une étude rétrospective et comparative]	2024	Journal Francais d'Ophtalmologie	√		
14	Matsuo M.; Ichioka S.; Harano A.; Takayanagi Y.; Tanito M. (Matsuo et al., 2024)	Minimally Invasive Direct Internal Cyclopexy in the Management of Goniotomy-Related Cyclodialysis Cleft with Hypotony Maculopathy	2024	International Medical Case Reports Journal	√		
15	Messmer E.M.; Baudouin C.; Benitez-Del-Castillo J.-M.; Iester M.; Anton A.; Thygesen J.; Topouzis F. (Messmer et al., 2024)	Expert Consensus Recommendations for the Management of Ocular Surface Inflammation in Patients with Glaucoma	2024	Journal of Glaucoma	√	√	√
16	Montolío-Marzo E.; Fernández-Narros R.; Morales-Fernández L.; García-Bella J.; Sáenz-Francés F.; García-Feijoo J.; Martínez-de-la-Casa J.M. (Montolío-Marzo et al., 2024)	Improvement of objective ocular redness measured with Keratograph 5M in glaucoma patients after instilling brimonidine drops	2024	European Journal of Ophthalmology	√	√	
17	Motta G.S.; da Costa Andrade J.; Kasahara N. (Motta et al., 2024)	How glaucoma patients balance between the advantages and disadvantages of acceptance to the recommended treatment regimen in real-life: Perspectives from a middle-income country	2024	Pharmacoepidemiology and Drug Safety	√	√	
18	Nagstrup A.H. (Nagstrup, 2023)	The use of benzalkonium chloride in topical glaucoma treatment	2023	Acta Ophthalmologica	√	√	√
19	Oydanich M.; Roll E.H.; Uppuluri S.; Khouri A.S.(Oydanich et al., 2024)	Effectiveness of netarsudil 0.02% in lowering intraocular pressure in patients with secondary glaucoma	2024	Canadian Journal of Ophthalmology	√	√	
20	Park I.K.; Bae S.H.; Jeong J.H.; Kim K.W.; Yi K.; Chun Y.S. (Park et al., 2024)	Comparison of allergy prevalence using brinzolamide 1.0% / brimonidine 0.2% fixed combination with and without β-blocker in glaucoma patients: a retrospective cohort study	2024	BMC Ophthalmology	√	√	

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NO	AUTHORS	TITLE	YEAR	SOURCE TITLE	SCOPUS	PUB MED	SCIENCE DIRECT
21	Sadiq D.R.; Mikhael E.M. (Sadiq & Mikhael, 2024)	The Achievement of IOP Target Among a Sample of Iraqi Patients with Glaucoma: A Retrospective Study	2024	Clinical Ophthalmology	√	√	√
22	Sakata R.; Mizoue S.; Yoshikawa K.; Adachi M.; Ohkubo S.; Hamada N.; Naito T.; Muramatsu T.; Hara T.; Asato R.; Aihara M. (Sakata et al., 2024)	Correction to: Additive effects of brimonidine tartrate 0.1%/brinzolamide 1% fixed-dose combination in prostaglandin analog-treated Japanese glaucoma patients (Japanese Journal of Ophthalmology, (2023), 67, 6, (668-677), 10.1007/s10384-023-01022-6)	2024	Japanese Journal of Ophthalmology	√	√	
23	Shah S.N.; Zhou S.; Sanvicente C.; Burkemper B.; Apolo G.; Li C.; Li S.; Liu L.; Lum F.; Moghimi S.; Xu B. (Shah et al., 2024)	Prevalence and Risk Factors of Blindness Among Primary Angle Closure Glaucoma Patients in the United States: An IRIS Registry Analysis	2024	American Journal of Ophthalmology	√	√	√
24	Shi Y.; Zhang Y.; Sun W.; Huang A.S.; Chen S.; Zhang L.; Wang W.; Xie L.; Xie X. (Shah et al., 2024)	24-Hour efficacy of single primary selective laser trabeculoplasty versus latanoprost eye drops for Naïve primary open-angle glaucoma and ocular hypertension patients	2023	Scientific Reports	√	√	
25	Tabuchi H.; Nishimura K.; Akada M.; Ishikami T.; Shirakami T.; Kamiura N.; Kiuchi Y. (Tabuchi et al., 2024)	Real-world evaluation of novel eye drop bottle sensors: Cloud-based AI support for eye drop adherence	2024	Heliyon	√		
26	Taushanova M.; Yermukhanova L.; Tazhbenova S.; Aitmaganbet P.; Muratov Y.; Irmekbayev R.; Balday I.; Abilkassym D. (Taushanova et al., 2024)	Evaluating the Impact of Educational Interventions on Medication Adherence Among Glaucoma Patients in Kazakhstan: A Public Health Perspective	2024	Bangladesh Journal of Medical Science	√		√
27	Wang Y.-C.; Ling X.C.; Tsai W.-H.; Liu J.-S.; Kuo K.-L. (Wang et al., 2023)	Risks of Topical Carbonic Anhydrase Inhibitors in Glaucoma Patients With Chronic Kidney Disease: A Nationwide Population-Based Study	2023	American Journal of Ophthalmology	√	√	√
28	Weber C.; Quintin P.; Holz F.G.; Fea A.; Mercieca K. (Weber et al., 2024)	Ocular drug delivery systems: glaucoma patient perceptions from a German university hospital eye clinic	2024	Graefe's Archive for Clinical and Experimental Ophthalmology	√	√	
29	Wu T.; Cui C.; Li Y.; Hong Y.; Zhang C. (Wu et al., 2024)	Outcome of illuminated microcatheter-assisted circumferential trabeculotomy following failed angle surgery in PAX6 aniridic glaucoma: a case report and literature review	2024	BMC Ophthalmology	√	√	

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NO	AUTHORS	TITLE	YEAR	SOURCE TITLE	SCOPUS	PUB MED	SCIENCE DIRECT
30	Xia J.; Guo S.; Hu F.; Fan L.; Yu L.; Ye J. (J. Xia et al., 2024)	Changes in Corneal Higher-Order Aberrations and Ocular Biometric Measurements after Phacoemulsification Combined with Goniosynechialysis in Primary Angle Closure/Glaucoma Patients	2024	Journal of Ophthalmology	√	√	
31	Xia Y.; Blecher N.A.; Custer P.L.; Sieck E.G. (Y. Xia et al., 2024)	Optimizing topical drop efficacy with proper eyelid positioning	2024	American Journal of Ophthalmology Case Reports	√	√	√

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Result and Finding

This study examined 31 selected articles focused on SIED among glaucoma patients. The thematic analysis identified three main themes: Medication Adherence and Patient Behavior in glaucoma patients, Effectiveness and Safety of Glaucoma Treatments and Preservatives, Drug Delivery Systems, and Adverse Effects. The findings revealed that adherence to glaucoma medication is heavily influenced by patient behavior, with issues such as forgetfulness, physical difficulty, and misunderstanding of instructions leading to inconsistent use. Notably, the effectiveness and safety of glaucoma treatments are closely tied to patients' ability to correctly administer their eye drops, with improper techniques resulting in either reduced efficacy or increased risk of adverse effects. Additionally, the presence of preservatives in eye drops was associated with ocular discomfort, potentially affecting adherence. At the same time, advances in drug delivery systems, such as preservative-free formulations and improved applicators, were highlighted as crucial for enhancing patient comfort and treatment outcomes. The analysis underscores the critical need for patient education, training in self-instillation techniques, and ongoing innovation in drug delivery systems to improve adherence, safety, and overall effectiveness of glaucoma treatment.

Medication Adherence and Patient Behavior

Recent studies underscore the pivotal role of medication adherence and patient behavior in managing glaucoma effectively. The findings by Kolko et al. (2024) revealed that long-term adherence to glaucoma medications significantly impacts disease progression (Kolko et al., 2024). Their observational registry study, encompassing over 30,100 Danish patients, indicated that non-adherence is associated with an increased risk of visual field loss and overall disease progression. This aligns with the results presented by Barakat et al. (2024), who conducted a randomized controlled trial and discovered interventions designed to improve adherence. This includes patient education and support, which markedly enhance medication compliance and improve clinical outcomes (Barakat et al., 2024). These findings suggested that fostering patient adherence through structured interventions could be a key strategy in slowing the progression of glaucoma.

Moreover, Lee et al. (2024) conducted a prospective randomized controlled trial investigating the use of self-video feedback to enhance eyedrop instillation techniques among glaucoma patients (Lee et al., 2024). Their study highlighted the significance of correct instillation techniques in maintaining effective IOP control. The findings suggested that patients who receive self-video feedback demonstrate significant improvement in their technique, enhancing medication efficacy. This study underscored the need for continuous patient education and technique monitoring to improve adherence and therapeutic outcomes. The exploration of β-blocker eye drops by Kiyota et al. (2024) added another dimension to understanding patient behavior (Kiyota et al., 2024). Their retrospective longitudinal study assessed the impact of these drops on pulse rate, ocular blood flow, and glaucoma progression. The results indicated that while β-blocker drops effectively lower IOP, they also have systemic effects that may influence patient compliance. In addition, the study highlighted the need for personalized treatment plans that consider both the efficacy of the medication and the patient's tolerance to potential side effects, which could otherwise lead to decreased adherence.

Effectiveness and Safety of Glaucoma Treatments

The effectiveness and safety of various glaucoma treatments have been the focus of numerous studies, each contributing critical insights into optimizing patient outcomes. Messmer et al.

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(2024) provided expert consensus recommendations for managing ocular surface inflammation in glaucoma patients, emphasizing the significance of addressing side effects associated with long-term topical medication use (Messmer et al., 2024). Their findings underscored that while medications like prostaglandin analogs and beta-blockers effectively reduce IOP, they can exacerbate ocular surface disease, necessitating adjunctive therapies to protect ocular health. These recommendations are pivotal in guiding clinicians to balance treatment efficacy with the preservation of the ocular surface, thereby ensuring comprehensive patient care. In exploring the optimization of glaucoma treatment, Xia et al. (2024) investigated the impact of proper eyelid positioning on the efficacy of topical eye drops (Y. Xia et al., 2024). Their study demonstrated that correct eyelid positioning can significantly enhance the absorption and effectiveness of glaucoma medications, leading to better IOP control. This research highlighted the often-overlooked aspect of patient technique in administering eye drops, suggesting that patient education on proper application methods is essential for maximizing the benefits of treatment. This finding complements the work of Motta et al. (2024), who examined how glaucoma patients in middle-income countries balance the advantages and disadvantages of long-term medication adherence (Motta et al., 2024). Their study revealed that patients' acceptance of treatment regimens is influenced by the perceived effectiveness and the side effects and financial burden associated with chronic therapy. Together, these studies emphasized the need for a holistic approach to glaucoma management, where patient education and support play a crucial role in ensuring treatment adherence and efficacy.

Further investigation into patient adherence was conducted by Kyei et al. (2023), who studied adherence to ocular hypotensive medication among patients with Primary Open-Angle Glaucoma (POAG) in Ghana (Kyei et al., 2023). Their findings revealed significant barriers to adherence, including limited medication access, financial constraints, and lack of patient education. This research underscored the challenges faced by patients in low-resource settings and the need for targeted interventions to improve adherence. Similarly, Sadiq and Mikhael (2024) highlighted the difficulty in achieving target IOP levels among Iraqi glaucoma patients, pointing out that multiple medications and the complexity of treatment regimens often hinder patient compliance (Sadiq & Mikhael, 2024). Their study, alongside AlQahtani et al. (2024), who explored the knowledge, attitudes, and practices of glaucoma patients and their relatives in Saudi Arabia, reinforced the importance of culturally and contextually tailored patient education programs to improve treatment outcomes across diverse populations (AlQahtani et al., 2024). Notably, the advancements in technology also play a significant role in enhancing glaucoma treatment adherence, as demonstrated by Tabuchi et al. (2024) (Tabuchi et al., 2024). Their real-world evaluation of novel eye drop bottle sensors, supported by cloud-based artificial intelligence (AI) technology, provided a promising approach to monitoring and improving patient adherence to prescribed regimens. This innovative solution helps ensure that patients administer their medications correctly and provides valuable data for clinicians to make informed adjustments to treatment plans. Similarly, Weber et al. (2024) explored patient perceptions of ocular drug delivery systems, highlighting the potential of these systems to reduce the burden of daily eye drop administration and improve overall adherence (Weber et al., 2024). These technological innovations, coupled with personalized patient care, offer new avenues for improving the effectiveness of glaucoma treatments. The study by Wang et al. (2023) on the risks associated with topical Carbonic Anhydrase Inhibitors (CAIs) in glaucoma patients with Chronic Kidney Disease (CKD) added a crucial layer to the discussion on treatment safety (Wang et al., 2023). Their findings indicated that while these medications are effective in reducing IOP, they pose significant risks of metabolic acidosis and worsening renal

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function in patients with advanced CKD. This study underscored the importance of careful patient selection and monitoring when prescribing these medications, ensuring that the benefits of treatment outweigh the potential risks.

Preservatives, Drug Delivery Systems, and Adverse Effects

The exploration of preservatives, drug delivery systems, and their associated adverse effects in glaucoma treatments has been a focal point of recent research, shedding light on critical aspects that influence patient outcomes. Eraslan and Celikay (2023) conducted a study to evaluate the effects of prostaglandin analogs such as latanoprost, bimatoprost, and travoprost on corneal thickness in patients with POAG (Eraslan & Celikay, 2023). Their findings indicated that these medications, while effective in reducing IOP, lead to significant thinning of the corneal layers over prolonged use. This thinning was observed across the central Corneal Epithelial Thickness (CET), central Corneal Stromal Thickness (CST), and total Central Corneal Thickness (CCT). However, the degree of impact varied among the drugs. Despite these changes, the overall effect on corneal thickness was comparable among the three drugs, suggesting that the preservatives and active ingredients within these eye drops have a uniform impact on the cornea. These findings underscored the significance of regularly monitoring corneal health in patients undergoing long-term glaucoma treatment, particularly when using preserved eye drops. The risks associated with glaucoma treatments extend beyond the ocular surface, as demonstrated by Wang et al. (2023), who investigated the impact of topical CAIs in glaucoma patients with CKD (Wang et al., 2023). Their study revealed that patients using CAIs faced higher risks of long-term dialysis and metabolic acidosis compared to non-users. This highlighted the systemic effects that glaucoma medications can have, particularly in vulnerable patient populations. The findings from Wang et al. underscored the need for cautious prescribing and rigorous monitoring of glaucoma patients with comorbid conditions to mitigate potential adverse effects. The study added a crucial layer to understanding how systemic health can be impacted by ocular treatments, particularly when preservatives and other additives in eye drops interact with pre-existing health conditions.

In exploring alternative methods to traditional eye drops, Tabuchi et al. (2024) provided insights into the use of novel eye drop bottle sensors, supported by cloud-based AI, to enhance adherence and reduce the risk of preservative-related side effects (Tabuchi et al., 2024). Their evaluation demonstrated that these smart systems could significantly improve patient adherence by providing real-time feedback and data to both patients and clinicians. This technological advancement is particularly relevant in reducing the frequency of eye drop administration and limiting exposure to preservatives known to cause ocular surface toxicity over time. In addition, integrating such drug delivery systems could represent a significant shift in glaucoma management, moving towards more personalized and less invasive treatment approaches. The issue of preservative-induced ocular surface disease is further elaborated by Montolío-Marzo et al. (2024), who examined the effects of brimonidine, a common glaucoma medication, on ocular redness (Montolío-Marzo et al., 2024). Their study utilized the Keratograph 5M to objectively measure ocular redness before and after brimonidine instillation in patients under long-term hypotensive treatment. The results revealed a significant reduction in redness following the use of brimonidine, suggesting its potential as an adjunctive therapy to manage preservative-induced ocular surface inflammation. Moreover, the study also highlighted the comparable effects of preservative-free versus preserved formulations. This indicates that while preservatives contribute to ocular surface irritation, the active components in the medication can also play a role in managing these adverse effects. Collectively, these

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studies emphasized the complex interplay between drug delivery systems, preservatives, and adverse effects in glaucoma management. They highlighted the need for ongoing research and innovation in developing safer, more effective treatment modalities that minimize systemic risks and ocular surface toxicity. Accordingly, the integration of advanced drug delivery systems and the careful consideration of patient-specific factors, such as comorbid conditions and long-term medication use, are essential for optimizing glaucoma care and improving patient outcomes.

Discussion

Recent studies on medication adherence and patient behavior underscore their critical role in managing glaucoma effectively. Kolko et al. (2024) and Barakat et al. (2024) provided complementary insights into the impact of long-term adherence to glaucoma medications on disease progression (Kolko et al., 2024) (Barakat et al., 2024). Kolko et al.'s large-scale observational registry study of over 30,100 Danish patients illustrated that non-adherence is significantly linked to an increased risk of visual field loss and overall disease progression. This evidence is reinforced by Barakat et al. (2024), whose randomized controlled trial demonstrates that interventions such as patient education and support can markedly improve medication compliance, leading to better clinical outcomes (Barakat et al., 2024). Both studies suggested that structured interventions aimed at fostering patient adherence are pivotal in mitigating glaucoma progression. In addition to medication adherence, the correct technique in eyedrop instillation plays a vital role in ensuring the effectiveness of glaucoma treatment. Lee et al. (2024) explored this aspect in their prospective randomized controlled trial, which focused on the use of self-video feedback to enhance patients' instillation techniques (Lee et al., 2024). Their findings revealed that patients who receive self-video feedback demonstrate significant improvements in their technique, which directly enhances the efficacy of the medication by ensuring proper IOP control. This study highlighted the need for continuous patient education and monitoring to ensure patients adhere to the medication schedule and the correct instillation technique, further supporting therapeutic outcomes.

Another dimension of patient behavior influencing medication adherence is the systemic effects of certain medications, such as β-blocker eye drops, as explored by Kiyota et al. (2024) (Kiyota et al., 2024). Their retrospective longitudinal study examined the impact of β-blocker drops on pulse rate, ocular blood flow, and glaucoma progression. The study discovered that while β-blockers effectively lower IOP, their systemic effects, such as changes in pulse rate, could potentially affect patient compliance. This finding suggested that personalized treatment plans, which consider both the efficacy of the medication and the patient's tolerance to side effects, are essential to maintaining adherence and optimizing treatment outcomes. Collectively, these studies illustrate the multifaceted nature of medication adherence and patient behavior in glaucoma treatment. The integration of patient-centered interventions, such as tailored education, feedback mechanisms, and individualized treatment plans, is crucial for improving adherence and ultimately enhancing clinical outcomes in glaucoma management.

The effectiveness and safety of glaucoma treatments have been the subject of extensive research, with various studies providing essential insights into optimizing patient outcomes. Messmer et al. (2024) emphasized the importance of managing ocular surface inflammation in patients undergoing long-term glaucoma treatment, particularly those using prostaglandin analogs and beta-blockers (Messmer et al., 2024). Note that while these medications effectively reduce IOP, they can contribute to ocular surface disease. This significant side effect can

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impact patient comfort and adherence. Hence, the expert consensus recommends adjunctive therapies to mitigate these adverse effects, highlighting the need for a balanced approach that maintains treatment efficacy while preserving ocular surface health. These findings are crucial for clinicians seeking to provide comprehensive care that addresses both the therapeutic and side effect profiles of glaucoma medications. In the quest to optimize glaucoma treatment, Xia et al. (2024) investigated the role of proper eyelid positioning in enhancing the efficacy of topical eye drops (Y. Xia et al., 2024). Their study demonstrated that correct eyelid positioning during administration significantly improves the absorption of glaucoma medications, leading to better IOP control. This aspect of patient technique is often overlooked, yet it plays a vital role in the overall effectiveness of treatment. This research complements the work of Motta et al. (2024), who explored how patients in middle-income countries manage the challenges of long-term medication adherence (Motta et al., 2024). At the same time, Motta et al. discovered that patient acceptance of treatment regimens is influenced by factors such as side effects and financial burden, in addition to perceived efficacy (Motta et al., 2024). These studies collectively underscored the importance of a holistic approach to glaucoma management, where patient education on proper application techniques and support for managing side effects are integral to ensuring adherence and optimizing treatment outcomes.

Patient adherence remains a critical factor in the success of glaucoma treatment, as highlighted by Kyei et al. (2023) in their study of adherence to ocular hypotensive medication among patients in Ghana (Kyei et al., 2023). The research identified significant barriers to adherence, including limited medication access, financial constraints, and inadequate patient education. These findings are echoed by Sadiq and Mikhael (2024), who discovered that the complexity of treatment regimens and the use of multiple medications often hinder patient compliance in Iraq (Sadiq & Mikhael, 2024). AlQahtani et al. (2024) further explored the knowledge, attitudes, and practices of glaucoma patients and their relatives in Saudi Arabia, reinforcing the need for culturally tailored educational programs to improve adherence (AlQahtani et al., 2024). These studies illustrated the global challenges faced in maintaining consistent treatment adherence and highlighted the necessity for targeted interventions that address specific barriers within different cultural and socio-economic contexts. In addition, technological advancements have also significantly contributed to improving glaucoma treatment adherence. Tabuchi et al. (2024) conducted a real-world evaluation of novel eye drop bottle sensors supported by cloud-based AI, which offers a promising solution for monitoring and enhancing patient adherence (Tabuchi et al., 2024). These sensors provide real-time data on eye drop usage, allowing clinicians to adjust treatment plans and ensure patients administer their medications correctly. Weber et al. (2024) also explored patient perceptions of ocular drug delivery systems, finding that these systems could reduce the burden of daily eye drop administration and improve adherence (Weber et al., 2024). Therefore, integrating these technological innovations into clinical practice, alongside personalized patient care, represents a significant step forward in addressing the challenges of glaucoma treatment adherence.

Safety concerns are a critical consideration in the management of glaucoma, particularly for patients with comorbidities. Wang et al. (2023) highlighted the risks associated with topical CAIs in glaucoma patients with CKD, finding that these medications can increase the risk of metabolic acidosis and worsen renal function in patients with advanced CKD (Wang et al., 2023). This study underscored the importance of careful patient selection and monitoring when prescribing these medications, ensuring that the potential benefits of treatment outweigh the associated risks. The findings from Wang et al., alongside the broader discussions on treatment

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efficacy and patient adherence, emphasized the need for a nuanced approach to glaucoma management that carefully balances effectiveness and safety in diverse patient populations.

Recent research on glaucoma treatments has increasingly focused on understanding the role of preservatives, drug delivery systems, and their associated adverse effects. Eraslan and Celikay (2023) investigated the impact of prostaglandin analogs like latanoprost, bimatoprost, and travoprost on corneal health, particularly in patients with POAG (Eraslan & Celikay, 2023). Their study revealed that these medications, although effective in reducing IOP, lead to significant thinning of various corneal layers over prolonged use. The findings indicated a consistent thinning effect across the central CET, central CST, and total CCT. Despite these changes, the overall impact on corneal thickness was comparable among the different drugs, suggesting a uniform effect of the preservatives and active ingredients across these medications. This underscored the critical need for regular corneal health monitoring in patients undergoing long-term treatment with preserved eye drops to detect and manage potential adverse effects early. Beyond ocular surface complications, systemic risks associated with glaucoma treatments have also been highlighted. Wang et al. (2023) explored the effects of topical CAIs in glaucoma patients who also suffer from CKD (Wang et al., 2023). The study discovered that patients using CAIs were at a significantly higher risk of developing long-term dialysis needs and metabolic acidosis compared to those not using these medications. This research draws attention to the systemic implications of glaucoma medications, particularly in patients with pre-existing comorbidities. Wang et al.'s findings emphasized the importance of cautious prescribing and thorough monitoring of glaucoma patients, particularly those with complex health profiles, to avoid exacerbating systemic conditions. This adds a crucial perspective to understanding how ocular treatments can interact with broader health conditions, necessitating a holistic approach to patient care.

Innovations in drug delivery systems have provided promising alternatives to traditional eye drop methods, aiming to reduce preservative-related side effects and improve treatment adherence. Tabuchi et al. (2024) examined the effectiveness of novel eye drop bottle sensors supported by cloud-based AI (Tabuchi et al., 2024). These smart systems have demonstrated the potential to significantly enhance patient adherence by offering patients and healthcare providers real-time feedback. The integration of these innovative drug delivery systems could represent a significant shift in glaucoma management, moving towards more personalized and less invasive approaches that prioritize both efficacy and patient safety. Preservative-induced ocular surface disease remains a significant concern in glaucoma management, as highlighted by Montolío-Marzo et al. (2024) (Montolío-Marzo et al., 2024). Their study focused on the effects of brimonidine, a commonly used glaucoma medication, on ocular redness—a common sign of ocular surface inflammation. Using the Keratograph 5M, the study objectively measured the reduction in ocular redness after brimonidine instillation, suggesting its potential as adjunctive therapy for managing preservative-induced ocular surface inflammation. Notably, the study also discovered that preservative-free formulations offered similar therapeutic benefits with potentially fewer side effects. This indicates that both the active ingredients and the preservatives in glaucoma medications play crucial roles in managing and mitigating adverse effects. These findings highlighted the need for careful consideration in selecting medication formulations balancing the benefits of the active drug with the potential risks posed by preservatives. In particular, the interplay between preservatives, drug delivery systems, and adverse effects in glaucoma management is complex and multifaceted. The studies reviewed underscored the importance of continuous innovation and patient-specific

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treatment strategies in minimizing systemic risks and ocular surface toxicity. As the field of glaucoma treatment advances, the integration of new drug delivery technologies and a deeper understanding of patient-specific factors will be essential for optimizing care and improving long-term patient outcomes.

Conclusion

Recent studies on glaucoma treatment have highlighted the critical role of medication adherence and patient behavior in effectively managing the disease and mitigating its progression. Kolko et al. (2024) and Barakat et al. (2024) provided substantial evidence that long-term adherence to glaucoma medications is crucial in reducing the risk of visual field loss and disease progression. Their research underscored the necessity of structured interventions, such as patient education and support, to improve medication compliance and enhance clinical outcomes. These findings emphasized the need for continuous patient engagement and the implementation of tailored strategies to foster adherence, which is pivotal in the successful management of glaucoma. The correct technique in administering glaucoma medications, particularly eyedrop instillation, is vital in treatment efficacy. Lee et al. (2024) demonstrated that improving patients' instillation techniques through self-video feedback significantly enhances the effectiveness of glaucoma medications by ensuring proper IOP control. This study, along with the work of Kiyota et al. (2024) on the systemic effects of β-blocker eye drops, highlighted the importance of personalized treatment plans that consider both the efficacy of the medication and the patient's tolerance to side effects. Together, these studies suggested that a holistic approach to glaucoma management—integrating patient education, monitoring, and personalized care—is essential for optimizing treatment outcomes.

Furthermore, the effectiveness and safety of glaucoma treatments continue to be a focus of research, with significant attention given to managing side effects associated with long-term medication use. Messmer et al. (2024) highlighted the need to balance treatment efficacy with the preservation of ocular surface health, particularly in patients using prostaglandin analogs and beta-blockers. Complementary studies by Xia et al. (2024) and Motta et al. (2024) underscored the importance of proper eyelid positioning and the consideration of patient-specific factors such as financial burden and side effects in ensuring treatment adherence and effectiveness. These findings reinforced the necessity of a comprehensive, patient-centered approach in glaucoma management, which addresses both the therapeutic and side effect profiles of the medications. The interplay between preservatives, drug delivery systems, and adverse effects is a complex but crucial aspect of glaucoma management. Studies by Eraslan and Celikay (2023) and Wang et al. (2023) have highlighted the ocular and systemic risks associated with long-term use of preserved eye drops, particularly in vulnerable populations with comorbid conditions like CKD. The integration of innovative drug delivery systems, such as the smart eye drop bottle sensors evaluated by Tabuchi et al. (2024), offers promising solutions for enhancing adherence while minimizing preservative-related side effects. Meanwhile, Montolío-Marzo et al. (2024) further emphasized the need for careful selection of medication formulations to balance the benefits of active drugs with the potential risks posed by preservatives.

In conclusion, managing glaucoma requires a multifaceted approach that integrates patient adherence, proper medication administration techniques, and the careful consideration of both ocular and systemic safety. Furthermore, the studies reviewed demonstrate the importance of continuous innovation in treatment strategies and the need for personalized care that addresses

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the unique needs of each patient. Nevertheless, as the field of glaucoma treatment evolves, integrating new technologies and a deeper understanding of patient-specific factors will be key to optimizing care and improving long-term outcomes.

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