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EDITORIAL **OPEN ACCESS**

Glaucoma Management: A Pharmacological Perspective

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Glaucoma, a progressive optic neuropathy, is a leading cause of irreversible blindness worldwide [1]. The disease is characterized by distinctive optic nerve damage, often accompanied by elevated intraocular pressure (IOP). Consequently, reducing IOP remains the cornerstone of glaucoma management, a goal achieved primarily through pharmacological interventions [2]. While established therapies are effective, the future of glaucoma treatment is rapidly evolving. Recent advances are pioneering novel mechanisms of action, enhancing patient adherence through innovative drug delivery systems, and shifting the focus toward direct neuroprotection. This editorial highlights state-of-the-art advancements and promising future trends in glaucoma pharmacotherapy.

The current glaucoma treatment is founded on several classes of drugs that effectively lower IOP. Prostaglandin analogues (PGAs) are typically first-line agents that enhance uveoscleral outflow, while beta-blockers and carbonic anhydrase inhibitors (CAIs) work by reducing the production of aqueous humor [3]. Alpha-2 adrenergic agonists, such as brimonidine, also play a crucial role by both decreasing aqueous production and modestly increasing uveoscleral outflow. Although these medications are mainstays in managing glaucoma, challenges related to side effects, tolerability, and patient adherence necessitate continuous innovation. A significant limitation in current therapy is the reliance on patient adherence to complex daily dosing schedules, which can compromise treatment efficacy.

Recent breakthroughs have introduced new drug classes that target different physiological pathways. Rho-associated protein kinase (ROCK) inhibitors, such as netarsudil, represent a significant advance by directly targeting the trabecular meshwork to increase aqueous outflow [4]. Furthermore, emerging drugs, such as nitric oxide-donating prostaglandins and dual FP/EP3 receptor agonists, aim to provide superior IOP reduction by engaging multiple outflow pathways simultaneously [5]. These novel mechanisms not only offer new options for lowering IOP but may also provide secondary benefits, including improved ocular blood flow.

Perhaps the most significant challenge in patient care is adherence to daily eye drop regimens. To address this, sustained-release drug delivery systems are transforming treatment paradigms. Biodegradable implants, such as the bimatoprost implant (Durysta™), can deliver medication steadily over several months from a single administration, thereby freeing patients from the burden of daily dosing [6]. Similarly, fixed-combination therapies, which combine multiple medications into a single product, reduce the number of daily drops, improving adherence and minimizing exposure to preservatives. Concurrently, nanotechnology-based platforms, including advanced hydrogels and nanoformulations, are being developed to optimize drug bioavailability, prolong corneal contact time, and minimize systemic side effects [7].

Beyond IOP control, the ultimate goal of glaucoma therapy is to preserve vision by protecting retinal ganglion cells (RGCs) from damage. This has opened new frontiers in neuroprotective and regenerative strategies. Orally administered nicotinamide (Vitamin B3) has shown significant promise, with a recent clinical trial demonstrating improved inner retinal function in patients with glaucoma [8]. More advanced approaches are also under active investigation. Gene therapies using adeno-associated virus (AAV) vectors aim to provide sustained neuroprotection by modulating key cellular pathways [9], while stem cell therapies seek to replace damaged RGCs or create a supportive microenvironment to foster neuronal survival [10]. While these cutting-edge therapies face considerable challenges in clinical translation, including delivery, safety, and cost, they hold promise for preserving sight.

In the future, the management of glaucoma is poised to become increasingly sophisticated and personalized. Future directions will focus on developing a comprehensive and holistic treatment strategy. This involves developing highly targeted therapies for IOP reduction, such as novel small-molecule drugs that modulate specific outflow pathways with greater efficacy and fewer side effects. For the management of neurodegeneration, the focus will be on advancing gene therapies that can be delivered *via* safe, minimally invasive routes and developing regenerative medicine techniques to restore lost neuronal function. Silencing RNA (siRNA) technology offers the potential to suppress disease-related genes with high specificity and precision. Meanwhile, artificial intelligence (AI) is being leveraged to analyze complex patient data, predicting treatment responses and enabling the development of tailored therapeutic regimens that optimize efficacy and tolerability for each individual [11]. While cannabinoids have been investigated for their IOP-lowering effects, their clinical utility remains limited by psychotropic side effects and a short duration of action, and they are not currently recommended for glaucoma treatment by major ophthalmological societies [12].

It is also important to acknowledge that while this editorial focuses on pharmacotherapy, non-pharmacological options, such as laser therapy (*e.g.*, Selective Laser Trabeculoplasty - SLT) and surgical interventions, are critical components of glaucoma management, particularly when medication fails to achieve target IOP levels.

CONCLUSION

In conclusion, the pharmacological landscape of glaucoma is undergoing a profound transformation. While lowering IOP remains central, the field is moving toward a more holistic approach that integrates novel drug targets, advanced sustained-release delivery systems, and direct neuroprotective interventions. By harnessing the power of precision medicine, innovative molecular biology, and data analytics, we are entering an era where individualized treatment protocols have the potential to dramatically improve outcomes and enhance the quality of life for millions of patients with glaucoma worldwide.

AUTHORS' CONTRIBUTIONS

It is hereby acknowledged that all authors have accepted responsibility for the manuscript's content and consented to its submission. They have meticulously reviewed all results and unanimously approved the final version of the manuscript.

CONFLICT OF INTEREST

The authors declare no conflict of interest, financial or otherwise.

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DECLARATION

This editorial, title "Glaucoma Management: A Pharmacological Perspective," has been professionally edited for English language clarity, grammar, punctuation, spelling, and syntax to meet international publication standards.

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