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CBCT Evaluation of Cortical Bone Thickness for Orthodontic Mini-Screw

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Objectives: This study aimed to assess mandibular and maxillary cortical bone thickness using a cone beam computer tomogram (CBCT) image to determine the safe zone to insert mini-screws. **Methods:** In this three factorial design study, we included 100 subjects divided into age group 1 (age 16-44 yrs.) and age group 2 (age 26-42 yrs.) that had taken a CBCT in the Department of Orthodontics, School of Dentistry, Mongolian National University Medical Sciences (MNUMS) from 2014-2021 We used CBCT images in the 100 subjects that were obtained with DENTRI (HDXWILL, Seoul, Korea) using OnDemand3D software for linear measurements. **Results:** The maxillary cortical bone thickness was heavier in the male gender at the premolar region level of 5 mm in age group I. Maximum maxillary cortical bone thickness as measured 7 mm from the Cemento-Enamel Junction (CEJ) between the 1st premolar and 2nd premolar was 0.99 mm, and the mandibular cortical bone thickness as measured 7 mm from the CEJ between the 1st molar and 2nd molar was 2.11 mm. **Conclusion**: This suggests that the maxillar and mandibular molar teeth cortical bone thickness on the buccal side of 7mm from the CEJ is considered to be the safest position to implant mini screws in cortical bone.

Keywords: CBCT, Dentofacial Deformities, Cortical Bone, Bone Anchored Devices

Introduction

Dentofacial deformities (DFD) are a major problem in dental medicine, and it affects the person's facial appearance, occlusion, and quality of life [1]. The diagnosis and treatment of the conditions are managed by the orthodontist and as well as oral maxillofacial surgeons. Traditionally, an orthodontic bracket system is exclusively used to treat DFD [2]. However, the orthodontic bracket system alone may not be sufficient to treat DFD due to its complexity of biomechanics and time-consuming treatment without a complete treatment efficiency even in mastered orthodontist hands [3-5].

In recent years, there has been increased emphasis on the skeletal anchoring system as an alternative modality to treat DFD cases. This system is a bone-borne device that is used as a temporary anchorage and consists of titanium or stainless-steel plates and mini-mini screws. Both anchorage devices are named Temporary Anchorage Devices (TAD's) [6 - 8]. DFD cases are challenging and for their treatment orthodontist must perform the following difficult dental movements such as intrusion/extrusion of teeth, space closure, distal/mesial movement, whole arch distalization, molar uprighting, occlusal cant correction, and 3D control of teeth. Those movements are extremely difficult without proper anchorage. TAD's allowed orthodontists to perform those difficult movements using its absolute anchorage system without difficulty [9, 10]. However, the insertion of the mini screw is challenging because the conventional radiography provides inaccurate information [11-13]. Therefore, the positioning of the mini screw is largely based upon clinicians' experience. Improper positioning of the mini-screws in the alveolar bone could lead to damage to the teeth roots, inferior alveolar nerve, and perforation of the maxillary sinus [14-16].

To avoid these complications, interestingly, inaccurate measurement of cortical bone thickness has been increased greatly [17-19]. Cone-Beam Computed Tomography (CBCT) and Orthopantomogram (OPG) are two common imaging modalities used in dentistry. CBCT is the one of recent technological advantages in clinical dentistry and provides a detailed three-dimensional image of bones as well as accurate measurements of clinical parameters [18, 20-22]. Yet, OPG is still used as a conventional radiographic technic even though it only provides two-dimensional information of bones [23].

Assessment of cortical bone thickness using CBCT to determine the exact positioning of the skeletal anchoring system has been studied extensively [19, 24]. However, to date, assessment of cortical bone thickness has not been investigated in the Mongolian population. The objective of this study was to assess the mandibular and maxillary cortical bone thickness using CBCT image and determine the safe zone to insert mini screws in the Mongolian population.

Materials and Methods

Study design and subjects

In this retrospective study, we included 100 subjects that were taken by CBCT in the Department of Orthodontics, School of Dentistry, Mongolian National University Medical Sciences (MNUMS) of Mongolia, from 2014-2021. The inclusion criteria were no periodontal disease with no alveolar bone loss, no missing teeth. Exclusion criteria were fractures and pathological conditions in the maxilla and mandible, and root anomalies including severe dilacerations and idiopathic root resorption.

We performed the three-way ANOVA in order to determine if there is an interaction effect between variables. Here, we have examened impact of three independent variables such as age, gender and premolar or molar teeth levels on the thickness of cortical bones in the age groups of 18-25 and 26-42 years (51 and 49 participants per group).

Measurements

All the CBCT images were obtained with DENTRI (HDXWILL, Seoul, Korea) at 85 kVp, 7 mA, second exposure setting. OnDemand3D software (CyberMed. Seoul. Korea) was used for the linear measurements. In 14 randomly selected cases, all measurements were made twice to assess intra-rater reliability, 3 weeks apart.

Using the CBCT scan and looking at the sagittal plane, the Cemento-Enamel Junction (CEJ) was identified first. Then, in the coronal plane, it was possible to measure the linear measurements in the following maxillary and mandibular teeth: first premolar, second premolar, first molar, and second molar (Figure 1). Measurements were made between bi-cortical bones at a distance of 3, 5 and 7mm from the buccolingual surface to the root according to the method described by Baugaertel et al. [17] (Figure 1). The cortical bone thickness was assessed only on one side of the maxilla and mandible.

Statistical analysis

Three-way mixed ANOVA was used to analyze the accuracy/recovery at three different levels. Repeated measure ANOVA was used to analyze the precision of the stability of measurements at three different times. A critical p-value of < 0.05 was used. The repeated measurements within subjects were then compared the previous time interval using paired t-tests. The male and female groups' differences at each time interval were tested using the independent t-tests. A Bonferroni-type correction was applied to all t-test results resulting in a significance level set at $p < 0.025$ (= 0.05/2). SPSS version 24 software (SPSS Inc., Chicago, IL, USA) was used for statistical analysis.

Ethical statement

The study was approved by the Research Ethics Committee of Mongolian National University of Medical Sciences on August 03, 2019 (No. 2019/3-08).

Results

Descriptives and reproducibility

In total, 100 subjects met the inclusion criteria and cortical bone thickness was assessed in maxilla and mandible. The mean age was 26.7 ± 7.1 years, and 70 were female. There was no statistically significant difference between gender and age.

The Intraclass Correlation Coefficient (ICC) for reproducibility of the maxillary cortical bone thickness was 0.88 (95% CI, 0.71; 0.96), and in the mandible was 0.93 (95% CI, 0.90; 0.96).

Table 1. Maxillary cortical bone thickness.

Teeth	Measuring distance (mm)	Age group I (n = 51)	Age group II (n = 49)	
		Mean ± SD	Mean ± SD	p-value
I premolar-II premolar (Pm I-Pm II)	3	0.89 ± 0.22	0.92 ± 0.30	0.491
	5	0.94 ± 0.24	0.95 ± 0.31	0.954
	7	1.01 ± 0.26	0.98 ± 0.35	0.633
II premolar-I molar (Pm II-M I)	3	0.93 ± 0.29	0.86 ± 0.30	0.235
	5	0.99 ± 0.30	0.95 ± 0.37	0.658
	7	0.99 ± 0.28	0.97 ± 0.31	0.851
I molar-II molar (M I-M II)	3	0.91 ± 0.30	0.80 ± 0.15	0.024
	5	1.00 ± 0.37	0.86 ± 0.17	0.010
	7	1.03 ± 0.43	0.91 ± 0.20	0.085

Table 2. Maxillary cortical bone thickness by age groups.

Teeth	Measuring distance (mm)	Age group I (n = 51)			Age group II (n = 49)		
		Male[a] (n = 20)	Female[b] (n = 31)		Male[c] (n = 10)	Female[d] (n = 39)	
		Mean ± SD	Mean ± SD	*p-value	Mean ± SD	Mean ± SD	*p-value
I premolar-II premolar (PmI-PmII)	3	0.95 ± 0.28	0.85 ± 0.18	0.121	1.04 ± 0.51	0.90 ± 0.23	0.191
	5	0.98 ± 0.29	0.93 ± 0.22	0.446	0.99 ± 0.41	0.94 ± 0.29	0.682
	7	1.04 ± 0.26	0.99 ± 0.27	0.532	0.95 ± 0.44	0.99 ± 0.34	0.748
II premolar-I molar (PmII-MI)	3	0.99 ± 0.38	0.90 ± 0.23	0.261	0.73 ± 0.05	0.99 ± 0.33	0.010
	5	1.10 ± 0.40	0.91 ± 0.21	0.059	0.87 ± 0.11	0.97 ± 0.41	0.421
	7	1.06 ± 0.39	0.94 ± 0.23	0.203	0.86 ± 0.14	1.00 ± 0.35	0.044
I molar-II molar (MI-MII)	3	0.94 ± 0.41	0.89 ± 0.22	0.562	0.73 ± 0.12	0.82 ± 0.16	0.066
	5	1.02 ± 0.51	0.99 ± 0.25	0.813	0.81 ± 0.13	0.87 ± 0.19	0.298
	7	1.02 ± 0.58	1.04 ± 0.31	0.908	0.84 ± 0.13	0.93 ± 0.21	0.174

Three-way mixed ANOVA results: Interaction of time and age $F(1.92, 316.6) = 23.13$, $p < 0.012$; Main effect of time $F(1.94, 337.6) = 336.3$, $p < 0.031$; Main effect of age $F(1,16) = 0.77$, $p = 0.695$; *Independent t-test male vs. female; Pairwise comparison: [a]PmII-MI-5 vs. PmII-MI-7, p=0.041; [b]PmII-MI-5 vs. PmII-MI-7, p=0.015; [c]PmII-MI-3 vs. PmII-MI-7, p=0.031; [d]PmII-MI-3 vs. PmII-MI-7, p=0.014.

Table 3. Mandibular cortical bone thickness and age groups.

Teeth	Measuring distance (mm)	Age group I (n = 57) Mean ± SD	Age group II[a] (n = 43) Mean ± SD	*p-value
I premolar-II premolar (Pm I-Pm II)	3	1.28 ± 0.37	1.13 ± 0.33	0.044
	5	1.38 ± 0.37	1.33 ± 0.32	0.382
	7	1.60 ± 0.43	1.55 ± 0.36	0.566
II premolar-I molar (Pm II-M I)	3	1.49 ± 0.53	1.42 ± 0.54	0.554
	5	1.60 ± 0.52	1.48 ± 0.57	0.301
	7	1.77 ± 0.49	1.72 ± 0.52	0.695
I molar-II molar (M I-M II)	3	1.59 ± 0.45	1.49 ± 0.51	0.320
	5	1.81 ± 0.52	1.78 ± 0.63	0.791
	7	2.18 ± 0.55	2.04 ± 0.63	0.255

Three-way mixed ANOVA results: Interaction of time and age F (1.91, 140.0) = 17.015, $p < 0.638$; Main effect of time F (1.88, 317.4) = 336.3, $p < 0.092$; Main effect of age F (1,19) = 0.266, p = 0.310; *Independent t-test age group I vs. age group II; Pairwise comparison: [a]PmII-MI-5 vs. PmII-MI-7, p=0.041.

Table 4. Mandibular cortical bone thickness by age groups.

Teeth	Measuring distance (mm)	Age group I (n = 57) Male (n = 20) Mean ± SD	Age group I Female (n = 37) Mean ± SD	p-value	Age group II (n = 43) Male[a] (n = 14) Mean ± SD	Age group II Female[b] (n = 29) Mean ± SD	*p-value
I premolar-II premolar (Pm I-Pm II)	3	1.34 ± 0.41	1.25 ± 0.36	0.421	1.23 ± 0.46	1.08 ± 0.25	0.277
	5	1.51 ± 0.47	1.32 ± 0.29	0.065	1.31 ± 0.46	1.33 ± 0.23	0.875
	7	1.67 ± 0.47	1.56 ± 0.42	0.391	1.64 ± 0.46	1.51 ± 0.31	0.314
II premolar-I molar (Pm II-M I)	3	1.60 ± 0.59	1.42 ± 0.50	0.221	1.29 ± 0.59	1.48 ± 0.53	0.280
	5	1.70 ± 0.61	1.55 ± 0.47	0.313	1.40 ± 0.57	1.53 ± 0.59	0.492
	7	1.89 ± 0.59	1.70 ± 0.42	0.208	1.62 ± 0.58	1.78 ± 0.51	0.376
I molar-II molar (M I-M II)	3	1.73 ± 0.54	1.51 ± 0.39	0.138	1.37 ± 0.63	1.55 ± 0.45	0.271
	5	2.00 ± 0.70	1.71 ± 0.36	0.093	1.51 ± 0.52	1.91 ± 0.65	0.051
	7	2.21 ± 0.61	2.16 ± 0.53	0.730	1.83 ± 0.53	2.14 ± 0.67	0.129

Three-way mixed ANOVA results: Interaction of time and age F (1.93, 336.6) = 23.17, $p < 0.032$; Main effect of time F (1.93, 336.6) = 335.3, $p < 0.043$; Main effect of age F (1,19) = 0.70, p = 0.678; *Independent t-test male vs. female; Pairwise comparison: [a]MI-MII-5 vs. MI-MII-7, p = 0.027; [b]MI-MII-5 vs. MI-MII-7, p = 0.001.

Cortical bone thickness in the maxilla

Maximum maxillary cortical bone thickness was measured 7 mm above from CEJ between 1st premolar and 2nd premolar (0.99 mm), followed by 5 mm above from CEJ between 2nd premolar and 1st molar area (0.97 mm), and between 1st molar and 2nd molar (0.97 mm). As shown in Table 1, there were no significant differences between two age groups in Pm I-Pm II and Pm II-M I measurements. However, M I-M II measurement revealed statistically significant differences ($p < 0.05$) in 3 and 7 mm of thickness. Moreover, there was tendency of thicker maxillary cortical bone in Pm I-Pm II area at age group II. Further, in order to examine whether there was difference in observed variables according to age, we performed three-way ANOVA analysis (Table 2).

As can be seen here, there was no significant difference in Pm I-Pm II measurement of both age groups, while some variables in Pm II-M I measurement obtained statistical significance. In detail, there was significant differences between male and female in 3- and 7-mm thickness of Pm II-M I measurement of age group II ($p < 0.05$). Also, maxillary cortical bone was thicker in male than female in age group I, while the same bone was thicker in female participants of age group II in Pm II-M I area.

Cortical bone thickness in the mandible

The maximum mandibular cortical bone thickness was measured 7 mm above from CEJ between 1st molar and 2nd molar was (2.11), and between 2nd premolar and 1st molar area (1.75 mm). As can be seen in Table 3, when comparing each age group, results showed significant difference in 3 mm thickness of Pm I-Pm II measurement only ($p < 0.05$). Further, there was tendency of thicker maximum mandibular cortical bone in male participants in both age group. When examined whether there is a difference between male and female participants when considering age in group I and II, we have performed three-way ANOVA analysis. As shown in Table 4, there was no significant difference in mandibular cortical bone thickness in the two age groups. However, mandibular cortical bone of male participants was thicker in all measurement areas at age group I, while Pm II-M I and M I-M II area was thicker in female participants at age group II.

Discussion

Over the past decades, the use of mini screws in orthodontic treatment has become increasingly popular. It is significantly critical procedure especially in anchorage of orthodontic purpose. A successfully inserted and highly patient accepted mini screws are essential because it guarantee the teeth move predictably and without reciprocal move.

There are several sites that have been used for mini screws: palatal bone, palatal side of the maxillary alveolar process, mandibular retromolar area, infrazygomatic crest, maxillary and mandibular bucco alveolar cortical plate and posterior palatal alveolar process. Therefore, positioning depends significantly on the quality and quantity of the bone due to these anatomical factors affect the stability of the mini screws. Nucera et al. reported that the insertion site with the optimal anatomic characteristics is the buccal bone corresponding to the distal root of second molar, with screw insertion 4 mm buccal to the cementoenamel junction. These sites showed cortical bone depth thickness greater than 2 mm [25, 26]. Further, there are age, gender as well as racial differences in the cortical bone thickness of commonly used maxillary and mandibular mini screw implant placement sites. The cone-beam computed tomography data showed that showed no significant differences in cortical bone thickness between the genders. However, thickness between adolescents and adults were significant and adult cortices significantly thicker in all areas except the infrazygomatic crest, the mandibular buccal first molar-second molar site, and the posterior palate site. In the adults, it has been shown that interradicular bone in the maxillary first premolar-second premolar, and second premolar-first molar sites was thicker than bone at the lateral incisor-canine and first molar-second molar sites. Maxillary and mandibular cortical bones at commonly used miniscrew implant placement sites are thicker in adults than in adolescents [27]. In a previous study, the cortical bone thickness was assessed in dry skulls using a similar method to our study. The maximum thickness in the maxilla is 1.32 mm at a distance of 6 mm from the alveolar crest between the second molars, 1.34 mm at a distance of 6 mm between the second molars and the first molars, and 1.35 mm between the first molars and the second molars [17]. Moreover, the three-dimensional CBCT images of patients with age range of 19-25years, maxillary and mandibular cortical bone thickness between first and second bicuspids and first molars and between first and second molars was measured at 8mm level from CEJ. Maxillary buccal cortical bone thickness ranged from 1.2 to 2.4 mm and mandibular buccal cortical bone thicknesses was 1.1 to 2.3 mm [28]. The result revealed that the thickness of the bone is greater than ours. We believe that this is due to the fact that we started the measurement from a slightly higher point.

The current study found that maxillary cortical bone thickness was heavier in the male gender at the premolar region level of 7 mm in the age group I (16-41 years). Moreover, we observed thicker cortical bone in the male gender in the age group II (26-42 years) at premolar region at level of 3 mm. In the mandible, we only observed statistically significant bone thickness at the premolar region at a level of 3 mm from the CEJ ($p < 0.05$) in the age group II. In the age group I, there was a tendency of thicker cortical bone in the male gender, however, statistically significant did not found ($p > 0.05$). Anatomically and biomechanically, male gender has greater bite forces and masticatory muscles compared with the female gender [25]. Despite the critical of cortical bone thickness in min screw stability, there are several studies showed strong correlation between the bone thickness and age [29-31]. Sathapana et al. reported that there were significant correlations between cortical bone thickness and age in the maxillary incisor and maxillary premolar regions ($p = 0.01$ and $p = 0.047$ respectively). Significant correlation between the bone thickness and gender was found only at the buccal aspect of the maxillary molar region ($p = 0.022$). In the mandible, a statistically significant correlation between the bone thickness and age was found in the cortical bone of the labial side of the mandibular incisor region ($p = 0.017$). There was also a significant difference in change in the bone thickness with age between males and females in the lingual side of the retromolar region, in which female bone thickness increased more than in males (slope = 0.015) [32]. On the other hand, we found that the maxillary cortical bone thickness from 3 mm ($p < 0.02$) and 5 mm ($p < 0.01$) from the CEJ in the maxillary posterior region were found to be statistically significantly different between age group I and II. Based on our study, the thickest cortical bone was observed at the 7mm from the CEJ on the buccal side at molar teeth maxillary and mandible. Therefore, the safest position to insert mini-screws is preferably positioned more apically and posteriorly. The method we have described in this study provides accurate measurements regarding the cortical bone thickness with a good to the excellent intra-rater correlation coefficient.

The findings of our study have important implications for planning orthodontic treatment for DFD patients. Pre-treatment assessment of morphometry of maxillary and mandibular bone using CBCT is important and positively affects the outcome of further treatment. The use of the morphometric dimensions of the study as a reference dimension in the treatment of post orthodontics and orthodontics is important to improve treatment outcomes and to avoid errors during treatment.

To the best of our knowledge, this study provides the first three-dimensional measurement of the cortical bone thickness of the maxilla and mandible in the Mongolian population. Perhaps, our study provided clinically relevant outcomes to the orthodontists to accurately position the mini screws in their daily practice.

However, the limitations of our study is following. First, our date is based on relatively few samples due to the large number of edenteliuos and malocclusion patients in our samples. Second, the measurement of maxillary and mandibular cortical bone thickness is not always done in the same person. Since all our measurements and analysis were achieved separately by maxilla and mandible, this limitation will not affect the quality of the study. Therefore, in a future study, it may be preferable to increase the sample size. Moreover, beacuse we have conducted the measurement using a single CBCT machine in the present study, in order to confirm these results, it would be useful to use other CBCT machines at different voxel sizes.

Conclusion

The cortical bone thickness was observed thicker in maxillary and mandibular at the level of 7mm from CEJ. This suggests that the maxillary, mandibular molar teeth cortical bone thickness on the buccal side far from 7mm CEJ is considered to be the safe zone to implant mini screws on cortical bone.

Conflict of Interest

The authors state no conflict of interest.

Acknowledgements

Not available.

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