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Lipid profile patterns associated with pre-diabetes: a comparative study with normoglycemic and diabetic individuals

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ABSTRACT

BACKGROUND & OBJECTIVE: Disturbed glucose metabolism is associated with dyslipidemia, a potent risk factor for cardiovascular diseases. Pre-diabetes is the intermediate state between normoglycemia and overt diabetes. Our study aims to find lipid profile patterns associated with pre-diabetes.

METHODOLOGY: This analytical cross-sectional study was conducted at the OPD of Punjab Institute of Cardiology, Lahore. This study included 360 individuals in total, 120 individuals from each glycemic group. Glycemic status was defined using the guidelines of the American Diabetes Association. Blood samples were drawn after overnight fasting and tested for lipid profile parameters and HbA1c. We used one-way ANOVA to compare lipid profile parameters between glycemic groups. We used a chi-square test to assess the association between various lipid profile patterns and glycemic groups. We used regression analysis to estimate the odds of each pattern being associated with pre-diabetes.

RESULTS: Lipid abnormalities increased with changes of glycemic status, i.e., 80.2% in the normoglycemic group, 85.8% in the pre-diabetic group and 90.8% in the diabetic group. Isolated low HDL-C, Atherogenic dyslipidemia and mixed dyslipidemia were significantly associated with change in glycemic status. Univariate regression analysis showed that the odds of getting mixed dyslipidemia increased by 250% in pre-diabetes (OR=3.509, 95%CI: 1.783-6.903, p<0.001). After adjustment for confounders, mixed dyslipidemia remained the independent predictor of pre-diabetes (OR=3.114, 95%CI: 1.477-6.566, p=0.003).

CONCLUSION: NLR Qualitative lipid profile abnormalities better define glycemic status. Mixed dyslipidemia is associated with pre-diabetes, while atherogenic lipid profiles are pronounced in diabetes, representing increased cardiovascular risk with worsening glycemic states.

KEYWORDS: Dyslipidemias, Diabetes Mellitus, Insulin Resistance.

INTRODUCTION

Pre-diabetes, characterized by impaired glucose tolerance and fasting glucose, is an intermediate state of metabolism between normoglycemia and type 2 diabetes mellitus (T2DM). According to the World Health Organization, the diagnostic criteria for pre-diabetes include either impaired fasting glucose (IFG) or impaired glucose tolerance (IGT). IFG is defined as fasting plasma glucose levels ranging from 110 mg/dL to 126mg/dL, while IGT is identified when plasma glucose levels after a 75 g oral glucose load range from 140 to 200 mg/dL^[1]. The American Diabetes Association (ADA) later expanded these criteria by introducing the glycated

hemoglobin (HbA1c) level of 5.7–6.4% for diagnosing pre-diabetes^[2]. Impaired glucose metabolism is associated with many metabolic disturbances such as dyslipidemia, characterized by abnormalities in one or more components of the lipid profile either qualitatively or quantitatively^[3].

The primary mechanism of dyslipidemia in pre-diabetes is insulin resistance, which increases the hepatic uptake of free fatty acids, leading to the increased synthesis of triglycerides (TG) and very low-density lipoprotein (VLDL-C). The small dense LDL particles produced after metabolism of VLDL-C particles are highly atherogenic, making the arterial wall more susceptible to oxidation and glycation^[4]. This

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endothelial dysfunction due to disturbed lipid metabolism and hyperglycemia exacerbates vascular damage, and the risk of cardiovascular events in patients with impaired glucose tolerance increases. Thus, there exists a linear relationship between pre-diabetes and cardiovascular risk [5].

In recent years, the prevalence of pre-diabetes has increased markedly, with an estimated progression rate of pre-diabetes into T2DM recorded at 5-10% annually due to improper management [6]. Pre-diabetic patients are often asymptomatic and thus remain undiagnosed. According to the ADA, diabetic patients have an abnormal lipid profile, which is commonly characterized by increased triglycerides (TG), total cholesterol (TC), low-density lipoprotein (LDL-C), very-low-density lipoprotein (VLDL-C), and reduced high-density lipoprotein (HDL-C), called diabetic dyslipidemia and a similar pattern has also been observed in Pre-diabetic individuals. However, its prevalence may vary [7].

The increasing incidence of pre-diabetes progression into diabetes mellitus and its related complications, including cardiovascular risk, urgently requires effective public health strategies aimed at early diagnosis and risk stratification. Importantly, pre-diabetes can be reversed; it may regress to a normoglycemic state if appropriate lifestyle modification is adopted and, where necessary, pharmacological interventions are implemented [8]. Even in normoglycemic individuals, subtle metabolic and lipid alterations have been observed, suggesting that dyslipidemia occurs before the onset of insulin resistance. Therefore, understanding the predictive role of lipid parameters in the progression of pre-diabetes is crucial for early risk identification and intervention [9].

Several studies have examined individual lipid profile parameters in pre-diabetic and diabetic individuals and reported the presence of significant dyslipidemia during the pre-diabetic stage. Due to the low sensitivity and specificity of these traditional lipid profile measures TG, TC, HDL-C, LDL-C, there is a growing consensus in the scientific community on the need to improve diagnostic criteria by incorporating overall lipid profile patterns and their combinations [10]. Non-traditional parameters of lipid profile like non-HDL-C, VLDL-C, TG/HDL-C, TC/HDL-C, and LDL-C/HDL-C are all directly linked to the risk of pre-diabetes and T2DM [11]. However, these markers and qualitative lipid patterns have received less attention. Comprehensive data on atherogenic lipid patterns and the extent of alteration in lipid profiles comparing pre-diabetic individuals with normoglycemic and diabetic individuals remain limited, especially in countries like Pakistan where there is a high incidence of cardiovascular diseases. In the light of these considerations, further research is needed to compare lipid abnormalities across different glycemic categories.

This study aims to assess and compare the patterns of dyslipidemia across the pre-diabetic group and compare these patterns with normoglycemic and diabetic individuals. By identifying the key changes in abnormal lipid patterns and evaluating their differences between these groups, this study seeks to provide insights into early metabolic changes associated with pre-diabetes. Such findings may

help in timely detection and risk assessment and will play an important role in halting the disease progression as well as in its prevention.

METHODOLOGY

The cross-sectional study was conducted jointly by the Department of Cardiology (Outpatient Unit) and Pathology at Punjab Institute of Cardiology, Lahore. The data for this study were collected over a period of six months, from September 2025 to February 2026, after obtaining permission from the Ethical Review Committee (ERC letter # RTPGME-Research-433, dated 28th August, 2025). Our study population consisted of individuals attending the Outdoor Patient Department for routine cardiac evaluation. Based on a previous study demonstrating significant differences in triglyceride and VLDL levels across normal, pre-diabetic, and diabetic HbA1c groups, a minimum sample size of 120 participants per group was calculated for a one-way ANOVA assuming an effect size of Cohen's $f=0.164$, $\alpha=0.05$, and 80% power [12]. This study included 360 participants (120 per group): normoglycemic, pre-diabetic, and diabetic, recruited through consecutive sampling. The grouping of participants in these groups was based on the glycated haemoglobin (HbA1c) levels as defined by the American Diabetes Association (ADA):

Normoglycemic group: HbA1c $<5.7\%$

Pre-diabetic group: HbA1c from 5.7% to 6.4%.

Diabetic group: HbA1c $\geq 6.5\%$

The eligibility criteria for the study population included individuals aged ≥ 18 years and individuals with no history of use of glucose-lowering or lipid-lowering drugs. Individuals with a history of glucose-lowering drugs, lipid-lowering drugs, corticosteroid therapy, thyroid illness, chronic liver disease, kidney disease and any haemoglobinopathies were excluded from the study. The demographic details of the study participants included gender, height (cm), weight (kg), and smoking status. BMI was noted in kg/m^2 after measuring the weight and height of each participant. The demographic details were noted using a structured, predesigned proforma. All the selected participants were advised to fast for 8 to 12 hours, and blood samples were drawn for fasting lipid profile and HbA1c levels. The parameters of the fasting lipid profile included TG, TC, HDL-C, LDL-C, non-HDL-C and VLDL-C. TG, TC, HDL-C, and LDL-C were tested on a fully automated Siemens Atellica CH analyzer, while non-HDL-C was calculated as $\text{TC} - \text{HDL-C}$ and VLDL-C by the Friedewald formula ($\text{TG}/5$). HbA1c was tested through high-performance liquid chromatography technique using the Bio-Rad D10 Haemoglobin system.

The normal ranges for lipid profile parameters were defined using NCEP ATP III criteria. The cut-off values used are as follows: TG <150 mg/dL; TC <200 mg/dL; HDL-C <40 mg/dL for males, <50 mg/dL for females; LDL-C <130 mg/dL; VLDL-C <40 mg/dL. Various lipid-derived ratios included TG/HDL-C, LDL-C/HDL-C, and TC/HDL-C. Lipid profile patterns included Isolated Hypertriglyceridemia, defined as high TG; Isolated Hypercholesterolemia: high TC; Isolated Low HDL-C: Low HDL-C; Atherogenic dyslipidemia: high TG and low HDL-C

Lipid profile patterns across glycemic categories

Mixed dyslipidemia: elevation of TG and TC, and/or LDL-C, VLDL-C.

We used the Statistical Package for the Social Sciences (SPSS) version 26.0 for data analysis. Continuous variables (e.g., age) were noted as mean $\pm$ SD, while categorical variables were noted as frequency (n) and percentage (%) in each group. One-way analysis of variance (ANOVA) was used to compare lipid profile parameters (TG, TC, HDL-C, LDL-C, non-HDL-C and VLDL-C) and lipid profile-derived parameters (TG/HDL-C, TC/HDL-C, and LDL-C/HDL-C) among normoglycemic, pre-diabetic, and diabetic groups. Post hoc Tukey's analysis was used to find pairwise differences between these groups.

We reported these parameters as means, with group comparisons based on ANOVA and post hoc Tukey's analysis. We used chi-square to assess the association between glycemic status and lipid status, and between distinct lipid profile patterns and glycemic groups. Univariate binary logistic regression analysis was performed to estimate the odds ratio (OR) with 95% confidence interval (95% CI) for the association of lipid profile patterns with pre-diabetes. Patterns that showed the significant association in univariate binary logistic regression were entered into the multivariate logistic regression model. Multivariate logistic regression identified independent predictors for lipid profile patterns after adjustment for confounders such as smoking status, age, gender, and BMI. A p-value <0.05 was considered statistically significant.

RESULTS

Our study consisted of 360 participants, including 198 males and 162 females. The mean age of the study participants was 46.08 ± 12.17 years. The demographic details, including age ranges, mean age, total participants, number and percentage of males, females, smokers, individuals with normal lipid profile and individuals with deranged lipid profile in each group, are presented in Table-I.

We used one-way ANOVA to compare lipid profile parameters and HbA1c among 3 glycemic groups: normoglycemic, pre-diabetic, and diabetic. Results of one-way ANOVA revealed that HbA1c, BMI, TG, non-

HDL-C, VLDL-C, and TG/HDL-C ratio showed significant differences among all groups ($p < 0.001$). The comparison of all lipid profile parameters in different groups is listed in Table-II.

Post hoc Tukey's analysis showed that values of TG, Non-HDL-C, and VLDL-C varied significantly between the normoglycemic, the pre-diabetic and the diabetic groups. Post hoc Tukey's analysis also revealed that the normoglycemic group and the pre-diabetic group had overlapping values of the TG/HDL-C ratio. Still, the diabetic group demonstrated the highest value of TG/HDL-C ratio. The results of the post hoc Tukey's HSD test showing group-wise comparison of TG, non-HDL-C, VLDL-C, and TG/HDL-C are listed in Table-III.

The prevalence of a normal lipid profile decreased from the normoglycemic to the diabetic group. The prevalence of a normal lipid profile was 19.2%, 14.2% and 9.2% in normoglycemic, pre-diabetic and diabetic populations, respectively. A progressive increase in mixed dyslipidemia and atherogenic lipid profile was observed as we moved from normoglycemic to the diabetic group. The chi-square test applied between glycemic status and dyslipidemia status showed a statistically significant association ($\chi^2(8)=21.566$, $p=0.006$). The chi-square test also showed a statistically significant association between isolated low HDL-C and glycemic groups ($\chi^2(2)=7.756$, $p=0.021$), atherogenic dyslipidemia and glycemic groups ($\chi^2(2)=9.040$, $p=0.01$), and mixed dyslipidemia and glycemic groups ($\chi^2(2)=16.5$, $p < 0.001$). No statistically significant association was observed between glycemic groups and normal lipid profile ($p=0.081$), isolated hypertriglyceridemia ($p=0.937$), and isolated hypercholesterolemia ($p=0.069$).

Univariate binary logistic regression analysis (pre-diabetes vs normoglycemia) demonstrated that the odds of getting isolated low HDL-C decrease to 50% with pre-diabetes (OR=0.495, 95% CI: 0.279-0.878, $p=0.016$), and odds of getting mixed dyslipidemia increase by 250% (OR=3.509, 95% CI: 1.783-6.903, $p < 0.001$) with the shift in glycemic category from normoglycemic to pre-diabetes. Remaining lipid profile patterns showed no significant association with the progression of pre-diabetes from normoglycemia.

Table- I: Baseline characteristics of the study participants.

Parameters	Normoglycemic Group (n=120) n (%)	Pre-diabetic group (n=120) n (%)	Diabetic group (n=120) n (%)
Age Range (years)	18-72	23-80	21-77
Age (Mean $\pm$ S.D.) (years)	40.33 ± 11.43	48.85 ± 11.68	49.04 ± 11.38
Number of males	69 (57.5)	61 (50.8)	68 (56.6)
Number of females	51 (42.5)	59 (48.2)	52 (43.4)
Number of smokers	5 (4.4)	6 (5)	20 (16.6)
Individuals with normal lipid profile	23 (19.2)	17 (14.2)	11 (9.2)
Individuals with deranged lipid profile	97 (80.8)	103 (85.8)	109 (90.8)

Table- II: Comparison of various lipid profile parameters in different glycemic categories using one-way ANOVA.

Parameters	Normoglycemic Group (n=120) n (%) Mean ± SD	Pre-diabetic group (n=120) n (%) Mean ± SD	Diabetic group (n=120) n (%) Mean ± SD	F-value	P-value
HbA1c (%)	5.32±0.23	5.99±0.22	7.74±2.05	130.95	<0.001
BMI (kg/m ²)	27.28±4.4	30.69±5.47	30.79±5.58	17.801	<0.001
TG (mg/dL)	134.21±59.2	160.59±68.03	197.10±82.66	19.30	<0.001
TC (mg/dL)	180.15±33.08	188.74±41.36	185.97±43.05	1.48	0.228
LDL-C (mg/dL)	113.41±29.55	117.28±31.61	113.20±32.83	0.64	0.526
HDL-C (mg/dL)	42.58±9.59	42.85±10.22	40.69±9.08	1.78	0.169
Non-HDL-C (mg/dL)	91.63±62.99	117.3±71.38	156.41±85.44	18.99	<0.001
VLDL-C (mg/dL)	26.84±10.45	32.11±12.41	39.42±16.79	19.30	<0.001
TG/HDL-C ratio	3.41±1.96	4.05±2.29	5.38±3.97	14.73	<0.001
T.Chol /HDL-C ratio	4.42±1.24	4.57±1.28	4.90±3.06	1.77	0.171
LDL-C/HDL-C ratio	2.81±1.01	2.85±0.93	2.97±1.82	0.48	0.619

Table III: Results of Post hoc Tukey's HSD showing group-wise comparison for parameters that differed significantly in one-way ANOVA.

Parameters	Pre-diabetic vs Normoglycemic group		Pre-diabetic vs Diabetic group		Diabetic vs Normoglycemic group	
	MD	P-value	MD	P-value	MD	P-value
TG (mg/dL)	26.38	0.027	-36.51	0.001	62.89	<0.001
Non HDL-C (mg/dL)	26.12	0.037	-38.67	0.001	64.78	<0.001
VLDL-C (mg/dL)	5.36	0.006	-5.66	0.004	11.02	<0.001
TG/HDL-C ratio	0.63	0.203	-1.36	0.001	1.97	<0.001

Table-IV: Table of association between lipid profile patterns and glycemic groups.

Patterns	Response	Normoglycemic Group	Pre-diabetic Group	Diabetic Group	χ ²	P-value
Normal lipid profile	Yes	23 (19.2)	17 (14.2)	11 (9.2)	4.934	0.081
	No	97 (80.8)	103 (85.8)	109 (90.8)		
Isolated hypertriglyceridemia	Yes	5 (4.2)	6 (5)	5 (4.2)	0.131	0.937
	No	115 (95.8)	114 (95)	115 (95.8)		
Isolated hypercholesterolemia	Yes	22 (18.3)	15 (12.5)	10 (8.3)	5.335	0.069
	No	98 (81.7)	105 (87.5)	110 (91.7)		
Isolated low HDL-C	Yes	43 (35.8)	26 (21.7)	27 (22.5)	7.756	0.021
	No	77 (64.2)	94 (78.3)	93 (77.5)		
Atherogenic dyslipidemia	Yes	13 (10.8)	18 (15)	30 (25)	9.040	0.01
	No	107 (89.2)	102 (85)	90 (75)		
Mixed dyslipidemia	Yes	14 (11.7)	38 (31.7)	37 (30.8)	16.5	<0.001
	No	106 (88.3)	82 (68.3)	83 (69.2)		

Table -V: Univariate binary logistic regression analysis showing Odds ratios of various lipid profile patterns associated with pre-diabetes.

Outcomes	Regression Co-efficient (B)	S. E	OR	95% CI	P-value
Normal lipid profile	-0.362	0.350	0.696	0.351-1.382	0.300
Isolated hypertriglyceridemia	0.191	0.620	1.211	0.359-4.079	0.758
Isolated hypercholesterolemia	-0.452	0.363	0.636	0.312-1.297	0.213
Isolated low HDL-C	-0.703	0.292	0.495	0.279-0.878	0.016
Atherogenic dyslipidemia	0.373	0.389	1.452	0.677-3.116	0.338
Mixed dyslipidemia	1.255	0.346	3.509	1.783-6.903	<0.001

Table VI: Multivariate binary logistic regression showing predictors of dyslipidemia patterns significantly associated with pre-diabetes.

Variables	Isolated low HDL-C			Mixed dyslipidemia		
Predictor	Adjusted OR	95%CI	p-value	Adjusted OR	95%CI	p-value
Prediabetes	0.585	0.298-1.151	0.21	3.114	1.477-6.566	0.003
Smoking	1.03	0.387-2.742	0.99	0.875	0.203-3.771	0.858
Age	0.99	0.969-1.018	0.48	0.967	0.967-1.025	0.762
Gender	4.33	2.122-7.553	<0.001	0.417	0.237-0.963	0.039
BMI	0.924	0.866-0.985	0.01	1.074	1.006-1.148	0.037

After adjustment for the confounding factors such as smoking status, age, gender and BMI, Multivariate binary logistic regression analysis identified that mixed dyslipidemia retained a significant association with pre-diabetes (OR=3.114, 95% CI: 1.477-6.566, p=0.003) while isolated low HDL-C did not show a statistically significant association with pre-diabetes (OR=0.585, 95% CI: 0.298-1.151 p=0.21). Among confounders, gender and BMI emerged as significant predictors of mixed dyslipidemia and isolated low HDL-C. However, smoking status and age did not demonstrate any significant association with these lipid profile patterns.

DISCUSSION

This study was designed to evaluate lipid profile patterns that are associated with pre-diabetes and also to compare these patterns with the normoglycemic and the diabetic populations. This study consisted of a total of 360 individuals, including 162 females and 198 males. 120 individuals from each glycemic class were included to minimize any bias in comparison across each glycemic category. The percentage of individuals with deranged lipid profiles in the pre-diabetic group was 85.8%, while in the normoglycemic group and diabetic group it was 80.8% and 90.8%, respectively. The high percentage of individuals with deranged lipid profiles, even in the normoglycemic group, suggests that lipid derangement starts early in the course of glycemic dysregulation^[13].

The comparison of lipid profile parameters between various glycemic groups revealed a stepwise alteration in many lipid profile parameters with worsening glycemic status. These parameters included TG, non-HDL-C, VLDL-C and the TG/HDL-C ratio. The levels of TG showed a consistent rising trend with advancing glycemic impairment. The observed increase can be explained by the increased hepatic production of triglyceride-rich lipoprotein particles along with decreased lipoprotein lipase activity, which reduces the clearance of triglyceride-rich lipoprotein particles^[14]. Non-HDL-C, which consists of all the Apo B-containing lipoprotein particles, also showed a rising trend. The rising levels of non-HDL-C particles with advancing dysglycemia represent increased atherogenic lipoprotein particles and high cardiovascular risk^[15].

The progressive increase in levels of VLDL-C with worsening glycemic status is attributed to the insulin resistance, which increases lipolysis, resulting in increased free fatty acid flux to the liver and promoting VLDL-C particle synthesis by the liver^[16]. The higher levels of VLDL-C lead to cardiovascular

risk, as they are the atherogenic remnant particles. The production of small dense lipoprotein particles during VLDL-C metabolism penetrates the arterial vasculature and promotes plaque formation. VLDL-C particles are metabolized into LDL particles, which enhances cholesterol deposition and increases atherosclerosis in the presence of insulin resistance^[17]. The TG/HDL-C ratio did not differ significantly between the normoglycemic and pre-diabetic groups, but it rose notably in the diabetic population. This highlights the need to incorporate the TG/HDL-C ratio as a surrogate marker of diabetic dyslipidemia. This reflects the combined effect of increased TG and reduced HDL-C levels, both of which are linked to cardiometabolic risk in diabetic individuals.

Our study reported the progressive deterioration in lipid status with changes in glycemic group. The percentage of dyslipidemia increased from 80.8% to 90.8% with a shift in glycemic status from normoglycemia to diabetes. These findings suggest that dyslipidemia is not restricted to overt diabetes but starts early during glycemic dysregulation. The strong association between the glycemic status and dyslipidemia status (χ^2 (8) =21.566, p=0.006) shows a strong interrelation between glucose homeostasis and lipid metabolism.

The comparison of lipid profile patterns across glycemic groups provided important details. Significant associations of glycemic classes were observed with isolated low HDL-C, atherogenic dyslipidemia and mixed dyslipidemia. Glycemic classes were not significantly associated with isolated hypertriglyceridemia or isolated hypercholesterolemia. This suggests that single lipid abnormalities do not fully reflect metabolic dysfunction; instead, qualitative lipid patterns better capture glycemic changes. The prevalence of isolated low HDL-C was the highest in the normoglycemic Group (35.8%), which substantially decreased in pre-diabetes (21.7%) and diabetes (22.5%). This suggests that isolated low HDL-C is common even in individuals with a normal metabolic state. Isolated low HDL-C may be an early feature of dyslipidemia^[18].

Atherogenic dyslipidemia and mixed dyslipidemia showed notable changes with worsening of glycemic status. Atherogenic dyslipidemia showed a serial rise in incidence from pre-diabetes to diabetes. In contrast, the prevalence of mixed dyslipidemia remained almost the same in the pre-diabetic (31.7%) and the diabetic Group (30.8%). This observation suggests that atherogenic dyslipidemia appears in the advanced stages of insulin resistance and is linked with the increased cardiovascular risk^[19].

The results of univariate binary logistic regression analysis revealed that in pre-diabetes, the odds of having mixed dyslipidemia increase by 250% as compared to normoglycemia. This is well explained by the dominance of mixed dyslipidemia in pre-diabetes; multiple fractions of lipids get concurrently deranged^[20]. In multivariate logistic regression analysis, mixed dyslipidemia served as the independent predictor of pre-diabetes after adjustment for confounding factors such as smoking status, age, gender, and BMI. This corroborates that mixed dyslipidemia reflects underlying insulin resistance and serves as an early marker for individuals with cardiometabolic risk. An important finding of the present study was the contrasting association of gender with different dyslipidemic patterns. In multivariable analysis, gender was strongly associated with isolated low HDL-C (OR=4.33), whereas it was inversely associated with mixed dyslipidemia (OR=0.417). This opposite-direction association suggests that the relationship between gender and dyslipidemia may vary according to the specific lipid phenotype rather than representing a uniform effect across all lipid abnormalities. Differences in body fat distribution, hormonal status, dietary patterns, physical activity, and other metabolic factors may contribute to these variations. However, these mechanisms could not be directly evaluated in the present study and therefore should be considered possible explanations rather than established causes.

The present study adds to the limited Pakistan-specific evidence on the relationship between glycemic status and dyslipidemia by examining not only the prevalence of lipid abnormalities but also their qualitative patterns across normoglycemia, pre-diabetes, and diabetes. Overall, these findings suggest that lipid abnormalities reflect the nature of metabolic dysfunction. Traditional lipid parameters alone may not fully capture early metabolic deterioration, whereas qualitative patterns can provide deeper insights. A progressive increase in the frequency of deranged lipid profiles, particularly mixed dyslipidemia and elevated VLDL levels, was observed across worsening glycemic categories. These findings suggest that clinically relevant lipid disturbances may emerge during the pre-diabetic stage rather than becoming apparent only after the development of overt diabetes. By characterizing specific dyslipidemic patterns within a Pakistani clinical population, this study provides locally relevant evidence that may support earlier identification and risk assessment of individuals with abnormal glycemic status.

LIMITATIONS:

This study has several limitations. First, its single-centre design and recruitment from a cardiology/OPD-referral population may limit the generalizability of the findings to community-based populations. Second, the cross-sectional design precludes establishing temporal or causal relationships between glycemic status and lipid abnormalities. Third, LDL-C was estimated using the Friedewald formula, which may be unreliable when triglyceride levels exceed approximately 400 mg/dL; therefore, estimation error may have occurred in individuals with markedly elevated

triglycerides. Finally, direct measures of insulin resistance, such as HOMA-IR, were not available, limiting confirmation of the proposed insulin-resistance-mediated mechanisms underlying the observed dyslipidemia patterns.

CONCLUSION

The findings emphasise that lipid abnormalities progress across glycemic groups, i.e., from normoglycemia to diabetes. The presence of significant dyslipidemia in pre-diabetes suggests early metabolic dysfunction before overt diabetes. The strong association of a mixed dyslipidemia pattern with pre-diabetes indicates its role as the marker of early insulin resistance, which suggests that alterations in triglyceride-rich lipoprotein particles accompany pre-diabetes. The findings of our study suggest that qualitative lipid profile patterns, especially mixed dyslipidemia patterns in routine lipid profiles, may contribute to the early detection of pre-diabetes. This may contribute to preventive strategies to reduce the progression of pre-diabetes and its associated cardiovascular risk.

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