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Date: June 30, 2010

A COMPARISON OF CROWN AND ROOT POSITION OF THE MANDIBULAR INCISORS BEFORE AND AFTER ORTHODONTIC TREATMENT USING CONE BEAM COMPUTED TOMOGRAPHY

By

Lindsey Schilling, DMD

Submitted in partial fulfillment of the requirements for the degree of Masters of Science in Dentistry

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A COMPARISON OF CROWN AND ROOT POSITION OF THE MANDIBULAR INCISORS BEFORE AND AFTER ORTHODONTIC TREATMENT USING CONE BEAM COMPUTED TOMOGRAPHY

Abstract

by

LINDSEY SCHILLING DMD

Objective: The purpose of this study was to develop a reliable method to assess crown and root position of the mandibular incisors before and after orthodontic treatment using CBCT scans. **Methods:** Fifty-one patients with initial and final CBCT scans were randomly selected from the eligible patients. Measurements were made at the incisal edge and a point located at one third the root length. Means and standard deviations were calculated for displacement of the crowns and roots and compared using students t-test. **Results:** Mean root movement in the sagittal plane was lingual. Right lateral root was displaced -0.49±1.01mm, right central -0.50±0.98mm, left central -0.47±1.03mm and left lateral -0.54±0.92mm ($p=0.001$, $p<0.001$, $p=0.002$ and $p<0.001$,

respectively). Mean root movement in the coronal plane was lateral. Right lateral root was displaced 0.74±1.0mm, right central 0.07±1.04mm, left central 0.13±0.96mm and left lateral 0.61±1.30mm ($p<0.001$, $p=0.607$, $p=0.344$, and $p=0.001$, respectively). Mean crown movement in the sagittal plane was labial. Right lateral crown was displaced 1.08±1.75mm, right central 0.63±1.53mm, left central 0.53±1.56mm and left lateral 1.27±1.94mm ($p<0.001$, $p=0.005$, $p=0.019$ and $p<0.001$, respectively). Mean crown movement in the coronal plane was distal for all except for left central that moved mesial. Right lateral crown was displaced 0.12±1.11mm, right central 0.13±0.99mm, left central -0.08±0.82mm and left lateral 0.24±1.01mm ($p=0.418$, $p=0.349$, $p=0.469$, and $p=0.085$, respectively). **Conclusions:** CBCT scans can be used to measure the displacement of the crowns and roots during orthodontic treatment. Mean movement of crowns in this sample was labial and distal and roots was lingual and distal.

Literature Review

Orthodontists have always been interested in the position of the lower incisor. Tweed was one of the first to emphasize the importance of the position of the lower incisor. In a paper published in 1941, Tweed proposed that the lower incisor be placed at an angle of 90 degrees plus or minus five degrees to the lower boarder of the mandible. He came to this conclusion after review of his own patients with good facial esthetics. He studied the cut plaster models and found that the lower incisors were "upright over basal bone." Herbert Margolis, in 1943, reviewed skulls, illustrations, plaster models, and radiographs of untreated and treated individuals and reported "that the best results are obtained when the lower incisors are 'vertical' and form a right angle with the mandibular plane."

Tweed continued with his study of cases that did not have the facial improvement that he would have liked at the conclusion of treatment and found that when the

mandibular plane angle was increased or decreased the mandibular incisors should no longer be at 90 degrees to the mandibular plane. Tweed wrote in 1946 that as the Frankfort-mandibular plane angle varies from 25^0s the prognosis of the case decreases. Tweed then described in 1953 and 1954, the relationship of the Frankfort-mandibular plane angle to the inclination of the lower incisor. For every degree that the Frankfort-mandibular plane angle increases past 25^0, the lower incisor angulation to the mandibular plane should be decreased 1 degree. With the normal of 25^0 for the FMA and 90 degrees for IMPA, the relation of the lower incisor to Frankfort Horizontal should be 65 degrees (FMIA). Thus, Tweed has shown that as the FMA increases the IMPA should decrease to compensate for the higher mandibular plane angle, and the lower incisors will stay in harmony with the facial esthetics. Even though Tweed was possibly biased in the sample selected, many orthodontists still use the norm of 90 degrees to mandibular plane to diagnose their patients.

Others followed by publishing other ways to analyze the lower incisor's position in the face. Steiner

published in 1953 an article titled "Cephalometrics for You and Me." He proposed measuring the relationship of the lower incisors to the NB line in millimeters and as an angle between the long axis of the tooth to the NB line. He found Porion a difficult point to locate and therefore chose sella - nasion to be a more reliable reference plane then Frankfort Horizontal. He also stated that the inferior boarder of the mandible is a curved surface, so there is difficulty in fitting a straight line to the lower boarder of the mandible. The norm for the lower incisor was suggested to be 4mm in front of the NB line and 25 degrees to the line.

Downs, in 1948, reported on an analysis to relate the lower incisor to the APo line. The linear measurement is on average 0mm, with the lower incisors resting on the APo line. Again he is relating the position of the lower incisors to a facial plane instead of using the mandibular plane as the reference line.

The alignment and stability of the dentition is of great interest to the orthodontist and the orthodontic patient. Lower anterior crowding is one of the most frequently occurring malocclusions and one of the most

concerning for patients seeking orthodontic services. The Irregularity Index was published in 1975 by Little, as a way to measure and compare lower anterior discrepancies. His proposed measuring method involves measuring the linear displacement of the anatomic contact points of each mandibular incisor from the adjacent tooth anatomic contact point, the sum of these five displacements representing the relative degree of anterior irregularity. The index proved to be a reliable measure with no significant differences between multiple measures of the same dental casts. The index also proved to be valid with a predictable linear relationship ($r = 0.81$) between subjects clinical assessment and ranking of crowding against the quantitative Irregularity Index. The major limitation to the index is its tendency to exaggerate cases with irregularity but little arch length shortage. Also the index does not take into account other factors such as cephalometric patterns, facial esthetics, and age that could play a very important role in determining a treatment plan for the patient.

Sinclair and Little (1983) reported on the change in the dentition over time in the absence of orthodontic treatment. Sixty-five untreated persons with normal

occlusions were evaluated to determine the natural changes in the dentition with time and growth. They found an increase in incisor irregularity from 13 to 20 years with females exhibiting more incisor irregularity than males at the adult stage. In 1985, Sinclair and Little published again on the changes in dentofacial maturation of untreated individuals. They studied cephalometric head films of 65 untreated individuals and found that the lower incisor angulation to cranial base is relatively stable. Additionally they demonstrated incisor compensations to skeletal changes, which resulted in the maintenance of the occlusal relationship. They found no correlations between these radiographic findings and the previous cast measurements. Eslambolchi studied longitudinal changes in both untreated children and adults over a 29.8 year period for the children and a 33.7 year period for the adults. In contrast to Sinclair, they reported no differences between the sexes with regard to overjet, overbite, mandibular intercanine width, mandibular interfirst premolar width, mandibular interfirst permanent molar width, mandibular arch length, mandibular arch length, mandibular incisor irregularity index, or mandibular anterior space analysis. An

increase in incisor irregularity occurs throughout life and well into the seventh decade of life. However, the rate seems to decrease with age.

Similar studies were conducted to investigate the changes in orthodontically treated dentitions to assess the stability and relapse of orthodontic treatment. Little reports, in the University of Washington Studies, that treated individuals and untreated individuals show similar physiologic changes including the increase in mandibular anterior crowding well into the 20 to 40 year age bracket and likely beyond. The amount of postretention anterior crowding was unpredictable, and variable and no pretreatment variables seemed to be helpful predictors of this crowding.

Tweed, Steiner, and Downs are just a few of the many orthodontists that have put forward measurements to assess the position of the lower incisor in the face. The cephalometer, however, is only able to assess landmarks and anatomic structures in 2 dimensions. Little's Irregularity index is able to assess the lower anterior crowding, but is limited to the crowns of the teeth. With its introduction in the late 1990's, Cone

Beam Computed Tomography (CBCT) has quickly become a remarkable radiographic tool in all aspects of dentistry. The whole tooth and its position in the skull can be analyzed and measured in 3D.

Huang et al. (2005) outline several of the benefits of using the CBCT in orthodontics. Some of the benefits include, but are not limited to, generation of a 3-D volume that can be manipulated to infinite views of the patient, generation of images that are similar to conventional headfilms yet are a true 1:1 representation of the patient, excision of irrelevant structures to avoid superimposition, visualization of surface irregularities of the jaws and alveolus, visualization of the soft tissue overlying the bone, occlusal views of the arch form, visualization of the tempromandibular joint and its relation to the intercuspal positions, 3-D view of the crown and root of the teeth and the position of the root in the alveolus, and, finally, the special and volumetric analysis of the sinuses and airway. With increased use of the CBCT scans for orthodontic patients, we are just beginning to explore the possible uses of the information gained by a simple ten second scan.

Periago et al (2008) investigated the reliability and accuracy of linear measurements made on 3D reconstructions to direct measurements made on ex vivo human skulls. They hypothesized that the accuracy of linear measurements obtained from 3D surface renderings of CBCT datasets is similar to direct measurements made on ex vivo human skulls. Twenty-three anonymous dry human skulls with reproducible occlusions and full dentition were included in the study. Fourteen landmarks were marked on each skull and 20 linear distances were measured. All distances were measured three times by two observers using an electronic digital caliper. The mean of the six measurements was considered the dimensional truth. Cone beam CT images were acquired using the i-CAT system and viewed using Dolphin 3D. The same 14 landmarks were identified on the CBCT image, and the same 20 linear distances were measured using the software. The 3D CBCT measurements were reported to be reliable with an intraclass correlation coefficient of 0.976. The 3D CBCT data was found to have significant differences to actual skull measurements for 13 of the 20 measurements. The mean percentage difference between the mean skull and

3D-based linear measurements was -1.13% ± 1.47%. They found that 90% of the measurements had an average difference of less than 2mm. The authors also state that measurement accuracy could be due to voxel size.

In another study by Brown et al (2009), they compared the in vitro reliability and accuracy of linear measurements between cephalometric landmarks from CBCT derived 3D surface renderings from variable number of projection images. Using a similar research design as Periago et al. fifteen landmarks were identified and sixteen linear distances were measured. The skulls were then placed in the plastic holder in a similar manner and a 10 second scan (153 projections), a 20 second scan (306 projections), and a 40 second scan (612 projections) was completed for each skull. Overall mean percentage measurement error for anatomic skull dimensions (0.45mm ± 0.08 mm) was significantly lower than for any of the CBCT measurements (CBCT 10 0.44mm, CBCT 20 0.38mm and CBCT 40 0.32mm). However, there was no statistical difference between the CBCT modalities. In conclusion, reducing the number of image projections needed to construct a 3D image does not result in reduced dimensional accuracy.

A recent study by Chen et al. demonstrates the use of the CBCT to quantify 3D tooth displacement and tests its accuracy. Images of the same mandible were taken 2 weeks apart with no treatment. Four teeth remained unmoved or were artificially displaced a known amount to simulate after-treatment conditions. Superimposition of the two images was completed using he unchanged boney areas and to find the transformation matrix between the tooth's 2 positions. Tooth displacement was calculated from the transformation matrix. The results showed that errors could be managed and were less than 5% in translation and 10% in rotation. The advantage of this study was that they were using mandibles that were not changing. They were not blinded to the quantity or direction of the changes.

With the ability to study the dentition in 3D and the ongoing question of the position and relapse of the lower anterior teeth, the purpose of this research was to develop a reliable method to assess crown and root position of the mandibular incisors before and after orthodontic treatment using CBCT scans. The new method will allow for the collection of means and ranges of

crown and root position before and after orthodontic treatment using the CBCT scans. This study will also allow for the development of an index of crown and root irregularity.

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Statement of Thesis

The purpose of this research is to develop a reliable method to assess crown and root position of the mandibular incisors before and after orthodontic treatment using CBCT scans. The new method will allow for the collection of means and ranges of crown and root position before and after orthodontic treatment using the CBCT scans. This study will also allow for the development of a crown and root displacement measurement.

A COMPARISON OF CROWN AND ROOT POSITION OF THE MANDIBULAR INCISORS BEFORE AND AFTER ORTHODONTIC TREATMENT USING CONE BEAM COMPUTED TOMOGRAPHY

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Objective: The purpose of this study was to develop a reliable method to assess crown and root position of the mandibular incisors before and after orthodontic treatment using CBCT scans. **Methods:** Fifty-one patients with initial and final CBCT scans were randomly selected from the eligible patients. Measurements were made at the incisal edge and a point located at one third the root length. Means and standard deviations were calculated for displacement of the crowns and roots and compared using students t-test. **Results:** Mean root movement in the sagittal plane was lingual. Right lateral root was displaced -0.49±1.01mm, right central -0.50±0.98mm, left central -0.47±1.03mm and left lateral -0.54±0.92mm ($p=0.001$, $p<0.001$, $p=0.002$ and $p<0.001$, respectively). Mean root movement in the coronal plane was lateral. Right lateral root was displaced 0.74±1.0mm, right central 0.07±1.04mm, left central 0.13±0.96mm and left lateral 0.61±1.30mm ($p<0.001$, $p=0.607$, $p=0.344$, and $p=0.001$, respectively). Mean crown movement in the sagittal plane was labial. Right lateral crown was displaced 1.08±1.75mm, right central 0.63±1.53mm, left central 0.53±1.56mm and left lateral 1.27±1.94mm ($p<0.001$, $p=0.005$, $p=0.019$ and $p<0.001$, respectively). Mean crown movement in the coronal plane was distal for all except for left central that moved mesial. Right lateral crown was displaced 0.12±1.11mm, right central 0.13±0.99mm, left central -0.08±0.82mm and left lateral 0.24±1.01mm ($p=0.418$, $p=0.349$, $p=0.469$, and $p=0.085$, respectively). **Conclusions:** CBCT scans can be used to measure the displacement of the crowns and roots during orthodontic treatment. Mean movement of crowns in this sample was labial and distal and roots was lingual and distal.

INTRODUCTION

Orthodontists have always been interested in the position of the mandibular incisors. Tweed first reported on the position of the lower incisor in 1941 after his study of plaster models.[1] He showed to achieve good facial esthetics the lower incisor should be upright over basal bone and placed at an angle of 90 degrees plus or minus five degrees to the lower boarder of the mandible.[2,3,4] Margolis[5] in 1943 confirmed Tweeds hypothesis and reported "that the best results are obtained when the lower incisors are 'vertical' and form a right angle with the mandibular plane."

Others followed by publishing other ways to analyze the lower incisors position in the face. Steiner[6], in 1953, proposed measuring the relationship of the lower incisors to the NB line in millimeters and as an angle between the long axis of the tooth to the NB line. The norm for the lower incisor was suggested to be 4mm in front of the NB line and 25 degrees to the line. Downs[7], in 1948, reports on an analysis to relate the lower incisor to the APo line. The linear measurement is on average 0mm, with the lower incisors resting on the APo line.

Not only has the position of the incisor become important but also the crowding of the lower incisors. The Irregularity Index was published in 1975 by Little[8], as a way to measure and compare lower anterior discrepancies. The Irregularity Index involves measuring the linear displacement of the anatomic contact points of each mandibular incisor from the adjacent tooth anatomic contact point, the sum of these five displacements representing the relative degree of anterior

irregularity. Sinclair and Little[9] reported on the change in the dentition over time in the absence of orthodontic treatment. They found an increase in incisor irregularity from 13 to 20 years with females exhibiting more incisor irregularity than males at the adult stage. In 1985, Sinclair and Little[10] also published on the changes in dentofacial maturation in untreated individuals. With regards to the lower incisor they found that the incisor angulation to the cranial base is relatively stable, showing compensations to skeletal changes which resulted in the maintenance of the occlusal relationship. Eslambolchi studied longitudinal changes in both untreated children and adults over a 29.8 year period for the children and a 33.7 year period for the adults. In contrast to Sinclair, they reported no differences between the sexes with regard to Irregularity Index. An increase in incisor irregularity occurs throughout life and well into the seventh decade of life. However the rate seems to decrease with age. [11]

Similar studies were conducted to investigate the changes in orthodontically treated dentitions to assess the stability and relapse of orthodontic treatment. Little[12] reports, in the University of Washington Studies, that treated individuals and untreated individuals show similar physiologic changes including the increase in mandibular anterior crowding well into the 20 to 40 year age bracket and likely beyond. The amount of postretention anterior crowding was unpredictable and variable and no pretreatment variables seemed to be helpful predictors of this crowding.

With the advent of the Cone Beam Computed Tomography (CBCT) to the field of dentistry, we can now study patients in 3D rather than with 2D radiographs or plaster models. The image obtained is a 1:1 representation of the skull and measurements can be made accurately and reliably.[13,14,15] The whole tooth and its position in the skull can be analyzed and measured in 3D.

In keeping with the ongoing question of the position and stability of the lower anterior teeth, the purpose of this study was to develop a reliable method to assess root position of the mandibular incisors before and after orthodontic treatment using CBCT scans. The new method will allow for the collection of means and ranges of crown and root position before and after orthodontic treatment using the CBCT scans. This study will also allow for the development of a measure of crown and root displacement.

MATERIALS AND METHODS

IRB approval was obtained prior to the selection of the study sample. The sample population was randomly selected from those patients that have completed orthodontic treatment at an established Graduate Program located in the midwest and whose records include both pre-treatment and post-treatment CBCT scans. All CBCT scans were taken with the Hitachi CB MercuRay at 8 inch field of view and 2mA. The following inclusion criteria were followed:

1. Fully erupted mandibular centrals and laterals.

2. No previous orthodontic treatment based on medical history form.

3. No congenitally missing teeth in mandibular arch based on CBCT scan.

4. No extracted permanent mandibular teeth before or during orthodontic treatment determined by CBCT scan.

5. Landmarks (incisal edge and root PDL) of mandibular centrals and laterals clearly visible on the pre and post treatment CBCT scans.

Sample size calculation was completed for a descriptive study as follows: standard deviation was taken from research by Sinclair and Little (1983) on the irregularity index.

Confidence intervals = 1mm
Confidence level = 95%
Continuous variables = displacement in mm
SD = 1.64 mm of irregularity
W/S = Desired total width/SD
= 1/1.64
= 0.61 the required sample size is 43 patients

Based on the sample size calculation, 43 patients were needed for this study. From the eligible patients 51 were randomly selected using a random table of numbers. The sample included 23 female and 28 male subjects (Table 1). The females tended to be slightly younger at the beginning of treatment with a mean age of 13 years 8 months compared to the 14 years 0 months for males at the beginning of treatment. The average treatment time was 22 months for both females and males.

The CBCT scans were constructed and viewed using OnDemand 3D Application (Cybermed Inc. Irvine, CA). The incisal edge was measured at the center of the incisal edge of the lower centrals and laterals. The root level was measured at two thirds the length of the root from the cementoenamel junction. All data was

recorded and stored using Microsoft Office Excel 2007. The following steps were completed for each CBCT to acquire all raw data:

1. In the axial view, widen the sagittal plane to include one side of the mandible. (Fig. 1)

2. In the sagittal view, align the axial plane along the inferior boarder of the mandible.

3. In the coronal view, again align the axial plane along the inferior boarder of the mandible, checking the left and right sides.

4. Once the mandibular plane was established, use the axial view to locate the mental foramen. Align the coronal plane with the most anterior points of the right and left mandibular foramen.

5. Again in the axial plane, locate the geniotubercles and center the sagittal plane between the geniotubercles.

6. In the sagittal plane, measure the mandibular incisor and determine the point one-third from the root apex. Position the axial plane at this point. (Fig. 2)

7. In the axial view, measure from the center of the root to the coronal and sagittal planes, obtaining two measurements for each tooth root. Complete measurements for lateral and central incisors. Capture an image including all measurements.

8. Once all root measurement have been completed and captured, move the axial plane to the incisor incisal edge using the sagittal plane as a guide. (Fig. 3)

9. Once again complete measurements from the center of the incisal edge. Capture an image including all the measurements.

Reliability was measured by repeating measurements on 15 initial and 15 final CBCTs 4 weeks after the initial measurements. Intraclass correlations were calculated using Statistical Package for the Social Sciences (SPSS 13.0, Inc. Chicago, IL). The intraclass correlations for all measurements were 0.96, for root measurements in the

coronal plane was 0.93, for root measurements in the sagittal plane 0.90, for crown measurements in the coronal plane 0.97 and for crown measurements in the sagittal plane 0.97.

The Displacement Measurement of root alignment was calculated as the sum of the difference of each root from the most protrusive or anterior positioned root. The measure was also calculated for the crown alignment. Means and standard deviations for crown and root movement in both the sagittal plan and coronal plan were calculated by subtracting initial treatment values from final treatment values. Negative values indicate lingual and mesial movement, while positive values indicate buccal and distal movements. Total crown and root movement were calculated as the sum of the absolute value of the movement for the crown and root in the coronal and sagittal planes.

Unpaired student's t-test was used to compare initial crown position to initial root position. Paired student's t-test was used to compare initial and final root position and initial and final crown positions. Significance was defined as $p \leq 0.05$.

RESULTS

Significant difference was found between initial crown and root positions in the sagittal plane for the right and left central incisors ($p = 0.026$ and $p=0.038$, respectively). Significant difference was found between initial crown and root positions in the coronal plane for all four incisors ($p < 0.001$). After treatment, there

was a significant difference between crown and root positions for all four incisors in both the sagittal and coronal planes ($p<0.001$).

The movement of each crown and root was calculated as the final position minus the initial position (Table II). A negative value in the sagittal plane represents displacement in the lingual direction. A negative value in the coronal plane represents displacement in the mesial direction. The mean root movement in the sagittal plane was toward the lingual for all teeth. The right lateral root was displaced -0.49±1.01mm, the right central -0.50±0.98mm, the left central -0.47±1.03mm and the left lateral -0.54±0.92mm ($p=0.001$, $p<0.001$, $p=0.002$ and $p<0.001$, respectively). The mean root movement in the coronal plane was lateral and away from the midline for all teeth. The right lateral root was displaced 0.74±1.0mm, the right central 0.07±1.04mm, the left central 0.13±0.96mm and the left lateral 0.61±1.30mm ($p<0.001$, $p=0.607$, $p=0.344$, and $p=0.001$, respectively). The mean crown movement in the sagittal plane was toward the labial for all teeth. The right lateral crown was displaced 1.08±1.75mm, the right central 0.63±1.53mm, the left central 0.53±1.56mm and the left lateral 1.27±1.94mm ($p<0.001$, $p=0.005$, $p=0.019$ and $p<0.001$, respectively). The mean crown movement in the coronal was distal for all teeth except for the left central that moved mesial. The right lateral crown was displaced 0.12±1.11mm, the right central 0.13±0.99mm, the left central -0.08±0.82mm and the left lateral 0.24±1.01mm ($p=0.418$, $p=0.349$, $p=0.469$, and $p=0.085$, respectively). These data can also be view in graphical format as seen in Fig. 4. The crowns begin at the same level or labial to the root position. At the end of treatment the crowns

have been displaced labial and the roots have been displaced lingual. Lateral displacement of the crowns and roots are observed. The greatest lateral displacement can be seen in the lateral incisor roots.

Total crown and root displacement was calculated as the sum of the absolute value of displacement (Table III). The crowns and roots are displaced equally in the coronal plane, 3.02±2.00mm and 3.48±2.19mm respectively. However, in the sagittal plane the crowns are displaced about twice that of the roots, 6.07±4.12mm and 3.68±1.96mm respectively. The range of displacement is quite high with some displacement less than one millimeter and as high as fifteen millimeters.

Displacement measurement was calculated as the sum of the distance of each root from the most anterior positioned root. This measure was also calculated for crown alignment (Table IV). The mean displacement measurement increased after orthodontic treatment for the roots from 2.47±0.99 to 3.00±1.23. However the displacement measurement decreased for the crowns from 4.66±1.79 to 3.15±0.67. The range for root irregularity increased from initial to final, 0.8-4.9 and 0.8-6.6 respectively. The range for crown irregularity decreased from initial to final, 1.3-9.1 and 1.6-5 respectively.

DISCUSSION

These data show that on average the lower incisor crowns are displaced labial and distal and the roots of the lower incisor teeth are displaced lingual and distal over the course of treatment. Labial tipping of the teeth can be caused by a variety of

treatment mechanics including but not limited to the relief of crowding, opening a deepbite, leveling the curve of spee, class II elastics, or function appliances. All the patients in this study were non-extraction causing the majority of crowding to be resolved through expansion and proclination of the teeth. The expansion could either be through proclination of the teeth or possibly through expansion buccally. This buccal expansion, also seen in the distal movement of the crowns, could potentially expand the intercanine width. Expansion of the intercanine width has been shown to be an unstable change and tends to return to the original width.[16, 17, 18] These case could be recalled after several years and reassessed for potential relapse. With this method it would be possible to assess not only the relapse of the crowns but also the roots.

The lingual movement of the roots could potentially lead to a more stable position. Enlow[19] describes the remodeling of the mandibular symphisis with resorption on the labial cortex, deposition on the alveolar surface of the labial cortex, resorption on the alveolar surface of the lingual cortex and deposition on the lingual side of the lingual cortex. With these boney changes, the roots are moving into a region of deposition as they move lingually and away from the region of resorption. This might imply they would be moving to a position that may be more stable. Again, by following these patients, we can assess the changes in the Displacement index at both the crown and the root.

The displacement measurement decreased for both the roots and the crowns. The decrease in crown irregularity is expected with the elimination of any crowding of the lower incisors. The range of the irregularity of the crowns decreased about 4.4mm compared to the root irregularity in which the range of irregularity increased by about 1.7mm. This shows how the crowns are aligning while the roots are becoming more irregular. Evaluation of the angulations of the teeth is possible using a panoramic radiograph, however the torque can only be evaluated clinically by palpating the roots or assessing the emersion profile or using a CBCT. Possibly using this measurement will allow clinicians to better evaluate the finish of a case or the need for additional torque of the lower incisors.

However, the displacement measurement does not report the rotations in the teeth because it is measured from the center of the incisal edge. The measurement could be low and there might still be moderate crowding if the center of the incisal edges line up. The measurement would not be expected to be zero at final alignment like with Little's Irregularity Index. This is because the lower anterior teeth are positioned on an arc and not in a straight line. Since every archform is unique, it is hard to calculate a norm to which each case could be compared. A tapered archform would result in a higher final index then a square or ovoid archform.

This new method will open the door to many future research projects. Of which might include the position of the dentition to the mandibular body during class II correction and the comparison of class II correction with growing and non-growing

patients. The displacement measurement could be used to asses both nonextraction cases and extraction cases. Stability could be assessed by recalling these patients to evaluate the stability.

CONCLUSIONS

1. CBCT scans can be used to measure the displacement of the crowns and roots during orthodontic treatment.
2. The mean movement of the crowns during orthodontic treatment is labial and distal. The mean movement of the roots during orthodontic treatment is lingual and distal.
3. The displacement measurement decreased for both the crowns and the roots.

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Figure 1: A) Alignment of the axial plane along the lower boarder of the mandible viewed from the sagittal plane. B) Aligment of the axial plane at menton viewed from the coronal plane. C) Alignment of the axial plane at gonion viewed from the coronal plane. D) Alignment of the coronal plane at the mesial of the mental foramen viewed from the axial plane. E) Alignment of the sagittal plane with the geniotubercles.

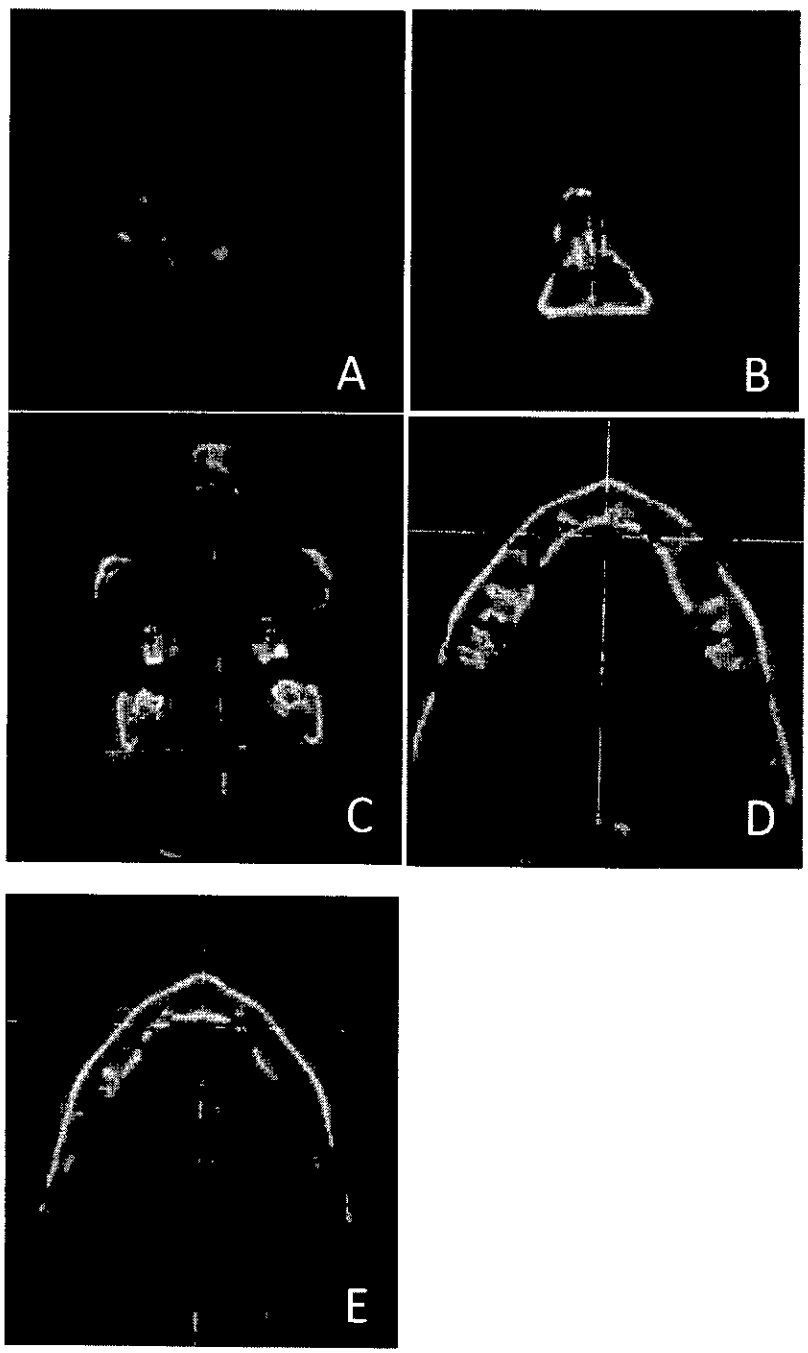


Figure 2: A) Measure the length of the incisor from the CEJ to the apex. B) Measure one third from the apex and position the axial plane at this point. C) View of the axial plane at one third from the apex. D) Measure from coronal plane to center of root (sagittal measurement). E) Measure from sagittal plane to center of root (coronal measurement).

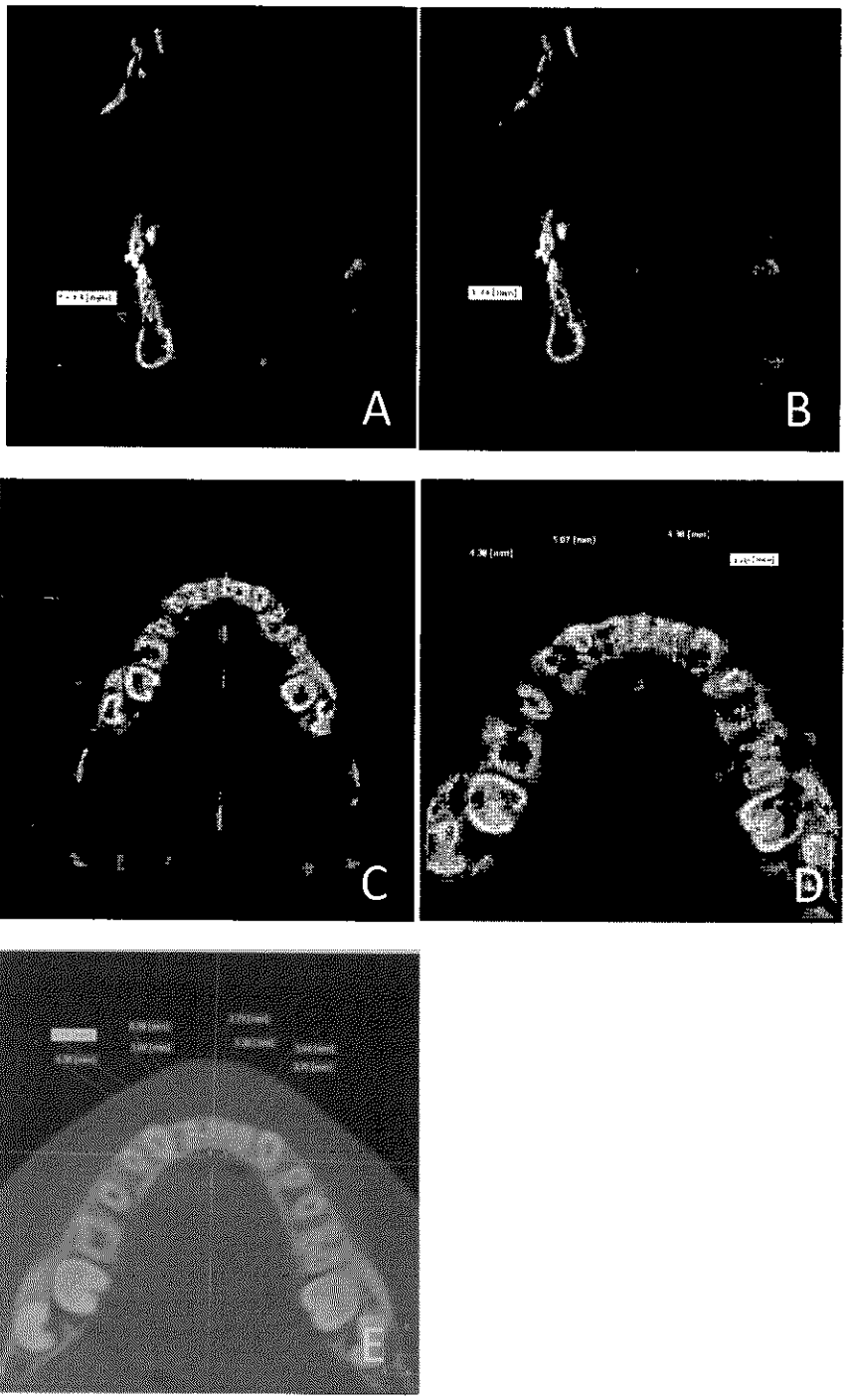


Figure 3: A) Positioning of the axial plane and that incisal edge in the sagittal plane. B) Axial view of the incisal edges of the lower incisors. C) Measurements in the coronal and sagittal planes at the center of the incisal edges for the lower incisors.

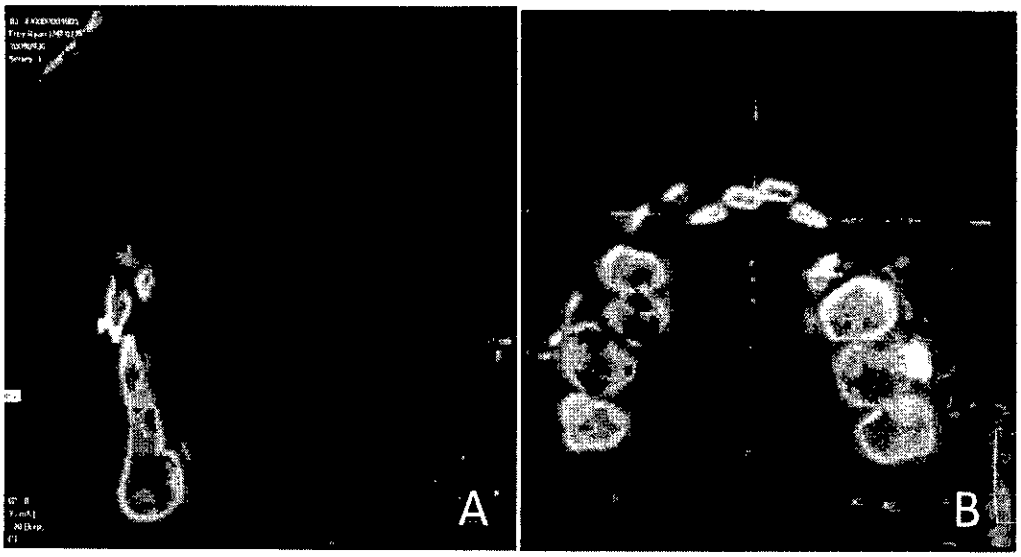
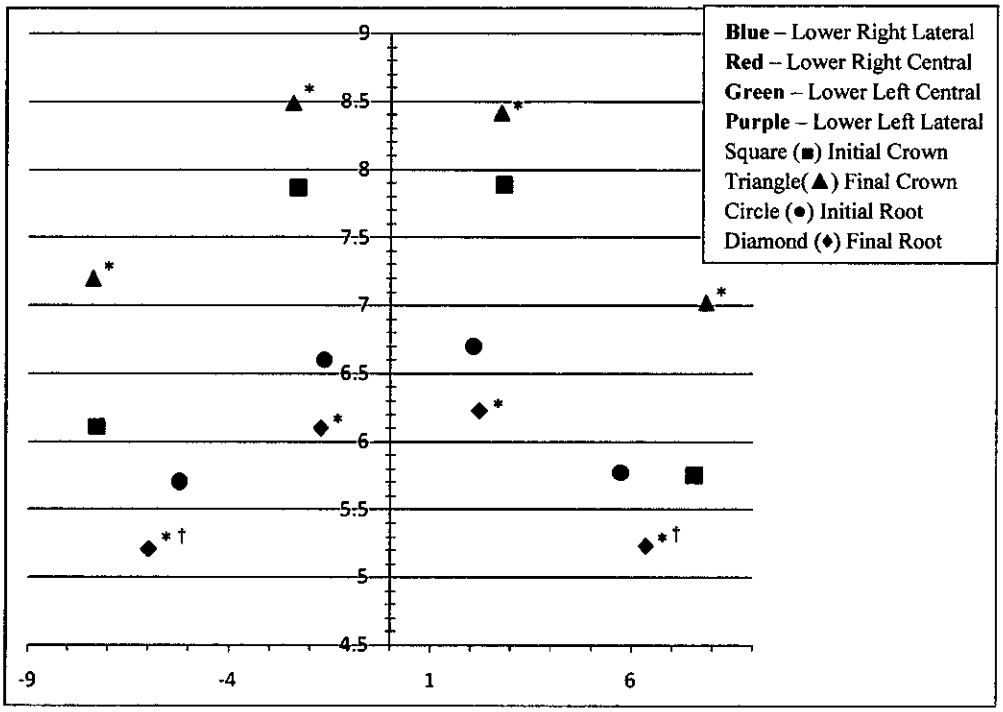




Figure 4: Graphical representation of mean crown and root position before and after treatment. The crowns are displaced buccally and the roots lingually. There is also lateral displacement of the crowns and roots laterally.



*Sagittal: $p<0.01$, Coronal: $^{\dagger}p<0.001$

Table I: Demographic Data for study sample.

	n, (%)	Initial Mean Age	Final Mean Age
Male	23 (45)	14 years 0 months	15 years 10 months
Female	28 (55)	13 years 8 months	15 years 7 months
Total	51 (100)	13 years 10 months	15 years 9 months

Table II: Mean Differences in crown and root position from initial to final (measured in mm).

	Root		Crown	
	Sagittal	Coronal	Sagittal	Coronal
Right Lateral	-0.49 ± 1.01†	0.74 ± 1.0†	1.08 ± 1.75†	0.12 ± 1.11
Right Central	-0.50 ± 0.98†	0.07 ± 1.04	0.63 ± 1.53*	0.13 ± 0.99
Left Central	-0.47 ± 1.03†	0.13 ± 0.96	0.53 ± 1.56*	-0.08 ± 0.82
Left Lateral	-0.54 ± 0.92†	0.61 ± 1.30†	1.27 ± 1.94†	0.24 ± 1.01

*p<0.05, †p<0.001

Table III: Total Tooth Displacement (measured in mm) measured as the sum of the absolute value of the movement for the crown and root in the coronal and sagittal planes.

Root:	**Mean ± SD**	**Range**
Sagittal	3.68 ± 1.96	0.7 – 8
Coronal	3.48 ± 2.19	1.1 – 15.1
Crown:		
Sagittal	6.07 ± 4.12	0.9 – 15.9
Coronal	3.02 ± 2.00	0.7 – 12.7

Table IV: Discrepancy Measurement (measured in mm).

Root:	**Mean ± SD**	**Range**
Initial	2.47 ± 0.99	0.8 – 4.9
Final	3.00 ± 1.23	0.8 – 6.6
Crown:		
Initial	4.66 ± 1.79	1.3 – 9.1
Final	3.15 ± 0.67	1.6 – 5

Appendix A: IRB Approval

Case Western Reserve University

Institutional Review Board

NOTICE OF EXEMPTION (#4)

Research involving the collection or study of existing data, documents, records, pathological specimens, or diagnostic specimens, if these sources are publicly available or if the information is recorded by the investigator in such a manner that subjects cannot be identified, directly or through identifiers linked to the subjects.

This protocol is exempt under the #4 category because this involves existing retrospective de-identified data. Prospective data are NOT included in this exemption. De-identified pre-existing data to be collected on 09/12/2009 and after are NOT covered by this exemption.

Responsible Investigator: Manish Valiathan

Department: Dental Orthodontics

IRB Protocol Number: 20090909

Title: A comparison of Crown and Root Alignment Before and After Orthodontic Treatment Using Cone Beam CT

Co-Investigator: Lindsey Schilling

Exemption Date: September 11, 2009

The Institutional Review Board (IRB) has deemed the above protocol EXEMPT under 45 Code of Federal Regulations (CFR) part 46.101(b)(4). The IRB will not conduct subsequent reviews of this protocol.

Any changes to the protocol that put it under the purview of the IRB would require a formal application to, and approval of, the IRB prior to implementation of the change IRB applications are available at the CWRU IRB Pages, or from the Office of Research Compliance (ORC) at Sears Library Building, #660.

Appendix B: Raw Data

Patient Code	Gender (0=male, 1=female)	RL	1/3 RL
AD37	1	11.5	3.83333333
BI54	1	12.62	4.20666667
BI43	1	10.33	3.44333333
BL67	1	15.2	5.06666667
BU123	1	10.9	3.63333333
CA202	1	10.6	3.53333333
AL97	1	13.7	4.56666667
DU53	1	12.2	4.06666667
CO237	1	12.5	4.16666667
DU69	0	10.6	3.53333333
FO74	0	13.6	4.53333333
FR89	1	9.9	3.3
GA118	1	12.82	4.27333333
BR212	0	12.97	4.32333333
HA316	1	11.4	3.8
HA340	0	13.8	4.6
IS24	1	13.7	4.56666667
JO34	1	11	3.66666667
JU21	0	13.8	4.6
KN3	0	9.1	3.03333333
LA77	1	14.2	4.73333333
LE17	1	11.3	3.76666667
MA281	0	12.07	4.02333333
MA339	0	11.2	3.73333333
MA257	0	12.4	4.13333333
ME14	1	9.7	3.23333333
MI171	0	11.4	3.8
MU83	0	12.8	4.26666667
PE139	1	12.2	4.06666667
PI67	0	11.9	3.96666667
PO112	1	13	4.33333333
PR74	1	11.9	3.96666667
RE11	1	13.25	4.41666667
RO159	1	11.5	3.83333333
RU47	0	11.3	3.76666667
GI61	0	13.9	4.63333333
SC24	1	11.2	3.73333333
SI96	0	13	4.33333333
SH129	1	12.4	4.13333333
CA71	1	14.5	4.83333333
SI56	0	12.8	4.26666667
SC142	1	12.5	4.16666667
TA109	1	12.4	4.13333333
TO64	0	12.91	4.30333333
CA201	0	11.7	3.9
WI227	0	11.7	3.9
WI237	0	12.49	4.16333333
ZA27	1	10.9	3.63333333
ZI25	0	11.2	3.73333333
ZO7	0	12.7	4.23333333
ZU16	0	12.4	4.13333333

	Init Rt	LL2	LL1	LR1	LR2	Init Rt	LL2	LL1	LR1	LR2
Patient Code	**Sag**	LL2	LL1	LR1	LR2	**Cor**	LL2	LL1	LR1	LR2
AD37		3.2	3.8	4	3.5		4.9	2	1.4	4.5
BI54		3.89	4.27	3.73	3.07		4.4	1.42	1.55	5.02
BI43		4.08	5.25	4.83	4.51		5.56	2.45	1.6	4.29
BL67		4.3	5.2	5.5	4.9		6.3	2	2.4	5.7
BU123		4.1	4.2	4.8	3.2		4.8	1.7	1.2	4.9
CA202		2.9	2.9	2.5	1.7		6.1	2.8	1.8	5
AL97		7.6	8.4	8.3	7.3		6.1	2.1	0.5	4.3
DU53		6.9	8.2	8.7	7.5		4.4	1	1.4	5
CO237		3.2	6.2	6.1	4.4		3	1.7	1.1	4.6
DU69		4.9	6.1	5.8	4.3		4.9	2.6	0.2	3.5
FO74		5.8	7	6.8	5.7		6.6	2.5	1.4	5.4
FR89		5.2	6.2	6.3	5.1		6.6	2.6	1.7	5.1
GA118		3.34	4.52	4.74	2.91		5.06	2.04	2.58	5.06
BR212		6.02	7.33	7.33	6.46		6.13	2.3	1.87	5.25
HA316		4.1	4.9	5.1	4.8		6.4	2.9	0.6	4.8
HA340		3.1	4.3	4.5	3.6		7	2.9	2.1	6
IS24		9.6	9.9	10.1	8.9		6.2	1.6	1.8	5.8
JO34		7	8.1	8.4	7		5.1	1.6	2.4	6.3
JU21		4	4	4.4	3.6		6.8	2.6	2.1	5.6
KN3		10.9	11.4	11.2	10.6		7.5	3.4	1.9	5.5
LA77		6.1	6.7	6.5	6.3		5.3	2.1	1.8	5.7
LE17		4.06	6.28	5.91	4.56		4.81	1.97	1.11	3.94
MA281		5.88	6.89	7.29	5.64		7.4	3.44	2.56	6.27
MA339		9	9.4	9.8	8.7		5.2	2.1	1.8	5.1
MA257		10.6	11	10.3	9.8		4.8	1.3	2	5.3
ME14		7.3	8.3	8.7	6.8		5	1.2	2.1	6.4
MI171		6.9	7.8	7.8	7.3		6	1.3	1.7	4.7
MU83		5.5	6.1	5.8	5.2		4.7	1	2.6	6.5
PE139		7.51	8.07	7.95	7.41		6.45	1.77	1.5	5.2
PI67		5.3	6.5	6.6	6.7		7	2.9	1.3	5.7
PO112		11.2	12.1	12.1	12.2		6.2	2.1	1.9	6
PR74		6.4	7.2	7.3	6.1		4.7	1.1	2.2	5.4
RE11		7.21	8.35	8.2	6.55		4.61	1.52	1.13	4.72
RO159		4.6	5.5	5.3	4.8		5.7	1.6	2.2	5.6
RU47		2	2.6	2.9	2		6	1.2	2.3	6.3
GI61		6.5	6.8	5.9	5.7		4.7	1.5	1.5	4.3
SC24		5.13	5.27	5.41	4.86		4.16	0.97	0.97	3.61
SI96		8.6	10.5	10.3	8.8		8	3.2	1.1	5.5
SH129		2.3	3.2	2.9	2.1		6.1	1.7	1.8	5.2
CA71		8.1	9.1	8.7	7.6		6.2	3	1.3	4.9
SI56		5.6	7.2	6.6	5.3		5.5	1.7	1.9	6.3
SC142		2.9	3.9	3.4	2.4		6.6	3.2	0.1	4.3
TA109		6.2	7.6	7.6	6.2		5.8	2.6	1.8	5
TO64		3.92	5.74	4.91	4.21		6.3	2.8	2.1	5.04
CA201		5.6	6	5.5	4.9		5.7	1.9	2.3	5.9
WI227		10.2	11.1	10.7	9.5		5.2	1.7	2.3	6.8
WI237		6.39	7.78	7.24	6.63		5.33	1.91	0.85	3.72
ZA27		5.9	6.7	6.7	6.1		5.3	1.9	1.8	5.3
ZI25		2.6	4.2	3.2	1.9		6.5	2	1.9	5.4
ZO7		5	5.2	5.5	5.5		6.5	2.1	1.8	5.8
ZU16		5.8	6.2	6.5	5.7		7.3	3.2	1.6	6.1

	Fin Rt	LL2	LL1	LR1	LR2	Fin Rt	LL2	LL1	LR1	LR2
Patient Code	**Sag**	LL2	LL1	LR1	LR2	**Cor**	LL2	LL1	LR1	LR2
AD37		2.7	2.3	2.3	2		4.3	0.7	2.3	6.3
BI54		4.2	5.5	5.8	4.5		5.5	1.6	2.9	6.5
BI43		3.1	3.5	3.4	3.2		5.4	1	2.3	6.1
BL67		2.7	4.4	5.2	3.8		5.5	1.7	1.9	5.9
BU123		2.7	3.8	4.5	3.3		7.7	3.7	0.5	4.7
CA202		1.1	1.9	1.3	0.4		7.4	3.2	0.5	5.5
AL97		7.3	8.2	7.5	7.3		7.6	1.8	2.2	5.9
DU53		7.3	8.8	8.9	7.6		5.4	1.3	2.7	6.1
CO237		3.3	4.9	5.4	3.9		4.7	1.6	1.3	6.2
DU69		3.2	4.7	4.5	3.2		6	2.8	1.7	5
FO74		4.2	6	6	5.5		8	3	0.5	4.6
FR89		6.2	8	7.7	6.3		6.4	2.5	2	5.8
GA118		3.5	6.1	4.5	3.7		5.4	1.7	2.3	6.4
BR212		5.8	7.7	7.2	4.9		5.5	1.6	2.4	6.1
HA316		2.8	3.8	4.3	3.8		8	4	0.8	4
HA340		1.7	2.7	3.3	2.4		1.7	2.8	1.4	5.4
IS24		10.4	10	10	9.9		6.4	1.7	2.8	7.3
JO34		7.1	8.3	8.6	7.6		6.3	1.9	2.9	6.8
JU21		4.2	4.9	5.2	4.2		7	3.1	0.8	5.2
KN3		10.3	11.2	10.7	10		7.4	2.1	1.4	5.6
LA77		6	6.3	6.9	6.5		6.6	1.9	1.7	6
LE17		5.2	7.5	6.8	5.4		6.9	3.7	1.1	4.9
MA281		5.7	6.7	5.7	4.9		8.3	2.9	2.1	6.6
MA339		8.7	9.1	9.5	8.2		6.3	2.3	2.1	5.5
MA257		12.3	12.9	12.3	11.2		4.8	1.4	2.7	6.4
ME14		6.4	7.5	7.3	5.2		6.6	1.6	2.4	6.7
MI171		7	6.4	6.7	7.2		5.2	2.6	0.8	6.2
MU83		3.7	4.4	4.9	4		9.4	5.6	-1.4	4.7
PE139		6.1	6.8	6.8	5.7		8.2	2.2	2	7.8
PI67		4	5.4	5.9	5.4		7.6	3	-0.4	4.7
PO112		9.5	11.1	11.4	11.4		6.8	2.5	1.5	5.8
PR74		7.4	6.7	6.8	6.7		3.9	0.4	2.2	6.4
RE11		6.7	8.7	7.8	5.9		5.5	1.4	3.2	8.2
RO159		4.6	5	5.4	4.9		6.4	2	1.8	5.7
RU47		0.9	1.4	-0.3	-0.5		5.2	0.9	3.3	8.5
GI61		6.6	6.2	6	6.6		5.3	1.8	2.1	5.1
SC24		3.9	4.5	4.2	2.8		4.7	1.2	2.8	6
SI96		6.7	8.3	8.6	7.3		9	3.7	1.2	6.8
SH129		1.4	3.1	2.9	2.6		6	1.4	1.9	6.5
CA71		6.8	8.3	7.2	6.7		6.7	3.6	0.5	4.9
SI56		4.6	5.2	5	3.5		6.6	1.8	2.8	8
SC142		0.3	2.3	1.9	0.2		7.5	2.1	1.7	6.8
TA109		5.2	6.5	6.8	5.2		6.6	2.9	0.9	5.2
TO64		2.8	3.9	3.4	1.9		7.2	1.6	2.9	6
CA201		4.9	6	4.7	4.8		5.8	1.3	1.8	5.6
WI227		10.4	11.6	11.4	10.2		5.4	1.4	2.1	6.3
WI237		6	6.3	6.6	5.9		6.4	2	1.9	6.1
ZA27		6.4	7	6.7	5.8		6.3	2.4	1.2	4.6
ZI25		1.6	3.4	2.5	1.2		7.9	3.2	1.2	5.6
ZO7		5.7	6.7	6.7	5		6.4	2.4	1.7	6.4
ZU16		5.2	5.4	6	6		6.9	1.8	1.4	6.2

	Init Cm	LL2	LL1	LR1	LR2	Init Cm	LL2	LL1	LR1	LR2
Patient Code	**Sag**	LL2	LL1	LR1	LR2	**Cor**	LL2	LL1	LR1	LR2
AD37		0	3.1	2.5	2		6	2.6	2.9	7.5
BI54		5.91	7.85	7.44	4.9		8.12	1.95	2.56	7.42
BI43		2.89	4.83	4.71	3.87		6	1.7	2.03	6.12
BL67		6.7	8.1	8.1	7.5		6.6	2.1	3.2	8.6
BU123		2.2	5.3	5.3	2.9		7.9	3.7	1.6	5.3
CA202		1.3	2.9	3.1	0.9		7.4	2.8	2.2	6.9
AL97		6.7	10	8.5	7.9		7.7	3.8	1.7	6.5
DU53		7.8	10.3	10.9	7.2		5	1.6	2.9	6.8
CO237		3.6	6.4	6.1	5		7.6	2.9	2.7	8
DU69		2.1	6.6	7.1	3.5		6.4	4.3	0.8	4.6
FO74		6.9	10.2	10.1	7		9.3	3.8	1.6	7.6
FR89		7.4	9.7	10	7.7		8.6	3.5	1.9	7.4
GA118		4.09	7.64	8.4	4.73		6.46	1.83	3.55	8.4
BR212		6.46	9.19	9.19	6.68		5.47	2.19	2.73	6.68
HA316		5.7	7.5	7.3	4.9		8.2	3.1	1.1	5.5
HA340		3	3.3	3.5	2.9		7.5	3.1	2.3	7
IS24		10.1	13.3	12.8	10.6		8.4	3.1	2.6	8.8
JO34		7.3	8.8	9	7.9		8.2	2.7	2.8	9.1
JU21		4.6	6.9	6.1	4.1		7.8	3.3	1.6	6.3
KN3		14.2	15.5	15.8	14.9		9.9	3.4	1.4	6.8
LA77		10.3	12.1	12.3	9.7		8.6	2.7	3	9
LE17		4.93	7.76	7.27	4.56		6.53	3.33	1.97	6.16
MA281		8.06	9.21	9.07	8.07		8.17	3.06	2.17	7.29
MA339		9	11.2	10.9	7.4		7.3	2.8	1.8	5.2
MA257		11.4	13.4	12.8	11.6		7.3	1.9	4	9.4
ME14		8.1	9.5	9.3	8.2		6.5	1.9	2.6	6.2
MI171		5.3	9.3	9.1	6.5		7.1	3.5	2.2	6.9
MU83		5.9	7.5	7.5	5.8		7.5	2.5	3.1	8.8
PE139		5.06	8.49	8.9	7.81		7.39	3.29	2.62	8.08
PI67		4.5	7.9	7.5	6		9	3.9	0.9	5.9
PO112		13.6	16.3	15.8	13.8		9	2.8	2.8	8.6
PR74		6.1	8.3	8.7	5.6		6.3	2.1	4.5	8.8
RE11		6.82	10.3	10.3	7.11		7.34	2.51	2.37	7.52
RO159		3.2	4.7	5.5	4.2		7.5	2.6	2.6	7.7
RU47		-1.2	-0.6	-0.2	-0.5		8.1	0.6	0.2	7.2
GI61		6.7	8.5	9.3	6.1		8.1	2.7	3.1	8.7
SC24		3.61	6.1	5.97	4.17		6.38	1.94	2.5	7.64
SI96		8.3	8.3	9.5	8.9		8.6	4.3	1.1	5
SH129		4.4	2.8	4.3	3.8		7.6	2.8	2.1	7.2
CA71		8.1	8.5	8.4	7.2		9	3.8	2	6.7
SI56		2	4	4.1	2		6.4	1.4	3	8.3
SC142		-0.1	1.9	1.7	0.1		8.6	4	1	5.6
TA109		5.3	8.4	7.1	6.8		8.4	3.5	1.5	7.3
TO64		2.38	5.47	5.61	4.62		7.56	3.22	2.52	8.12
CA201		4.9	7.5	6.9	6.1		7	3	2.3	7.7
WI227		9.2	11.4	11	9.5		6.5	1.7	3.9	8.5
WI237		5.12	6.71	6.92	6.06		8.52	3.4	1.59	7.25
ZA27		7.9	9.3	9.4	8.3		7.2	2.2	2.6	7.1
ZI25		0.9	2.9	2.8	1		7.8	3.1	2	6
ZO7		8.2	9.9	9.6	7.5		8.4	2.6	2.7	7.9
ZU16		6.2	7.5	7.5	6.5		8.3	3.5	2.3	8

Patient Code	Fin Crn Sag	LL2 LL2	LL1 LL1	LR1 LR1	LR2 LR2	Fin Crn Cor	LL2 LL2	LL1 LL1	LR1 LR1	LR2 LR2
AD37		4.3	5.8	5.8	4.8		6.3	1.1	4.1	8.6
BI54		6.6	7.6	7.8	6.4		6.5	1	3.2	8.5
BI43		3.4	4.9	5.1	4.1		5.9	0.9	2.9	6.7
BL67		6.5	7.9	8.4	7.3		6.9	2.5	2.9	7.3
BU123		5.8	7.2	7.3	6.2		8.8	4.2	1.2	6.3
CA202		1.9	3	3.6	1.9		8.9	3.6	1.3	5.7
AL97		8.6	10	9.8	8.3		8.3	3	2.8	7.5
DU53		11.3	12.3	12.1	10.5		6.5	1.8	3.6	7.7
CO237		8.1	9.9	10.1	8.9		7.5	2.3	3.3	9.3
DU69		5.8	6.5	6.5	5.6		7.3	2.6	1.7	6.7
FO74		8	9.7	9.9	9		9.4	3.7	1.5	6.4
FR89		7.8	9.7	9.6	8.4		8.7	3.7	1.8	6.9
GA118		8.4	9.9	10.6	9.2		8.8	3.2	2.7	8.5
BR212		8.1	9.5	9.3	8.4		6.6	1.6	3.7	8.1
HA316		6.1	7.3	7.8	6.6		9.6	4.7	0.2	6.4
HA340		3	4.1	4.3	3		8.3	3	1.7	6.2
IS24		12.1	13.8	13.8	12.3		7.5	2.7	3.2	9.4
JO34		8	10	10	8.3		7.3	1.9	3.1	9
JU21		6.7	7.6	7.3	5.6		8.9	3.7	2.1	6.4
KN3		12.7	14.1	14.5	13.4		8.2	3.4	1.9	7.3
LA77		9.8	11.4	11.7	10.2		8.1	2.8	3.5	8.6
LE17		9.2	10.2	10.5	9.3		8.5	3.9	1	6.1
MA281		5.1	6.6	6.7	5.4		8.3	3	1.6	6.6
MA339		10.2	11.5	11.4	10.1		7.4	2.1	2.9	7.5
MA257		14.6	16.3	15.5	13.8		6.8	1.3	4.3	9.3
ME14		6.7	7.9	7.6	6.6		6.3	1.9	2.1	6.3
MI171		10.8	12	11.9	10.5		8.3	2.9	2.6	7.9
MU83		5.4	6.6	6.4	5.1		10.3	5.4	0	4.9
PE139		7.5	9.5	9.9	8.5		8.4	2.8	2.8	7.9
PI67		5.4	7.6	7.9	6.7		10.1	3.9	0.5	5.2
PO112		12.5	14.5	14.3	12.8		8.4	2.9	2.8	8.8
PR74		9.1	10.6	10.5	9.4		6.8	1.3	3.9	8
RE11		8.8	10.2	10	8.2		7	1.4	4.1	9.6
RO159		5.5	6.5	6.5	5.2		6.9	2.8	2.6	6.9
RU47		-0.8	0.5	0.3	-1.4		5.9	1.4	3.8	8.2
GI61		8.5	10.6	11	10		9.8	3.9	2.1	7.8
SC24		5.3	6.2	6.2	5.5		6.1	1.5	3.4	8.7
SI96		6.6	8.1	8.4	7.7		8.6	4.1	1.1	6
SH129		5.7	7.1	7.4	5.9		7.9	2.6	2.3	8.2
CA71		6.8	8.1	8.3	6.8		9	4	1.1	6.1
SI56		3.4	4.4	4.1	2.8		6.2	1.9	3.1	8.4
SC142		-2.6	-1.4	-1.4	-2.2		7.1	3.1	2.2	6.2
TA109		8.2	9.9	10.3	8		9.3	4.2	1.7	7.2
TO64		6.1	7.9	7.9	7		8	2.2	2.9	8.1
CA201		6.7	7.9	8.2	6.6		6.5	1.8	3.3	8.7
WI227		10.1	11.3	11.1	9.8		6.5	1.2	3.3	8
WI237		7.3	8.7	8.5	7.3		8	3	3.1	8.4
ZA27		9	10.4	10.7	9.6		7.9	3	1.6	5.7
ZI25		1.9	2.9	2.8	1.7		8.4	3	1.2	5.5
ZO7		7.8	8.7	8.9	6.7		8.2	3	2.6	7.9
ZU16		4.3	5.5	5.9	5.2		8	2.9	1.5	6

	Init Rt	LL2	LL1	LR1	LR2		Fin Rt	LL2	LL1	LR1	LR2	
Discrepancy Index		LL2	LL1	LR1	LR2	SUM		LL2	LL1	LR1	LR2	SUM
AD37		0.8	0.2	0	0.5	1.5		0	0.4	0.4	0.7	1.5
BI54		0.38	0	0.54	1.2	2.12		1.6	0.3	0	1.3	3.2
BI43		1.17	0	0.42	0.74	2.33		0.4	0	0.1	0.3	0.8
BL67		1.2	0.3	0	0.6	2.1		2.5	0.8	0	1.4	4.7
BU123		0.7	0.6	0	1.6	2.9		1.8	0.7	0	1.2	3.7
CA202		0	0	0.4	1.2	1.6		0.8	0	0.6	1.5	2.9
AL97		0.8	0	0.1	1.1	2		0.9	0	0.7	0.9	2.5
DU53		1.8	0.5	0	1.2	3.5		1.6	0.1	0	1.3	3
CO237		3	0	0.1	1.8	4.9		2.1	0.5	0	1.5	4.1
DU69		1.2	0	0.3	1.8	3.3		1.5	0	0.2	1.5	3.2
FO74		1.2	0	0.2	1.3	2.7		1.8	0	0	0.5	2.3
FR89		1.1	0.1	0	1.2	2.4		1.8	0	0.3	1.7	3.8
GA118		1.4	0.22	0	1.83	3.45		2.6	0	1.6	2.4	6.6
BR212		1.31	0	0	0.87	2.18		1.9	0	0.5	2.8	5.2
HA316		1	0.2	0	0.3	1.5		1.5	0.5	0	0.5	2.5
HA340		1.4	0.2	0	0.9	2.5		1.6	0.6	0	0.9	3.1
IS24		0.5	0.2	0	1.2	1.9		0	0.4	0.4	0.5	1.3
JO34		1.4	0.3	0	1.4	3.1		1.5	0.3	0	1	2.8
JU21		0.4	0.4	0	0.8	1.6		1	0.3	0	1	2.3
KN3		0.5	0	0.2	0.8	1.5		0.9	0	0.5	1.2	2.6
LA77		0.6	0	0.2	0.4	1.2		0.9	0.6	0	0.4	1.9
LE17		2.22	0	0.37	1.72	4.31		2.3	0	0.7	2.1	5.1
MA281		1.41	0.4	0	1.65	3.46		1	0	1	1.8	3.8
MA339		0.8	0.4	0	1.1	2.3		0.8	0.4	0	1.3	2.5
MA257		0.4	0	0.7	1.2	2.3		0.6	0	0.6	1.7	2.9
ME14		1.4	0.4	0	1.9	3.7		1.1	0	0.2	2.3	3.6
MI171		0.9	0	0	0.5	1.4		0.2	0.8	0.5	0	1.5
MU83		0.6	0	0.3	0.9	1.8		1.2	0.5	0	0.9	2.6
PE139		0.56	0	0.12	0.66	1.34		0.7	0	0	1.1	1.8
PI67		1.4	0.2	0.1	0	1.7		1.9	0.5	0	0.5	2.9
PO112		1	0.1	0.1	0	1.2		1.9	0.3	0	0	2.2
PR74		0.9	0.1	0	1.2	2.2		0	0.7	0.6	0.7	2
RE11		1.14	0	0.15	1.8	3.09		2	0	0.9	2.8	5.7
RO159		0.9	0	0.2	0.7	1.8		0.8	0.4	0	0.5	1.7
RU47		0.9	0.3	0	0.9	2.1		0.5	0	1.7	1.9	4.1
GI61		0.3	0	0.9	1.1	2.3		0	0.4	0.6	0	1
SC24		0.28	0.14	0	0.55	0.97		0.6	0	0.3	1.7	2.6
SI96		1.9	0	0.2	1.7	3.8		1.9	0.3	0	1.3	3.5
SH129		0.9	0	0.3	1.1	2.3		1.7	0	0.2	0.5	2.4
CA71		1	0	0.4	1.5	2.9		1.5	0	1.1	1.6	4.2
SI56		1.6	0	0.6	1.9	4.1		0.6	0	0.2	1.7	2.5
SC142		1	0	0.5	1.5	3		2	0	0.4	2.1	4.5
TA109		1.4	0	0	1.4	2.8		1.6	0.3	0	1.6	3.5
TO64		1.82	0	0.83	1.53	4.18		1.1	0	0.5	2	3.6
CA201		0.4	0	0.5	1.1	2		1.1	0	1.3	1.2	3.6
WI227		0.9	0	0.4	1.6	2.9		1.2	0	0.2	1.4	2.8
WI237		1.39	0	0.54	1.15	3.08		0.6	0.3	0	0.7	1.6
ZA27		0.8	0	0	0.6	1.4		0.6	0	0.3	1.2	2.1
ZI25		1.6	0	1	2.3	4.9		1.8	0	0.9	2.2	4.9
ZO7		0.5	0.3	0	0	0.8		1	0	0	1.7	2.7
ZU16		0.7	0.3	0	0.8	1.8		0.8	0.6	0	0	1.4

	Init Crn	LL2	LL1	LR1	LR2		Fin Crn	LL2	LL1	LR1	LR2	
Discrepancy Index		LL2	LL1	LR1	LR2	SUM		LL2	LL1	LR1	LR2	SUM
AD37		3.1	0	0.6	1.1	4.8		1.5	0	0	1	2.5
BI54		1.94	0	0.41	2.95	5.3		1.2	0.2	0	1.4	2.8
BI43		1.94	0	0.12	0.96	3.02		1.7	0.2	0	1	2.9
BL67		1.4	0	0	0.6	2		1.9	0.5	0	1.1	3.5
BU123		3.1	0	0	2.4	5.5		1.5	0.1	0	1.1	2.7
CA202		1.8	0.2	0	2.2	4.2		1.7	0.6	0	1.7	4
AL97		3.3	0	1.5	2.1	6.9		1.4	0	0.2	1.7	3.3
DU53		3.1	0.6	0	3.7	7.4		1	0	0.2	1.8	3
CO237		2.8	0	0.3	1.4	4.5		2	0.2	0	1.2	3.4
DU69		5	0.5	0	3.6	9.1		0.7	0	0	0.9	1.6
FO74		3.3	0	0.1	3.2	6.6		1.9	0.2	0	0.9	3
FR89		2.6	0.3	0	2.3	5.2		1.9	0	0.1	1.3	3.3
GA118		4.31	0.76	0	3.67	8.74		2.2	0.7	0	1.4	4.3
BR212		2.73	0	0	2.51	5.24		1.4	0	0.2	1.1	2.7
HA316		1.8	0	0.2	2.6	4.6		1.7	0.5	0	1.2	3.4
HA340		0.5	0.2	0	0.6	1.3		1.3	0.2	0	1.3	2.8
IS24		3.2	0	0.5	2.7	6.4		1.7	0	0	1.5	3.2
JO34		1.7	0.2	0	1.1	3		2	0	0	1.7	3.7
JU21		2.3	0	0.8	2.8	5.9		0.9	0	0.3	2	3.2
KN3		1.6	0.3	0	0.9	2.8		1.8	0.4	0	1.1	3.3
LA77		2	0.2	0	2.6	4.8		1.9	0.3	0	1.5	3.7
LE17		2.83	0	0.49	3.2	6.52		1.3	0.3	0	1.2	2.8
MA281		1.15	0	0.14	1.14	2.43		1.6	0.1	0	1.3	3
MA339		2.2	0	0.3	3.8	6.3		1.3	0	0.1	1.4	2.8
MA257		2	0	0.6	1.8	4.4		1.7	0	0.8	2.5	5
ME14		1.4	0	0.2	1.3	2.9		1.2	0	0.3	1.3	2.8
MI171		4	0	0.2	2.8	7		1.2	0	0.1	1.5	2.8
MU83		1.6	0	0	1.7	3.3		1.2	0	0.2	1.5	2.9
PE139		3.84	0.41	0	1.09	5.34		2.4	0.4	0	1.4	4.2
PI67		3.4	0	0.4	1.9	5.7		2.5	0.3	0	1.2	4
PO112		2.7	0	0.5	2.5	5.7		2	0	0.2	1.7	3.9
PR74		2.6	0.4	0	3.1	6.1		1.5	0	0.1	1.2	2.8
RE11		3.48	0	0	3.19	6.67		1.4	0	0.2	2	3.6
RO159		2.3	0.8	0	1.3	4.4		1	0	0	1.3	2.3
RU47		1	0.4	0	0.3	1.7		1.3	0	0.2	1.9	3.4
GI61		2.6	0.8	0	3.2	6.6		2.5	0.4	0	1	3.9
SC24		2.49	0	0.13	1.93	4.55		0.9	0	0	0.7	1.6
SI96		1.2	1.2	0	0.6	3		1.8	0.3	0	0.7	2.8
SH129		0	1.6	0.1	0.6	2.3		1.7	0.3	0	1.5	3.5
CA71		0.4	0	0.1	1.3	1.8		1.5	0.2	0	1.5	3.2
SI56		2.1	0.1	0	2.1	4.3		1	0	0.3	1.6	2.9
SC142		2	0	0.2	1.8	4		1.2	0	0	0.8	2
TA109		3.1	0	1.3	1.6	6		2.1	0.4	0	2.3	4.8
TO64		3.23	0.14	0	0.99	4.36		1.8	0	0	0.9	2.7
CA201		2.6	0	0.6	1.4	4.6		1.5	0.3	0	1.6	3.4
WI227		2.2	0	0.4	1.9	4.5		1.2	0	0.2	1.5	2.9
WI237		1.8	0.21	0	0.86	2.87		1.4	0	0.2	1.4	3
ZA27		1.5	0.1	0	1.1	2.7		1.7	0.3	0	1.1	3.1
ZI25		2	0	0.1	1.9	4		1	0	0.1	1.2	2.3
ZO7		1.7	0	0.3	2.4	4.4		1.1	0.2	0	2.2	3.5
ZU16		1.3	0	0	1	2.3		1.6	0.4	0	0.7	2.7

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