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REVIEW ARTICLE

"Beyond the Exam Chair" – A Review of Emerging Approaches in Glaucoma Care

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ABSTRACT

Glaucoma represents a complex degenerative optic neuropathy that is initially asymptomatic and undetectable until later stages. Historically, glaucoma management has relied on periodic, office-based measurements of intraocular pressure (IOP). While this method guided glaucoma clinical practice for decades, expanding insights into disease pathophysiology are more suggestive of a complex interplay between genetic, physiologic, and systemic factors that extend beyond the ophthalmic exam chair. Emerging technologies and biomedical discoveries are prompting a shift toward a more proactive and comprehensive approach to glaucoma management. Advances in predictive tools and remote monitoring modalities are expanding clinicians' ability to diagnose patients and monitor disease progression more effectively. Polygenic risk scores (PRS) provide a quantitative measure of genetic susceptibility and may help identify high-risk patients before clinical disease develops. When combined with traditional clinical risk factors, PRS may enhance screening strategies and guide treatment intensity. Home tonometry enables continuous measurement of diurnal and nocturnal IOP fluctuations, capturing clinically significant pressure spikes that are frequently missed during routine office visits. Emerging visual field-testing platforms may also enable more frequent and accessible monitoring, further improving the ability to detect early disease progression. There is growing recognition that systemic comorbidities contribute meaningfully to glaucoma pathophysiology. Conditions such as obstructive sleep apnea, systemic hypertension, vascular dysregulation, and pseudoexfoliation syndrome can influence optic nerve perfusion and disease progression. This highlights the importance of evaluating systemic physiologic parameters and considering their contributions to any potential adverse effects on ocular perfusion pressure and optic nerve health. Leveraging this concept, systemic medications are also emerging as potential modifiers of glaucoma risk and progression. Glucagon-like peptide-1 receptor agonists (GLP-1RAs), widely used for diabetes and weight management, demonstrate anti-inflammatory and neuroprotective properties that may benefit retinal ganglion cells. Conversely, certain antihypertensive medications such as calcium channel blockers may negatively affect retinal perfusion and potentiate vision loss. Together, these developments suggest that glaucoma should be approached as a multifactorial systemic disease rather than solely an ocular condition. Integrating advanced diagnostics, continuous physiologic monitoring, systemic disease management, and emerging therapeutic insights may enable earlier intervention and more individualized care, ultimately reducing the burden of glaucoma-related blindness.

Introduction

Glaucoma represents a complex degenerative optic neuropathy that is initially asymptomatic and undetectable; in later stages, it is characterized by significant retinal ganglion cell and axonal deterioration leading to visual field changes and functional loss.[1] Elevated intraocular pressure (IOP) is broadly accepted as a major risk factor for glaucoma development. In turn, elevated IOP places mechanical strain on the optic nerve head which can lead to ischemia/hypoxia, disrupted axonal transport, and deficiency of growth factors.[2–5] The management of glaucoma has largely followed a consistent model for decades, relying on periodic in-office measurements of IOP, the only modifiable risk factor for glaucoma that is correlated with vision loss.[6] Despite well-established paradigms in management, knowledge regarding the pathophysiology of glaucoma continues to evolve. The objective of this article is to review emerging approaches that extend glaucoma management beyond traditional ophthalmic methods and considerations.

Background

Recent advancements in technology have helped facilitate a deeper understanding of glaucoma pathophysiology on several notable fronts. Similar trends are observed throughout medicine as patient physiologic data are increasingly obtainable outside the clinic through tools such as continuous glucose monitoring in diabetes, 24-hour blood pressure monitoring for hypertension, home sleep studies for sleep apnea, and even single-lead EKGs on smart watches. Such technology has shaped a data-rich environment empowering patients to be proactive participants in their care rather than relying on reactive, office-based monitoring alone. Furthermore, detailed analysis of these physiologic parameters has facilitated improved healthcare and disease outcomes.[7,8] Similarly, modern glaucoma management is advancing, afforded by access to new technologies enabling remote monitoring and a burgeoning appreciation for how systemic conditions and medications can impact aqueous humor dynamics and optic nerve health. Integration of these holistic medical perspectives and insights improves early detection, provides a method of risk stratification, and may reduce the risk of severe long-term outcomes such as blindness. The way clinicians are approaching glaucoma care is changing with respect to three major domains: advanced and more sensitive diagnostics, awareness of associated systemic comorbidities, and the impact of emerging systemic therapeutics all of which are integrated as illustrated by Figure 1. As an understanding of genetic, physiologic, and systemic risk factors expands, glaucoma care will be poised to intervene earlier when necessary and partner with other healthcare professionals, thereby reducing its long-term impact and improving patient outcomes.

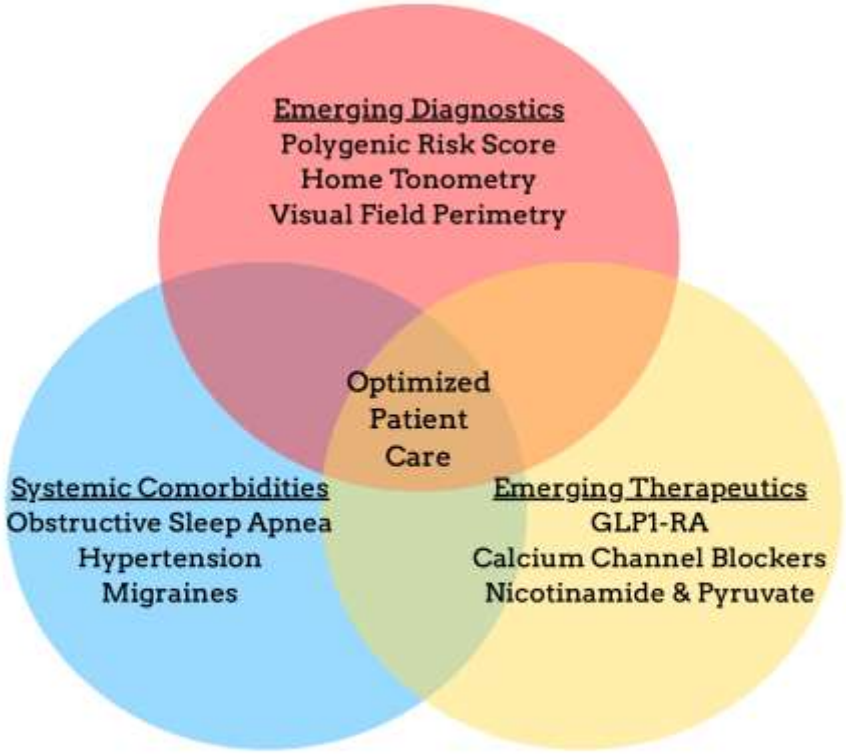

Figure 1: Three major domains in which management of glaucoma is changing

Methods

A narrative literature review was conducted using the PubMed English database from January 1, 2022 to March 20, 2026. Search terms included combinations of "glaucoma", "intraocular pressure", "home tonometry", "polygenic risk score", "obstructive sleep apnea", and "GLP-1RA". Articles were selected based on relevance to emerging diagnostics, systemic comorbidities, and therapeutic strategies in glaucoma. The selected literature was qualitatively synthesized to evaluate trends in personalized and proactive glaucoma care.

Emerging Diagnostics

A relatively new tool being developed for use in glaucoma management is the polygenic risk-score (PRS), which quantifies an individual's overall genetic predisposition for developing glaucoma. This information can help predict a patient's risk prior to any evidence of disease or potentially provide insight into disease progression for those already diagnosed with glaucoma.[9] These scores can help refine a patient's glaucoma risk when used in conjunction with traditional factors such as IOP, central corneal thickness (CCT), family history, and findings on clinical exam. In an independent cohort study of patients with POAG from Australia and New Zealand, the group with high risk PRS had a significantly higher maximum IOP, was more likely to have a family member affected by glaucoma, and was more likely to require incisional glaucoma surgery compared with the low-risk group.[10] Among patients with ocular hypertension (OHT), PRS was significantly higher among those converted to POAG, with each increase in PRS decile associated with a 1.36% increase in POAG risk.[11] Other studies using biobank data have also found that PRS accounts for up to 12.9% of phenotypic IOP variance and is a more accurate predictor of POAG conversion than other systemic risk factors like BMI and blood pressure.[12] As a glaucoma risk stratification tool, this score helps guide surveillance frequency and treatment intensity in glaucoma monitoring and management. In the future, PRS may be able to help predict age of glaucoma onset and

even the need for ocular surgery prior to irreversible damage.

Despite these promising findings, there are several limitations that should be considered when implementing PRS in clinical practice. Most PRS models have been developed using populations of primarily European ancestry, which may limit generalizability to a more diverse patient population.[13,14] Considerations of cost, accessibility, and ethical implications of genetic screening remain important factors as well. While PRS can improve risk stratification, its predictive power remains modest when used in isolation and is most effective when used in conjunction with clinical risk factors such as IOP, family history, and visual field loss.[11,15] One such clinical risk factor is IOP, which is routinely measured in the clinic. Recently, studies have demonstrated the utility of measuring IOP over extended periods using a home tonometer.[16,17]

For example, the iCare HOME2 (iCare USA, Raleigh, NC) is a regulatory-cleared, validated prescription device that allows patients to monitor their eye pressure remotely. Though physicians rely heavily on IOP as a measure of how well glaucoma is controlled, infrequent office-based tonometry captures only a snapshot of a patient's diurnal/nychthemeral IOP. Home tonometry provides a method of assessing diurnal and nocturnal IOP for weeks to months at a time and has been shown to critically alter management decisions.[17] It has also been demonstrated that patients with glaucoma often experience their highest IOP spikes in the early morning between the hours of 4-6 AM which is missed by in-office only visits.[18] It has been well established that diurnal fluctuations are linked to vision loss, but clinicians previously lacked an efficient and easy way to characterize IOP variation outside of the office.[19,20] Home tonometry allows providers and patients to identify details regarding diurnal variation and early morning spikes that are missed in office.[16] Using this information, personalized care plans can be crafted to administer pressure-lowering therapies with optimal timing and improve efficacy.[17]

Visual field (VF) perimetry is an important tool for assessing visual outcomes and disease progression in glaucoma patients. Traditional visual field perimetry requires a large and expensive piece of equipment, designated clinic space, and valuable technician time. Furthermore, although the American Academy of Ophthalmology preferred practice pattern guidelines recommend patients with POAG undergo at least one VF test per year, many patients undergo fewer visual field tests than is recommended.[21] The test itself can be uncomfortable and time consuming, sometimes leading to reduced patient cooperation and longer testing time intervals. Innovative options now include programming for virtual reality (VR) based headsets and even computer-based systems. These options may improve patient comfort and enable more frequent testing. Increasing the frequency of VF testing has been shown to reduce time to detect progression, and studies have shown that clustering VF tests at the time of glaucoma diagnosis can more accurately identify fast progressors; however, the burden of increased testing with in-clinic perimetry undermines the feasibility of translating research to clinical practice.[22,23] Research is currently being conducted to validate VR testing as an appropriate adjunct to traditional in-office Humphrey visual field testing.[24] Regardless, these innovations provide options to clinicians in resource-limited and rural settings while also improving patient engagement and adherence to recommended monitoring guidelines.

Interplay with Systemic Comorbidities

There is a growing appreciation for the significant role that systemic comorbidities play in the development and progression of glaucoma.

Screening for such conditions can help optimize glaucoma diagnosis and management. For example, obstructive sleep apnea (OSA) is a strong risk factor for development of open angle glaucoma with data demonstrating an odds ratio over 2.0 at 3, 5, and 10 years after an OSA diagnosis.[25] Although OSA is fundamentally a respiratory disorder, it causes severe disruptions in the body's internal circadian clock.[26] The pathophysiology regarding the correlation between glaucoma, circadian sleep disturbances, and OSA is not fully understood, but proposed mechanisms involve both vascular and mechanical factors.[27] Vascular pathways include recurrent hypoxia leading to increased vascular resistance, autonomic dysregulation, and oxidative stress from hypoxia-reperfusion cycles and direct hypoxia to the optic nerve.[28] Mechanical factors include elevated IOP at night related to supine positioning and obesity, raised intracranial pressure and elastic fiber depletion in the lamina cribrosa and trabecula.[28] Researchers are currently assessing diurnal IOP fluctuations in glaucomatous patients with OSA using iCare HOME2 tonometry (manuscript pending). Characterizing these IOP fluctuations in relation to apneic events and sleep patterns will lead to a better understanding of the pathophysiology underlying OSA, circadian sleep disturbances, and possible risk factors for glaucoma.

One form of glaucoma that is particularly influenced by a systemic genetic pathology is pseudoexfoliation syndrome (PEX), a leading cause of secondary open-angle glaucoma.[29] PEX is associated with an increased risk of cardiovascular disease, coronary heart disease, and cerebrovascular disease possibly suggesting shared vasculopathy.[30] Hypertension, endothelial dysfunction, Raynaud's disease, and migraines are associated with normal tension glaucoma, further suggesting shared characteristics in vascular dysregulation contributing to glaucomatous optic nerve damage and highlighting the importance of systemic vascular health.[31] Given this perspective, glaucoma can be considered a systemically influenced optic neuropathy disease in many patients.

While elevations in IOP are closely monitored in glaucoma, blood pressure is a second physiologic parameter that is an equally important factor to consider when managing glaucoma. Together, blood pressure and IOP influence ocular perfusion pressure (OPP), the pressure gradient that drives blood flow to the optic nerve and retina. Elevations in IOP with low blood pressure decrease OPP. It is important to note that OPP is not static; the magnitude and duration of nocturnal hypotension have been associated with accelerated glaucoma progression presumably due to sustained reductions in optic nerve perfusion.[32] Emerging evidence further suggests long-term variability of blood pressure, independent of mean blood pressure, may also correlate with worse visual outcomes in glaucoma patients.[33] These findings underscore a critical point: Optic nerve vulnerability is likely driven by both elevated pressure and vascular perfusion instability. Recognizing and addressing the systemic contributors to impaired ocular perfusion may represent an opportunity to improve both visual outcomes and overall cardiovascular health. These findings suggest glaucoma management may benefit from a broader physiologic approach extending beyond IOP reduction alone.

Evolving Therapeutics

In accordance with the discussion on systemic health factors and their relationship with glaucoma, new information is being discovered regarding systemic therapeutics impacting optic nerve health and IOP. Topical pressure-lowering medications have long been the standard in glaucoma pharmacology and therapeutics. As the only treatment target identified that successfully slows disease progression, both medications and procedures used to treat glaucoma aim to reduce or control IOP. More recently,

observational and preliminary studies have demonstrated anti-inflammatory and neuroprotective effects of glucagon-like peptide 1 receptor agonists (GLP-1RAs), suggesting a potential therapeutic impact on optic nerve health and vision preservation.[34,35]

While these medications were initially intended to induce weight loss in diabetics, recent interest and widespread use has led to the discovery of other systemic effects. Because GLP-1 receptors are present throughout the gastrointestinal, cardiovascular, and central nervous systems, their anti-inflammatory effects manifest in a variety of ways.[36] Initial studies suggest that GLP-1RAs reduce IOP, protect retinal ganglion cells and reduce inflammation, with both animal and human findings indicating potential neuroprotective benefits in glaucoma.[35–38] Additionally, GLP-1RAs are believed to impact IOP more directly via interaction with cAMP-dependent and nitric oxide (NO) pathways leading to suppressed cerebrospinal fluid secretion and lowered intracranial pressure in rats.[39,40] It is possible that aqueous humor production is similarly impacted. Furthermore, GLP-1RA-mediated NO upregulation has been observed in the CNS and other organs of the body in animal studies.[41,42] Systemic upregulation of NO may improve trabecular meshwork outflow and even reduce retinal and episcleral vascular tone to cooperatively reduce IOP.

An antihypertensive medication class with increased relevance in glaucoma care is the oral calcium channel blocker (CCB). Interestingly, findings now suggest an IOP-independent mechanism that can actually aggravate vision loss, implicating deleterious structural impacts on the retina.[43,44] It was previously postulated that CCBs may be neuroprotective, however, the hypotensive effects of these medications might ultimately compromise blood flow to highly metabolic retinal cells.[45] Balancing this delicate relationship between systemic and ocular factors further speaks to the evolving medical nature of glaucoma care.

Finally, findings from early clinical trials investigating the effects of oral supplementation with nicotinamide and pyruvate are showing encouraging results. Increasing levels of these two molecules is thought to reduce early mitochondrial damage and metabolic deficits in retinal ganglion cells (RGC) that would otherwise lead to optic nerve degeneration. Nicotinamide raises NAD+ levels while pyruvate provides a glycolysis substrate, effectively rescuing stressed but viable RGCs, boosting metabolism and preventing neurodegeneration.[46,47] Participants in clinical trials have demonstrated improved visual field outcomes and inner retinal function.[48,49] Numerous clinical trials are currently being conducted to validate the efficacy and safety profile of nicotinamide and pyruvate for patients with glaucoma.[50]

Conclusion

Glaucoma management is increasingly shifting towards a more personalized and proactive, systemic medical approach that enables both patients and multidisciplinary care teams to play active roles. The traditional model of care where glaucoma was managed primarily by eye specialists alone is evolving. Historically, management has been largely reactive, often initiated after irreversible optic nerve damage and vision loss has occurred, with emphasis placed on responding to disease progression rather than anticipating it. Additionally, treatment strategies have primarily focused on IOP reduction, with less attention given to multiple systemic and genetic factors that may influence disease risk and progression.

Advances in ophthalmic technology and broader medical research have introduced new opportunities to enhance glaucoma diagnosis and care. PRS may

offer utility in screening and risk stratification, particularly when integrated with traditional risk factors. Similarly, remote monitoring technologies, including home tonometry and wearable visual field devices, enable the collection of longitudinal, real-world data that may better characterize disease dynamics and individual genetic, medical, and ophthalmic variability. Furthermore, increasing evidence supports the role of systemic comorbidities in glaucoma, underscoring the importance of comprehensive evaluation and management beyond the eye.

Collectively, these approaches support a shift towards earlier detection, more precise monitoring, and individualized treatment strategies. Future research is needed to validate these tools across diverse populations, establish standardized implementation protocols, and determine whether targeting systemic pathways can meaningfully alter glaucoma progression.

Conflict of Interest Statement

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