A CBCT Study Comparing the Outcomes of Volumetric Bone Mass and Mini-Implant Success with Different Types of Malocclusions

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Abstract

Objective: The present study aimed to determine the favorable site for orthodontic mini-implant insertion in both the maxilla and mandible in terms of cortical and trabecular bone thickness and density in different types of skeletal malocclusion using cone-beam computed tomography (CBCT).

Methods: In this study, seventy-five CBCT examinations that were requested for different purposes were used, twenty-five in each malocclusion group (class I, class II and class III), class I (ANB: 2°-4°), class II (ANB > 4°), and class III (ANB < 2°) groups. RadiAnt Dicom Viewer was utilized, measurements were done at different sites in the jaws using standardized orientations, and the three malocclusion groups were compared for cortical bone thickness and density as well as the density of trabecular bone, using the Kruskal-Wallis and Mann-Whitney test for non-parametric data and one-way ANOVA for parametric data.

Results: The highest cortical bone thickness was between 1st and 2nd molars at a 6 mm distance from the alveolar crest ranging from 1.03 mm to 1.2 mm in maxilla and 2.13 mm to 2.26 mm in the mandible. The difference between groups was only noticed between canine and 1st premolar which showed less buccal cortical bone thickness in class II cases with 1.07 mm. Cortical bone density was not significantly different between the three groups with maximum density between canine and 1st premolar with a density of 997.9 to 1078 HU in the maxilla and the mandible 1245.4 to 1329.3 HU. The trabecular bone density was also highest between canine and 1st premolar of both jaws, in maxilla 422.13 to 564.15 HU and mandible 509.81 to 799.04 HU. The difference between the groups was only in the anterior location between canine and 1st premolars which was less in class III cases with 509.81 HU.

Conclusions: Skeletal relations can have an impact on the thickness of the cortical bone, although all skeletal classes have the same pattern in the maxilla, in the mandible between the canine and the 1st premolar, variations in bone thickness and trabecular density may be seen in various skeletal malocclusions. So, it is important to properly consider the placement of mini-implants with the skeletal relation to achieve the maximum primary stability. Further researches are recommended, with long term follow up, on stability of mini-implants and its correlation with bone thickness and density.

Keywords: Cortical bone, skeletal malocclusions, CBCT, Mini-implants, Volumetric bone mass, Bone density.

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Introduction

With absolute anchoring, orthodontists may anticipate more positive results from therapy. Nearly 20 years ago, practitioners were given this option for the first time without relying on patient cooperation from temporary anchoring devices (TADs)\(^1,2\). The stated success rate for mini-implants in the literature varies greatly, from 70% to 92%, but their success rate is less when compared to mini plates and dental implants\(^3,4\). According to a previous study, the failure of mini-implants is associated with the presence of an inadequate amount of bone from the resorption of the trabecular bone, which makes the mini-implant unable to withstand the forces applied to it. The thickness of the cortical bone is also a factor; if the thickness is less than 1 mm, the stress in the bone will be increased, thus making the implant more unstable\(^5\). According to Costa et al. and Miyawaki et al., cortical bone quality and quantity have a significant role in the primary stability of mini-implants, perhaps because mechanical retention rather than osseointegration is used to produce this stability\(^6\). Orthodontic mini-implants can be loaded immediately as primary stability is obtained with only 10% contact of the mini-implant with the bone and osseointegration is not required in orthodontic mini-implants. It can withstand about 300 grams of force\(^7\).

Cortical bone thickness, total bone mineral density, cortical bone mineral density, and bone hardness were all substantially correlated with the mean failure force of orthodontic mini-implants, according to research by Iijima et al. in 2012\(^8\). For maximum stability, the soft tissue condition must also be considered. Evidence shows that age can be related to the stability of mini-implants, as with increasing age, the skeleton will also be more mature\(^9\). Trabecular bone density is also important for increasing the primary stability of mini-implants. With an increase in the mineral density of the trabecular bone, the primary stability of mini-implants will also increase\(^10\).

Many previous studies have investigated mini implants and factors affecting their stability, including the insertion angle and the anatomical structures in the area, and the effect of changing shape, length, and diameter on stability and failure rates\(^11,32\).

Radiological assessment before the placement of orthodontic mini-implants is crucial for precise treatment planning and for ensuring optimal positioning and minimizing the risk of complications, contributing to the overall success of the orthodontic procedure. CBCT is a widely used modality nowadays due to the advantages it has, like quick image acquisition, a lower radiation dose than conventional CT scans, and the detailed three-dimensional information that can be obtained from it\(^13\). CBCT proved to be an effective imaging modality for determining the thickness of the cortical bone and the amount of bone in the interarticular area\(^14\). For studying bone density, the CBCT is also applicable by studying the Hounsfield units (HU), which can determine the density as they have different values in different tissue types\(^15\).

When assessing sagittal skeletal relations in orthodontic patients, their malocclusion group is identified within one of three categories (class I, class II, or class III). The skeletal class I malocclusion only has dental malocclusion problems, and both jaws are in harmony with each other and with the cranium, and patients have a straight facial profile. Skeletal class II malocclusion exhibits distal development of the mandible in relation to the maxilla and a convex facial profile, while the skeletal class III malocclusion group has an obtuse mandibular angle and overgrowth of the mandible with the concave facial profile\(^16\). These distinct classes not only dictate the nature of the malocclusion but also reveal variations in bone thickness and density as the results obtained from previous research about bone thickness and density varied across different malocclusion groups\(^17\). Orthodontic patients present with different malocclusion classes and each may require mini-implant placement at different stages of treatment; hence, this study aims to compare the influence of volumetric bone mass on mini-implant success across various malocclusion types, potentially offering clinical guidance for orthodontic treatment planning. The null hypothesis of the study was that there are no significant differences in volumetric bone mass and mini-implant success among different types of malocclusions as assessed by CBCT.

Methods

The CBCT images used to conduct this research were obtained from a private radiology center. The data were retrospectively collected and were requested for different diagnostic purposes between January 2021 and January 2023. Image acquisition was done using the “Casestream Dental “CS 9600 CBCT Scanner with a scanning protocol of 120 KVp, 5 mA, 24 seconds exposure time, and 0.3 mm voxel size, with a field of view of 16 x17 cm. This study was registered and approved by the College of Dentistry at Sulaimani University (registration no.165/23 on May 3, 2023).

The sample

Using the software G*Power 3.1.7, the required sample size was calculated before the study started\(^18\). Twenty patients were determined to be necessary for each group at a significance level of 5%, to determine differences in cortical bone thickness and density between the three malocclusion groups with a power of 80% and an effect size of 0.40 mm\(^19\). In total, 75 CBCT images were used, 25 in each malocclusion group.
Inclusion criteria

The inclusion criteria were patients aged between 15 and 35 years, with no alveolar bone loss, no prior orthodontic treatment history, no severe skeletal discrepancy, no congenitally missing teeth (aside from third molars), mild to moderate crowding, no developmental anomalies like cleft lip and palate, or syndromes, and acceptable oral hygiene without periodontal issues.

The study protocol

Cephalometric radiographs were obtained from the CBCTs with the use of CS 3D Imaging software (Version3.10, Casestream Dental LLC, Atlanta) and using the ANB angle for each case to classify the cases for the different malocclusions: class I, class II, and class III. The cephalometric tracings and measurements were done with the WebCeph™ web-based orthodontic application (Version 1.5.0, Assemble Circle Corp., Gyeonggi-do, Republic of Korea). Consequently, the samples were separated into class I (ANB: 2°-4°), class II (ANB > 4°), and class III (ANB < 2°) groups.

The RadiAnt DICOM viewer (version 2022.1.1, Medixant, Poznań, Poland) was used to view the imported DICOM files of CBCT scans. The measurements were taken in the following locations in both the maxilla and mandible: anteriorly between canine and 1st premolar, middle point between 2nd premolar and 1st molar, and posteriorly between 1st and 2nd molars.

The measurements were made at two distinct heights at each site. Mini implants are more stable at distances of 4 mm and 6 mm from the alveolar crest. As there is no significant difference between measurements of the right and left sides of the same individual, in this study, all measurements were taken only on the right side of both the maxilla and mandible.

RadiAnt Viewer was used to reorient the images in 3D multiplanar reconstruction (MPR), which helps to standardize the images and reduce measurement errors as shown in Figure 1. In sagittal view, the two guiding lines were oriented in such a way that the horizontal line was with the alveolar crest and the vertical line was at the center of the two teeth roots; in axial view, the two lines were oriented with the occlusal plane and the center of the two teeth. Then the measurements were taken in coronal view by adjusting the lines to be exactly with the crest of the alveolar bone. The main value of cortical bone density was measured buccally at the same levels, and trabecular bone density was also measured at the same heights from the alveolar crest (4 mm and 6 mm) at the midpoint point between the buccal and lingual cortical bones. The reliability of measurements was assessed through both inter and intra-examiner tests. Two observers independently conducted measurements on images from each group to evaluate inter-examiner reliability. Additionally, intra-examiner reliability was examined by having the same observers remeasure images from each group two weeks apart. The purpose of this approach was to ensure consistency and accuracy in the measurement process and to evaluate the reliability of the obtained data.

Statistical analysis

After creating an Excel sheet of the data and cleaning it, the analysis was done by IBM SPSS version 23 software. Then Shapiro-Wilk normality test was done and showed that part of the data was parametric and the rest was non-parametric. For comparison between groups, for the non-parametric data, the Kruskal-Wallis test was performed along with pairwise comparison, and for the parametric data, ANOVA was used to compare the three malocclusion groups. Also, the Friedman test was performed for intragroup comparison. A p-value less than 0.05 was considered statistically significant.

Results

Seventy five CBCT scans in total were assessed. The sample included 17 men and 58 women. Patients in classes I, II, and III had mean ages of 20.60±5.91, 20.88±5.70, and 20.60±4.56 years, respectively. Between the three groups, there was no variation in the mean age.

Intra-class correlation coefficient (ICC) and confidence interval were more than 0.90 for both intra-observer reliability and inter-observer reliability tests.

The Bland-Altman plot was also used for comparing the measurements taken by the two observers, as shown in Figure 2.

Values of cortical bone thickness measurements in all malocclusion groups are shown in Figure 3 and demonstrated with boxplots which offer more preferable graphical presentation of non-parametric data.

The results showed that the area of maximum thickness in both the maxilla and mandible is the posterior location.
Figure 1: Standardized images orientation and taking measurements. (A) shows Sagittal view indicating the position of the pointer in the center of the interradicular space with the red line and the yellow line indicating the crest of the alveolar bone, (B) shows the Axial plane indicating pointer position in the center of the ridge in a buccolingual direction with the red line perpendicular to the occlusal plane and the blue line parallel to the occlusal plane, (C) shows the Coronal view indicating the two reference lines to determine the distance from the alveolar crest 4 mm and 6 mm, the numbers on the right show thickness and density of cortical bone, while numbers on the left are trabecular bone density at the two distances.

Figure 2: Bland–Altman plot of differences in alveolar bone thickness and density between two operators.

Figure 3: Abbreviations: Max; maxilla, Man, mandible, A; anterior location between canine and 1st premolar, B; middle location between 2nd premolar and 1st molar, C; posterior location between 1st and 2nd molars, 4; 4 mm distance from alveolar bone, 6; 6 mm distance from alveolar bone. Each box shows the bone thickness value in the corresponding location, the line in the center of the box indicates the median, the upper whisker indicates the maximum value and the lower one indicates the minimum value, above or below the whisker lines show the outliers, indicated by small circles when the extreme values of outliers are shown as stars.
between the first and the second molars at a 6 mm distance from the alveolar crest. The Friedman test and Wilcoxon signed ranks test were also done to test the difference in cortical bone thickness within the groups. The result showed that the only difference between the maxilla and mandible was in the anterior location between canine and 1st premolar, where the mandibular cortical alveolar bone thickness was more than that of the maxilla, which can be interpreted by the increased functional demand in the lower arch. And when the difference between the anterior and posterior positions was assessed the result showed a non-significant difference.

Kruskal-Wallis test was used to compare the differences in cortical bone thickness between the three malocclusion groups and the only difference found was in the mandible between canine and 1st premolar at both distances from the alveolar crest (4 mm and 6 mm) (\( p < 0.05 \)).

A pairwise comparison was done between the three malocclusion groups and showed a difference at the 4 mm level between class I and class II measurements with a P value of 0.03 and more cortical thickness in class I cases, while at the 6 mm level there was a difference between class II and class III patients, with a P value of 0.04, showing more cortical bone thickness in class III cases (Table 1).

The results of descriptive statistics of cortical bone density in all determined locations are shown in Table 2. The result shows that the maximum cortical bone density in all malocclusion groups was between canine and 1st premolar at 6 mm distance from the alveolar crest for both maxillary and mandibular arch, except in the class II maxillary arch, where the maximum bone density was between the 1st and the 2nd molars at 6 mm distance from the alveolar crest.

As the data of cortical bone density was normally distributed, one-way ANOVA test with Bonferroni Correction was used to compare bone density between and within the malocclusion groups and the null hypothesis of no difference between the three malocclusion groups regarding cortical bone density was retained.

Median, rank, and interquartile range were used as descriptive statistics for trabecular bone density data and the results are shown in Table 3.

According to the results and descriptive statistics maximum trabecular density in the mandibular arch was found between canine and 1st premolar in all malocclusion groups, but in the maxilla maximum trabecular bone density was found between 1st and 2nd molars in class I and class II groups and between canine and 1st premolar in class III cases.

The Kruskal-Wallis test was performed to compare trabecular bone density between the three groups and showed no difference at any locations except for between mandibular canine and 1st premolar at 4 mm height level that showed a p-value of 0.02 and pairwise comparison was done to determine exactly where the difference was. According to the pairwise comparison, there were differences between class II and class III, also between class I and class III groups, showing that the trabecular bone density was less in class III cases in this location.

Table 1: Pairwise comparison of mandibular cortical thickness between canine and first premolar at 4- and 6-mm alveolar crest distances in different malocclusion groups.

<table>
<thead>
<tr>
<th>Sample 1- sample 2</th>
<th>Adj. Sig 4 mm level</th>
<th>Decision 4 mm level</th>
<th>Adj. Sig 6 mm level</th>
<th>Decision 6 mm level</th>
</tr>
</thead>
<tbody>
<tr>
<td>Class I- Class II</td>
<td>0.37</td>
<td>Reject the null hypothesis</td>
<td>0.356</td>
<td>Retain the null hypothesis.</td>
</tr>
<tr>
<td>Class I- Class III</td>
<td>1.000</td>
<td>Retain the null hypothesis.</td>
<td>1.000</td>
<td>Retain the null hypothesis.</td>
</tr>
<tr>
<td>Class II- Class III</td>
<td>0.99</td>
<td>Retain the null hypothesis.</td>
<td>0.44</td>
<td>Reject the null hypothesis.</td>
</tr>
</tbody>
</table>

*Adj. Sig indicates adjusted P value for reducing the chance of making wrong decisions.
*Reject the null hypothesis that states there is no difference in cortical bone thickness between the malocclusion groups, which means there is a difference.
Discussion

Complex tooth movements are now simpler and more predictable due to the invention of mini-implants. Mini orthodontic implants are safe and efficient and may be obtained at a reasonable price. Although their ease of installation makes them useful at various anatomical sites, considerations like the thickness and density of the available bone should be considered before placement. To determine the best locations to place orthodontic mini-implants, this research analyzed the available bone thickness and density of both cortical and trabecular bone in patients belonging to different groups with skeletal malocclusion. It is crucial to measure bone thickness and density to determine the prognosis in various skeletal patterns since bone thickness and density are linked elements impacting the stability of implants.

Previous studies on the assessment of cortical bone thickness were conducted on cadavers. The relation between age and cortical bone thickness was studied by Farnsworth et al. and Fayed et al., with both studies reporting a statistically significant age-related difference in bone morphology can be influenced by muscle activity.
and masticatory forces, and since those two factors differ in patients with different sagittal skeletal relations\textsuperscript{36}, it is logical to assume that there is a difference in cortical bone thickness between various types of sagittal relationships. In a study by Watanabe et al.\textsuperscript{31}, the reported success rate of miniscrews in different sagittal relations varied greatly. So, this study aimed to determine the relationship between bone thickness and density with different sagittal malocclusions.

In a study on a Thai population, Khumsarn et al. compared the buccal cortical thickness in 24 cases of Class I and Class II sagittal skeletal relationships. Measurements were taken at five different heights from the cementoenamel junction. Results of the study showed no difference between the two classes in the mandibular arch, while in the maxillary arch, the thickness was greater in class II than in class I\textsuperscript{37}. In another study, where 94 CBCT scans were retrospectively viewed, buccal cortical bone thickness was obtained at the alveolar processes from canine to second molar at 2 different vertical levels (6 and 8mm) from the cementoenamel junction. The thickness of the maxillary arch was greater in class I than in class II between the 2nd premolar and the 1st molar\textsuperscript{22}. In this study, there was no significant difference between the three malocclusion groups in any of the locations in the maxillary arch. The only significant result obtained from this research was between the canine and 1st premolars in the mandible; this can be explained by differences in muscle activity between those classes\textsuperscript{32}. Cassetta et al. conducted a retrospective study on 48 CBCT scans and measurements were done with the alveolar crest as the reference line, as was done in this study, and the cortical bone thickness and density were measured at 2-, 4-, 6- and 8-mm intervals apical to the alveolar crest at thirteen inter radicular sites from the right 2nd molar to the left 2nd molar in both maxilla and mandible. They concluded that the cortical thickness increases the more posterior the location is in the arch and the more distant it is from the alveolar crest, which is similar to the results obtained from this study\textsuperscript{33}.

Maximum cortical bone thickness was found between 1st and 2nd molars in both the maxilla and mandible, agreeing with results from other literature studies indicating that the thickness of the buccal cortical bone is higher in the posterior than in the anterior locations in the dental arch\textsuperscript{23,34,35}. Whereas, in another study, conducted on 155 images of adult patients (20-45 years old), the thicknesses of the buccal cortical plates of the maxilla and the mandible and the palatal cortical plates of the maxilla were measured, with maximum cortical thickness found in class II malocclusion individuals between canine and 1st premolar at a 4 mm distance from the alveolar crest\textsuperscript{37}. Also, in a study that was done on dry skulls, the results showed that the more posterior the location in the arch, the greater the thickness of the cortical bone\textsuperscript{34}. In a study done in 2014 in which CBCT images of 196 adult subject aged 20-45 were evaluated, cortical bone thickness was measured 4 mm from the alveolar crest and it was found that the maxillary palatal thickness decreased posteriorly, while the mandibular buccal thickness increased. The study concluded that there is no difference between the three malocclusion groups regarding the cortical thickness\textsuperscript{35}, unlike in our study, which found that the thickness differed significantly between the three groups in the anterior mandible.

Rather than bone thickness being higher in the posterior of the mandible, a study based on 128 CBCT scans and measurement of the bone density of 236 potential implant sites found the cortical and trabecular bone density to be higher in the anterior mandible, with the results recorded using Hounsfield units\textsuperscript{36}. Previous studies have reported a weak correlation between bone thickness and density in the mandible and more thickness in the posterior mandible, while density was higher in the anterior mandible. The reason for this could be that the anterior mandible needs to withstand the horizontal forces that are applied from the root of the anterior teeth to the surrounding bone, which in turn requires higher density bone in these anterior locations\textsuperscript{37}.

The structure and density of the bone may change with malocclusions, but no previous studies compared the differences in the cortical and trabecular bone density according to malocclusion groups. It was demonstrated in earlier studies that by changing the occlusal vertical dimension, not only the bone quality in the mandible but also the structure and anatomy of the related muscles change\textsuperscript{38}. The density of the bone changes according to the amount of load applied\textsuperscript{39}. This explains why the trabecular bone density was lower in the mandible in class III individuals as compared with class I and class II cases.

The current study has several limitations, including its inability to fully determine whether the samples were influenced by environmental factors such as the extent of smoking and alcohol consumption, hormonal levels, and nutritional supplements that could affect the mandibular bone density. Another limitation was the wider age range of cases, since bone density is different
in pubertal and post-pubertal periods. Also, the disproportion in the number of males and females who participated in the study made the comparison of the effect of age and gender factors on cortical bone density and thickness with trabecular bone density more difficult. Therefore, to overcome these limitations further studies are suggested with equal numbers of male and female participants, smaller age range, and follow up of the stability of mini-implants in association with the density and thickness of the bone.

The study focused on cortical bone thickness and density, but future research could explore the impact of cortical bone microarchitecture on mini-implant stability.

**Conclusion**

The more posterior the location in the arch and the greater the distance from the alveolar crest, the better the primary stability of the mini-implants should be as the cortical bone thickness is higher in the posterior regions in the arch. In class II individuals the cortical bone thickness in the anterior mandible was found to be less than in the other two malocclusion groups. Meanwhile, the reverse was the case with density of the cortical bone, which was higher in the anterior positions of the jaw between canine and 1st premolar. Regarding the trabecular bone density, it differed between different malocclusion groups in the anterior mandible between canine and 1st premolar, and was lower in the class III malocclusion group than the two other groups.

**References**

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