

Article

Evaluation of Mandibular Bone Characteristics in Children with Onychophagy

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Highlights

What are the main findings?

- Children with onychophagy demonstrated significantly higher fractal dimension values than controls in all evaluated mandibular regions.
- Panoramic mandibular index values were significantly higher in the onychophagy group, whereas anterior, symphysis, molar, and posterior indices did not differ significantly between groups following Bonferroni correction.

What are the implications of the main findings?

- Chronic onychophagy was associated with differences in mandibular trabecular organization and localized cortical morphology during growth.
- The potential oral effects of nail biting may extend beyond dentoalveolar changes to mandibular bone characteristics.

Abstract

Background/Objectives: This study aimed to evaluate mandibular bone characteristics in children with onychophagy using fractal analysis (FA) and panoramic radiomorphometric indices. **Methods:** Ninety children aged 7–11 years were included in this retrospective cross-sectional study and allocated to an onychophagy group ($n = 45$) or a healthy control group ($n = 45$). Fractal dimension (FD) was measured in four mandibular regions (condyle, mandibular angle, the interdental trabecular bone of the posterior dentate mandibular region, and the trabecular bone at the level of the tooth apices in the anterior dentate mandibular region) on panoramic radiographs. Radiomorphometric evaluation included the symphysis index (SI), anterior index (AI), molar index (MI), posterior index (PI), panoramic mandibular index (PMI), and mandibular cortical index (MCI). Between-group comparisons were performed using appropriate statistical tests ($\alpha = 0.05$). **Results:** Children with onychophagy demonstrated significantly higher FD values than controls in all evaluated mandibular regions (all $p < 0.0125$ following Bonferroni correction). PMI values were also significantly higher in the onychophagy group ($p < 0.001$), whereas AI, SI, MI, and PI did not differ significantly between groups after Bonferroni correction. All participants were classified as MCI category C1. Intraobserver reliability was excellent for both FD and radiomorphometric measurements. **Conclusions:** Onychophagy was associated with differences in mandibular radiographic measurements in children. However, the retrospective cross-sectional design does not establish causality, and the clinical significance

Academic Editor: Cinzia Maspero

Received: 18 September 2026

Revised: 18 October 2026

Accepted: 21 October 2026

Published: 22 October 2026

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of these findings remains uncertain. Further longitudinal studies are needed to clarify these associations.

Keywords: fractals; nail biting; panoramic radiography; pediatric dentistry

1. Introduction

Onychophagy, commonly referred to as nail biting (NB), is a common body-focused repetitive behavior that typically begins during childhood and adolescence. Its prevalence has been reported to range from approximately 20–25% in children and to increase to nearly 45% during early adolescence [1,2]. Although its etiology is multifactorial, involving both genetic and environmental influences, persistent NB has been associated with psychological distress and reduced quality of life [3,4]. Persistent oral parafunctional habits may alter the neuromuscular balance of the stomatognathic system and contribute to dentoalveolar and craniofacial alterations during growth [5–7]. As a repetitive oral habit, NB may generate continuous mechanical forces on dentofacial structures, potentially affecting tooth position as well as mandibular growth [5]. Because the pediatric mandible undergoes continuous remodeling during growth, repetitive functional or parafunctional loading may influence bone remodeling and trabecular organization. Therefore, prolonged NB may theoretically affect not only dental alignment but also mandibular bone microarchitecture. However, whether NB influences mandibular trabecular microarchitecture during craniofacial growth remains unclear.

Panoramic radiography (PR) is widely used in dental practice because it provides a practical, readily available, and cost-effective method for evaluating the jaws and surrounding maxillofacial structures. In addition to monitoring growth and development, PRs are commonly used for diagnosis, treatment planning, and radiomorphometric assessment of bone quality [8–10]. Although radiomorphometric indices can provide indirect information regarding bone mineral density, increasing evidence suggests that comprehensive assessment of mandibular bone quality should also include evaluation of trabecular microarchitecture [11,12]. Fractal analysis (FA) is a mathematical method that quantitatively evaluates the complexity of trabecular bone architecture using the box-counting algorithm. The resulting fractal dimension (FD) reflects trabecular structural complexity, with higher FD values generally indicating a more complex trabecular pattern [13–15]. Changes in FD values have been associated with alterations in trabecular organization secondary to mechanical loading, growth, metabolic disorders, and systemic diseases [8,15]. Accordingly, FA has emerged as a reproducible and non-invasive method for evaluating mandibular trabecular bone microarchitecture on PRs.

Previous studies have demonstrated the usefulness of FD analysis in evaluating mandibular trabecular bone changes in various systemic and local conditions, suggesting that it may serve as a sensitive imaging biomarker for alterations in bone microarchitecture [8,9,14,15]. Although the dentofacial effects of NB have been investigated primarily with respect to occlusion and dental alignment, its possible influence on mandibular trabecular bone architecture and cortical morphology has not been evaluated. Therefore, the aim of this study was to evaluate mandibular cortical morphology and trabecular microarchitecture in children with onychophagy using mandibular radiomorphometric indices and FD analysis, and to compare the findings with those of healthy controls. The null hypothesis was that no significant differences would be observed in mandibular cortical morphology or trabecular microarchitecture between children with onychophagy and healthy controls.

2. Materials and Methods

2.1. Study Design and Ethics

This retrospective cross-sectional study was conducted in accordance with the ethical principles of the World Medical Association Declaration of Helsinki and its subsequent amendments. Ethical approval was obtained from the Recep Tayyip Erdoğan University Non-Interventional Clinical Research Ethics Committee (Decision No: 2026/315; Date: 23 July 2026). Following approval by the ethics committee, the study was registered on ClinicalTrials.gov under the identifier NCT07740889 on 28 July 2026. Written informed consent for the use of clinical and radiographic records for research purposes was obtained from the parents or legal guardians of all participants.

Clinical findings, including the presence or absence of onychophagy, bruxism, temporomandibular disorders (TMDs), and skeletal malocclusion, were routinely recorded based on patient history and clinical examination (including assessment of temporomandibular joint sounds, pain, and mouth-opening range and limitation for TMDs [16] and clinical screening for skeletal malocclusion through evaluation of maxillomandibular relationships in centric occlusion) at the patient's first visit by the attending pediatric dentist.

Children were classified into the onychophagy and control groups based on parental reports and the findings recorded during the initial clinical examination. Onychophagy was defined as a nail-biting habit persisting for at least one year according to parental reports and confirmed by clinical examination. Clinical examinations were performed by a pediatric dentist to document the presence or absence of characteristic nail findings consistent with chronic NB, including shortened nail plates, irregular nail margins, and periungual tissue changes. However, the average daily duration, frequency, and severity of nail biting were not quantitatively recorded in the existing clinical records. Clinical records and panoramic radiographs obtained between 2022 and 2024 were retrospectively reviewed. Following assessment of the eligibility criteria, 60 eligible children with onychophagy and 60 eligible children without onychophagy constituted separate sampling pools for the onychophagy and control groups, respectively. Frequency matching was performed at the group level based on age and sex to achieve comparable distributions between the groups. From these pools, 45 children per group were selected using a computer-generated random sampling procedure (Randomizer.org), resulting in a final sample of 90 participants (45 per group). Random selection was performed solely for participant selection and not for group allocation, as group membership was determined by the presence or absence of onychophagy documented in the clinical records. The children had attended the dental faculty for routine dental care, including caries assessment and treatment. Panoramic radiographs had been obtained when clinically indicated for diagnosis and treatment planning, rather than specifically for the present study.

All PRs were acquired using the same panoramic imaging unit (Planmeca ProMax 2D S2, Planmeca Oy, Helsinki, Finland) with standardized exposure parameters of 66 kVp, 8 mA, and 16.6 s. The panoramic images had a resolution of 1024 × 536 pixels. As all images were acquired using the same device and standardized exposure parameters, no digital enlargement or resizing was performed before fractal analysis.

Before each linear radiomorphometric measurement, calibration was performed to correct the Planmeca system's magnification factor of 1.2, thereby establishing a 1:1 measurement scale. All linear measurements were recorded in millimeters. Patients were positioned according to the manufacturer's instructions, with the Frankfort horizontal plane parallel to the floor and the midsagittal plane aligned with the vertical plane of the panoramic unit.

2.2. Eligibility Criteria

The inclusion criteria were as follows: (1) age between 7 and 11 years; (2) PRs of sufficient diagnostic quality for radiomorphometric and fractal dimension (FD) analyses; and (3) a NB habit lasting for at least one year for the onychophagy group or no history of NB for the control group, as confirmed by parental reports and clinical examination. All participants were in the mixed dentition period.

The exclusion criteria were the presence of systemic diseases or syndromes; metabolic bone disorders or other conditions affecting bone metabolism; previous or current use of medications known to influence bone metabolism; clinically suspected skeletal Class II or Class III malocclusion; a history of dental trauma, mandibular surgery, cystic lesions, or tumors involving the mandible; bruxism or temporomandibular disorders; other oral habits; and agenesis of permanent teeth in the mandible.

2.3. Fractal Dimension Analysis of Panoramic Radiographs

FD analysis was performed using ImageJ software (version 1.52; National Institutes of Health, Bethesda, MD, USA). Bilateral FD measurements were obtained from four predefined regions of interest (ROIs) on each PR, and the mean of the right and left measurements was used for statistical analysis. Each ROI measured 35×35 pixels and was positioned within the trabecular bone [17]. This ROI size was selected as the largest common square area that could be consistently positioned within the trabecular bone across all four anatomical regions while avoiding superimposed anatomical structures. The selected ROIs included the subcortical region of the mandibular condyle (FD1), the supracortical region above the mandibular angle (FD2), the interdental trabecular bone of the posterior dentate mandibular region (FD3), and the trabecular bone at the level of the tooth apices in the anterior dentate mandibular region (FD4) (Figure 1). ROI placement was standardized using the predefined anatomical regions. ROIs were positioned within trabecular bone while excluding developing teeth, tooth roots, cortical boundaries, and superimposed anatomical structures. No digital enlargement or resizing was performed before fractal analysis.

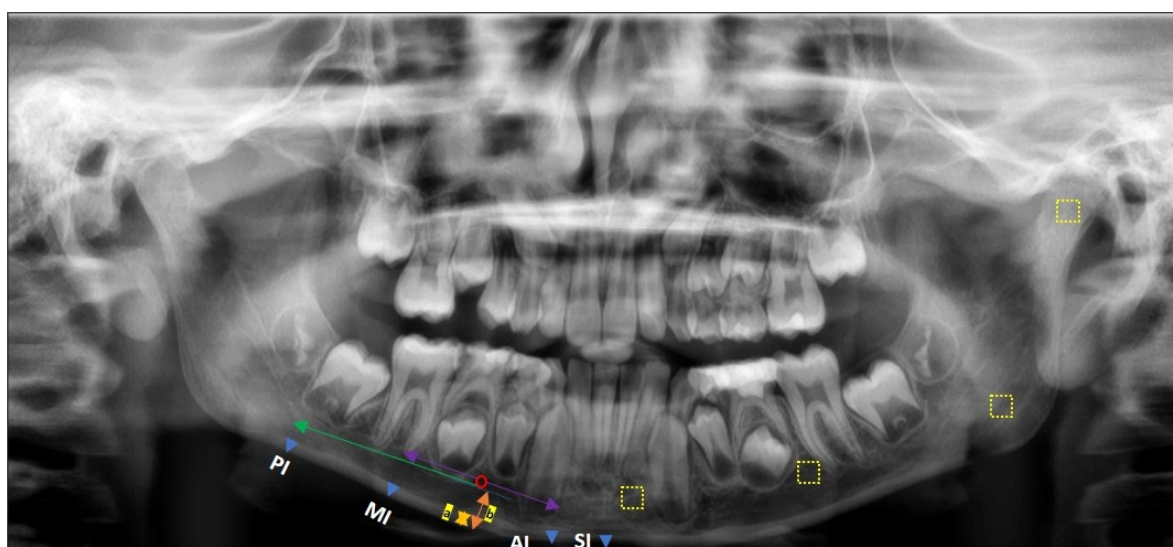


Figure 1. Panoramic radiograph illustrating the radiomorphometric measurements and regions of interest (ROIs) used in the study. The right hemimandible demonstrates the radiomorphometric indices, including the panoramic mandibular index (PMI), anterior index (AI), posterior index (PI), molar index (MI), and symphysis index (SI). The PMI was calculated as the ratio of mandibular cortical thickness (a) to the distance between the inferior border of the mandibular cortex and the

inferior border of the mental foramen (b) ($PMI = a/b$). Mandibular cortical thickness measurements included the posterior index (PI), measured at a point 2.5 cm distal to the mental foramen (MF); the molar index (MI), measured at a point 1.0 cm distal to the MF; the anterior index (AI), measured at a point 1.0 cm mesial to the MF; and the symphysis index (SI), measured at the midpoint between the centers of the right and left mental foramina. The red circle indicates the mental foramen. The green arrow indicates a distance of 2.5 cm, and the purple arrow indicates a distance of 1.0 cm. The yellow dashed squares on the left hemimandible indicate the ROIs selected for fractal analysis, including the subcortical region of the mandibular condyle, the supracortical region of the mandibular angle, the interdental trabecular bone of the posterior dentate mandibular region, and the trabecular bone at the level of the tooth apices in the anterior dentate mandibular region.

The analysis followed the box-counting method described by White and Rudolph [18]. PRs were converted to tagged image file format (TIFF) to preserve image quality. A total of 720 ROIs were selected, cropped, and duplicated for analysis. A Gaussian blur filter (radius = 35 pixels) was applied to the duplicated image to reduce brightness variations associated with overlying soft tissues and differences in bone thickness. The blurred image was then subtracted from the original image, after which a gray value of 128 was added to each pixel to differentiate trabeculae from marrow spaces. The processed image subsequently underwent binarization, erosion, dilation, inversion, and skeletonization. Finally, FD values were calculated using the built-in Fractal Box Count tool in ImageJ (version 1.52), with box sizes of 2, 3, 4, 6, 8, 12, 16, and 32 pixels. The fractal dimension was determined from the negative slope of the log–log regression of box counts against box sizes (Figure 2).

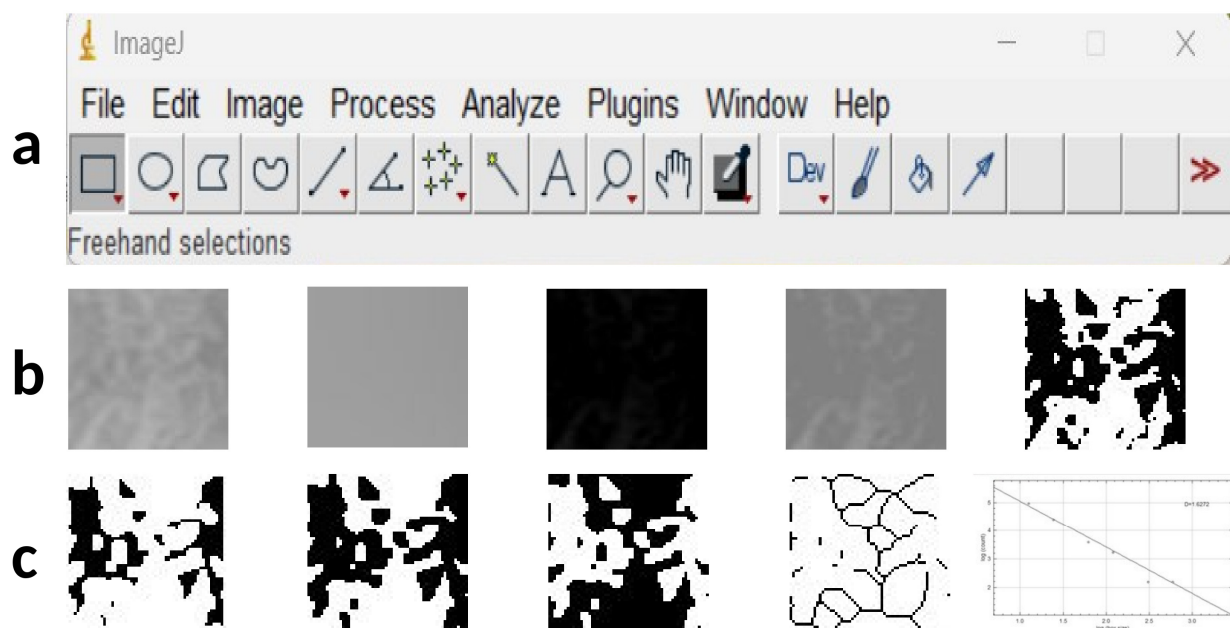


Figure 2. Workflow of the fractal analysis. (a) ImageJ software interface used for fractal analysis based on the box-counting method. (b) Image processing steps: the ROI was duplicated, blurred using a Gaussian filter, subtracted from the original image, adjusted by adding a gray value of 128, and thresholded at a grayscale value of 128 to obtain a binary image. (c) The binary image was subjected to erosion, dilation, inversion, and skeletonization, followed by calculation of the fractal dimension using the box-counting method.

2.4. Radiomorphometric Indices

All radiomorphometric measurements were performed using Planmeca Romexis software (version 4.6.2.R; Planmeca Oy, Helsinki, Finland). Cortical thickness measurements, originally described by Barra et al. [19] for cone-beam computed tomography images, were adapted for PRs in the present study. This adaptation was based on identifiable anatomical landmarks, including the mental foramen and inferior mandibular border, and was supported by previous studies applying the same cortical indices to panoramic radiographs [20,21]. Measurements were obtained bilaterally for the anterior index (AI), molar index (MI), and posterior index (PI), and the mean of the right and left measurements was used for statistical analysis. In contrast, the symphysis index (SI) was measured as a single midline measurement at the midpoint between the centers of the right and left mental foramina, perpendicular to the inferior mandibular cortex, without bilateral averaging [19] (Figure 1).

The symphysis index (SI) was measured perpendicular to the inferior mandibular cortex at a point equidistant from the centers of the right and left mental foramina. The anterior index (AI) was measured 1 cm anterior to the mental foramen, parallel to the long axis of the mandible and perpendicular to the inferior mandibular cortex. The molar index (MI) was measured 1 cm posterior to the mental foramen using the same orientation, whereas the posterior index (PI) was measured 2.5 cm posterior to the mental foramen, parallel to the long axis of the mandible and perpendicular to the inferior mandibular cortex.

The panoramic mandibular index (PMI) was measured according to the method described by Benson et al. [22]. PMI was calculated bilaterally as the ratio of the mandibular cortical width (MCW) to the distance between the inferior border of the mental foramen and the inferior border of the mandible. MCW was measured on a line drawn perpendicular to the inferior mandibular border through the center of the mental foramen, and the mean of the right and left measurements was recorded as the final PMI value (Figure 1).

The mandibular cortical index (MCI), also known as the Klemetti index [23], was used to evaluate the morphological appearance of the mandibular cortex distal to the mental foramen. The cortex was classified into three categories: C1, a normal cortex with a smooth and sharp endosteal margin; C2, a mildly to moderately eroded cortex showing semilunar defects or endosteal cortical residues; and C3, a severely eroded cortex characterized by marked porosity and irregularity.

All measurements were performed by an experienced oral and maxillofacial radiologist, who was blinded to all clinical records and participant group assignment.

To assess intraobserver reliability, 18 panoramic radiographs (20% of the total sample) were randomly selected and re-evaluated two weeks after the initial measurements. FD measurements were repeated using newly selected 35 × 35-pixel ROIs from the same predefined anatomical regions. The original ROIs were not reused, and the entire image processing and FD calculation procedure was independently repeated.

2.5. Statistical Analysis

The primary outcomes were the fractal dimension (FD) measurements obtained from four predefined regions of interest (FD1–FD4), whereas the five panoramic radiomorphometric indices (SI, AI, MI, PI, and PMI) were designated as secondary outcomes.

The required sample size was calculated a priori using G*Power software (version 3.1.9.7; Heinrich Heine University, Düsseldorf, Germany). Fractal dimension (FD) measurements in the mandibular angle region (FD2) were considered the primary outcome for the sample size calculation. The anticipated effect size was estimated based on a previous study by Günaçar et al. [20], which reported mean FD values of 1.42 ± 0.08 and 1.47 ± 0.09 in the hyperlipidemia and healthy control groups, respectively, corresponding to a

calculated Cohen's d of approximately 0.59. This value was rounded to 0.60 for the present study. Based on an independent-samples t -test, a two-tailed significance level (α) of 0.05, a statistical power of 80%, and Cohen's $d = 0.60$, the target sample size was 45 participants per group (total $n = 90$). Accordingly, the study included 45 children with onychophagy and 45 healthy controls, frequency-matched at the group level for age and sex.

Statistical analyses were performed using IBM SPSS Statistics for Mac, version 29.0.2.0 (IBM Corp., Armonk, NY, USA). Data normality was evaluated using the Shapiro–Wilk test. Intergroup comparisons were carried out using either the independent samples t -test or the Mann–Whitney U test, according to the distribution of the variables. To account for multiple between-group comparisons, the Bonferroni correction was applied separately to the four primary fractal dimension outcomes (FD1–FD4) and the five secondary radiomorphometric indices (SI, AI, MI, PI, and PMI). Accordingly, the adjusted significance thresholds were set at $p < 0.0125$ ($0.05/4$) and $p < 0.010$ ($0.05/5$), respectively. To quantify the magnitude and precision of between-group differences, mean differences with 95% confidence intervals (CIs) and Hedges' g were reported for independent-samples t -tests. For Mann–Whitney U tests, Hodges–Lehmann location-shift estimates with 95% CIs and rank-biserial correlations were reported. Differences among the four mandibular regions and cortical thickness indices within each group were assessed using the Friedman test. When the Friedman test showed statistical significance, post hoc pairwise comparisons were performed using the Dunn–Bonferroni procedure. Categorical variables were compared using the χ^2 test. Intraobserver reliability was evaluated using the intraclass correlation coefficient (ICC), based on a two-way mixed-effects model with absolute agreement for single measurements, and agreement between repeated measurements was further assessed using Bland–Altman analysis. The limits of agreement (LoA) were calculated as the mean difference ± 1.96 standard deviations of the paired differences, and approximate 95% confidence intervals for the lower and upper LoA were estimated using the normal-theory method. Statistical significance was set at $p < 0.05$, except for between-group comparisons subjected to Bonferroni correction, for which the adjusted significance thresholds were applied.

To address potential confounding, additional multivariable linear regression analyses were performed for each FD measurement (FD1–FD4) and each radiomorphometric index (PMI, SI, AI, MI, and PI), with study group (onychophagy vs. control) as the main independent variable and age (years, continuous) and sex as covariates (outcome = group + age + sex). Age and sex were retained in all models regardless of the results of the between-group comparisons of these variables. For each outcome, the age- and sex-adjusted between-group difference (onychophagy minus control) is reported with its 95% CI and p value, together with adjusted (estimated marginal) means calculated at the mean age and sex distribution of the total sample. Model assumptions were examined using residual quantile–quantile (Q–Q) plots, the Shapiro–Wilk test of the residuals, and the Breusch–Pagan test. Because heteroscedasticity was detected for some outcomes, heteroscedasticity-consistent (HC3) robust standard errors were used for all adjusted estimates; for outcomes with non-normally distributed residuals, a rank-based analysis of covariance (linear regression of the rank-transformed outcome with the same covariates) was additionally performed as a sensitivity analysis. Multicollinearity was negligible (all variance inflation factors < 1.1). The Bonferroni-adjusted significance thresholds of $p < 0.0125$ for the FD outcomes and $p < 0.010$ for the radiomorphometric indices were retained for the adjusted analyses. The adjusted analyses were performed using Python (version 3.13; statsmodels 0.15).

3. Results

A total of 90 participants were included in the study, including 45 children with onychophagy and 45 healthy controls. The onychophagy group consisted of 26 males and 19 females, whereas the control group included 25 males and 20 females. The mean age was 8.6 ± 1.16 years in the onychophagy group and 8.4 ± 1.09 years in the control group, with no significant differences in age ($p = 0.140$) or sex distribution ($p = 0.832$). According to the Klemetti index, all participants were classified as C1; therefore, no intergroup comparison was performed for this parameter. Because the absence of statistically significant differences in age and sex does not rule out confounding, all between-group comparisons were additionally adjusted for age and sex.

The FD measurements obtained from the four regions of interest (ROIs) are presented in Table 1. Compared with the control group, the onychophagy group exhibited significantly higher FD values in all four mandibular regions (FD1–FD4; all $p < 0.0125$, following Bonferroni correction). Within-group comparisons using the Friedman test demonstrated significant differences among the four ROIs in both the control group ($p < 0.001$) and the onychophagy group ($p = 0.001$). In the control group, FD1 and FD2 were significantly higher than FD3 (all $p < 0.05$), and FD2 was also significantly higher than FD4 ($p < 0.05$). In the onychophagy group, FD1 was significantly higher than FD3 and FD4 (both $p < 0.05$), whereas the remaining pairwise comparisons were not statistically significant. The detailed Dunn–Bonferroni post hoc pairwise comparisons are presented in Supplementary Table S1. Effect-size estimates indicated notable between-group differences across the four FD measurements, including a large standardized difference in FD3 (Hedges' $g = 1.179$). The corresponding between-group differences, 95% confidence intervals, and effect sizes are presented in Supplementary Table S2.

Table 1. Fractal dimension measurements and statistical comparisons between the healthy and onychophagy groups.

Healthy (<i>n</i> = 45)			Onychophagy (<i>n</i> = 45)								
	Mean	SD	25th	Median	75th	Mean	SD	25th	Median	75th	<i>p</i>
FD1	1.38	0.04	1.35	1.37	1.40	1.43	0.05	1.39	1.43	1.46	<0.001 ¹
FD2	1.38	0.04	1.35	1.37	1.40	1.41	0.04	1.37	1.39	1.44	0.002 ²
FD3	1.34	0.04	1.32	1.35	1.37	1.41	0.05	1.36	1.40	1.45	<0.001 ²
FD4	1.34	0.04	1.31	1.34	1.38	1.40	0.06	1.35	1.38	1.42	<0.001 ¹
<i>p</i> ^f	<0.001 ³					0.001 ³					

n: Number; FD: Fractal dimension; FD1: The subcortical area in the condyle; FD2: The supracortical area above the angle of the mandible; FD3: the interdental trabecular bone of the posterior dentate mandibular region; FD4: the trabecular bone at the level of the tooth apices in the anterior dentate mandibular region. Values are presented as mean $\pm$ standard deviation (SD) and median (25th–75th percentiles). ¹ Mann–Whitney U test (nonparametric), ² Independent samples *t*-test (parametric)—Between-group comparisons are presented as unadjusted *p* values, with statistical significance determined using the Bonferroni-adjusted threshold of $p < 0.0125$ ($0.05/4$). ³ Friedman test for overall within-group differences among the four FD regions, with $p^f < 0.05$ considered statistically significant. Dunn–Bonferroni post hoc pairwise comparisons are presented in Supplementary Table S1, with Bonferroni-adjusted *p* values and a significance threshold of $p < 0.05$. Statistically significant *p* values are presented in bold.

The descriptive statistics and intergroup and intragroup comparisons of SI, AI, MI, PI, and PMI are presented in Table 2. Following Bonferroni correction for multiple between-group comparisons (adjusted significance threshold: $p < 0.010$), the onychophagy group exhibited significantly higher PMI values than the control group ($p < 0.001$).

Although AI values were higher in the onychophagy group ($p = 0.046$), this difference did not remain statistically significant after correction. No statistically significant between-group differences were observed for SI, MI, or PI (all $p > 0.05$). Within-group comparisons using the Friedman test demonstrated significant differences among the cortical thickness indices in both the control and onychophagy groups (both $p < 0.001$). In the control group, SI was significantly lower than MI and PI (both $p < 0.05$). In the onychophagy group, SI was significantly lower than AI and MI (both $p < 0.05$), whereas both AI and MI were significantly higher than PI (both $p < 0.05$). Detailed Friedman test results and Dunn–Bonferroni post hoc pairwise comparisons are presented in Supplementary Table S3. Among the radiomorphometric indices, PMI showed a relatively large standardized between-group difference (Hedges' $g = 0.773$), whereas SI, AI, MI, and PI exhibited smaller rank-biserial correlations (0.108–0.244). Detailed between-group differences, 95% confidence intervals, and effect sizes are presented in Supplementary Table S4.

In the age- and sex-adjusted analyses (Supplementary Table S5), the between-group differences in all four FD measurements persisted. The adjusted differences (onychophagy minus control) were as follows: FD1: 0.052 (95% CI 0.032–0.072; $p < 0.001$); FD2: 0.028 (95% CI 0.010–0.047; $p = 0.003$); FD3: 0.058 (95% CI 0.038–0.079; $p < 0.001$); FD4: 0.049 (95% CI 0.027–0.071; $p < 0.001$). All four remained below the Bonferroni-adjusted threshold of $p < 0.0125$, and the adjusted estimates were close to the corresponding unadjusted differences (0.054, 0.029, 0.061, and 0.051, respectively). The PMI difference also persisted after adjustment (adjusted difference 0.031; 95% CI 0.015–0.047; $p < 0.001$; adjusted means 0.368 vs. 0.337). For the other radiomorphometric indices, the adjusted differences did not reach the Bonferroni-adjusted threshold of $p < 0.010$ (SI: 0.22 mm, 95% CI −0.03 to 0.48, $p = 0.084$; AI: 0.33 mm, 95% CI 0.07–0.60, $p = 0.013$; MI: 0.23 mm, 95% CI −0.04 to 0.50, $p = 0.100$; PI: 0.18 mm, 95% CI −0.10 to 0.46, $p = 0.206$). Although the adjusted p value for AI was lower than the unadjusted p value, it remained above the corrected threshold, and the rank-based sensitivity analyses led to the same conclusions for all four indices (all $p \geq 0.057$). Thus, no outcome lost or gained statistical significance after adjustment, and the direction and magnitude of the between-group estimates were essentially unchanged. Age was not significantly associated with any outcome, whereas male sex was independently associated with lower FD1 ($p = 0.007$) and FD4 ($p = 0.040$) values and higher PMI values ($p = 0.002$); because the sex distribution was nearly identical in the two groups, these associations did not alter the between-group estimates.

Table 2. Mandibular radiomorphometric indices and statistical comparisons between the healthy and onychophagy groups.

Healthy (<i>n</i> = 45)						Onychophagy (<i>n</i> = 45)					
	Mean	SD	25th	Median	75th	Mean	SD	25th	Median	75th	<i>p</i>
PMI	0.33	0.04	0.31	0.33	0.36	0.36	0.03	0.34	0.37	0.39	<0.001 ¹
SI	2.72	0.51	2.25	2.56	3.18	2.94	0.66	2.33	2.82	3.41	0.184 ²
AI	2.76	0.47	2.34	2.63	3.20	3.09	0.69	2.41	3.04	3.58	0.046 ²
MI	2.84	0.51	2.36	2.91	3.23	3.07	0.70	2.50	2.95	3.44	0.184 ²
PI	2.81	0.54	2.29	2.69	3.25	2.99	0.70	2.37	2.82	3.50	0.377 ²
<i>p</i> ^f	<0.001 ³					<0.001 ³					

n : Number; SD: Standard deviation; PMI: Panoramic Mandibular Index; SI: Symphysis Index; AI: Anterior Index; MI: Molar Index; PI: Posterior Index. Values are presented as mean $\pm$ standard deviation (SD) and median (25th–75th percentiles). ¹ Independent samples t -test (parametric), ² Mann–Whitney U test (nonparametric)—Between-group comparisons are presented as unadjusted p values, with statistical significance determined using the Bonferroni-adjusted threshold of $p < 0.010$ (0.05/5). ³ Friedman test was used to assess overall within-group differences among the four indices,

with $p^f < 0.05$ considered statistically significant. Dunn–Bonferroni post hoc pairwise comparisons are presented in Supplementary Table S3, with Bonferroni-adjusted p values and a significance threshold of $p < 0.05$. Statistically significant p values are presented in bold.

Intraobserver reliability analyses are presented in Tables 3 and 4, with the corresponding Bland–Altman plots shown in Figures 3 and 4. Bland–Altman analysis demonstrated small mean differences between repeated measurements, with the limits of agreement and their 95% confidence intervals reported in Tables 3 and 4. Intraobserver agreement was excellent, with ICC values ranging from 0.907 to 0.947 for FD measurements and from 0.991 to 0.994 for radiomorphometric indices.

Table 3. Intraobserver reliability and Bland–Altman agreement analysis of repeated fractal dimension measurements.

Measurement	ICC (95% CI)	Mean Bias (95% CI)	Lower LoA (95% CI)	Upper LoA (95% CI)
FD1	0.947 (0.825–0.981)	0.0107 (0.0026–0.0189)	−0.0235 (−0.0368–−0.0102)	0.0450 (0.0317–0.0583)
FD2	0.907 (0.784–0.962)	0.0040 (−0.0060–0.0139)	−0.0379 (−0.0541–−0.0216)	0.0459 (0.0296–0.0621)
FD3	0.927 (0.825–0.970)	−0.0015 (−0.0100–0.0069)	−0.0369 (−0.0507–−0.0231)	0.0339 (0.0201–0.0477)
FD4	0.915 (0.801–0.965)	−0.0046 (−0.0148–0.0055)	−0.0472 (−0.0638–−0.0306)	0.0380 (0.0214–0.0546)

FD: Fractal dimension; FD1: The subcortical area in the condyle; FD2: The supracortical area above the angle of the mandible; FD3: The interdental trabecular bone of the posterior dentate mandibular region; FD4: The trabecular bone at the level of the tooth apices in the anterior dentate mandibular region; CI: Confidence Interval; ICC: Intraclass correlation coefficient; LoA: Limits of agreement.

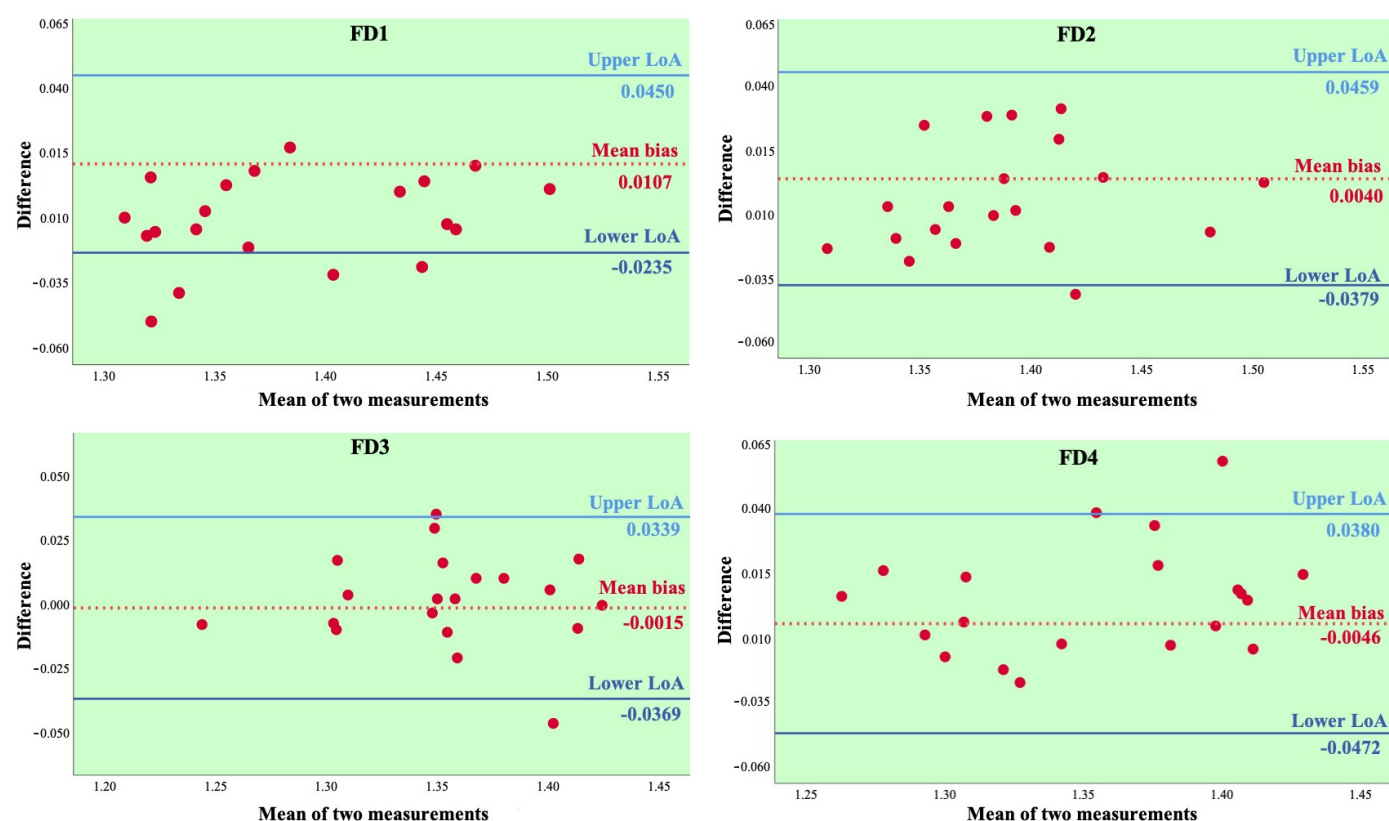
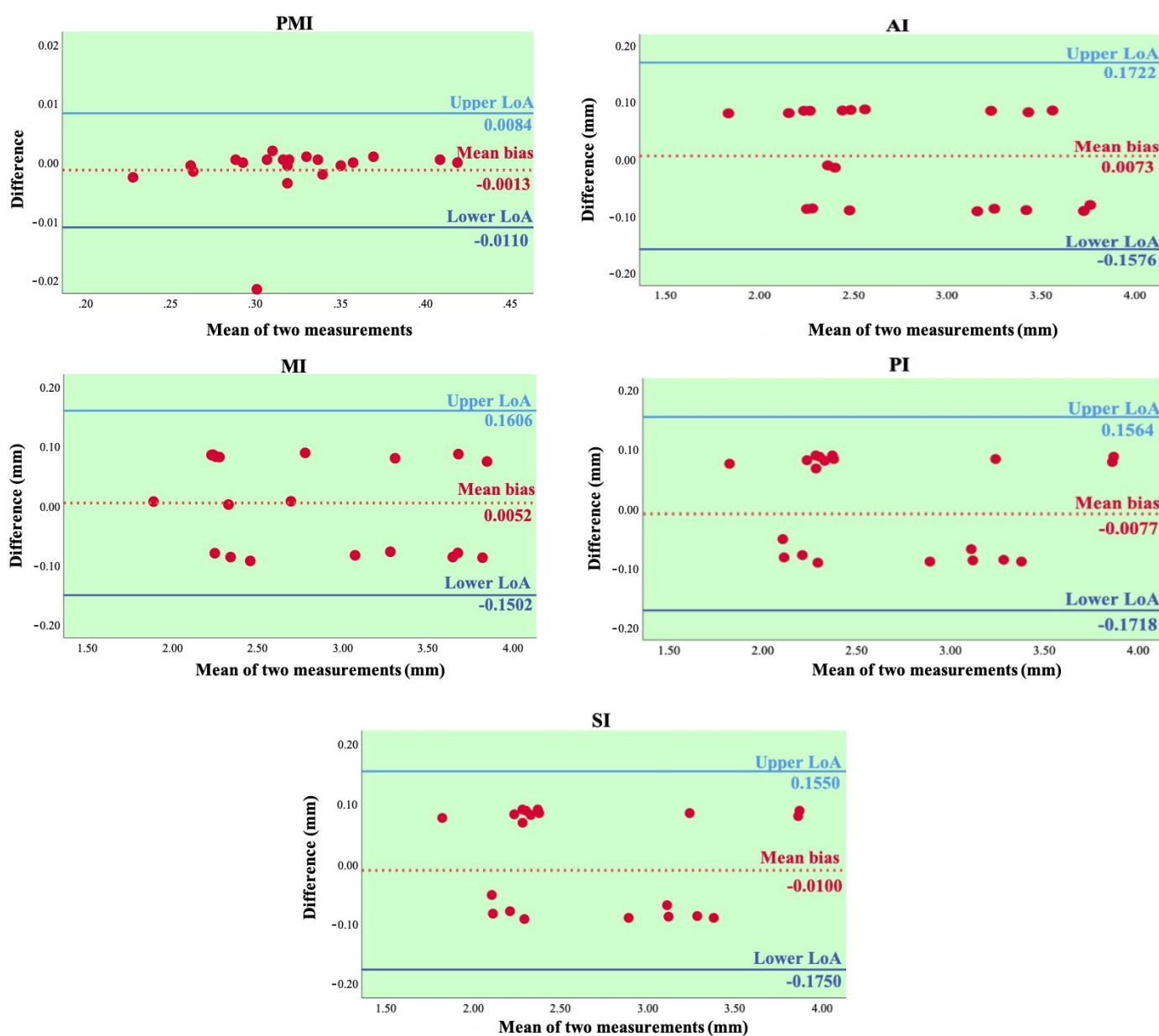


Figure 3. Bland–Altman plots of the first and second fractal dimension measurements obtained from the mandibular condyle (FD1), the mandibular angle (FD2), the interdental trabecular bone of the posterior dentate mandibular region (FD3), and the trabecular bone at the level of the tooth apices in the anterior dentate mandibular region (FD4).

Table 4. Intraobserver reliability and Bland–Altman agreement analysis of repeated radiomorphometric measurements.

Index	ICC (95% CI)	Mean Bias (95% CI)	Lower LoA (95% CI)	Upper LoA (95% CI)
PMI	0.994 (0.986–0.998)	−0.0013 (−0.0036–0.0010)	−0.0110 (−0.0147–−0.0072)	0.0084 (0.0046–0.0122)
SI	0.991 (0.977–0.996)	−0.0100 (−0.0494–0.0294)	−0.1750 (−0.2392–−0.1109)	0.1550 (0.0909–0.2192)
AI	0.991 (0.977–0.996)	0.0073 (−0.0321–0.0466)	−0.1576 (−0.2217–−0.0935)	0.1722 (0.1081–0.2363)
MI	0.993 (0.983–0.997)	0.0052 (−0.0319–0.0422)	−0.1502 (−0.2106–−0.0898)	0.1606 (0.1001–0.2209)
PI	0.991 (0.978–0.997)	−0.0077 (−0.0469–0.0315)	−0.1718 (−0.2356–−0.1080)	0.1564 (0.0926–0.2202)

PMI: Panoramic Mandibular Index; SI: Symphysis Index; AI: Anterior Index; MI: Molar Index; PI: Posterior Index; CI: Confidence Interval; ICC: Intraclass correlation coefficient; LoA: Limits of agreement.

**Figure 4.** Bland–Altman plots of the first and second panoramic mandibular index (PMI), anterior index (AI), molar index (MI), posterior index (PI), and symphysis index (SI) measurements.

4. Discussion

The present study demonstrated that children with onychophagy exhibited significantly higher FD values across all evaluated mandibular regions together with significantly higher PMI values compared with healthy controls following Bonferroni correction. These differences persisted after adjustment for age and sex. Therefore, the null hypothesis was rejected.

Onychophagy is a repetitive oral parafunctional habit that has been associated with several dentoalveolar consequences, including gingival trauma, root resorption, altered incisor inclination, malocclusion, increased tooth mobility, and periodontal changes [1,24–26]. These findings suggest that repetitive NB may influence not only the dentition but also the supporting tissues through continuous functional loading, providing a biological rationale for investigating its potential effects on mandibular bone.

Higher FD values are generally interpreted as indicating increased structural complexity, whereas lower values suggest a more simplified and less intricate architectural pattern [27]. In the present study, children with onychophagy exhibited significantly higher FD values in all evaluated mandibular regions than healthy controls, suggesting alterations in mandibular trabecular organization and microarchitectural complexity. Trabecular bone architecture is known to be influenced by various systemic and local factors, including changes in mechanical loading [8,15,17,28–30]. In this context, parafunctional activities such as bruxism have been reported to induce alterations in the alveolar bone structure of the mandible [28,29]. Although bruxism and onychophagy differ in terms of force magnitude, direction, and duration, both habits involve repetitive mechanical stimulation of the stomatognathic system. One possible explanation for the higher FD values observed in the onychophagy group is adaptive trabecular remodeling in response to repetitive mechanical loading, potentially consistent with Wolff's law [31]. However, because muscular activity and the magnitude, direction, and frequency of mechanical forces were not directly assessed, this proposed mechanism remains speculative. Other biological and developmental factors may also contribute to the observed differences in mandibular trabecular architecture.

Previous pediatric studies have reported heterogeneous FD findings, including region-specific increases, decreases, and no detectable differences in mandibular trabecular architecture. Increased FD values have been reported in children with sleep bruxism [29], attention deficit hyperactivity disorder [15], and severe infraocclusion [32], whereas reduced values have been observed in selected mandibular regions in children with hypodontia [33], premature birth with low birth weight [17], cleft lip and/or palate [30], and amelogenesis imperfecta [34]. In contrast, no significant FD differences were reported in children with familial Mediterranean fever [35], congenital heart disease [8], molar–incisor hypomineralization [36], or delayed formation and agenesis of the mandibular second premolar germ [37]. These findings indicate that FD alterations may manifest as regional increases, decreases, or no detectable changes depending on the biological and biomechanical characteristics of the condition examined. Unlike most previous pediatric studies in which FD alterations were confined to specific mandibular regions, significantly higher FD values were observed in all evaluated regions in the present study, suggesting a more widespread association with mandibular trabecular organization. However, as no previous study has evaluated mandibular trabecular bone microarchitecture in children with onychophagy using fractal dimension analysis, direct comparisons with the existing literature remain limited.

Mandibular indices assessed on PRs are useful for evaluating mandibular morphological alterations and bone volume [15]. Accordingly, mandibular cortical morphology was evaluated using the SI, AI, MI, PI, PMI, and MCI, all of which have been previously applied in radiomorphometric assessments of the mandible [20,21]. In the present study,

children with onychophagy exhibited significantly higher PMI values than healthy controls following Bonferroni correction, whereas no statistically significant differences were observed for SI, AI, MI, or PI. Although AI values were numerically higher, this difference did not remain statistically significant after correction. The increased PMI may suggest a localized difference in cortical morphology near the mental foramen; however, the absence of significant differences in the other indices does not support a consistent pattern of cortical adaptation.

Although statistically significant between-group differences were observed in all evaluated FD regions and PMI following Bonferroni correction, the absolute differences were relatively small. Specifically, the mean FD differences ranged from 0.03 to 0.07, while the mean PMI difference was 0.03. Although AI showed a mean difference of 0.33 mm, this finding did not remain statistically significant after Bonferroni correction. Despite the excellent intraobserver reliability, Bland–Altman analysis revealed a small positive mean bias for FD1 (0.0107; 95% CI: 0.0026–0.0189), indicating a statistically detectable systematic difference between repeated measurements. Although the high ICC values support measurement reproducibility, they do not exclude systematic measurement differences or establish whether the observed between-group differences exceed absolute measurement error or represent clinically meaningful alterations. Therefore, these findings should be interpreted cautiously, considering both the magnitude of the differences and measurement variability.

Previous pediatric studies have likewise yielded heterogeneous and index-specific findings regarding mandibular radiomorphometric parameters. Increased PMI and MI values have been reported in children with attention-deficit/hyperactivity disorder [15], while children with familial Mediterranean fever exhibited increased MI values without significant differences in PMI or MCI [35]. No significant differences in MCW, PMI, or MCI were identified in children with congenital heart disease [8], whereas lower MCW and PMI values were reported in children with molar–incisor hypomineralization [36]. MCI findings also remained comparable between children with amelogenesis imperfecta and healthy controls [34]. Collectively, these findings indicate that mandibular radiomorphometric alterations in pediatric populations are neither uniform nor consistently reflected across all indices. The observed differences may depend on the underlying condition, anatomical region, and characteristics of the indices evaluated.

In the present study, MCI assessment also showed that all participants in both groups were classified as Grade 1 according to the Klemetti index. This finding may be related to the young age of the study population [38] and suggests that no qualitative cortical deterioration detectable by the Klemetti classification was observed in either group. The significant difference in PMI, without corresponding differences in the other radiomorphometric indices or MCI classification, may reflect a localized difference in cortical morphology rather than generalized cortical alterations. Nevertheless, because panoramic radiomorphometric indices are indirect measures of bone morphology, these findings should not be interpreted as direct evidence of altered bone mineral density.

To the best of our knowledge, this is the first study to evaluate both mandibular trabecular microarchitecture and cortical morphology in children with onychophagy using FD analysis and panoramic radiomorphometric indices. Furthermore, standardized panoramic imaging protocols, bilateral measurements, age- and sex-matched groups, confirmation of the main findings in age- and sex-adjusted analyses, and excellent intraobserver reliability strengthen the validity of the present findings.

From a clinical perspective, the present findings suggest that onychophagy may be associated with differences in mandibular trabecular complexity and selected radiomorphometric measurements in children. However, these radiographic differences do not necessarily indicate pathological bone alterations or clinically significant changes.

Awareness of onychophagy as a common oral parafunctional habit remains relevant during routine pediatric dental examinations. Nevertheless, the present findings do not justify additional radiographic examinations or specific interventions targeting mandibular bone characteristics solely on the basis of onychophagy. Further longitudinal studies are required to determine the clinical significance of these associations.

This study has several limitations. First, the retrospective cross-sectional design precludes establishing a causal relationship between onychophagy and the observed mandibular differences. Additionally, the initial sample size calculation was based on a significance level of $\alpha = 0.05$ and 80% statistical power. The subsequent application of a Bonferroni-adjusted significance threshold of $\alpha = 0.0125$ for the four FD outcomes may have reduced the statistical power relative to the original estimate. Therefore, nonsignificant findings should be interpreted with caution. Although age and sex were addressed through frequency matching and additional age- and sex-adjusted analyses, which did not materially change the findings, and several potential confounding factors were addressed through predefined exclusion criteria, residual confounding by unmeasured factors cannot be excluded. Nutritional status, vitamin D and calcium status, body mass index, physical activity, and skeletal maturation may influence mandibular bone characteristics during childhood. Neither skeletal maturation nor individual dental developmental stages were formally assessed, and these potential confounding variables were not systematically available in the retrospective clinical records. Therefore, their influence on the observed associations could not be evaluated.

Furthermore, panoramic radiography is subject to magnification, superimposition, and geometric distortion, which may affect fractal and radiomorphometric measurements. FD values may also be influenced by ROI selection and standardization. As these two-dimensional methods provide only indirect estimates of bone characteristics, neither three-dimensional trabecular architecture nor bone mineral density could be directly assessed.

Although nail biting had persisted for more than one year in all children with onychophagy, its frequency, average daily duration, and severity were not quantitatively assessed. Moreover, onychophagy may occur as an automatic behavior without conscious awareness, potentially complicating accurate estimation of its daily duration [39]. Therefore, a possible dose–response relationship between habit intensity and the observed FD and index differences could not be determined.

Future multicenter and longitudinal studies with larger and more diverse pediatric populations, standardized assessments of onychophagy severity, consideration of potential confounding factors, and complementary three-dimensional imaging are needed to confirm these associations and clarify their clinical significance.

5. Conclusions

The main conclusions of this study are as follows:

- Onychophagy was associated with differences in mandibular trabecular complexity in children aged 7–11 years, as reflected by higher fractal dimension values across the evaluated regions.
- The radiomorphometric findings suggested a localized difference in mandibular cortical morphology rather than generalized cortical alterations.
- Taken together, these findings highlight a previously unexplored relationship between chronic onychophagy and mandibular bone characteristics during childhood.

Further longitudinal investigations incorporating standardized assessments of onychophagy severity are warranted to better understand the relationship between this habit and mandibular bone characteristics during craniofacial growth.

Supplementary Materials: The following supporting information can be downloaded at <https://www.mdpi.com/article/10.3390/children13111455/s1>: Supplementary Table S1. Within-group Friedman tests and Dunn–Bonferroni post hoc pairwise comparisons of fractal dimension measurements. Supplementary Table S2. Between-group differences and effect sizes for fractal dimension measurements. Supplementary Table S3. Within-group Friedman tests and Dunn–Bonferroni post hoc pairwise comparisons of mandibular radiomorphometric indices. Supplementary Table S4. Between-group differences and effect sizes for mandibular radiomorphometric indices. Supplementary Table S5. Unadjusted and age- and sex-adjusted between-group differences in fractal dimension measurements and radiomorphometric indices.

Author Contributions: Conceptualization, D.N.G.; methodology, B.A. and D.N.G.; investigation, E.Ş.A.; data curation, E.Ş.A. and D.N.G.; formal analysis, E.Ş.A., B.A. and S.A.; writing—original draft preparation, B.A.; writing—review and editing, E.Ş.A., B.A., D.N.G. and S.A.; supervision, D.N.G. and S.A. All authors have read and agreed to the published version of the manuscript.

Funding: This study has been supported by the Recep Tayyip Erdogan University Development Foundation. (Grant No: 0202600100040704).

Institutional Review Board Statement: The study protocol was approved by the Non-Invasive Clinical Research Ethics Committee of Recep Tayyip Erdoğan University (Decision No.: 2026/315) on 23 July 2026. The study was conducted in accordance with the Declaration of Helsinki of 1975, as revised in 2013.

Informed Consent Statement: Since the participants were younger than 16 years of age, detailed information about the research was given to the children’s parents or legal guardians before the study and informed consent was obtained.

Data Availability Statement: The datasets used and/or analysed during the current study are available from the corresponding author on reasonable request.

Conflicts of Interest: The authors declare no conflicts of interest.

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