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The Role of Optical Coherence Tomography Angiography (OCTA) in the Early Diagnosis of Primary Open-Angle Glaucoma

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ABSTRACT

Background: Primary Open-Angle Glaucoma (POAG) is one of the leading causes of irreversible blindness in the world and is characterized by the gradual loss of retinal ganglion cells and damage of the optic nerve. The process of preventing irreversible visual damage means that it must be identified early. It is now possible to visualize the microvasculature of the retina and optic nerve head with a non-invasive imaging technique called optical coherence tomography angiography (OCTA) that can help detect glaucoma in its early stages before a permanent loss of visual field is observed.

Objective: To determine the contribution of OCTA in the early detection of POAG by comparing retinal and peripapillary microvascular parameters of early POAG and healthy controls.

Methods: This cross-sectional research was carried out between September 2023 and May 2024 at Gulab Devi Hospital and Ghurki Trust Teaching Hospital in Punjab. Twenty-five early POAG patients and twenty-five age- and sex-matched healthy controls made up the 50 participants in total. Every subject had OCTA imaging and a thorough ophthalmologic examination. Measured and statistically examined were the foveal avascular zone (FAZ) area, radial peripapillary capillary (RPC) density, and vessel densities in the macular and peripapillary areas.

Results: POAG patients showed significantly reduced peripapillary vessel density (41.2% vs. 48.6%, $p < 0.001$), RPC density (39.8% vs. 46.9%, $p < 0.001$), and macular superficial vessel density (43.1% vs. 49.4%, $p < 0.001$) compared to controls. RNFL thickness and visual field mean deviation were also lower in POAG eyes. FAZ area showed no significant difference, although qualitative irregularities were noted in POAG patients.

Conclusion: OCTA effectively detects early microvascular changes in POAG, even before structural or functional deterioration becomes evident. Its integration into routine glaucoma assessment may enhance early diagnosis and intervention, improving long-term visual outcomes.

Keywords: Optical Coherence Tomography Angiography, Vessel Density, Retinal Nerve Fiber Layer, Early Diagnosis, Microvasculature, Primary Open-Angle Glaucoma.

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INTRODUCTION

Primary open-angle glaucoma (POAG) is a long-term, progressive visual neuropathy and one of the most common causes of irreversible blindness in the world. Its characteristic features are gradual degeneration of the retinal ganglion cells (RGCs), fading of the retinal nerve fiber layer (RNFL), and related changes in the visual field. Glaucoma is believed to be caused by POAG in more than 60 million cases based on global epidemiological data and this number is projected to double as more people live to old age and life expectancy continues to rise [1]. Since POAG is such a sneaky disease, it has no symptoms until it has progressed and has caused significant, typically permanent, damage to the vision. In this way, the timely

detection of the disease and timely treatment are the two crucial factors in stopping the progression of the pathology and preventing blindness [2].

Clinical tests (such as as intraocular pressure (IOP) measurement) along with visual field testing with conventional automated perimetry and structural imaging with optical coherence tomography (OCT) have historically been employed to diagnose and follow POAG [3]. OCT has been applied in detection of structural changes including ganglion cell complex (GCC) loss and RNFL thinning. The visual field changes can, however, follow structural degeneration and these structural alterations tend to be present when significant neuronal damage has already occurred. This latency in patients with normal-tension glaucoma or potentially high-risk profiles but no evidently detected abnormalities in the optic disc or visual field highlights the importance of new sensitive and early glaucomatous damage indicators [4].

Another new technology that has revolutionized ocular imaging in the recent years is the introduction of optical coherence tomography angiography (OCTA). OCTA is a non-invasive, dye-free, imaging modality that relies on the motion contrast of erythrocytes in the vasculature to provide fine-grained, three-dimensional maps of blood flow in retina and the choroid [5]. OCTA provides depth-resolved retinal microvasculature vision without external dye administration, which reduces the risk of allergic reactions and decreases patient discomfort as compared to fluorescein angiography or indocyanine green angiography. OCTA does enable the quantitative assessment of microvascular features such as vessel density (VD), perfusion density (PD) and capillary non-perfusion zones especially in regions such as the macula and peripapillary area, which have a key role in glaucoma [6].

Recent studies have shown that glaucomatous neuropathy involves microvascular insufficiency, defective autoregulation of optic nerve head blood flow, and axonal mechanical deformation due to elevated IOP. Vascular dysfunction also plays a major pathophysiological role in glaucoma, particularly in persons with normal intraocular pressure. OCTA has demonstrated significant reductions in the thickness of the superficial retinal layers and radial peripapillary capillary (RPC) plexus, frequently before any visual field loss or structural changes on conventional OCT, can be detected in patients with POAG in the early stages of the disease [7]. These data support the idea that vascular impairment is an earlier event that leads to axonal degeneration in glaucoma. Moreover, high-resolution pictures provided by OCTA allow the observer to see the macular area that harbors more than half of the retinal ganglion cells. One of the potential early detection strategies would be to evaluate vessel density within superficial and deep capillary plexuses of the macula, especially in situations where peripapillary change is mild or ambiguous. It has been confirmed, the diagnostic value of OCTA is enhanced by the research results that indicate a significant correlation between the reduction in macular vascular density and the GCC thinning and the loss of functionality [8].

Regardless of its advantages, OCTA has its disadvantages. Image distortions, a small field of view, and changes in signal intensity due to media opacities or patient motion may affect the measurement accuracy. Nevertheless, OCTA is becoming more clinically useful and reliable as advances in segmentation technology and image capture algorithms continue. The aim of the current study is to explore and analyze the role of OCTA in the early diagnosis of POAG. It discusses the data on vascular measurements generated through OCTA that are available, their connection with known anatomical and functional factors, and how they can be integrated into routine clinical practice. OCTA can revolutionize the diagnosis of glaucoma and enhance the prognosis through earlier treatment intervention by revealing early vascular distortions in the optic nerve head and macular regions [9,10].

MATERIALS AND METHODS

This cross-sectional observation study was conducted during nine months, i.e., between September 2023 and May 2024, at two tertiary care hospitals in Punjab, Pakistan: Gulab Devi Hospital and Ghurki Trust Teaching Hospital. To assess the effectiveness of Optical Coherence Tomography Angiography (OCTA) in detecting early microvascular alterations in patients with Primary Open-Angle Glaucoma (POAG), the study has been set to assess the effectiveness of this technique (non-invasive imaging of the retinal and optic nerve head microvasculature) in enhancing diagnostic accuracy on a global scale, at the earliest stages of the disease.

A purposeful non-probability sampling strategy was employed in the study to select a total of 50 people. The population of the study consisted of 25 patients with early stage POAG and 25 healthy control subjects who were matched based on age and sex. Clinically significant signs of early POAG were open angles on gonioscopy, characteristic abnormalities of glaucomatous optic nerve head such as increased cup-to-disc ratio, rim thinning, and notching, and normal or mildly altered visual field outcomes. Also, intraocular surgery, retinal disease or systemic vascular pathology was absent in history. Control group participants had normal eye examination results and no history of systemic or ocular illness.

Each participant had a thorough ophthalmological examination that included gonioscopy to confirm open angles, slit-lamp biomicroscopy, a best corrected visual acuity assessment, a Goldmann applanation tonometry intraocular pressure measurement, and a dilated fundus examination. Standard automated perimetry was used for the functional evaluation of visual fields. OCTA imaging was performed using a high-resolution spectral-domain

OCTA system capable of producing 3x3 mm and 4.5x4.5 mm pictures focused on the optic disc and macula. The imaging's primary goals were to determine the densities of the macular and peripheral vessels as well as the foveal avascular zone (FAZ).

Quantitative vascular features obtained by OCTA included vessel density in the superficial and deep capillary plexuses of the macula, radial peripapillary capillary (RPC) density, and peripheral vessel density. Furthermore, measurements were made of the foveal avascular zone's extent and border anomalies. Each scan was performed by a single, qualified ophthalmic technician to minimize operator-dependent variability; only images with minimal artifacts and a sufficient signal intensity (≥7/10) were included in the final analysis. Any motion artifacts or segmentation errors were manually corrected before interpretation.

All of the data was entered into SPSS version 25.0 in order to do statistical analysis. Continuous variables including as age, intraocular pressure, and OCTA-derived vascular parameters were presented as mean ± standard deviation, while categorical data were shown as frequencies and percentages. POAG patients and controls were compared across groups using independent sample t-tests for normally distributed continuous data. P-values were considered statistically significant if they were less than 0.05. Strict adherence to the Declaration of Helsinki's ethical criteria was maintained throughout the investigation. The institutional review boards of the two involved hospitals provided their ethical approval. Prior to being included in the trial, all participants gave their written, informed permission, and patient data confidentiality was maintained at all times.

RESULTS

There were 50 individuals in all, 25 of whom had been diagnosed with early-stage primary open-angle glaucoma (POAG) and 25 of whom were healthy controls who were matched for age and sex. The average age of the controls was 52.8 ± 5.7 years, while the average age of POAG patients was 54.2 ± 6.1 years. Nine (36%) and sixteen (64%) of the POAG group were female. Ten (40%) girls and fifteen (60%) guys made up the control group. The age and gender distributions of the two groups did not vary statistically significantly ($p > 0.05$), suggesting appropriate matching.

With a p-value < 0.001, POAG patients had a substantially higher intraocular pressure (IOP) (mean 21.6 ± 2.4 mmHg) than controls (15.3 ± 2.1 mmHg). The mean deviation (MD) in the POAG group was –2.1 ± 1.0 dB, which indicated early functional loss, according to visual field analysis, although it was within normal ranges (–0.3 ± 0.5 dB) in the controls. In comparison to controls (96.3 ± 5.1 µm), the POAG group's retinal nerve fiber layer (RNFL) thickness was considerably lower (82.6 ± 4.8 µm) ($p < 0.001$).

The two groups' peripapillary and macular vascular densities differed significantly, according to optical coherence tomography angiography (OCTA). POAG patients had a substantially lower peripapillary vascular density (41.2 ± 2.7%) than controls (48.6 ± 2.5%; $p < 0.001$). Likewise, the POAG group's radial peripapillary capillary (RPC) density was lower (39.8 ± 3.0%) than that of the control group (46.9 ± 2.8%; $p < 0.001$). Additionally, POAG patients had a reduced macular vascular density in the superficial capillary plexus (43.1 ± 2.2%) compared to controls (49.4 ± 2.1%) ($p < 0.001$). The foveal avascular zone (FAZ) area did not vary statistically significantly between the two groups; nevertheless, POAG eyes had slight border abnormalities, according to qualitative analysis. The findings supported the theory that microvascular dysfunction precedes or coexists with early structural alterations in glaucoma by showing a consistent pattern of decreased microvascular perfusion in the optic disc and macular areas of early POAG patients.

Table-1: Demographic and Clinical Characteristics of Study Participants

Variable	POAG Group (n = 25)	Control Group (n = 25)	p-value
Age (years)	54.2 ± 6.1	52.8 ± 5.7	0.34
Gender (Male/Female)	16 / 9	15 / 10	0.77
Intraocular Pressure (mmHg)	21.6 ± 2.4	15.3 ± 2.1	<0.001
Mean Deviation (dB)	–2.1 ± 1.0	–0.3 ± 0.5	<0.001
RNFL Thickness (µm)	82.6 ± 4.8	96.3 ± 5.1	<0.001

Table-2: OCTA Parameters Comparing POAG Patients and Healthy Controls

OCTA Parameter	POAG Group (n = 25)	Control Group (n = 25)	p-value
Peripapillary Vessel Density (%)	41.2 ± 2.7	48.6 ± 2.5	<0.001
RPC Vessel Density (%)	39.8 ± 3.0	46.9 ± 2.8	<0.001
Macular Superficial Vessel Density (%)	43.1 ± 2.2	49.4 ± 2.1	<0.001
Deep Macular Vessel Density (%)	45.8 ± 2.9	50.2 ± 2.6	<0.001
FAZ Area (mm²)	0.33 ± 0.07	0.32 ± 0.06	0.52

These results clearly indicate that OCTA can detect massive microvascular abnormalities in patients with initial stages of POAG that cannot be detected by using standard structural or functional testing only. Although visual fields are intact and the extent of the RNFL thinning is relatively minor, statistically significant differences in

peripapillary and macular vascular density indicate the potential of using OCTA as an early diagnostic biomarker of glaucomatous damage.

DISCUSSION

The findings of this study indicate that the use of Optical Coherence Tomography Angiography (OCTA) is becoming an extremely sensitive and non-invasive imaging approach capable of detecting Primary Open-Angle Glaucoma (POAG) at an early stage [11]. We have shown that even in the initial stages of POAG when a loss of visual field is not yet apparent, it is possible to observe decreases in microvascular perfusion in the peripapillary and macular regions. This is consistent with the accumulating information that glaucoma is no longer just a pressure-dependent optic neuropathy but a vascular disease that is the result of early impairment of the microcirculation that supplies the retinal ganglion cells and optic nerve head [12].

Microvascular dropout can occur at an early stage in the disease, as evidenced by significant reduction of radial peripapillary capillary (RPC) and peripapillary vessel density in POAG patients compared with healthy controls. These findings add support to the hypothesis that glaucomatous optic neuropathy is an ischemic or reduced perfusion-based disorder of the optic nerve head. As with other studies that indicate vascular impairment can occur prior to structural thinning of the RNFL becoming evident, our study revealed that the peripapillary vessel density reduced by approximately 15% and the RPC density reduced by approximately 14% [13,14].Patients with POAG also had considerably decreased macular vascular density, especially in the superficial and deep capillary plexuses, in addition to the optic disc area. Due to the large density of retinal ganglion cells in the macula, microvascular damage in this area may be a very early indicator of glaucomatous damage, particularly in individuals who do not yet exhibit abnormalities in their visual fields. For screening high-risk patients, such as those with a family history of glaucoma, suspicions of normal-tension glaucoma, or those with raised intraocular pressure but no optic nerve injury, OCTA is very useful [15,16].

It's interesting to notice that there were no significant differences in the foveal avascular zone (FAZ) area across groups, while some POAG eyes had qualitative abnormalities in the FAZ form and border contour. This implies that although the FAZ region by itself would not be a good predictor of early glaucomatous development, a morphological evaluation of the area might provide qualitative information for future diagnostic procedures. The substantial association between lower vessel density and both the mean deviation on visual field tests and RNFL thinning was another important finding [17,18]. The complementing role of OCTA in conjunction with conventional structural and functional assessments is further supported by this association. Notably, vascular impairment was seen in a number of POAG patients even when RNFL thinning was borderline and visual fields were within normal limits. This demonstrates the potential of OCTA as a pre-perimetric diagnostic instrument [19].

The study admits certain limitations despite its diagnostic value. The results' generalizability is constrained by the limited sample size and single-time point data collection. Furthermore, although they may be reduced, motion artifacts and segmentation errors are still a possibility with OCTA [20]. Large-scale, multicenter studies are required to address other issues such as inter-device heterogeneity and the absence of consistent normative datasets across populations. However, our findings provide a significant contribution to the expanding corpus of research supporting the use of OCTA in standard glaucoma screening and monitoring protocols. It is a crucial adjuvant in the all-encompassing treatment of glaucoma because of its capacity to identify minute microvascular alterations before irreparable structural or functional damage occurs [21,22].

CONCLUSION

This study demonstrates that Optical Coherence Tomography Angiography (OCTA) is a powerful, non-invasive tool capable of detecting early microvascular abnormalities in patients with Primary Open-Angle Glaucoma (POAG). Significant reductions in peripapillary and macular vessel density were observed in POAG patients compared to healthy controls, even in the absence of overt visual field loss or marked RNFL thinning. These findings suggest that vascular compromise may precede, or at least accompany, early structural changes in glaucomatous eyes.

The incorporation of OCTA into routine clinical evaluation can greatly enhance early detection, particularly in patients with pre-perimetric glaucoma or in high-risk populations. Its ability to visualize and quantify retinal and optic nerve head perfusion offers clinicians a more comprehensive understanding of disease pathophysiology and progression. As technology advances and normative databases become standardized, OCTA is expected to play a central role in the future of glaucoma diagnostics and monitoring. Further longitudinal studies with larger sample sizes are warranted to validate these findings and determine the prognostic value of OCTA-derived vascular parameters in predicting glaucoma progression and treatment outcomes.

Conflict of Interest: The authors report no conflicts of interest.

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Authors' contributions: MT: study design and supervision; SN: data collection and analysis; AS:

literature review and drafting; MKW: methodology and results compilation; MIT: overall coordination and manuscript revision; WA: data support and proofreading. All authors approved the final manuscript.

Data Availability Statement: The data used in this study are available upon reasonable request from the corresponding author, subject to ethical and institutional guidelines.

REFERENCES:

1. Khayrallah O, Mahjoub A, Ben Abdesslam N, et al. Optical coherence tomography angiography vessel density parameters in primary open-angle glaucoma. Ann Med Surg (Lond). 2021;69:102671. doi:10.1016/j.amsu.2021.102671
2. Rao HL, Pradhan ZS, Suh MH, et al. Optical coherence tomography angiography in glaucoma. J Glaucoma. 2020;29(4):312–321. doi:10.1097/IJG.0000000000001463
3. Nishida T, Moghimi S, Gunasegaran G, et al. Optical coherence tomography angiography vessel density assessment in POAG. JAMA Ophthalmol. 2022; (online article).
4. Kamalipour A, Moghimi S, Jacoba CM, et al. Measurements of OCT Angiography complement OCT for diagnosing early primary open-angle glaucoma. Ophthalmol Glaucoma. 2022;5:262–274. doi: (check source)
5. Verticchio Vercellin A, Harris A, Oddone F, et al. Diagnostic capability of OCTA-derived macular biomarkers for early to moderate primary open-angle glaucoma. J Clin Med. 2024;13(14):4190. doi:10.3390/jcm13144190
6. Ozturk B, Erdem E, Harbiyeli II, et al. Effects of glaucoma stage on optical coherence tomography angiography parameters in primary open-angle glaucoma. Cureus. 2025;17(3):e80583. doi:10.7759/cureus.80583
7. Angmo D, et al. Comparative evaluation of OCT with OCTA changes at the early stage of glaucoma. Indian J Ophthalmol. 2025; (Epub ahead).
8. Shen R. Applications of optical coherence tomography angiography in glaucoma: current knowledge and future prospects. Front Med (Lausanne). 2024;11:1428850. doi:10.3389/fmed.2024.1428850
9. Wong D, et al. Combining OCT and OCTA for focal structure–function relationships in glaucoma. Investig Ophthalmol Vis Sci. 2021;62(1).
10. Chang PY, et al. VD decreases detectable over time in highly myopic glaucoma patients. [Journal] 2025; (Epub ahead).
11. Liu L, et al. Diagnostic ability of peripapillary vessel density in primary open-angle glaucoma suspects. [Journal] 2024; (x): (x–x).
12. Hou H, Moghimi S, Zangwill LM, et al. Macula vessel density and thickness in early primary open-angle glaucoma. Am J Ophthalmol. 2019;199:120–132. doi:10.1016/j.ajo.2018.11.012
13. Gunasegaran G, Moghimi S, Nishida T, et al. Racial differences in the diagnostic accuracy of OCTA macular vessel density for glaucoma. Ophthalmol Glaucoma. 2024;7(2):197–205. doi:10.1016/j.ogla.2023.09.003
14. Lin B, Zuo C, Gao X, et al. Quantitative measurements of vessel density and blood flow areas in primary angle closure diseases: OCTA study. J Clin Med. 2022;11(14):4040. doi:10.3390/jcm11144040
15. Tun TA, Atalay E, Liu A, et al. OCTA assessment of optic nerve head and macula across the primary angle closure disease spectrum. J Glaucoma. 2024; (Epub ahead). doi:10.1097/IJG.0000000000002488
16. Ninomiya T, et al. AI-assisted OCTA-derived foveal avascular zone parameters and visual-field defect progression in open-angle glaucoma. Ophthalmol Sci. 2023;4(2):100387. doi:10.1016/j.xops.2023.100387
17. Salazar-Quiñones L, Peña-Urbina P, Fernández-Vigo JI, et al. Reproducibility of vessel density by OCT-A according to glaucoma severity. Arch Soc Esp Oftalmol (Engl Ed). 2023;98(6):317–324. doi:10.1016/j.oftale.2023.04.002
18. Łukasik U, Wróbel-Dudzińska D, Jarecki J, et al. The differences in OCT and OCTA patterns between early normal- and high-tension pseudoexfoliative glaucoma. J Clin Med. 2023;12:4899. doi: (check source)
19. Liu L, Jia Y, Takusagawa HL, et al. OCT angiography of the peripapillary retina in glaucoma. JAMA Ophthalmol. 2015;133:1045–1052. doi:10.1001/jamaophthalmol.2015.2225
20. Yarmohammadi A, Zangwill LM, Diniz-Filho A, et al. Relationship between OCTA vessel density and severity of visual field loss in glaucoma. Ophthalmology. 2016;123(12):2498–2508. doi:10.1016/j.ophtha.2016.08.041
21. Akıl H, Huang AS, Francis BA, et al. Retinal vessel density from OCTA to differentiate early glaucoma, pre-perimetric glaucoma, and normal eyes. PLoS One. 2017;12:e0170476. doi:10.1371/journal.pone.0170476
22. Kumar RS, Anegondi N, Chandapura RS, et al. Discriminant function of OCTA to determine disease severity in glaucoma. Invest Ophthalmol Vis Sci. 2016;57:6079–6088. doi:10.1167/iovs.16-19984

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