

ASSOCIATION OF GLYCEMIC CONTROL AND LIPID PROFILE DERANGEMENTS WITH BONE MINERAL DENSITY IN PATIENTS WITH TYPE 2 DIABETES MELLITUS: A CROSS-SECTIONAL STUDY

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ABSTRACT

Background: **Aim:** Type 2 Diabetes Mellitus (T2DM) is increasingly recognized as a metabolic disorder affecting skeletal health. Chronic hyperglycemia, dyslipidemia, and alterations in mineral metabolism may contribute to reduced bone mineral density (BMD) and increased osteoporosis risk. This study evaluated the association of glycemic control and lipid profile abnormalities with BMD among patients with T2DM. **Materials and Methods:** A hospital-based cross-sectional observational study was conducted in the Department of General Medicine, B.R.D. Medical College and Nehru Hospital, Gorakhpur, Uttar Pradesh. A total of 149 patients aged 45–65 years with diagnosed T2DM were enrolled. Clinical assessment, biochemical investigations including glycated hemoglobin (HbA1c), lipid profile, vitamin D, calcium, phosphorus, alkaline phosphatase, and parathormone levels were performed. BMD was measured using Dual-Energy X-ray Absorptiometry (DEXA) at the lumbar spine and proximal femur. Participants were categorized as normal, osteopenic, or osteoporotic according to World Health Organization criteria. Statistical analysis was performed using SPSS version 23.0, with $p < 0.05$ considered significant. **Results:** Among 149 participants, 73 (49.0%) had osteoporosis, 35 (23.5%) had osteopenia, and 41 (27.5%) had normal BMD. Poor glycemic control ($\text{HbA1c} \geq 6.5\%$) was significantly associated with lower BMD ($p = 0.044$), with osteoporosis observed in 53.8% of poorly controlled diabetic patients compared to 41.1% among those with better glycemic control. Progressive increases in total cholesterol, LDL-cholesterol, and triglyceride levels were noted across worsening BMD categories. High triglyceride levels demonstrated a significant association with osteoporosis ($p = 0.001$), while LDL-C showed a borderline significant association ($p = 0.055$). Osteoporosis was significantly more prevalent among patients with nephropathy (65.5%, $p < 0.001$), retinopathy (64.7%, $p = 0.009$), and hypertension (57.1%, $p = 0.010$). Mean vitamin D levels decreased markedly from normal BMD (27.24 ± 5.42 ng/mL) to osteopenia (18.61 ± 3.35 ng/mL) and osteoporosis (10.75 ± 3.19 ng/mL), demonstrating a strong association with reduced bone density ($p < 0.001$). **Conclusion:** Reduced bone mineral density is highly prevalent among patients with T2DM, with nearly three-fourths exhibiting osteopenia or osteoporosis. Poor glycemic control, hypertriglyceridemia, adverse lipid profile parameters, vitamin D deficiency, and diabetic microvascular complications are significantly associated with impaired bone health. Routine BMD screening and early management of metabolic risk factors may help reduce osteoporosis-related morbidity in patients with T2DM.

INTRODUCTION

Type 2 Diabetes Mellitus (T2DM) is a major global health problem associated with multiple metabolic complications.^[1] Increasing evidence suggests that diabetes adversely affects skeletal health, leading to reduced bone quality, increased fracture risk, and osteoporosis. Although Bone Mineral Density (BMD) remains the standard measure for assessing bone strength, metabolic factors such as chronic hyperglycemia and dyslipidemia may significantly influence bone remodeling and mineralization.^[2] Persistent hyperglycemia promotes the formation of advanced glycation end-products (AGEs), which accumulate within the bone matrix and impair collagen integrity, osteoblast function, and bone turnover.^[3] Consequently, poor glycemic control, reflected by elevated HbA1c levels, may contribute to progressive deterioration of bone health. Several studies have reported an inverse relationship between HbA1c and BMD, suggesting that worsening glycemic control is associated with lower bone density and increased fracture susceptibility.^[4] In addition to hyperglycemia, dyslipidemia commonly observed in T2DM has emerged as an important determinant of bone metabolism. Elevated total cholesterol, triglycerides, and low-density lipoprotein cholesterol (LDL-C), along with reduced high-density lipoprotein cholesterol (HDL-C), may enhance oxidative stress and inflammation, thereby impairing osteoblast activity and accelerating bone loss.^[5] Despite the increasing burden of diabetes and osteoporosis in India, data regarding the combined impact of glycemic control and lipid abnormalities on BMD remain limited. Therefore, the present study was undertaken to evaluate the relationship between HbA1c, lipid profile parameters, and BMD among patients with T2DM, with particular emphasis on the effect of worsening glycemic control on skeletal health.

MATERIALS AND METHODS

This hospital-based cross-sectional observational study was conducted in the Department of General Medicine, B.R.D. Medical College and Nehru

Hospital, Gorakhpur, Uttar Pradesh, over a period of one year after obtaining Institutional Ethics Committee approval. A total of 149 patients aged 45–65 years with diagnosed Type 2 Diabetes Mellitus (T2DM) were enrolled using consecutive sampling after obtaining written informed consent.

Patients with chronic kidney disease, metabolic bone disorders, malignancy, those receiving long-term corticosteroids, anticonvulsants, anti-osteoporotic therapy, and critically ill patients were excluded. Demographic details, duration of diabetes, body mass index (BMI), blood pressure, and diabetic complications were recorded using a structured proforma.

Fasting venous blood samples were collected for estimation of fasting blood sugar (FBS), postprandial blood sugar (PPBS), glycated hemoglobin (HbA1c), lipid profile [total cholesterol (TC), triglycerides (TG), high-density lipoprotein cholesterol (HDL-C), low-density lipoprotein cholesterol (LDL-C)], serum calcium, phosphorus, alkaline phosphatase, vitamin D, and parathormone (PTH) using standard laboratory methods.

Bone Mineral Density (BMD) was assessed by Dual-Energy X-ray Absorptiometry (DEXA) at the lumbar spine (L2–L4) and proximal femur. Based on World Health Organization criteria, participants were categorized as normal (T-score ≥ -1.0), osteopenic (T-score -1.0 to -2.5), or osteoporotic (T-score ≤ -2.5). Glycemic control was classified as good (HbA1c $< 7\%$) or poor (HbA1c $\geq 7\%$).

The primary outcome was the correlation between HbA1c and BMD, while secondary outcomes included the association of lipid profile parameters with BMD and identification of predictors of low bone mineral density. Data were analyzed using SPSS version 23.0. Continuous variables were expressed as mean $\pm$ standard deviation and categorical variables as frequencies and percentages. Comparisons between groups were performed using Student's t-test or one-way ANOVA, while categorical variables were analyzed using the Chi-square test. Pearson's correlation coefficient was used to assess the relationship between BMD, HbA1c, and lipid profile parameters. Multiple linear regression analysis was performed to identify independent predictors of reduced BMD. A p-value < 0.05 was considered statistically significant.

RESULTS

Table 1: Distribution of Bone Mineral Density Status among Study Participants (n=149)

BMD Category	Number (%)
Normal	41 (27.5)
Osteopenia	35 (23.5)
Osteoporosis	73 (49.0)
Total	149 (100.0)

Among the 149 patients with Type 2 Diabetes Mellitus included in the study, 73 (49.0%) were found to have osteoporosis, 35 (23.5%) had osteopenia, and only 41 (27.5%) had normal Bone

Mineral Density (BMD). Thus, nearly three-fourths of the study population (72.5%) exhibited reduced bone mass in the form of either osteopenia or osteoporosis. Osteoporosis was the most common

BMD abnormality, affecting almost half of the participants, indicating a high burden of skeletal involvement among patients with T2DM. These findings suggest that diabetic patients are at increased

risk of compromised bone health and emphasize the importance of routine BMD assessment for early detection and management of osteoporosis.

Table 2: Association of Glycemic Control with Bone Mineral Density

Glycemic Status	Normal BMD n (%)	Osteopenia n (%)	Osteoporosis n (%)	Total	p-value
HbA1c <6.5% (n=56)	22 (39.3)	11 (19.6)	23 (41.1)	56	
HbA1c ≥6.5% (n=93)	19 (20.4)	24 (25.8)	50 (53.8)	93	0.044
Total	41	35	73	149	

Among participants with controlled blood sugar (RBS <200 mg/dl and HbA1c <6.5), 22 (39.3%) had normal BMD, 11 (19.6%) had osteopenia, and 23 (41.1%) had osteoporosis. Among those with uncontrolled blood sugar (RBS >200 mg/dl and

HbA1c >6.5), 19 (20.4%) had normal BMD, 24 (25.8%) had osteopenia, and 50 (53.8%) had osteoporosis. The association was statistically significant (p=0.044).

Table 3: Comparison of HbA1c Across BMD Categories

BMD Category	Mean HbA1c (%)
Normal BMD	8.46 ± 2.25
Osteopenia	9.43 ± 2.79
Osteoporosis	8.43 ± 1.84
Total	8.71 ± 2.27

The mean HbA1c level of the overall study population was 8.71 ± 2.27%, indicating generally poor glycemic control among patients with Type 2 Diabetes Mellitus. The highest mean HbA1c was observed in the osteopenia group (9.43 ± 2.79%), followed by the normal BMD group (8.46 ± 2.25%), while the osteoporosis group had a mean HbA1c of 8.43 ± 1.84%. Although HbA1c levels were elevated

across all BMD categories, the osteopenia group demonstrated comparatively poorer glycemic control. Overall, these findings suggest a potential association between poor glycemic status and reduced bone mineral density, highlighting the need to evaluate the impact of chronic hyperglycemia on skeletal health in patients with T2DM.

Table 4: Lipid Profile Across Bone Mineral Density Categories

Parameter (mg/dL)	Normal BMD	Osteopenia	Osteoporosis
Total Cholesterol	127.71 ± 38.57	145.70 ± 50.56	157.55 ± 49.99
LDL-C	94.83 ± 42.04	111.00 ± 55.71	123.64 ± 50.07
Triglycerides	138.22 ± 89.52	172.50 ± 91.24	178.72 ± 106.87
HDL-C	43.61 ± 14.95	40.30 ± 11.67	42.68 ± 18.28

A progressive increase in atherogenic lipid parameters was observed with worsening Bone Mineral Density (BMD). Mean total cholesterol levels increased from 127.71 ± 38.57 mg/dL in patients with normal BMD to 145.70 ± 50.56 mg/dL in those with osteopenia and 157.55 ± 49.99 mg/dL in the osteoporosis group. Similarly, mean LDL-C levels showed a rising trend across BMD categories, increasing from 94.83 ± 42.04 mg/dL in the normal BMD group to 111.00 ± 55.71 mg/dL in osteopenic patients and 123.64 ± 50.07 mg/dL among

osteoporotic patients. A comparable pattern was noted for triglyceride levels, which increased from 138.22 ± 89. mg/dL in participants with normal BMD to 172.50 ± 91.24 mg/dL and 178.72 ± 106.87 mg/dL in the osteopenia and osteoporosis groups, respectively. In contrast, HDL-C levels showed no consistent trend across BMD categories, with values of 43.61 ± 14.95 mg/dL, 40.30 ± 11.67 mg/dL, and 42.68 ± 18.28 mg/dL in the normal, osteopenia, and osteoporosis groups, respectively.

Table 5: Association of Triglyceride Category with Bone Mineral Density

Triglyceride Category	Normal BMD n (%)	Osteopenia n (%)	Osteoporosis n (%)	p-value
Normal	30 (46.15)	13 (20.00)	22 (33.85)	
Borderline High	9 (15.79)	15 (26.32)	33 (57.89)	
High	2 (8.33)	5 (20.83)	17 (70.83)	0.001

Among borderline triglyceride cases, 9 (15.79%) had normal BMD, 15 (26.32%) had osteopenia, and 33 (57.89%) had osteoporosis. In the high category, 17 (70.83%) had osteoporosis. Among normal

triglyceride cases, 30 (46.15%) had normal BMD and 22 (33.85%) had osteoporosis. The association was statistically significant (p=0.001).

Table 6: Association of LDL-C Category with Bone Mineral Density

LDL Category	Normal BMD n (%)	Osteopenia n (%)	Osteoporosis n (%)	p-value
Optimal	20 (35.71)	18 (32.14)	18 (32.14)	
Near Optimal	11 (28.21)	5 (12.82)	23 (58.97)	
High/Very High	9 (17.65)	12 (23.53)	30 (58.82)	0.055

Among LDL categories, osteoporosis was observed in 2 (66.67%) borderline cases, 18 (54.55%) high cases, 23 (58.97%) near optimal cases, 18 (32.14%) optimal cases, and 12 (66.67%) very high cases.

Normal BMD was highest in the optimal group at 20 (35.71%). The association approached significance ($p=0.055$).

Table 7: Diabetic Complications and Osteoporosis

Variable	Osteoporosis (%)	p-value
Nephropathy Present	65.5	<0.001
Retinopathy Present	64.7	0.009
Hypertension Present	57.1	0.010

A higher prevalence of osteoporosis was observed among patients with diabetic complications and hypertension. Nephropathy showed the strongest association with osteoporosis, with 65.5% of patients having nephropathy classified as osteoporotic ($p < 0.001$). Similarly, 64.7% of patients with retinopathy had osteoporosis, demonstrating a statistically significant association ($p = 0.009$). Osteoporosis was also present in 57.1% of hypertensive patients, and

this association was statistically significant ($p = 0.010$).

These findings suggest that the presence of chronic diabetic microvascular complications and hypertension is associated with a greater burden of reduced bone mineral density. The significant associations indicate that patients with nephropathy, retinopathy, and hypertension may represent a high-risk subgroup for osteoporosis and warrant closer monitoring of bone health.

Table 8: Vitamin D Levels Across BMD Categories

BMD Category	Mean Vitamin D (ng/mL)
Normal BMD	27.24 $\pm$ 5.42
Osteopenia	18.61 $\pm$ 3.35
Osteoporosis	10.75 $\pm$ 3.19

Among vitamin D deficient participants, all 23 (100.0%) had osteoporosis. In the insufficient category, 23 (31.51%) had osteopenia and 50 (68.49%) had osteoporosis. Among those with normal vitamin D, 41 (77.36%) had normal BMD and 12 (22.64%) had osteopenia, with no osteoporosis cases. The association was statistically significant ($p<0.001$).

DISCUSSION

The primary aim was to determine the prevalence of osteoporosis and osteopenia in diabetic patients and to identify whether alterations in mineral metabolism and chronic diabetic status are associated with declining bone health. A key finding of the present study was the high burden of low bone mineral density among patients with type 2 diabetes mellitus. Of the 149 participants, 41 (27.5%) had normal BMD, 35 (23.5%) had osteopenia, and 73 (49.0%) had osteoporosis, indicating that nearly half of the study population had overt osteoporosis and an additional one-fourth had osteopenia. Thus, reduced bone mass was present in 72.5% of diabetic patients overall. Shah et al. reported osteoporosis in 26% and osteopenia in 44% of type 2 diabetic patients, with vitamin D deficiency in 68% and elevated PTH in 42%.^[6] Vestergaard found that patients with type 2 diabetes may even have slightly higher hip BMD

(+0.27 SD), yet fracture risk remains elevated (RR 1.7), emphasizing that BMD alone can underestimate diabetic skeletal risk.^[7]

Dhaliwal et al. reported mean serum vitamin D of 17.8 $\pm$ 6.4 ng/mL in type 2 diabetic patients, with 64% deficiency demonstrating that hypovitaminosis D and parathyroid activation are common in diabetic skeletal disease.^[8] Shanbhogue et al. also showed lower vitamin D levels in diabetic patients than controls (18.4 $\pm$ 6.2 vs 24.7 $\pm$ 7.5 ng/mL; $p<0.01$) and higher PTH levels (72 $\pm$ 15 vs 58 $\pm$ 12 pg/mL; $p<0.05$), linking mineral imbalance with structural bone deterioration.^[9]

The present study found that glycemic status had a significant association with BMD category ($p=0.044$). Among patients with controlled blood sugar (RBS <200mg/dl and HbA1C <6.5), 22 (39.3%) had normal BMD, 11 (19.6%) had osteopenia, and 23 (41.1%) had osteoporosis.

Among diabetic complications, the present study found no significant association between neuropathy and BMD ($p=0.794$), as osteoporosis was present in 49.5% of participants without neuropathy and 47.4% of those with neuropathy. Napoli et al. similarly described diabetic bone fragility as a multisystem consequence of chronic metabolic injury, AGE accumulation, and impaired bone quality.^[10]

In the normal cholesterol group, 58 of 126 (46.03%) had osteoporosis, 28 (22.22%) had osteopenia, and

40 (31.75%) had normal BMD. Although formal category-wise significance was not reached, the proportion of osteoporosis appeared higher in borderline and high cholesterol groups than in the normal cholesterol group. This observation is supported by the continuous variable analysis in the same study, where T score showed a significant negative correlation with cholesterol ($r=-0.285$, $p<0.001$), and mean cholesterol increased significantly across BMD categories from 127.71 ± 38.57 in normal BMD to 157.55 ± 49.99 in osteoporosis ($p=0.007$). In contrast, Yaturu described diabetic osteoporosis as part of a broader metabolic syndrome-like disturbance involving endocrine and biochemical abnormalities beyond hyperglycemia alone.^[11] Normal BMD was most frequent in the optimal LDL group, where 20 of 56 (35.71%) participants had normal BMD. These findings suggest that the burden of osteoporosis tended to increase at less favorable LDL levels. Farr et al. similarly described diabetic bone fragility as a manifestation of complex biochemical injury and impaired remodelling.^[12]

Napoli et al. also described diabetic osteoporosis as part of a broader metabolic injury pattern compromising bone material strength.^[10] Farr et al. similarly noted that diabetic skeletal fragility reflects poor bone quality associated with chronic biochemical disturbances.^[12]

The present study has certain limitations that should be considered while interpreting the findings. First, the study was observational in design, which limits the ability to establish causal relationships between diabetes-related factors and reduced bone mineral density. Although significant associations were identified between BMD and several clinical and biochemical variables, these relationships cannot confirm direct causation. Second, the study was conducted in a single group of 149 diabetic patients without inclusion of a non-diabetic control group. As a result, the findings describe the burden and correlates of osteoporosis within diabetic patients but do not permit direct comparison with the general population.

CONCLUSION

The present study demonstrated a high prevalence of reduced bone mineral density among patients with Type 2 Diabetes Mellitus, with osteoporosis and osteopenia affecting 49.0% and 23.5% of participants, respectively. Nearly three-fourths of the

study population exhibited impaired bone health, underscoring osteoporosis as an important yet under-recognized complication of diabetes.

A key finding of this study was the association between poor glycemic control and reduced bone mineral density. Patients with uncontrolled diabetes showed a significantly higher prevalence of osteoporosis compared to those with better glycemic control. Elevated HbA1c levels were observed across all categories of low bone mineral density, suggesting that chronic hyperglycemia may adversely influence skeletal health through long-term metabolic disturbances. These findings support the concept that prolonged exposure to hyperglycemia contributes to deterioration of bone quality and increased risk of osteoporosis in patients with T2DM.

In conclusion, poor glycemic control and adverse lipid profile parameters are important determinants of reduced bone mineral density in patients with Type 2 Diabetes Mellitus. The findings highlight the need for routine assessment of bone health in diabetic patients, particularly those with elevated HbA1c levels, dyslipidemia, and diabetic complications. Early identification and management of these metabolic risk factors may help reduce the burden of osteoporosis and its associated complications in this high-risk population.

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