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Evaluation of Ophthalmic Artery by Color Doppler Ultrasound in Patients with Primary Glaucoma

[1]Dr Lovely Kaushal, Professor and HOD, Department of Radiodiagnosis, Gandhi Medical College, Bhopal, Madhya Pradesh, India

[2]Dr Swati Goyal, Associate Professor, Department of Radiodiagnosis, Gandhi Medical College, Bhopal, Madhya Pradesh, India

[3]Dr Shubham Lekhwani, Junior Resident, Department of Radiodiagnosis, Gandhi Medical College, Bhopal, Madhya Pradesh, India

[4]Dr Lavanya Vullakulla, Department of Radiodiagnosis, Gandhi Medical College, Bhopal, Madhya Pradesh, India

[5]Dr Arjun Jat, Department of Radiodiagnosis, Gandhi Medical College, Bhopal, Madhya Pradesh, India

Corresponding Author: Dr Shubham Lekhwani, Junior Resident, Department of Radiodiagnosis, Gandhi Medical College, Bhopal, Madhya Pradesh, India.

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Abstract

Background: Glaucoma, a group of optic neuropathies characterized by progressive retinal ganglion cell loss and corresponding visual field defects. Glaucoma's pathophysiology centres on the progressive degeneration of the optic nerve. In addition to the mechanical stress induced by elevated IOP, the vascular theory posits that compromised ocular blood flow may contribute to glaucomatous optic neuropathy.

Methodology: Conducted as a cross-sectional study at Gandhi Medical College and Hamidia Hospital, Bhopal, from May 2023 to October 2024, this research included 50 patients referred from Department of ophthalmology with diagnosed primary glaucoma and 50 age matched controls with no features of glaucoma. Data was gathered on various Doppler (Peak systolic velocity (PSV), End diastolic velocity (EDV) & Resistive index (RI)) and ocular parameters (Intraocular pressure (IOP), Cup Disc Ratio (CD Ratio) & Axial length), with statistical comparisons performed on these metrics.

Results: The analysis revealed that PSV and EDV were significantly lower, and RI was significantly higher in glaucoma cases compared to controls.

Conclusion: Glaucoma patients exhibited reduced ophthalmic artery blood flow velocity and increased vascular resistance, as evidenced by lower PSV and EDV, and higher RI values, respectively. These findings underscore the potential role of vascular factors in glaucoma pathogenesis and highlight the potential of colour Doppler ultrasound imaging as a non-invasive tool for prediction & monitoring of glaucoma.

Keywords: End diastolic velocity, Glaucoma, Peak systolic velocity; Resistive index

Introduction

The impact of glaucoma extends beyond visual impairment, significantly affecting patients' quality of life by limiting their daily activities, mobility, and overall well-being[1].

Glaucoma's pathophysiology centres on the progressive degeneration of the optic nerve, the crucial conduit for transmitting visual information from the retina to the brain. This degeneration is primarily attributed to the loss of retinal ganglion cells; whose axons form the optic nerve[2]. Elevated intraocular pressure (IOP) is recognized as a pivotal risk factor, however exact mechanisms remain incompletely understood [3]. Increased IOP exerts mechanical stress on the optic nerve head, leading to axonal damage and impaired axonal transport[4]. However, glaucoma can also occur in individuals with normal IOP, suggesting the involvement of additional factors in its pathogenesis.

In addition to the mechanical stress induced by elevated IOP, the vascular theory posits that compromised ocular blood flow may contribute to glaucomatous optic neuropathy[5]. This theory suggests that inadequate blood supply to the optic nerve head, potentially resulting from reduced perfusion or dysregulation of ocular blood vessels, can lead to ischemic injury and subsequent axonal degeneration[6].

Several lines of evidence support this hypothesis, including observations of reduced ocular blood flow in glaucoma patients, associations between vascular risk factors and glaucoma development, and the beneficial effects of interventions aimed at improving ocular blood flow [7,8].

The ophthalmic artery, the first major branch of the internal carotid artery, plays a crucial role in supplying the eye and its surrounding structures, including the optic nerve[9]. Any compromise in blood flow through this vessel could potentially impact the optic nerve's health and contribute to glaucomatous damage.

The diagnosis and management of glaucoma rely on a comprehensive assessment encompassing various clinical parameters. Tonometry for measuring IOP (>22mmHg), ophthalmoscopy for evaluating the optic nerve head, and perimetry for assessing visual field defects are considered the cornerstones of glaucoma diagnosis[10]. Optical coherence tomography (OCT) has emerged as a valuable adjunct, providing detailed structural information about the optic nerve and retinal nerve fibre layer[11]. However, these conventional methods primarily focus on structural and functional changes associated with glaucoma, with limited ability to directly assess ocular blood flow. While IOP measurement remains crucial, it is increasingly recognized that glaucoma is a multifactorial disease, and factors beyond IOP, such as ocular blood flow, may play a significant role in its pathogenesis and progression[12].

To quantify and visualize blood flow within vessels Colour Doppler imaging (CDI) utilizes the Doppler effect. It superimposes color-coded information representing blood flow direction and velocity onto a gray scale ultrasound image, providing real-time hemodynamic data[13]. CDI's non-invasive nature, safety profile, and ability to assess blood flow parameters in various ocular vessels, including the ophthalmic artery, make it a promising tool for investigating the vascular aspects of glaucoma. By measuring parameters such as peak systolic velocity (PSV), end-diastolic velocity (EDV), and resistive index (RI), CDI can offer insights into the hemodynamic characteristics of the ophthalmic artery, potentially revealing alterations associated with glaucoma[14].

While the vascular theory of glaucoma has gained traction, further research is warranted to elucidate the precise relationship between ocular blood flow and

glaucomatous optic neuropathy. Current diagnostic modalities primarily focus on structural and functional changes, leaving a gap in our understanding of the hemodynamic aspects of the disease. Colour Doppler imaging, with its ability to non-invasively assess blood flow parameters in key ocular vessels like the ophthalmic artery, offers a unique opportunity to bridge this gap. This study aims to contribute to the growing body of evidence by comprehensively evaluating ophthalmic artery hemodynamic in patients with primary glaucoma, thereby shedding light on the potential role of vascular factors in disease pathogenesis.

Aims and Objectives

- To determine the colour doppler indices in ophthalmic artery in patients with diagnosed primary glaucoma and age matched controls.
- Compare the velocimetric indices in between patient with diagnosed primary glaucoma and age matched controls.

Methodology

The study was conducted at the Department of Radiodiagnosis, Gandhi Medical College and associated hospital, Bhopal. This was a case-control study. The study population included patients referred from the Department of Ophthalmology with diagnosed primary glaucoma and age-matched controls with normal intraocular pressure (IOP). A total of 50 cases and 50 controls were enrolled.

Inclusion Criteria

1. Patients with diagnosed primary glaucoma aged 20 years or older.
2. Controls with normal IOP.

Exclusion Criteria

1. Patients younger than 20 years.
2. Patients with secondary acute angle-closure glaucoma, corneal trauma, uveitis, or ocular surface inflammation.

Source of Data

Permission was taken from ethical committee of Gandhi Medical college to conduct the study. All patients referred to the Department of Radio-Diagnosis with a diagnosis of primary glaucoma, matching the inclusion criteria, at Gandhi Medical College and Hamidia Hospital Bhopal were enrolled after taking an informed consent and explaining the purpose of the study.

Complete evaluation of all patients was done using the following format:

- History sheet & Ophthalmic examination sheet (used for obtaining IOP values and C: D ratio)

USG Procedure

1. Each participant was asked to lie supine and look straight up with their eyes closed.
2. The patient was scanned using a high-frequency linear probe (5-10MHz) in B-scan mode to measure axial length and then to check for the arteries and their waveform.
3. Low wall filter settings and an angle correction of ≤20° were used to obtain the waveform. The waveform was then used to calculate the color Doppler indices, namely PSV, EDV, and RI.

Statistical Analysis

- **Descriptive Statistics:** Continuous variables (e.g., age, PSV, EDV, RI) were summarized using mean, standard deviation, median, and range.
- **Inferential Statistics: Comparison of Groups:** Independent samples Mann Whitney U test was used to compare the mean values of continuous variables (e.g., PSV, EDV, RI) between the glaucoma patients and controls.

Statistical Significance: P-values less than 0.05 were considered statistically significant.

Statistical analysis was performed using MS Excel and SPSS Version 26.0.

Observations and Results:

Table 1: Distribution of participants according to the age group in years and study group

Age Group in years	Group		Total	Chi square value P value
	Cases	Controls		
	N (%)	N (%)	N (%)	0.056
21-40	10 (50.0)	10 (50.0)	20 (100.0)	
41-60	26 (49.1)	27 (50.9)	53 (100.0)	0.972
≥61	14 (51.9)	13 (48.1)	27 (100.0)	
Total	50 (50.0)	50 (50.0)	100 (100.0)	

Graph 1: Number of participants according to the age group in years and group

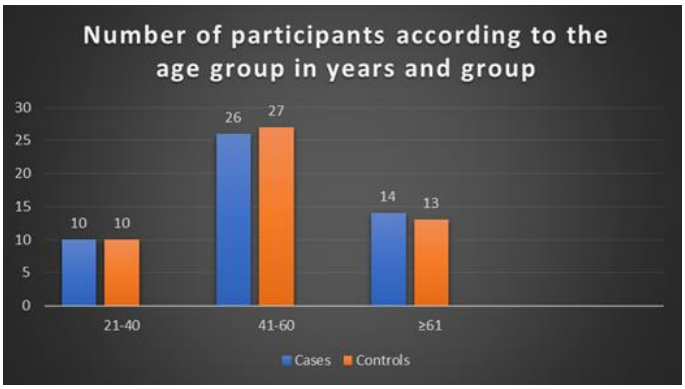

Table 1 and Graph 1 presents the age distribution of the 100 participants, divided equally into 50 cases and 50 controls. The age groups were categorized as ≤ 40, 41-60, and ≥ 61 years. In the youngest group (≤ 40), there were 10 participants in each of the case and control groups, totaling 20. In the middle age group (41-60), there were 26 cases and 27 controls, totaling 53. In the oldest age group (≥ 61), there were 14 cases and 13 controls totaling 27. The Chi-square test yielded a value of 0.056 with a p-value of 0.972, indicating no statistically significant difference in age distribution between the case and control groups.

Table 2: Distribution of participants according to the gender and study group

Gender	Group		Total	Chi square value P value
	Cases	Controls		
	N (%)	N (%)	N (%)	0.043
Male	32 (50.8)	31 (49.2)	63 (100.0)	
Female	18 (48.6)	19 (51.4)	37 (100.0)	0.836
Total	50 (50.0)	50 (50.0)	100 (100.0)	

Graph 2– Number of participants according to the gender and study grOUP

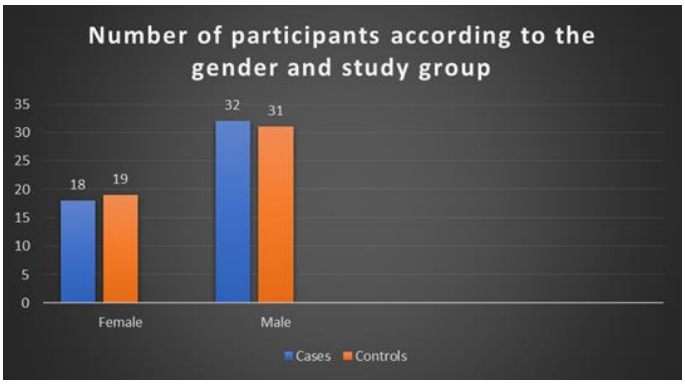

Table 2 and Graph 2 shows the gender distribution among the 100 participants, divided into 50 cases and 50 controls. Among the male participants, 32 were in the case group and 31 were in the control group, totalling 63 males. For female participants, 18 were in the case group and 19 were in the control group, totalling 37 females. The Chi-square test resulted in a value of 0.043 with a p-value of 0.836, indicating no statistically significant difference in gender distribution between the case and control groups.

Table 3: Descriptive Statistics of Intraocular Pressure, Cup-to-Disc Ratio, ONSD and Axial Length of cases of glaucoma

Variable	N	Minimum	Maximum	Median	Mean	Std. Deviation
C/D Ratio of Right Eye	50	.4	.8	0.60	.582	0.092
C/D Ratio of Left Eye	50	.4	.8	0.60	.570	0.107
ONSD of right eye	50	4.3	4.9	4.6	4.614	0.164
ONSD of left eye	50	4.3	4.9	4.6	4.602	0.15
Axial Length Right Eye	50	23.0	24.4	23.80	23.848	0.318
Axial Length Left Eye	50	22.9	24.4	23.80	23.802	0.326

Table 3 presents the descriptive statistics for intraocular pressure (IOP) (Normal values= 10-22mmHg), cup-to-disc (C/D) ratio (Normal values 0.3-0.4) and axial length (normal values-22-24.8mm)[73] in the 50 glaucoma cases. For the right eye, IOP ranged from 17 to 44 mmHg, with a median of 24.0 mmHg and a mean of 25.30 mmHg, and a standard deviation of 4.93 mmHg. For the left eye, IOP ranged from 16 to 46 mmHg, with a median of 23.50 mmHg and a mean of 25.06 mmHg, and a standard deviation of 4.96 mmHg.

The C/D ratio for the right eye ranged from 0.4 to 0.8, with a median of 0.60 and a mean of 0.582, and a standard deviation of 0.092. For the left eye, the C/D ratio also ranged from 0.4 to 0.8, with a median of 0.60 and a mean of 0.570, and a standard deviation of 0.107.

The axial length for the right eye ranged from 23.0 to 24.4 mm, with a median of 23.80 mm and a mean of 23.848 mm, and a standard deviation of 0.318 mm. For the left eye, the axial length ranged from 22.9 to 24.4 mm, with a median of 23.80 mm and a mean of 23.802 mm, and a standard deviation of 0.326 mm.

Table 4: Descriptive Statistics of Intraocular Pressure, Cup-to-Disc Ratio, ONSD and Axial Length of control population

Variable	N	Minimum	Maximum	Median	Mean	Std. Deviation
Intra Ocular Pressure – Right Eye	50	12	21	16.0	15.80	1.912

Intra Ocular Pressure – Left Eye	50	12	22	16.0	16.24	2.28
C/D Ratio of Right Eye	50	.3	.5	0.30	.354	0.065
C/D Ratio of Left Eye	50	.3	.5	0.40	.358	0.054
Axial Length Right Eye	50	22.0	24.2	23.0	23.16	0.633
Axial Length Left Eye	50	22.6	24.4	23.60	23.42	0.501

Table 4 presents the descriptive statistics intraocular pressure (IOP) (Normal values= 10-22mmHg), cup-to-disc (C/D) ratio (Normal values 0.3-0.4) and axial length (normal values-22-24.8mm)[73] in the 50 participants of the control group.

For the right eye, IOP ranged from 12 to 21 mmHg, with a median of 16.0 mmHg and a mean of 15.80 mmHg, and a standard deviation of 1.912 mmHg. For the left eye, IOP ranged from 12 to 22 mmHg, with a median of 16.0 mmHg and a mean of 16.24 mmHg, and a standard deviation of 2.28 mmHg.

The C/D ratio for the right eye ranged from 0.3 to 0.5, with a median of 0.30 and a mean of 0.354, and a standard deviation of 0.065. For the left eye, the C/D ratio also ranged from 0.3 to 0.5, with a median of 0.40 and a mean of 0.358, and a standard deviation of 0.054.

The axial length for the right eye ranged from 22.0 to 24.2 mm, with a median of 23.0 mm and a mean of 23.16 mm, and a standard deviation of 0.633 mm. For the left eye, the axial length ranged from 22.6 to 24.4 mm, with a median of 23.60 mm and a mean of 23.42 mm, and a standard deviation of 0.501 mm.

Table 5: Descriptive Statistics of Doppler Parameters in Ophthalmic Artery among the patients with glaucoma

Variable	N	Minimum	Maximum	Median	Mean	Std. Deviation
Peak Systolic Velocity of Right Eye	50	21.5	41.8	36.50	35.68	4.36
End Diastolic Velocity of Right Eye	50	5.80	13.00	8.65	8.64	1.46
Resistive Index of Right Eye	50	0.68	0.82	0.76	0.753	0.03
Peak Systolic Velocity of Left Eye	50	22.30	44.00	36.85	36.43	4.08
End Diastolic Velocity of Left Eye	50	5.80	14.20	8.90	9.03	1.75
Resistive Index of Left eye	50	0.66	0.82	0.755	0.749	0.035

Table 5 presents the descriptive statistics for Doppler parameters in the ophthalmic artery of 50 glaucoma patients. For the right eye, the peak systolic velocity (PSV) ranged from 21.5 to 41.8 cm/s, with a median of 36.50 cm/s and a mean of 35.68 cm/s, and a standard deviation of 4.36 cm/s. The end diastolic velocity (EDV) ranged from 5.80 to 13.00 cm/sec, with a median of 8.65 cm/sec and a mean of 8.64 cm/sec, and a standard

deviation of 1.46 cm/sec. The resistive index (RI) ranged from 0.68 to 0.82, with a median of 0.76 and a mean of 0.753, and a standard deviation of 0.03.

For the left eye, PSV ranged from 22.30 to 44.00 cm/s, with a median of 36.85 cm/s and a mean of 36.43 cm/s, and a standard deviation of 4.08 cm/s. EDV ranged from 5.80 to 14.20 cm/s, with a median of 8.90 cm/s and a mean of 9.03 cm/s, and a standard deviation of 1.75 cm/s. RI ranged from 0.66 to 0.82, with a median of 0.755 and a mean of 0.749, and a standard deviation of 0.035.

Table 6: Descriptive Statistics of Doppler Parameters in Ophthalmic Artery among the control population

Variable	N	Minimum	Maximum	Median	Mean	Std. Deviation
Peak Systolic Velocity of Right Eye	50	36.8	46.0	42.70	41.97	2.23
End Diastolic Velocity of Right Eye	50	10.40	16.80	14.45	14.22	1.25
Resistive Index of Right Eye	50	.60	.75	0.66	0.66	0.027
Peak Systolic Velocity of Left Eye	50	38.40	46.50	42.50	42.36	2.17
End Diastolic Velocity of Left Eye	50	11.70	16.50	14.65	14.39	1.26
Resistive Index of Left eye	50	.61	0.71	0.65	0.657	0.025

Table 6 presents the descriptive statistics for Doppler parameters in the ophthalmic artery of the 50 participants in the control group.

For the right eye, the peak systolic velocity (PSV) ranged from 36.8 to 46.0 cm/s, with a median of 42.70 cm/s and a mean of 41.97 cm/s, and a standard deviation of 2.23 cm/s. The end diastolic velocity (EDV) ranged from 10.40 to 16.80 cm/sec, with a median of 14.45 cm/sec and a mean of 14.22 cm/sec, and a standard deviation of 1.25 cm/sec. The resistive index (RI) ranged from 0.60 to 0.75, with a median of 0.66 and a mean of 0.66, and a standard deviation of 0.027. For the left eye, PSV ranged from 38.40 to 46.50 cm/s, with a median of 42.50 cm/s and a mean of 42.36 cm/s, and a standard deviation of 2.17 cm/s. EDV ranged from 11.70 to 16.50 cm/sec, with a median of 14.65 cm/sec and a mean of 14.39 cm/sec, and a standard deviation of 1.26 cm/sec. RI ranged from 0.61 to 0.71, with a median of 0.65 and a mean of 0.657, and a standard deviation of 0.025.

Table 7: Mann-Whitney U Test Results for Ocular Parameters

Ocular Parameter	Group	N	Mean Rank	Sum of Ranks	Mann-Whitney U	p-value
Intra Ocular Pressure – Right Eye	1	50	75.1	3755	20	<0.001
	2	50	25.9	1295		
Intra Ocular Pressure – Left Eye	1	50	74.26	3713	62	<0.001
	2	50	26.74	1337		
C/D Ratio Right Eye	1	50	74.2	3710	65	<0.001
	2	50	26.8	1340		
C/D Ratio Left Eye	1	50	73.05	3652.5	122.5	<0.001
	2	50	27.95	1397.5		
Axial Length Right Eye	1	50	65.74	3287	488	<0.001
	2	50	35.26	1763		

Axial Length Left Eye	1	50	61.38	3069	706	<0.001
	2	50	39.62	1981		

Table 7 presents the Mann-Whitney U test results comparing ocular parameters between two groups (cases and controls). Group1= cases and Group 2= controls

For intraocular pressure in the right eye (IOP RE), Group 1 (cases) had a mean rank of 75.1 and a sum of ranks of 3755, while Group 2 (controls) had a mean rank of 25.9 and a sum of ranks of 1295. The Mann-Whitney U value was 20, and the p-value was less than 0.001, indicating a statistically significant difference. Similarly, for IOP in the left eye (IOP LE), Group 1 had a mean rank of 74.26, Group 2 had a mean rank of 26.74, the U value was 62, and the p-value was less than 0.001.

For the cup-to-disc (C/D) ratio in the right eye (C/D Ratio RE), Group 1 had a mean rank of 74.2, Group 2 had a mean rank of 26.8, the U value was 65, and the p-value was less than 0.001. For the C/D ratio in the left eye (C/D Ratio LE), Group 1 had a mean rank of 73.05, Group 2 had a mean rank of 27.95, the U value was 122.5, and the p-value was less than 0.001.

For axial length in the right eye (Axial Length RE), Group 1 had a mean rank of 65.74, Group 2 had a mean rank of 35.26, the U value was 488, and the p-value was less than 0.001. For axial length in the left eye (Axial Length LE), Group 1 had a mean rank of 47.35, Group 2 had a mean rank of 39.62, the U value was 706, and the p-value was less than 0.001.

In summary, ocular parameters (IOP, C/D ratio, and axial length for both eyes) showed statistically significant differences between the two groups, with p-values less than 0.001.

Table 8: Mann-Whitney U Test Results for Doppler Parameters

Doppler Parameter	Group	N	Mean Rank	Rank Sum	Mann-Whitney U	p-value
Peak Systolic Velocity of Right Eye	1	50	29.21	1460.5	185.5	<0.001
	2	50	71.79	3589.5		
Peak Systolic Velocity of Left Eye	1	50	29.93	1496.5	221.5	<0.001
	2	50	71.07	3553.5		
End Diastolic Velocity of Right Eye	1	50	25.77	1288.5	13.5	<0.001
	2	50	75.23	3761.5		
End Diastolic Velocity of Left Eye	1	50	26.1	1305	30.0	<0.001
	2	50	74.9	3745		
Resistive Index Right Eye	1	50	74.64	3732	43.0	<0.001
	2	50	26.36	1318		
Resistive Index Left Eye	1	50	74.44	3722	53.0	<0.001
	2	50	26.56	1328		

Table 8 presents the Mann-Whitney U test results comparing Doppler parameters between two groups (presumably cases and controls). For peak systolic velocity in the right eye (PSV RE), Group 1 (cases) had a mean rank of 29.21 and a sum of ranks of 1460.5, while Group 2 (controls) had a mean rank of 71.79 and a sum of ranks of 3589.5. The Mann-Whitney U value was 185.5, and the p-value was less than 0.001, indicating a

statistically significant difference. Similarly, for peak systolic velocity in the left eye (PSV LE), Group 1 had a mean rank of 29.93, Group 2 had a mean rank of 71.07, the U value was 221.5, and the p-value was less than 0.001.

For End Diastolic Velocity in the right eye (EDV RE), Group 1 had a mean rank of 25.77, Group 2 had a mean rank of 75.23, the U value was 13.5, and the p-value was less than 0.001. For End Diastolic Velocity in the left eye (EDV LE), Group 1 had a mean rank of 26.1, Group 2 had a mean rank of 74.9, the U value was 30.0, and the p-value was less than 0.001.

For the resistive index in the right eye (RI RE), Group 1 had a mean rank of 74.64, Group 2 had a mean rank of 26.36, the U value was 43.0, and the p-value was less than 0.001. For the resistive index in the left eye (RI LE), Group 1 had a mean rank of 74.44, Group 2 had a mean rank of 26.56, the U value was 53.0, and the p-value was less than 0.001.

In summary, all Doppler parameters (PSV, EDV, and RI for both eyes) showed statistically significant differences between the two groups, with p-values less than 0.001.

Discussion

This study aimed to evaluate ophthalmic artery blood flow in patients diagnosed with primary glaucoma using color Doppler ultrasound, and to compare these findings with those obtained from a cohort of healthy control subjects. While elevated intraocular pressure (IOP) remains a significant risk factor, growing evidence suggests that vascular factors play a critical role in its pathogenesis and progression. Understanding the hemodynamic changes within the ophthalmic artery, the primary source of blood supply to the optic nerve, is essential for elucidating the complex interplay between vascular dysfunction and glaucomatous optic neuropathy. Prior research, such as that conducted by Pinto et al. [15] in 2012, has indicated that alterations in ophthalmic artery blood flow patterns and impaired autoregulation may contribute to the disease process, even in cases where IOP is within normal limits.

Therefore, the present study sought to quantify and compare ophthalmic artery blood flow parameters between glaucoma patients and healthy controls, thereby contributing to a more comprehensive understanding of the vascular component of glaucoma.

Demographic Data and Baseline Characteristics

The demographic distribution of the study participants revealed a balanced representation of age and gender between the case and control groups. The lack of statistically significant differences in age ($p = 0.972$) and gender ($p = 0.836$) between the groups underscores the robustness of the study design, ensuring that any observed differences in ocular blood flow parameters are not attributable to these demographic variables. This balance is crucial for minimizing bias and enhancing the internal validity of the study, allowing for a more accurate comparison of ophthalmic artery hemodynamics between glaucoma patients and healthy controls.

Ocular Parameters

The analysis of ocular parameters revealed significant differences between the glaucoma case and control groups, reflecting the structural and functional changes associated with glaucomatous optic neuropathy.

Intraocular pressure (IOP) was significantly higher in glaucoma cases compared to controls ($p < 0.001$). Specifically, the mean IOP in the right and left eyes of the glaucoma group was 25.30 mmHg and 25.06 mmHg, respectively, while the mean IOP in the right and left eyes of the control group was 15.80 mmHg and 16.24 mmHg, respectively. These elevated IOP values in the glaucoma group are consistent with the fundamental pathophysiology of primary glaucoma, wherein increased

IOP contributes to progressive optic nerve damage. This finding aligns with the results reported by Singh et al. [16] in 2015, who also observed significantly higher IOP in primary open-angle glaucoma (POAG) patients compared to healthy controls.

The cup-to-disc (C/D) ratio, a crucial indicator of optic nerve damage, was also significantly higher in glaucoma cases ($p < 0.001$). The mean C/D ratio in the right and left eyes of the glaucoma group was 0.582 and 0.570, respectively, compared to 0.354 and 0.358 in the control group. A higher C/D ratio signifies increased cupping of the optic disc, reflecting the extent of glaucomatous damage. This result is consistent with the clinical understanding of glaucoma, where progressive optic neuropathy leads to an increased C/D ratio.

Furthermore, the axial length was significantly higher in glaucoma cases ($p < 0.001$). The mean axial length in the right and left eyes of the glaucoma group was 23.848 mm and 23.802 mm, respectively, compared to 23.16 mm and 23.42 mm in the control group. Increased axial length has been associated with an increased risk of glaucoma, potentially due to structural changes that predispose the optic nerve to damage.

In summary, the significant differences observed in IOP, C/D ratio, and axial length between the glaucoma and control groups underscore the structural and functional changes that characterize glaucomatous optic neuropathy.

Doppler Parameters in Ophthalmic Artery

The analysis of Doppler parameters in the ophthalmic artery revealed significant hemodynamic differences between the glaucoma case and control groups, indicative of impaired ocular blood flow in glaucoma patients.

Peak systolic velocity (PSV) was significantly lower in glaucoma cases compared to controls ($p < 0.001$). Specifically, the mean PSV in the right and left eyes of the glaucoma group was 35.68 cm/s and 36.43 cm/s, respectively, while the mean PSV in the right and left eyes of the control group was 41.97 cm/s and 42.36 cm/s, respectively. This reduction in PSV suggests diminished blood flow velocity in the ophthalmic artery, potentially compromising the perfusion of the optic nerve head. These findings are consistent with previous research. For example, Eniola M.A. et al.[17] in 2018 reported significantly lower PSV in the ophthalmic artery of primary open-angle glaucoma (POAG) patients compared to controls. Similarly, Senger et al. [18] in 2019 also observed a statistically significant decrease in PSV in the ophthalmic artery of POAG patients.

End diastolic velocity (EDV) was also significantly lower in glaucoma cases ($p < 0.001$). The mean EDV in the right and left eyes of the glaucoma group was 8.64 cm/s and 9.03 cm/s, respectively, compared to 14.22 cm/s and 14.39 cm/s in the control group. Reduced EDV implies diminished blood flow during diastole, further compromising ocular perfusion. Jimenez-Aragon et al. [19] in 2013 also reported lower EDV in the ophthalmic artery of glaucoma patients who progressed, compared to those who did not.

Conversely, the resistive index (RI) was significantly higher in glaucoma cases ($p < 0.001$). The mean RI in the right and left eyes of the glaucoma group was 0.753 and 0.749, respectively, compared to 0.66 and 0.657 in the control group. Increased RI indicates elevated vascular resistance, which can impede blood flow to the optic nerve. Almeida-Freitas et al. (2011)[20] in 2012 also found a significantly higher mean RI in the ophthalmic artery of chronic heart failure patients. Chaturvedy et al.[21] in 2022 found that all POAG patients had a raised RI compared to controls.

In summary, the significant differences in PSV, EDV, and RI between the glaucoma and control groups consistently indicate impaired ocular blood flow in glaucoma patients.

The reduced blood flow velocity and increased vascular resistance in the ophthalmic artery likely contribute to the pathogenesis and progression of glaucoma by compromising the perfusion of the optic nerve head.

Limitations

This study is not without limitations. The cross-sectional design precludes the establishment of temporal relationships between ocular blood flow parameters and glaucoma progression. A longitudinal study would provide more robust evidence regarding the predictive value of Doppler parameters.

Furthermore, the sample size, while adequate for detecting significant differences, might limit the generalizability of the findings to a broader population.

The single-center nature of this study also introduces potential biases related to patient selection and local practices.

Potential confounding factors, such as systemic vascular diseases were not exhaustively controlled. While the study attempted to minimize the impact of age and gender through balanced group distributions, other factors could have influenced the observed results.

Future Recommendations

Future research should focus on addressing the limitations of this study. Longitudinal studies with larger, multi-center cohorts are warranted to validate the predictive value of Doppler parameters in glaucoma progression.

The potential of combining Doppler ultrasound with other imaging modalities, such as optical coherence tomography angiography (OCT-A), should also be investigated. Combining these techniques could provide a more comprehensive assessment of both microcirculation and macrocirculation in glaucoma.

Additionally, studies exploring the impact of therapeutic interventions on ocular blood flow in glaucoma are needed. Investigating whether IOP-lowering medications or vascular interventions can improve Doppler parameters could provide valuable insights into the management of glaucoma

Conclusion

In conclusion, this study demonstrates significant differences in ophthalmic artery hemodynamics between primary glaucoma patients and healthy controls. Glaucoma patients exhibited reduced ophthalmic artery blood flow velocity and increased vascular resistance, as evidenced by lower PSV and EDV, and higher RI values, respectively. These findings underscore the potential role of vascular factors in glaucoma pathogenesis and highlight the use of colour Doppler ultrasound imaging as a non-invasive tool for prediction and monitoring of primary glaucoma.

Illustrations

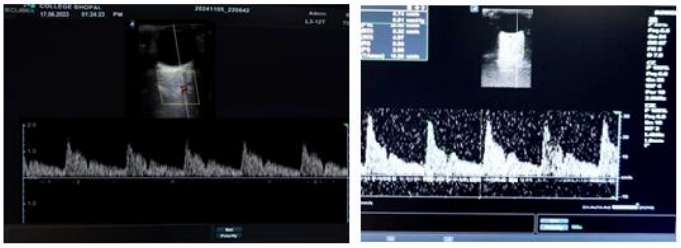

Figure 1: Ophthalmic artery doppler in glaucoma patient

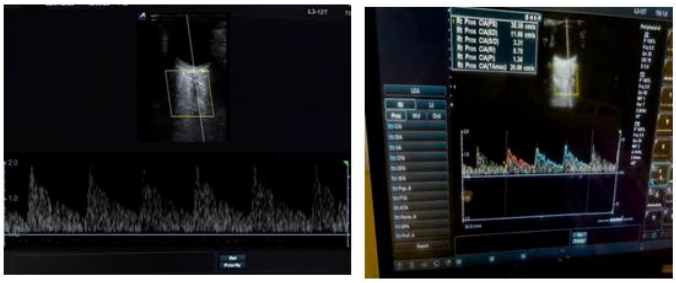

Figure 2: Ophthalmic artery doppler in controls

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Abbreviations

USG - Ultrasonography

Hz - Hertz

CDI - Color doppler imaging

POAG - Primary open angle glaucoma

OCT - Optical Coherence Tomography

OA - Ophthalmic artery

IOP - Intra ocular pressure

CD ratio - Cup: disc ratio

PSV - Peak systolic velocity

EDV - End Diastolic velocity

RI - Resistive Index