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Original Research Article

Evaluation of Orbital Vessels in Diabetic Retinopathy Using Color Doppler Ultrasound

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Abstract

Background: Diabetic retinopathy (DR) is a major microvascular complication of diabetes mellitus and a leading cause of preventable visual impairment worldwide. Hemodynamic alterations in retrobulbar circulation play a key role in the pathogenesis and progression of DR. Colour Doppler imaging (CDI) enables non-invasive evaluation of orbital vascular parameters, including peak systolic velocity (PSV), end-diastolic velocity (EDV), and resistive index (RI).

Objectives: To assess and compare hemodynamic alterations in the ophthalmic artery (OA), central retinal artery (CRA), and short posterior ciliary artery (SPCA) in diabetic patients without and with retinopathy using colour Doppler ultrasound, and to evaluate RI as a potential imaging biomarker correlating with DR severity.

Materials and Methods: This comparative two-group clinical study included 80 diabetic patients (40 without DR and 40 with DR) over 12 months. All patients underwent orbital CDI evaluation of OA, CRA, and SPCA in both eyes. PSV, EDV, and RI were recorded. Statistical analysis was performed using Student's t-test, Chi-square test, and one-way ANOVA, with $p<0.05$ considered significant.

Results: Duration of diabetes and random blood sugar levels were significantly higher in patients with DR ($p=0.002$ and $p\leq0.001$, respectively). In the OA and CRA, EDV was significantly reduced and RI significantly elevated in DR patients ($p<0.001$), while PSV showed no consistent significant difference. In the SPCA, both PSV and EDV were significantly reduced, and RI significantly increased in DR patients ($p<0.001$). RI demonstrated a progressive and statistically significant rise from no DR to NPDR and PDR across all vessels ($p<0.001$).

Conclusion: Orbital hemodynamic alterations are significantly associated with diabetic retinopathy. Elevated resistive index correlates strongly with disease severity and may serve as a reliable non-invasive imaging biomarker for early detection and monitoring of DR progression.

Keywords: Diabetic Retinopathy; Colour Doppler Imaging; Resistive Index; Ophthalmic Artery; Retrobulbar Circulation.

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Introduction

Diabetes mellitus is one of the most prevalent non-communicable diseases worldwide, with a steadily increasing global burden [1]. As the prevalence of diabetes rises, its systemic complications including retinopathy, neuropathy, nephropathy, and cardiovascular involvement are also increasing in parallel [2]. Diabetic retinopathy (DR) is a microvascular complication resulting from chronic hyperglycaemia, characterized by structural and functional alterations in the retinal microvasculature [3]. Globally, the prevalence of diabetic retinopathy among individuals with diabetes is estimated to be 27.0%, contributing to approximately 0.4 million cases of blindness worldwide [1]. The severity of hyperglycaemia and the duration of diabetes are recognized as major risk factors for the development of retinopathy [2,3]. On average, a duration of 5–10 years of diabetes is required for the onset of DR, and nearly 80% of individuals with type 2 diabetes mellitus

may eventually develop some degree of retinopathy [2,3]. The pathophysiology of diabetic retinopathy primarily involves hemodynamic and microvascular alterations leading to retinal ischemia. Chronic hyperglycaemia induces endothelial dysfunction, capillary basement membrane thickening, and increased vascular permeability. Retinal ischemia subsequently stimulates neovascularization, resulting in complications such as microaneurysms, exudates, haemorrhages, glaucoma, tractional retinal detachment, and ultimately visual loss. DR is the most common cause of preventable visual impairment among the working-age population [4]. The disease typically progresses from non-proliferative diabetic retinopathy (NPDR) to proliferative diabetic retinopathy (PDR), especially in the presence of long-standing poor glycaemic control [5]. Early diagnosis and strict glycaemic regulation play a crucial role in halting or slowing these microvascular changes.

Colour Doppler ultrasonography (CDU) has emerged as a non-invasive imaging modality capable of assessing both anatomical and hemodynamic changes in orbital vessels [5-7]. It enables qualitative and quantitative evaluation of retrobulbar circulation, particularly in the ophthalmic artery (OA), central retinal artery (CRA), and short posterior ciliary artery (SPCA) [8]. Parameters such as peak systolic velocity (PSV), end-diastolic velocity (EDV), and resistive index (RI) are routinely measured to evaluate vascular resistance and perfusion. Some studies have reported reduced blood flow velocities in one or more of these vessels in DR patients [9,10], whereas others have demonstrated increased or unchanged values [11,12], with inconsistencies also observed in RI measurements.

These hemodynamic alterations appear to be more pronounced in advanced stages of DR [13,14]. Given that over 70 million individuals in India are affected by diabetes, the population remains highly susceptible to its vascular complications [15].

In view of these observations and the existing discrepancies in literature, the present study aimed to assess and compare the hemodynamic alterations in orbital vessels—namely the ophthalmic artery (OA), central retinal artery (CRA), and short posterior ciliary artery (SPCA) in diabetic patients without and with retinopathy using colour Doppler ultrasonography, and to evaluate the resistive index as a potential imaging biomarker correlating with the severity of diabetic retinopathy.

Materials and Methods

This comparative two-group clinical study was conducted in the Department of Radiodiagnosis in collaboration with the Department of Ophthalmology at Mahatma Gandhi Medical College and Research Institute (MGMCRI), Puducherry, India, over a period of 12 months from January 2023 to January 2024. The study population comprised patients with diabetes mellitus attending the Ophthalmology outpatient department. Based on funduscopic examination using indirect ophthalmoscopy, patients were categorized into two groups: diabetic patients without retinopathy (Group I) and diabetic patients with retinopathy (Group II), and were subsequently referred for orbital color Doppler imaging. A total sample size of 80 was calculated using the formula $n = 4PQ/d^2$ (P=7%, Q=93%, d=8%), and equally divided into 40 patients in each group.

Patients aged ≥35 years with diabetes duration more than 5 years were included in the study. Exclusion criteria comprised patients with congenital orbital pathology, orbital trauma, infections or inflammatory lesions, orbital tumors, cerebrovascular insult, prior laser or surgical intervention for diabetic retinopathy, hypertension, dyslipidemia, glaucoma, smoking history, or intake of vasodilatory drugs. Ethical clearance was obtained from the Institutional Human Ethics Committee, and written informed consent was secured from all participants prior to enrollment.

All patients underwent detailed clinical evaluation including demographic details and random blood sugar estimation. Both eyes of each patient were examined using Color Doppler Imaging (CDI) with a Mindray DC-8 ultrasound machine equipped with a linear array transducer (3–12 MHz). Examinations were performed in the supine position with minimal pressure over closed eyelids. Peak systolic velocity (PSV), end diastolic velocity (EDV), and resistive index (RI) were assessed in the ophthalmic artery (OA), central retinal artery (CRA), and short posterior ciliary artery (SPCA). RI was calculated using the formula: $RI = (PSV - EDV) / PSV$.

Statistical analysis was performed using SPSS version 22.0 and R software (version 3.2.2). Continuous variables were expressed as mean ± standard deviation and categorical variables as frequency and percentage. Independent Student's t-test was used for comparison of continuous variables between groups, while Chi-square or Fisher's exact test was applied for categorical variables. One-way ANOVA was used for comparison across severity groups. A p-value <0.05 was considered statistically significant.

Results

The baseline characteristics of the study population showed that the majority of participants were aged above 50 years (71.3%), followed by 40–50 years (27.5%), with only 1.3% below 40 years. The mean age was comparable between Group I (54.53 ± 8.57 years) and Group II (56.73 ± 8.05 years), with no

statistically significant difference (p=0.240). Gender distribution was also similar between groups, with males constituting 60% and females 40% of the total study population (p=0.823). Thus, both groups were comparable with respect to age and gender (Table 1).

Table 1: Baseline Characteristics of Study Participants (n = 80)

Variable		Group I (No DR) n=40	Group II (DR) n=40	Total n=80	P value
Age (years)	**<40**	1 (2.5%)	0 (0%)	1 (1.3%)	0.240
	40–50	11 (27.5%)	11 (27.5%)	22 (27.5%)	
	>50	28 (70%)	29 (72.5%)	57 (71.3%)	
	Mean ± SD	54.53 ± 8.57	56.73 ± 8.05	55.63 ± 8.34	
Gender	**Female**	17 (42.5%)	15 (37.5%)	32 (40%)	0.823
	Male	23 (57.5%)	25 (62.5%)	48 (60%)	

The duration of diabetes mellitus was significantly longer in patients with diabetic retinopathy.

Among those with 5–10 years duration, 77.5% belonged to Group I compared to 57.5% in Group II, whereas 42.5% of Group II had 10–15 years duration compared to 22.5% in Group I. The mean duration was significantly higher in Group II (10.00 ± 3.00 years) compared to Group I (8.08 ± 2.46 years) (p=0.002).

All participants had RBS >140 mg/dl, but the mean RBS was significantly higher in Group II (248.08 ± 29.78 mg/dl) than in Group I (222.65 ± 24.03 mg/dl) (p≤0.001), indicating poor glycemic control in retinopathy patients (Table 2).

Table 2: Clinical Parameters Comparison between Groups

Variable		Group I (No DR)	Group II (DR)	Total	P value
Duration of DM (years)	**5-10**	31 (77.5%)	23 (57.5%)	54 (67.5%)	0.002
	10-15	9 (22.5%)	17 (42.5%)	26 (32.5%)	
	Mean ± SD	8.08 ± 2.46	10.00 ± 3.00	9.04 ± 2.90	
RBS (mg/dl)	**>140**	40 (100%)	40 (100%)	80 (100%)	≤0.001
	Mean ± SD	222.65 ± 24.03	248.08 ± 29.78	235.36 ± 29.77	

In the ophthalmic artery, PSV did not differ significantly between groups in either eye.

However, EDV was significantly reduced in Group II in both right (5 ± 1.58 vs 9 ± 3.77) and left eyes (5.24 ± 1.84 vs 8.45 ± 2.34), with strong statistical significance (p<0.001). The resistive index was significantly higher in Group II in both eyes (Right: 0.80 ± 0.14 vs 0.71 ± 0.09, p=0.002; Left: 0.84 ± 0.08 vs 0.72 ± 0.06, p<0.001), indicating increased vascular resistance in patients with diabetic retinopathy (Table 3).

Table 3: Comparison of Doppler Parameters in Ophthalmic Artery (OA)

Parameter		Group I	Group II	Total	P value
Right Eye	**PSV**	32.4 ± 9.61	29.1 ± 9.2	30.75 ± 9.49	0.120
	EDV	9 ± 3.77	5 ± 1.58	7 ± 3.51	<0.001
	RI	0.71 ± 0.09	0.80 ± 0.14	0.76 ± 0.12	0.002
Left Eye	**PSV**	30.96 ± 6.15	31.57 ± 8.08	31.27 ± 7.14	0.705
	EDV	8.45 ± 2.34	5.24 ± 1.84	6.84 ± 2.64	<0.001
	RI	0.72 ± 0.06	0.84 ± 0.08	0.78 ± 0.09	<0.001

In the central retinal artery, PSV showed no significant difference in the right eye (p=0.195) and borderline significance in the left eye (p=0.050). However, EDV was significantly reduced in Group II in both eyes (p<0.001). The resistive index was markedly elevated in Group II in both right (0.81 ± 0.22 vs 0.67 ± 0.10) and left eyes (0.83 ± 0.18 vs 0.68 ± 0.06), with strong statistical significance (p<0.001), suggesting impaired retinal perfusion in retinopathy (Table 4).

Table 4: Comparison of Doppler Parameters in Central Retinal Artery (CRA)

Parameter		Group I	Group II	Total	P value
Right Eye	**PSV**	11.63 ± 4.11	12.96 ± 4.98	12.29 ± 4.58	0.195
	EDV	3.79 ± 1.75	2.30 ± 0.84	3.05 ± 1.55	<0.001
	RI	0.67 ± 0.10	0.81 ± 0.22	0.74 ± 0.18	<0.001
Left Eye	**PSV**	10.86 ± 1.01	12.10 ± 3.80	11.48 ± 2.83	0.050
	EDV	3.59 ± 0.75	2.26 ± 0.82	2.92 ± 1.03	<0.001
	RI	0.68 ± 0.06	0.83 ± 0.18	0.75 ± 0.15	<0.001

In the short posterior ciliary artery, both PSV and EDV were significantly reduced in Group II in right and left eyes ($p<0.001$). The resistive index was significantly elevated in Group II in both eyes (Right: 0.82 ± 0.05 vs 0.70 ± 0.04; Left: 0.81 ± 0.04 vs 0.70 ± 0.03; $p<0.001$). These findings indicate pronounced hemodynamic alterations in the posterior ciliary circulation among patients with diabetic retinopathy (Table 5).

Table 5: Comparison of Doppler Parameters in Short Posterior Ciliary Artery (SPCA)

Parameter		Group I	Group II	Total	P value
Right Eye	**PSV**	20.13 ± 1.81	15.92 ± 1.83	18.03 ± 2.78	<0.001
	EDV	6.01 ± 0.72	2.84 ± 0.76	4.43 ± 1.76	<0.001
	RI	0.70 ± 0.04	0.82 ± 0.05	0.76 ± 0.07	<0.001
Left Eye	**PSV**	20.04 ± 1.69	16.15 ± 1.61	18.09 ± 2.55	<0.001
	EDV	5.98 ± 0.71	3.07 ± 0.61	4.52 ± 1.60	<0.001
	RI	0.70 ± 0.03	0.81 ± 0.04	0.75 ± 0.07	<0.001

Among patients with diabetic retinopathy (Group II), 60% had non-proliferative diabetic retinopathy (NPDR) and 40% had proliferative diabetic retinopathy (PDR), indicating that NPDR was more prevalent in the study population (Table 6).

Table 6: Distribution of Diabetic Retinopathy Severity (Group II, n=40)

Severity	Frequency	Percentage
NPDR	24	60%
PDR	16	40%
Total	40	100%

Resistive index values demonstrated a progressive increase from No DR to NPDR and PDR across all vessels examined. In the ophthalmic artery, CRA, and SPCA of both eyes, RI showed a statistically significant stepwise rise with increasing severity of retinopathy ($p<0.001$). This trend suggests that RI correlates positively with the progression and severity of diabetic retinopathy and may serve as a potential hemodynamic marker of disease severity (Table 7).

Table 7: Comparison of Resistive Index (RI) According to Severity

Vessel	No DR	NPDR	PDR	P value
OA RE	0.71 ± 0.09	0.75 ± 0.17	0.86 ± 0.04	<0.001
OA LE	0.72 ± 0.06	0.80 ± 0.05	0.89 ± 0.09	<0.001
CRA RE	0.67 ± 0.10	0.77 ± 0.05	0.86 ± 0.32	<0.001
CRA LE	0.68 ± 0.06	0.77 ± 0.06	0.91 ± 0.24	<0.001
SPCA RE	0.70 ± 0.04	0.79 ± 0.03	0.85 ± 0.04	<0.001
SPCA LE	0.70 ± 0.03	0.79 ± 0.03	0.84 ± 0.03	<0.001

Discussion

Diabetic retinopathy (DR) remains the leading cause of preventable visual impairment among the working-age population [4]. The disease results from multifactorial microangiopathy driven by chronic hyperglycaemia and tissue hypoxia, progressing from non-proliferative stages to proliferative disease in the presence of long-standing poor glycaemic control.

Hemodynamic compromise and retinal ischemia are central to this progression. Colour Doppler imaging (CDI) has emerged as a valuable, non-invasive modality for evaluating retrobulbar circulation without ionizing radiation. By assessing peak systolic velocity (PSV), end-diastolic velocity (EDV), and resistive index (RI) in the ophthalmic artery (OA), central retinal artery (CRA), and short posterior ciliary artery (SPCA), CDI provides insight into vascular resistance and perfusion changes associated with DR progression. In the present study, 60% of patients with DR had NPDR and 40% had PDR. Age and gender distribution were comparable between groups, while longer duration of diabetes and higher random blood sugar levels were significantly associated with retinopathy. These findings are consistent with previous reports highlighting duration of diabetes and glycaemic status as major determinants of DR severity. Sood S et al. reported similar demographic patterns and significant associations between duration of diabetes and retinopathy [16]. Kanagaraju et al. also demonstrated that duration of diabetes and metabolic control were significantly related to DR severity [17]. Madhpuriya G et al. further observed higher mean duration of diabetes and elevated glycaemic indices among patients with retinopathy, findings comparable to the present study [18]. Such demographic comparability strengthens the validity of hemodynamic comparisons between groups.

With respect to Doppler parameters, significant hemodynamic alterations were observed across all three vessels. In the OA, EDV was significantly reduced and RI significantly increased in patients

with DR, while PSV did not show significant difference, findings comparable to those reported by Madhpuriya G et al. [18] and Karami M et al. [19], who also observed elevated RI values in DR patients. In the CRA, EDV reduction and RI elevation were strongly significant, consistent with findings by Madhpuriya G et al. [18], while Neudorfer M et al. demonstrated altered RI patterns across different stages of DR [20]. Similarly, in the SPCA, both PSV and EDV were significantly reduced and RI significantly increased in DR patients, aligning with observations by Madhpuriya G et al. [18] and Mendivil MP et al. [21], although Krasnicki P et al. reported limited changes in PSV without assessment of RI [22]. Overall, these findings demonstrate reduced diastolic flow and increased vascular resistance in retinopathy, particularly affecting the posterior ciliary circulation.

A key observation of this study was the progressive and statistically significant increase in RI from No DR to NPDR and PDR across OA, CRA, and SPCA ($p<0.001$). This stepwise rise supports the concept that increasing retrobulbar vascular resistance parallels disease severity. Similar conclusions were drawn by Kanagaraju et al. [17], Madhpuriya G et al. [18], Dimitrova et al. [23], Basturk et al. [14], and Sood S et al. [16], all of whom reported significantly elevated RI in patients with diabetic retinopathy. Collectively, these findings suggest a strong association between increased retrobulbar vascular resistances and the occurrence as well as progression of DR, supporting the potential role of RI as a reliable imaging biomarker for early detection and monitoring of diabetic retinopathy.

Conclusion

The present study demonstrates significant hemodynamic alterations in the retrobulbar circulation of diabetic patients with retinopathy compared to those without retinopathy. A consistent reduction in end-diastolic velocity and a significant elevation in resistive index were observed in the ophthalmic artery, central retinal artery, and short posterior ciliary artery, with the most pronounced changes noted in patients with proliferative diabetic retinopathy. The progressive increase in resistive index from no retinopathy to NPDR and PDR highlights its strong correlation with disease severity. These findings suggest that color Doppler imaging is a valuable, non-invasive modality for detecting early vascular changes, and that resistive index may serve as a reliable imaging biomarker for assessing progression and severity of diabetic retinopathy, thereby aiding in timely intervention to prevent visual impairment.

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