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Research Article

Assessment of Bone Mineral Density Using Dual-Energy X-ray Absorptiometry in Children and Adolescents with Type 1 Diabetes Mellitus

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Abstract

Background: Diabetes negatively impacts the skeleton. The mechanisms underlying diabetic-related osteopathy are poorly understood and presumed to be multifactorial. ***Objective***: to assess the bone mineral density (BMD) in children and adolescents with type 1 diabetes mellitus (T1DM) using dual-energy X-ray absorptiometry (DXA) bone scanning and to figure out the correlation between the different risk factors and the changes in BMD in those children. ***Methods***: A cross-sectional study was conducted on children and adolescents (ages 6–16) with T1DM and diabetes duration of ≥4 years. Data collected included age, sex, diabetes duration, insulin dose, height, weight, and BMI. Puberty was assessed. HbA1c, serum calcium, and 25-hydroxyvitamin D levels were measured. All patients underwent DEXA scanning of the lumbar spine (L1–L4) and left femur. ***Results***: The study included 50 patients with a mean age of 11.9±2.15 years. Most (84%) were older than 10 years, and 68% were female. Over half (52%) used an insulin dose of ≥1 unit/kg/day, and 84% had HbA1c levels ≥7.5%. 78% had osteoporosis. BMD changes are not significantly associated with age, sex, DM duration, insulin dose, or pubertal status. However, 81% of patients with HbA1c ≥ 7.5% had osteoporosis. Higher weight and BMI are significantly linked to better BMD. ***Conclusions***: The DEXA scan results indicate reduced BMD in children and adolescents with T1DM. Poor glycemic control increases the risk of decreased BMD, while higher weight and BMI positively influence bone density.

Keywords: Bone mineral density, Children, DEXA, Glycemic control, Osteopathy, Type 1 diabetes.

تقييم كثافة المعادن في العظام باستخدام قياس امتصاص الأشعة السينية ثنائي الطاقة لدى الأطفال والمراهقين المصابين بداء السكري من النوع 1

الخلاصة

الخلفية: يؤثر مرض السكري سلبا على الهيكل العظمي. الآليات الكامنة وراء اعتلال العظام المرتبط بمرض السكري غير مفهومة جيدا ويفترض أنها متعددة العوامل. **الهدف**: تقييم كثافة المعادن في العظام (BMD) لدى الأطفال والمراهقين المصابين بداء السكري من النوع 1 (T1DM) باستخدام مسح العظام ثنائي الطاقة بالأشعة السينية (DXA) ومعرفة العلاقة بين عوامل الخطر المختلفة والتغيرات في BMD لدى هؤلاء الأطفال.**الطرائق**: أجريت دراسة مقطعية على الأطفال والمراهقين (الذين تتراوح أعمارهم بين 6 و 16 عاما) المصابين بمرض السكري T1 ومدة مرض السكري ≤4 سنوات. وشملت البيانات التي تم جمعها العمر والجنس ومدة مرض السكري وجرعة الأنسولين والطول والوزن ومؤشر كتلة الجسم. تم قياس مستويات HbA1c والكالسيوم في الدم و 25-هيدروكسي فيتامين د. خضع جميع المرضى لمسح DEXA للعمود الفقري القطني (L1-L4) وعظم الفخذ الأيسر. **النتائج**: شملت الدراسة 50 مريضا بمتوسط عمر 11.9±2.15 سنة. كان معظمهم (84٪) أكبر من 10 سنوات ، و 68٪ من الإناث. استخدم أكثر من النصف (52٪) جرعة أنسولين تبلغ ≤1 وحدة /كجم /يوم، و 84٪ لديهم مستويات HbA1c ≥7.5٪. 78٪ يعانون من هشاشة العظام. لا ترتبط تغيرات كثافة العظام بشكل كبير بالعمر أو الجنس أو مدة DM أو جرعة الأنسولين أو حالة البلوغ. ومع ذلك، فإن 81٪ من المرضى الذين يعانون من HbA1c ≥ 7.5٪ يعانون من هشاشة العظام. يرتبط الوزن المرتفع ومؤشر كتلة الجسم بشكل كبير بتحسين كثافة العظام. **الاستنتاجات:** تشير نتائج فحص DEXA إلى انخفاض كثافة العظام لدى الأطفال والمراهقين المصابين ب T1DM. يزيد ضعف التحكم في نسبة السكر في الدم من خطر انخفاض كثافة العظام ، بينما يؤثر الوزن المرتفع ومؤشر كتلة الجسم بشكل إيجابي على كثافة العظام.

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INTRODUCTION

Type 1 Diabetes Mellitus (T1DM) is a significant public health challenge, primarily affecting the pediatric age group [1]. Diabetes negatively impacts the skeleton, and those with type 1 diabetes mellitus are more likely to experience skeletal problems than those with type 2 diabetes. According to the majority of research, T1DM is linked to poor bone mineral density (BMD). The mechanisms underlying diabetic-related osteopathy are poorly understood and presumed to be multifactorial, including chronic inflammation, abnormalities in bone mineral metabolism, including excessive calcium loss in the urine, and chronic hyperglycemia, which can weaken bone strength by accumulating advanced glycation

end products in the bone [2]. Long-term diabetes, poor glycemic control, the presence of complications such as retinopathy, nephropathy, and limited joint mobility, as well as nutritional deficiencies, such as a lack of vitamin D, and physical inactivity are risk factors for low BMD in children with diabetes [3–8]. There are no established guidelines for screening children's bone health [2]. The Dual-Energy X-ray absorptiometry (DEXA) of the hip and lumbar spine is recommended by the American College of Radiology as being extremely appropriate for pediatric patients who have a high risk of osteoporosis [9]. In contrast to adults, Z-scores are used to evaluate pediatric BMD results, comparing a child's bone density to that of other children of the same age and sex [10]. A few studies explored how T1DM and BMD values correlate with each other [11]. Guidelines for measuring BMD in children have been published by the American Academy of Pediatrics; however, they primarily address children with cancer and cystic fibrosis and do not address type 1 diabetes [12]. There is currently no established description of diabetic osteopathy, and osteoporosis is not typically identified as a characteristic complication of diabetes mellitus [13]. Our study aims to assess the BMD in children and adolescents with T1DM using DXA bone scanning and figure out the correlation between the different risk factors and the changes in BMD in those diabetic children. To the best of our knowledge, this is the first study conducted in Iraq to address the impact of T1DM on BMD in the pediatric age group.

METHODS

Study design and sample selection

A cross-sectional study was conducted from March 1 to September 30, 2024, on children and adolescents (ages 6–16 years) diagnosed with T1DM based on American Diabetes Association (ADA) guidelines [14]. The study took place at the pediatric endocrinology outpatient clinic in the National Diabetic Center, Mustansiriyah University, with informed parental consent.

Inclusion criteria

T1DM patients aged 6–16 years, body mass index (BMI) <85th percentile, and diabetes duration of ≥4 years.

Exclusion criteria

Patients with thyroid disorders, celiac disease, obesity (BMI ≥ 95th percentile), overweight (BMI 85th–95th percentile), patients with high renal indices, those on medications affecting BMD, and those patients with traumatic or non-pathological fractures or with bone diseases. Initially, 68 eligible patients were included, but 8 were excluded due to celiac disease, and 10 were lost to follow-up, leaving 50 participants.

Data collection

Age, sex, diabetes duration, insulin dose, chronic disease history, medication history, and past illnesses/fractures. Patients were classified by age (<10 years, 10–13 years, >13 years), diabetes duration (<7 years, 7–10 years, >10 years), and insulin dose (<1 unit/kg/day vs. ≥1 unit/kg/day).

Physical examination

Height, weight, and BMI were measured and plotted on CDC growth charts to obtain a percentile ranking and Z-score [15]. Puberty was assessed using the Tanner sexual maturity score for boys [16] and girls [17]. Females and males who showed breast stage B1 and gonads stage 1 (G1) of sexual development, respectively, were considered as prepubertal; otherwise, they were considered as pubertal stage.

Laboratory analysis

Blood samples were collected between 8:00 and 11:00 AM for HbA1c, serum calcium, 25-hydroxyvitamin D, free T4, TSH, and antitissue transglutaminase antibodies. Serum phosphorus, alkaline phosphatase, and PTH were unavailable in the lab unit at the time of collecting samples. Patients were classified based on glycemic control (HbA1c < 7.5% *vs*. ≥ 7.5%) [18]. HbA1c had been taken as an average of the previous 4 readings in the previous year prior to the visit.

Clinical evaluation

Regarding nephropathy as a complication, 38 patients (meeting ADA criteria) [19] were screened using the albumin-to-creatinine ratio (ACR). Two of three specimens of ACR were obtained within a 3–6 month period. An ACR of 30–300 mcg/mg signifies microalbuminuria, and values above 300 mcg/mg are considered macroalbuminuria [20]. Concerning retinopathy**,** 38 patients (meeting ADA criteria) [19] were referred to Al-Yarmouk Teaching Hospital for ophthalmologic evaluation. For BMD measurements, all 50 patients underwent DEXA scanning of the lumbar spine (L1–L4) and left femur at the rheumatology outpatient clinic in Al-Yarmouk Teaching Hospital. The test was done by DMS-DXA. Startes-J14015-D395 scanner and performed by the technicians who were certified trainers in performing DEXA scanning. Then BMD results were adjusted for age, gender, weight, and height. Patients were categorized into two groups [21]: the osteopenia group, whose BMD scores ranged between -1 and -2 SD, indicating moderately reduced bone density, and the osteoporosis group, whose BMD scores were less than -2 SD, indicating severely reduced bone density.

Ethical considerations

Approval of this study was provided by the Ethical Committee of the College of Medicine, Mustansiriyah University (approval certificate no. 6/2025). A written informed consent was obtained from the parents.

Statistical analysis

Data analysis was conducted using SPSS version 26. Descriptive statistics summarized continuous variables using mean and standard deviation, while categorical variables were described using frequencies. The chi-square test assessed associations between categorical variables. Analysis of Variance (ANOVA) was used for continuous variables. The strength and direction of correlations were determined using the Pearson correlation coefficient (r), with statistical significance set at $p < 0.05$.

RESULTS

The total number of participants in the study was 50 patients, with a mean age of 11.9±2.15 years. Most of the patients (84%) were older than 10 years of age. Thirty-four patients (68%) were female, and 16 (32%) were male. The duration of diabetes varied from 4 to 13 years, with a mean duration of 5.86±1.87 years. Most patients (39, or 78%) had DM duration of less than 7 years, 10 (20%) had duration between 7 and 10 years, and 1 (2%) had duration of DM of more than 10 years. In terms of insulin usage, 26 (52%) of the patients used an insulin dose of ≥ 1 unit/kg/day. The anthropometric data indicates a mean height of patients of 146.75 cm ± 13.15 SD with a height Z score of -0.47 ± 1.22 SD. The mean weight was 41.7 kg ± 12.42 SD with a weight Z score of -0.14 ± 1.22 SD, and the mean BMI was 19.0 ± 3.72 SD with a BMI Z score of -0.11 ± 1.20 SD. Regarding the pubertal status, 29 patients (58%) are in the pubertal group. Regarding the clinical investigations, the mean HbA1c of patients was 10.25±2.11%, with 42 participants (84.0%) having HbA1c levels ≥ 7.5%. The serum calcium levels of patients ranged from 1.1 to 2.6 mmol/L; additionally, serum vitamin D3 levels ranged from 8.0 to 37.17 nmol/L. Regarding the prevalence of nephropathy and retinopathy as long-term diabetes complications among the selected 38 study participants, the majority of them, 33 out of 38 (86.8%), did not present any complications. Nephropathy was observed in 4 patients (10.6%), while retinopathy was found only in 1 patient (2.6%). Figure 1 illustrates the DEXA scan results, measuring BMD in the spine and left femur of pediatric patients.

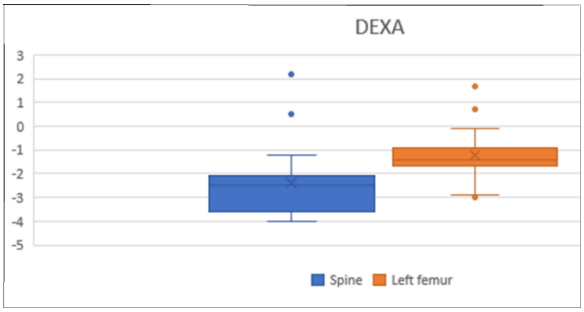

Figure 1: DEXA scan results for spine and left femur in diabetic children and adolescents.

For the spine, BMD values range from a high of 2.3 to a low of -4, with a median around -2.7. Similarly, for the left femur, BMD values range from 1.7 to -3, with a median value near -1.6. The BMD results for the spine derived from DEXA scans indicate that only 2 patients (4%) had normal BMD levels. Nine patients (18%) were categorized as having osteopenia. The majority, 39 patients (78%), fell into the osteoporosis category, meaning severely reduced bone density. The mean age, sex, duration of DM, and total daily insulin dose are not statistically significant with BMD changes (*p*-values were 0.34, 0.44, 0.75, and 0.31, respectively). Pre-pubertal patients were more likely to have osteoporosis (86.7%) compared to pubescent patients (69.6%), though this was not statistically significant (*p*-value: 0.36). A significant result is that 81.0% of patients with HbA1c ≥ 7.5% had osteoporosis (*p*-value: 0.004), as shown in Table 1.

Table 1: Association of various patient variables with BMD Categories

Variables		DEXA scan results			*p*-value
		Normal (> -1 SD)	Osteopenia (-1 to -2 SD)	Osteoporosis (< -2 SD)	
Age (year)	< 10	0(0.0)	0(0.0)	8(100)	0.34
	10 – 13	1(3.1)	6(18.8)	25(78.1)	
	> 13	1(10)	3(30)	6(60)	
Sex	Female	2(5.9)	7(20.6)	25(73.5)	0.44
	Male	0(0.0)	2(12.5)	14(87.5)	
DM duration (year)	<7	1(2.6)	8(20.5)	30(76.9)	0.75
	7-10	1(10)	1(10)	8(80)	
	>10	0(0.0)	0(0.0)	1(100)	
Insulin Dose (IU/kg/day)	< 1	2(8.3)	5(20.8)	17(70.8)	0.31
	≥ 1	0(0.0)	5(19.2)	21(80.8)	
Pubertal status	Pre-pubertal	0(0.0)	2(13.3)	13(86.7)	0.36
	Pubertal	2(8.7)	5(21.7)	16(69.6)	
HbA1c (%)	< 7.5%	2(2.5)	1(12.5)	5(62.5)	0.004
	≥ 7.5%	0(0.0)	8(19)	34(81)	

Values are presented as frequency and percentage.

Higher values of weight were observed in the normal BMD group (59.0 ± 8.49 kg), and significantly lower in the osteoporosis group (38.8 ± 12.13 kg), with a *p*-value of 0.008. BMI was also significantly lower in

the osteoporosis group (18.23±3.51) compared to the normal group (22.05±3.04), with a *p*-value of 0.018. On the other hand, height, height Z-score, weight Z-score, and BMI Z-score showed no significant differences between groups, as indicated by higher *p*-values (all > 0.05), as shown in Table 2.

Table 2: Association of anthropometric variables with BMD categories

Variables	DEXA scan results			*p*-value
	Normal (> -1 SD)	Osteopenia (-1 to -2 SD)	Osteoporosis (< -2 SD)	
Weight (kg)	59.0± 8.49	49.5± 7.09	38.8± 12.13	0.008
Weight Z Score	0.65±0.35	0.27±0.85	-0.26±1.3	0.329
Height (cm)	163.5±0.71	151.3± 10.7	144.7± 13.23	0.072
Height Z Score	0.34±0.14	-0.39±1.21	-0.52±1.26	0.616
BMI (kg/m^2)	22.05±3.04	21.86±3.38	18.23±3.51	0.018
BMI Z Score	0.56±0.48	0.51±0.71	-0.26±1.18	0.184

Values are presented as mean±SD.

Regarding serum calcium and vitamin D levels, there was no statistically significant difference across BMD categories, with *p*-value of 0.1 and 0.041, respectively, as shown in Table 3.

Table 3: Association of serum calcium and vitamin D level with BMD categories

Variables	DEXA scan results			*p*
	Normal (> -1 SD)	Osteopenia (-1 to -2 SD)	Osteoporosis (< -2 SD)	
Serum Ca (mmol/L)	1.65±0.64	2.26±0.15	2.19±0.39	0.10
Serum Vit D3 (nmol/L)	26.83±14.62	17.74±10.08	19.99±7.78	0.41

Values are presented as mean±SD.

Table 4 presents the relationship between long-term complications of T1DM and BMD categories. Although the differences are not statistically significant ($p = 0.076$), results showed that 3 out of 4 patients with nephropathy had osteoporosis, and the single affected patient with retinopathy had osteopenia.

Table 4: Association of diabetes complications with BMD categories

Complication	DEXA			*P*
	Normal (> -1SD)	Osteopenia (-1 to -2SD)	Osteoporosis (< -2SD)	
Nil	1(3)	6(18.2)	26(78.8)	
Nephropathy	1(25)	0(0.0)	3(75)	0.076
Retinopathy	0(0.0)	1(100)	0(0.0)	

Values are presented as frequency and percentage.

The correlation between 'DEXA spine' and BMI was a moderate positive correlation, with a correlation coefficient of 0.440 and an R^2 value of 0.18, suggesting that 18.0% of the variation in 'DEXA spine' scores was significantly associated with BMI ($p = 0.0029$), as shown in Figure 2.

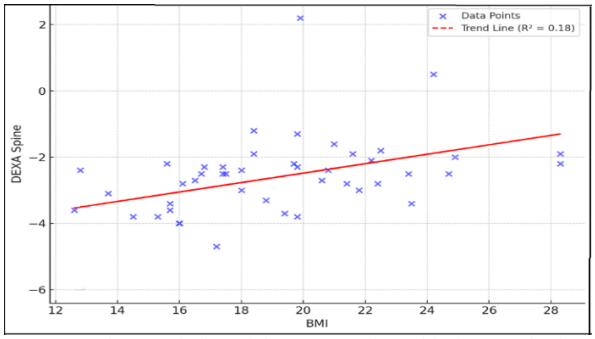

Figure 2: The correlation of the DEXA spine with the BMI in the patients.

DISCUSSION

Although bone fragility is a recognized side effect of type 1 diabetes, there is currently little data connecting the disease to decreased bone mineral density in children and adolescents. Childhood bone formation must be protected since low-quality bone can lead to low-impact fractures and growth problems [3,22]. Evaluating growth, cognitive function, and nutritional status in children with type 1 diabetes has prompted researchers to examine bone health, as T1DM affects multiple body systems [23–25]. According to our research, 78% of the patients had osteoporosis, with BMD scores below -2 SD, indicating significantly low bone density. This finding is consistent with a meta-analysis study by Zhu *et al*. that examined nine cross-sectional studies to determine whether there was a relationship between T1DM and BMD in children; all these studies concluded that children with T1DM had significantly lower BMD Z scores [10]. Joshi *et al*. study [26] reported the same conclusion. However, our results did not align with the findings of the Kumar *et al*. study, which indicated that 8% of cases had a BMD Z-score <-2. This could be explained by the smaller number of patients and shorter duration of diabetes in his study [22] and is not compatible with that reported by Mosso *et al*. [27]. Regarding age, in our study, it had no statistical significance ($p = 0.34$) with BMD results. This result is not compatible with Sayarifard *et al*. study, in which there was a significant correlation between BMD and patient age ($p < 0.001$) [28]. This discrepancy could be explained by varying glycemic control among age groups; in other words, glycemic control seems to have a more significant impact on BMD than age alone, according to a study conducted by Clements *et al*. (2014) among 2218 pediatric patients with T1DM [29]. Concerning the sex differences in this study, males with low BMD were higher than females despite lacking the statistical significance; Santiprabhob *et al*. concluded that the deleterious effect of T1DM on BMD is sex specific [30]. On the other hand, Wierzbicka *et al*. found the relationship between densitometric values and sex was not significant [31]. The current study revealed no statistically significant difference between the duration of the disease and the decline in BMD; this is comparable with a study performed by Pascual *et*

al. [32]. Pre-pubertal patients in our study seemed to be at higher risk for osteoporosis. Evidence suggests that delayed puberty may result in decreased BMD in adolescence, even though both bone mass potential and the time of puberty are highly heritable [33]. Our study showed a strong association between elevated HbA1c (≥7.5%) and an increased risk of osteoporosis, which is consistent with research by Wierzbicka *et al*. [31]. Diabetic osteopathy is linked to poor glycemic control, possibly as a result of decreased osteocalcin levels and compromised osteoblast function [34]. Moreover, even prediabetic patients have been found to have a higher fracture risk and diabetic complications [35,36]. Better BMD is correlated with higher weight and BMI, indicating that body mass preserves bone health in T1DM patients. This is consistent with Leão *et al*.'s findings that higher body mass increases mechanical load, highlighting how crucial it is for T1DM patients to maintain a healthy weight for their bones [37]. Similarly, Bilha *et al*. found that lower BMI is frequently associated with decreased BMD in patients with type 1 diabetes, indicating that maintaining a healthy BMI is essential for bone health and enhances entire skeletal strength [38]. Additionally, Roh *et al*. found that body mass had a greater impact on bone density than either height or other growth indices [39]. Even while calcium and vitamin D are known to play important roles in bone health, our results suggest that they might not be able to predict BMD in T1DM patients on their own. This is consistent with the findings of a study by Sayarifard *et al.* [28]. According to Wongdee *et al*., T1DM might affect calcium metabolism and bone remodeling by reducing calcium absorption and changing bone turnover, which helps to explain why serum calcium levels may not directly correlate with BMD [40]. Even if serum calcium levels seem unaltered, these underlying mechanisms may be responsible for bone fragility [41]. Khadilkar *et al*., on the other hand, concluded in their study that children with T1DM benefited from calcium and vitamin D supplements and that the Z score of lumbar spine BMD of supplemented participants of both sexes was significantly higher than those without supplementation [42]. The lack of a direct correlation between serum vitamin D levels and BMD in our study is in line with the systematic review by Gil-Díaz *et al*. [43]. This review emphasizes that while vitamin D insufficiency is prevalent in type 1 diabetes, BMD does not seem to be directly improved by isolated vitamin D levels when glycemic management and physical activity are not taken into account. This implies that managing bone health in T1DM patients effectively requires a multifaceted strategy that goes beyond vitamin D prescription [44,45]. Additionally, a study conducted by Fadl *et al*. with 90 patients revealed that although vitamin D deficiency was common in children with type 1 diabetes, it did not predict BMD results on its own. However, a more important factor in determining bone health was metabolic management, as indicated by HbA1c [46]. This observation aligns with our study. Concerning the relationship between T1DM complications and BMD, a significant portion of patients without complications (78.8%) presented with osteoporosis. This finding is comparable to that of Vora *et al*., who examined 64 adolescents with T1DM who had DM for more than ten years and found no noticeable difference in BMD in relation to retinopathy or nephropathy [4]. Osteoporosis and coronary artery disease often coexist, and a single computed tomography (CT) scan could be used to evaluate both conditions and detect subclinical atherosclerosis, which is especially important in females and young and diabetic patients [47,48]. The findings of the current study show a moderate positive correlation (with an R^2 value of 0.18) between BMI and DEXA spine values in pediatric diabetic patients. This is similar to the study by Lloyd *et al*., which shows that BMI and BMD have a positive connection that is unaffected by age, sex, or race. Furthermore, there is a protective, cross-sectional relationship between BMI and BMD; a 10-unit rise in BMI would cause an individual to go from having osteoporotic BMD to having normal BMD [49]. According to the Seo *et al*. study, which supports our findings, children and adolescents with high BMI seem to have better BMD [50].

Study limitations

The main limitation of this study is the limited sample size, which can be attributed to the restricted number of DEXA scans (1-2 tests allowed within a week) due to their high cost. This prevented us from setting up a control group.

Conclusions

The DEXA scan results indicate reduced BMD in children and adolescents with T1DM, highlighting the significant impact of the disease on bone health. Poor glycemic control increases the risk of decreased BMD, while higher weight and BMI positively influence bone density.

Conflict of interests

The authors declared no conflict of interest.

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Data sharing statement

Supplementary data can be shared with the corresponding author upon reasonable request.

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