6-24-2016

The Influence of the Facial Pattern on Bone Density Pre and Post Orthodontic Treatment

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The Influence of the Facial Pattern on Bone Density Pre and Post Orthodontic Treatment

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A Thesis
Submitted in Partial Fulfillment of the
Requirements for the Degree of
Masters of Dental Science
At the
University of Connecticut
2016
APPROVAL PAGE

Master of Dental Science Thesis

The Influence of the Facial Pattern on Bone Density Pre and Post Orthodontic Treatment

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Acknowledgement

I take this opportunity to express my sincere gratitude to the people who have been instrumental in the successful completion of this project. I would like to show my greatest appreciation to my major advisor Dr. Sumit Yadav. I can’t say thank you enough for his tremendous support and guidance. I would also like to thank my committee members, Dr. Aditya Tadinada, Dr. Ravindra Nanda, and Dr. Madhur Upadhyay for their encouragement and insightful comments. Furthermore, I would also like to acknowledge the crucial role of Dr. Derek Sanders who provided all of the required data for this project.
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Abstract

Objective: To evaluate if the facial type has an effect on the inferior cortical bone thickness and density in patients prior to orthodontic treatment, and to evaluate if undergoing orthodontic treatment has an effect on inferior cortical bone thickness and density as well as the alveolar bone density in three facial types using cone beam computed tomography (CBCT). Materials and Methods: CBCT scans of 296 patients seeking orthodontic treatment were retrospectively analyzed for this study. CBCT-generated lateral cephalograms were used to classify patients as hypodivergent, normodivergent, and hyperdivergent on the basis of linear and angular measurements. The patients of each facial type were further divided by age and gender. Cortical thickness and density measurements were standardized using a reconstructed panorex to identify the center of the mental foramen, and the corresponding cross section was used for the measurements. Cortical bone thickness was measured from the inner to the outer cortical plate, and bone density was measured using pixel intensity values (PIVs). Cortical bone measurements were made in patient’s pre orthodontic treatment. A smaller sample of pre and post treatment CBCT scans were used to measure cortical bone thickness and density and alveolar bone density. Results: We found that hypodivergent males have significantly more bone thickness than hyperdivergent males. Hypodivergent females have more bone thickness than hyperdivergent and normodivergent females, but the difference is not significant. There is no difference in bone thickness across genders. In males, bone thickness is greater in nongrowing individuals. There is no difference between bone thickness of growing and nongrowing females. In nongrowing hypodivergent males, bone thickness is significantly higher than
growing hypodivergent males. Hyperdivergent males and females have the highest bone density (quality) among the different facial types. Females of all facial types have greater bone density than males. Bone density is significantly higher in nongrowing males and females than in growing males and females. When comparing pre and post treatment CBCTs of 47 patients, cortical bone density and thickness did not change, while alveolar bone density decreased in all facial types. However, due to the small sample size, these findings are not statistically significant. **Conclusions:** There is a statistically significant relationship between facial type, age, and sex with regards to cortical bone thickness and density. The facial type has an effect on the inferior cortical thickness and density. After orthodontic tooth movement, alveolar bone density appears to decrease while cortical bone density and thickness remain unchanged. However, further studies with a larger sample of pre and post treatment scans are needed to confirm this finding with statistical significance.
Literature Review

Growth Pattern of the Face: Development and Characteristics

Numerous studies have tried to characterize the changes and variations that are seen with the growth of the face. In 1937, Broadbent was the first to suggest that the facial pattern develops early in life. He believed that the development of the facial pattern coincided with the completion of the primary dentition. In addition, Broadbent concluded that once the growth pattern of the face is established considerable changes in the proportion of the face are not seen with continued growth\(^1\). Brodie showed similar findings in his studies in 1941 and 1946 where he concluded that the morphogenetic pattern of the face is established early in life and once reached it does not change\(^2,3\). Nanda conducted a longitudinal study in 1988 which showed consistent findings with earlier studies and further confirmed that the “pattern of development in each facial form is established at a very early age”\(^4\).

In 1959, Sassouni concluded that there are two extremes of vertical facial pattern: increased or decreased vertical growth\(^5\). These vertical facial patterns have been characterized in the literature as “skeletal open bite” or “skeletal deep bite”\(^6\). In 1964, Shudy defined the skeletal open bite as “hyperdivergent” and the skeletal deep bite as “hypodivergent”\(^7\). Bjork described the vertical facial pattern in terms of rotation, using the term “backward rotation” to describe an individual with a long face and excessive anterior facial height, and the term “forward rotation” to describe a short faced individual\(^8\). Schendel used the term “long face syndrome” to describe individuals with excessive vertical growth of the maxilla\(^9\). These are some of the various terms that have been developed to describe vertical growth patterns of the face.
It is important to have a thorough understanding of the dental and skeletal characteristics associated with the hyperdivergent, normal, and hypodivergent growth patterns, as orthodontic treatment will vary accordingly. The dental and skeletal characteristics of the hyperdivergent and hypodivergent patients have been described throughout the orthodontic literature, with Bjork being one of first individuals to describe these characteristics. He discussed the morphologic characteristics associated with forward (hypodivergent) and backward (hyperdivergent) mandibular rotation during growth. Bjork found that the skeletal and dental characteristics of hyperdivergent subjects include: distal “backward” condylar inclination, straight mandibular canal, antegonial notching, obtuse gonial angle, thin and long symphysis, acute intermolar and interincisal angulation, and long lower anterior facial height. Studies have consistently shown that the only maxillary changes evident in hyperdivergent patients are increased anterior and posterior dentoalveolar heights, which makes the primary issue in the maxilla of hyperdivergent patient’s dentoalveolar, rather than skeletal. Research has also shown that hyperdivergent subjects have a smaller ramus and increased mandibular plane angle. In contrast, the skeletal and dental characteristics of the hypodivergent subjects are opposite of those seen in the hyperdivergent subjects. In the previously mentioned study by Bjork, he reported the following in hypodivergent subjects: forward condylar inclination, curved mandibular canal, acute gonial angle, thick symphysis with pronounced bone apposition, large intermolar and interincisal angulation, and compressed (short) lower anterior facial height.
The Relationship between Facial Divergence and the Musculature

The morphology of the face is primarily determined by genetics, but growth and development of the craniofacial complex can be influenced by functional demands. Controversy exists in the literature as to whether or not the genetically determined facial morphology determines the muscle strength or vice versa. The correlation between bite force and the vertical facial pattern has led to the theory that the strength of the masticatory muscles partly influences the form of the face. According to Kiliaridis, increased strength and activity of the masticatory muscles may influence the growth of the craniofacial complex, thus producing faces with similar morphologic features (i.e. hypodivergent subjects), but the same trend is not seen when muscle activity is reduced. Proffit and Fields found that adults with a hyperdivergent growth pattern exhibit reduced biting forces when compared to normal individuals. However, the relationship between bite force and facial pattern appears to be variable in children. Proffit and Fields did not find an association between bite force and mandibular plane angle in children. On the other hand, Ingervall and Minder found a correlation between maximum bite force and mandibular plane angle in females, but the same finding was not seen in males. Garcia-Morales et al found that hyperdivergent children had a lower maximum bite force and a reduced mechanical advantage, which is similar to the relationship reported for adults.

In addition to bite force differing in individuals with increased vertical growth, the size of the masseter muscle is also different. Lione et al used ultrasound imaging to determine the volume of the masseter muscle in growing children, and they found that
the volume of the masseter muscle was significantly smaller in hyperdivergent patients when compared to hypodivergent and normal patients\textsuperscript{18}.

\textbf{Cone Beam Computed Tomography (CBCT) as a tool to evaluate bone density}

The use of cone beam computed tomography has continued to increase in the field of dentistry for numerous reasons such as more compact equipment, lower equipment operational costs, and more importantly the radiation dosage is much lower\textsuperscript{19}. Grey values are typically used to evaluate bone mineral density on CBCT images, but the reliability of this has been questioned\textsuperscript{20}. Lagravere et al reported a linear relationship between actual densities and the HU values (grayscale values) obtained in a CBCT scan and found that the density of materials can be determined by using this this linear relationship\textsuperscript{21}. In addition, a study conducted by Mah et al showed that grey levels in CBCT can be converted in Hounsfield units (HU) by using linear attenuation coefficients\textsuperscript{22}.

\textbf{The Relationship between Cortical Bone Thickness/Density and Facial Pattern}

Cortical bone thickness seems to be dependent on functional demands, although it is also believed that the morphology of the bone is primarily determined by genetics\textsuperscript{12}. The mechanostat hypothesis introduced by Frost suggests that bone adapts to the strains to which it is subjected\textsuperscript{23}. It has been reported that there is a range of strain values that maintain the form and mass of the bone\textsuperscript{24}. The correlation reported between facial pattern and cortical bone thickness could be explained by the relationship between muscular forces and bony adaptations\textsuperscript{12}. An animal study conducted on rats showed that masticatory hypofunction resulted in a significant
decrease in cortical and alveolar bone mineral density. From this study we can conclude that the cortical and alveolar bone of the jaws is affected by the mechanical stresses exerted by the muscles during function\textsuperscript{25}. Furthermore, the thickness and density of the cortical bone could provide information about the forces it experiences.

The relationship between cortical bone thickness and facial divergence has been an area of interest in the orthodontic literature. Tsunori et al examined the mandibles in dry skulls of Asiatic Indians and found thicker cortical bone in short-faced subjects in comparison to their long-faced counterparts\textsuperscript{26}. A similar study was conducted using modern Japanese skulls and they found that the cortical bone around the mandibular first and second molars was thicker in short-faced subjects\textsuperscript{27}. A cross-sectional study using CBCT showed that hyperdivergent subjects have slightly less thick mandibular cortical bone but the results were not consistent\textsuperscript{28}. Horner et al used CBCT to evaluate dentoalveolar cortical bone thickness between hypodivergent and hyperdivergent young adults, and found that cortical bone tends to be thicker in hypodivergent subjects\textsuperscript{29}.

Cortical bone thickness has been related to facial divergence but there has been limited research evaluating the cortical bone density in subjects with different vertical facial types. A recent cone beam computed tomography study conducted by Ozdemir et al showed that adults with a hyperdivergent facial type have less dense buccal cortical bone in the maxillary and mandibular alveolar process\textsuperscript{30}. The palatal bone of the maxilla did not differ between facial types, but it was significantly denser in female subjects when compared to males\textsuperscript{30}.
**Relationship Between Bone Density and Orthodontic Tooth Movement**

It is known that orthodontic forces, which induce tooth movement, provide a mechanical stimulus that results in both modeling and remodeling of the bone\(^3\). Frost describes “modeling” as the process that uses new bone material to form structures, while he describes “remodeling” as the process of skeletal turnover and maintenance throughout life\(^3\). Animal research conducted by Bridges et al demonstrated a significant reduction in alveolar bone density in rats following orthodontic tooth movement\(^3\). Chang et al conducted the first human study to evaluate bone density pre and post orthodontic treatment and found that the alveolar bone density around the teeth decreased by approximately 24% in 7 months of orthodontic treatment\(^3\). However, there has not been a study to date that evaluates whether or not the bone density returns to normal during the retention phase.

**Rationale and Objective**

Orthodontic tooth movement is dependent on both the quantity and quality of the bone. An understanding of the relationship between facial divergence and bone density could provide the clinician with valuable information that may have significant clinical implications. In addition, it is necessary to understand the changes in bone density that may occur with orthodontic tooth movement. The results of this study may help orthodontists to identify patients who are at an increased risk for mini implant failure, increased anchorage loss, or movement of incisors beyond alveolar bone support as a result of decreased bone density.

The orthodontic literature lacks studies that correlate the density of the alveolar and cortical bone with the facial divergence. In addition, there is very little research that
evaluates alveolar bone density pre and post orthodontic treatment. Therefore, the first aim of this study is to quantify the cortical bone density and thickness at the inferior border of the mandible in subjects with different vertical facial types. A second aim of this research is to evaluate the cortical and alveolar bone density pre and post orthodontic treatment in subjects with different facial types.

**Hypothesis and Specific Aims**

**Specific Aim 1:** To measure the cortical bone density and thickness in three different facial types prior to orthodontic treatment

**Null Hypothesis for Specific Aim 1:** There will be no difference in the cortical bone density and thickness in relation to facial type.

**Specific Aim 2:** To measure the cortical bone density and thickness and alveolar bone density pre and post-orthodontic treatment in three different facial types

**Null Hypothesis for Specific Aim 2:** There will be no difference in the cortical bone density and thickness or the alveolar bone density of patients pre and post treatment in relation to facial type.

**Material and Methods**

CBCT images of 296 patients who were seeking orthodontic treatment from a private practice in Miami, Florida were retrospectively analyzed for this study and an institutional review board exemption was obtained. All CBCT scans were made using the iCAT Next Generation (Imaging Sciences International, Hatfield, Pa) CBCT unit. A standardized protocol of the iCAT for the extended (17 x 23 cm) field of view (FOV) with
0.3 mm slice thickness, 26.9 seconds acquisition time was used. All scans were saved in the DICOM-3 format and were evaluated using a third party CBCT reconstruction software InVivo5.0 (Anatomage, San Jose, California). The exclusion criteria were 1) cases with congenitally missing teeth, 2) CBCT scans showing supernumerary teeth, enlarged/cystic follicle or any other pathology, 3) Systemic disease affecting bone of the patients, and 4) Extraction of teeth for orthodontic purposes. The volumes were loaded into Invivo5 (Ver. 5.3) (Anatomage Inc, CA) software and a single examiner reviewed all of the scans independently. The investigator reviewed the images on a split screen dual display monitor (HP Compaq LA2205wg) under standardized conditions of ambient light and sound. The investigator had the full capability to evaluate the volumes and manipulate contrast and histogram. Once the scans were imported into the reconstruction program, all scans were aligned parallel to the Frankfort's horizontal plane.

Cephalograms generated from pre-treatment CBCT scans were imported and traced in Dolphin to determine the vertical growth pattern. Angular and linear measurements were made on the images to group the patients according to the following different vertical facial types: hypodivergent, normodivergent, and hyperdivergent. Categories were determined using the following cephalometric measurements: 1) Facial height index [the ratio of the posterior facial height to the anterior facial height using the measurements of sella (S) to gonion (Go) divided by the distance of nasion (N) to menton (Me),] 2) Mandibular Plane Angle [the angle between the anterior cranial base (sella to nasion SN) and the mandibular plane (formed from menton to gonion (Me-Go)), and 3) FMA [the angle between Frankfort Horizontal (porion
to orbitale) and the mandibular plane (formed from menton to gonion)]. For the facial height index, a ratio of <61%, 61% to 69%, >69% indicated increased, normal, and decreased facial heights, respectively. With regards to MP-SN, angles of <21°, 21° to 29°, >29° indicated decreased, normal, and increased facial heights, respectively. With regards to FMA, angles of <27°, 27° to 37°, >37° indicated decreased, normal, and increased facial heights, respectively. If two out of the three measurements did not indicate the same group, or if the values were borderline, then those images were excluded from the study. Within each vertical growth pattern the scans were further divided on the basis of the age and sex into four groups: Group 1: growing male (<16 yrs of age); Group 2: growing female (<16yrs of age); Group 3: non-growing male (>16 yrs of age); Group 4: non-growing female (>16yrs of age).

A reconstructed panorex was used to identify the center of the mental foramen and the corresponding coronal sections were used to measure the thickness and density of the inferior cortex of the mandible and the alveolar bone density at the level of the mental foramen (Figure 1).
The thickness of the inferior cortex of the mandible was measured by drawing a line from the inner to the outer cortical plate (Figure 2). The density was measured by using the Hounsfield unit (HU) equivalent pixel intensity value (PIV) scale in the software program. To standardize the area of the density measurement a 2x2 mm area was selected in the inferior cortex of the mandible for each image (Figure 3).
For the second aim of this study, images from 47 patients with pre and post orthodontic treatment CBCT scans were used. The inferior cortical bone thickness and density were measured pre and post orthodontic treatment as previously described. The same methods used for the first aim were used to standardize the slice for the alveolar bone density measurements. The location of the density measurement within the slice was standardized between pre and post scans by drawing a line from the top of the alveolar crest downward 10mm on the pre treatment scan. Then, a second line was drawn from the inferior border of the mandible to this 10mm mark. This value was recorded. The same cross section was found in the post treatment scan for each patient, and then a line of the previously recorded length was drawn upward from the inferior cortical border. This ensured that the alveolar bone density measurement was recorded at the same location in pre and post scans and prevented incorporation of any
bony changes that may have occurred at the alveolar crest during orthodontic treatment. The alveolar bone density was measured in the same manner as the inferior cortical density at the aforementioned height (Figure 4)

![Figure 4: Coronal section showing measurement of alveolar bone density](image)

To test the intraexaminer reliability, 20 randomly selected scans were measured 4 weeks later by the same person for inferior cortical bone thickness and density and alveolar bone density.

**Statistics**

Simple descriptive statistics were used to summarize the outcomes. Mean, standard deviation, percentile distribution and confidence interval were computed for inferior cortical thickness and pixel intensity value in males (growing and non growing) and females (growing and non growing). Inter-examiner reliability was computed by Cronbach alpha values. D'Agostino & Pearson omnibus normality test was used to examine the normality of the data distribution. The inferior cortical thickness and pixel
intensity values for hypodivergent, hyperdivergent and normodivergent in growing males, growing females, non-growing males and non-growing females were normally distributed. One-way ANOVA was used to determine the significance between the different sites measured. Tukey’s test was used for multiple comparisons between the groups. The alveolar bone density pre-treatment and post-treatment were not normally distributed and non-parametric test was done for alveolar bone density outcome. All statistical tests were two sided and a $P$ value of $<0.05$ was deemed to be statistically significant. Statistical analyses were computed using Graph Pad software (La Jolla, CA, USA).

**Results**

A total of 296 patients were included in the study. The hypodivergent group included 23 growing males (14 years and 6 months), 16 growing females (14 years and 5 months), 25 nongrowing males (30 years and 2 months), and 25 nongrowing females (30 years and 5 months). The normal group included 28 growing males (14 years and 6 months), 24 growing females (14 years and 4 months), 26 nongrowing males (24 years and 2 months), and 25 nongrowing females (31 years and 3 months). The hyperdivergent group included 26 growing males (14 years and 6 months), 25 growing females (14 years and 8 months), 27 nongrowing males (28 years and 11 months), and 26 nongrowing females (29 years and 9 months).

The cortical bone thickness was significantly greater in the male hypodivergent subjects ($4.43 \pm 0.86$mm) when compared to the hyperdivergent subjects ($3.915 \pm 0.72$mm) (Figure 1). Hypodivergent females had increased bone thickness when
compared to the hyperdivergent and normal subjects, but it was not statistically significant (Figure 2).

The cortical bone thickness between males and females was also compared in matched categories of facial type. There was no difference in the bone thickness between males and females in matched categories of facial type (Figure 3). The cortical bone thickness was also compared in growing and nongrowing patients in matched categories of facial type. In males, the bone thickness increased in all groups after 16 years of age. However, the bone thickness in adult hypodivergent males (4.763 ± 0.81mm) was significantly higher than the growing hypodivergent males (4.07 ± 0.77mm) (Figure 4). In females, there was no significant difference between growing and nongrowing subjects in matched categories of facial type (Figure 5).
The cortical bone quality (density) was increased in the hyperdivergent (1732 ± 123.5 PIV) and normal subjects (1682 ± 143.5 PIV) when compared to the hypodivergent subjects (1615 ± 132.6 PIV) (Figure 6). In females the cortical bone
quality (density) was significantly greater in the hyperdivergent subjects (1823 ± 121 PIV) when compared to the normal (1756 ± 135 PIV) and hypodivergent subjects (1708 ± 121.4) (Figure 7).

When comparing the bone quality in males and females of matched facial types, females had higher bone quality when compared to males in all categories (Figure 8).
The bone quality was significantly higher in all groups of adult male patients when compared to the matched categories of growing males (Figure 9). The bone quality was also significantly higher in all groups of adult female patients when compared to the growing subjects (Figure 10).

Figure 12: Females have increased bone quality when compared to males

Figure 13: Bone density is significantly higher in all groups of adult male individuals

Figure 14: Bone density is significantly higher in all groups of adult female individuals
For the second aim, pre and post treatment scans for 47 patients were included (13 hypodivergent, 24 normal, 13 hyperdivergent). The cortical bone thickness and density did not change with orthodontic tooth movement (Figure 11 and 12). The results of this aim further confirmed that hypodivergent individuals have the thickest cortical bone and hyperdivergent individuals have the densest bone.

The alveolar bone density decreased in all facial types with orthodontic tooth movement. However, due to the small sample size the results are not statistically significant (Figure 13).
Discussion

To our knowledge, this is the first study that has evaluated mandibular cortical bone thickness and density at the inferior border of the mandible, in three groups of orthodontic patients with different vertical facial types, using CBCT. It is also important to note the large sample size that was used for this study, which allowed us to segment each facial type into 4 groups based on age and sex.

Our null hypothesis was rejected for the first aim, as there was statistically significant variation in the cortical bone thickness and density within the vertical facial types. Masumoto et al, used spiral CT to examine the molar region of 31 Japanese male skulls, and found that the buccal, basal, and lingual cortical bone was thicker in short-faced subjects when compared to average or long-faced subjects. Our study confirmed that the inferior cortex of the mandible is significantly thicker in hypodivergent males compared to hyperdivergent males, and it is numerically higher in hypodivergent
females but the difference in comparison to hyperdivergent females was not significant. A study of 39 male Asiatic Indian skulls evaluated the cortical bone thickness of the mandible and found thicker cortical bone in short-faced subjects on the buccal of all regions and lingual of the molars. However, the basal portion of the cortical bone was only increased in the lower incisor region of the short-faced group when compared to the long faced-group\textsuperscript{26}. The results of this study are in contrast to our findings, which found the basal portion of the cortical bone to be significantly thicker in hypodivergent males. Swasty et al evaluated 111 CBCT’s and found that the long-face subjects had slightly thinner mandibular cortical bone when compared to short-face and average subjects, but the statistically significant sites were variable\textsuperscript{28}. They also found that there were no statistically significant differences in cortical bone thickness between males and females\textsuperscript{28}, which is in agreement with the results of our study. Swasty et al used CBCT to evaluate how the mandibular cortical bone thickness changes with age, and the results showed that subjects who are 10 to 19 years old have thinner cortical bone when compared with all older age groups\textsuperscript{34}. In addition, they found that the mandible continues to mature through 40 to 49 years of age and then decreases in thickness after this period\textsuperscript{34}. The results of our study confirmed that the inferior cortex of the mandible is thicker in nongrowing males when compared to growing. However, only the hypodivergent nongrowing males had statistically significant thicker cortical bone when compared to hypodivergent growing males. The same trend was not seen in growing and nongrowing females.

There is limited orthodontic research, which correlates cortical bone density with the vertical facial type. Ozdemir et al conducted the only study that evaluated alveolar
cortical bone density in adult patients with different vertical facial types, and they found that hyperdivergent patients tend to have less dense buccal cortical bone in both the maxillary and mandibular alveolar processes when compared to hyperdivergent and normodivergent patients. However, the results of our study do not agree with these findings as we found that hyperdivergent and normal males have denser bone when compared to hypodivergent males, and hyperdivergent females have the densest bone when compared to patients with other facial types. When comparing bone density between males and females, Ozdemir et al found that the alveolar cortical bone of the palate is denser in women than in men, but there was no difference in buccal cortical bone. Our study evaluated the cortical bone density at the inferior border of the mandible, and surprisingly we found that females have more density when compared to males in all vertical facial types. We also compared the bone density between growing and non-growing males and females, and found that the nongrowing group has increased bone density in both sexes. Newly formed bone is less mineralized and the process of secondary mineralization continues for years after growth is complete. Once bone is formed the mineral content increases to about 70% of full mineralization within a month, but the remaining 30% of the mineralization is attributed to secondary mineralization, which can take years to complete. This could explain why non-growing males and females have increased bone density when compared to growing males and females.

The sample size for our second aim was small, making it difficult to draw definitive conclusions from the results. However, the cortical bone density and thickness were not affected by orthodontic treatment, and there was no statistically
significant difference amongst the facial types between pre and post treatment. These results were expected because orthodontic tooth movement should not affect the inferior cortical bone of the mandible. However, we did see a decrease in the alveolar bone density, but due to the sample size we cannot consider it statistically significant. This finding is in agreement with the study by Chang et al, which found a 24% reduction in bone density around maxillary anterior teeth after orthodontic treatment with the use of CBCT. The sample size of this study was also quite small (8 patients), but 144 areas were analyzed pre and post orthodontic treatment. It appears that there is an immediate reduction in the bone density following orthodontic tooth movement, but whether or not the bone density returns to pre treatment values is still in question.

**Conclusions**

1. Females have higher bone density than males in all of the three different facial types
2. Adults (both males and females) have better bone quality (bone density) than growing individuals
3. Hyperdivergent individuals (males/females) have the best bone quality (bone density) among the different facial types
4. Hypodivergent individuals (males/females) have more bone quantity (more bone thickness)
5. Cortical bone thickness and density are not affected by orthodontic tooth movement

6. Alveolar bone density appears to decrease with orthodontic tooth movement
References


