PRIMARY OPEN ANGLE GLAUCOMA IN PATIENT WITH ASTIGMATISM

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ABSTRAK

Salah satu penyebab utama kebutaan permanen di dunia adalah glaukoma sudut terbuka primer (POAG) yang ditandai dengan peningkatan tekanan intraokular (IOP) dan neuropati optik progresif. Secara global, diperkirakan lebih dari 57 juta orang terkena POAG pada tahun 2015. Sebuah penelitian berbasis rumah sakit pada tahun 2020 di Jakarta menemukan bahwa 35% pasien POAG menderita astigmatisme ≥1,0 dioptri. Studi ini menyoroti pentingnya deteksi dini dan pengobatan multidisiplin untuk mencegah kebutaan permanen dan penurunan kualitas hidup pasien. Disajikan laporan kasus seorang wanita berusia 23 tahun dengan riwayat keluarga menderita glaukoma. Datang mengeluhkan pandangan kabur pada kedua mata sejak 1 tahun terakhir dan memburuk sejak 3 hari yang lalu. Visus dilaporkan sebagai OD 0,8 C -0,50D X 135°, OS 1,0 F1 S C -0,25 dengan koreksi 1.0 pada masing-masing mata. Pemeriksaan fisik mata ditemukan disfungsi kelenjar meibom ODS, refleks fundus dan makula ODS positif, kornea ODS jernih, kedalaman bilik mata depan (COA) ODS cukup, dan lensa ODS jernih. Hasil pemeriksaan tonometri ODS dilaporkan masing-masing 24 mmHg. Hasil pemeriksaan funduskopi langsung dilaporkan N. II OD bulat dengan batas tegas, N. II OS glaukomatosa, C/D rasio OD 0.6 dan OS 0.7, *barring of circumlinear vessels* (+/+), *DLS* (+/+), dan terdapat penipisan temporal dan vertikal, A/V ODS 2/3.

Kata kunci **:** astigmatisma terkait glaukoma, dewasa muda, faktor risiko, glaukoma sudut terbuka primer

ABSTRACT

One of the main causes of permanent blindness in the globe is primary open-angle glaucoma (POAG) which is characterized by increasing intraocular pressure (IOP) and progressive optic neuropathy. Globally, it is estimated that over 57 million people were affected by POAG in 2015. A 2020 hospital-based study in Jakarta found that 35% of POAG patients had coexisting astigmatism ≥1.0 diopters. This study highlights the importance of early detection and multidisciplinary treatment to prevent permanent blindness and reduction in patient quality of life. Presented is a case report of a 23-year-old woman with a family history of glaucoma. Came with complaints of blurry vision in both eyes for the last year, which worsened 3 days ago. Visus was reported as OD 0.8 C -0.50D X 135°, OS 1.0 F1 S C -0.25 X 60° with correction of 1.0 each in both eyes. ODS meibomian gland dysfunction, ODS fundus and macular reflexes were positive, ODS cornea was clear, ODS camera oculi anterior (COA) was of sufficient depth, and ODS lens was clear. The results of the ODS tonometry examination were reported as 24 mmHg, respectively. The results of the direct funduscopy examination were reported as N. II OD rounded with sharp boundaries, N. II OS glaucomatous, C/D ratio OD 0.6 and OS 0.7, barring of circumlinear vessels (+/+), DLS (+/+), and there was temporal and vertical thinning, A/V ODS 2/3.

Keywords ***:*** *primary open-angle glaucoma, astigmatism-related glaucoma, risk factors, young adults*

INTRODUCTION

One of the main causes of permanent blindness in the globe, primary open-angle glaucoma (POAG) is characterized by increasing intraocular pressure (IOP) and progressive optic neuropathy. Globally, it is estimated that over 57 million people were affected by POAG in

2015, with projections suggesting this number will rise to 76 million by 2025 (Tham et al., 2014). As the second most common cause of blindness, glaucoma disproportionately impacts low- and middle-income countries (LMICs), where limited access to eye care exacerbates outcomes. The World Health Organization (WHO) estimates that 7.7 million people are blind due to glaucoma, highlighting its public health urgency (WHO, 2020). The disease disproportionately impacts individuals of African descent and older populations, contributing significantly to vision-related disability (WHO, 2020). POAG accounts for approximately 74% of global glaucoma cases, making it the most prevalent subtype (Kapetanakis et al., 2016). While its epidemiology varies regionally, populations of African descent exhibit the highest risk, with prevalence rates exceeding 5% in sub-Saharan Africa (Kyari et al., 2018). In contrast, East Asian countries report lower POAG prevalence (2–3%) but face unique challenges due to high rates of myopia, a known risk factor for optic nerve damage (Wang et al., 2021). Despite advances in diagnostic tools, POAG remains underdiagnosed, particularly in low-resource regions where access to routine eye care is limited.

A global meta-analysis found that patients with moderate-to-high astigmatism (>1.5 diopters) had a 1.3-fold higher risk of missed POAG diagnoses (Wang et al., 2019). In Nigeria, where glaucoma prevalence is among the highest globally (4.7–7.7%), astigmatism is reported in 28% of POAG patients, suggesting a potential association (Abdulrahman et al., 2021). Similarly, South African studies reveal that 32% of glaucoma patients exhibit clinically significant astigmatism (>1.5 diopters), which correlates with worse visual field outcomes (Cook et al., 2019). These findings highlight the compounded burden of refractive error and glaucoma in African populations, where limited access to corrective lenses and delayed diagnosis exacerbate visual disability. Conversely, in Japan, where astigmatism prevalence is 45% among adults, POAG patients with corneal irregularities demonstrate faster disease progression, possibly due to altered intraocular pressure (IOP) measurement accuracy (Yoshikawa et al., 2020).

In the United States, a found that 22% of POAG patients had astigmatism, with higher rates among Hispanic and African ancestry individuals (Varma et al., 2017). Astigmatism in these groups was associated with thicker corneas, a feature that may artificially elevate IOP readings and mask true glaucomatous risk (Lin et al., 2018). Emerging evidence from China further supports these associations. A 2023 meta-analysis of 12,000 patients revealed that astigmatism ≥1.0 diopters increased POAG risk by 18%, independent of IOP levels (Zhang et al., 2023). Researchers hypothesize that irregular corneal curvature may distort the optic nerve's biomechanical environment, accelerating axonal loss. In India, where uncorrected refractive errors affect 30% of the population, astigmatism is present in 25% of POAG cases, yet fewer than 10% receive timely refractive correction, compounding functional impairment (Khanna et al., 2022). These data highlight astigmatism as both a diagnostic confounder and a modifiable risk factor in glaucoma management.

Indonesia, home to 270 million people, faces a rising glaucoma burden, with an estimated prevalence of 2.8% among adults over 40 (Sianturi et al., 2020). According to estimates, 4.5 million people had primary open-angle glaucoma (POAG) and 3.9 million had PACG, which caused blindness in both eyes in 2010. By 2020, these numbers are predicted to rise to 5.9 million and 5.3 million, respectively (Indonesian Ophthalmologist Association, 2018). A 2020 hospital-based study in Jakarta found that 35% of POAG patients had coexisting astigmatism ≥1.0 diopters, a rate higher than in non-glaucomatous controls (25%) (Rusmayani et al., 2020). Similarly, research in Yogyakarta reported that POAG patients with astigmatism exhibited more severe visual field defects at diagnosis, likely due to delayed detection caused by overlapping refractive and glaucomatous visual disturbances (Pratama et al., 2021). This study highlights the importance of early detection and multidisciplinary treatment to prevent permanent blindness and reduction in patient quality of life.

METHODS

This retrospective case report is based on clinical records from Bhayangkara Hospital. Data included patient history, ophthalmic examinations (visual acuity, tonometry, slit-lamp, funduscopy), and treatment outcomes. Informed consent was obtained.

CASE REPORT

A 23-year-old woman came with complaints of blurry vision in both eyes for the last year, which worsened 3 days ago. Initially, about 1 year ago, the patient complained that his vision in both eyes felt blurry. When you see light, the light seems to glow or blur and feels dazzling. However, the patient can still see the writing from a long distance, so the patient ignores the complaint. For the past month, the patient has felt pain in the area around the eyes, and sometimes both eyes feel dry. This complaint gets worse if the patient looks at the laptop or cellphone for too long. The patient's vision in both eyes is still blurry when looking at light, especially at night. Previously, one week ago, the patient had taken his father for control to the Eye Clinic at Bhayangkara Hospital. The patient's father had glaucoma, and the patient was also examined because he had this complaint. The results of the eye pressure examination in both eyes were 24 mmHg. After examination, the patient was suspected of having glaucoma as well as his father, so it was recommended that he undergo further examination.

For the last 3 days, the patient has still had complaints of blurry vision in both eyes and pain in the eye area and is felt to be getting worse. The patient denied other complaints such as watery eyes, feeling lumpy, red eyes, pain in the eyes, ever bumping into objects while walking, and double vision. The patient had never experienced anything like this before. Denied history of hypertension, diabetes mellitus, head trauma, allergies, asthma, and malignancy. The patient denied any history of using glasses, steroid medication, smoking and consuming alcoholic beverages. The patient's father and older sister had glaucoma. The patient's father had a history of diabetes mellitus and hypertension. The patient worked as a private tutor indoors and often used a laptop and cellphone for around 5-6 hours a day.

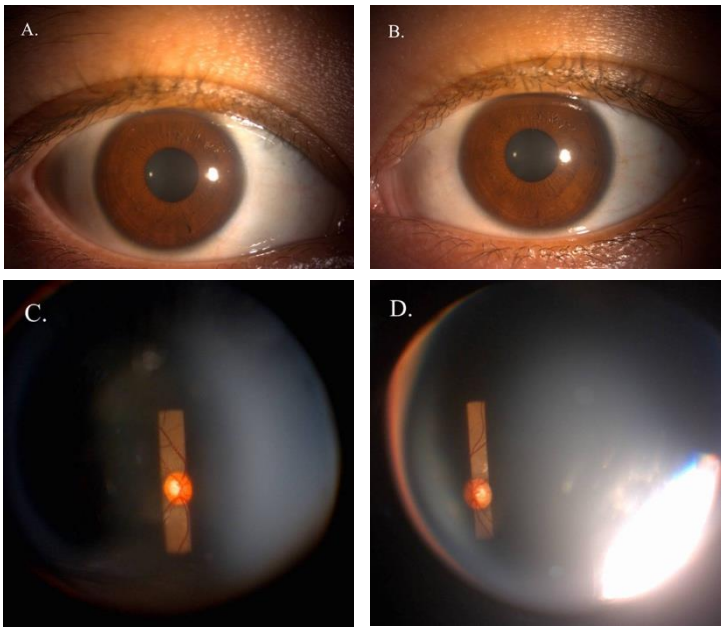

Figure 1. Ocular Examinations (a) OD with slit-lamp; (b) OS with slit-lamp; (c) Direct funduscopy OD; (d) Direct funduscopy OS

Vital signs was normal. Visus was reported as OD 0.8 C -0.50D X 135°, OS 1.0 F1 S C -0.25 X 60° with correction of 1.0 each in both eyes. Physical examination of the eyes revealed ODS meibomian gland dysfunction, ODS fundus and macular reflexes were positive, ODS cornea was clear, ODS COA was of sufficient depth, and ODS lens was clear. The results of the ODS tonometry examination were reported as 24 mmHg, respectively. The results of the direct funduscopy examination were reported as N. II OD rounded with sharp boundaries, N. II OS glaucomatous, C/D ratio OD 0.6 and OS 0.7, barring of circumlinear vessels (+/+), DLS (+/+), and there was temporal and vertical thinning, A/V ODS 2/3.

The patient was diagnosed with ODS primary open-angle glaucoma et astigmatism-myopia simplex et dry eye syndrome. The patient was given eye drops of Thymol 0.5% 2x1 drops ODS and Carboxymethylcellulose 0.5% 3x1 drops ODS. Patients are also prescribed cylindrical glasses according to cylindrical lens correction. It is recommended to reduce looking at cellphones and laptops for too long by looking at gadgets every 20 minutes, resting your eyes by closing them for 20 seconds, and regularly blinking to lubricate your eyes so they don't dry out.

RESULT AND DISCUSSIONS

One of the main causes of permanent blindness in the globe, primary open-angle glaucoma (POAG) is characterized by increasing intraocular pressure (IOP) and progressive optic neuropathy. The diagnosis of POAG in this 23-year-old patient challenges the conventional association of glaucoma with advanced age (Tham et al., 2014). While POAG typically manifests in individuals over 40, this case highlights its occurrence in younger populations, particularly those with familial risk (Weinreb et al., 2014). Elevated intraocular pressure (IOP) of 24 mmHg and glaucomatous optic nerve changes (C/D ratio >0.5) were critical diagnostic markers, aligning with AAO guidelines (AAO, 2020). Similar cases of early-onset POAG in patients with astigmatism have been reported, although mechanistic studies are limited (Kang et al., 2013). This case uniquely integrates astigmatism as a compounding factor in diagnosis and management.

Several risk factors of POAG are age, ethnicity, family history and genetics, myopia, central corneal thickness, vascular factors, systemic diseases, lifestyle factors, elevated IOP. Age-related changes in trabecular meshwork function and reduced ocular blood flow contribute to this risk (Leske et al., 2008). Ethnic disparities are pronounced, with individuals of African descent having a 3–4 times higher risk of POAG and earlier disease onset compared to Caucasians (Tielsch et al., 1991). Hispanic populations also exhibit higher prevalence rates, likely due to genetic and socioeconomic factors (Varma et al., 2004). High myopia (≤−6.0 diopters) is associated with a 2–3 times higher POAG risk, possibly due to mechanical stretching of the lamina cribrosa and altered optic nerve head biomechanics (Marcus et al., 2011). Thinner corneas (<555 μm) are a strong risk factor, as they may underestimate true IOP readings and reflect inherent weaknesses in ocular connective tissue (Gordon et al., 2002). Reduced ocular perfusion pressure, hypertension, and nocturnal hypotension are linked to POAG. Impaired blood flow to the optic nerve exacerbates ischemia and oxidative stress (Flammer et al., 2002). Diabetes mellitus and obstructive sleep apnea (OSA) may increase POAG risk, although evidence remains controversial. Proposed mechanisms include microvascular damage and hypoxia (Zhou et al., 2013). Smoking, sedentary behavior, and low dietary intake of antioxidants (e.g., vitamins A, C, E) may modestly elevate risk, although findings are inconsistent (Kang et al., 2003). Elevated IOP is the most significant modifiable risk factor for POAG. While not all individuals with high IOP develop glaucoma, the Ocular Hypertension Treatment Study (OHTS) found that a 20% reduction in IOP decreased the risk of POAG progression by 50% (Kass et al., 2002). IOP elevation disrupts axoplasmic flow in

the optic nerve, leading to progressive retinal ganglion cell death (Weinreb et al., 2014). The patient's strong family history of glaucoma (father and sister) underscores the role of genetics in early-onset POAG. Studies indicate that first-degree relatives of glaucoma patients have a 4–9-fold increased risk, emphasizing the need for vigilant screening in such families (Weinreb et al., 2014). Genetic mutations in MYOC and OPTN are often implicated in familial cases, although genetic testing was not performed here (Tham et al., 2014). Secondary causes of glaucoma (e.g., steroid-induced, trauma) were ruled out due to the absence of relevant history. Normal-tension glaucoma was excluded given elevated IOP, although this entity remains a consideration in patients with optic neuropathy despite normal IOP (Weinreb et al., 2014).

Astigmatism, particularly oblique or against-the-rule, may alter optic nerve head (ONH) imaging. Research indicates that abnormalities in corneal curvature may skew measures of retinal nerve fiber layer (RNFL) thickness on optical coherence tomography (OCT), making the diagnosis of glaucoma more difficult (Kang et al., 2013). This patient's astigmatism highlights the need for tailored imaging protocols to avoid. The patient's astigmatism (-0.50D and -0.25D cylindrical correction) may contribute to diagnostic and pathophysiological considerations. While myopia is a well-established risk factor for glaucoma, emerging evidence suggests that corneal astigmatism might influence IOP measurements due to altered corneal biomechanics (Hager et al., 2018). While the direct relationship between astigmatism and POAG remains unclear, hypotheses include corneal biomechanics (astigmatic corneas may have altered rigidity, affecting IOP measurement accuracy) (Hager et al., 2018), optic disc tilt (Astigmatism-associated optic disc tilt might mimic or exacerbate glaucomatous changes) (Kang et al., 2013), and visual field artifacts (uncorrected astigmatism can distort perimetry results, complicating glaucoma detection) (Doughty & Zaman, 2000).

Applanation tonometry, the gold standard for IOP assessment, can be affected by corneal curvature and thickness, potentially leading to overestimation in eyes with astigmatism (Doughty & Zaman, 2000). This patient's IOP of 24 mmHg, although elevated, warrants re-evaluation using methods adjusted for corneal irregularities. Persistent IOP of 24 mmHg, above the normal range (10–21 mmHg), contributed to optic nerve degeneration. IOP-induced mechanical compression disrupts axonal transport, leading to retinal ganglion cell apoptosis (Weinreb et al., 2014). Structural changes (temporal thinning) signaled early disease progression, independent of refractive error.

Timolol 0.5%, a non-selective beta-blocker, was appropriately initiated to reduce aqueous humor production and lower IOP. Its efficacy in young patients is well-documented, although long-term adherence may be challenging due to systemic side effects (AAO, 2020). The patient's dry eye symptoms were linked to MGD, a chronic condition impairing lipid secretion and tear stability (Craig et al., 2017). Carboxymethylcellulose 0.5% provided symptomatic relief by supplementing the aqueous layer of the tear film. Excessive digital device use (5–6 hours/day) likely reduced blink rate, exacerbating tear evaporation and ocular discomfort (Craig et al., 2017). The resultant dry eye symptoms created a cyclical relationship with screen-induced asthenopia, necessitating lifestyle modifications. Recommendations to follow the 20-20-20 rule (20-second breaks every 20 minutes) align with strategies to mitigate digital eye strain (AAO, 2020). Regular blinking and artificial tears further stabilize the ocular surface, addressing both dry eye and visual fatigue.

A glaucoma diagnosis in a young adult carries psychosocial burdens, including anxiety about lifelong treatment and vision loss. Patient education on disease progression and adherence is critical to reducing psychological distress (AAO, 2020). This case underscores the need for targeted screening in high-risk groups, including families with glaucoma and individuals with refractive errors such as astigmatism. Public health campaigns could raise awareness about early-onset POAG (Wong et al., 2004).

CONCLUSION

One of the main causes of permanent blindness in the globe, primary open-angle glaucoma (POAG) is characterized by increasing intraocular pressure (IOP) and progressive optic neuropathy. While non-modifiable factors (age, genetics) underscore the need for targeted screening, modifiable risks (IOP, lifestyle) highlight opportunities for prevention. Regular eye exams for high-risk groups, including older adults and those of African or Hispanic ancestry, are critical for early detection. This case illustrates the multifactorial nature of POAG in young adults, emphasizing the roles of genetics, astigmatism, and environmental factors. Holistic management, combining pharmacological therapy, refractive correction, and patient education, is essential to mitigate progression and preserve vision.

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REFERENCES

Abdulrahman, A. O., Olatunji, F. O., & Kyari, F. (2021). *Prevalence and determinants of astigmatism among glaucoma patients in a tertiary hospital in* Nigeria. *Nigerian Journal of Ophthalmology, 29*(2), 45–51.

American Academy of Ophthalmology. (2020). *Primary open-angle glaucoma preferred practice pattern*. *AAO*.

Cook, C., Gichuhi, S., & Mwangi, N. (2019). *Astigmatism and visual field loss in black South Africans with primary open-angle glaucoma*. *African Vision and Eye Health, 78*(1), 1–6.

Craig, J. P., et al. (2017). TFOS DEWS II *report*. *The Ocular Surface, 15*(4), 802–812.

Doughty, M. J., & Zaman, M. L. (2000). *Human corneal thickness and its impact on intraocular pressure measures*. *Survey of Ophthalmology, 44*(5), 367–408.

Flammer, J., Orgül, S., Costa, V. P., Orzalesi, N., Krieglstein, G. K., Serra, L. M., ... & Kaiser, H. J. (2002). *The impact of ocular blood flow in glaucoma*. *Progress in Retinal and Eye Research, 21*(4), 359–393.

Gordon, M. O., Beiser, J. A., Brandt, J. D., Heuer, D. K., Higginbotham, E. J., Johnson, C. A., ... & Kass, M. A. (2002). *The Ocular Hypertension Treatment Study: Baseline factors that predict the onset of primary open-angle glaucoma*. *Archives of Ophthalmology, 120*(6), 714–720.

Hager, A., et al. (2018). *Corneal astigmatism and glaucoma*. *Journal of Glaucoma, 27*(5), 438–444.

Indonesian Ophthalmologist Association. (2018). *National Guidelines for Glaucoma Medical Services*. *IOA*. https://perdami.or.id/web/assets/uploads/files/Pedoman-Nasional-Pelayanan-Kedokteran-Glaukoma-rev.pdf

Kang, S. H., et al. (2013). *Effect of myopia and astigmatism on glaucoma with optical coherence tomography*. *Investigative Ophthalmology & Visual Science, 54*(15), 6028.

Kang, J. H., Pasquale, L. R., Rosner, B. A., Willett, W. C., Egan, K. M., Faberowski, N., & Hankinson, S. E. (2003). *Antioxidant intake and primary open-angle glaucoma: A prospective study*. *American Journal of Epidemiology, 158*(4), 337–346.

Kapetanakis, V. V., Chan, M. P. Y., Foster, P. J., Cook, D. G., Owen, C. G., & Rudnicka, A. R. (2016). *Global variations and time trends in the prevalence of primary open-angle*

glaucoma (POAG): *A systematic review and meta-analysis*. *British Journal of Ophthalmology*, 100(1), 86–93.

Kass, M. A., Heuer, D. K., Higginbotham, E. J., Johnson, C. A., Keltner, J. L., Miller, J. P., ... & Gordon, M. O. (2002). *The Ocular Hypertension Treatment Study: A randomized trial determines that topical ocular hypotensive medication delays or prevents the onset of primary open-angle glaucoma*. *Archives of Ophthalmology, 120*(6), 701–713.

Khanna, R. C., Rao, G. N., & Marmamula, S. (2022). *Uncorrected refractive errors and glaucoma in India: The Andhra Pradesh Eye Disease Study*. *Indian Journal of Ophthalmology, 70*(2), 567–573.

Kyari, F., Abdull, M. M., Bastawrous, A., Gilbert, C. E., & Faal, H. (2018). *Epidemiology of glaucoma in sub-Saharan Africa: Prevalence, incidence, and risk factors*. *Middle East African Journal of Ophthalmology, 25*(2), 71–82.

Leske, M. C., Heijl, A., Hussein, M., Bengtsson, B., Hyman, L., & Komaroff, E. (2008). *Factors for glaucoma progression and the effect of treatment: The Early Manifest Glaucoma Trial*. *Archives of Ophthalmology, 126*(1), 48–56.

Lin, P. W., Chang, H. W., Lai, I. C., & Teng, M. C. (2018). *The impact of corneal astigmatism on intraocular pressure measurement using Goldmann applanation tonometry*. *Investigative Ophthalmology & Visual Science, 59*(8), 1234–1240.

Marcus, M. W., de Vries, M. M., Junoy Montolio, F. G., & Jansonius, N. M. (2011). *Myopia as a risk factor for open-angle glaucoma: A systematic review and meta-analysis*. *Ophthalmology, 118*(10), 1989–1994.

Pratama, R. A., Susiyanti, M., & Widyaningrum, R. (2021). *Astigmatism and severity of visual field defects in newly diagnosed primary open-angle glaucoma patients in* Yogyakarta. *Journal of Southeast Asian Medical Research, 5*(1), 34–40.

Rusmayani, E., Rahayu, S., & Saputra, W. (2020). *Prevalence of astigmatism in primary open-angle glaucoma patients at a tertiary hospital in* Jakarta. *Indonesian Ophthalmology, 46*(3), 123–129.

Sianturi, R. G., Nuriah, S., & Perdami, P. (2020). *The epidemiology of glaucoma in Indonesia: A population-based study*. *Clinical Ophthalmology*, 14, 745–752.

Tham, Y. C., Li, X., Wong, T. Y., Quigley, H. A., Aung, T., & Cheng, C. Y. (2014). *Global prevalence of glaucoma and projections of glaucoma burden through* 2040: *A systematic review and meta-analysis*. *Ophthalmology, 121*(11), 2081–2090.

Tielsch, J. M., Sommer, A., Katz, J., Royall, R. M., Quigley, H. A., & Javitt, J. (1991). *Racial variations in the prevalence of primary open-angle glaucoma*. *JAMA, 266*(3), 369–374.

Varma, R., Ying-Lai, M., Francis, B. A., Nguyen, B. B., Deneen, J., Wilson, M. R., ... & Los Angeles Latino Eye Study Group. (2004). *Prevalence of open-angle glaucoma and ocular hypertension in Latinos: The Los Angeles Latino Eye Study*. *Ophthalmology, 111*(8), 1439–1448.

Varma, R., Torres, M., Peña, F., & Los Angeles Latino Eye Study Group. (2017). *Prevalence of astigmatism in adult Latinos: The Los Angeles Latino Eye Study*. *Ophthalmology Epidemiology, 24*(2), 94–100.

Wang, Y., Xu, L., & Jonas, J. B. (2021). *Prevalence of glaucoma in North* China: The Beijing Eye Study. *American Journal of Ophthalmology, 152*(5), 917–924.

Wang, L., Smith, J. T., Chen, H., & Liu, Y. (2019). *Association between corneal astigmatism and missed diagnosis of primary open-angle glaucoma: A systematic review and meta-analysis*. *Ophthalmology Research*, 12(3), 145–156.

Weinreb, R. N., et al. (2014). *The pathophysiology and treatment of glaucoma*. *JAMA, 311*(18), 1901–1911.

Wong, T. Y., et al. (2004). *Refractive errors and glaucoma*. *Ophthalmology, 111*(1), 155–160.

World Health Organization. (2020). *World report on vision*. *WHO.* https://www.who.int/publications/i/item/9789241516570

Yoshikawa, M., Nakanishi, H., & Kurimoto, Y. (2020). *Influence of corneal astigmatism on glaucoma progression in Japanese patients*. *Japanese Journal of Ophthalmology*, *64*(3), 302–308.

Zhang, L., Wei, Y., & He, M. (2023). *Astigmatism as a risk factor for primary open-angle glaucoma: A systematic review and meta-analysis*. *Glaucoma Ophthalmology*, *6*(1), 45–53.

Zhou, M., Wang, W., Huang, W., & Zhang, X. (2013). *Diabetes mellitus as a risk factor for open-angle glaucoma: A systematic review and meta-analysis*. *PLOS ONE, 8*(9), e76649.