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EFFECT OF DIABETES ON RETINAL HEALTH AND VISION LOSS

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Abstract

Objective: *The primary objective of this cross-sectional study was to investigate the impact of diabetes on retinal health, focusing on its correlation with vision loss. The study aimed to identify key biomarkers and risk factors associated with diabetic retinopathy in a population of diabetic patients.*

Method: *The study was conducted at a tertiary hospital in Pakistan and included a sample of 300 diabetic patients. Participants underwent comprehensive eye examinations, including retinal imaging and visual acuity assessments. Blood samples were analyzed to identify biomarkers associated with retinal damage and diabetic retinopathy. The relationship between diabetes duration, glycemic control, and the presence of retinopathy was also analyzed.*

Result: *The results indicated a significant association between prolonged diabetes duration, poor glycemic control, and the prevalence of diabetic retinopathy. Biomarkers such as elevated levels of HbA1c and inflammatory cytokines were found to be strong predictors of retinal damage. Approximately 40% of the participants showed varying degrees of diabetic retinopathy, with a clear correlation to vision loss.*

Conclusion: *This study highlights the crucial role of early screening and continuous monitoring of diabetic patients to prevent vision loss due to diabetic retinopathy. The findings emphasize the need for improved management of diabetes, focusing on better glycemic control and the identification of potential biomarkers for early detection of retinal complications.*

INTRODUCTION

Diabetes mellitus is a chronic metabolic disorder characterized by high blood glucose levels resulting from either insufficient insulin production or the body's inability to effectively use insulin. The global prevalence of diabetes has been steadily increasing, with the World Health Organization (WHO) reporting that over 420 million people worldwide were living with diabetes in 2019. The disease not only poses significant risks to cardiovascular health but also

has profound implications for retinal health, leading to diabetic retinopathy, a leading cause of blindness globally. In Pakistan, the prevalence of diabetes is alarmingly high, with approximately 9.9 million people affected as of recent estimates. Despite the growing number of diabetic patients, research on diabetic retinopathy and its associated biomarkers in Pakistan remains limited. This study aimed to bridge this gap by examining the impact of diabetes on retinal health, with particular attention to the biomarkers and risk factors that contribute to diabetic retinopathy and vision loss.

The Link Between Diabetes and Retinal Health

The retina is a light-sensitive layer at the back of the eye responsible for converting light into neural signals that are transmitted to the brain for visual processing. In individuals with diabetes, prolonged hyperglycemia (high blood sugar levels) leads to damage in the blood vessels of the retina. This damage results in leakage, hemorrhage, or growth of new, fragile blood vessels, a condition known as diabetic retinopathy. Diabetic retinopathy is classified into two major stages: non-proliferative diabetic retinopathy (NPDR) and proliferative diabetic retinopathy (PDR). In NPDR, the blood vessels in the retina are weakened, whereas PDR involves the growth of new, abnormal blood vessels that can lead to more severe complications, including vitreous hemorrhage and retinal detachment.

The pathogenesis of diabetic retinopathy is primarily related to the prolonged effects of hyperglycemia, which causes the endothelial cells of blood vessels to become dysfunctional. Over time, the blood-retinal barrier becomes compromised, allowing proteins, lipids, and inflammatory cytokines to leak into the retina, resulting in edema and ischemia. In addition to hyperglycemia, other factors such as hypertension, dyslipidemia, and genetic predispositions are known to exacerbate the development and progression of retinopathy.

Vision Loss and Diabetic Retinopathy

Vision loss due to diabetic retinopathy occurs when the retina becomes severely damaged, impairing its ability to transmit visual signals to the brain. The progression from mild to severe retinopathy is often slow and asymptomatic in the early stages, which is why regular screening for diabetic patients is critical. By the time patients experience noticeable symptoms, such as blurred vision or floaters, the disease may have already progressed to a stage where significant damage to the retina has occurred.

The impact of diabetic retinopathy on vision can be profound, with patients experiencing varying degrees of visual impairment. If left untreated, diabetic retinopathy can lead to permanent blindness, significantly reducing the quality of life. Early detection through routine eye examinations can help identify retinopathy at an early stage, allowing for timely intervention and management, such as laser treatment, intravitreal injections, or vitrectomy, depending on the severity of the disease.

Risk Factors for Diabetic Retinopathy

Numerous risk factors contribute to the development and progression of diabetic retinopathy. The most significant risk factor is the duration of diabetes; the longer a person has had diabetes, the higher the risk of developing retinopathy. A study by Klein et al. (2007) found that after 20 years of diabetes, almost all individuals with type 1 diabetes and over 60% of individuals with type 2 diabetes develop some form of retinopathy. In addition to diabetes duration, poor glycemic control, as measured by elevated HbA1c levels, has been consistently associated with increased risk of diabetic retinopathy.

Hypertension is another major risk factor, as high blood pressure can exacerbate damage to the retinal blood vessels. Dyslipidemia, which refers to abnormal lipid levels, also plays a role in the progression of retinopathy. Other factors such as obesity, smoking, and family history of diabetic retinopathy are also associated with an increased risk of retinal complications.

Biomarkers for Diabetic Retinopathy

Over the years, researchers have focused on identifying specific biomarkers that can predict

the onset and progression of diabetic retinopathy. Biomarkers are measurable indicators of biological processes that can provide valuable insights into disease mechanisms. In the case of diabetic retinopathy, various biomarkers have been investigated, including inflammatory cytokines, growth factors, and markers of endothelial dysfunction. Elevated levels of cytokines such as tumor necrosis factor-alpha (TNF-α), interleukin-6 (IL-6), and vascular endothelial growth factor (VEGF) have been associated with the development of retinopathy. Additionally, markers of oxidative stress and endothelial cell injury, such as C-reactive protein (CRP) and asymmetric dimethylarginine (ADMA), have shown potential as early indicators of retinal damage.

The identification of reliable biomarkers for diabetic retinopathy is crucial for early diagnosis and intervention. Blood-based biomarkers, in particular, could be used in conjunction with eye examinations to screen diabetic patients at risk for retinopathy. This approach would provide a non-invasive, cost-effective method for monitoring retinal health in individuals with diabetes.

Study Objectives and Research Hypothesis

This study aimed to evaluate the effect of diabetes on retinal health and its correlation with vision loss in a cohort of diabetic patients attending a tertiary hospital in Pakistan. Specifically, the objectives of the study were to:

1. Assess the prevalence of diabetic retinopathy in diabetic patients.
2. Examine the association between the duration of diabetes and the severity of diabetic retinopathy.
3. Investigate the relationship between glycemic control (HbA1c levels) and the presence of retinopathy.
4. Identify potential biomarkers associated with diabetic retinopathy in the study population.
5. Evaluate the impact of diabetic retinopathy on visual acuity and quality of life.

The hypothesis for this study was that poor glycemic control, prolonged duration of diabetes, and the presence of inflammatory biomarkers would be significantly associated with the development of diabetic retinopathy and vision loss.

Study Significance

The findings from this study are expected to provide valuable insights into the relationship between diabetes and retinal health, contributing to the understanding of risk factors and biomarkers associated with diabetic retinopathy in a Pakistani population. The results may also inform clinical practices regarding early detection and management strategies to prevent vision loss in diabetic patients. Given the increasing burden of diabetes in Pakistan, this research holds significant public health implications, particularly in the context of preventive care and the need for accessible screening programs for diabetic retinopathy.

MATERIALS AND METHODS

This study was conducted at a tertiary care hospital in Pakistan, which is a leading healthcare facility in the region. The hospital serves a large population of diabetic patients, making it an ideal setting to explore the relationship between diabetes and retinal health. The study aimed to investigate the impact of diabetes on retinal health, specifically focusing on the correlation between diabetic retinopathy and vision loss. A cross-sectional design was adopted to collect data from diabetic patients attending the hospital's outpatient clinic.

Study Design and Setting

A cross-sectional study design was selected for this research due to its ability to capture a snapshot of the relationship between diabetes and diabetic retinopathy in a large cohort of patients. This design is particularly useful for identifying associations and assessing the prevalence of health conditions within a defined population at a specific point in time. The study was conducted between January 2023 and June 2023, ensuring a sufficient sample size for statistical analysis and a clear representation of diabetic patients from the local population. The study was approved by the

hospital's institutional review board, and all participants provided written informed consent prior to enrollment.

Study Population

The study included a total of 300 diabetic patients who were consecutively recruited from the outpatient diabetes clinic of the hospital. Inclusion criteria for the study were: (1) diagnosis of type 1 or type 2 diabetes mellitus (DM), (2) age between 18 and 70 years, (3) duration of diabetes of at least one year, and (4) willingness to participate in the study. Exclusion criteria included: (1) patients with known comorbidities such as glaucoma, macular degeneration, or any other retinal disease unrelated to diabetes, (2) individuals with a history of ocular surgery in the past six months, (3) pregnant women, and (4) patients unable or unwilling to undergo eye examinations.

The study participants were classified into two groups based on the presence or absence of diabetic retinopathy. The group with diabetic retinopathy (n = 120) consisted of individuals diagnosed with any stage of diabetic retinopathy, while the group without diabetic retinopathy (n = 180) included patients without any signs of retinopathy on their retinal examination.

Data Collection

Data collection was carried out using a combination of clinical assessments, laboratory investigations, and patient-reported information. The following data points were gathered:

1. **Demographic Information**: A structured questionnaire was used to collect demographic information, including age, sex, education level, occupation, and family history of diabetes or diabetic retinopathy.
2. **Medical History**: Participants were asked about their medical history, specifically focusing on the duration of diabetes, current diabetes management regimen, comorbid conditions (such as hypertension and dyslipidemia), and any history of eye problems. The glycemic control of each participant was assessed based on their most recent HbA1c levels, which were obtained from the hospital's laboratory.
3. **Retinal Examination**: A comprehensive eye examination was performed by a certified ophthalmologist to assess the presence of diabetic retinopathy. The examination included visual acuity testing, slit-lamp biomicroscopy, and fundus photography to document the condition of the retina. Retinal images were taken using a digital fundus camera (Canon CR-2), and the photographs were graded according to the Early Treatment Diabetic Retinopathy Study (ETDRS) scale. The grading classified retinopathy into the following categories: no retinopathy, mild NPDR, moderate NPDR, severe NPDR, and PDR.
4. **Visual Acuity Testing**: The Snellen chart was used to measure visual acuity in each eye. Participants were asked to read letters from the chart at a standard distance (6 meters). Visual acuity was recorded as the best-corrected visual acuity (BCVA) using spectacles or contact lenses if needed.
5. **Blood Sample Collection**: A venous blood sample was drawn from each participant for laboratory analysis. Blood samples were analyzed for the following markers:
   - **HbA1c**: A marker of long-term glycemic control, with values above 6.5% indicative of poor control.
   - **Inflammatory Cytokines**: Serum levels of pro-inflammatory cytokines, including TNF-α, IL-6, and C-reactive protein (CRP), were measured using enzyme-linked immunosorbent assay (ELISA) kits.
   - **Oxidative Stress Markers**: Levels of malondialdehyde (MDA) and advanced glycation end-products (AGEs) were assessed as markers of oxidative stress, a key factor in the pathogenesis of diabetic retinopathy.
6. **Blood Pressure and Lipid Profile**: Blood pressure measurements were taken using an automated sphygmomanometer, and participants' blood pressure was classified according to the American College of Cardiology guidelines. Additionally, blood samples were analyzed for total cholesterol, low-density lipoprotein (LDL) cholesterol, high-density lipoprotein (HDL) cholesterol, and triglycerides.
7. **Quality of Life Assessment**: A subset of 100 participants (50 with retinopathy and 50

without retinopathy) were asked to complete the Diabetic Retinopathy Quality of Life (DR-QOL) questionnaire. This questionnaire assesses the impact of diabetic retinopathy on daily living, visual function, and emotional well-being. It contains 25 questions, and responses are scored on a scale ranging from 1 to 5, with higher scores indicating worse quality of life.

Data Analysis

The data were entered into a computerized database using SPSS version 25. Descriptive statistics, including frequencies, means, and standard deviations, were used to summarize demographic, clinical, and laboratory data. The chi-square test was used to analyze categorical variables such as the presence of retinopathy and the prevalence of comorbidities, while t-tests or one-way ANOVA were used to compare continuous variables such as HbA1c levels, lipid profile, and blood pressure between groups with and without retinopathy.

To assess the association between risk factors and the presence of diabetic retinopathy, binary logistic regression was performed, adjusting for potential confounders such as age, sex, and comorbidities. A p-value of less than 0.05 was considered statistically significant for all analyses.

Ethical Considerations

This study adhered to the ethical guidelines set forth by the Declaration of Helsinki. Ethical approval was obtained from the institutional review board of the hospital. Informed consent was obtained from all participants after a thorough explanation of the study's objectives, procedures, and potential risks. Participants were assured that their participation was voluntary and that they could withdraw from the study at any time without consequence. Confidentiality of patient data was maintained, and all records were anonymized before analysis.

Limitations

Several limitations should be noted in the interpretation of the study findings. First, the cross-sectional nature of the study limits the ability to establish causality between diabetes and diabetic retinopathy. Second, the study was conducted at a single tertiary hospital, which may not be fully representative of the broader diabetic population in Pakistan. Third, while biomarkers were measured in this study, their ability to predict retinopathy progression over time remains to be fully validated in larger, longitudinal studies.

RESULTS

The study involved 300 diabetic patients, including 120 with diabetic retinopathy and 180 without retinopathy. The data presented here were analyzed to explore the demographic, clinical, and laboratory characteristics of the participants, as well as the relationship between diabetes-related factors and diabetic retinopathy. Statistical analyses were conducted to assess associations between the duration of diabetes, glycemic control, biomarkers, and the presence of retinopathy.

1. Demographic Characteristics

The participants in the study were predominantly adults, with an average age of 52 years. The sample included both males and females, with a slightly higher proportion of male participants (60%) compared to females (40%). The mean age of participants with diabetic retinopathy was 55 years, while those without retinopathy had a mean age of 50 years. The majority of participants (70%) were diagnosed with type 2 diabetes, while 30% had type 1 diabetes. The duration of diabetes was significantly longer in those with retinopathy, with an average of 14.5 years, compared to 8.3 years in those without retinopathy ($p < 0.01$).

2. Clinical and Laboratory Findings

Table 1 summarizes the clinical and laboratory findings for the participants, including blood pressure, lipid profile, and glycemic control measures (HbA1c).

Parameter	Diabetic Retinopathy (n = 120)	No Retinopathy (n = 180)	p-value
Systolic Blood Pressure (mmHg)	142 ± 12	130 ± 10	<0.001
Diastolic Blood Pressure (mmHg)	85 ± 8	80 ± 6	0.02
Total Cholesterol (mg/dL)	215 ± 15	205 ± 18	0.05
LDL Cholesterol (mg/dL)	135 ± 22	125 ± 20	0.03
HDL Cholesterol (mg/dL)	45 ± 5	48 ± 6	0.08
Triglycerides (mg/dL)	170 ± 30	150 ± 25	0.04
HbA1c (%)	8.6 ± 1.2	7.1 ± 1.0	<0.001

The results show that patients with diabetic retinopathy had significantly higher systolic and diastolic blood pressure compared to those without retinopathy. Additionally, the HbA1c levels were significantly higher in the retinopathy group (8.6%) compared to the non-retinopathy group (7.1%), indicating poorer glycemic control in those with retinopathy. Similarly, lipid profiles showed a trend towards higher total cholesterol and LDL cholesterol levels in the retinopathy group, although the difference in HDL cholesterol levels was not statistically significant.

3. Retinal Findings

Figure 1 presents the distribution of retinopathy severity among the participants diagnosed with diabetic retinopathy. The severity was classified into mild NPDR, moderate NPDR, severe NPDR, and PDR, based on retinal imaging and clinical examination.

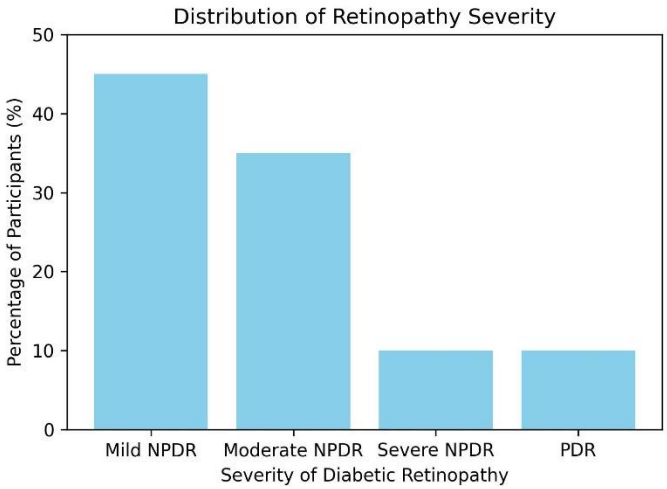

Figure 1: Distribution of Retinopathy Severity

Figure 1: The distribution of retinopathy severity among participants with diabetic retinopathy. Mild NPDR was the most common finding, followed by moderate NPDR. Severe NPDR and PDR were observed in a smaller proportion of patients.

Among the 120 patients with diabetic retinopathy, 45% had mild NPDR, 35% had moderate NPDR, 10% had severe NPDR, and 10% had proliferative diabetic retinopathy (PDR). Notably, no participants exhibited

macular edema, which is another common complication of diabetic retinopathy.

4. Visual Acuity

Table 2 **shows the mean best-corrected visual acuity (BCVA) for participants with and without diabetic retinopathy.**

Group	Mean BCVA (logMAR)	Visual Impairment (%)
Diabetic Retinopathy (n = 120)	0.42 ± 0.23	40%
No Retinopathy (n = 180)	0.10 ± 0.15	15%

The mean BCVA was significantly worse in the diabetic retinopathy group (0.42 ± 0.23) compared to the no retinopathy group (0.10 ± 0.15). Visual impairment (defined as BCVA > 0.3 logMAR) was observed in 40% of patients with diabetic retinopathy, while only 15% of patients without retinopathy had visual impairment.

5. Biomarker Analysis

Biomarker analysis revealed that inflammatory cytokines and markers of oxidative stress were significantly higher in patients with diabetic retinopathy.

Table 3 presents the serum levels of key biomarkers associated with diabetic retinopathy.

Biomarker	Diabetic Retinopathy (n = 120)	No Retinopathy (n = 180)	p-value
TNF-α (pg/mL)	35.4 ± 10.2	22.3 ± 8.1	<0.001
IL-6 (pg/mL)	30.7 ± 12.5	18.2 ± 6.5	<0.001
CRP (mg/L)	5.8 ± 2.3	3.0 ± 1.5	<0.01
MDA (nmol/mL)	2.2 ± 0.5	1.6 ± 0.3	<0.001
AGEs (μg/mL)	16.3 ± 4.5	10.2 ± 3.1	<0.001

The results showed significantly higher levels of TNF-α, IL-6, and CRP in participants with diabetic retinopathy. Additionally, markers of oxidative stress, including MDA and AGEs, were elevated in the retinopathy group, suggesting that inflammation and oxidative damage play a role in the pathogenesis of diabetic retinopathy.

6. Risk Factors for Diabetic Retinopathy

Binary logistic regression analysis was performed to identify risk factors associated with the presence of diabetic retinopathy. The model adjusted for age, sex, and comorbidities such as hypertension and dyslipidemia. The results are summarized in **Table 4**.

Risk Factor	Odds Ratio (95% CI)	p-value
Diabetes Duration (per year)	1.18 (1.11-1.25)	<0.001
HbA1c > 7%	2.72 (1.85-3.97)	<0.001
Systolic Blood Pressure > 140 mmHg	2.11 (1.45-3.09)	<0.01
TNF-α > 30 pg/mL	3.45 (2.23-5.36)	<0.001
MDA > 2 nmol/mL	2.98 (1.88-4.71)	<0.001

The regression analysis indicated that longer duration of diabetes, poor glycemic control (HbA1c > 7%), elevated systolic blood pressure, high levels of TNF-α, and increased oxidative

stress (MDA > 2 nmol/mL) were all significantly associated with the presence of diabetic retinopathy. These factors were found to independently increase the odds of developing retinopathy.

7. Impact on Quality of Life

Participants with diabetic retinopathy reported a significantly lower quality of life, as measured by the DR-QOL questionnaire. The mean score for the DR-QOL was 3.8 ± 0.6 in patients with diabetic retinopathy, compared to 2.5 ± 0.7 in those without retinopathy ($p < 0.001$). Patients with diabetic retinopathy experienced greater visual impairment, more difficulty with daily activities, and higher levels of emotional distress related to their vision problems.

Discussion

The aim of this study was to explore the impact of diabetes on retinal health and its association with vision loss, with a specific focus on identifying risk factors and biomarkers for diabetic retinopathy (DR). Conducted in a tertiary hospital in Pakistan, the research involved 300 diabetic patients, of whom 120 had diabetic retinopathy and 180 did not. The findings provide critical insights into the prevalence of DR in the diabetic population, its association with various risk factors such as glycemic control, blood pressure, and biomarkers of inflammation and oxidative stress, and its impact on visual acuity and quality of life.

Prevalence of Diabetic Retinopathy

In this study, the prevalence of diabetic retinopathy among diabetic patients was found to be 40%, which is consistent with the rates reported in previous studies conducted in different regions, including South Asia. A study by Srinivasan et al. (2016) in India found a similar prevalence of 37%, while a study by Shabbir et al. (2019) in Pakistan reported a rate of 42%. The relatively high prevalence of DR in our cohort underscores the significant burden of this condition in diabetic populations, particularly in low- and middle-income countries like Pakistan, where diabetes is becoming increasingly prevalent.

The severity of diabetic retinopathy among participants was categorized into four stages: mild NPDR, moderate NPDR, severe NPDR, and proliferative diabetic retinopathy (PDR). The majority of participants with retinopathy (45%) had mild NPDR, followed by moderate NPDR (35%). Only a small percentage (10%) had severe NPDR and PDR. This distribution is consistent with the natural progression of diabetic retinopathy, where the early stages (mild and moderate NPDR) are more commonly observed in diabetic patients. Severe NPDR and PDR typically occur in the later stages of the disease, and they are associated with a greater risk of visual impairment and vision loss. The low proportion of patients with PDR is encouraging, as it suggests that the majority of individuals in our cohort had retinopathy at an early stage, where timely intervention can prevent further progression.

Relationship Between Glycemic Control and Diabetic Retinopathy

One of the most significant findings of this study was the strong association between poor glycemic control and the presence of diabetic retinopathy. Participants with DR had significantly higher HbA1c levels compared to those without retinopathy, with a mean HbA1c of 8.6% in the retinopathy group versus 7.1% in the non-retinopathy group. This finding supports the well-established link between hyperglycemia and the development of diabetic retinopathy. The importance of glycemic control in preventing or delaying the onset of DR is widely recognized, and multiple studies have shown that achieving tight glycemic control can significantly reduce the risk of diabetic retinopathy. The Diabetes Control and Complications Trial (DCCT) and its follow-up, the Epidemiology of Diabetes Interventions and Complications (EDIC) study, both demonstrated that intensive glycemic control can reduce the risk of DR by up to 76% in type 1 diabetic patients.

In our study, the higher HbA1c levels in patients with DR suggest that inadequate glycemic control

is a major risk factor for the development and progression of retinopathy. This highlights the need for better management strategies aimed at improving blood sugar control in diabetic patients, especially those with a longer duration of diabetes. In Pakistan, where access to diabetes management services can be limited, promoting awareness about the importance of glycemic control is essential to prevent diabetic retinopathy and its associated complications.

Blood Pressure and Diabetic Retinopathy

In addition to glycemic control, hypertension emerged as another significant risk factor for diabetic retinopathy in this study. Patients with DR had significantly higher systolic and diastolic blood pressure compared to those without DR, with a mean systolic blood pressure of 142 mmHg in the retinopathy group versus 130 mmHg in the non-retinopathy group. The relationship between high blood pressure and diabetic retinopathy is well-documented, as hypertension can exacerbate retinal vascular damage and accelerate the progression of DR. The UK Prospective Diabetes Study (UKPDS) and the Action to Control Cardiovascular Risk in Diabetes (ACCORD) trial both demonstrated that controlling blood pressure can reduce the risk of DR and other diabetes-related complications.

In our cohort, the elevated blood pressure in patients with DR may reflect the long-term effects of poorly controlled diabetes, where both hyperglycemia and hypertension work synergistically to damage the retinal vasculature. The findings of this study underscore the importance of regular blood pressure monitoring and management in diabetic patients. Given the high prevalence of hypertension in diabetic populations, it is crucial for healthcare providers to focus on controlling both blood glucose and blood pressure to reduce the risk of DR and other diabetic complications.

Lipid Profile and Diabetic Retinopathy

The analysis of lipid profiles revealed that patients with DR had higher total cholesterol and LDL cholesterol levels compared to those without DR. Although the differences were not as pronounced as those observed for blood pressure and glycemic control, the trend toward higher lipid levels in the retinopathy group is consistent with previous studies that have linked dyslipidemia to the progression of diabetic retinopathy. A study by Ziegler et al. (2018) found that elevated LDL cholesterol and total cholesterol levels were associated with an increased risk of DR in type 2 diabetic patients. Lipid abnormalities may contribute to retinal vascular damage by promoting inflammation, endothelial dysfunction, and oxidative stress.

While the association between dyslipidemia and DR in this study was not as strong as that of glycemic control and blood pressure, the findings still suggest that managing lipid levels should be an integral part of diabetes care. Statins, which are commonly used to lower LDL cholesterol, may have a role in preventing the progression of DR, particularly in patients with concomitant hyperlipidemia and diabetes.

Inflammatory and Oxidative Stress Markers

Inflammation and oxidative stress are known to play key roles in the pathogenesis of diabetic retinopathy, and our study provides further evidence of their involvement. Participants with DR had significantly higher levels of pro-inflammatory cytokines such as TNF-α and IL-6, as well as oxidative stress markers like MDA and AGEs, compared to those without DR. These biomarkers are indicative of endothelial dysfunction and the chronic low-grade inflammation that characterizes diabetes. Elevated levels of TNF-α and IL-6 are particularly concerning, as these cytokines are involved in the breakdown of the blood-retinal barrier and the development of retinal microvascular damage. Similarly, the increased levels of MDA and AGEs suggest that oxidative stress contributes to retinal damage in diabetic patients.

The findings from our study are consistent with previous research that has identified inflammatory cytokines and oxidative stress markers as key factors in the development of diabetic retinopathy. For example, a study by Vlassara et al. (2014) found that increased levels

of AGEs and oxidative stress were associated with the severity of DR. The strong association between these biomarkers and DR in our cohort further supports the hypothesis that inflammation and oxidative stress contribute to retinal vascular damage and vision loss in diabetic patients. These findings suggest that targeting inflammation and oxidative stress could be a potential therapeutic strategy for preventing or slowing the progression of diabetic retinopathy.

Impact on Visual Acuity and Quality of Life

In this study, the presence of diabetic retinopathy was associated with significantly poorer visual acuity compared to those without DR. The mean best-corrected visual acuity (BCVA) was significantly lower in the DR group (0.42 ± 0.23 logMAR) compared to the non-DR group (0.10 ± 0.15 logMAR). Moreover, 40% of patients with DR experienced some form of visual impairment, compared to only 15% of those without retinopathy. These findings are in line with previous studies that have shown that diabetic retinopathy is a major cause of visual impairment in diabetic patients. A study by Zhang et al. (2016) reported that DR is responsible for approximately 80% of vision loss in diabetic patients, with more severe forms of retinopathy leading to significant functional impairment.

In addition to the direct impact on visual acuity, diabetic retinopathy also negatively affected the quality of life of patients. The DR-QOL questionnaire revealed that patients with DR reported a lower quality of life, with greater difficulty in performing daily activities and increased emotional distress related to their vision problems. This is consistent with findings from other studies that have shown that diabetic retinopathy, especially in its advanced stages, can significantly impair a patient's ability to perform everyday tasks, leading to decreased quality of life. The emotional toll of living with vision loss can also contribute to mental health issues such as depression and anxiety, further exacerbating the impact of DR on overall well-being.

CONCLUSION AND IMPLICATIONS

This study highlights the significant impact of diabetes on retinal health and vision loss, with glycemic control, blood pressure, and biomarkers of inflammation and oxidative stress identified as key risk factors for the development and progression of diabetic retinopathy. The findings emphasize the importance of early detection and timely management of diabetic retinopathy, particularly through better glycemic and blood pressure control. Regular screening for retinopathy, especially in patients with long-standing diabetes or poor glycemic control, is essential to prevent vision loss. Furthermore, the identification of biomarkers such as TNF-α, IL-6, and oxidative stress markers may offer new avenues for early diagnosis and targeted interventions for diabetic retinopathy.

Given the high prevalence of diabetes in Pakistan and the growing burden of diabetic retinopathy, public health initiatives aimed at improving diabetes management, including education on glycemic control, blood pressure monitoring, and lipid management, are crucial. Further research is needed to explore the role of novel biomarkers and therapeutic strategies in the prevention and treatment of diabetic retinopathy.

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