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3D treatment changes in alveolar bone thickness around the mandibular incisors

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THESIS

3D TREATMENT CHANGES IN ALVEOLAR BONE THICKNESS AROUND THE MANDIBULAR INCISORS

by

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DEDICATION

I would like to dedicate this work to my mother Dr. Debra George, my father Dr. Raymond George Jr and my grandfather Dr. Raymond George Sr.

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ABSTRACT

The limit of mandibular incisor correction is dependent on the amount of crowding and the incisor position within the mandibular alveolar bone. Moving teeth outside of the alveolar bone can have detrimental effects on the periodontium. The purpose of this study was to evaluate in 3D incisor angulation, B point, root apex position changes, facial and lingual cortical bone thickness at four levels on each tooth, and 2D lower incisor angulation to the true vertical plane and intercanine width changes. Pre- and post-treatment Cone Beam Computed Tomography images of 67 orthodontic patients were included from the BU repository. 276 mandibular incisors and 138 canines were evaluated. A mandibular plane was used as a horizontal reference plane. 3D measurements of angular changes in apex to constructed Menton plane for all four lower incisors increased by a statistically significant amount. ($p<0.0001$) Intercanine width ($p=0.0032$), arch length discrepancy ($p<0.0001$) incisor angulation for each incisor also showed statistically significant differences (mean change 2.3°, mean $p=0.009$). Changes in L1-NB were also found to be statistically significant ($p < 0.005$). Incisor bone

thickness changes were statistically significant. Lingual bone change in LL1 at point A, was –0.18 mm, p=0.0072: at point B, -0.38, p<0.0001: at point C, -0.56, p<0.0001: at apex point -0.65 mm, p<0.0001. Similar lingual bone thickness changes were noted for all incisors. The results show that lingual bone loss increased from superior reference point (A) to apex, suggesting that roots are tipped around the center of resistance.

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LIST OF ABBREVIATIONS

BU .... Boston University

CBCT .... Cone Beam Computed Tomography

IMPA... Incisor Mandibular Plane Angle

LR1 .... Lower right central incisor

LR2 .... Lower right lateral incisor

LL1.. Lower left central incisor

LL2.. Lower left lateral incisor

LR3 .... Lower right canine

LL3.. Lower left canine

CEJ .... Cemento-enamel junction

MP.. Mandibular plane

INTRODUCTION

Well-aligned lower incisors are an important factor in considering the success of orthodontic treatment. Aligned incisors are more esthetic and a crowded lower arch is a common chief complaint from patients seeking orthodontic treatment. Well aligned lower incisors can affect treatment planning aspects such as overjet, overbite and maxillary incisor position. When the lower incisors are ideally placed in relation to the maxillary incisors, anterior guidance can allow the TMJ to move so the posterior teeth can disclude. The position of the incisors in an anteroposterior position can also affect esthetics by the fullness of the lips.[1]

Crowding of mandibular incisors is a critical issue in orthodontic treatment methods, prognosis and retention and can also be a limiting factor when planning orthodontic treatment. The treatment decision of extraction vs non-extraction is greatly influenced by the extent of crowding and the relationship between bone and incisor position.[2] Howe et al[3] defined dental crowding as a disparity in the relationship between tooth size and jaw size which results in crowding and rotation of teeth. In their study, the subjects with more crowding had smaller dental arch dimensions than the subjects with less crowding.

Some cases tend to be "borderline" and can be treated with or without extractions. These borderline patients need to be examined to estimate the possible impact of treatment on facial profile, smile esthetics, stability and other factors[4]. In nonextraction cases, interproximal reduction can be used to reduce tooth size and help eliminate crowding.[5,6] Another way to treat a crowded nonextraction case would be to procline or expand the teeth.[7]

A study by Claduio et al[4] examined intercanine width changes in extraction and nonextraction cases. In the extraction group, an increase of 1.4 mm was found in the mandibular intercanine width, which can be explained by the distalization of the canines into a wider part of the dental arch during canine retraction. In the nonextraction group, the mandibular intercanine width increased by 1.2 mm. Arch width constriction over time is a normal physiological process that can occur. Little et al[8] concluded that arch “development” usually fails and the dental arch tends to return to pretreatment size and shape.

Lower incisors can be moved anteriorly, posteriorly and transversely by bodily movement and tipping. To evaluate how lower incisors move during treatment, sequential sagittal cephalograms are taken and mandibular incisor position relative to mandibular plane and other cephalometric parameters are measured. The lower incisor should be moved with care due to the limited capability of the alveolar bone to withstand changes that occur as a result of tooth movement.

The inclination also affects the lower incisor's stability due to the tooth’s position in the bone;[9] when the incisors are within cortical bone there is less risk of relapse compared to when they are out of bone or at their biological limit. Excessive inclination can cause recession of the gingival margin or bone dehiscences. Insufficient angulation of mandibular incisors can cause fenestrations. Ten Hoeve and Mulie[10] studied tooth movement in adolescent patients who underwent orthodontic treatment using the Begg technique by using cephalometric radiographs and laminagraphs. They concluded that when the root contacts the lingual cortical plate of the symphysis, tooth movement ceases but if greater forces are applied, then perforations or dehiscences can happen.

The "washboard" effect is sometimes seen along the labial aspect of the lower anterior teeth. This is possibly a result of proclining the teeth to reduce overjet or relieve crowding by arch lengthening. This effect can result in bone loss or root resorption as the teeth contact the cortical bone. Washboard appearance is often seen in compensated Class III malocclusions and Class II division II malocclusions.[11]

The limit of incisor correction is not only dependent on the amount of crowding but also the incisor position within the mandibular alveolar bone. Sarikaya et al[12] examined the changes in alveolar bone thickness due to retraction of anterior teeth. Their findings showed that reduced alveolar bone thickness followed the direction of tooth movement. The long-term consequences of alveolar bone loss and dehiscences are unknown; however, new bone formation may be expected after several months. These risks should be disclosed to patients and care should be given when retracting incisors by using light forces and also in the long-term use of activators and other orthopedic appliances.

A study done by Artun et al[13] examined the periodontal status of mandibular incisors following excessive proclination. They examined the clinical crown heights before and after treatment as well as the visible plaque index, gingival bleeding index, probing pocket depth and length of supracrestal connective tissue attachment. Results showed that excessive proclination of the mandibular incisors may lead to retraction of gingival margins, particularly if the alveolar housing is thin. The development of bone dehiscences and some gingival recession will most likely happen as a result of excessive proclination.

Wainwright[14] investigated the histological effects of faciolingual tooth movement with particular regard to damage and other tissue responses, as the root apex was moved through cortical plate and then back into the cancellous bone. Results showed that once the cortical plate was penetrated, the buccal root surface became devoid of cortical bone. The study also showed that teeth moved back into cancellous bone 50% faster than when moved through the cortical plate. This implies that the density of the bone affects the rate of tooth movement.

Uysal et al[2] examined the relationship between mandibular anterior bony support and incisor crowding by using cone beam computed tomography (CBCT). A labial positioned incisor can have less bone support at the labial aspect than a lingual positioned incisor. Results showed that the thickness of alveolar bone may be an etiologic factor for incisor crowding. Decreased thickness of alveolar bone is a result of incisor crowding because rotated incisors have a reduced labiolingual dimension in the surrounding bone due to the oval shape of the roots.

Wehrbein et al[15] examined dry human mandibles from deceased adults that had undergone orthodontic therapy. The study examined the tooth movements of lower incisors and analyzed the alveolar bone and symphysis using scanning electron microscopy. Their conclusions were that in cases of a narrow and high symphysis a reduced bone support labial and lingual to the root would already be present before treatment. They also found that sagittal incisor movement and correction of rotations seem to be risks for progressive lingual and labial bone loss. Tsunori et al[16] examined the relationship between structures of the mandibular body and facial type.

Their results showed that buccal cortical bone was thicker in short-faced individuals than average and long-faced groups.

Garlock et al[17], evaluated the marginal alveolar bone in the anterior mandible; by examining CBCTs of pre and post treatment patients with non-extraction treatment. This study used lateral cephalograms constructed from CBCTs and traced the mandibular incisor area as well as the Incisor Mandibular Plane Angle (IMPA) on pre and post treatment scans. They then measured bone thickness and height three dimensionally. Results showed that a thinner mandibular symphysis at the tooth apex was associated with an increase in facial vertical bone loss. Also, the authors showed that thinner pretreatment cortical bone at the apex level was correlated with greater facial vertical bone loss.

Sagittal cephalograms are used in orthodontics to analyze patients' skeletal and dental relationships that cannot be assessed clinically. Some points placed are strictly skeletal and others are dental, but some points are dentoalveolar landmarks that can be influenced by the growth of a patient or bone remodeling during orthodontic treatment. Al-Abdwani[18] examined whether A point or B point changes as a result of orthodontic tooth movement. They found that A point position will change and there is a possibility of B point change in the horizontal plane but not the vertical plane. The results they found were statistically significant, but clinically irrelevant.

Historically, sagittal cephalograms have been used to measure incisor inclination; however, this is not the most accurate method to determine the relationship and the association between incisors and their surrounding alveolar bone due to overlap of structures. Cone beam computed tomography (CBCT) is a high-resolution three-dimensional imaging technique that is better able to show fine details that two-dimensional plane film cannot. It has been shown to be one of the more reliable tools to locate impacted teeth, pathology and it can reveal other details about tooth and bone morphology.[19] It can also display accurate vertical and buccal-lingual dimensions of the mandible without inherent magnifications that are found in standard plane cephalometric radiographs.[17] However, when comparing CBCTs with conventional radiographs, the CBCT's disadvantage is that it has a higher exposure to radiation doses.

Many orthodontic practices are now using CBCT as a regular part of their routine diagnostic records for their patients, and the use of CBCT imaging in orthodontics will likely increase in the future. Some examples of the advantages that CBCTs offer are: locating unerupted teeth, external root resorption, airway volume assessment, a guide for temporary anchorage device (TAD) placement, surgical treatment planning as well as evaluating clefts and other craniofacial anomalies.[19] Menezes et al[20] evaluated the precision, reproducibility and accuracy of bone crest level measurements from CBCT cross sections. It was found that the measurements were good at a variety of voxel sizes. There was accuracy at 0.2 mm and 0.3 mm voxel sizes, but in the mandibular incisor region a 0.4 mm voxel size is needed for accuracy. [20]

Patcas et al[21] examined the accuracy of CBCT in the area of the bony covering of the mandibular anterior teeth. They found that CBCT is an appropriate tool for linear intraoral measurements, however the voxel size does affect the precision of the measurements. Choosing a different voxel size will limit the agreement of different resolution protocols. Additionally, soft tissues can impose a restriction on the accuracy of CBCT data when determining bony landmarks. Lastly there is also a risk of overestimating fenestrations and dehiscences on CBCT radiographs. The voxel size limits indicate that an alveolar bone thickness of 1 mm might be missed completely, even in a high-resolution protocol.

The aim of this study is to evaluate alveolar bone thickness changes following orthodontic treatment in relation to lower incisor angulation and position changes. Changes in buccal and lingual alveolar thicknesses at four different levels on each lower incisor and mandibular canines will be evaluated.

MATERIALS AND METHODS

This study was approved by The Boston University Institutional Review Board (IRB #H-36072). Using the BU repository [BU IRB H32515], a database of 2500 patients, subjects were initially screened for having both pre and post treatment CBCT scans and nonextraction orthodontic treatment. Of the total 69 subjects were identified as fulfilling these initial inclusion criteria. All CBCT scans were taken at a private orthodontic practice in natural head position[22]. Inclusion criteria were all classifications of malocclusions, fully erupted permanent dentitions including the second molars, and nonextraction orthodontic treatments. Exclusion criteria were any evidence of pathology, significant medical or dental history (use of bisphosphonates or bone altering medications or diseases), significant facial asymmetries, and poor image quality and extraction treatment or missing permanent teeth in the mandibular arch. To the best of our knowledge, no subjects had prior orthodontic treatment.

After screening the scans, 2 were eliminated due to wrong input of date scan and birthdate. This made for a total of 67 subjects, 18 females and 49 males with a mean age at the time of the initial scan of 20 years old, (Range: 12 - 60 years old). A total of 268 incisors and 134 canines were examined. A mean treatment time was 1 year and 6 months (Range 8 months - 3.5 years). Sample size calculation was performed with G power (Faul, F., Erdfelder, E., Lang, A.-G., & Buchner, A. (2007). G*Power 3: A flexible statistical power analysis program for the social, behavioral, and biomedical sciences. *Behavior Research Methods*, *39*, 175-191.). According to the calculations for a two-tailed test with a significance of 0.05, 128 subjects were needed. However, due to the limitations of inclusion and exclusion criteria only 67 scans were available. Depending on the results a post-hoc power analysis was planned.

The pretreatment and posttreatment CBCT scans were imported into Dolphin Imaging software (Dolphin Imaging, Chatsworth, CA) for analysis. Sagittal cephalograms were reconstructed from CBCT scans to measure IMPA and L1-NB. Landmarks that were used to determine IMPA and L1-NB were: Nasion, mandibular incisor tip and apex, labial and lingual gingival borders, B point, gonion, gnathion and Menton, (Table 1). Intercanine and intermolar widths were measured on the three-dimensional CBCT images for the canines from canine cusp tip to canine cusp tip and for the molars from central fossa to central fossa. If there was attrition or restorations were present, a best estimate point was placed. Arch length discrepancy was also measured using the Lundstrom[23] technique to determine if there was a difference between the space required and space available.

The pre-treatment and post-treatment CBCT were imported into Mimics Software Version 20.0 (Materialized NV Leuven Belgium) to create three-dimensional reference planes, place three-dimensional landmark points, and make measurements. Images were obtained on an i-CAT CBCT machine (Imaging Sc. Int., Hatfield, PA, USA) set at 120 kVp and 5 mA to produce an image with a 0.3mm voxel size. A three-dimensional mandibular plane (Figure 1) was created by using the right and left lingula and midpoint of the genial tubercle.[24,25] A second reference plane was made by placing a point on Menton and having the plane be perpendicular to the mandibular plane to be able to make linear measurements from each lower incisor. (Figure 2).

In order to determine the three-dimensional incisor angulation for each lower incisor, three points were required: incisor tip, incisor apex and mesial point. The incisor tip point was placed between the mesial and distal heights of contour and buccal and lingual borders. The CEJ point was placed at the deepest point of the curvature along the CEJ on the sagittal view. The apex point was placed by using the long axis of the tooth using the CEJ and incisor tip points. If the root had a dilaceration the apex point was placed along the long axis and not on the curved portion of the root. A mesial point was placed on at the crestal bone height mesial to the incisor being examined. By using the incisor tip, incisor apex and mesial point, a long axis of each tooth was generated. A three-dimensional incisor angulation angle was measured from the three-dimensional mandibular plane and the long axis plane of each lower incisor. Another landmark that was also determined for each lower incisor was Down's B point, the most concave point on the mandibular symphysis.

To make bone thickness measurements along a lower incisor reference points needed to be determined. To create more reference points, the CEJ and incisor apex points were copied and transferred to 3-Matic software. This software was used to section the root length into equal parts. The first part was half the distance between the CEJ and apex points: this point was named point B. Similarly, a point between CEJ and point B was placed at exactly half the distance creating point A and another point between point B and apex to create point C. There were a total of 5 points equally spaced: CEJ, point A, point B, point C and apex, (Figure 3). Points A, B and C were then transferred back to Mimics to serve as reference points to measure the bone width. This process was done for all four lower incisors in both pre and post treatment scans.

Linear measurements were made from the long axis point to the buccal or lingual point. For example, in Figure 3, LL2 point A was measured in mm to LL2 A-Buccal and to LL2 A-Lingual. This was done for each point for buccal and lingual, for each lower incisor for pre and post treatment scans. Also, a linear measurement from Down's B point to Menton plane was determined. The root apex to Menton plane was also measured. A linear measurement was made from CEJ to mandibular plane to measure if a tooth was extruded or intruded.

For all measurements, statistical analysis was performed using SAS 9.4 software (SAS Institute, Cary, NC). Paired t-tests were performed, and the level of significance was set at $p=0.05$. Pearson correlation statistics and regression analyses were also performed to determine if there was any correlation between incisor and canine movement or changes in alveolar buccal and lingual bone thickness. After analyzing 22 subjects, 50% of the subjects were re-analyzed to determine intraexaminer reliability with intraclass correlation.

Landmark	**Description**
Nasion	Located at junction of nasal and frontal bones
Mandibular incisor tip	Most protruding point of tip
Mandibular incisor apex	Most protruding point of apex
Labial gingival border	Most anterior point of mandibular symphysis bone at the border of the mandibular incisor
Lingual gingival border	Most inferior point of the mandibular symphysis bone at the border of the mandibular incisor
Down’s B point	The deepest concavity anteriorly on the mandibular symphysis
Gonion	The most posterior, inferior point on the mandibular angle
Gnathion	The most anterior, inferior point on the mandibular symphysis
Menton	The most inferior point on the mandibular symphysis

Table 1: Summary of 2D landmarks featured in our analysis

Landmark	**Description**
LL1 apex	Using the long axis of the tooth using LL1 tip and CEJ – most inferior point
LL1 tip	At the incisal edge, between the mesial and distal height of contours as well as the buccal and lingual borders
LL1 mesial	The highest point on the alveolar crest mesial to the LL1
LL1 CEJ	At the deepest curvature and in line with the LL1 tip
LL1 B point	The point of deepest concavity anteriorly on the mandibular symphysis
LL1 A buccal	Perpendicular to the long axis of the tooth, perpendicular to A point on the buccal bone surface
LL1 A lingual	Perpendicular to the long axis of the tooth, perpendicular to A point on the lingual bone surface
LL1 B buccal	Perpendicular to the long axis of the tooth, perpendicular to B point on the buccal bone surface
LL1 B lingual	Perpendicular to the long axis of the tooth, perpendicular to B point on the lingual bone surface
LL1 C buccal	Perpendicular to the long axis of the tooth, perpendicular to C point on the buccal bone surface
LL1 C lingual	Perpendicular to the long axis of the tooth, perpendicular to C point on the lingual bone surface

LL1 apex buccal	Perpendicular to the long axis of the tooth, perpendicular to apex point on the buccal bone surface
LL1 apex lingual	Perpendicular to the long axis of the tooth, perpendicular to apex point on the lingual bone surface

Table 2: Summary of 3D landmarks featured in our analysis for LL1

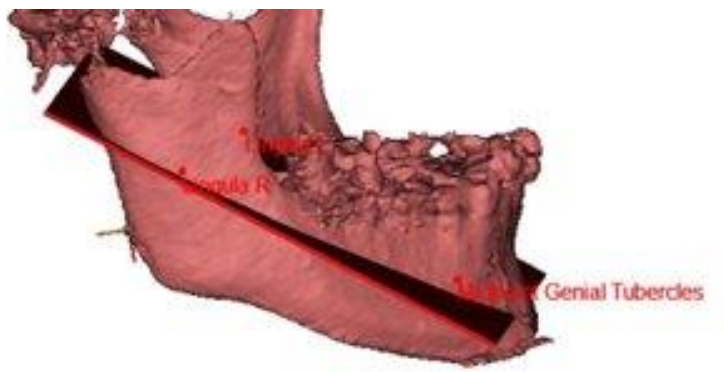

Figure 1: Three-dimensional mandibular reference plane using the right and left lingula and midpoint genial tubercle.

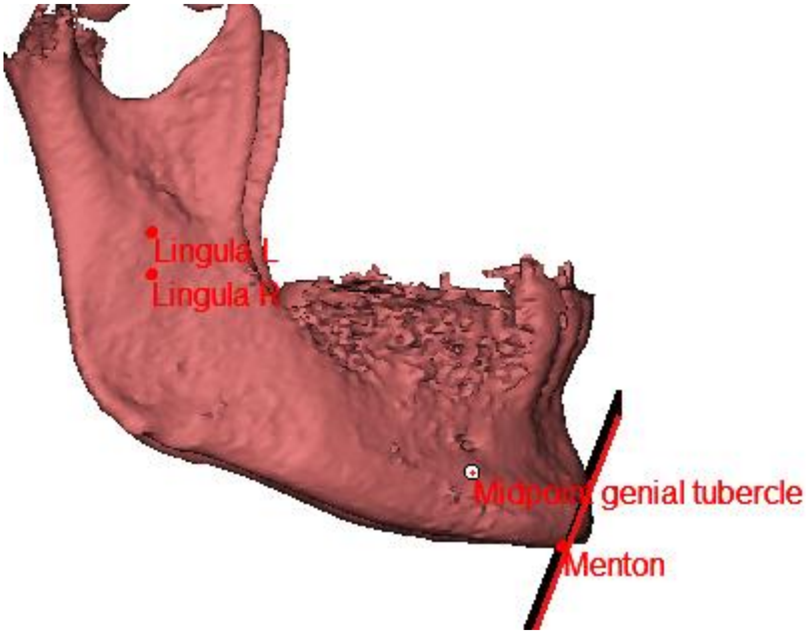

Figure 2: Constructed Menton plane.

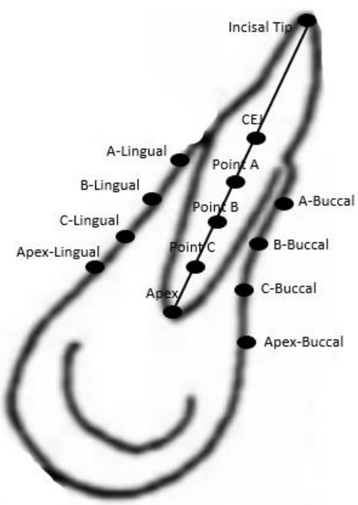

Figure 3: Five points along the lower incisor long axis with buccal and lingual bone points

RESULTS

A total of 268 mandibular incisors and 134 mandibular canines were evaluated. For measurement of intraexaminer reliability, ICC results showed a high reliability of the measurement method (Cronbach's alpha = 0.83) Intercanine width increased 0.63 mm +/- 1.68 mm (p=0.0032) Intermolar width was not statistically significant and showed a decrease of 0.15 mm +/- 5 mm (p=0.82). Arch length discrepancy was statistically significant (p<0.0001) proving that any crowding or spacing present in the pretreatment scans were eliminated in post treatment scans. Changes in L1-NB distance were statistically significant between pretreatment and posttreatment records (p=0.005); and showed an increase of lower incisor protrusion by 0.6 mm +/- 1.68 mm (Table 3).

Three-dimensional incisor angulation for each lower incisor was also statistically significant (Table 4). By using Menton plane we were able to determine if any linear changes were seen in root apex position for each incisor and if Downs B point changed as well. B point changes were not statistically significant, but the root apex point for each lower incisor to Menton plane measurement increased (Table 4). Lower incisor extrusion was found to be statistically significant (p=0.02), (Table 4). For pretreatment and posttreatment values see Appendix A.

Incisor bone thickness changes were statistically significant on the lingual but not on the buccal sides of the teeth (Table 5). For pretreatment and posttreatment means please see appendix 1. The data showed that there was a pattern of increased bone loss from point A to apex point on the lingual side of each lower incisor. Buccal and lingual bone thickness measurements were added together to determine the total amount of bone loss between pre and post treatment. For all points on all four lower incisors, there was a statistically significant difference between total bone width (from buccal point to lingual point) before and after treatment (Table 6).

Mandibular canine IMPA showed an increase of 2.14° +/- 1.5° (P=0.007) for LL3 and 1.52° +/- 6.3° (p=0.5) for LR3 (Table 7). Buccal and lingual bone thickness changes for both lower canines were not statistically significant (Table 8). For pretreatment and posttreatment values are reported in Appendix B.

Pearson correlation coefficients showed that LL1 IMPA is significantly correlated with the difference of bone thickness on the lingual bone thickness of point B, buccal and lingual of point C and the buccal and lingual at the apex between pre and post treatment with the p value of 0.006, <0.0001, <0.0001, 0.0003 and <0.0001 respectively. LL2 IMPA is significantly correlated with the same points as the LL1 at B lingual (p=0.005), C buccal (p=0.01), C lingual (0.0002), apex buccal (0.0027), and apex lingual (<0.0001). LR1 IMPA is significantly correlated with C buccal (p=0.08), C lingual (p=0.0015), and apex lingual (<0.0001). LR2 IMPA is significantly correlated with B lingual (p=0.0016), C buccal (<0.0001), C lingual (p=0.0002), apex buccal (p<0.0001) and apex lingual (p<0.0001). (Table 7). Correlations showed that when angulation (IMPA) increased, there was bone loss on the lingual.

Regression analysis showed that for every one degree in LL1 IMPA there was a 0.027 mm loss of bone at LL1A (p=0.1), 0.03 mm of bone loss at LL1B (p=0.008), 0.02 mm of bone loss at LL1C (p=0.15) and 0.05 mm of bone loss at the apex (p=0.006). One degree in LL2 IMPA change leads to 0.03 mm of bone loss at LL2A (p=0.03), 0.04 mm of bone loss at LL2B (p=0.03), 0.02 mm of bone loss at LL2C (p=0.2) and 0.04 mm of bone loss at LL2 apex (p=0.03). One degree of LR1 IMPA change leads to 0.002 mm of bone loss at LR1A (p=0.08), 0.02 mm of bone loss at LR1B (p=0.08), 0.03 mm of bone loss at LR1C (p=0.03) and 0.08 mm of bone loss at apex of LR1 (p=0.0001). One degree of LR2 IMPA change leads to 0.01 mm of bone loss at LR2A (p=0.3), 0.033 mm of bone loss at LR2B (p=0.015), 0.02 mm of bone loss at LR2C (p=0.03) and 0.01 mm of bone loss at apex of LR2 (P=0.4). (Table 8)

Variable	**T1 (SD)**	**T2 (SD)**	**T1-T2 (95% CI)**	**P value**
2D IMPA	94.8(8.16)	94.4 (8.0)	-0.40 (-1.9 - 1.19)	0.61
Intercanine	26.8 (2.0)	27.4 (1.67)	0.63 (0.21 - 1.04)	0.0032
Intermolar	44.12 (3.58)	44.0 (5.54)	-0.15 (-1.55 - 1.24)	0.82
ALD	-1.85 (2.14)	-0.02 (0.28)	1.82 (1.3 - 2.3)	<0.0001
L1-NB	3.05 (4.05)	3.65 (3.6)	-0.60 (-1.0 - -0.19)	0.005

Table 3: Two-dimensional measurements

		LL1	LL2	LR1	LR2
3D IMPA	Mean difference	1.94	2.5	2.31	2.6
	CI 95%	0.29 - 3.65	0.9 - 2.05	0.58 - 4.05	0.8 - 4.4
	P value	0.022	0.0021	0.0095	0.004
B point to Menton plane	Mean difference	0.23	0.28	0.259	0.17
	CI 95%	-0.27 - 0.75	-0.26 - 0.84	-0.2 - 0.7	-0.42 - 0.76
	P value	0.36	0.31	0.27	0.57
Apex to Menton plane	Mean difference	0.98	1.13	1.05	1.12
	CI 95%	0.53 - 1.4	0.7 - 1.6	0.59 - 1.52	0.64 - 1.6
	P value	<0.0001	<0.0001	<0.0001	<0.0001
CEJ to mandibular plane	Mean difference	0.58	0.53	0.71	0.79
	CI 95%	0.11-94	0.007-1.05	0.26-1.15	0.31-1.26
	P value	0.014	0.05	0.0023	0.0013

Table 4: Three-dimensional measurement

		LR2		LR1		LL1		LL2	
BUCCAL/LINGUAL		**B**	**L**	**B**	**L**	**B**	**L**	**B**	**L**
A	Mean difference	-0.03	-0.32	-0.10	-0.19	-0.09	-0.18	-0.1	-0.29
	CI 95%	-0.15 – 0.14	-0.56 - -0.08	-0.21 – 0.09	-0.32 - -0.07	-0.2 – 0.02	-0.3 - -0.5	-0.24 – 0.04	-0.5 – -0.09
	P value	0.96	0.009	0.07	0.0018	0.11	0.0072	0.16	0.005
B	Mean difference	0.05	-0.34	0.04	-0.46	-0.055	-0.38	-0.03	-0.50
	CI 95%	-0.10 – 0.21	-0.59 - -0.08	-0.07 – 0.17	-0.65 - -0.29	-0.18 - 0.07	-0.57 - -0.2	-0.16 – 0.10	-0.7 - -0.27
	P value	0.49	0.0097	0.47	<0.0001	0.39	<0.0001	0.64	<0.0001
C	Mean difference	0.21	-0.5	-0.008	-0.58	-0.03	-0.56	0.064	-0.51
	CI 95%	-0.009 – 0.4	-0.85- -0.25	-0.21 – 0.2	-0.83 - -0.33	-0.22 – 0.15	-0.79 - -0.32	-0.14 – 0.27	-0.74 - - 0.29

	P value	0.06	0.0006	0.93	<0.0001	0.72	<0.0001	0.53	<0.0001
APEX	Mean difference	0.27	ˉ0.54	0.015	ˉ0.72	0.027	ˉ0.65	0.22	ˉ0.59
	CI 95%	ˉ0.03 – 0.58	ˉ0.89 - ˉ 0.19	ˉ0.25 - 0.27	ˉ1.03 - ˉ0.41	ˉ0.3 – 0.3	ˉ0.93 - ˉ0.35	ˉ0.05 – 0.049	ˉ0.90 - ˉ 0.28
	P value	0.08	0.003	0.091	<0.0001	0.84	<0.0001	0.11	0.0003

Table 5: Buccal and lingual bone measurements

		LL1	LL2	LR1	LR2
A	Mean difference	-0.026	-0.37	-0.3	-0.29
	CI 95%	-0.4- -0.12	-0.6- -0.16	-0.4- -0.2	-0.51- -0.08
	P value	0.0004	0.001	<0.0001	0.008
B	Mean difference	-0.41	-0.52	-0.42	-0.28
	CI 95%	--0.57- -0.25	-0.73- -0.31	-0.6- -0.24	-0.51- -0.06
	P value	<0.0001	<0.0001	<0.0001	0.013
C	Mean difference	-0.57	-0.46	-0.6	-0.35
	CI 95%	-0.76- -0.4	-0.7- -0.23	-0.78- -0.4	-0.60- -0.09
	P value	<0.0001	<0.0001	<0.0001	0.0073
Apex	Mean difference	-0.62	-0.39	-0.67	-0.28
	CI 95%	-0.84- -0.4	-0.66- -0.12	-1.0- -0.33	-0.54- -0.02
	P value	<0.0001	0.005	0.0002	0.031

Table 6: Total bone measurements

Variable	**T1 (SD)**	**T2 (SD)**	**T1-T2 (95% CI)**	**P value**
LL3impa	69.5 (6.7)	71.6 (7.1)	2.14 (0.58 - 3.69)	0.007
LR3impa	70.5 (7.3)	72.0 (7.4)	1.52 (-0.02 - 3.1)	0.05

Table 7: Mandibular 3D IMPA

		LL3		**LR3**	
		BUCCAL	LINGUAL	BUCCAL	LINGUAL
A	Mean difference	0.048	0.85	0.17	0.053
	CI 95%	-0.13 – 0.24	-0.24 – 0.40	-0.02 – 0.3	-0.22 – 0.33
	P value	0.06	0.6	0.05	0.71
B	Mean difference	0.045	0.024	-0.0003	0.08
	CI 95%	-0.12 – 0.21	-0.4 – 0.46	-0.37 – 0.37	-0.9 – 0.2
	P value	0.58	0.91	0.99	0.35
C	Mean difference	0.014	0.006	-0.002	-0.064
	CI 95%	-0.18 – 0.21	-0.48 – 0.5	-0.2 – 0.2	-0.4 – 0.3
	P value	0.89	0.97	0.98	0.73
Apex	Mean difference	0.09	-0.14	0.072	0.04
	CI 95%	-0.15 – 0.3	-0.6 – 0.39	-0.2 – 0.3	-0.32 – 0.4
	P value	0.46	-0.59	0.64	0.83

Table 8: Mandibular canine buccal lingual bone measurements

		diffA buccal	**diffA lingual**	**diffB buccal**	**diffB lingual**	**diffC buccal**	**diffC lingual**	**diffapex buccal**	**diffapex lingual**
LL1 IMPA	Coefficient of correlation	-0.04	-0.18	0.09	-0.33	0.46	-0.53	0.43	-0.66
	P value	0.76	0.13	0.47	0.006	<0.0001	<0.0001	0.0003	<0.0001
LL2 IMPA	coefficient of correlation	-0.12	-0.2	0.13	-0.33	0.31	-0.44	0.36	-0.56
	P value	0.3	0.09	0.27	0.005	0.01	0.0002	0.0027	<0.0001
LR1 IMPA	Coefficient of correlation	-0.25	0.14	0.07	-0.17	0.21	-0.38	0.12	-0.51
	P value	0.04	0.24	0.53	0.16	0.08	0.0015	0.30	<0.0001
LR2 IMPA	Coefficient of correlation	0.19	-0.22	0.22	-0.38	0.46	-0.44	0.50	-0.51
	P value	0.12	0.06	0.071	0.0016	<0.0001	0.0002	<0.0001	<0.0001

Table 9: Correlation of bone measurements and IMPA

		LL1 IMPA	LL2 IMPA	LR1 IMPA	LR2 IMPA
Point A	Parameter estimate	-0.017	-0.03	-0.002	-0.01
	Standard error	0.01	0.02	0.009	0.02
	P value	0.10	0.03	0.8	0.3
Point B	Parameter estimate	-0.03	-0.04	-0.02	-0.033
	Standard error	0.01	0.02	0.012	0.015
	P value	0.008	0.03	0.08	0.03
Point C	Parameter estimate	-0.02	-0.02	-0.03	-0.02
	Standard error	0.014	0.02	0.013	0.02
	P value	0.15	0.2	0.03	0.3
Apex	Parameter estimate	-0.05	-0.04	-0.08	-0.01
	Standard error	0.02	0.02	0.02	0.02
	P value	0.006	0.03	0.0001	0.4

Table 10: Regression table of bone measurements and IMPA changes

DISCUSSION

Successful orthodontic treatment depends on accurate diagnosis and forming a treatment plan that addresses stability. A study done by Motamedi et al[26] examined the stability changes in mandibular intercanine and intermolar distances following cases treated with and without extractions. In their study they examined 20 nonextraction cases, 30 extraction cases and 20 control cases with no treatment. Their results showed that intercanine width for both treated groups increased while the control group decreased. In the nonextraction group, intercanine width increased 1.18 mm from beginning of treatment (26.14 mm +/- 1.75mm) to the end of treatment (27.32 mm +/- 2.04mm). This compares to our study showing that nonextraction treatment of our 67 patients, intercanine width increased by 0.63 mm. Their study also examined the post retention intercanine value, and it showed a decreased (25.88 mm +/- 1.78mm), almost returning to the original intercanine width at the beginning of treatment. Knowing that expanding intercanine width is unstable, it is even more important to consider lower incisor position and its stability during diagnosis and treatment planning.

A study by Gorucu-Coskuner[27] examined non-extraction, IPR and extraction treatment and evaluated the stability in these three groups. They found that there was more relapse in nonextraction treated cases followed by air-rotor stripping (interproximal reduction) than in extraction treatment. For the nonextraction treatment group without the air rotor stripping, the intercanine width, interpremolar width, arch length and arch depth increased, and a significant relapse was seen in the post-retention period.

Yu et al[1] examined the labial/lingual inclination of the lower central incisor and how that angulation correlated with the contour of the adjacent mandibular alveolar bone. They examined 38 patients with mild to moderate malocclusion, with reasonably aligned lower incisors without severe crowding, that had a CBCT taken of the lower incisors and surrounding alveolar bone. Their results showed that as the lower incisor becomes more proclined the lingual alveolar bone becomes thinner. This matches the findings in our study; when the lower incisor becomes more proclined, there is loss of lingual bone thickness. Their linear regression analysis indicated that the alveolar bone contour correlated with the lower central incisor suggesting that the bone is affected by the inclination of the tooth. They concluded that the labio-lingual inclination of the lower incisor and its relation to the alveolar cortical bone should be thought of as a limiting or boundary factor during tooth movement in orthodontic treatment.

In the present study, each lower incisor as well as the lower canines were examined. All four lower incisors were measured for their own incisor mandibular plane angle changes and it was found that all four increased in angulation. In conventional cephalograms, the most prominent incisor is most often measured which may not represent the average position of all four lower incisors[1]. By using CBCT scans in this study, we were able to measure bone thicknesses for each lower incisor individually for their inclination and surrounding alveolar bone.

Our study found that as lower incisor angulation increases, there is bone loss on the lingual side but not the buccal. In our study we created multiple reference points along the long axis of each lower incisor to collect multiple bone thickness measurements. The bone loss was greatest at the apex on the lingual and this trend was seen on all four incisors. By using the Menton three-dimensional plane, we were able to determine linear measurements for each lower incisor. The root apex to Menton plane distance increased after treatment suggesting that as the tooth proclines, the root apex moves lingually. This suggests that the tooth tips around the center of resistance.

Our study also examined whether the change in incisor angulation or position would affect the position of Down's B point. Our results were not statistically significant for Down's B point changes, suggesting that an increase in lower incisor angulation does not affect Down's B point position. Lower incisor protrusion was also examined in this study by using a vertical line of Nasion to Down's B point on a two-dimensional radiograph and results showed that the incisal edge moved labially.

A study undertaken by Thongudomporn et al [28] examined anterior maxillary bone thickness following incisor extrusion and proclination. Although this study was not done in the mandibular area, they found that the alveolar bone thickness after treatment decreased but was not clinically relevant. Our study found that bone loss occurred when lower incisors were extruded and changed when they changed angulation.

The use of CBCTs in the orthodontic field offer many advantages for diagnosis, treatment planning and mechanotherapy. Menezes et al[20] evaluated the precision, reproducibility and accuracy of alveolar crest level measurements on CBCT images with different voxel sizes. CBCT exams were done on 12 dried human mandibles with voxel sizes of 0.2, 0.3 and 0.4 mm. Measurements were done on the CBCTs and the physical mandible. Precision and reproducibility of alveolar bone level measurements were good for all voxel sizes tested, but accuracy was only good for 0.2 mm and 0.3 mm voxel sizes. They concluded that the mandibular incisor region required a 0.4 mm voxel size for bone crest level measurements. In our study we only had 0.3 mm voxel size so this could be a limitation. Study by Sun et al[29] examined the accuracy of CBCT to for detecting naturally occurring alveolar bone dehiscences and fenestrations. They concluded that if there was a severe dehiscence on the CBCT image, there was probably a true dehiscence, but the situation might be as serious as the CBCT showed. They also found that when a fenestration was found on a CBCT, it was a true fenestration about 20% of the time and when there was no fenestration found on a CBCT, there was no actual fenestration present.

Canine bone thickness measurements were not statistically significant in this study. Perhaps this is a limitation due to the curvature of the canines around the arc of the mandible. This could also be true for the linear measurements to Menton plan from the lateral incisors. A possible fix to this problem would be a perpendicular plane to each tooth for measurements Another limitation of this study is not knowing the exact mechanics of each case. The treatment carried out was nonextraction treatment, but it is unknown if braces or clear aligner treatment was carried out or if any IPR was performed in these cases.

This study showed many statistically significant data about lower incisor angulation and bone loss. Even though the bone loss is minimal, there is some clinical significance to this. It is important to look at the lingual bone before orthodontic diagnosis and treatment planning to evaluate thickness.

CONCLUSION

We concluded that there is a significant correlation with lower incisor angulation and alveolar bone thickness. As lower incisors become more proclined, lingual bone is lost. From these findings, we can reject the null hypothesis that there is no change in mandibular alveolar width before and after treatment with a change in lower incisor angulation. This conclusion is essential in orthodontic diagnosis and treatment planning and should be a considered as a boundary limit for tooth movement.

APPENDIX A

Variable	T1 (SD)	T2 (SD)	T1-T2 (95% CI)	P value
LL1impa	77.1 (8.23)	79.1(8.2)	1.94 (0.29 to 3.65)	0.022
LL2impa	76.3 (7.48)	78.8 (7.9)	2.5 (0.9 to 2.05)	0.0021
LR1impa	76.6 (7.9)	78.9 (8.4)	2.31 (0.58 to 4.05)	0.0095
LR2impa	76.1 (7.6)	78.68(7.9)	2.6 (0.8 to 4.4)	0.004

Variable	T1 (SD)	T2 (SD)	T1-T2 (95% CI)	P value
LL1Bpointmenton	7.08 (2.4)	7.32 (2.6)	0.23 (-0.27 to 0.75)	0.36
LL2Bpointmenton	8.03 (2.5)	8.3 (2.5)	0.28 (-0.26 to 0.84)	0.21
LR1Bpointmenton	7.3 (2.4)	7.5 (2.5)	0.259 (-0.2 to 0.7)	0.27
LR2Bpointmenton	8.12 (2.5)	8.3 (2.6)	0.17 (-0.42 to 0.76)	0.57

Variable	**T1 (SD)**	**T2 (SD)**	**T1-T2 (95% CI)**	**P value**
LL1Apexmenton	11.4 (2.1)	12.4 (2.6)	0.98 (0.53 to 1.4)	<0.0001
LL2apexmenton	12.0 (2.1)	13.13 (2.3)	1.13 (0.7 to 1.6)	<0.0001
LR1apexmenton	11.25 (2.2)	12.3 (2.7)	1.05 (0.59 to 1.52)	<0.0001
LR2apexmenton	11.83 (2.1)	12.96 (2.48)	1.12 (0.64 to 1.6)	<0.0001

Variable	**T1 (SD)**	**T2 (SD)**	**T1-T2 (95% CI)**	**P value**
LL1CEJmp	22.34 (3.05)	22.9 (2.8)	0.58 (0.11-94)	0.014
LL2CEJmp	21.6 (3.05)	22.1 (2.7)	0.53 (0.007-1.05)	0.05
LR1CEJmp	22.2 (3.07)	22.9 (2.9)	0.71 (0.26-1.15)	0.0023
LR2CEJmp	21.3 (3.23)	22.05 (2.83)	0.79 (0.31-1.26)	0.0013

APPENDIX B

Variable	T1 (SD)	T2 (SD)	T1-T2 (95% CI)	P value
LL1Abuccal	3.04(0.51)	2.95 (0.51)	-0.09 (-0.2 to 0.02)	0.11
LL1Bbuccal	2.94 (0.64)	2.9 (0.68)	-0.055 (-0.18 to 0.07)	0.39
LL1Cbuccal	3.4 (0.95)	3.4 (1.1)	-0.03 (-0.22 to 0.15)	0.72
LL1apexbuccal	4.5 (1.4)	3.7 (1.4)	0.027 (-0.23 to 0.3)	0.84
LL1Alingual	3.14 (0.52)	2.96 (0.53)	-0.18 (-0.3 to -0.5)	0.0072
LL1Blingual	3.7 (0.73)	3.3 (0.77)	-0.38 (-0.57 to -0.2)	<0.0001
LL1Clingual	4.2 (0.95)	3.65 (1.1)	-0.56 (-0.79 to -0.32)	<0.0001
LL1apexlingual	4.3 (1.17)	3.72 (1.42)	-0.65(-0.93 to -0.35)	<0.0001

Variable	T1 (SD)	T2 (SD)	T1-T2 (95% CI)	P value
LL2Abuccal	3.32(0.58)	3.2 (0.4)	-0.1 (-0.24 to 0.04)	0.16
LL2Bbuccal	3.0 (0.58)	3.0 (0.57)	-0.03 (-0.16 to 0.10)	0.64
LL2Cbuccal	3.49 (1.01)	3.6 (1.1)	0.064 (-0.14 to 0.27)	0.53
LL2Apexbuccal	4.7 (1.3)	4.6 (1.45)	0.22 (-0.05 to 0.49)	0.11
LL2Alingual	3.7 (0.73)	3.5 (0.7)	-0.29(-0.50 to -0.090)	0.005
LL2Blingual	4.7 (1.02)	4.2 (1.05)	-0.50 (-0.7 to -0.27)	<0.0001
LL2Clingual	5.0 (1.25)	4.48 (1.18)	-0.51 (-0.74 to -0.29)	<0.0001
LL2apexlingual	4.8 (1.46)	4.3 (1.5)	-0.59 (-0.90 to -0.28)	0.0003

Variable	**T1 (SD)**	**T2 (SD)**	**T1-T2 (95% CI)**	**P value**
LL3Abuccal	3.57 (0.91)	3.6 (0.61)	0.048 (-0.13 to 0.24)	0.06
LL3Bbuccal	3.14 (0.85)	3.18 (0.65)	0.045 (-0.12 to 0.21)	0.58
LL3Cbuccal	2.93 (1.11)	2.95 (0.9)	0.014 (-0.18 to 0.21)	0.89
LL3apexbuccal	3.32 (1.4)	3.4 (1.3)	0.09 (-0.15 to 0.3)	0.46
LL3Alingual	4.19 (1.46)	4.3 (1.1)	0.85 (-0.24 to 0.40)	0.6
LL3Blingual	4.98 (2.04)	5.01 (1.59)	0.024 (-0.4 to 0.46)	0.91
LL3Clingual	5.35 (2.07)	5.36 (2.1)	0.006(-0.48 to 0.50)	0.97
LL3apexlingual	5.27 (2.0)	5.13 (2.3)	-0.14 (-0.6 to 0.39)	0.59

Variable	**T1 (SD)**	**T2 (SD)**	**T1-T2 (95% CI)**	**P value**
LR1Abuccal	2.99 (0.48)	2.89 (0.47)	-0.10 (-0.21 to 0.09)	0.07
LR1Bbuccal	2.9 (0.57)	2.9 (0.63)	0.04 (-0.07 to 0.17)	0.47
LR1Cbuccal	3.5 (0.95)	3.5 (1.26)	-0.008 (-0.21 to 0.2)	0.93
LR1apexbuccal	4.5 (1.3)	4.6 (1.3)	0.015 (-0.25 to 0.27)	0.091
LR1Alingual	3.2 (0.56)	3.0 (0.5)	-0.19(-0.32 to -0.07)	0.0018
LR1Blingual	3.9 (0.91)	3.4 (0.80)	-0.46 (-0.65 to -0.29)	<0.0001
LR1Clingual	4.3 (1.2)	3.76 (1.17)	-0.58 (-0.83 to -0.33)	<0.0001
LR1apexlingual	4.5 (1.4)	3.8 (1.6)	-0.72 (-1.03 to -0.41)	<0.0001

Variable	**T1 (SD)**	**T2 (SD)**	**T1-T2 (95% CI)**	**P value**
LR2Abuccal	3.29 (0.5)	3.3 (0.52)	-0.03 (-0.15 to 0.14)	0.96
LR2Bbuccal	3.0 (0.54)	3.05 (0.61)	0.05 (-0.10 to 0.21)	0.49
LR2Cbuccal	3.35 (1.04)	3.56 (1.13)	0.21 (-0.009 to 0.4)	0.06
LR2apexbuccal	4.31 (1.51)	4.59 (1.54)	0.27 (-0.03 to 0.58)	0.08
LR2Alingual	3.95 (0.83)	3.63 (0.75)	-0.32 (-0.56 to -0.08)	0.009
LR2Blingual	4.82 (1.15)	4.48 (1.17)	-0.34 (-0.59 to -0.08)	0.0097
LR2Clingual	5.24 (1.4)	4.7 (1.4)	-0.575(-0.85 to -0.25)	0.0006
LR2apexlingual	5.00 (1.6)	4.4 (1.5)	-0.55 (-0.89 to -0.20)	0.003

Variable	**T1 (SD)**	**T2 (SD)**	**T1-T2 (95% CI)**	**P value**
LR3Abuccal	3.34 (0.88)	3.52 (0.82)	0.17 (-0.02 to 0.3)	0.05
LR3Blingual	5.1 (2.4)	5.1 (2.3)	-0.0003 (-0.37 to 0.37)	0.99
LR3Cbuccal	2.79 (1.17)	2.76 (1.06)	-0.002 (-0.2 to 0.2)	0.98
LR3apexbuccal	3.07 (1.4)	3.1 (1.6)	0.072 (-0.2 to 0.3)	0.64
LR3Alingual	4.27 (1.48)	4.32 (1.2)	0.053 (-0.22 to 0.33)	0.71
LR3Blingual	5.1 (2.4)	5.1 (2.3)	-0.0003 (-0.37 to 0.37)	0.99
LR3Clingual	5.32 (2.4)	5.23 (2.3)	-0.064 (-0.4 to 0.3)	0.73
LR3apexlingual	5.14 (2.2)	4.98 (2.2)	0.04 (-0.32 to 0.4)	0.83

APPENDIX C

Variable	T1 (SD)	T2 (SD)	T1-T2 (95% CI)	P value
LL1A	6.16 (0.66)	5.9 (0.65)	-0.26 (-0.4- -0.12)	0.0004
LL1B	6.62 (0.99)	6.2 (0.97)	-0.41 (-0.57- -0.25)	<0.0001
LL1C	7.62 (1.5)	7.05 (1.53)	-0.57 (-0.76- -0.4)	<0.0001
LL1apex	8.86 (1.94)	8.25 (2.01)	-0.62 (-0.84- -0.4)	<0.0001
LL2A	7.06 (0.79)	6.68 (0.79)	-0.37 (-0.6- -0.16)	0.001
LL2B	7.73 (1.19)	7.21 (1.16)	-0.52 (-0.73- -0.31)	<0.0001
LL2C	8.48 (1.74)	8.02 (1.63)	-0.46 (-0.7- -0.23)	<0.0001
LL2apex	9.35 (2.0)	8.96 (1.98)	-0.39 (-0.66- -0.12)	0.005
LR1A	6.2 (0.71)	5.9 (0.64)	-0.3 (-0.4- -0.2)	<0.0001
LR1B	6.71 (1.13)	6.3 (0.92)	-0.42 (-0.6- -0.24)	<0.0001
LR1C	7.8 (1.7)	7.2 (1.5)	-0.6 (-0.78- -0.4)	<0.0001
LR1apex	9.15 (2.1)	8.5 (2.2)	-0.67 (-1.0- -0.33)	0.0002
LR2A	7.2 (0.89)	6.9 (0.77)	-0.29 (-0.51- -0.08)	0.008
LR2B	7.8 (1.4)	7.5 (1.23)	-0.28 (-0.51- -0.06)	0.013
LR2C	8.6 (1.78)	8.25 (1.9)	-0.35 (-0.60- -0.09)	0.0073
LR2apex	9.37 (2.1)	9.1 (2.0)	-0.28 (-0.54- -0.02)	0.031

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August 2012-May 2016
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Bachelor of Science (B.S.) in Biology

PROFESSIONAL EXPERIENCE
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July 2015-October 2015
Completed a 10 week externship providing dental care. Performed extractions, denture fabrication and restorations.

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Applied Professional Experience (APEX)
Worked hands on in a fast-paced general dental office as a dental assistant. Analysis of weekly literature reviews pertaining to dentistry; treatment plan creation and behavior management techniques

PROFESSIONAL MEMBERSHIPS
American Dental Association (ADA)
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