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ORIGINAL RESEARCH

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Evaluation of mandibular bone characteristics on panoramic radiographs using radiomorphometric indices in obese children with and without vitamin D deficiency

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Abstract

Background: Obesity can affect bone structure through various metabolic disturbances, including inflammatory processes, altered mechanical loading, hormonal imbalances, and vitamin D deficiency. This study aimed to evaluate mandibular bone density in obese children, both with and without vitamin D deficiency, compared to healthy children, using radiomorphometric indices. **Methods**: A total of 120 panoramic radiographs were analyzed, equally divided into three groups (n = 40 each): obese children with vitamin D deficiency, obese children without the deficiency, and healthy controls. Radiomorphometric indices included the mandibular cortical index (MCI), mental index (MI), and panoramic mandibular index (PMI). Statistical analyses were performed using SPSS V23 and R 4.4.1. **Results**: PMI and MI values were significantly higher in both obese groups than in the healthy control group ($p < 0.001$), whereas no meaningful differences were observed between obese children with and without vitamin D deficiency. MCI distribution did not differ significantly among the groups ($p = 0.152$). **Conclusions**: MI and PMI values were higher in obese children than in healthy controls, whereas no meaningful differences were observed between obese children with and without vitamin D deficiency. These findings suggest that quantitative radiomorphometric indices obtained from panoramic radiographs may provide supportive information for the assessment of mandibular bone characteristics in pediatric patients.

Keywords

Panoramic radiography; Radiomorphometric indices; Vitamin D; Obesity; Children

1. Background

Obesity is defined as an excessive accumulation of adipose tissue. Its prevalence has increased significantly among children and adolescents worldwide [1]. Consequently, the World Health Organization (WHO) identifies childhood overweight and obesity as a critical public health challenge of the 21st century [2].

Obesity influences bone metabolism via inflammatory, mechanical, and hormonal pathways [3]. Adipokines (*e.g.*, leptin), sex hormones, and altered mechanical loading are potential mediators of obesity-induced changes in skeletal metabolism [4–6]. However, the specific radiographic manifestations of these mechanisms in the pediatric mandible remain unclear.

Vitamin D deficiency is highly prevalent in obese pediatric populations [7] and critically affects calcium–phosphorus homeostasis and bone mineralization [8]. Insufficient vitamin D impairs bone mineral density (BMD), driving increased bone remodeling and progressively reducing mechanical strength [8, 9]. Despite this, the combined effect of obesity and vitamin D deficiency on pediatric mandibular bone structure is not fully understood.

Bone mineral density and bone quality are essential clinical parameters in dentistry. Radiomorphometric indices, such as the mandibular cortical index (MCI), panoramic mandibular index (PMI), and mental index (MI), serve as indirect assessment tools for mandibular bone status [10, 11].

Previous studies have used radiomorphometric indices to investigate the effects of systemic diseases on the pediatric mandible [12–14]. However, data specifically addressing the effects of vitamin D deficiency on mandibular bone characteristics in obese children remain scarce. Therefore, this study aimed to evaluate mandibular bone density in obese children with and without vitamin D deficiency compared with healthy controls using mandibular indices (MCI, MI, and PMI).

2. Materials and methods

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2.1 Power analysis

Sample size calculation was performed prior to data collection using G*Power (version 3.1.9.6, Heinrich-Heine-Universität Düsseldorf, Düsseldorf, NRW, Germany). To achieve a 95% power ($1 - \beta$) at a 95% confidence level ($1 - \alpha$) with an effect size of $f = 0.3$, which was based on effect-size estimates derived from the data reported by Bayrak *et al.* [15], 177 participants (59 per group) were required. Lowering the statistical power to 80% yielded a minimum requirement of 111 participants (37 per group). Accounting for potential dropouts and the exclusions of suboptimal images, panoramic radiographs from 120 children were ultimately included.

2.2 Patient selection

This prospective study was conducted collaboratively by the Departments of Pediatrics and Pediatric Dentistry at Tokat Gaziosmanpaşa University between 2023 and 2025. Participants were recruited consecutively during the study period. Panoramic radiographs were obtained from 40 obese children without vitamin D deficiency (serum 25(OH)D $\geq$30 ng/mL), 40 obese children with vitamin D deficiency (serum 25(OH)D $<$30 ng/mL) who had received supplementation for no longer than 15 days, and 40 age- and sex-matched healthy controls.

Body mass index (BMI) percentiles specific to Turkish children, established by Neyzi *et al.* [16], served as reference values; obesity was defined as BMI $\geq$95th percentile. Vitamin D sufficiency was defined as serum 25(OH)D $\geq$30 ng/mL [17].

Inclusion criteria were as follows: patients aged 5–15 years with panoramic radiographs taken using a standardized Castellini X-Radius Trio Plus device (CEFLA S.C., Imola, Italy) that demonstrated clear visibility of the mental foramen, inferior mandibular cortex, and bilateral condylar margins.

Exclusion criteria comprised: age outside the 5–15-year range; panoramic radiographs with positioning errors, image artifacts, or insufficient quality; a history of orthodontic treatment; temporomandibular joint disorders or bruxism; systemic diseases affecting bone metabolism (*e.g.*, osteogenesis imperfecta, Paget's disease, fibrous dysplasia, hypo-/hyperparathyroidism); maxillofacial pathologies (*e.g.*, cysts or tumors); and a history of maxillofacial trauma or surgery.

All panoramic radiographs were obtained using a Castellini X-Radius Trio Plus device (Italy) with standardized exposure parameters (70 kVp, 10 mA, 8 s exposure, $\times$1.34 magnification). Patient positioning was standardized by aligning the sagittal plane perpendicular to the floor and the Frankfurt plane parallel to the ground. Images were exported in Tagged Image File Format (TIFF) and evaluated on a workstation with a display resolution of 2441 $\times$ 1149 pixels, 600 dpi, and 8-bit color depth. All measurements were conducted using ImageJ software (NIH, USA).

2.3 Radiomorphometric indices

The mandibular cortical index (MCI), mental index (MI), and panoramic mandibular index (PMI) were used for radiomorphometric evaluation. MCI is a qualitative metric based on the morphology of the mandibular inferior cortex, whereas MI and PMI are quantitative indices derived from cortical measurements. Because bone quality is multifactorial, integrating these indices enables a more comprehensive and reliable assessment of cortical bone characteristics. MI and PMI were measured bilaterally on the right and left sides. For image calibration, the mesiodistal width of the lower central incisors served as a radiographic reference.

MCI: Evaluation followed the method defined by Klemetti *et al.* [18]. This index classifies the morphology of the mandibular inferior cortex distal to the mental foramen into three categories: Type 1 (smooth and sharp endosteal margin); Type 2 (endosteal margin exhibiting semi-lunar defects or cortical residues); and Type 3 (endosteal margin containing dense cortical residues and appearing distinctly porous) (Fig. 1).

MI: Measurements were performed according to the technique defined by Ledgerton *et al.* [19]. This metric represents the mandibular cortical width (in mm) at the level of the mental foramen. Cortical thickness was measured along a line perpendicular to the lower border of the mandible, intersecting the midpoint of the mental foramen (Fig. 2).

PMI: Calculation was based on the protocol by Benson *et al.* [20]. PMI is defined as the ratio of mandibular cortical width to mandibular height at the mental foramen. The calculation formula is PMI = MI/(distance from the inferior border of the mental foramen to the lower border of the mandible) (Fig. 2).

2.4 Statistical analysis

Statistical analyses were performed using IBM SPSS Statistics version 23.0 (IBM Corp., Armonk, NY, USA) and R version 4.4.1. Data normality was assessed via the Kolmogorov-Smirnov and Shapiro-Wilk tests. For non-normally distributed continuous variables, the Mann-Whitney U test and the Kruskal-Wallis H test were applied for comparisons between two groups and among three or more groups, respectively. Associations between categorical variables were analyzed using Pearson's Chi-square test and Fisher's exact test with Monte Carlo simulation. Correlation analyses were performed using Spearman's rho test for MI and Pearson correlation analysis for PMI. Measurement reliability was determined using the intraclass correlation coefficient (ICC) for continuous variables and Cohen's kappa coefficient for categorical variables. Continuous variables are presented as mean $\pm$ standard deviation or median (minimum–maximum), whereas categorical variables are presented as frequencies and percentages. Statistical significance was set at $p < 0.05$. Following the Kruskal-Wallis test, effect sizes (η^2) were calculated to quantify the magnitude of group differences.

3. Results

This study included 120 panoramic radiographs, evenly distributed across three groups (n = 40 per group): obese children without vitamin D deficiency, obese children with vitamin D deficiency, and healthy controls. Age distribution did not differ significantly among the cohorts ($p = 0.997$). The sex distribution was perfectly balanced, with 50% girls and 50% boys in each group (Table 1).

Intra-observer reliability analysis revealed excellent agree-

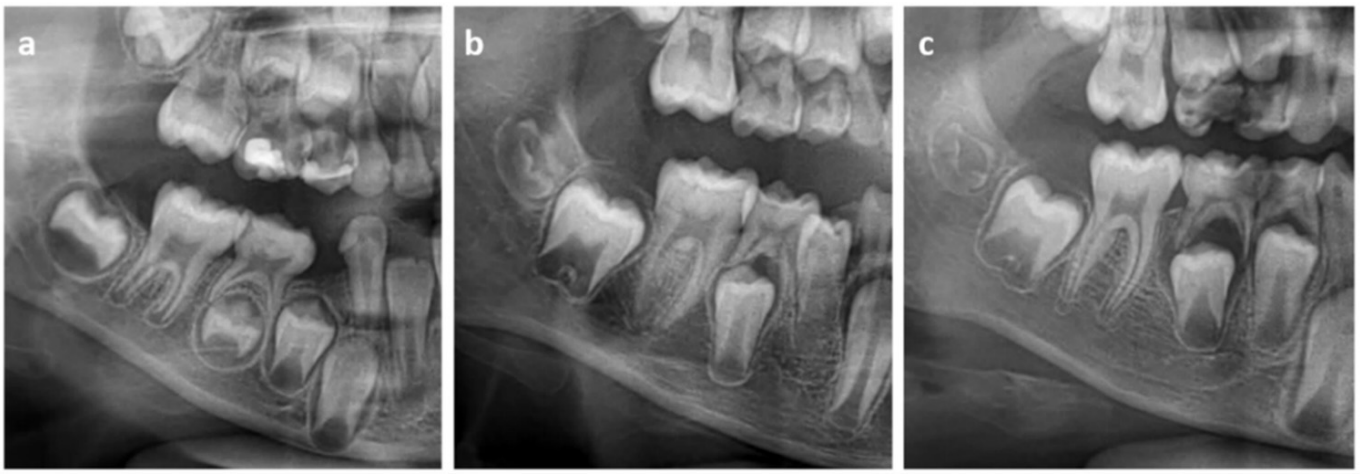


FIGURE 1. Klemetti classification for morphological analysis of the mandibular inferior cortex (a) Type 1, (b) Type 2, (c) Type 3.

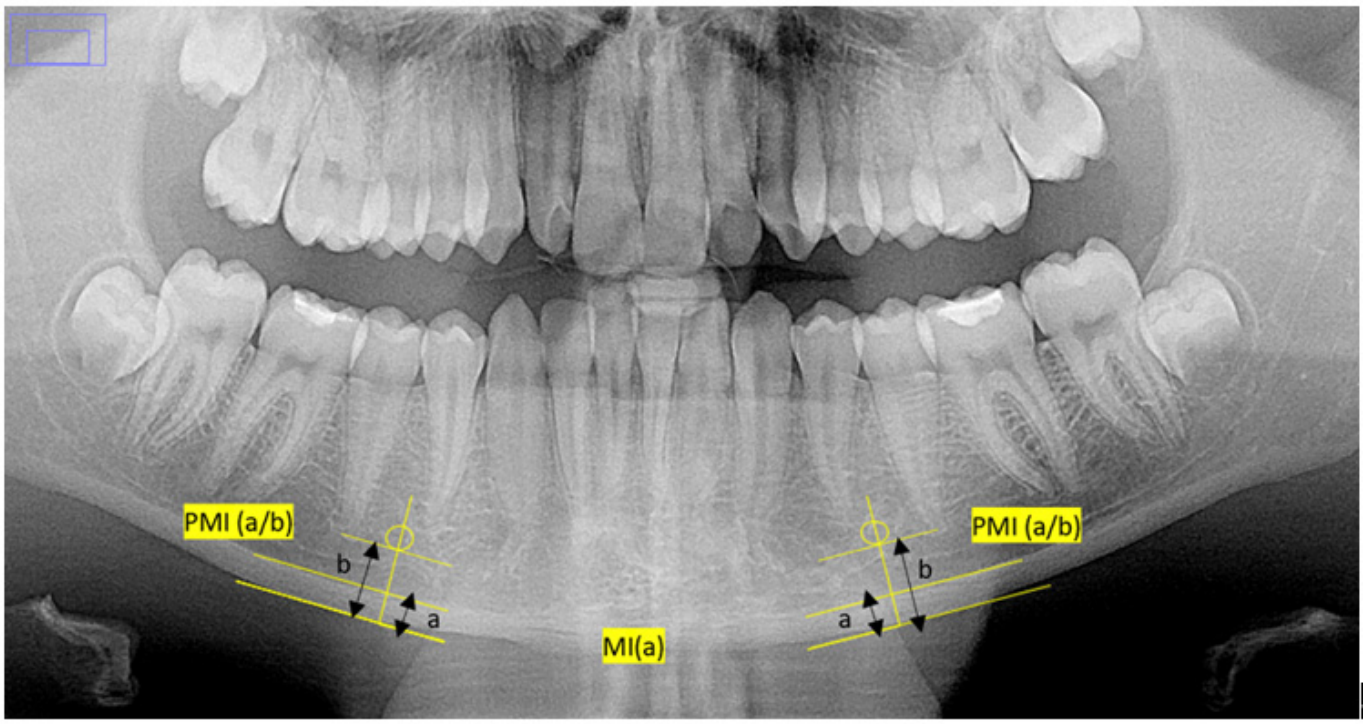


FIGURE 2. Measurement of MI and PMI in mandibular radiomorphometric analysis. MI: mental index; PMI: panoramic mandibular index.

TABLE 1. Examination of demographic characteristics.

Variables	N (%)			*p*-value
	Obese without vitamin D deficiency (n = 40)	Obese with vitamin D deficiency (n = 40)	Control (n = 40)	
Gender				
Female	20 (50%)	20 (50%)	20 (50%)	1.000
Male	20 (50%)	20 (50%)	20 (50%)	
Age (yr), mean ± SD	9.75 ± 2.63	9.72 ± 2.63	9.71 ± 2.62	0.997

Data are presented as n (%) or mean ± standard deviation (SD). Pearson's chi-square test was used for categorical variables, and Kruskal-Wallis test was used for continuous variables.

ment for the bilateral (right and left) MI and PMI values ($p < 0.001$) (Table 2). The Cohen's Kappa coefficient demonstrated good agreement for the MCI classification ($\kappa = 0.753$; $p < 0.001$) (Table 3).

TABLE 2. Intraclass correlation coefficients for MI and PMI.

	ICC (95% CI)	*p*-value
MI right	0.921 (0.827–0.965)	<0.001
PMI right	0.915 (0.814–0.962)	<0.001
MI left	0.957 (0.904–0.981)	<0.001
PMI left	0.945 (0.878–0.976)	<0.001

ICC values were interpreted as follows: <0.50 poor, 0.50–0.75 moderate, 0.75–0.90 good, and >0.90 excellent reliability. MI: mental index; PMI: panoramic mandibular index; ICC: intraclass correlation coefficient; CI: confidence interval.

TABLE 3. Intra-observer agreement for the MCI classification.

First assessment	Second assessment		Total
	Type 1	Type 2	
Type 1	10 (76.9%)	0 (0.0%)	10 (41.7%)
Type 2	3 (23.1%)	11 (100.0%)	14 (58.3%)

Data are presented as n (%). Cohen's kappa = 0.753; $p < 0.001$.

TABLE 4. Comparison of MCI types between groups.

Variables	N (%)			*p*-value
	Obese without vitamin D deficiency (n = 40)	Obese with vitamin D deficiency (n = 40)	Control (n = 40)	
MCI				
Type 1	22 (55.0%)	19 (47.5%)	15 (37.5%)	
Type 2	17 (42.5%)	20 (50.0%)	19 (47.5%)	0.152
Type 3	1 (2.5%)	1 (2.5%)	6 (15.0%)	

Data are presented as n (%). Fisher's exact test (Monte Carlo simulation) was used for comparisons. MCI: mandibular cortical index.

The distribution of MCI types did not differ significantly across the study groups (Table 4).

Bilateral (right and left) MI and PMI values were significantly higher in obese children with and without vitamin D deficiency compared with healthy controls ($p < 0.05$). Effect size analysis (η^2) revealed moderate effects for MI right ($\eta^2 = 0.106$) and MI left ($\eta^2 = 0.136$), and large effects for PMI right ($\eta^2 = 0.218$) and PMI left ($\eta^2 = 0.236$) (Table 5).

Age exhibited a statistically significant, moderate positive correlation with both the right MI ($r = 0.544$; $p < 0.001$) and left MI ($r = 0.516$; $p < 0.001$). Conversely, no significant correlation was observed between age and PMI on either side (right PMI: $p = 0.659$; left PMI: $p = 0.423$) (Table 6).

4. Discussion

Assessing bone density and structure is important for diagnosing and managing bone-related pathologies. Systemic diseases affecting bone metabolism may induce alterations in mandibular bone characteristics [15], which can be evaluated using panoramic radiographs, a standard modality in dental practice [11]. Although previous studies have independently investigated the effects of obesity and vitamin D status on mandibular bone characteristics, their combined impact has not been evaluated using radiomorphometric indices [14, 21, 22]. To our knowledge, this study is among the first to simultaneously assess the combined effects of obesity and vitamin D deficiency on pediatric mandibular bone structure using radiomorphometric approaches, providing potentially relevant clinical insights.

Obesity influences bone metabolism via complex interactions involving adipokines, sex hormones, inflammatory mediators, and mechanical loading. Leptin modulates chondrocyte proliferation and skeletal growth, while estrogen is critical for bone maturation and remodeling [23–25]. Furthermore, the increased mechanical loading associated with greater body weight can stimulate bone formation [6]. These systemic metabolic shifts may also influence mandibular alveolar bone thickness and structure, which correlate strongly with skeletal bone mineral density (BMD) [26]. In the present study, mandibular cortical thickness was significantly greater in obese children compared to their normal-weight counterparts, in line with previous findings. For instance, Jeddi *et al.* [27] and van Leeuwen *et al.* [28] demonstrated significantly higher Dual-energy X-ray absorptiometry (DXA) measured BMD values in overweight and obese youth. Manzoni *et al.* [29] similarly reported increased total and regional bone mineral content in obese pediatric cohorts. In panoramic radiographic assessments, Yasa *et al.* [14] observed elevated mental index (MI) and panoramic mandibular index (PMI) values in overweight and obese adolescents. Collectively, these findings suggest that increased mechanical loading and hormonal shifts intrinsic to obesity may contribute to the observed thickening of the mandibular cortex.

Conversely, circulating vitamin D levels are typically reduced in obese individuals due to increased sequestration in adipose tissue and decreased cutaneous synthesis [30]. Vitamin D deficiency impairs calcium and phosphorus

TABLE 5. Comparison of MI and PMI between groups.

	Median (Minimum–Maximum)			Statistical analysis	η^2	*p*-value
	Obese without vitamin D deficiency (n = 40)	Obese with vitamin D deficiency (n = 40)	Control (n = 40)			
MI Right	4.77 (2.87–6.79)^a	4.53 (3.35–6.70)^a	3.86 (2.57–6.82)^b	14.459	0.106	<0.001*
PMI Right	0.42 (0.27–0.60)^a	0.41 (0.32–0.59)^a	0.35 (0.27–0.45)^b	27.556	0.218	<0.001*
MI Left	4.74 (2.76–6.17)^a	4.53 (2.84–7.61)^a	3.75 (2.55–5.70)^b	17.900	0.136	<0.001*
PMI Left	0.40 (0.24–0.59)^a	0.41 (0.25–0.52)^a	0.32 (0.23–0.57)^b	29.600	0.236	<0.001*

*Data are presented as median (minimum–maximum). Kruskal-Wallis test was used for group comparisons. Post hoc pairwise comparisons were performed using Dunn's test with Bonferroni correction. Different superscript letters (a, b) indicate statistically significant differences between groups ($p < 0.05$). *indicates a statistically significant overall difference among the three groups (Kruskal-Wallis test, $p < 0.05$). Effect sizes (η^2) were calculated. Values of 0.01, 0.06, and 0.14 were considered small, medium, and large effects, respectively. MI: mental index; PMI: panoramic mandibular index.*

TABLE 6. Correlation between age and mandibular radiomorphometric indices.

	Age	
	r	*p*-value
Right MI	0.544	<0.001*
Right PMI	−0.041	0.659
Left MI	0.516	<0.001*
Left PMI	−0.074	0.423

*Values are presented as correlation coefficient (r) and p-value. Spearman's rho correlation was used for MI and Pearson correlation for PMI. *Statistically significant ($p < 0.05$). MI: mental index; PMI: panoramic mandibular index.*

metabolism, decreasing intestinal calcium absorption and disrupting bone metabolism [8]. These alterations may influence bone metabolism and mineralization processes in growing individuals [31, 32]. In a study by Korkmaz *et al.* [21], evaluating the effects of vitamin D deficiency on mandibular bone structure using fractal analysis and mandibular indices, PMI values were significantly lower in individuals with severe vitamin D deficiency. However, in the present study, no marked differences were observed in PMI values between obese children with and without vitamin D deficiency. This discrepancy may be explained by differences in study populations, as the pediatric population is characterized by ongoing skeletal growth and remodeling. In addition, increased mechanical loading associated with obesity may have attenuated the potential effects of vitamin D deficiency on mandibular radiomorphometric indices in growing children.

No significant difference was observed in the distribution of MCI types among the study groups. While MCI is predominantly applied in adult populations, its utility in pediatric studies is documented [12, 33, 34]. Because MCI relies on visual qualitative assessment, its interpretation may be influenced by observer-dependent variability [35]. Therefore, MCI may be considered an adjunctive parameter rather than a standalone diagnostic tool in pediatric assessments.

During craniofacial growth, cortical bone thickening is driven by increased bite force, enhanced masticatory muscle activity, and tensile forces generated at muscular attachment sites (*e.g.*, masseter and buccinator) along the inferior border of the mandible [36]. Knezović Zlatarić *et al.* [36] demonstrated a significant increase in MI values with age in children aged 6–12 years, while Tayebi *et al.* [37] reported similar findings in children aged 7–13 years. Accordingly, mandibular indices have been suggested to be clinically relevant parameters for assessing mandibular growth and maturation. Our results align with these observations, revealing a moderate positive correlation between MI and age, which may support the notion that cortical bone thickness increases with advancing age in children. In contrast, findings regarding the relationship between PMI and age remain inconsistent. While some studies report age-related decreases in adult PMI [38] or higher pediatric PMI in children under 10 [33], others, such as Temur *et al.* [13], found no significant association between PMI and age in pediatric cohorts. Our data are consistent with the findings of Temur *et al.* [13], suggesting that systemic factors such as obesity and vitamin D status may have a greater influence on bone morphometric indices than age alone. Therefore, PMI should be evaluated as an indicator of an individual's metabolic and systemic condition rather than a strict function of age.

To ensure a comprehensive evaluation, we integrated multiple radiomorphometric indices [12, 33, 39]. Because individual indices capture distinct anatomical features, such as cortical morphology and cortical thickness, their combined application may provide a more comprehensive assessment than any single parameter.

This study presents several limitations. First, the absence of DXA measurements precluded direct validation against

systemic BMD. Second, lifestyle covariates, such as dietary habits, physical activity, sun exposure, and pubertal staging were not evaluated. Third, panoramic radiograph evaluations are inherently subject to image resolution limits and projection geometry variability. In addition, the relatively small number of participants classified as MCI Type 3 may have limited the reliability of comparisons between groups. However, this finding may be expected in pediatric populations, where severe cortical erosion patterns are less commonly observed.

Although this study specifically included obese children without other systemic conditions affecting bone metabolism, mandibular bone characteristics remain influenced by multiple biological and developmental factors. Future investigations utilizing larger cohorts, comprehensive biochemical and lifestyle profiling, and longitudinal designs may help better understand the relationship between obesity, vitamin D status, and mandibular bone changes in children.

5. Conclusions

Overall, the present findings indicate that childhood obesity may be associated with increases in quantitative mandibular radiomorphometric indices, particularly MI and PMI values. Vitamin D deficiency, however, was not associated with additional differences in the evaluated indices among obese children. Quantitative radiomorphometric indices obtained from panoramic radiographs may provide supportive information in the evaluation of mandibular bone characteristics in pediatric patients. Further studies with larger cohorts and longitudinal designs are needed to better understand the relationship between obesity and mandibular radiomorphometric changes in children.

AVAILABILITY OF DATA AND MATERIALS

The datasets generated and/or analyzed during the current study are available from the corresponding author upon reasonable request.

AUTHOR CONTRIBUTIONS

BBA—acquired the data and performed data analysis and interpretation. BBA and AC—drafted the manuscript. AG—contributed to patient recruitment and data collection. All authors conceived and designed the study. All authors reviewed and revised the manuscript and approved the final version for submission.

ETHICS APPROVAL AND CONSENT TO PARTICIPATE

All procedures were performed in accordance with the Declaration of Helsinki. The study was approved by the Tokat Gaziosmanpaşa University Clinical Research Ethics Committee (approval number: 23-KAEK-102). Written informed consent was obtained from all participants and their legal guardians prior to participation.

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CONFLICT OF INTEREST

The authors declare no conflict of interest.

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