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The Effect of Orthodontic Treatment on Sagittal Root Position of the Maxillary Central Incisor

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in conjunction with the
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The Effect of Orthodontic Treatment on Sagittal Root Position of the Maxillary Central Incisor

by

Jeremy Haines

A Thesis submitted in partial satisfaction of
the requirements for the degree
Master of Science in Orthodontics and Dentofacial Orthopedics

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September 2016

Each person whose signature appears below certifies that this thesis in his opinion is adequate, in scope and quality, as a thesis for the degree of Master of Science.

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Kitichai Rungcharassaeng, Professor of Orthodontics and Dentofacial Orthopedics

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____
Joseph Kan, Professor of Implant Dentistry

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ABBREVIATIONS

ANB (angle)	Angle formed by cephalometric landmarks A point, Nasion and B point
CA	Collum angle
CBCT	Cone beam computed tomography
CEJ	Cemento-enamel junction
Cl I	Class I
Cl II div 1	Class II division 1
Cl II div 2	Class II division 2
Cl III	Class III
CrA	Crown angulation
CS (image)	Sagittal cross section image of a central incisor
DICOM	Digital imaging and communications in medicine
IIP	Immediate implant placement
IQR	Inter-quartile range
L1-L5	Labial bone thickness measurements (mm) at levels 1-5
MPR (view)	Multiplanar reconstruction view
NIC	Negative inclination change
P1-P5	Palatal bone thickness measurements (mm) at levels 1-5
PIC	Positive inclination change
px	Pixel
RI	Root inclination
SN	Sella-Nasion plane
SRP	Sagittal root position
T1	Pre-orthodontic treatment
T2	Post-orthodontic treatment
W1-W5	Alveolar width measurements (mm) at levels 1-5

ABSTRACT OF THE THESIS

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Jeremy Haines

Master of Science, Graduate Program of Orthodontics and Dentofacial Orthopedics
Loma Linda University, September 2016
Dr. Kitichai Rungcharassaeng, Chairperson

Introduction: Sagittal root position (SRP) of maxillary incisors is an important factor in implant treatment planning. Kan et al defined four classes of SRP in an effort to aid implant placement treatment planning and these SRP classifications represent a novel approach to describing bone changes around the maxillary incisors. The effect of orthodontic tooth movement, specifically changes in inclination, on SRP is of interest in potentially facilitating immediate implant placement.

Purpose: The purpose of this study was to use Cone Beam Computed Tomography (CBCT) to evaluate the adaptation of alveolar bone around the maxillary incisors as a result of orthodontic tooth movement and describe the effect of said changes on SRP classification.

Methods: This study compared changes in dimension (mm) of labial/palatal bone of the anterior maxilla surrounding the central incisors on CBCT images acquired before (T1) and after (T2) orthodontic treatment. Initial (T1) and final (T2) digital imaging and communications in medicine (DICOM) CBCT images of 77 patients were imported into Osirix MD software for analysis. Mid-sagittal images of 127 central incisors that met inclusion criteria were obtained. SRP was recorded for each incisor at T1 and T2. Labial, palatal, and total alveolar width changes (mm) were analyzed using Wilcoxon Signed Rank Test, Mann-Whitney U Test, and Independent Samples Kruskal-Wallis Test ($\alpha = 0.05$).

Results: Statistically significant differences in dimension changes between T1 and T2 were found for teeth that experienced positive inclination change (PIC). Labial bone dimensions increased and palatal dimensions decreased, differing in magnitude ($p < 0.05$), resulting in a decrease in total alveolar width dimension. Most changes in the negative inclination change (NIC) group were not statistically significant. 82% of teeth were class I SRP and 18% were class II SRP at T1. SRP classification changed in 54% of teeth between T1 and T2 (67% and 19% of PIC and NIC groups, respectively).

Conclusion: Statistically significant adaptation of the alveolar process around maxillary central incisors occurs in teeth that experience PIC and follows a predictable pattern. Orthodontic movement that causes changes in inclination also results in changes in SRP classification.

CHAPTER ONE

REVIEW OF THE LITERATURE

Sagittal root position (SRP) of maxillary incisors is an important factor in implant treatment planning, especially in immediate implant placement (IIP) situations. Initial root position in the bone in part defines the character of the post extraction site and bony housing for the implant. The bony housing of the post extraction site affects initial implant stability and adequate bone apical to the extraction site and socket walls without defects are essential to immediate implant success.[8] Several qualities of bone have been investigated and evaluated for their impact on initial implant stability including type of bone, thickness of cortical plates, and density of bone.[3-7] Sugiura et al used finite element analysis to study micromotion and peri-implant bone strain and found that increased thickness of cancellous bone decreases peri-implant bone strain and thereby increases the likelihood of implant success.[3] In studies using the implant stability quotient (ISQ) to evaluate initial implant stability, bone thickness and modulus of elasticity were found to correlate well with increased ISQ while implant length did not.[5,6] In a study that tested 22 implants placed in human cadaver bones, analysis of histomorphometrical parameters showed no correlation with ISQ, but bone thickness did.[4] Methods used for evaluation of initial implant stability in these and other studies (including ISQ) have shown low sensitivity and poor correlation with other techniques[7], so the effect of bony parameters on initial implant stability while not definitive, do suggest an important role of bone thickness in initial implant stability.

Data from studies evaluating buccal bone thickness specifically have shown that a minimum of 2mm in this area is essential for optimal esthetic and functional outcomes.[59-

[61] Average width dimensions of the anterior maxillary alveolus in fully dentate patients has been measured to be between 8.3 and 9.6 mm, but in a study by Zhang et al no correlation to IIP success was established for alveolar width - except for the suggestion that buccal undercuts in alveolar widths may lead to surgical complications and the need for additional bony augmentation or the use of custom/angled abutments.[62] Influencing the thickness and placement of bone in potential implant sites through positioning of the root within the alveolar housing therefore is a plausible tool for improving the success of implant placement.

Classifying SRP in an effort to aid implant placement treatment planning was the goal of a study conducted by Kan et al at Loma Linda University. This study defined four classes of SRP within its osseous housing for the maxillary incisors.[9]

- Class I: The root is positioned against the labial cortical plate.
- Class II: The root is centered in the alveolar housing without engaging either the labial or palatal cortical plates at the apical third of the roots.
- Class III: The root is positioned against the palatal cortical plate.
- Class IV: At least two thirds of the root is engaging both the labial and palatal cortical plates.

Each classification and its associated bony structure surrounding the tooth root represents a unique environment for IIP. Following extraction of teeth with class I SRP a significant amount of bone on the palatal aspect provides support for IIP and any gaps between the implant and bony housing are filled with bone grafting material.[10,11] In class II SRP the amount of bone present in the labial and palatal plates following extraction may not be sufficient to ensure initial implant stability without sufficient apical bony support. In class III SRP the bone available is the labial, more trabecular bone which is prone to post placement remodeling making it a poor candidate for IIP. Class IV SRP provides little support for IIP and usually requires bony augmentation. Considering these characteristics in planning for IIP, class IV SRP could be termed a contraindication to IIP while class I SRP an indicator of adequate bony support according to guidelines established in the current literature.[8-11] Altering root positions to change SRP classification by orthodontic treatment could logically alter the feasibility of treatment with IIP.

Orthodontic tooth movement is made possible in part by interactions of teeth and bones with the periodontal ligament (PDL).[12,33] The PDL plays a central role in the "pressure-tension theory" of tooth movement and is responsible for the symmetric zones of apposition and resorption that allow teeth to move through bone - according to this theory.[34] Other theories of tooth movement emphasize the mechanical transduction of forces - forces that cause new bone to be added through alveolar bending or conversely, cause bone to be removed from the absence of strain such as in the "stretched fiber hypothesis."[35, 36] In all cases, forces acting on teeth are translated to a biological level and result in the reorganization of intra- and extra-cellular matrices and local vascularization.[37, 38] These biological events are ultimately responsible for movement of teeth.

Orthodontic movement of teeth within bone occurs either by movement of teeth *through* the bone or *with* the bone.[12] In tooth movement *with* bone, resorption and apposition by osteoclasts and osteoblasts in the periodontal ligament space is balanced much like in physiological tooth movement.[12,39] Apposition at the external surface of the alveolus and resorption along the inner surface in the direction of the force allows teeth to be moved beyond the boundaries of the original alveolar process[39] and maintains bone thickness dimension. Correction of defects through coordinated resorption and apposition is also possible as has been shown in patients with periodontal compromised teeth characterized by infrabony defects that demonstrate significant improvements to marginal bone height and bone defect radiologic dimension following orthodontic tooth movement.[40,41]

Movement of teeth through the bone is seen when the ratio of resorption and apposition is unequal.[39] Large forces on teeth cause undermining resorption from adjacent marrow spaces and tip the balance toward bony resorption because little apposition occurs as a result of limited tooth displacement on the tension side as the pressure side is resorbed.[12,33] While direction of tooth movement is easily anticipated,[16,18,22,32] the response of surrounding bone as a result of imbalanced apposition and resorption makes it hard to estimate bone thickness changes.

Several studies have investigated how movement of the teeth in the anterior maxilla affects alveolar bone dimensions. In a study by Yodthong et al bony changes were evaluated at three levels for maxillary incisors during retraction and changes were recorded at each level for labial, palatal, and alveolar widths. Inclination changes of 10.9 ± 3.9° in the negative direction were correlated with significant increases to labial bone at the cervical level and total alveolar width at the apical level despite the type of movement (tipping or torqueing of maxillary incisors).[43] A similar study conducted by Hyo-Won et al reported alveolar bone area (mm2) changes in cervical, middle, and apical sections on both labial and palatal sides for maxillary incisors that changed inclination by 10.4 ± 5.9°

in the negative direction. The middle section of labial bone increased by 0.65 mm^2 and all three sections on the palatal side decreased in alveolar bone area.[18] Another study, by Thongudomporn et al, showed correlation of proclination and extrusion of maxillary incisors to changes in alveolar bone dimensions. After a mean proclination change of 3 degrees, palatal and total alveolar width measurements at midroot and apical levels decreased by a range of 0.21 to 0.48 mm and were statistically significant whereas labial bone changes during the same movements were not.[17] The absence of labial bone change in this study were attributed to light forces used during movement. Other studies corroborate the light force explanation for differential bone changes and postulate that better cellular activity produced by the use of light forces may contribute to more consistent bone remodeling which would alter the amount and type of bony changes seen in the movement of all teeth.[23,24]

In comparing bony changes of maxillary incisors in extraction vs non-extraction cases Picanco et al showed that despite differing amounts and types of movement the only statistically significant difference in alveolar dimension was at the cervical third of the incisors.[63] Changes at other levels of the tooth root are related to cephalometric landmarks used for orthodontic evaluation and have been studied extensively. In one study 17˚ of incisor proclination and 2mm of movement of the root apex lead to a 1.04mm change in location of Pt A.[21] This 2:1 ratio of root movement to Pt A change is confirmed by several other studies examining the effect of maxillary incisor movement on the location and movement of Pt. A.[19-21]

As these studies show, movement of the maxillary incisors can cause changes in the labial palatal plates of the alveolar housing, causing an increase or decrease in bone thickness. Either type of change can be beneficial or harmful to prospective implant placement depending on where it occurs. Decreases in bone thickness on the labial side of maxillary incisors for example may lead to dehiscence or fenestrations[22] that would complicate implant placement in these areas. When planning particular movements in orthodontic treatment the direction of bony changes can be anticipated,[16,18,22,32] but the magnitude of change has not been well defined. Accurate knowledge of how the alveolar housing will respond to specific tooth movements would be valuable in planning for IIP.

Changes in root position are manifest clinically by inclination changes of tooth crowns. Different malocclusions have varying amounts of incisor proclination when compared to norms[53] and the architecture of the alveolus surrounding these teeth differs as a result.[54] Treating different malocclusions to ideal incisor position therefore requires varying amounts of change to incisor inclination and will have a varied effect on alveolar architecture. Examining the treatment of different malocclusions with differing amounts and direction of incisor inclination changes is of interest in assessing and quantifying changes within alveolar bone as the root position changes.

The Collum angle of maxillary incisors has been examined over the years and evidence suggests that there are differences in Collum angle between different malocclusions, specifically class II div 2 and class III malocclusions show marked differences from other malocclusions.[48-50] These differences were examined and compared in a study by Srinivasan et al in which they traced 120 lateral cephalograms and showed statistically significant differences between Class I, class II div 1 and class II div 2 groups.[51] Cl I, Cl II div1, and div2 means were 1.05 ± 1.50°, 0.95 ± 1.06° and 3.24 ± 4.69°, respectively. Another study on maxillary incisor crown and root shape showed a difference of shape in only the class II div 2 group based on landmarks that form the Collum angle.[52] Harris et al showed class III Collum angles were significantly difference than other malocclusion types.[50]

Many studies have shown that CBCT is a valuable tool in the evaluation of hard tissue changes[26-28] such as those being examined in the proposed study. CBCT uses a cone of ionizing radiation to acquire images in an arc pattern with a single pass collecting sufficient data to generate a diagnostic image. Three dimensional images are then created from these scans in a one-to-one image-to-reality ratio which allows clinicians to make measurements to a high degree of accuracy.[29-31] The limit of this accuracy has been reported as .2mm for linear measurements in one study and as a resolution range of 0.4 - 0.125 mm in another.[64,65] Scans taken frequently in clinical practice, not at the highest resolution, show accuracy of .5 to.6 mm.[27,29] In spite of these limitations several studies have validated the accuracy of CBCT measurements of bone thickness, both in the maxillary alveolar region[27, 30] and in the buccal bone of posterior teeth.[28] The presence of soft tissue in scans compared to scans done without (on cadavers) show similar accuracy albeit with greater standard deviations.[27] In one study the presence of the PDL in images of teeth and alveolar bone increased the accuracy of bone thickness measurements, but still only to the .5mm level.[29] As CBCT continues to improve and develop, accuracy will continue to improve. Even in the studies quoted here a trend in increased accuracy as newer technology has become available is apparent between 2003 and 2011.[27,64,65]

In conclusion, CBCT technology is ideally suited for the investigation of how orthodontic tooth movement affects the root position of maxillary incisors and surrounding bone. While some research has been done relating inclination change of maxillary incisors to alveolar bone changes, no research has currently addressed these movements and bone changes in the context SRP classification. Further research is required in order to better understand changes in alveolar bone during moving of the maxillary anterior teeth.

CHAPTER TWO

THE EFFECT OF ORTHODONTIC TREATMENT ON SAGITTAL ROOT POSITION OF THE MAXILLARY CENTRAL INCISOR

by

Jeremy Haines

Master of Science, Graduate Program of Orthodontics and Dentofacial Orthopedics
Loma Linda University, August 2016
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Abstract

Instroduction: Sagittal root position (SRP) of maxillary incisors is an important factor in implant treatment planning. Kan et al defined four classes of SRP in an effort to aid implant placement treatment planning and these SRP classifications represent a novel approach to describing bone changes around the maxillary incisors. The effect of orthodontic tooth movement, specifically changes in inclination, on SRP is of interest in potentially facilitating immediate implant placement.

Purpose: The purpose of this study was to use Cone Beam Computed Tomography (CBCT) to evaluate the adaptation of alveolar bone around the maxillary incisors as a result of orthodontic tooth movement and describe the effect of said changes on SRP classification.

Methods: This study compared changes in dimension (mm) of labial/palatal bone of the anterior maxilla surrounding the central incisors on CBCT images acquired before (T1) and after (T2) orthodontic treatment. Initial (T1) and final (T2) digital imaging and communications in medicine (DICOM) CBCT images of 77 patients were imported into Osirix MD software for analysis. Mid-sagittal images of 127 central incisors that met inclusion criteria were obtained. SRP was recorded for each incisor at T1 and T2. Labial, palatal, and total alveolar width changes (mm) were analyzed using Wilcoxon Signed Rank Test, Mann-Whitney U Test, and Independent Samples Kruskal-Wallis Test ($\alpha = 0.05$).

Results: Statistically significant differences in dimension changes between T1 and T2 were found for teeth that experienced positive inclination change (PIC). Labial bone dimensions increased and palatal dimensions decreased, differing in magnitude (p <

0.05), resulting in a decrease in total alveolar width dimension. Most changes in the negative inclination change (NIC) group were not statistically significant. 82% of teeth were class I SRP and 18% were class II SRP at T1. SRP classification changed in 54% of teeth between T1 and T2 (67% and 19% of PIC and NIC groups, respectively).

Conclusions: Statistically significant adaptation of the alveolar process around maxillary central incisors occurs in teeth that experience PIC and follows a predictable pattern. Orthodontic movement that causes changes in inclination results in changes in SRP classification.

Introduction

Statement of the Problem

Sagittal root position (SRP) of maxillary incisors is an important factor in implant treatment planning in the esthetic zone, especially in immediate implant placement (IIP) situations. Initial root position in the bone in part defines the character of the post extraction site and the bony housing of the post extraction site affects initial implant stability which is a primary determinate of implant success.[1-3] The qualities of bone that have been investigated for their impact on initial implant stability include type of bone, thickness of bone, density and modulus of elasticity.[1, 4-7] Of these qualities, bone thickness consistently shows high correlation with initial implant stability.[1, 4-6] Adequate bone apical to the extraction site and socket walls without defects are also essential to the success of IIP.[8]

Classifying SRP in an effort to aid implant placement treatment planning was the goal of a study conducted by Kan et al at Loma Linda University.[9] This study defined four classes of SRP within its osseous housing for the maxillary incisors (Figure 1).

- Class I: The root is positioned against the labial cortical plate.
- Class II: The root is centered in the alveolar housing without engaging either the labial or palatal cortical plates at the apical third of the roots.
- Class III: The root is positioned against the palatal cortical plate.
- Class IV: At least two thirds of the root is engaging both the labial and palatal cortical plates.

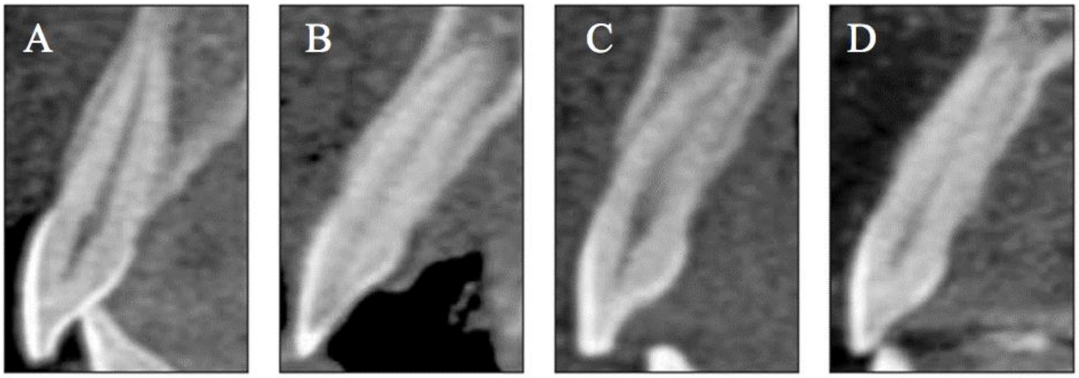

Figure 1. SRP Classification – image courtesy of Kan et al. (A) Class I, (B) Class II, (C) Class III, (D) Class IV.

Following extraction of teeth with Class I SRP a significant amount of bone on the palatal aspect provides support for IIP and any gaps between the implant and bony housing are filled with bone grafting material.[10,11] In class II SRP the amount of bone present in the labial and palatal plates following extraction may not be sufficient to ensure initial implant stability without sufficient apical bony support.[8] In class III SRP the bone available is the labial, more trabecular bone which is prone to post placement remodeling making it a poor candidate for IIP. Class IV SRP provides little support for IIP and usually requires bony augmentation. Considering these characteristics in planning for IIP, class IV SRP could be termed a contraindication to IIP while class I SRP would be an indicator of adequate bony support according to guidelines established in the current literature.[8-11] Orthodontic tooth movement that alters SRP and facilitates improvement in bony support therefore could provide a valuable tool in preparing for IIP.

That teeth move and bone is altered by applying forces to teeth is a foundational principle of orthodontics[12-15], but how tooth movement occurs and what affects the amount and direction of bone adaptation is still under investigation. Different theories have emerged from this investigation about whether bone traces tooth movement or teeth move through bone and evidence for each theory exists. Several studies illustrate that orthodontic movement of teeth in the anterior maxilla can cause change to the position of cephalometric landmarks and changes to alveolar bone thickness.[16-21] In some cases decreases in bone thickness results in bone dehiscence and fenestrations of maxillary incisors.[22] Alternatively, the use of light forces in the anterior maxilla has been shown to cause limited changes to labial bone thickness and has led to more consistent and less damaging bone remodeling.[17,23,24] Accurate knowledge of how the alveolar housing will respond to specific tooth movements would be valuable in planning for IIP.

Root changes within the bone are manifest clinically by changes to the position of the tooth crown and the ideal functional and esthetic position of the crown is one of the main goals of orthodontic treatment. Therefore, a factor of interest in orthodontic treatment is the angulation of the crown to the root of the tooth as it affects both clinical results and governs the interaction of the tooth with the bone.[25] Root inclination and tooth inclination measurements define tooth position in reference to the alveolus and cranial base. Examination of these angles in addition to crown root angulation bridges clinically visible treatment results to the underlying bone changes associated with tooth movement.

Cone beam computed tomography (CBCT) is a useful tool in the evaluation of hard tissue changes[26-28], such as those being examined in the current study. Three dimensional images created from CBCT scans are less affected by orientation of the skull than other image modalities and are in a one-to-one image-to-reality ratio which allows clinicians to make measurements to a high degree of accuracy and evaluate hard tissue changes in three dimensions.[27,29] Several studies have validated the accuracy of CBCT measurements of bone thickness, specifically in the maxillary alveolar region.[27, 30] Just as

CBCT has been used to evaluate buccal bone changes to posterior teeth during rapid palatal expansion,[28] in this study CBCT will be used to analyze changes to labial and palatal bone in the anterior maxilla.

The purpose of this study was to use CBCT images to quantitatively evaluate changes to the labial and palatal bone of maxillary incisors as a result of sagittal inclination change and determine the effects of these changes on SRP classification. A secondary purpose was to evaluate crown-root angulation and root/tooth inclinations of maxillary incisors and evaluate differences in these measurements between malocclusions.

Hypothesis

The null hypothesis was that no change in labial/palatal/alveolar width bone dimensions (mm) or SRP classification would occur in response to orthodontic tooth movement.

Materials and Methods

Patient Selection

This study was approved by the Institutional Review Board of Loma Linda University, Loma Linda, California. Pre- (T1) and post-orthodontic treatment (T2) cone beam computed tomography (CBCT) [NewTom 5G, 110 kV, 3.6 second exposure time, 0.3 mm voxel resolution, and 180 x 160 mm field of view; NewTom, Verona, Italy] records of patients who received full orthodontic treatment at the Graduate Orthodontic Clinic, Loma Linda University School of Dentistry from July 2011 to March 2016 were reviewed and the records fulfilling the following criteria were included in the study: (1) completed treatment with available T1 and T2 CBCT records and (2) central incisor inclination change from T1 to T2 that is ≥ 5 degrees (in either direction). Cases with missing anterior teeth, radiographic evidence of infection, trauma to maxillary incisors, cases having received any bony augmentation in the anterior maxilla, or cases with severe crowding and/or rotation of maxillary incisors that effected required measurements were excluded from the study. DICOM files from each patient were evaluated using the Osirix MD software, version 6.5.2, 64-bit (Pixmeo Bernex, Switzerland). In order to keep measurements consistent, one examiner performed all reconstructions and measurements.

Each case included in the study was first categorized according to Steiner's ANB angle, defined as the angle formed by drawing a line from A point to Nasion and back to B point on a midsagittal cut of a CBCT scan (Figure 2). The following definitions were applied to the ANB angles of all cases:

- Class I = $0^\circ \leq$ ANB $\leq 4^\circ$
- Class II = ANB $> 4^\circ$
- Class III = ANB $< 0^\circ$

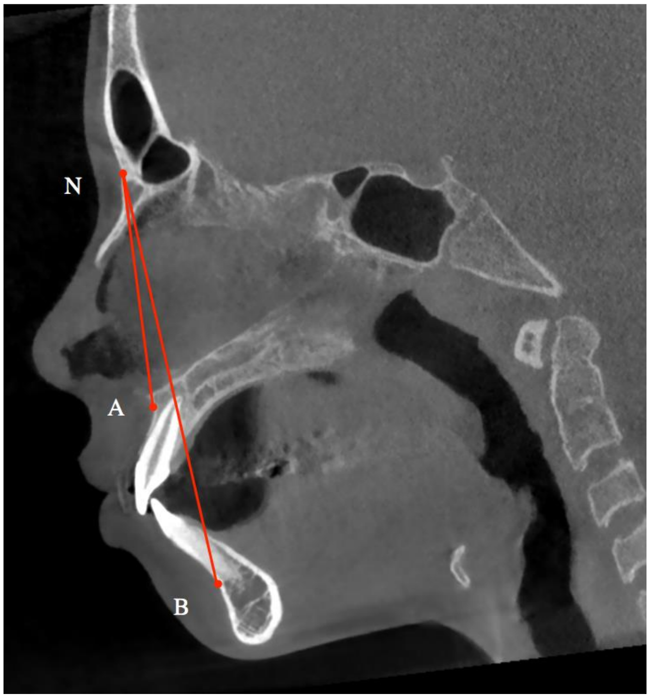

Figure 2. ANB angle

Volume Orientation

Cone beam computed tomography (CBCT) volumes were then manipulated in the Multiplanar Reconstruction (MPR) view. In the mid-sagittal view, the Sella Nasion plane (SN), defined as the line connecting the cephalometric landmarks Nasion and Sella, was set to the horizontal plane (Figure 3A) and the image screen captured and stored. This image was used for ANB measurement for skeletal classification. Images of each incisor were then generated in this SN orientation by centering the sagittal, coronal, and axial planes to bisect the target incisor in each respective view and then screen capturing the result (Figure 3. B-E).

Inclination and Collum Angle Measurements

The root inclination of each incisor was determined in relation to SN using a line bisecting the root and extending through the midpoint of the cemento-enamel junction (CEJ) (Figure 4A). Tooth inclination was also determined in relation to SN by a line extending through the long axis of the tooth (Figure 4B). Inclination change was calculated by subtracting the T1 root inclination measurement from the T2 root inclination measurement. Positive inclination change (PIC) indicates a more proclined T2 incisor position and negative inclination change (NIC) indicates a more retroclined T2 incisor position.

Collum angle is the angle formed between the long axis of the root and the long axis of the crown.[25] Collum angle measurements were made on each incisor image and recorded. Collum angles were measured by extending a line through the center of the root from the midpoint of the CEJ and another line from the center of the incisal edge passing through the CEJ midpoint and measuring the angle created by these lines (Figure 5). Crown angulation (CrA) was also calculated by subtracting Collum angle (CA) from root inclination (RI) (CrA = RI – CA).

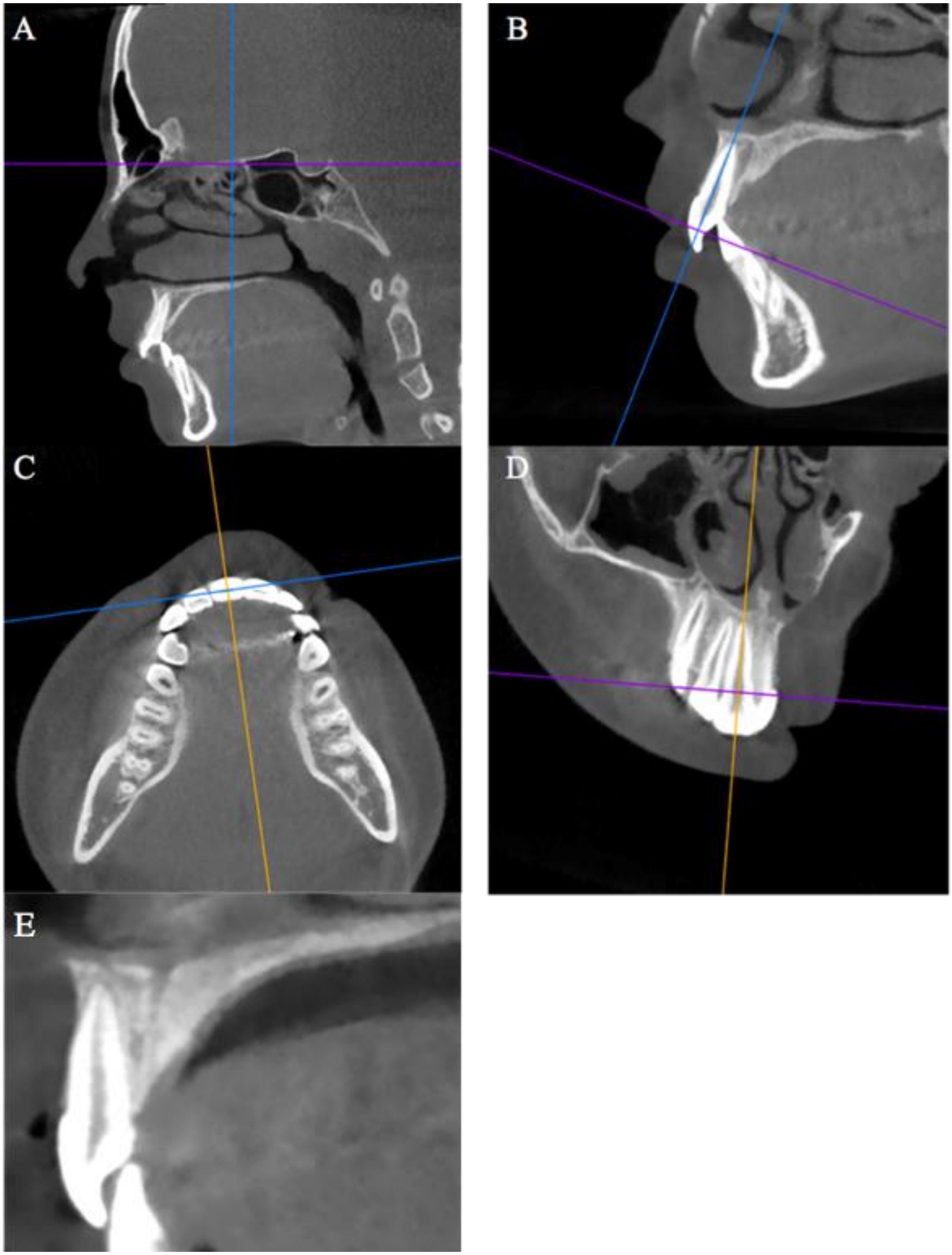

Figure 3. (A) SN plane set parallel to horizontal, (B) viewer centered on central incisor, (C) sagittal cut set to bisect the central incisor – coronal view, (D) sagittal cut set to bisect the central incisor – axial view, (E) final sagittal cross section of incisor.

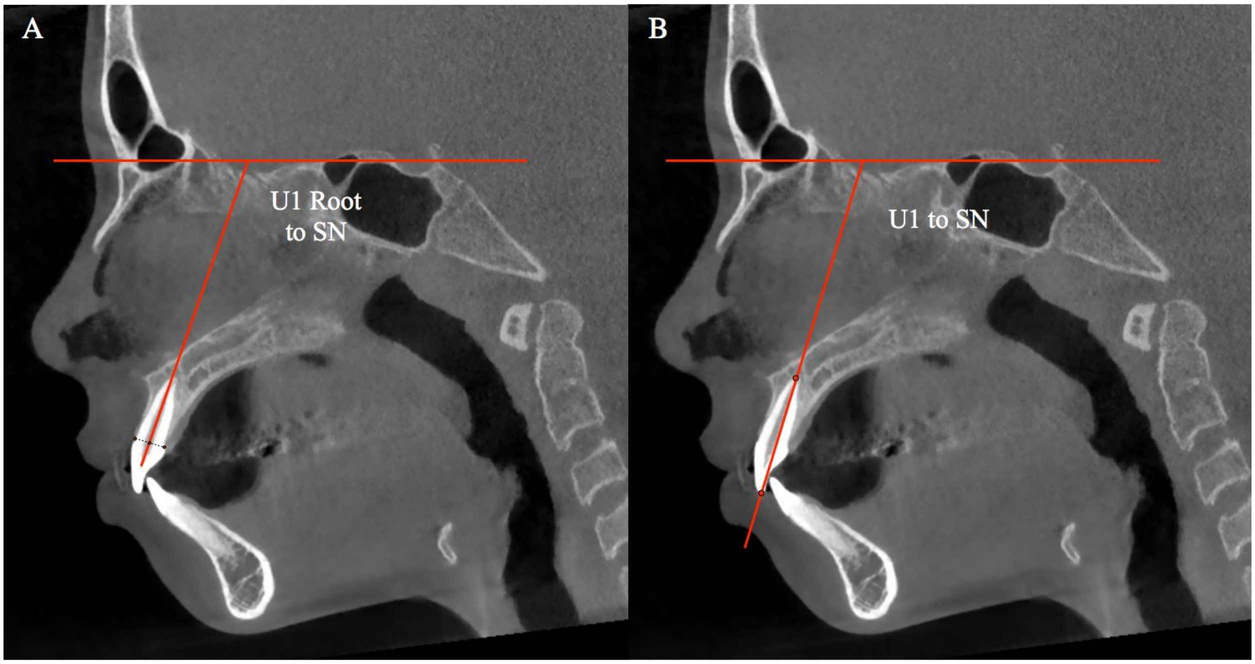

Figure 4. (A) Root inclination, (B) tooth inclination.

Bone Thickness Measurements

Incisor images were scaled to a 10 pixel (px):1 mm ratio using Keynote software (Apple, Inc.). Scaled images were then oriented so that a line drawn through the CEJ was parallel with the horizontal plane and 5 lines were added to each image parallel to and at a distance of 3, 5, 7, 9, and 11 mm from the CEJ line (Figure 6). Points (1 px × 1 px) were placed on each line at the labial and palatal limits of alveolar bone and at the labial and palatal limits of the tooth root (Figure 7). These points were used to calculate the amount and direction of bone change for the labial, palatal, and total alveolar width measurements. As with inclination change calculations, positive results indicated an increase in bone thickness whereas negative results indicated a decrease. Table 1 describes each measurement and its abbreviation which are used throughout this study.

Table 1. *Description of bone measurements.*

Measurement	**Description** (1 = 3mm, 2 = 5mm, 3 = 7mm, 4 = 9mm, and 5 = 11mm from the CEJ)
L1-L5	Labial plate thickness measured from anterior border of labial cortex to labial limit of the tooth root
P1-P5	Palatal plate thickness measured from the border of the alveolar cortex nearest the oral cavity to the palatal extent of the tooth root
W1-W5	Width of alveolus measured from border of the alveolus nearest the palatal vault to the outer border of the labial cortex

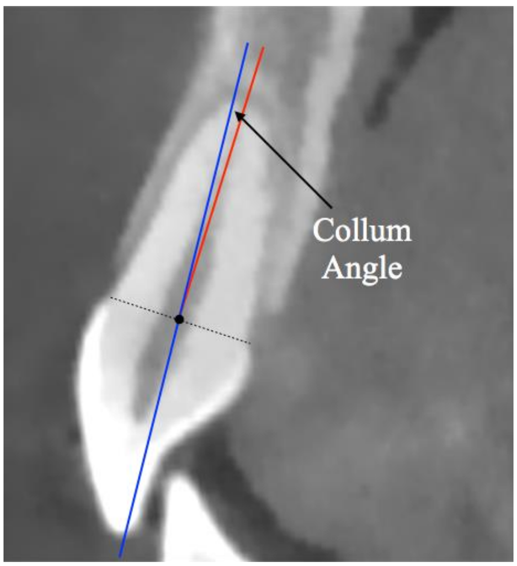

Figure 5. Collum angle is the angle formed between the long axis of the crown (blue line) and the long axis of the root (red line).

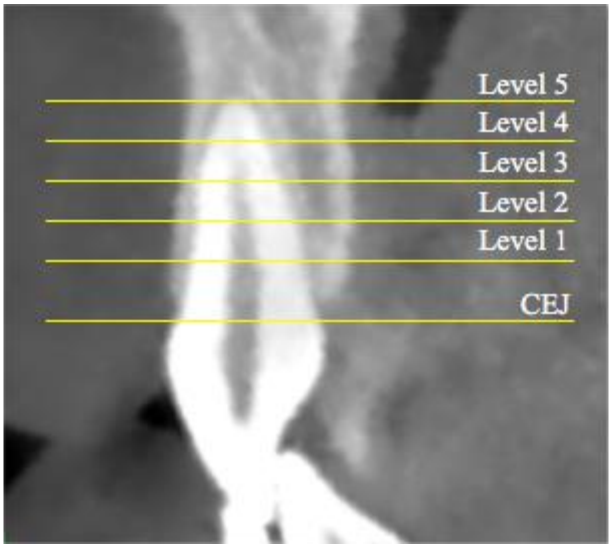

Figure 6. CEJ line and measurement levels

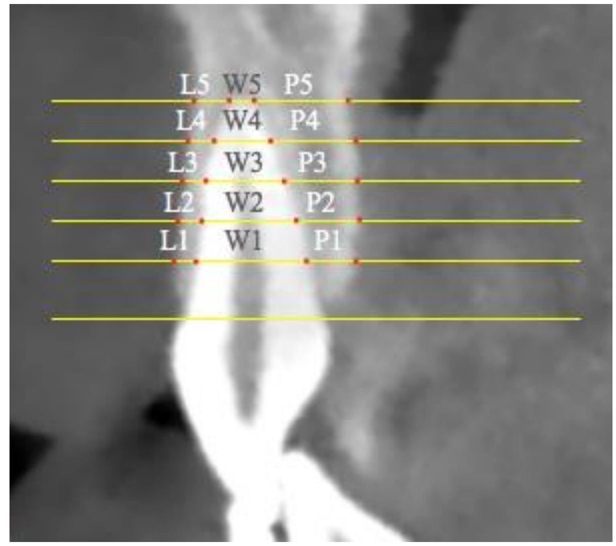

Figure 7. Bone thickness measurements

SRP Classification

Lastly, the SRP of each central incisor was determined using the classification described by Kan et al. [9] Each incisor image was independently assessed by two evaluators (JH and KR) and classified according to root position within the alveolus. Any discrepancies in SRP classification were reconciled by discussion between evaluators until agreement on the correct classification was determined.

Statistical Analyses

Statistical analyses were performed using IBM SPSS Statistics (Version 22; IBM Corporation 1989, 2013.). Descriptive statistics were reported as means with standard deviations for normally distributed data and medians with interquartile ranges for all other data. The Kruskal-Wallis test was used to determine statistical significance between groups of normally distributed data. The Wilcoxon Signed Rank Test was used to test the significance of each measurement and the Mann Whitney U test was used to compare the medians of bone change between groups. Alpha was set at the 0.05 significance level. The reliability of measurements was assessed using Cronbach's alpha. Measurements on 20 teeth (>15%) were repeated 6 weeks apart and intra-class correlation determined.

Results

Seventy-seven (32 males and 45 females) patients with the mean age of 19.0 ± 11.4 years (range = 10.0 – 66.7 years) were included in the study. A total of 127 (67 Cl I, 17 Cl II div1, 19 Cl II div2, and 24 Cl III) teeth were evaluated.

Cronbach's alphas were greater than 0.95 for all tested measurements (Table 2) indicating high reproducibility for all measurements in this study.

Table 2. *Tests for reliability.*

Measure	Cronbach's Alpha
T1 bone thickness	.995
T2 bone thickness	.992
Inclination	.993
Collum Angle	.954

The range of positive and negative inclination change were 5 to 29 and -5 to -26 degrees, respectively. The Cl II div 2 group showed the highest mean inclination change at 17.1 ± 7.6˚. Table 3 shows the mean inclination change and standard deviation according to skeletal classification separated into positive inclination change (PIC) and negative inclination change (NIC) groups. Figure 8 illustrates the difference between positive and negative inclination change.

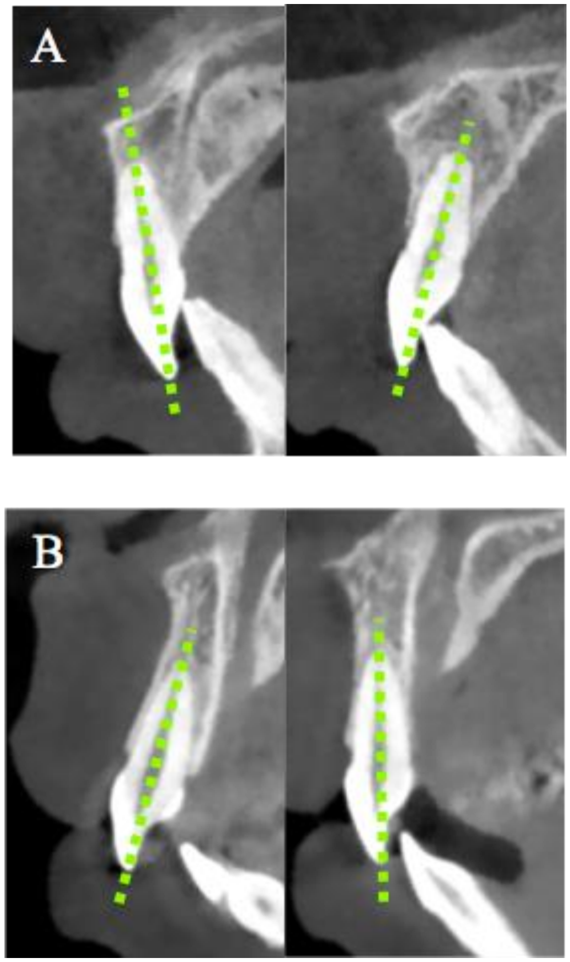

Figure 8. (A) Depiction of positive inclination change, and (B) negative inclination change.

Collum Angle and Crown Angulation

Mean and standard deviations of Collum angle for Cl I, Cl II div1, Cl II div2, and Cl III groups were 2.1 ± 3.5°, -0.2 ± 4.1°, 3.9 ± 3.1°, and 1.5 ± 3.6° respectively. Statistically significant difference in mean Collum angles was found only between Cl II div 1 (-0.2°) and Cl II div 2 (3.9°) groups ($p = .007$). Mean and standard deviations of T2 crown angulations for Cl I, Cl II div1, Cl II div2, and Cl III groups were 105.2 ± 8.5°, 103.5 ± 9.6°, 101.7 ± 7.1°, and 115.2 ± 9.0° respectively.

Table 3. *Mean and standard deviation (SD) of inclination change by malocclusion classification*

Groups	Positive Inclination Δ (degrees) Mean ± SD	Negative Inclination Δ (degrees) Mean ± SD
Class I	10.8 ± 5.0	13.6 ± 7.0
(range)	(5 - 25)	(6 - 26)
[N = 67]	[51]	[16]
Class II div 1	9.0 ± 4.1	11.0 ± 5.2
(range)	(5 - 15)	(6 - 22)
[N = 17]	[5]	[12]
Class II div 2	17.1 ± 7.6	--
(range)	(6 - 29)	--
[N = 19]	[19]	[0]
Class III	11.4 ± 5.1	7.0 ± 1.8
(range)	(5 - 20)	(5 - 9)
[N = 24]	[20]	[4]
Overall	12.1 ± 6.0	11.6 ± 6.2
(range)	(5 – 29)	(5 – 26)
[N = 127]	[95]	[32]

Bone Thickness Changes

Overall median bone thickness changes (mm) by level are shown in Table 4. A one sample Wilcoxon Signed Rank Test at a significance level of $\alpha = 0.05$ was used for the statistical analysis of bone thickness change at each level. In the PIC group, statistically significant changes of all parameters were observed at all levels ($p < 0.05$, Table 4) except level 1 of labial bone ($p = .492$, Table 4); whereas in the NIC group, most of the changes were not statistically significant ($p > 0.05$, Table 4). When comparing bone thickness changes between the PIC and NIC groups significant differences were observed in all parameters at all levels ($p < 0.05$, Table 4) except at level 1 of the labial bone ($p = .202$, Table 4).

Table 4. *Median and interquartile range (IQR) of overall bone thickness changes.*

Measurement	Positive Inclination Δ			Negative Inclination Δ			PIC and NIC comparison
	Median (IQR)	N	P value	Median (IQR)	N	P value	P value
L1 (mm)	0.0 (0.3)	94	.492	0.0 (0.4)	32	.287	.202
L2 (mm)	0.1 (0.3)	94	.000*	0.1 (0.6)	33	.428	.000*
L3 (mm)	0.3 (0.5)	94	.000*	-0.1 (0.5)	33	.428	.000*
L4 (mm)	0.6 (0.7)	93	.000*	-0.1 (0.6)	32	.247	.000*
L5 (mm)	1.2 (1.4)	80	.000*	0.0 (1.3)	29	.072	.000*
P1 (mm)	-0.9 (1.0)	94	.000*	-0.3 (0.8)	33	.059	.000*
P2 (mm)	-1.6 (1.7)	94	.000*	-0.5 (1.4)	33	.038*	.000*
P3 (mm)	-2.2 (2.1)	94	.000*	-0.5 (2.0)	33	.130	.000*
P4 (mm)	-2.4 (2.6)	93	.000*	0.0 (1.9)	32	.694	.000*
P5 (mm)	-3.1 (3.6)	80	.000*	0.7 (1.9)	29	.304	.000*
W1 (mm)	-0.8 (1.1)	94	.000*	-0.3 (0.7)	32	.222	.000*
W2 (mm)	-1.3 (1.7)	94	.000*	-0.4 (1.3)	33	.056	.000*
W3 (mm)	-1.8 (2.1)	94	.000*	-0.4 (1.8)	33	.047*	.000*
W4 (mm)	-1.8 (2.3)	93	.000*	-0.1 (2.1)	32	.247	.000*
W5 (mm)	-2.1 (2.6)	79	.000*	0.5 (2.3)	29	.647	.000*

*Statistically significant

Tables 5 – 8 show the amount of bone changes at each level according to the different malocclusions.

Table 5. *Median and interquartile range (IQR) of class I bone thickness changes.*

Measurement	Positive Inclination Δ			Negative Inclination Δ			PIC and NIC Comparison
	Median (IQR)	N	P value	Median (IQR)	N	P value	P value
L1 (mm)	0.0 (0.3)	51	.337	0.0 (0.2)	15	.093	.079
L2 (mm)	0.1 (0.3)	51	.000*	0.0 (0.6)	16	.603	.003*
L3 (mm)	0.3 (0.4)	51	.000*	-0.3 (0.8)	16	.603	.002*
L4 (mm)	0.7 (0.7)	50	.000*	-0.3 (0.6)	15	.806	.000*
L5 (mm)	1.0 (1.1)	47	.000*	0.2 (1.7)	14	.382	.000*
P1 (mm)	-0.9 (0.9)	51	.000*	-0.4 (1.1)	16	.132	.008*
P2 (mm)	-1.6 (1.2)	51	.000*	-0.1 (1.7)	16	.149	.012*
P3 (mm)	-2.2 (1.5)	51	.000*	-0.7 (2.9)	16	.164	.000*
P4 (mm)	-2.4 (1.9)	50	.000*	-0.1 (3.2)	15	.233	.000*
P5 (mm)	-3.0 (2.5)	47	.000*	-0.6 (4.2)	14	.754	.000*
W1 (mm)	-0.9 (1.1)	51	.000*	-0.3 (1.0)	15	.125	.013*
W2 (mm)	-1.3 (1.2)	51	.000*	-0.3 (1.9)	16	.118	.009*
W3 (mm)	-1.8 (1.5)	51	.000*	-0.7 (2.3)	16	.078	.001*
W4 (mm)	-1.8 (1.9)	50	.000*	-0.3 (2.6)	15	.132	.001*
W5 (mm)	-2.1 (2.0)	47	.000*	-0.5 (3.6)	14	.184	.020*

*Statistically significant

Table 6. *Median and interquartile range (IQR) of class II division 1 bone thickness changes.*

Measurement	Positive Inclination Δ			Negative Inclination Δ			PIC and NIC Comparison
	Median (IQR)	N	P value	Median (IQR)	N	P value	P Value
L1 (mm)	0.0 (1.9)	5	1.000	-0.1 (0.7)	12	.969	.849
L2 (mm)	0.0 (0.4)	5	.144	0.1 (0.7)	12	.865	.171
L3 (mm)	0.3 (1.1)	5	.144	0.1 (0.5)	12	.865	.171
L4 (mm)	0.0 (2.0)	5	.465	0.0 (0.6)	12	.672	.435
L5 (mm)	0.3 (1.9)	3	1.000	-0.1 (0.9)	10	.176	.776
P1 (mm)	-0.4 (1.2)	5	.279	-0.2 (0.6)	12	.498	.284
P2 (mm)	-0.6 (2.0)	5	.225	-0.4 (1.5)	12	.326	.524
P3 (mm)	-1.6 (2.4)	5	.223	-0.4 (1.5)	12	.888	.222
P4 (mm)	-1.7 (3.2)	5	.225	0.1 (1.3)	12	.262	.093
P5 (mm)	-0.7 (4.3)	3	1.000	0.8 (1.3)	10	.017*	.376
W1 (mm)	-0.5 (0.9)	5	.136	-0.2 (0.9)	12	.674	.065
W2 (mm)	-0.4 (1.8)	5	.225	-0.3 (1.6)	12	.779	.435
W3 (mm)	-0.5 (2.0)	5	.345	-0.2 (1.4)	12	1.000	.354
W4 (mm)	-0.5 (2.3)	5	.345	-0.1 (1.7)	12	.396	.171
W5 (mm)	-0.8 (2.6)	3	1.000	1.0 (1.8)	10	.107	.497

*Statistically significant

Table 7. *Median and interquartile range (IQR) of class II division 2 bone thickness changes.*

Measurement	Positive Inclination Δ			Negative Inclination Δ	
	Median (IQR)	N	P value	Median (IQR)	N
L1 (mm)	0.0 (0.2)	19	.286	- -	0
L2 (mm)	0.2 (0.5)	19	.003*	- -	0
L3 (mm)	0.3 (0.6)	19	.003*	- -	0
L4 (mm)	0.6 (0.9)	19	.001*	- -	0
L5 (mm)	1.3 (1.6)	16	.004*	- -	0
P1 (mm)	-1.1 (1.2)	19	.000*	- -	0
P2 (mm)	-2.4 (2.5)	19	.000*	- -	0
P3 (mm)	-3.4 (2.3)	19	.000*	- -	0
P4 (mm)	-4.2 (4.7)	19	.000*	- -	0
P5 (mm)	-5.4 (5.4)	16	.001*	- -	0
W1 (mm)	-0.9 (1.3)	19	.000*	- -	0
W2 (mm)	-2.2 (2.4)	19	.000*	- -	0
W3 (mm)	-3.0 (3.0)	19	.000*	- -	0
W4 (mm)	-2.9 (2.8)	19	.000*	- -	0
W5 (mm)	-3.7 (5.2)	15	.016*	- -	0

*Statistically significant

Table 8. *Median and interquartile range (IQR) of class III bone thickness changes.*

Measurement	Positive Inclination Δ			Negative Inclination Δ			PIC and NIC Comparison
	Median (IQR)	N	P value	Median (IQR)	N	P value	P Value
L1 (mm)	-0.2 (0.5)	20	.443	0.1 (0.2)	4	.102	.210
L2 (mm)	-0.1 (0.7)	20	.191	-0.1 (0.3)	4	.180	.249
L3 (mm)	0.1 (1.0)	20	.191	-0.1 (0.3)	4	.180	.249
L4 (mm)	0.6 (1.5)	20	.024*	-0.4 (1.0)	4	.180	.039*
L5 (mm)	1.4 (2.4)	15	.006*	-1.0 (2.1)	4	.144	.015*
P1 (mm)	-0.5 (1.5)	20	.001*	-0.4 (0.7)	4	.102	.554
P2 (mm)	-0.8 (2.0)	20	.001*	-0.7 (0.8)	4	.066	.963
P3 (mm)	-1.1 (2.4)	20	.001*	-0.2 (1.5)	4	.465	.148
P4 (mm)	-1.5 (2.1)	20	.002*	0.4 (1.6)	4	.715	.039*
P5 (mm)	-1.9 (3.7)	15	.001*	0.7 (1.6)	4	.715	.006
W1 (mm)	-0.6 (1.3)	20	.013*	-0.2 (0.7)	4	.285	.211
W2 (mm)	-0.7 (1.7)	20	.003*	-0.6 (0.7)	4	.068	.820
W3 (mm)	-0.8 (1.4)	20	.014*	-0.3 (1.8)	4	.465	.335
W4 (mm)	-0.8 (1.7)	20	.019*	-0.1 (2.5)	4	.465	.494
W5 (mm)	-0.4 (3.4)	15	.108	-0.3 (3.7)	4	.715	.703

*Statistically significant

SRP Classification

Overall, 82% (104) of teeth were class I SRP at T1 and the remaining 18% (23) were class II SRP. No teeth included in the study were class III or IV SRP at T1. At T2 37% (47) were class I SRP, 53% (68) were class II SRP, and 8% (10) & 2% (2) were class III and class IV SRP respectively (Figure 9). Figure 9 shows the frequency distribution of SRP classification according to the inclination change at T1 and T2.

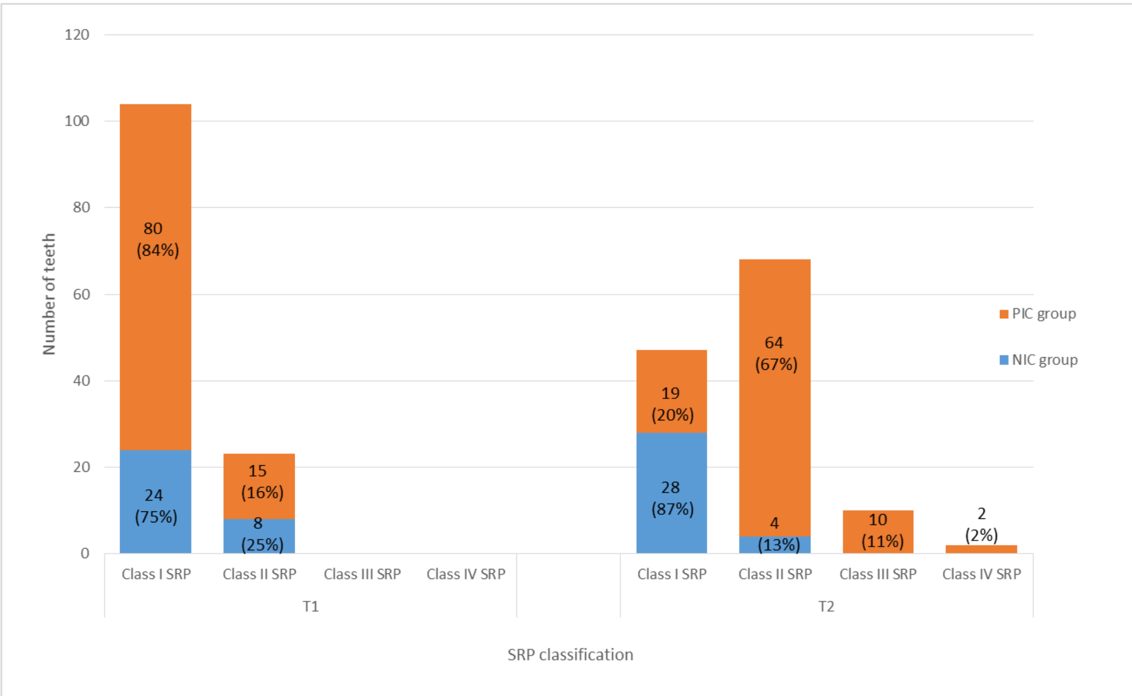

Figure 9. Frequency distribution of SRP classification for PIC and NIC groups at T1 and T2

Figure 10 shows the frequency distribution of SRP classification change according to the inclination change. In the PIC group 33% of teeth did not experience SRP change. Of the 67% that experienced SRP change, the majority (55%) changed from Cl I to Cl II SRP (Figure 10). In contrast, in the NIC group most of the teeth (81%) of teeth did not experience SRP change. Of the 19% that experienced SRP change, 3% changed from Cl I to Cl II SRP and 16% changed from Cl II to Cl I SRP (Figure 10).

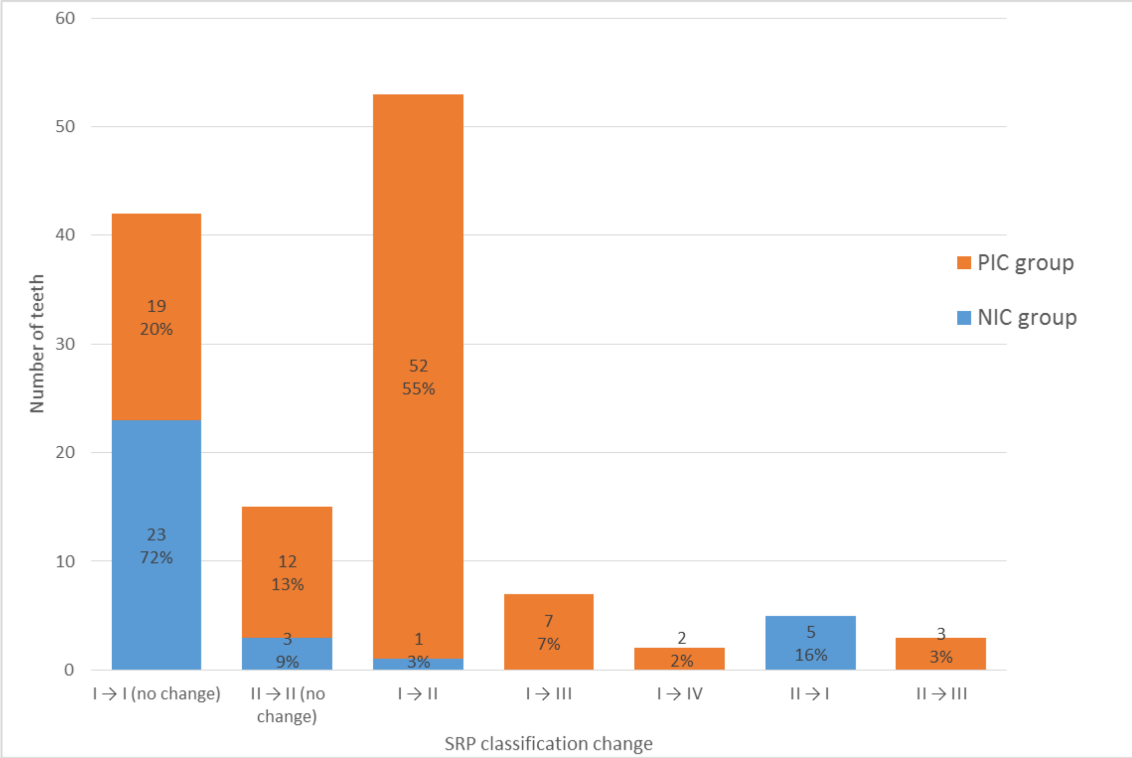

Figure 10. Frequency distribution of SRP classification change according to the inclination change

Discussion

Orthodontic tooth movement is made possible in part by interactions of teeth and bones with the periodontal ligament (PDL).[12,33] The PDL plays a central role in the "pressure-tension theory" of tooth movement and is responsible for the symmetric zones of apposition and resorption that allow teeth to move through bone - according to this theory.[34] Other theories of tooth movement emphasize the mechanical transduction of forces - forces that cause new bone to be added through alveolar bending or conversely, cause bone to be removed from the absence of strain such as in the "stretched fiber hypothesis."[35,36] In all cases, forces acting on teeth are translated to a biological level and result in the reorganization of intra- and extra-cellular matrices and local vascularization.[37, 38] These biological events are ultimately responsible for movement of teeth.

Orthodontic movement of teeth within bone occurs either by movement of teeth *through* the bone or *with* the bone.[12] In tooth movement *with* bone, resorption and apposition by osteoclasts and osteoblasts in the periodontal ligament space is balanced much like in physiological tooth movement.[12,39] Apposition at the external surface of the alveolus and resorption along the inner surface in the direction of the force allows teeth to be moved beyond the boundaries of the original alveolar process and maintains bone thickness dimension.[39] Correction of defects through coordinated resorption and apposition is also possible as has been shown in patients with periodontal compromised teeth characterized by infrabony defects that demonstrate significant improvements to marginal bone height and bone defect radiologic dimension following orthodontic tooth movement.[40,41]

Movement of teeth through the bone is seen when the ratio of resorption and apposition is unequal.[39] Large forces on teeth cause undermining resorption from adjacent marrow spaces and tip the balance toward bony resorption because little apposition occurs as a result of limited tooth displacement on the tension side as the pressure side is resorbed.[12,33] While direction of tooth movement is easily anticipated,[16,18,22,32] the response of surrounding bone as a result of imbalanced apposition and resorption makes it hard to estimate bone thickness changes.

In the current study bone thickness changes in the overall sample for the PIC group were significant ($p < 0.05$, Table 4) for all measurements except L1 ($p = .492$, Table 4). Although the increase in labial alveolar bone at the cervical level was minimal, the labial bone thickness increased at each ascending level. In this study, palatal bone thickness decreased significantly at all levels ($p < 0.05$, Table 4) and these decreases were significantly greater than the labial bone thickness increases at the same levels ($p < 0.05$, Table 4), resulting in the total alveolar width decrease at all levels. These results were similar to results reported by Thongudompron et al, despite a substantial difference in mean PIC (12.1° vs 3°).[17]

In the NIC group of this study, most of the dimensional changes were not significant ($p > 0.05$, Table 4). These results are not consistent with the results from other studies with similar mean NIC.[18,43] Yodthong et al (NIC = 10.9 ± 3.9°) evaluated bone change around maxillary incisors during retraction after extraction of first premolars at three levels and reported significant increases to labial bone at the cervical level and total alveolar width at the apical level.[43] In a similar study, Ahn et al (NIC = 10.4 ± 5.9°) reported significant increases to the middle labial area of bone but decreases in palatal bone thickness/area.[18] The current study did not account for specific types of incisor movement and did not quantify the vertical (intrusion/extrusion) or mesio-distal movements which could explain some differences in our results compared to those of other studies. Extrusion for example is commonly associated with tipping of teeth.[43-45] Extrusion of the teeth toward the more narrow part of the alveolus as teeth are tipped into new positions would lead to changes in alveolar width measurements, specifically decreases in alveolar width, as was observed in this study.

On the labial side all measures except L5 changed by 0.6 mm or less (Table 4). With the limitations of scan resolution at 0.3 mm for scans in this study and considering that the accuracy of measurements on CBCT scans is approximately 0.2 mm[27,46] these measurements are nearly equivalent to zero. These observations suggests that the labial plate did not change significantly, if at all, and the process of apposition and resorption in this case caused the bone to move with the tooth root rather than maintain its dimension.

Data when examined by classification groups showed identical trends to those found in the overall data. Cl II div 2 cases had no teeth that showed NIC, but the trend of increasing labial thickness and decreasing palatal thickness and alveolar width held for the PIC group. Small sample sizes in the two class II and class III groups limited the power of statistical analysis and may have impacted the statistical significance of some measurements.

Inclination change as used throughout this study was defined as change in the inclination of the root as measurements of root inclination specifically targeted movement of the root within the bone which was the focus of this study. Measurement of tooth inclination incorporated the crown into the inclination change calculation and because of differences in Collum angles these measures were suspected of variation that might misrepresent inclination change. Actual measurements of tooth vs root inclination were significantly different ($p < 0.05$); however, changes in inclination calculated from either measure were not significantly different ($p = .943$).

The Collum angle of maxillary incisors has been examined over the years and evidence suggests that there are differences in Collum angle between different malocclusions; specifically, class II div 2 and class III malocclusions show marked differences in Collum angle from other malocclusions.[47-49] The results from this study show means for Cl I, Cl II div 1, Cl II div 2 and class III groups of 2.1 ± 3.5°, -0.2 ± 4.1°, 3.9 ± 3.1° and 1.5 ± 3.6° respectively, but the only statistically significant differences were between Cl II div 1 and div 2 groups ($P < 0.05$). Collum angle measurements in the current study were similar to those reported in other studies (Cl I = 1.05 ± 1.50°, Cl II div 1 = 0.95 ± 1.06°, and Cl II div 2 = 3.24 ± 4.69°)[49] but were made from individual images of each incisor from CBCT scans whereas other studies used lateral cephalograms that might limit the accuracy of Collum angle measurements.[52]

Collum angles were used to calculate final crown position by subtracting Collum angle from root inclination measurements (CrA = RI – CA), essentially combining a measure of the root position with a measure of how the crown relates to the root to generate a numerical representation of final crown position. Tooth inclination measurements also represent the final position of the tooth in relation to the cranial base and CA and tooth inclination represent the position of the tooth clinically. Comparison of crown angulation and tooth inclination yielded a statistically significant correlation ($r = .946$, $p = 0.001$) and no significant differences between actual values ($p > 0.05$) indicating that CrA describes crown position similar to tooth inclination.

It is interesting to note that despite the differences in Collum angle and root inclination changes between class II div1 and div 2 malocclusions, mean values for final (T2) tooth inclination and CrA in the same groups were not statistically different ($P > 0.05$) meaning incisors from both groups were treated to similar crown positions clinically. This observation can be expanded to include class I in the current study, as incisors in that group were also treated to tooth inclinations that were not significantly different than class II div 1 or div 2 groups ($p > 0.05$). Class III teeth in comparison were finished with significantly different crown angulations and tooth inclinations than the other groups (CrA = 114.8°, $P \leq 0.001$ and Tooth Inclination = 115.2°, $p \leq 0.003$). This result most likely reflects a common compromise in tooth position to compensate for a skeletal imbalance in Cl III cases.

The frequency distribution of SRP in this study at T1 (82% Class I, 18% Class II) was somewhat different from that reported by Kan et al (86.5% Class I, 5% Class II, 0.5% Class III and 8% Class IV).[9] The fact that cases were selected based on change in inclination rather than from random selection may have contributed to this result. At T2, however, the frequency distribution of SRP was markedly different (37% Class I, 53% Class II, 8% Class III and 2% Class IV). These results suggest that orthodontic tooth movement appears to have an impact on SRP classification. Positive inclination change appears to have a greater effect on change in SRP classification than negative inclination change as 67% of teeth in the PIC group changed SRP classification compared to 19% of teeth in the NIC group. 82% of teeth were Cl I SRP at T1 meaning the roots of most teeth closely approximated the labial cortical plate, so NIC (labial root movement) would not likely alter the SRP classification because the labial plate is already positioned next to the root. With PIC the possibility of changing SRP classification is more likely because more bone was present in the direction of movement of the root.

All teeth in the NIC group that changed SRP classification except one changed from class II SRP to class I SRP, which follows the anticipated direction of bony change. The one incisor that changed from class I SRP to class II SRP in spite of negative inclination change may have been affected by bodily movement during retraction treatment. This type of movement could potentially reposition the tooth within the alveolus to the extent that bony changes would not follow the pattern of isolated root movement through the bone. The paucity of results in the NIC group for all bone thickness changes may be a result of the confounding effects of various tooth movements.

In evaluation of those teeth that did change SRP classification compared to those that did not, a pattern in the amount of inclination was apparent. For both PIC and NIC groups teeth that changed SPR classification experienced more inclination change those that did not indicating that greater changes in tooth inclination are more likely to cause changes in SRP classification.

At first glance the results of this study may appear to support the tooth through the bone hypothesis: as the root increases inclination more bone is found on the labial surface and less on the palatal surface as a result of equal rates of resorption and apposition. But decreases in total alveolar width challenge this interpretation and indicate that the balance of bony changes favored resorption. From the current study results it is impossible to show *where* resorption is occurring, but studies examining the character of bone and its alteration following implant placement have demonstrated an increased susceptibility to resorption in the buccal area[53,54] where bone is typically thinner. Thus the resorption may be occurring on the buccal surface. Further study may shed light on the exact location and balance of resorption and apposition, but this study demonstrates a significant effect from positive inclination change on sagittal root position of the maxillary central incisor and bone thickness changes. Bone remodeling does not cease following the completion of treatment however and may cause changes to SRP post treatment.[55] T2 records in the current study were taken immediately following removal of appliances therefore long term follow up is necessary to verify the permanence of any SRP classification changes.

As indicated previously, class I SRP can be considered an indication for successful IIP, but Cl II SRP may not have sufficient bone on either side to sufficiently support an implant following extraction.[9] Cl III and IV SRP also present challenges to IIP that may eliminate IIP as a viable treatment option for patients. From the perspective of planning for IIP, changes to Cl I SRP from other SRP classifications would benefit the probable success of IIP but changes in the reverse would diminish the possibility of success. In the current study, no teeth changed from Cl III or IV SRP to Cl 1, but several teeth changed from Cl II SRP to Cl I. In order to change from Cl II to Cl I SRP root inclination has to decrease and allow the root to approximate the labial plate. In the current study, 8 teeth in the NIC group at T1 were Cl II SRP and 5 of these changed to Cl I (63%). This shows that orthodontic tooth movement can change SRP and potentially improve the bony support for IIP.

Conclusions

As a result of data gathered and analyzed in the current study the authors can make the following conclusions:

1. The impact of positive inclination change on the alveolar bone is different than negative inclination change.
2. Orthodontic tooth movement that causes inclination change can affect maxillary incisor SRP classification.
3. Crown position in Cl I, Cl II Div 1, and Cl II div2 cases are treated to similar positons clinically despite differences in T1 inclination and crown-root morphologies.

The null hypotheses were rejected: orthodontic tooth movement causes changes in alveolar dimensions and SRP classification.

CHAPTER THREE

EXTENDED DISCUSSION

Study Limitations

The limitations of this study should be considered in order to further interpret its results. First, CBCT measurements have limited accuracy for the type of fine measurements being made in this study and may not perfectly reflect actual changes in hard tissue.[46,56-58] Second, data in this study was gathered at two static points in time. Bone changes and adaptation to new tooth positions is a continuous process and records taken immediately following the termination of treatment may not reflect the complete bone changes as a result of tooth movement.[55] Long term follow up of these teeth may provide additional insight into the effect of tooth movement on alveolar changes.

Lastly, movements of teeth outside of the change in inclination were not quantified as a part of this study and these movements may have had an impact on changes in alveolar bone measurements.[17,18,43-45] Further stratification of data and accounting for different forms of tooth movement may help isolate the specific effect of inclination change on alveolar changes.

Future Study Direction

Considering the findings and limitations of the current study there is potential for further and improved study on bone and SRP classification changes as a result of orthodontic tooth movement. As CBCT continues to improve in resolution and accuracy it may be possible to make measurements of minute bony dimensions that more accurately reflect hard tissue changes. Further stratification of orthodontic tooth movement that occurs in combination with inclination changes might reveal more specific patterns of bone change. Examining bone change beyond T2 may also be valuable in determining the permanence of any bone or SRP classification changes.

Finally, more targeted examination of patients that are candidates for IIP and analyses of the specific effect of orthodontic treatment on the alveolar bone of these patients would be valuable in assessing the potential benefit of orthodontic treatment in planning for IIP.

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