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Impact of HbA1c, Blood Pressure, and Cholesterol on Ocular Complications in Type 2 Diabetes Mellitus: A Clinical Analytical Study from Libya

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تأثير *HbA1c* وضغط الدم والكوليسترول على المضاعفات العينية المرتبطة بداء السكري من النوع الثاني: دراسة سريرية تحليلية في ليبيا

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Abstract:
Type 2 Diabetes Mellitus (T2DM) is a major chronic condition globally and increasingly prevalent in Libya. Among its systemic complications, ocular disorders such as cataract, retinal detachment, and internal retinal hemorrhage pose significant risks to vision. This study evaluated the association between HbA1c, blood pressure (BP), and cholesterol levels with diabetic eye complications in Libyan patients. Data were obtained via electronic surveys distributed through the Libyan Diabetes Association and supplemented with clinical records from endocrinology centers.

Patients were categorized into groups with and without retinopathy, including specific subtypes. Laboratory measurements were conducted using standardized devices (Mindray BS-240, Hemo One ISE). The findings revealed a strong association between elevated HbA1c (≥9%), high BP (>160/90 mmHg), and serum cholesterol (>200 mg/dL) with the occurrence of ocular complications. Cataract cases showed progressive metabolic deterioration, while retinal detachment and internal hemorrhage were more pronounced in those with combined dysregulation.

Interestingly, patients without eye complications maintained stable metabolic parameters, highlighting the protective effect of early and integrated control. Gender-based differences in internal hemorrhage suggested possible physiological influences beyond chronic markers.

The results reinforce the need for comprehensive diabetic care models incorporating glycemic, cardiovascular, and lipid monitoring. Community organizations like the Libyan Diabetes Association play a key role in data collection, patient education, and screening. The study advocates for multi-specialty collaboration and the implementation of national preventive frameworks to reduce diabetes-related visual loss.

Keywords: Type 2 Diabetes, Diabetic Retinopathy, Glycated Hemoglobin (HbA1c), Blood Pressure, Cholesterol, Metabolic Control, Chronic Complications.

الملخص
يُعد داء السكري من النوع الثاني من أكثر الأمراض المزمنة انتشارًا في ليبيا، ويُرافقه العديد من المضاعفات الجهازية، أبرزها العينية كالمياه البيضاء، انفصال الشبكية، والنزيف الداخلي في الشبكية. هدفت هذه الدراسة إلى تقييم العلاقة بين HbA1c، ضغط الدم، والكوليسترول في الدم، ومدى ارتباطها بمضاعفات العين لدى مرضى السكري الليبيين.
تم جمع البيانات عبر استبيان إلكتروني بالتعاون مع جمعية ليبيا لمرضى السكري، مع دعم من مراكز طبية في مجال الغدد الصماء. تم تصنيف المرضى حسب الحالة العينية إلى مجموعات تعاني أو لا تعاني من اعتلال الشبكية، بما في ذلك أنواع محددة كالمياه البيضاء والانفصال الشبكي والنزيف الداخلي.
أظهرت النتائج وجود ارتباط قوي بين ارتفاع(≥9%) HbA1c ، ضغط الدم (160/90< مم زئبقي)، والكوليسترول (200<ملغم/ديسيلتر) مع حدوث المضاعفات العينية. الحالات المصابة بالمياه البيضاء أظهرت تدهورًا أيضيًا تدريجيًا، بينما ارتبط انفصال الشبكية والنزيف الداخلي بانخفاض في ضبط المؤشرات الثلاثة.
في المقابل، حافظت المجموعة غير المصابة على استقرار في HbA1c وضغط الدم والكوليسترول، مما يدل على أهمية السيطرة المبكرة والمتكاملة. كما أشارت النتائج إلى فروقات محتملة مرتبطة بالجنس، خاصة في حالات النزيف الداخلي.
تؤكد الدراسة أهمية دمج متابعة السكر، الضغط، والدهون ضمن نماذج الرعاية الطبية الشاملة. وتبرز دور الجمعيات الصحية في ليبيا في جمع البيانات وتقديم التوعية الصحية. كما تدعو إلى تعزيز التعاون بين التخصصات وإطلاق برامج وطنية للوقاية من فقدان البصر المرتبط بالسكري.

الكلمات المفتاحية: السكري من النوع الثاني، اعتلال الشبكية السكري، الهيموغلوبين السكري HbA1c، ضغط الدم، الكوليسترول، التحكم الأيضي، المضاعفات المزمنة.

Introduction

Chronic metabolic disorders—namely diabetes mellitus, hypertension, and dyslipidemia—are among the most prevalent global health challenges and major contributors to systemic and ocular complications. Type 2 diabetes mellitus (T2DM), in particular, has surged in prevalence in low- and middle-income countries, with over 830 million affected individuals globally. Poorly managed diabetes disrupts multiple organ systems, leading to cardiovascular disease, nephropathy, and vision-threatening complications such as diabetic retinopathy (DR) [1]–[5].

Diabetic retinopathy, the leading cause of blindness in working-age adults, results from hyperglycemia-induced microvascular damage within the retina. This process involves oxidative stress, polyol pathway activation, advanced glycation end-products (AGEs) formation, and vascular endothelial growth factor (VEGF) overexpression [6]–[9]. Additional systemic factors—like uncontrolled hypertension and elevated LDL cholesterol—exacerbate retinal ischemia, vascular permeability, and inflammatory responses, accelerating DR progression [10]–[13].

Hypertension affects nearly 1.4 billion people worldwide and often coexists with diabetes, creating a synergistic risk for vascular injury and DR development. Similarly, hypercholesterolemia, especially elevated LDL and triglycerides, contributes to atherogenesis and capillary degeneration in retinal tissues [14]–[17]. Furthermore, diabetic nephropathy, resulting from chronic renal stress and glomerular damage, shares common pathogenic pathways with DR, intensifying ocular and systemic deterioration [18]–[20].

Gestational diabetes (GDM), an increasingly common condition during pregnancy, and type 1 diabetes mellitus (T1DM), driven by autoimmune β-cell destruction, are also linked to ocular complications through similar biochemical mechanisms [21], [22]. These interconnected risk factors underscore the need for an integrated approach to early diagnosis and management of T2DM, prioritizing glycemic control, blood pressure regulation, and lipid balance to prevent the onset and progression of diabetic retinopathy.

This study aims to assess the impact of HbA1c, blood pressure, and cholesterol levels on the development of diabetic retinopathy among type 2 diabetes patients at the Diabetes and Endocrinology Hospital – Tripoli, offering insight into preventive strategies that enhance patient care outcomes.

Material and methods

Materials

This study employed a range of certified laboratory instruments and reagents to ensure analytical reliability and clinical precision.

- **Biochemical Equipment:** Mindray BS-240 Biochemistry Analyzer was used to assess glucose, lipid, liver, and renal profiles [23]. Photometer 4040 V5+ aided in spectrophotometric assays; glucose and cholesterol enzymatic reagents were sourced from standard kits per ADA-recommended protocols [1]. Blood samples were collected using EDTA tubes, handled with calibrated pipettes and cuvettes, and prepared using centrifuges and drying ovens [24].

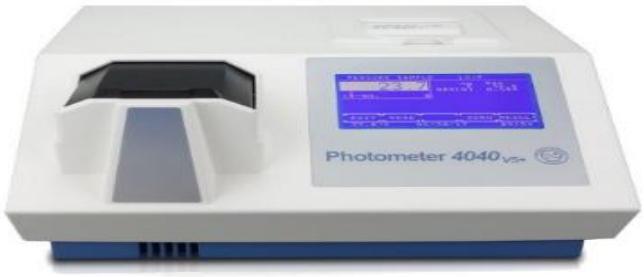


Figure.1. Photometer 4040 V5+

Figure. 2. Mindray BS-240 Biochemistry Analyzer.

- **Hematologic Monitoring:** Glucose and hemoglobin levels were measured using the Hemo One ISE Analyzer based on ion-selective electrode technology [25].

Figure. 3. Hemo One ISE.

- **Ophthalmic Diagnostics:** Indirect ophthalmoscopy was performed using OCULAR STO 90 D and MaxField STD90 D. For non-dilated retinal screening, a direct ophthalmoscope was used in line with ETDRS protocols [26].

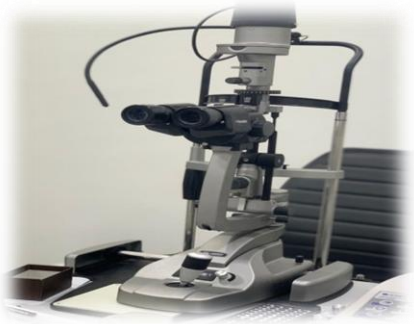


Figure. 4. OCULAR STO 90 D

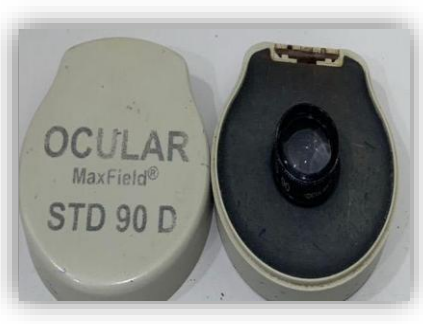


Figure. 5. OCULAR MaxField STD90 D

- **Clinical Monitoring Devices:** Blood pressure was measured using a mercury sphygmomanometer, following WHO guidelines for cardiovascular risk assessment.

Methods

Blood Glucose Estimation

Venous blood samples were drawn into EDTA tubes and centrifuged at 3000 rpm for 10–30 minutes. Quantitative glucose estimation was carried out using the Hemo One ISE analyzer, ensuring proper sample identification and calibration per manufacturer guidelines [23].

HbA1c Analysis

Whole blood samples were analyzed using ALC protocol settings. The analyzer interface was configured to "blood" sample type. HbA1c results were interpreted per ADA standards: 7% confirms poor glycemic control and diabetic diagnosis [1].

Cholesterol Measurement with Mindray BS-240

Plasma or serum samples were obtained via centrifugation. After verifying reagent placement, test parameters were set through the system's interface. Enzymatic assays measured total cholesterol, LDL, HDL, and triglycerides. Results were documented in the laboratory system [25].

Results and discussion

Results

The sample included patients with type 2 diabetes mellitus (T2DM), categorized based on ocular complications:

1. T2DM with Diabetic Retinopathy

Cataract Subgroup

A progressive elevation in HbA1c, systolic/diastolic blood pressure, and cholesterol levels was observed among female and male patients (see *Table 1–2* and *Chart 1–2*). This pattern suggests a strong correlation between poor glycemic control and cataract formation, intensified by coexisting hypertension and hyperlipidemia.

Table.1. Showing the relationship between HBA1C¸Blood Pressure and Cholesterol levels for female.

Female	HBA1C	Blood Pressure(mmHg)	Cholesterol
✔	7	140/80	179.8
✔	7.5	150/90	180
✔	8.6	159/80	182.6
✔	9	160/80	195
✔	9.2	162/80	201.4
✔	9.5	165/92	203
✔	10.6	170/80	215
✔	11	174/108	237.4

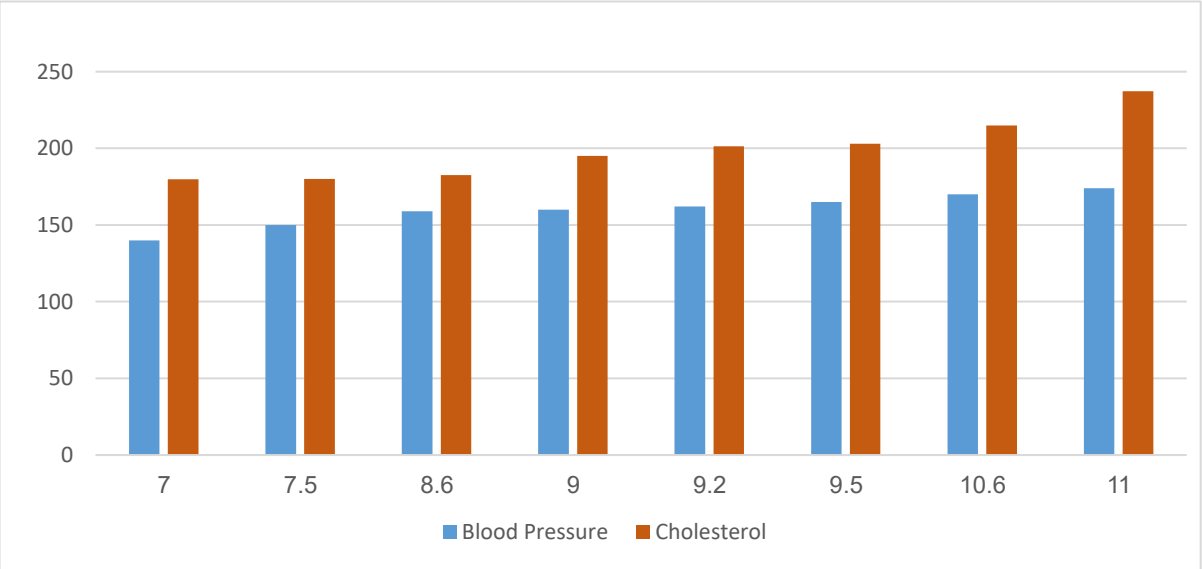


Chart.1. relationship between HBA1C¸Blood Pressure and Cholesterol Levels for females.

Table.2. Showing the relationship between HBA1C¸Blood Pressure and Cholesterol levels for male.

Male	HBA1C	Blood Pressure(mmHg)	Cholesterol
✔	6.2	130/90	150.2
✔	6.5	145/80	157
✔	6.9	145/90	177.4
✔	8.2	165/90	196.8
✔	9	170/90	206
✔	10	172/85	215.2

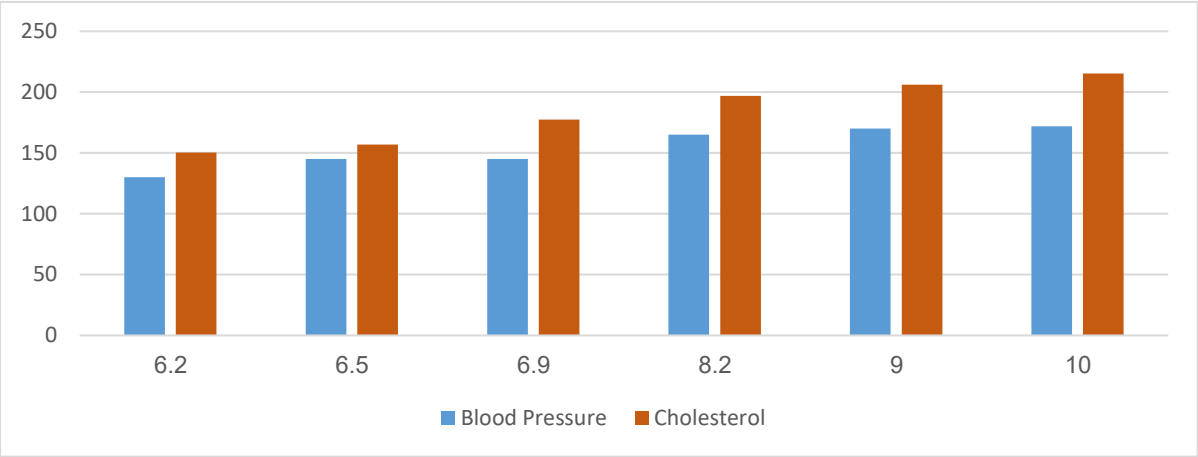


Chart.2. relationship between HBA1C¸Blood Pressure and Cholesterol Levels for males.

Retinal Detachment Subgroup

Both female and male patients with retinal detachment exhibited significantly elevated HbA1c (>9%), blood pressure (>160/90 mmHg), and cholesterol (>200 mg/dL) levels (*Table 3–4*, *Chart 3–4*). This triad appears to be a shared pathological pathway contributing to retinal separation.

Table.3. Showing the relationship between HBA1C¸Blood Pressure and cholesterol levels for female.

Female	HBA1C	Blood Pressure(mmHg)	Cholesterol
✔	6.9	140/90	169
✔	7	150/95	170
✔	8	159/80	180
✔	9	159/80	181.8
✔	11.5	170/90	248.6
✔	12	165/105	254

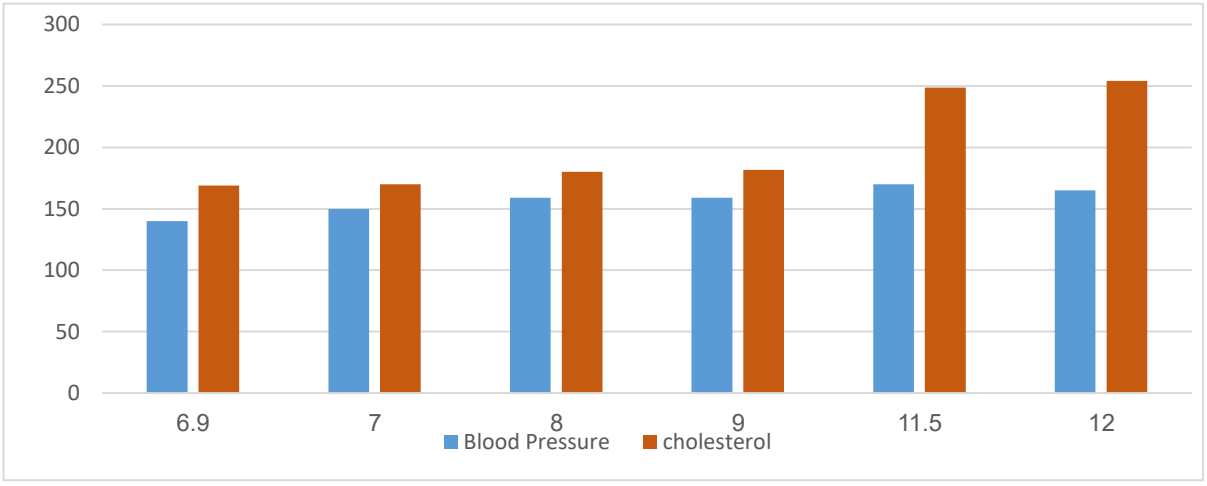


Chart.3. relationship between HBA1C¸Blood Pressure and Cholesterol Levels for Females.

Table.4. Showing the relationship between HBA1C¸Blood Pressure and Cholesterol levels for male.

Male	HBA1C	Blood Pressure(mmHg)	Cholesterol
✔	6.9	145/80	146
✔	7	150/92	159.8
✔	8.1	150/92	172
✔	8.5	158/79	176.4
✔	8.6	160/99	187.6
✔	11	180/105	203.6
✔	11.8	174/108	207

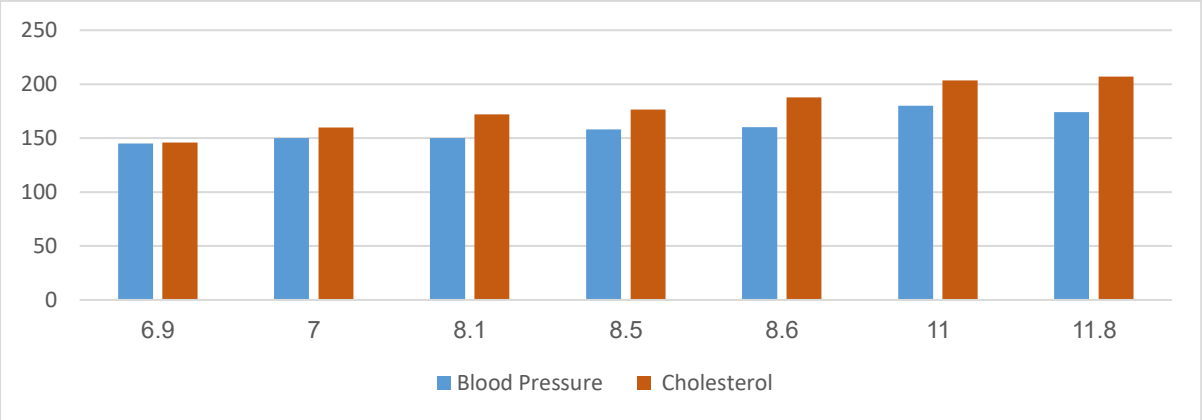


Chart.4. relationship between HBA1C¸Blood Pressure and Cholesterol Levels for males.

Vitreous Hemorrhage Subgroup

In males, a consistent increase in HbA1c and cardiovascular parameters was seen (*Table 5–6*, *Chart 5–6*). However, female data showed variability. This irregularity may reflect transient physiological changes (e.g., hormonal cycling) more than chronic disease progression.

Table.5. Showing the relationship between HBA1C¸Blood Pressure and Cholesterol levels for female.

Female	HBA1C	Blood Pressure(mmHg)	Cholesterol
✔	7.5	155/90	225
✔	8	140/90	169
✔	8.5	150/95	198.2
✔	9	178/108	198.8
✔	9.5	145/90	196
✔	10.5	170/90	255

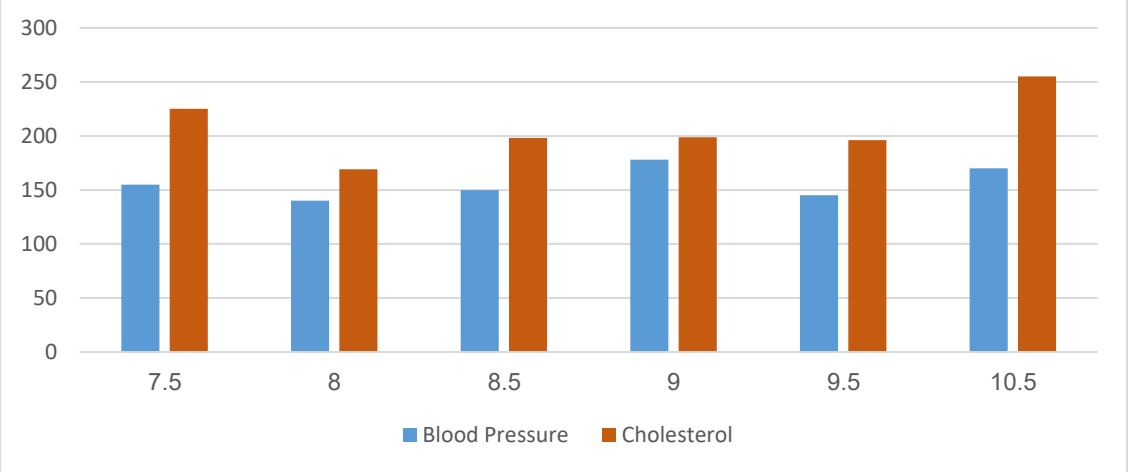


Chart.5. relationship between HBA1C¸Blood Pressure and Cholesterol Levels for Females.

Table.6. Showing the relationship between HBA1C¸Blood Pressure and Cholesterol levels for male.

Male	HBA1C	Blood Pressure(mmHg)	Cholesterol
✓	7	145/90	171
✓	7	158/90	175.2
✓	8.5	160/80	188.8
✓	9	165/95	190.4
✓	9	170/80	234
✓	11	180/90	263

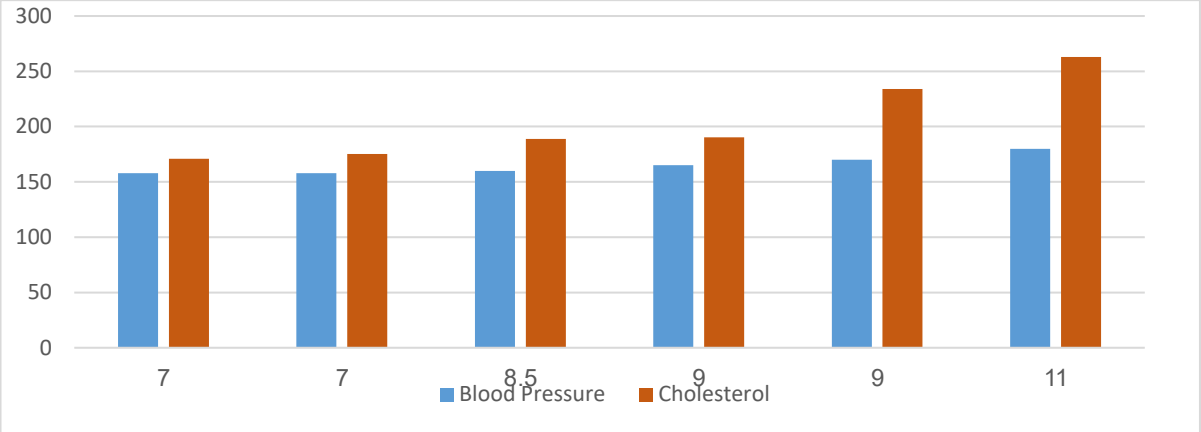


Chart.6. relationship between HBA1C¸Blood Pressure and Cholesterol Levels for males.

2. T2DM without Diabetic Retinopathy

Patients without retinopathy had HbA1c (*Table 7–8*, *Chart 7–8*), indicating that early and balanced control of metabolic variables may reduce ocular complications in diabetic individuals.

Table.7. Showing the relationship between HBA1C¸Blood Pressure and Cholesterol levels for female.

Female	HBA1C	Blood Pressure(mmHg)	Cholesterol
✓	6	125/78	155
✓	6.2	120/80	171.4
✓	7	130/85	167
✓	7	140/80	187
✓	7.6	135/85	198.2
✓	8	125/78	168
✓	9	120/80	164
✓	9	135/85	175
✓	9.7	120/75	182.6

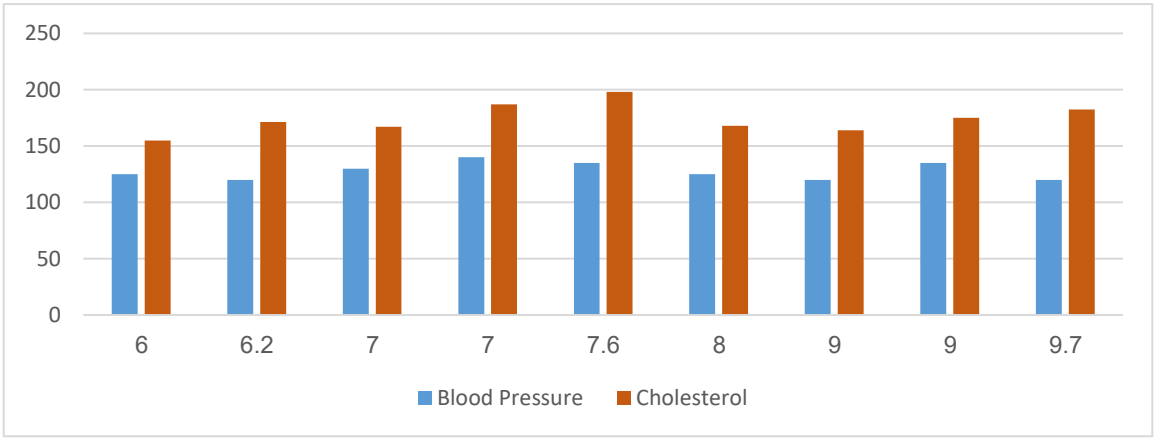


Chart.7. relationship between HBA1C¸Blood Pressure and Cholesterol Levels for Females.

Table.8. Showing the relationship between HBA1C¸Blood Pressure and Cholesterol Levels for male.

Male	HBA1C	Blood Pressure (mmHg)	Cholesterol
✔	6.4	124/80	167
✔	6.5	122/75	163
✔	6.5	120/90	186
✔	6.7	123/76	162.4
✔	7	119/74	189.8
✔	7.5	123/76	166.4
✔	7.5	120/80	181
✔	8	135/80	158
✔	9	120/80	175
✔	9.5	115/75	167

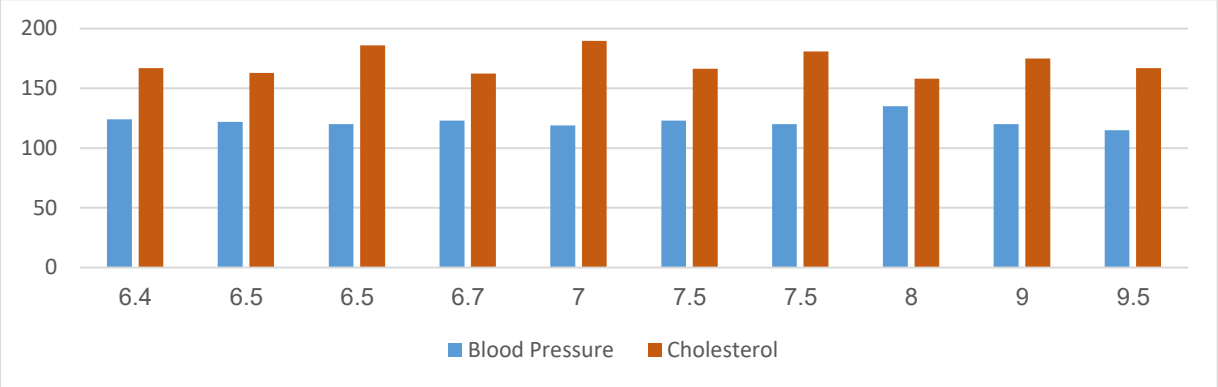


Chart.8. relationship between HBA1C¸Blood Pressure and Cholesterol Levels for males.

Discussion

The findings support prior literature linking poor glycemic control, hypertension, and hyperlipidemia to diabetic ocular pathologies [25], [1]. In retinopathy and retinal detachment cases, elevated HbA1c consistently paralleled vascular stress and lipid imbalance, suggesting a cumulative pathogenic effect.

Cataract formation appeared more pronounced in patients with HbA1c above 9%, aligning with oxidative stress mechanisms affecting lens transparency [21]. Retinal detachment was associated with hypertensive vascular insults and capillary lipid deposits, highlighting the need for multidisciplinary management.

While vitreous hemorrhage in males followed expected metabolic trends, female fluctuation patterns imply that acute hormonal shifts may transiently affect retinal integrity. Patients without ocular complications maintained stable parameters, reinforcing that early intervention and control can markedly delay or prevent retinopathic changes [26].

Conclusion

1. Conclusion:

The results of this study highlight the multi-layered interaction between glycemic status (HbA1c), blood pressure, and serum cholesterol in shaping ocular complications among patients with type 2 diabetes mellitus. A significant correlation was found between poor metabolic control and the onset of diabetic eye diseases, particularly cataract, retinal detachment, and internal retinal hemorrhage. Patients with uncontrolled HbA1c and hypertensive profiles consistently exhibited elevated cholesterol levels, suggesting a synergistic effect contributing to microvascular degeneration in retinal tissues. On the contrary, patients maintaining stable metabolic parameters were less likely to develop such complications, emphasizing the critical role of early preventive care. These findings affirm that diabetic eye health is not solely dependent on blood sugar, but on integrated cardiovascular and lipid regulation. The evidence gathered strongly advocates for multi-specialty approaches and targeted clinical screening to mitigate vision-threatening outcomes in diabetic populations.

2. Scientific Conclusions:

1. **Elevated HbA1c is a strong predictive marker** for diabetic ocular complications, particularly in patients with values ≥9%, reinforcing its role as a clinical target for preventive care.
2. **Hypertension and dyslipidemia synergistically intensify retinal damage**, especially when coexisting with poor glycemic control, suggesting the need for integrated cardiovascular monitoring in diabetic patients.

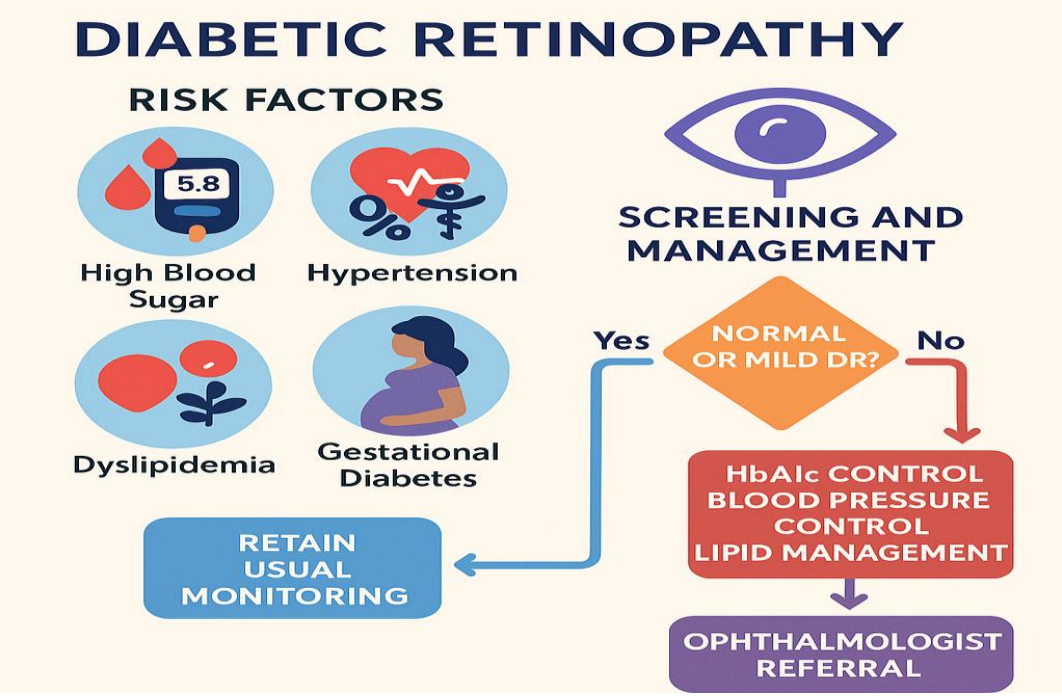
3. **Cataract formation correlates with sustained metabolic imbalance**, indicating that long-term hyperglycemia and lipid deposition may accelerate lens opacification.
4. **Retinal detachment and internal retinal hemorrhage are associated with combined metabolic insults**, not isolated glucose fluctuations, underscoring the cumulative effect of HbA1c, blood pressure, and cholesterol.
5. **Patients without retinopathy maintained stable values across all three parameters**, validating the protective value of early and multi-systemic metabolic regulation.
6. **Female fluctuation in hemorrhagic presentations may involve non-metabolic physiological triggers**, implying the importance of gender-specific assessment in diabetic ocular risk profiling.
7. **Systematic screening of ocular complications should include routine monitoring of HbA1c, lipid profile, and blood pressure**, as isolated ophthalmic exams may miss early metabolic signs.

3. Future Recommendations:

1. Implement nationwide screening programs for diabetic eye complications integrating HbA1c, lipid profile, and blood pressure metrics.
2. Establish bilingual educational protocols for patients on the importance of metabolic control to prevent retinopathy.
3. Encourage interdisciplinary collaboration between endocrinologists, ophthalmologists, and nutritionists in Libyan clinical settings.
4. Further longitudinal research is recommended to assess causality and progression over time.

Develop visual infographics and decision trees tailored for patient education and clinical awareness.

"This infographic illustrates the key risk factors for diabetic retinopathy and outlines the clinical assessment pathway, including decision-making and referral criteria."



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