



Relationship between alveolar bone thickness, tooth root morphology, and sagittal skeletal pattern

A cone beam computed tomography study

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Abstract

Purpose The goal of this work was to examine the relationship between sagittal facial pattern and thickness of alveolar bone in conjunction with root morphology of teeth by using cone beam computed tomography (CBCT).

Methods The study was carried out on the CBCT scans from 3 group of patients ($n = 20$ in each group). The first group involved skeletal class 1, the second group involved skeletal class 2, and the third group involved skeletal class 3 patients. In all, 14 permanent teeth and interdental regions in the maxilla and mandible were evaluated. Root length and root width were measured on each tooth. Buccal cortical bone thickness, cancellous bone thickness, and lingual cortical bone thicknesses were measured in each interdental region. Analysis of variance, Kruskal–Wallis H and Mann–Whitney U tests were used for statistical comparisons.

Results No significant difference was found between the groups for root length, root width, buccal cortical bone and lingual cortical bone thickness. A significant difference was observed between the groups for cancellous bone thickness as it was thicker in skeletal class 2 group. Cortical bone was thicker in the mandible compared to maxilla on both buccal and lingual sides and it was thicker in the posterior region compared to the anterior region on the buccal side.

Conclusions Differences in cancellous bone thickness between different sagittal facial patterns and differences in cortical bone thickness between different alveolar regions should be taken into consideration when planning orthodontic tooth movements and anchorage mechanics.

Keywords Alveolar thickness · Root length · Root width · Sagittal skeletal class · CBCT

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Zusammenhang zwischen Dicke des Alveolarknochens, Zahnwurzelmorphologie und skelettalen Klassen

Eine DVT-Studie

Zusammenfassung

Ziel Ziel der vorliegenden Studie war es, die Beziehungen zwischen der sagittalen skelettalen Klasse und der Dicke des Alveolarknochens sowie der Zahnwurzelmorphologie mittels digitaler Volumetomographie (DVT) zu untersuchen.

Methoden Die Studie wurde an DVTs von drei Patientengruppen durchgeführt. In der ersten Gruppe waren Patienten mit skelettaler Klasse 1 ($n=20$), in der zweiten Patienten mit skelettaler Klasse 2 ($n=20$) und in der dritten Gruppe Patienten mit skelettaler Klasse 3. Insgesamt wurden 14 bleibende Zähne und Interdentalbereiche in Ober- und Unterkiefer bewertet. Wurzellänge und Wurzelbreite wurden an jedem Zahn gemessen. In jeder Interdentalregion wurde die Dicke der bukkalen und lingualen Kortikalis sowie der Spongiosa bestimmt. Zur statistischen Auswertung dienten Varianzanalysen, Kruskal-Wallis-H- und Mann-Whitney-U-Tests.

Ergebnisse Es wurde kein signifikanter Unterschied zwischen den Gruppen in Bezug auf Wurzellänge, Wurzelbreite, Dicke der bukkalen und lingualen Kortikalis festgestellt. Es wurde ein signifikanter Unterschied zwischen den Gruppen für die Spongiosadicke beobachtet, die bei Patienten mit skelettaler Klasse 2 dicker war. Kortikaler Knochen war im Unterkiefer im Vergleich zum Oberkiefer sowohl auf der bukkalen als auch auf der lingualen Seite dicker und im posterioren im Vergleich zum anterioren Bereich auf der bukkalen Seite dicker.

Schlussfolgerungen Bei der Planung von orthodontischen Zahnbewegungen und der Verankerungsmechanik sollten die Unterschiede in der Dicke der Spongiosa zwischen verschiedenen sagittalen skelettalen Klassen und die Unterschiede in der Kortikalis zwischen den verschiedenen Alveolarregionen berücksichtigt werden.

Schlüsselwörter Alveolarknochendicke · Wurzellänge · Wurzelbreite · Sagittale skelettale Klasse · DVT

Introduction

Orthodontic tooth movement is initiated by mechanical force and proceeds by remodeling of periodontal ligament and alveolar bone [8]. The thickness of alveolar bone determines the limits of orthodontic tooth movement and exceeding these limits may result in damage to periodontal tissues [12]. Extreme buccal–lingual movements of teeth can decentralize teeth within the dentoalveolar bone envelope, resulting in dehiscence, fenestration, and gingival recession, depending on the initial alveolar bone morphology. Therefore, buccal and lingual bone thickness should be taken into consideration during orthodontic treatment planning.

Alveolar bone dimensions, more particularly buccal and lingual cortical bone thicknesses, are important factors that affect the stability and success of miniscrews which are commonly used by many orthodontists [4]. Miniscrews require mechanical retention to bone rather than osseointegration with bone to provide anchorage. Being more strong and resistant to deformation, cortical bone provides higher anchorage for miniscrews and it is responsible for their primary stability [13]. Hence, thick cortical areas are recommended for to increase the primary stability of miniscrews and prevent their failure at early stages [10, 11, 20, 22].

Thickness and height of buccal and lingual cortical bone layers may be altered in conjunction with alignment of teeth, inclination of root and occlusal forces [5]. The ver-

tical growth pattern has been shown to influence alveolar bone thickness and many researchers have reported that hypodivergent individuals have thicker alveolar bone morphology compared to hyperdivergent individuals [14, 20, 25].

Numerous papers investigating the relationship between vertical skeletal dimensions and alveolar bone thickness can be found in the literature [9, 14, 20, 25]. Nevertheless, the relationship between the sagittal skeletal pattern and alveolar bone thickness related with root morphology has not been studied until now. The diversity in cortical bone thickness among different alveolar regions has also not been evaluated comprehensively using cone beam computed tomography (CBCT) images. Hence, the primary aim of this study is to examine the relationship between sagittal facial pattern and thickness of alveolar cortical and cancellous bone in conjunction with root morphology of teeth by using CBCT. The H_0 hypothesis is that alveolar bone thickness and root morphology of teeth is similar in individuals having different sagittal facial pattern, whereas the H_1 hypothesis is that alveolar bone thickness and root morphology of teeth changes due to the sagittal facial pattern. The secondary aim of this study is to examine the diversity in cortical bone thickness between the maxillary and mandibular or between the anterior and posterior alveolar regions.

Table 1 Distribution of patients according to gender**Tab. 1** Patientenverteilung nach Geschlecht

	Class 1		Class 2		Class 3		Total	
	<i>n</i>	%	<i>n</i>	%	<i>n</i>	%	<i>n</i>	%
Male	2	10	9	45	10	50	21	35
Female	18	90	11	55	10	50	39	65
Total	20	100	20	100	20	100	60	100

n number, % percentage**Table 2** Comparison of groups according to age (Kruskal–Wallis H test)**Tab. 2** Gruppenvergleich nach Alter (Kruskal Wallis H test)

	Mean age (year)	SD	<i>p</i> -value
Class 1	18.20	3.33	0.788
Class 2	18.25	4.92	
Class 3	18.90	4.97	

p ≥ 0.05: non-significant

SD standard deviation

Materials and methods

This retrospective study carried out using the CBCT scans of 3 groups of patients obtained from the archive of a private maxillofacial scanning and screening center (Tomoloji Maksillofasiyal Görüntüleme Merkezi, Ankara, Turkey) was approved by Baskent University Institutional Review Board and Ethics Committee (project number D-DA13/06). A power analysis was performed based on 1:1 ratio between the groups by using data obtained from the literature [10, 14, 25]. The analysis revealed that a sample size of *n* = 18 patients per group was needed to achieve a power of 80% and *n* = 20 patients per group was needed to achieve a power of 85% at α = 0.05 significance level to detect statistically significant differences between the groups with a 0.30 (medium) effect size. Sample size estimation was performed by using NCSS and PASS software (Number Cruncher Statistical Systems. Version 2000. Kaysville, UT, USA).

Patients were included in the study based on the following criteria:

- No craniofacial deformity
- Permanent dentition stage
- No congenitally missing or extracted teeth
- No impacted or supernumerary teeth
- Root apices of all permanent teeth closed, except for third molars
- Postpubertal stage (CS5, CS6) according to cervical vertebrae maturation
- GoGn/SN angle between 28 and 36°
- CBCT scans present involving the area from the nasal bone to chin
- Maximum intercuspitation in CBCT scans
- No periodontal disease causing horizontal or vertical bone loss in CBCT scans

- No restorations involving the cementoenamel junction
- No history of orthodontic treatment

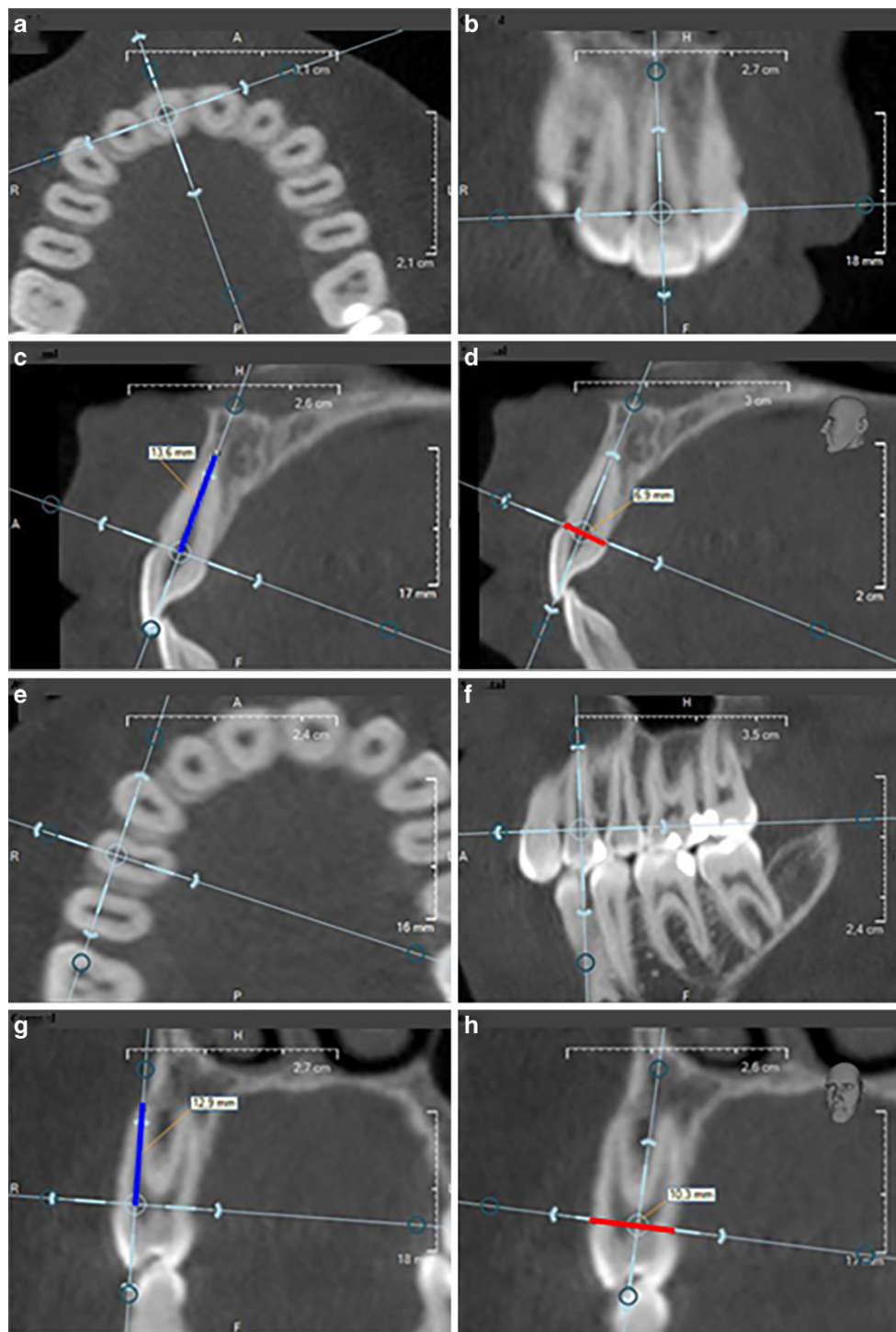
From a total of 201 CBCT scans, 60 scans which met the inclusion criteria for the 3 study groups were incorporated into the study and a power of 85% was achieved. The first group consisted of the CBCT scans of 20 skeletal class 1 patients with ANB angle between 0 and 4° (18 girls, 2 boys, mean age 18.20 ± 3.33 years). The second group consisted of the CBCT scans of 20 skeletal class 2 patients with ANB angle greater than 4° (11 girls, 9 boys, mean age 18.25 ± 4.92 years). The third group consisted of the CBCT scans of 20 skeletal class 3 patients with ANB angle less than 0° (10 girls, 10 boys, mean age 18.90 ± 4.97 years). The demographic distributions of the groups are presented in Tables 1 and 2.

The scans were obtained by using a CBCT device (ILUMA, IMTEC Europa, Oberursel, Germany) making 360° rotation, working with 120 kVp, 3.8 mA, scanning a 14 × 19.5 cm area within 40 s, and having 0.3 mm voxel size. The patients were sitting, their heads were oriented by locating the Frankfurt plane parallel to the horizontal plane and their teeth were in maximum intercuspitation during the CBCT scan. The raw data obtained from the CBCT scan were reconstructed using software provided by the producer (ILUMA Vision, IMTEC Europa, Oberursel, Germany) and saved as viewer files. All measurements were performed at a window level of 1000 and a window width of 4000 to provide the finest images for accurate measurements. Lateral cephalometric images were obtained from the CBCT scanning data for measuring GoGnSN and ANB angles. Sagittal, axial and coronal cross-sections were used to measure alveolar buccal cortical, lingual cortical and cancellous bone thicknesses or root length and width.

A total of 14 permanent teeth (central incisor, lateral incisor, canine, first premolar, second premolar, first molar, second molar) and 12 interdental regions between them

Fig. 1 Orientation of a right maxillary central tooth on axial (a) and coronal cross-sections (b). Measurement of right maxillary central root length (c) and root width (d) on the sagittal cross-section. Orientation of a right maxillary first premolar on axial (e) and sagittal cross-sections (f). Measurement of right maxillary first premolar root length (g) and root width (h) on the coronal cross-section

Abb. 1 Rechter mittlerer Schneidezahnes im axialen Schnitt (a) und im koronalen Querschnitt (b). Messung der Wurzellänge des oberen rechten Schneidezahns (c) und Wurzelbreite (d) am sagittalen Querschnitt. Oberer rechter erster Prämolare im axialen Schnitt (e) und sagittalem Querschnitt (f). Messungen der Wurzellänge (g) und der Wurzelbreite (h) am oberen rechten ersten Prämolare am koronalen Querschnitt

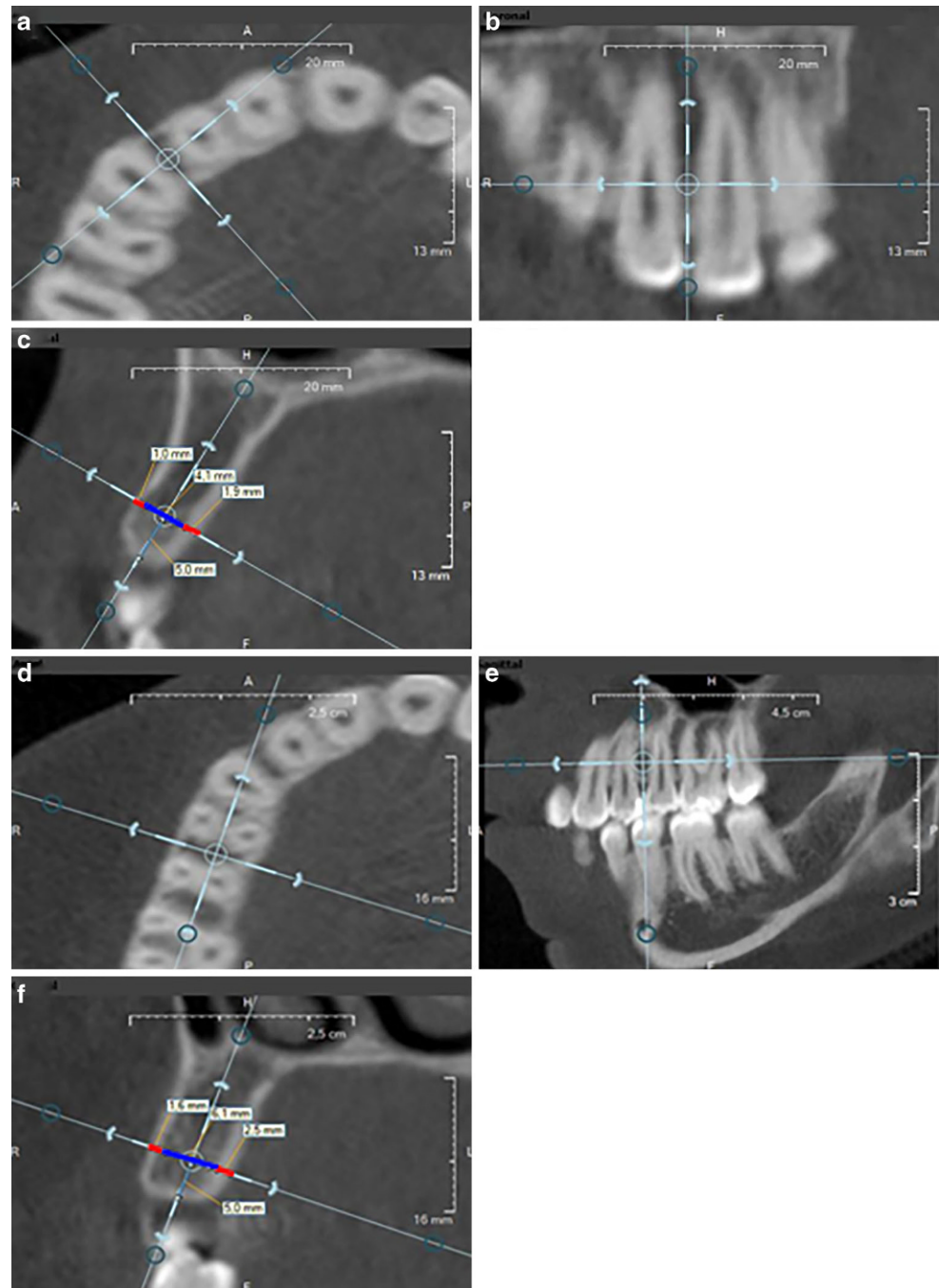


were evaluated in the maxilla and mandible on the right side. Root length and root width were measured on each tooth while buccal cortical bone thickness, cancellous bone thickness, and lingual cortical bone thickness were measured in each interdental region evaluated. Axial, coronal, and sagittal orientation planes were constructed for accurate positioning of the tooth or the interdental region to be evaluated before measuring.

Central incisor, lateral incisor, and canine were defined as anterior teeth, while the first premolar, second premolar, first molar, and second molar were defined as posterior teeth both in upper and lower jaws in this study. Root length and width measurements were performed on the buccal root in the upper premolars with two roots, on the mesial root in lower molars with two roots and on the mesiobuccal root in the upper molars with three roots. Root length measure-

Fig. 2 Orientation of the interdental region between right maxillary lateral and canine teeth on axial (a) and coronal cross-sections (b). Measurement of buccal cortical bone, cancellous bone and lingual cortical bone thicknesses on sagittal cross-sections (c). Orientation of the interdental region between right maxillary premolar teeth on axial (d) and sagittal cross-sections (e). Measurement of buccal cortical bone, cancellous bone and lingual cortical bone thicknesses on coronal cross-sections (f)

Abb. 2 Interdentalregion zwischen oberem rechten lateralen Schneidezahn und Eckzahn am axialen (a) und koronalen Querschnitt (b). Messung der Dicken von bukkaler Kortikalis, Spongiosa und lingualer Kortikalis an sagittalen Querschnitten (c). Interdentalregion zwischen den oberen rechten Prämolaren an axialen (d) und sagittalen Querschnitten (e). Messung der Dicken von bukkaler Kortikalis, Spongiosa und lingualer Kortikalis an koronalen Querschnitten (f)



ments were performed on the long axis of the root from the cemento enamel junction to the root apex, on the sagittal cross-section for anterior teeth and on coronal cross-section for posterior teeth. Root width measurements were performed from the buccal cemento enamel junction to the lingual cemento enamel junction, on the sagittal cross-section for anterior teeth and on the coronal cross-section for posterior teeth (Fig. 1).

Buccal cortical bone thickness, cancellous bone thickness, and lingual cortical bone thickness measurements were performed at the mesiodistal center point of each

interdental region 5 mm apical from the alveolar crest, on the sagittal cross-section for the anterior region, and on the coronal cross-section for the posterior region. Buccal and lingual cortical bone thicknesses were measured as the shortest buccolingual distances from the outer surface of cortical bone to the border between the cortical and cancellous bone. Cancellous bone thickness was measured as the shortest buccolingual distances from the buccal border between the cortical and cancellous bone to the lingual border between the cortical and cancellous bone (Fig. 2). All measurements were performed by the same observer (IC).

Table 3 Comparison of root length (mm) between groups using the ANOVA test**Tab. 3** Vergleich der Wurzellängen in den Gruppen nach ANOVA

	Class 1		Class 2		Class 3		<i>P</i> -value
	Mean	SD	Mean	SD	Mean	SD	
U1-RL	12.0	1.7	11.9	1.2	12.3	1.7	0.751
U2-RL	12.2	1.4	12.2	1.0	12.5	1.5	0.682
U3-RL	14.8	2.2	16.1	1.8	15.6	2.1	0.111
U4-RL	12.6	1.6	12.7	1.9	12.9	1.8	0.854
U5-RL	13.2	1.5	13.3	1.6	12.9	1.9	0.716
U6-RL	12.4	1.2	12.3	1.5	12.3	1.3	0.964
U7-RL	11.9	1.3	12.1	1.4	12.5	1.7	0.364
L1-RL	11.2	1.0	11.7	1.0	11.8	0.9	0.138
L2-RL	12.4	0.9	13.0	1.2	12.6	1.6	0.378
L3-RL	14.0	1.7	14.3	1.0	14.4	2.0	0.765
L4-RL	13.6	1.6	14.0	1.0	13.9	1.5	0.592
L5-RL	14.3	2.1	14.8	2.1	13.7	1.4	0.231
L6-RL	13.2	1.6	13.3	1.2	13.4	1.4	0.907
L7-RL	12.7	1.4	12.3	1.3	12.7	1.4	0.616

p ≥ 0.05: non-significant

SD standard deviation, ANOVA analysis of variance

Table 4 Comparison of root width (mm) between groups using the ANOVA test**Tab. 4** Vergleich der Wurzelbreiten (mm) in den Gruppen nach ANOVA

	Class 1		Class 2		Class 3		<i>P</i> -value
	Mean	SD	Mean	SD	Mean	SD	
U1-RW	6.6	0.3	6.7	0.4	6.8	0.5	0.463
U2-RW	6.0	0.4	6.1	0.4	6.2	0.5	0.304
U3-RW	7.7	0.5	8.1	0.7	7.9	0.9	0.344
U4-RW	8.9	0.4	8.8	0.6	8.7	0.8	0.762
U5-RW	8.8	0.7	8.7	0.6	8.8	0.9	0.952
U6-RW	10.9	0.4	11.0	0.6	11.0	0.8	0.703
U7-RW	11.0	0.8	11.1	0.7	11.1	0.9	0.885
L1-RW	5.8	0.4	6.0	0.5	5.8	0.4	0.209
L2-RW	6.1	0.4	6.4	0.4	6.3	0.5	0.167
L3-RW	7.5	0.5	7.8	0.8	7.7	0.5	0.241
L4-RW	7.2	0.5	7.4	0.4	7.3	0.6	0.473
L5-RW	7.6	0.4	7.8	0.4	7.6	0.7	0.708
L6-RW	9.2	0.5	9.2	0.5	9.3	0.6	0.719
L7-RW	9.1	0.7	9.2	0.5	9.1	0.5	0.775

p ≥ 0.05: non-significant

SD standard deviation, ANOVA analysis of variance

A total of 64 parameters (14 root length, 14 root width, 12 buccal cortical bone thickness, 12 lingual cortical bone thickness, 12 cancellous bone thickness) were evaluated. Two weeks after the first measurements, 30 CBCT images (10 images randomly selected from each group) were re-measured by the same observer (IC) to check intraobserver reliability.

Statistical analysis

Data analysis was performed by using SPSS for Windows, version 20 (SPSS Inc., Chicago, IL, USA). Descriptive statistics for gender are presented as percentage, whereas

all other parameters are presented as mean and standard deviation (SD). The differences between the three study groups were analyzed by the Analysis of Variance (ANOVA) test for variables showing normal distribution and by the Kruskal–Wallis H test for variables not showing normal distribution. The Scheffe test was used to distinguish the groups between which a statistically significant difference was observed if ANOVA revealed a significant difference. The Mann–Whitney U test was used for subgroup comparisons where the differences between 2 groups were analyzed and the variables were not showing normal distribution. A *p* value less than 0.05 was considered statistically significant with a 95% confidence interval (CI). The Wilcoxon's signed test was used to determine intraobserver

Table 5 Comparison of buccal cortical bone thickness (mm) between groups using the Kruskal–Wallis H test

	Class 1		Class 2		Class 3		<i>P</i> -value
	Mean	SD	Mean	SD	Mean	SD	
U1/2-BuCo	1.2	0.3	1.3	0.2	1.2	0.2	0.232
U2/3-BuCo	1.3	0.2	1.3	0.1	1.4	0.3	0.647
U3/4-BuCo	1.4	0.1	1.5	0.3	1.3	0.2	0.132
U4/5-BuCo	1.4	0.2	1.4	0.3	1.4	0.2	0.231
U5/6-BuCo	1.4	0.2	1.4	0.2	1.4	0.1	0.532
U6/7-BuCo	1.4	0.3	1.5	0.1	1.6	0.3	0.647
L1/2-BuCo	1.2	0.2	1.1	0.2	1.2	0.2	0.107
L2/3-BuCo	1.3	0.3	1.3	0.3	1.3	0.3	0.226
L3/4-BuCo	1.5	0.1	1.5	0.1	1.4	0.1	0.556
L4/5-BuCo	1.9	0.2	1.8	0.2	1.6	0.3	0.101
L5/6-BuCo	1.8	0.2	1.9	0.3	1.9	0.2	0.425
L6/7-BuCo	2.6	0.2	2.7	0.2	2.7	0.2	0.628

$p \geq 0.05$: non-significant
SD standard deviation

Table 6 Comparison of lingual cortical bone thickness (mm) between groups using the Kruskal–Wallis H test

	Class 1		Class 2		Class 3		<i>P</i> -value
	Mean	SD	Mean	SD	Mean	SD	
U1/2-LiCo	1.5	0.1	1.6	0.3	1.4	0.1	0.422
U2/3-LiCo	1.8	0.2	2.0	0.2	1.7	0.2	0.091
U3/4-LiCo	2.1	0.2	2.2	0.3	2.0	0.1	0.691
U4/5-LiCo	1.8	0.2	1.7	0.3	1.8	0.2	0.756
U5/6-LiCo	2.0	0.1	1.7	0.2	1.8	0.3	0.057
U6/7-LiCo	1.5	0.3	1.6	0.2	1.6	0.2	0.873
L1/2-LiCo	1.9	0.2	1.6	0.1	1.7	0.1	0.478
L2/3-LiCo	2.8	0.3	2.6	0.2	2.5	0.2	0.265
L3/4-LiCo	2.3	0.1	2.4	0.1	2.5	0.2	0.625
L4/5-LiCo	2.4	0.2	2.4	0.3	2.5	0.1	0.608
L5/6-LiCo	2.3	0.3	2.4	0.2	2.5	0.1	0.167
L6/7-LiCo	2.4	0.2	2.3	0.1	2.5	0.1	0.051

$p \geq 0.05$: non-significant
SD standard deviation

reliability by evaluation of data obtained from the remeasurement of 30 CBCT images. The observer was found to be consistent in the repeated measurements for all variables ($p \geq 0.05$).

Results

No significant difference was found between skeletal class 1, class 2, and class 3 groups for mean age, root length, root width, buccal cortical bone, and lingual cortical bone thickness measurements (Tables 2, 3, 4, 5 and 6; Figs. 3, 4, 5 and 6). However, significant differences were observed between skeletal class 1, class 2, and class 3 groups for cancellous bone thickness. Thus, skeletal class 2 group generally had greater cancellous bone thickness between maxillary molars and in all interdental regions in the mandible (Table 7 and Fig. 7).

The subgroup comparisons revealed significant differences between upper and lower buccal cortical bone thickness ($p=0.0001$) and between upper and lower lingual cortical bone thickness ($p=0.0001$) in class 1, 2, and 3 groups. Cortical bone was thicker in the mandible compared to the maxilla on both the buccal and lingual sides (Table 8).

Another subgroup comparison disclosed significant differences between anterior and posterior buccal cortical bone thickness ($p=0.0001$) in class 1, 2, and 3 groups. Cortical bone was observed to be thicker in the posterior region compared to the anterior region on the buccal side (Table 9). Nevertheless, no significant differences were observed between the anterior and posterior lingual cortical bone thickness.

Table 7 Comparison of cancellous bone thickness (mm) between groups using the ANOVA test

Tab. 7 Vergleich der Spongiosadicke (mm) in den Gruppen nach ANOVA

	Class 1		Class 2		Class 3		P-value	Scheffe Test
	Mean	SD	Mean	SD	Mean	SD		
U1/2-Can	4.3	0.8	4.4	0.9	4.8	0.9	0.229	–
U2/3-Can	3.9	1.2	4.5	1.3	4.5	1.0	0.176	–
U3/4-Can	5.0	1.0	5.4	1.0	5.2	1.2	0.481	–
U4/5-Can	6.1	1.3	6.8	1.3	6.4	1.4	0.329	–
U5/6-Can	7.9	1.4	8.7	1.6	8.2	1.5	0.206	–
U6/7-Can	10.7	1.2	11.8	1.3	11.1	1.3	0.021 *	CI 1–2, CI 2–3
L1/2-Can	2.6	1.1	3.7	1.1	2.4	1.1	0.001 *	CI 1–2, CI 2–3
L2/3-Can	2.1	0.7	3.1	1.1	2.4	1.2	0.016 *	CI 1–2
L3/4-Can	3.6	1.2	4.6	1.3	3.4	1.3	0.011 *	CI 2–3
L4/5-Can	3.7	0.9	4.7	1.0	3.6	1.2	0.005 *	CI 2–3
L5/6-Can	5.3	1.2	6.4	1.1	5.3	1.4	0.009 *	CI 1–2, CI 2–3
L6/7-Can	6.9	1.2	7.4	1.0	6.5	1.3	0.035 *	CI 2–3

$p \geq 0.05$: non-significant, *: $p < 0.05$ and significant

Scheffe test reveals the groups between which statistically significant difference was observed

SD standard deviation, ANOVA analysis of variance

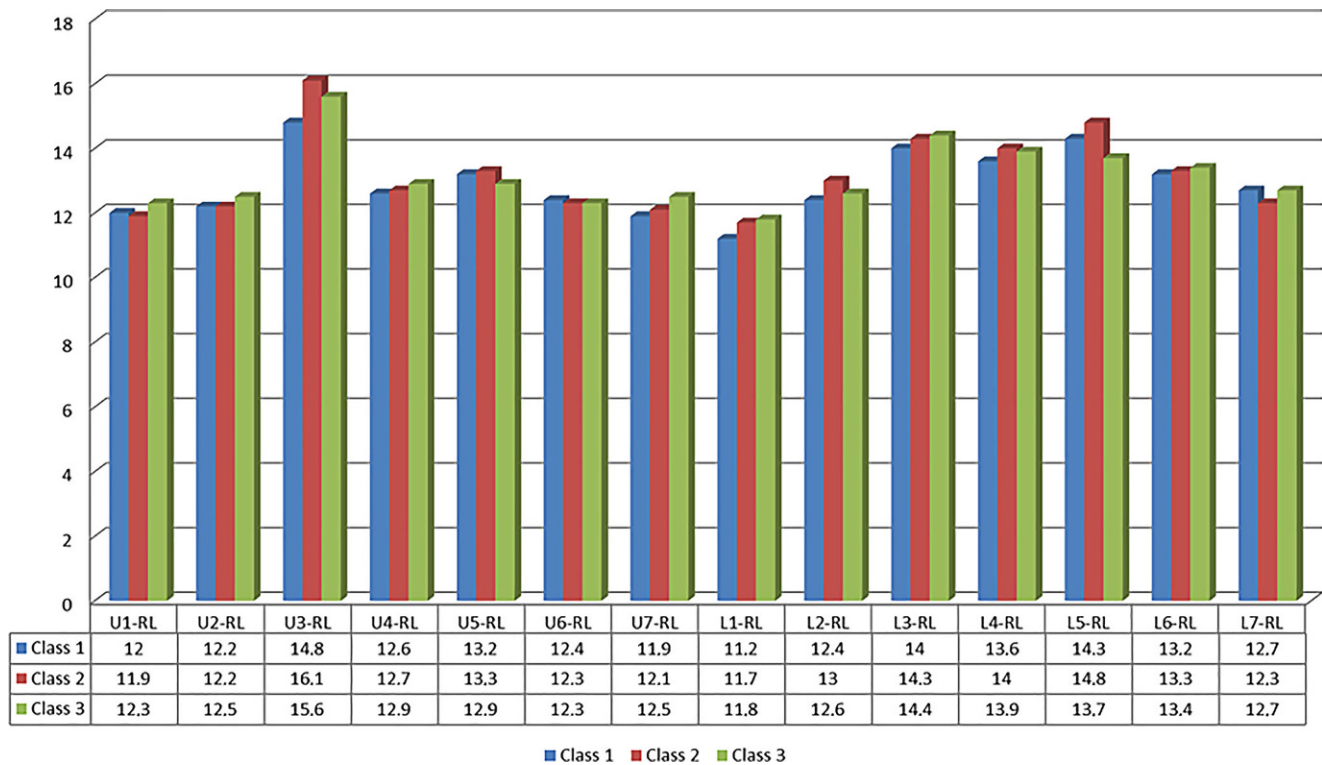


Fig. 3 Distributions of root length measurements in the groups

Abb. 3 Verteilung der Wurzellängen auf die Gruppen

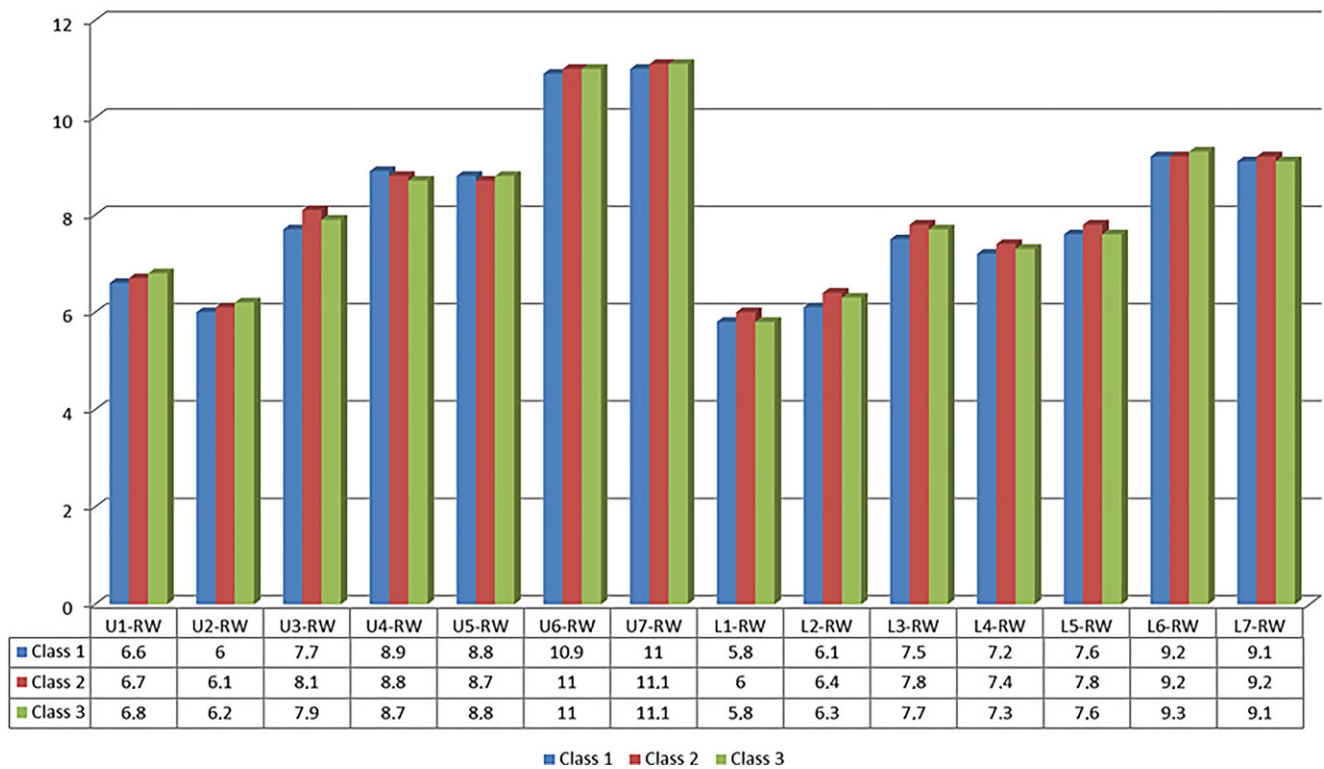


Fig. 4 Distributions of root width measurements in the groups

Abb. 4 Verteilung der Wurzelbreiten auf die Gruppen

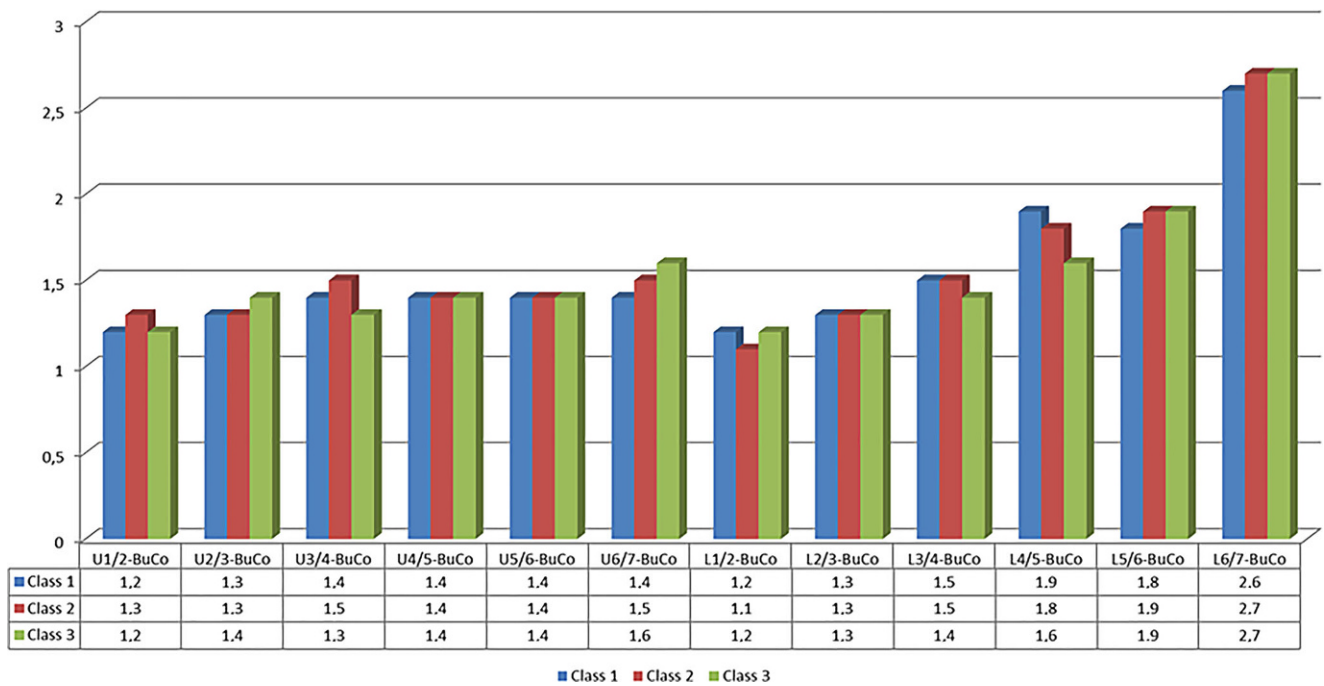


Fig. 5 Distributions of buccal cortical bone thickness measurements in the groups

Abb. 5 Verteilung der Dicke der bukkalen Kortikalis auf die Gruppen

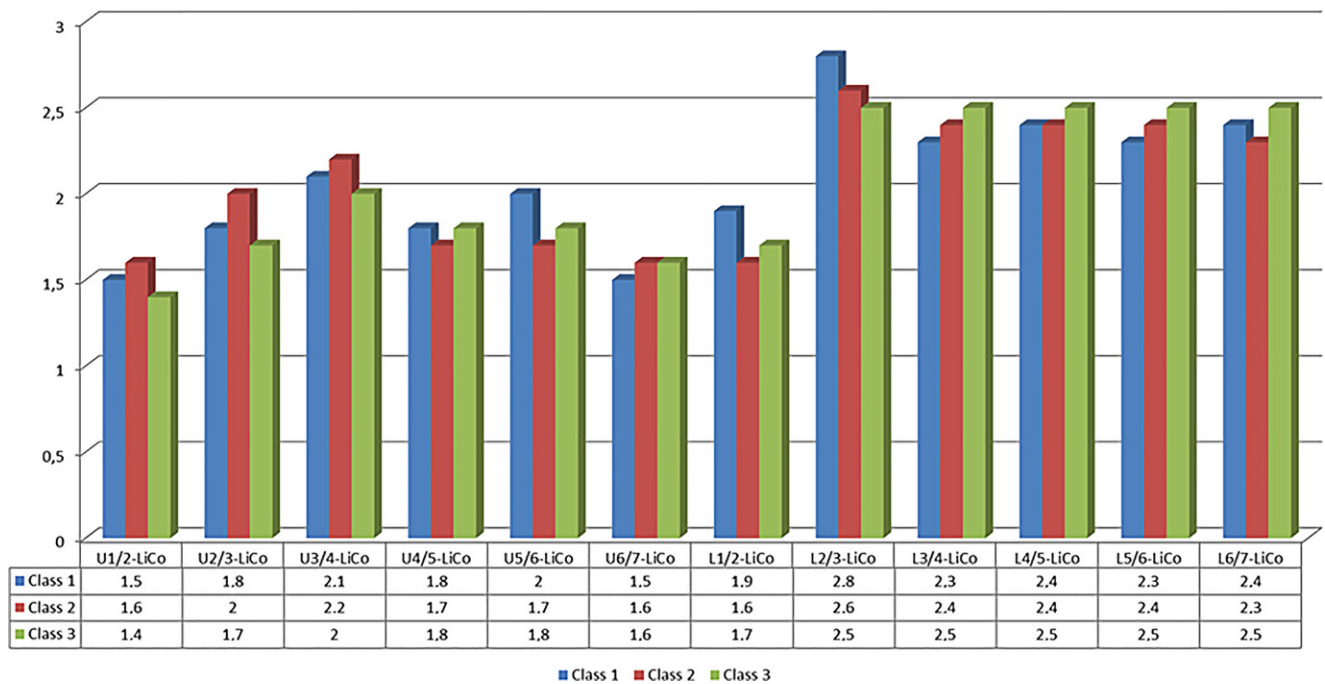


Fig. 6 Distributions of lingual cortical bone thickness measurements in the groups

Abb. 6 Verteilung der Dicke der lingualen Kortikalis auf die Gruppen

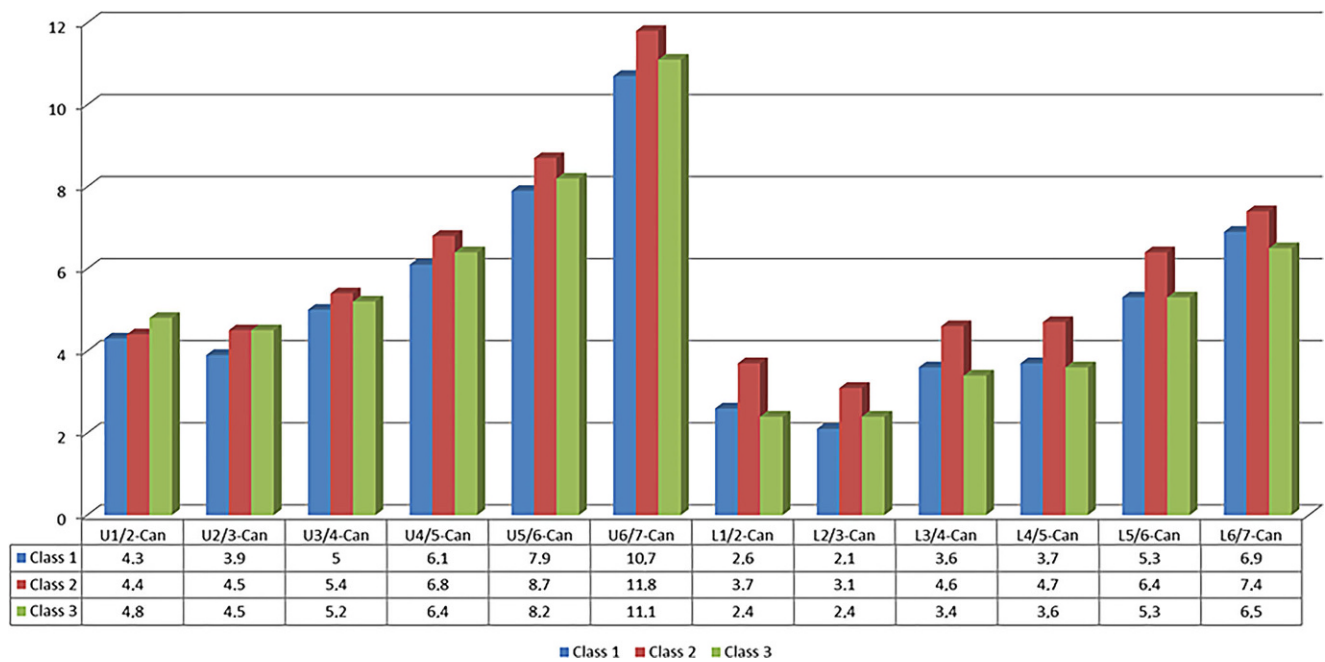


Fig. 7 Distributions of cancellous bone thickness measurements in the groups

Abb. 7 Verteilung der Dicke der Spongiosa auf die Gruppen

Table 8 Comparison of cortical bone thickness (mm) between upper and lower buccal regions, and also between upper and lower lingual regions (Mann–Whitney U test, ANOVA)**Tab. 8** Vergleich der lingualen und bukkalen Kortikalisdicke (mm) im oberen und unteren Bereich (Mann–Whitney U Test, ANOVA)

	Class 1		Class 2		Class 3		P-value
	Mean	SD	Mean	SD	Mean	SD	
Upper Buccal Cortical	1.36	0.18	1.41	0.16	1.37	0.19	0.798
Lower Buccal Cortical	1.70	0.23	1.71	0.18	1.69	0.15	0.792
	$p=0.0001^*$		$p=0.0001^*$		$p=0.0001^*$		
Upper Lingual Cortical	1.77	0.19	1.79	0.24	1.75	0.30	0.977
Lower Lingual Cortical	2.34	0.23	2.29	0.34	2.37	0.26	0.971
	$p=0.0001^*$		$p=0.0001^*$		$p=0.0001^*$		

$p \geq 0.05$: non-significant, *: $p < 0.05$ and significant
SD standard deviation, ANOVA analysis of variance

Table 9 Comparison of cortical bone thickness (mm) between anterior and posterior buccal regions, and also between anterior and posterior lingual regions (Mann–Whitney U test, ANOVA)**Tab. 9** Vergleich der lingualen und bukkalen Kompaktadicke (mm) in anteriorer und posteriorer Region (Mann–Whitney U Test, ANOVA)

	Class 1		Class 2		Class 3		P-value
	Mean	SD	Mean	SD	Mean	SD	
Anterior Buccal Cortical	1.31	0.14	1.34	0.14	1.31	0.11	0.867
Posterior Buccal Cortical	1.75	0.25	1.79	0.20	1.77	0.20	0.851
	$p=0.0001^*$		$p=0.0001^*$		$p=0.0001^*$		
Anterior Lingual Cortical	2.07	0.25	2.07	0.35	1.98	0.24	0.931
Posterior Lingual Cortical	2.05	0.23	2.01	0.17	2.14	0.24	0.933
	$p=0.481$		$p=0.698$		$p=0.076$		

$p \geq 0.05$: non-significant, *: $p < 0.05$ and significant
SD standard deviation, ANOVA analysis of variance

Discussion

It is known that facial types of individuals have an effect on the morphology of their maxillary and mandibular cortical plates. Despite the number of recently published papers emphasizing the influence of vertical growth pattern on alveolar bone morphology, no research examining the influence of sagittal growth pattern on the alveolar bone thickness between all tooth roots have been presented in detail [1, 9, 14, 20, 25, 27, 36]. In addition, the relationship between root length or width and alveolar morphology on either type of growth pattern has not been examined until now. Therefore, the primary objective of this study was to understand the relationship between sagittal facial pattern and thickness of alveolar cortical and cancellous bone layers in combination with root morphology of teeth. The secondary objective of this study was to examine the diversity in cortical bone thickness between the maxillary and mandibular or between the anterior and posterior alveolar regions.

Examination of average root length and root width values in conjunction with alveolar cortical and cancellous bone thickness is thought to be important and necessary for establishing normative data related to root and bone morphology for all permanent teeth and all interdental ar-

reas between them. This data can be used as a reference in all stages of orthodontic treatment planning by providing assistance for anchorage considerations, determination of tooth movement limitations and protection or improvement of periodontal conditions [1, 9, 12, 14, 16, 20, 25, 27]. In addition to establishing detailed normative data for individuals with normal vertical facial pattern, revealing the differences in root and bone morphology among skeletal class 1, class 2 and class 3 individuals may help orthodontists by indicating the potential advantageous or hazardous factors related with sagittal facial pattern.

Previous studies have shown that hormonal and functional changes associated with age have an influence on cortical bone thickness and patients under 14 years were reported to have low success rates with miniscrews due to the thin buccal cortical bone layer [10, 11, 26, 31, 33]. Thus, patients in the postpubertal stage (CS5, CS6) according to cervical vertebrae maturation and older than 15 years were included in this study, whereas no statistically significant difference was found between the groups for age. Additionally, patients with only normal vertical growth patterns (GoGn/SN angle between 28 and 36°) were included in this study to eliminate the potential influence of vertical growth pattern on dentoalveolar bone morphology.

The influence of gender on dentoalveolar morphology was not evaluated in this study since there were fewer males and the male/female ratios were unequal in the groups. Many researchers presented that although males have larger masticatory muscles and higher maximum biting forces, these high forces are rarely achieved in daily life and no significant difference was observed between males and females for cortical bone thickness [7, 10, 29, 33]. On the other hand, Rossi et al. [28] observed differences between class 3 males and females in cortical bone thickness at some mandibular regions apart from the alveolar bone.

A limitation of this study was the relatively small sample size which was 20 patients in each group due to a great number of inclusion criteria applied for elimination of any imperfect examination and measurement. Despite the fact that a power of 85% with a medium effect size was achieved, obtaining a higher power with a larger effect size would be favored.

Root length and root width measurements revealed no significant difference between the skeletal class 1, class 2 and class 3 groups in this study. Root length measurements were performed on the long axis of the root from the cemento-enamel junction to the root apex, whereas root width measurements were performed from the buccal cemento-enamel junction to the lingual cemento-enamel junction. Being a junction point of two tissues with different hydroxyapatite densities, the cemento-enamel junction can be easily identified on CBCT images and has been used as a reliable reference for both root length and root width measurements with high levels of repeatability [5, 16, 18, 30]. No study evaluating all permanent teeth in individuals having similar facial characteristics with this study was found in the literature. Therefore, the results of this study of the relationships of root length and root width measurements can not be compared with other studies. Hence, they can be used as reference data for skeletal class 1, class 2 and class 3 individuals with a normal vertical facial pattern.

Buccal and lingual cortical bone thickness measurements did not present statistically significant difference between skeletal class 1, class 2 and class 3 groups in this study. However, cancellous bone thickness revealed significant difference between the groups especially in the mandible and was thicker in the skeletal class 2 group. This difference can be attributed to the relatively greater buccal inclination of tooth crowns in the mandibular arch in the class 2 group. This inclination may also cause the roots of these teeth to be inclined and occupy larger spaces in the alveolus which gives rise to bone modeling. Being the dominant process of facial growth and adaptation to functional loads, bone modeling may be the reason of the thicker cancellous bone observed in the skeletal class 2 group. Furthermore, cancellous bone thickness increased gradually from the canine region to the posterior region in all 3 groups. A study inspecting

cortical and cancellous bone thicknesses in all interdental regions in both the maxilla and mandible in individuals with different sagittal skeletal patterns does not exist in the literature. On the other hand, studies with a somewhat similar group design examined cortical bone thicknesses either in buccal/lingual regions of teeth or in only certain interdental regions instead of all [1, 3, 9, 14, 17, 18, 20, 23, 25, 27]. Therefore, these results can not be compared with this study.

In this study, cortical bone was observed to be significantly thicker in mandible compared to maxilla both on the buccal and lingual sides in all three groups. This finding is compatible with other studies [7, 10, 14, 24, 29]. This situation can be explained with the anatomical inability of the mandible to distribute heavy biting forces to the whole cranium like the maxilla does, which causes a much stronger and stiffer structure to absorb entire load and resist distortion [35]. This structural difference between the maxilla and mandible is also clinically evident when orthodontically moving a tooth, placing a miniscrew, or predrilling [14].

Cortical bone was observed to be significantly thicker in the posterior region compared to the anterior region on the buccal side both in the maxilla and the mandible in all three groups of this study. Nevertheless, no significant difference was observed between anterior and posterior lingual cortical bone thickness. The gradual increase in buccal cortical bone thickness from anterior to posterior regions is one of the unique findings of this study as it was not examined up to now and should be taken into consideration during treatment planning if expansion of dental arch or protrusion, retrusion and torqueing of teeth is part of the treatment plan [1, 9, 14, 20, 25, 27].

In this study, lingual cortical bone thickness was greater than buccal cortical bone thickness both in the maxilla and mandible in all three groups. The only exception is between the mandibular first and second molars, where the buccal cortical bone is thicker. This finding is compatible with the study of Horner et al. [14] who also reported that cortical bone was thicker on the lingual side compared to the buccal side in both jaws. This information can be helpful in clinical practice for arranging buccal or lingual tooth movements and skeletal anchorage mechanics with miniscrews.

The thickest cortical bone on the lingual side was observed in the mandibular canine region in this study, which was formerly shown to face the greatest stress on the lingual side [14]. On the other hand, the thickest cortical bone on the buccal side was observed in the mandibular molar region, which is very close to the attachment region of masticatory muscles and therefore faces the greatest stress on the buccal side. This finding is also compatible with other studies that reported thicker buccal cortical bone compared to lingual cortical bone only between mandibular molars for

the same reason [10, 14, 19, 25]. It is thought that similar with the lingual canine region, the buccal molar region of the mandible is exposed to greater masticatory forces and higher stress levels and the cortical bone in these regions is thickened to withstand these [6, 15, 34].

Studies examining cortical bone thickness aimed to find the most suitable areas for miniscrew placement which are also easy to locate on CBCT images for being able to make standard repeated measurements [11, 14]. These areas should be within attached gingiva, have low risk of inflammation, and thus be 5 mm apical to the alveolar crest at the mesiodistal center point of each interdental region which is why they are preferred in this study. It is reported that a minimum 1 mm cortical bone thickness is required to obtain successful results with miniscrews [22]. Motoyoshi et al. [21] remarked that failure rates at regions with less than 1 mm cortical bone thickness are 6.9 times higher than the regions with more than 1 mm cortical bone thickness. The mean buccal and lingual cortical bone thicknesses measured in this study were greater than 1 mm for all interdental regions evaluated. However, some studies reported less than 1 mm cortical bone thicknesses in some regions of the maxilla and mandible. This difference may be related with evaluation of both young and adult patients in those studies, as age is known to have an influence on cortical bone thickness [10, 11, 26, 31].

Extremely thick cortical bone is another factor that may cause miniscrew failure. Placing a miniscrew in an extremely thick cortical bone layer may lead to excessive torque which causes too much compression of surrounding tissues that results in osteonecrosis and resorption rather than healing [32]. Therefore, torque values over 10 Ncm are reported to increase failure rates and predrilling is advised to avoid excessive torque for cortical bone layers thicker than 1.5 mm [2, 21].

Conclusions

- Skeletal class 1, class 2 and class 3 individuals are similar with regard to root length, root width, and buccal/lingual cortical bone thickness.
- Skeletal class 2 individuals have greater cancellous bone thickness in the maxillary molar region and in all mandibular interdental regions.
- The H_0 hypothesis is rejected and the H_1 hypothesis is accepted.
- Cortical bone is thicker in the mandible compared to the maxilla both on the buccal and lingual sides.
- Cortical bone is thicker in the posterior region compared to the anterior region on the buccal side.

- Lingual cortical bone is thicker than the buccal cortical bone both in the maxilla and mandible, except for the mandibular molar region.

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Compliance with ethical guidelines

Conflict of interest İ. Coşkun and B. Kaya declare that they have no competing interests.

Ethical standards This retrospective study was performed after consultation with the institutional ethics committee and in accordance with national legal requirements.

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