A Three-Dimensional Evaluation of Class II Subdivision Malocclusion Correction

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Dedication

This thesis is dedicated to my parents and my soul mate Christian who supported me every step of the way and were close to my heart, even thousands of miles away, during the past two years.

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Abstract

By

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INTRODUCTION: Our objective was to evaluate the dento-skeletal changes occurring during a comprehensive non-extraction orthodontic treatment of Class II subdivision malocclusion in the three planes of space using cone-beam computed tomography (CBCT).
METHODS: The pre- (T1) and post-treatment (T2) CBCTs of 25 adolescent subjects were oriented using the cranial nerve canals to set the 3 planes of reference and 19 landmarks were registered on maxillary, mandibular and dental structures. The data consisted of 3-dimensional coordinates representing the distances to the reference planes. The data was analyzed using t-test, Pearson’s Correlation and the intra-observer reliability was tested by Interclass Correlation Coefficient.
RESULTS: The vertical dimension was the most variable between patients and from T1 to T2. Treatment effects on the maxillary and mandibular molars on the Class II side were significantly different from the Class I side. There was no association between the transverse change in maxillary and mandibular contact points and the antero-posterior change of the maxillary and mandibular canines and molars respectively. Gonion and PNS showed a tendency for posterior displacement.
CONCLUSION: The coordinate method was found to be reliable for longitudinal studies in 3-Dimensions and allows the evaluation of amount and direction of treatment changes.

Keywords: Subdivision, Correction, Cone Beam Computed Tomography, Coordinate.

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Review of the Literature

In the late 1800s, as the concept of prosthetic occlusion developed, Edward H.Angle was among the first to extend it to the natural dentition. Angle’s classification of malocclusion was an important step in the development of the specialty of orthodontics because it not only subdivided major types of malocclusion but also included the first clear and simple definition of normal occlusion in the natural dentition (Proffit, 2007). Angle’s postulate was that the maxillary first molar was key to occlusion and that the maxillary and mandibular molars should be related so that the mesiobuccal cusp of the maxillary molar occludes in the buccal groove of the mandibular molar. If teeth were arranged on a smoothly curving line of occlusion and this molar relationship existed, then normal occlusion would result, except for aberrations in size or number of teeth. Angle then described three classes of malocclusion commonly used today, based on the occlusal relationship of the first molars: Class I, Class II and Class III.

With the establishment of a concept of normal occlusion and a classification scheme that incorporated the line of occlusion, by the early 1900s, orthodontics was no longer concerned with just the alignment of irregular teeth. Instead, it had evolved into the treatment of malocclusion, defined as any deviation from the ideal occlusal scheme described by Angle.

In his classification of malocclusion, Angle in 1899 defined Class II subdivisions as a Class I molar relationship on one side and Class II molar on the opposite side. According to his theory, subdivisions are caused by a distally erupting mandibular first molar on one side, sometimes accompanied by a mesially erupting maxillary first molar, resulting in the "mislocking" of the molars during their eruption (Angle, 1904). Today, confusion still exists in the orthodontic community regarding Angle's subdivision classification. A survey by Siegel in 2001 showed that the prevailing belief appears to be that the "subdivision" indicates the side with molar malocclusion.

The etiology of occlusal asymmetries from dental origin found in the literature is quite diverse. A malocclusion could develop in a normal dentition by the mandibular premolar teeth drifting distally into the excess space resulting from the replacement of the mandibular deciduous molars by their smaller permanent successors (Seward, 1967). This phenomenon, if asymmetric, could cause a subdivision malocclusion. Following the same principle of drift being responsible for malocclusions, certain Class IIs could be attributed to the early loss of maxillary deciduous molars following the ectopic eruption and mesial drift of the permanent maxillary first molars (Barberia-Leache et al., 2005). Angle hypothetized that the subdivisions were caused by a modified path of eruption whereas Smith and Bailit emphasized the multifactorial aspect

of the asymmetries in occlusion. Unilateral premature tooth loss of a deciduous tooth and lack of precision in the developmental process were cited as potential causes. The worsening of the asymmetry with age could be attributed to asymmetric environmental effects such as thumb sucking, pipe smoking and masticatory habits.

As for the prevalence of the Class II subdivisions, the same authors reported a great variability in the prevalence of subdivisions in two populations studied: while 25% of the Caucasian (N=150) patients displayed discrepancies greater than 2.5mm in the molar relationship, only 6% of the male and 3% of the female Malesian subjects (N=352) displayed the equivalent discrepancy. These results might be influenced by the nature of the Malesian sample not being orthodontic patients. Kula et al. in 1998 studied the transverse and antero-posterior intra-arch and inter-arch asymmetries in 151 children with large overjets (≥7mm). Ten percent of this 7-11 year-old sample had an asymmetry in molar relationship of 2mm or more. Alkofide found a prevalence of 45% of subdivisions in Class II division 1 patients examined. Harris and Bodford examined antero-posterior and transverse variables on 211 dental casts to quantify the extent and nature of asymmetries in routine adolescent patients. Asymmetry was found to be prevalent in the occlusion of routine orthodontic patients with no difference found across all three of Angle’s

categories but the average amount of asymmetry was greater in severe Class IIs.

When diagnosing a malocclusion, not only should we look at intra- and inter-dental arch tooth relations but we also should identify the skeletal relations that may contribute to the Class II dental problem. Coupling the information regarding denture relations and the information regarding skeletal relations points out the relationship of the dental arches to the skeletal framework in which they are located. In subdivision malocclusion, is the problem skeletal and are the dental arches misplaced in well-related skeletal bases or is it a combination of these possibilities? If the problem is skeletal, are the maxilla and/or the mandible at fault? Lack of growth of the mandible on the Class II side may be responsible for the unilateral distal position of the dental arch. In this case, the symphysis is located toward the shorter side of the mandible in relation to the facial midline and a skewing of the mandible is seen with the mandibular dental midline shifted towards the shorter side. As for the maxilla, it is doubtful whether one could prove a maxilla to be skeletally forward or overgrown in a unilateral manner so that one half of the maxilla was forward and was responsible for a Class II dental relation on that side (Wertz, 1975).

Finding symmetrically related basal jaw structures, unilateral Class II malocclusion must then be attributed to asymmetrical position of one of the dental arches upon its

skeletal base. On accurately trimmed dental casts with the heels trimmed at 90° angle to the midpalatal raphe, all four quadrants can be studied. On the Class II side either the maxillary buccal segment will be found to be forward or the mandibular buccal segment retruded. Functional shifts must also be considered; Alkofide found 36% of mandibular shift upon closure in a subdivision patient sample.

Since appropriate treatment starts with accurate diagnosis, several authors investigated the prevalence of mandibular asymmetries in subdivision patients, in 2-Dimensions first and more recently in 3-Dimensions.

Tadej et al., based on studies of the effect of functional appliances on the temporo-mandibular joint (TMJ), assumed that certain malocclusion influenced the TMJ as well. These authors used the Submento-Vertex (SMV) and tomographic films of 104 orthodontic patients prior to treatment. The size and location of the condyles were determined and tested for their correlation with clinical findings like age, sex, malocclusion type, facial type, TMJ symptoms, tooth eruption sequence, crossbite and midline discrepancy. Midline discrepancy was found to be correlated with the condylar size during growth. Transverse anomalies had a greater influence on condylar growth compared to the other characteristics of occlusion and the principal change in condylar size during growth was in the medio-lateral dimension, which correlated to midline discrepancies, age and sex. Sabah also used a SMV

analysis to compare a Class II subdivision group (N=20) and a Class I control group (N=20). Using the intercondylar line and axis, the relative differences were measured between mandibular landmarks in both antero-posterior and transverse dimensions. These dimensions, as well as the midline position and coronoid process showed statistically significant differences between the groups. Other types of 2-Dimensional imaging have been employed to analyze symmetry with the postero-anterior (PA) radiograph being used by several authors sometimes combined with another view and/or dental casts. Different authors agreed on the origin of the asymmetry of the groups studied being mostly mandibular dento-alveolar with the maxillary dento-alveolar complex playing a secondary role, without significant skeletal asymmetry (Araujo et al. 1994, Alavi et al. 1988, Azevedo et al. 2006, Rose et al. 1994 and Janson et al.2001, 2006).

Hoffman, however, with the intent to determine whether there is a greater degree of transverse skeletal asymmetry in Class II subdivision malocclusion patients, found several skeletal locations with “larger-than-normal” asymmetry. The results indicated that a significantly larger degree of skeletal asymmetry (9 of 16 linear measurements) occurs for asymmetric population compared to symmetric population with the most significant differences being the transverse position of the lateral borders of the maxilla and condylar-ramal lengths from the body of the mandible. Since previous research

had not determined a “normal” degree of skeletal asymmetry in the general population, Hoffman established an index of normal asymmetry as a reference for clinical diagnosis of PA radiographs from the 22 symmetric Class I subjects. Mandibular asymmetry alone has been studied on panoramic radiographs (Habets 1988, Sezgin OS et al. 2007, Kiki A et al. 2007, G Kurt. 2008) and condylar height seems to be affected more than ramal height with no statistically different values found for Class II subdivision patients. One could certainly question the results of 2-Dimensional studies when it comes to differences so small that they can easily be undetected due to the technique chosen.

At the beginning of the 20th century, two-dimensional (2-D) cephalometric radiography was the primary method used in orthodontic research and clinic to capture dental-facial morphology. Although it has played a major role in orthodontic diagnosis, outcome tracking and growth prediction, 2-D cephalometry has its inherent weaknesses. The main one is that 2-D inevitably loses some information when it is used to represent 3-D structures, because the patients are tri-dimentional. In traditional cephalometry, 3-D craniofacial structures are projected onto 2-D radiographic film creating a two-dimensional shadow of the three-dimensional object. On lateral cephalometric images, bilateral anatomical structures project a dual image on the radiograph and do not superimpose perfectly on the cephalograms, because the fan of the x-ray

beam diverges as it passes through the head. Clinicians average the bilateral structures which results in a loss of parasagittal information and any true asymmetry of the patient. Another weakness of 2-D projection is distorted enlargements by nonparallel X-ray beams which originate from a small source.

In an attempt to reproduce the 3-D live structures and minimize the systematic problems, Broadbent Jr. introduced the Broadbent Orientator which used the information gained from biplane film radiographs to create 3D data points. Although this method is sound, it could not be widely employed due to its difficult application with less accurate measurements than true anatomic values (Grayson et al., 1988). Therefore, 3D data collection was not routinely attempted. Longitudinal studies based on various linear and angular measurements inevitably lost some information about the full landmark configuration and it is impossible to determine how important this loss is to diagnosis and treatment planning. Berger attempted to evaluate the accuracy of structural representation in SMV view. The mandible shows the most distortion and enlargement because it is further away from the film so it is not accurate to measure the condyles and therefore its use is limited in asymmetry studies. As for panoramic radiographs, Kambylafkas et al. reported a poor sensitivity (ability to detect true positives) for condyle and ramus measurement. Habets et al. found that when the asymmetry

is less than 6% of the height of the structures measured, it might remain undetected and would then be under-diagnosed. Lateral cephalometric radiographs are of little value for Left-Right asymmetry studies because bilateral structures are superimposed and differently magnified due to the variations of proximity to the film.

The recent emergence of Cone Beam Computed Tomography (CBCT) has provided a 3-D reconstruction of the entire craniofacial skeleton allowing methods to evaluate internal structures. CBCT can also provide 3D data preserving fully the information of the geometry of the landmarks which is a more representative way for shape measurement than 2-D. The longitudinal study of normal facial growth requires high precision in measurement in order to investigate and interpret true biologic changes. Gribel et al. compared the accuracy of craniometric measurements made on lateral cephalograms and on CBCT images. Ten fiducial markers were placed on 25 dry skulls of which CBCTs and conventional lateral cephalograms were obtained and direct measurements were then compared with those from the two techniques. No statistically significant difference was noted between CBCT and direct measurements, mean difference 0.1mm. While all cephalometric measurements showed significant differences, a mean difference 5mm. A large variation was noted: some measurements were larger than the real structure dimension and some were smaller. These results suggest that CBCT measurements are accurate to the subvoxel

size and can potentially be used as a quantitative orthodontic tool. Olmez et al. did a similar study on 13 dry skulls and reached the same conclusion with the most magnified measurement on the lateral cephalogram found to be the one involving the farthest landmarks from the central X-ray beam. Brown et al. compared the reliability and accuracy of linear measurements between different basis projections (153, 306 and 612) and manual measurement on 19 dry skull. No significant difference was found between different projections, but the reliability of the manual measurements was greater than all CBCT measurements. The CBCT measurements mean error however ranged from 0.77 to 0.88mm, which was consistent with previously reported mean errors less than 1mm.

Another important advantage of 3-D is that the images are captured without the concern of head position whereas errors of 2-D projection can arise due to this variable when radiographs are obtained. In contrast, in 3-D a head position problem doesn’t exist and this removes the need for a commonly biased reference plane. For longitudinal studies however, if the comparison between successive images is needed, the orientation of the volume matters and the question then is: can we use landmarks from the 2-D images transitioned to 3-D? In this situation, the concern lies in the fact that a number of the commonly used structures of a 2D image are in fact optical illusion or constructed points, and do not reflect the real anatomy (“Key Ridge”, “Articulare”, etc.). In 2007, the

ABO adopted the method of superimposing on “the best fit of the anterior cranial base and center of sella turcica” proposed by De Coster. But in 2008, Enlow and Hans pointed out that Sella and Nasion are not exempt from growth as reported by Melsen (1974), Bjork and Skieller (1983) and Ricketts (1976) before them.

Among the attempts to find stable structures to analyze facial growth, Bjork’s method using metallic radiographic markers has obtained wide acceptance. Inspired by the unchanging mandibular nerve canal during growth, the assumption that some cranial nerves remained unchanged after a certain period of time was investigated. Since optical foramina and Foramina Ovale are both seated in sphenoid bone, the relatively mutual position of these structures in one bone was stable and these structures were less influenced after the brain size was almost complete at the age of 5. Although the cranial structures underwent lifelong surface remodeling, whether the inner surface of nerve canals has experienced the same changes is doubtful. Based on these assumptions, Wu et al. in 2011 tested the reproducibility of a 3-D image orientation using 8 anatomical structures including left and right Optical Foramina, left and right Foramina Ovale, Foramen Cecum, Basion and Opisthion. In the coronal view, the head is adjusted so that the axial plane was set through the center of the left and right optical foramina and aligning these structures prevented the head roll.

In the axial view, the head is adjusted so that the coronal plane was set through the center of left and right foramina ovale and aligning these structures prevented the yaw movement. After adjustment of the head in coronal and axial views, the sagittal plane was set on Foramen Cecum to the intersection of the coronal plane and the axial plane and the axial plane was then set to overlap the McRae's, plane denoted by a line touching the anterior border of Foramen Magnum (Basion) to the posterior border of Foramen magnum (Opisthion) and aligning these structures prevented the pitch movement. The 5 landmarks were placed 3 separate times by the same operator on 30 CBCT images. All the data showed measures of dispersion less than 0.3mm, making it a reliable and reproducible orientation method allowing one to use it as a Cartesian coordinate system in 3-D.

Renee Descartes (1596 – 1650) was a French philosopher, mathematician, and writer whose work revolutionized the scientific world, allowing algebraic equations to be expressed as geometric shapes in a two-dimensional coordinate system. This system can be adapted to the needs of 3-dimensional images, making it possible to specify each point uniquely in a plane by 3 numerical coordinates, which are the signed distances from the point to 3 fixed perpendicular directed lines. In our case these planes of reference are measured in the same unit of length. In addition to a high-level of accuracy, effective reproducibility is essential for 3D

measurements of CT images and a certain landmark is useless if the anatomical coordinate system cannot be reproduced.

Shibata et al. tested four coordinate systems created on images obtained by CBCT. Three-dimensional images of 10 patients were obtained with a large field of view and six dentists set four coordinate systems that were created in different ways. The 95% confidence ellipse of six objective landmarks related to the jaw and teeth (maxillary incisor, left maxillary first molar, mandibular incisor, left mandibular first molar, Menton, and left Gonion) was three-dimensionally drawn for each coordinate system. The ellipsoid volume was calculated to evaluate the reproducibility of the coordinate systems with the four anatomical coordinate systems set as follows: 1)Sella (S), Nasion (N), Basion (Ba), 2)Left Orbitale (Or-L), Left porion (Po-L), Right Porion (Po-R) and Ba, 3)Po-L, Po-R, Left Foramen Spinosum (Sp-L) and Ba, 4)Po-L, Po-R, Anterior Nasal Spine (ANS) and Ba. In all four systems, Basion was the Origin (O), in other words the coordinate (0,0,0). In order to test the coordinate system alone by excluding the objective landmark placement error, each one was placed only once and the same landmark’s coordinate was converted into a new coordinate when switching. The results were presented on 95% confidence ellipses, a smaller size ellipse meaning a higher reproducibility. The volumes of ellipsoids in systems 2 and 4 are significantly smaller than those in systems 1 and 3 for almost all objective landmarks,

thus showing higher reproducibility. A possible cause for this result would be the difference in the distance between the landmarks used for setting coordinate systems. Basion was revealed to be a key landmark because it was stable in all directions while the further away an objective landmark was from the Origin (Ba), the larger the ellipse. The small sample size and the A.L.A.R.A principle (radiation dose “as low as reasonably achievable”) have to be kept in mind when interpreting these results.

In order to evaluate the effects of treatment on adolescents, the final result must be visualized from the situation that would have prevailed with growth, had treatment not been employed (Ricketts, 1960) in order to be able to interpret and understand the results of a study on growing individuals, it is necessary to have knowledge of what “normally happens” from the growth point of view in the age range under consideration. A study involving teenagers will give results combining the effect of growth to those of treatment, which should be acknowledged in the interpretatin of the results. The Naso-maxillary complex shows a downward and forward displacement both by push of the cranial base and by sutural growth. Riolo et al. measured the Basion-Anterior Nasal Spine increments and the Basion-Posterior Nasal Spine increments, allows us to show about 25% greater forward growth rate of the nose compared to the maxilla (Riolo et al., 1974).

In the Mandible in the same study, the ramus height increase was evaluated at 1-2mm per year and the body length at 2-3mm per year. The weakness of this study was that it was cross-sectional which tends to smooth out growth spurts that occur in puberty (Proffit, 2007). The prominence of the chin increases by resorption at B-point area. The most common movement of the glenoid fossa is straight down or sometimes back (decreasing chin projection) but rarely forward.

The width is the first dimension to reach the “adult growth rate”, usually before adolescence and is minimally if at all affected by it. The intercanine width tends to decrease after age 12 but the maxillary arch width increases as the second and third permanent molars erupt. The mandibular arch at the level of the molars as well as bicondylar width shows an increase until the end of growth in length with the anterior segments of the dental arches stabilizing earlier. As for the length and height, in girls, the maxilla grows downward and forward until 2-3 years after menstruation, then shows a more straightforward pattern. In both sexes, vertical growth continues longer than length. The increase in the vertical dimension concomitant to eruption of teeth continues throughout life with a decline occurring around early twenties. Bjork and Skieller, using metallic implants, witnessed the rotation of the jaws during growth and observed on average 15° of internal forward rotation of the mandible (occurring in the core of the jaw). Combined to that was 11-

12° of external backward rotation (surface changes), producing a 3-4° decrease in the mandibular plane angle during childhood and adolescence. The maxilla is more variable, showing forward or backward internal rotation. The external rotation opposes the internal rotation in direction and magnitude in such a way that on cephalometric superimposition, the maxilla seems to translate without rotation. However, these observations can vary with different “facial patterns” with rotations in dolichofacial patients rotating in opposite directions compared to brachyfacial patients. Through adulthood, males tend to show a forward rotation of the jaws whereas women tend to show a backward rotation (Bjork and Skieller, 1983).

In addition to “normal growth” changes, orthodontic treatment induces some effects on tooth movement, inter-arch relationship and skeletal base relationship. Ricketts, studied five groups of 50 patients (pre-adolescents and adolescents) for a longitudinal study: 2 non-treated groups (Class I and Class II) used as controls, and 3 treated groups of Class II patients treated by headgear alone, intermaxillary elastics and headgear with mandibular anchorage. Using cephalometric tracing the following areas were evaluated: cranial base, mandible, maxillary components, changes in incisors and molars and growth of the nose. Growth of 0.86±0.3mm on the Sella-Nasion line was observed. The mandible did not seem to be affected in amount of growth by treatment but the directional behavior of the chin could be influenced by the technique

used. Growth on the Y-axis was 3.0±1.2mm per year with the effects of bite opening and rotation of the mandible varying in different facial patterns. A-point was modified in cases of vigorous intra-oral forces, with less nasal spine alteration. Patients treated with intermaxillary elastics showed a forward movement of the lower arch and a clockwise rotation of the occlusal plane by elevation of the lower posterior segments and extrusion and retroclination of the upper incisors with the anterior nasal spine (ANS) growing almost 1mm per year. The force of elastics, if nothing is done to control the upward and forward movement of the lower molars, results in a backward rotation of the mandible (undesirable in retrognathic cases) and forward movement of the lower arch, possibly causing a strain on facial musculature.

Fixed devices for sagittal advancement of the mandible that do not require the patient’s cooperation have been introduced to the orthodontic community offering the possibility of combining the use of the functional appliance with multibracket therapy in order to shorten treatment duration. The effects of several compliance-free appliances for mandibular anterior repositioning in association with fixed appliances have been investigated in the literature, like the Forcus ™ (3M). The Forcus, also known as the Forcus Fatigue Resistant Device [FRD]) is a semirigid telescoping system incorporating a superelastic nickel-titanium coil spring that can be assembled chair-side, to be used in

conjunction with complete fixed orthodontic appliances. A case-control study by Franchi et al.(2011) on the effects of the Forcus™ (3M) shows an increase in mandibular length, reduction in the overjet, proclination and intrusion of the mandibular incisors, mesial and vertical movement of the mandibular molars and restraint in the sagittal skeletal position of the maxilla.

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Statement of thesis

The aim of this retrospective study is to evaluate the tridimensional dento-skeletal changes taking place during Class II subdivision malocclusion correction.

It is hypothesized that: 1) There is no difference in the spatial position of the bilateral landmarks between the Class I side and Class II side at T1 and at T2 in Class II subdivision patients, 2) There is no difference in the movement of bilateral landmarks in the 3 planes of space between the Class II side (case) and the Class I (control) in the Class II subdivision patients, 3) There is no change in the 3 planes of space in the parasagittal landmarks with treatment of the Class II subdivision malocclusion, 4) There is no association between the antero-posterior change in molar and canine position on the Class II side and the transverse change in central incisors contact point in the 3 planes of space with treatment of Class II subdivision malocclusion, 5) There is no association between the antero-posterior change in Gonion and Condylion with the antero-posterior change in the mandibular molar in the 3 planes of space with treatment of Class II subdivision malocclusion.

A 3-D evaluation of Class II subdivision malocclusion correction

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Abstract

INTRODUCTION: Our objective was to evaluate the dento-skeletal changes occurring during a comprehensive non-extraction orthodontic treatment of Class II subdivision malocclusion in the three planes of space using cone-beam computed tomography (CBCT).
METHODS: The pre- (T1) and post-treatment (T2) CBCTs of 25 adolescent subjects were oriented using the cranial nerve canals to set the 3 planes of reference and 19 landmarks were registered on maxillary, mandibular and dental structures. The data consisted of 3-dimensional coordinates representing the distances to the reference planes. The data was analyzed using t-test, Pearson's Correlation and the intra-observer reliability was tested by Interclass Correlation Coefficient.
RESULTS: The vertical dimension was the most variable between patients and from T1 to T2. Treatment effects on the maxillary and mandibular molars on the Class II side were significantly different from the Class I side. There was no association between the transverse change in maxillary and mandibular contact points and the antero-posterior change of the maxillary and mandibular canines and molars respectively. Gonion and PNS showed a tendency for posterior displacement.
CONCLUSION: The coordinate method was found to be reliable for longitudinal studies in 3-Dimensions and allows the evaluation of amount and direction of treatment changes.

Keywords: Subdivision, Correction, Cone Beam Computed Tomography, Coordinate.

Introduction

Symmetry is a key criterion of an esthetic smile, and often a request from the patients seeking orthodontic treatment. Correcting asymmetric occlusions can be challenging and the question whether an asymmetry is only dental or has also a skeletal component has been investigated by several authors.

Correction of a Class II malocclusion may follow one of several courses. In most instances a Class I molar relation is the desired goal and may be achieved either with extraction of teeth or without which is the sample targeted in the present endeavor. A large number of longitudinal studies on Class II subdivision malocclusion treatment involve 3 or 4 premolar extraction and the results are analyzed in 2-D.

There seems to be a lack of evidence, however, about the effect of nonextraction treatment on Class II subdivision malocclusion in 2-D as well as in 3-D.

Janson et al.[1] (2004) studied the dental changes of a sample of Class II subdivision patients treated with asymmetric extractions and intermaxillary elastics on submento-vertex (SMV) and postero-anterior (PA) radiographs. The results were compared with a group of Class I patients and a group of non-treated Class II subdivision patients. Correction of the upper and lower midline was achieved without cant of the occlusal plane and no significant skeletal changes or transverse effects attributed to asymmetric mechanics were found. The same investigators[2] compared the treatment effects on Class II subdivisions with 3 or 4 premolars extracted. Significantly there was less mandibular incisor retraction observed in the asymmetric extraction group, as well as a greater mandibular incisor extrusion. Geramy[3] analyzed the changes that led to space closure, midline correction and overjet reduction after removal of one premolar on the side of the subdivision and canine retraction, using different designs of looped archwires. Researchers concluded that the A-P (antero-posterior) and medio-lateral movements of the upper incisors increase from the Class I side to the Class II

side and the supero-inferior displacements of the incisors result in canting of the occlusal plane.

Sanders et al.[4] used a 3-Dimensional coordinate system to compare the degree of dento-skeletal asymmetry in 30 subjects with Class II subdivision malocclusion, compared to 30 subjects with normal Class I occlusion. This was the first case-controlled study to find significant skeletal asymmetries among Class II subdivision patients, when past studies reported distal positioning of the mandibular molar as the main etiologic factor. If 3-D imaging proved to be more effective[5-8] to detect Class II subdivision malocclusion skeletal asymmetries, it might also be more sensitive than 2-D imaging to evaluate treatment changes, as it has been proven to give measurements closer to the reality. As in the study by Sanders et al., planes of reference were chosen as X, Y and Z axis as well as dento-skeletal landmarks, with some of them modified from lateral cephalometric landmarks.

Testing the reliability of the operator in landmark placement will be one of the focuses of this study. Baumrind et al.[9] tested the reliability of landmark identification on 20 lateral cephalograms and used acetate paper for five operators to place a series of 16 points by perforating the paper with a needle. A computer system allowed combining these results (a hundred points per landmark) into scatter plot graphs which revealed that each landmark has its own characteristic and usually noncircular envelope of error. If the landmarks are formed by sharp folds, for example the lower incisor edge, the estimation was relatively accurate and reliable. However, if the landmark points were characterized by gradual curves and surfaces, such as Gonion, the identification would be more difficult and errors of measurement were larger. These results should be considered when analyzing the reliability of out method.

Our aim is to evaluate where the changes took place and to what extent, using dento-skeletal landmarks and a 3-Dimensional coordinate system with selected planes of reference.

The other main focuses of this study are to: evaluate what landmarks differ in their spatial position before and after treatment in Class II subdivision patients, analyze the treatment changes on the Class I and the Class II sides and if it is the case identify what landmark was involved and in what direction, evaluate the changes of the parasagittal landmarks, especially the right Orbitale that can be expected to be stable throughout treatment on adolescents and finally identify any association between the different dento-skeletal changes.

Material and Methods

This retrospective study was approved by the Case Western Reserve University Institutional Review Board (IRB) (Appendix 1). Before the initiation of treatment, a legal guardian signed the American Association of Orthodontists Informed Consent (Appendix 2), including a paragraph consenting to the use of records for research purposes (Appendix 3). Subjects were selected from a sample of adolescent patients presenting to the Graduate Clinic of CWRU School of Dental Medicine for comprehensive orthodontic treatment. Data were derived from pre-treatment and post-treatment Cone Beam Computed Tomography (CBCT) scans (CB MercuRay^{TM}, Hitachi Medical Systems America Co. – Twinsburg, OH). All scans were taken in the Craniofacial Imaging Center at Case Western Reserve University School of Dental Medicine during routine records appointments using the 2mA setting and the largest field of view (0.38mm Voxel size). A total of 264 patient records consisting of CBCT scans, photographs and at least a set of pre-treatment dental casts trimmed in centric occlusion and medical history forms were available. The expected Effect Size (E) was set at 0.5mm that we consider to be more clinically relevant than the Voxel size (0.38mm). The standard deviation (SD) of 0.61 was taken from the subdivision study by Sanders et al.[4] (2010) and corresponds to the SD of the mean antero-posterior difference in millimeters between the Class I side of the subdivision group and the same side in the normal group. With a two-tailed α of 0.05 and

a confidence level of 95%, a sample size of 25 (E/S=0.82) was required when using a t-test to compare means of continuous variables, based on the sample size calculation table[10]. After reviewing the subjects that met the inclusion criteria, 30 remained but 5 subjects had to be excluded for 2 reasons: the field of view did not include Opisthion which is necessary to orient the images or the subjects were not biting in centric occlusion (CO) and instead were at rest. The 25 eligible subjects were included in the study.

The inclusion criteria were the following: 1) Patients from CWRU Department of Orthodontics, Core Clinic (range , 2) Class I molar on one side, end-on Class II (half-cusp) or full step Class II (full cusp) on the opposite side, 3) Permanent teeth mesial to the second molars clinically present, 4) Symmetric crowding or spacing up to 5mm per arch, 5) Class I molar and canine bilaterally at the end of treatment, 6) Initial and final records available: pictures, clinical exam report, medical history, CBCT, initial dental casts, 7) Class II correctors included: intermaxillary elastics or Forcus ™ (3M).

The exclusion criteria were: 1) Significant medical history (e.g. syndrome, cranio-facial anomalies, trauma, growth disturbance), 2) Shift in the path of closure determined by clinical examination, 3) Tooth size discrepancy, malformed or grossly decayed teeth, 4) Crossbite at the incisors or first molars, 5) Use of active molar distalization appliances (Distal jet, pendulum, headgear) or temporary anchorage devices (TADs), 6) Extraction therapy during comprehensive orthodontic treatment, 7) Use of palatal expander during comprehensive orthodontic treatment.

Nineteen landmarks were chosen to reflect dento-skeletal changes with treatment. They were chosen based on the asymmetry study by Sanders et al.[4] and modified cephalometric landmarks. 12 are bilateral, 7 are parasagittal (or unilateral in the case of OrR).

The dental landmarks are described as follows:

- MxC: Most incisal point of contact between the maxillary central incisors

- MdC: Most incisal point of contact between the mandibular central incisors
- Mx3Cl I and Mx3Cl II: Cusp tip of the maxillary canine on the Class I and Class II side
- Md3Cl I and Md3Cl II: Cusp tip of the mandibular canine on the Class I and Class II side
- Mx6Cl I and Mx6Cl II: Mesiobuccal cusp tip of the maxillary first molar on the Class I and Class II side
- Md6Cl I and Md6Cl II: Central fossa of the mandibular first molar on the Class I and Class II side

The maxillary landmarks were:

- ANS: Most anterior point of the anterior nasal spine of the maxilla
- PNS: Most posterior point of the posterior nasal spine of the maxilla
- OrR: Right Orbitale, most inferior point of the right infraorbital rim of the maxilla

The mandibular landmarks consisted of:

- Pog: Pogonion, most anterior midpoint on the mandibular symphysis
- Me: Most inferior midpoint of the chin on the outline of the mandibular symphysis
- GoCl I and GoCl II: Gonion, point of maximal convexity of the mandibular angle on the Class I and Class II side
- CdCl and CdCl II: Condylion, most superior point of the condylar head on the Class I and Class II side

Method of 3-D image orientation: The slice thickness will be set default at 0.38 mm as a standard Voxel height. If the bilateral nerve canals were not visible on one slice simultaneously, the slice thickness was increased until they were. Following the method described by Wu et al.[11] (2011) to orient each one of the pre- and post-treatment 3-D images: In the coronal view, the axial plane was aligned with the center of the left and right optical foramina by tilting the head. (Figure1). In the axial view the coronal plane was aligned with

the center of the left and right foramina ovale by rotating the head and then the axial plane was scrolled to the level of Foramen cecum. The sagittal plane was positioned to pass through Foramen cecum. (Figure2). Finally, in the sagittal view, the pitch of the head was adjusted so that the axial plane overlapped McRae's line (Basion to Opisthion) (Figure 3). This process allowed the image to be fixed in the 3 planes of space and without rotating the image in any direction; the axial plane overlapping McRae's line and the sagittal plane overlapping Foramen Cecum, the coronal plane was set at Basion (Fig. 4). The Origin, or (0,0,0) coordinate, was estimated around the Basion area because this is where all 3 planes intersect. This orientation and coordinate system was saved as default orientation, allowing the operator to reset it between every landmark registration.

Wu et al.[11]tested the reliability of this orientation method and found that all the landmarks illustrated circular envelopes of error, which means that the variation was distributed along all three planes evenly. This result is consistent with Baumrind[9]'s philosophy about mental averaging process. Sella for example, presents a circular envelope of error since the visual estimation of the midpoint is a kind of mental averaging process leading to reduced dispersion. All landmarks selected by Wu et al.[11] had circle-like features, which allows the visual estimation of the center of a structure to be applied and each measure of dispersion was less than 0.3mm.

All the dento-skeletal landmarks were registered by one operator on the volume slices and the 3-D image was used only as a general overview of the registration, never for landmark placement. In order to register CdClI and CdClII, a sculpting tool was used to clip the mandible alone and this way isolate it from the rest of the skull, providing a direct view of the head of the condyle. The orientation was reset to initial between each landmark registration and all the pre-treatment (T1) registrations were done first, followed by all the post-treatment (T2) images. No coordinate value was visible or even accessible during the

registration process until it was exported. Once all T1 and T2 measurements were recorded, the total of 50 images (T1 and T2) were given a number from 1 to 50 and 10 were chosen through a random numbers generator. The same operator reoriented and re-registered all 19 landmarks on these 10 images at least 3 weeks after the end of the previous registration. No landmark or coordinate from the first measurements were visible during the intra-observer reliability testing process since the raw volume was downloaded again into the computer program. Once all the landmarks registered, the data were exported directly to an Excel file without the need to transcript any measurement manually to minimize errors.

All statistics were calculated using the Statistical Package for the Social Sciences (SPSS 20.0, Inc. – Chicago, IL): 1) Means, standard deviations and ranges were calculated for the sample as well as gender distribution and treatment time, 2) The Frequencies were analyzed to evaluate the distribution of all variables, 3) Means, standard deviations and ranges were calculated for the absolute value of each bilateral landmark in the 3 planes of space. The sign was not taken into account because not every patient has the malocclusion on the same side, 4) Means, standard deviation and ranges were calculated for each parasagittal or unilateral landmarks in the 3 planes of space, 5) The reliability of the landmark registration was tested by repeating measurements on 10 images, 6) Paired sample t tests were used to compare the Class I side at T1 with Class I side at T2, the Class II side at T1 with Class II side at T2 and the parasagittal landmarks at T1 and T2, 7) A paired sample t test was used to compare the differences in change (T2-T1) on the Class II side and on the Class I sides, 8) The associatiopn (Pearson Correlation) was tested between the maxillary and mandibular central contact point and the maxillary and mandibular canines and molars respectively, as well as between the mandibular molars and Gonion and Condylion on the same side.

Results

The sample consisted of twenty-five subjects with Class II subdivision malocclusion treated with comprehensive orthodontics (Table 1). The consisted of a majority of Caucasians (N=22) and three belonged to other ethnic groups. These 25 subjects, 13 males and 12 females were all treated with intermaxillary elastics and only one had a combination of intermaxillary elastics and Forcus ™ (3M) for poor compliance reasons.

Eleven of them had the malocclusion (Class II) on the left side and fourteen had it on the right side and the distribution of the Class II among genders is described. The mean age of the subjects at the initial records (T1) was 13.5±1.6 years and at the final records (T2) was 15.8±1.6 years.

All variables in each plane of space showed bell-shaped curves on the frequencies histograms indicating a normal distribution which allowed the use of the means to compare the variables among each other.

It must be reminded that changes in the X plane (sagittal plane) reflect transverse changes; changes in the Y plane (axial plane) reflect the vertical changes and changes in the Z plane (coronal plane) reflect the antero-posterior changes.

The mean, range, minimum, maximum and standard deviation (SD) for the bilateral landmarks are shown in Table 2. Their absolute values were used because the Class II being on different sides in different subjects, the values would have cancelled each other by the process of averaging which would not have been representative of their real relationship to the reference planes. However, for the description of the parasagittal landmarks shown in Table 3, the signs were kept in all planes of space because they were all either extremely close to one of the reference planes (MxC, MdC, ANS, PNS, Pog, Me with the X plane) or all on the same side of it (OrR with X, Y and Z planes and MxC, MdC, ANS, PNS, Pog, Me with Y and Z planes).

Analyzing the spatial position of the different landmarks in different patients revealed that 1) for the bilateral landmarks, measurements in the Y axis (vertical dimensions) of the dental landmarks was the most variable (high standard deviation), 2) for Maxillary and Dental parasagittal landmarks, X and Y (transverse and vertical dimensions) values were the most variable, except OrR that was quite consistent between patients in the X plane, 3) for the mandibular parasagittal landmarks, Z values were most variable (antero-posterior dimension) and 4) the landmarks positioned further away from the Origin (estimated around Basion area) displayed higher standard deviation (thus dispersion) than the landmarks close to the Origin.

The description of changes from T1 to T2 for bilateral landmarks is shown in Table 4 and the direction of change is shown in Table 5. It should be noted that the only landmark that moved closer to the Z plane (backward) in a majority of the subjects and on both sides is Gonion. The general tendency for the majority of the subjects and all the landmarks is to move away from the reference planes which means laterally, downward and forward.
In the X plane the mean change was bigger on the Class I side for Md3, Md6, Go, Co and on the Class II side for Mx3 and Mx6. In the Y plane, the mean change was bigger on the Class I side for Mx6, Md6, Go, Co and on the Class II side for Mx3 and Md3. In the Z plane, the mean change was bigger on Class I side for Mx3, Mx6 and in the Class II side for Md3, Md6, Go, Cd.

The mean, range, minimum, maximum and standard deviation (SD) for the parasagittal landmarks are shown in Table 4 and the direction of changes is described in table 6. The description of the change from T1 to T2 reveals that, on average in the X plane, MxC and MdC moved closer to each other except in 2 patients (FR98 and WI235). Their mean change was 1.41± 0.96mm and 1.26±0.83mm respectively and they moved in opposite directions in only 7 out of 25 subjects. MxC is the only parasagittal landmark that displayed

an obvious tendency to move toward the Class II side (16 of the 25 subjects). OrR was found to be very consistent between patients and from T1 to T2 in the X plane with small range and standard deviation. The range of change in ANS and PNS was 3mm and they moved in the same direction in 15 of the 25 subjects. The ranges for the change of Pog and Me were 4mm and 3.5mm respectively. As for the direction of change in Pog and Me, Pog moved toward the Class II side in 13 subjects and away from it in 12 subjects whether Pog moved toward the Class II side in 12, away from it in 12 and stayed the same in 1 subject.

In the Y plane, both MxC and MdC changed with mean values of 2.34±1.77mm and 3.84±2.76mm respectively. OrR mean vertical change was 1.5±3.9mm, thus a high dispersion. More vertical change in ANS (mean= 1.76±1.53mm) than PNS (mean= 0.85±0.66 mm) was observed with a range double for ANS compared to PNS. Pog and Me mean changes were 3.88±3.07 mm and 4.27±3.30 mm and their ranges were identical (12.1mm).

In the Z plane, MdC showed more antero-posterior change (mean= 3.19±2.4 mm) than MxC (mean= 2.51±2.00 mm). The direction of change was variable for both MxC and MdC but a majority of the patients displayed a forward movement (16 and 22 of 25 subjects respectively). OrR displayed the most change in this plane (mean= 2.28±1.94 mm). ANS mean antero-posterior change was 2.64±1.95 mm, greater than PNS mean change of 1.52±1.36 mm. It should be noted that PNS is the only parasagittal landmark that moved backward in a majority of the subjects (13 of 25). Pog and Me displayed similar antero-posterior changes (2.89±2.04 mm and 2.83±2.16 mm respectively).

Interclass correlation coefficients (ICC or r^2) to evaluate the reliability of the method are shown in Tables 7 and 8. For the bilateral landmarks, the investigator was found to be the most reliable in the X plane, with values as high as 1.000. The least reliable bilateral landmark registration however was found to be Cd in the Z plane (r^2=0.857). However, the

investigator was found to be the least reliable in the X plane for parasagittal landmarks, the least reliable registration being OrR (r^2=0.713), the same landmark that was found to be very constant between subjects. With an ICC of 0.986, the registration of Pog in the Z plane was the most reliable.

The difference in spatial position between sides of the bilateral landmarks at T1 is depicted in Table 9. The significant differences were found in the Z plane only (antero-posterior), between Mx3, Mx6 and Md6 ($p<0.05$). However, when the same test is applied to the coordinates of the bilateral landmarks at T2, none of the values show significant differences (Table 10).

Looking at the changes on each side for both Mx3 and Md3, the change in vertical position was significant at the 0.05 level (Tables 11 and 12). Even though both landmarks displayed a significant antero-posterior change in the Class I side, Md3 showed a significant antero-posterior change on the Class II side, where Mx3 did not. For both Mx6 and Md6, the significant differences from T1 to T2 lie in the vertical and antero-posterior planes and not in the transverse dimension and in both sides (Tables 13 and 14). Go and Cd were found to be statistically different from T1 to T2 in the vertical dimensions of the Class II side and the A-P dimension of the Class I side (Tables 15 and 16). Go showed a significant change in the vertical dimensions of the Class I side.

The results of the t test on bilateral landmarks comparing sides without plane distinction are shown in Table 17 and reveal that only the maxillary first molars shows a significant difference from T1 to T2. When the distinction of planes is made, however, both maxillary and mandibular first molars on the Class II side in the antero-posterior direction show significantly different changes ($p<0.01$) compared with the Class I side (Table 18).

Surprisingly, MxC and MdC showed significant changes in both vertical and A-P directions, but not in the transverse (Tables 19 and 20). The amount of the midline

discrepancy was variable at T1 between subjects and sometimes even with the asymmetry in the posterior relationships, the midlines were close to being coincident. It must finally be reminded that the change in a point cannot reflect the change in the midline seen clinically. OrR and ANS showed a significant difference in their antero-posterior position from T1 to T2 (Table 21). Pog and Me both displayed a significant difference in means from T1 to T2 in the vertical as well as in the antero-posterior dimension.

The associations were tested between: 1) MxC, Mx3Cl1z, Mx3Cl2z, Mx6Cl1z, Mx6Cl2z (Table 22) to evaluate how the transverse change of the maxillary contact point and the antero-posterior change of the maxillary canines and first molars relate to each other, if they do. The change in MxC was found to be associated to none of the other maxillary dental landmarks. A moderate association was found between both maxillary canines as well as between the maxillary molar on the Class I and the maxillary canine on the Class II side ($p<0.05$). A moderate association was found between maxillary canine and molar of the Class II side and between the maxillary canine on the Class I and molar on the Class II ($p<0.01$). A high correlation at the 0.01 level relates the maxillary canine of the Class I side with the maxillary molar on the same side, as well as the maxillary molars of the Class I and Class II sides, 2) MdCx, Md3Cl1z, Md3Cl2z, Md6Cl1z, Md6Cl2z (Table 23) where we found a moderate association (0.05 level) between the transverse changes in the mandibular contact point and the changes in mandibular molar of the Class II side in the antero-posterior direction. Moderate and high correlations (0.01 level) exist between all of the other dental mandiblular landmarks, the highest being mandibular canine on the Class I side and mandibular molar on the same side. 3) Md6Cl1Z, GoCl1Z, CdCl1Z and Md6Cl2Z, GoCl2, CdCl2Z where no significant associations were found between these groups in the A-P direction but it is interesting to note that a negative correlation exists at the sub-significant

level between Gonion and the molar on the same side on both sides, as well as Condylion and Gonion on the Class II side (Tables 24 and 25).

Discussion

Cone Beam Computed Tomography has proven to be a powerful tool to perform clinical research. According to Ballrick et al.[12] (2008), CBCT can be used to make clinically accurate measurements with acceptable resolution. For longitudinal study purposes, Wu et al.[11] in 2011 found a reliable method to orient the 3-D images using cranial nerve canals. This method applied to our study raised questions about the extent of the asymmetry in the Class II subdivision malocclusion subjects and the involvement of the cranial base in the asymmetries would need further investigation. Variable conclusions have been drawn in the past about the skeletal involvement in subdivision patients and additional research would be needed in 3-D. Figures 5 to 14 show the pre- and post-treatment oriented images with the most striking asymmetries. Patient HE100 (figures 5 and 6) shows a discrepancy between the antero-posterior dimensions of his facial skeleton and the position of the Foramina Ovale, resulting in the rotation of the image to patient's left after orientation. Patients LO87 and TO65 (Figures 7 to 10) displayed an obvious vertical orbital dystopia (abnormal vertical displacement of the entire orbital cones) at clinical examination and a discrepancy in vertical position of the Optical Foramina in the coronal plane, resulting in a tilt of the image after orientation. Patients NO45 and FL43 (Figures 11 to 14) present a deviation of the chin point to their right, which is also the case on the image after orientation.

Treatment effects on Class II subdivision malocclusion have been analyzed in previous studies[1-3] but their results cannot realistically be related to ours because the treatment involved premolar extractions and 2-dimensional imaging was used. However, our findings can be compared to previous studies on Class II correction. Ricketts[13] in 1960 found

3.00±1.2mm of growth on the Y axis, with a downward and backward rotation of the mandible when intermaxillary elastics were worn and our study showed that the general tendency for Menton and Pogonion was to move downward and forward when 7 and 9 subjects respectively displayed backward change of these landmarks. As mentioned by Ricketts, not much treatment effect was observed at ANS where growth was estimated at 1mm per year in his adolescent subjects and our results showed a mean forward change of 2.64±1.95mm over the treatment period. The maxillary incisor contact point was found to change downward but also forward in a majority of the cases and not backward as described by Ricketts. The description of the change from T1 to T2 reveals that, on average in the X plane, both MxC and MdC moved closer to each other except in 2 patients (FR98 and WI235). The outliers FR98 and WI235 could be attributed to random errors in landmark registration because after review of the initial and final records of these patients, their midline discrepancy actually decreased after treatment, even if FR98 still had 1mm of midline discrepancy at T2. In our study, the dental landmarks showing a significant different change (at the 0.01 level) were the maxillary and mandibular molars on the Class II side (Tables 17 and 18). This result is partly supported by the findings of Ricketts in 1960 and Franchi[14] in 2011 who observed the Class II correction mostly by anterior movement of the mandibular molar.

The explanation for a greater tendency of the maxillary molar to move compared to the mandibular molar may lie in the type of bone[15] found in different locations of the jaws. The bone found in the posterior mandible is of type II (thick cortical layer, coarse trabecular bone) and sometimes type III (porous cortical layer, fine trabecular bone) whereas the posterior maxilla consists of type III and type IV (fine trabecular bone, thin or no cortical layer). If this is the case, tooth movement is facilitated in a bone less dense, in the posterior maxilla.

The vertical dimensions were the most variable between patients, with a high dispersion and large range. The landmarks located further away from the Origin displayed higher dispersion, reflected by the large standard deviation. The explanation lies in the variability of the vertical position of Ophistion and thus McRae's line, which was used to orient the images in the sagittal view. This resulted in a variable "pitch" of the head in different patient and the validity of this method to compare patients should be further investigated.

Jones et al.[16] in 2008 compared the treatment effects of intermaxillary elastics and the Forcus Fatigue Resistant Device with lateral cephalometric radiograph superimposition using the Pitchfork analysis[17]. This allows dissecting the skeletal from the dental changes by substracting the antero-posterior skeletal change from the gross dental change to obtain the net dental change. In the intermaxillary elastics group, they found 1.5mm forward movement of the maxilla, 0.6mm of net movement of the maxillary first molar and 0.3mm of net movement of the maxillary central incisors. Our results were slightly divergent for the net movement of the maxillary molar on the Class II side which was a backward movement of 0.61mm. While taking the forward movement of Orbitale (2.28mm) as a reference for the movement of the maxilla, the gross movement of the maxillary molar was only 1.67mm. This means that, in our sample, the treatment effects were to maintain the maxillary molar in a backward position against the forward movement of the maxilla, which explains the significant difference of the maxillary molar in Table 17 and 18. However, our results were similar to Ricketts in the net forward movement of the maxillary incisors (0.22mm and 0.3mm respectively as well as the mandible (2.88mm and 3.8mm respectively), the mandibular molar (0.68mm and 0.7mm respectively) and the lower incisors (0.22mm and 0.8mm respectively). The 3-dimensional imaging technique used in our study allowed us to make a side comparison using the same analysis. The Class I side was found to have similar

forward movements of the maxillary dento-alveolar components than the mandibular components, which represents in this case the maintenance of the Class I relationship on that side throughout treatment. Even though the Pitchfork analysis is supposed to be based on skeletal landmarks non-prone to surface remodeling which is not the case in our study, it gives a rough estimate of the proportion of dental versus skeletal change.

The general tendency for the landmarks to move away from the Y and Z planes (downward and forward) is not surprising when we consider the extrusive effect of the Class II mechanics and the direction of natural growth, which could also explain the backward movement of Gonion in the majority of the patients. PNS as well showed a backward displacement in 13 of the 25 subjects. Baumrind et al.[18] in 1987 reported a downward remodeling of the palate during the mixed dentition and adolescent growth periods with a mean downward displacement at PNS for the time interval between 8.5 and 15.5 years of age lying between 1.81 and 3.19 mm. The authors found strong evidence that the palate elongates anteroposteriorly mainly by distal extension in its posterior region, this assertion being based on Björk's implant superimposition showing that the posterior displacement at PNS is much greater than at ANS. Our results showed a mean antero-posterior change at PNS of 1.52±1.36mm.

The maxillary canine on the Class II side in the antero-posterior plane was the only canine landmark not showing a significant change. The forward movement of the 3 other canines, Md3ClII being maintained back by the elastics, accounted for the correction toward Class I canine on that side. As for the vertical change, the clinical records of the subjects revealed maxillary canines often blocked labially or not fully erupted, even on the Class I side, which can explain the significant change of all canines in the Y plane.

None of the landmarks significantly changed from T1 to T2 in the transverse dimension, which is not surprising if we consider that no expansion was done and that it is

unlikely that the skeletal landmarks change in that plane over the course of treatment considering the age of the subjects. Several authors[19-21] have discussed the benefits of early maxillary expansion of Class II malocclusion subjects with different conclusions. In the present study, none of the subjects showed the need for rapid palatal expansion in the comprehensive phase, based on clinical evaluation.

The explanation for the consistency of the transverse values of right Orbitale is to be found in anthropometry. N.A.Dodgson[22] (2004) studied the variation of human interpupillary distance (IPD) and stated that it is known to vary with respect to age, gender and race, with its range being 50-75mm for the majority of adults. Since our subjects are in the same age range and mostly Caucasian, they display similar measurements from Orbitale to the X plane. If the distance between Orbitale and the sagittal plane in our study was roughly 30 to 35 mm and if we double this value, a distance of 60 to 70 mm would fall in the range stated in Dodgson's article. This distance was not expected to increase over the course of treatment in our sample, which explains that the changes observed in the X plane registration were errors. Actually, Orbitale measurement to the X plane was, according to our test (Table 8), the least reliable registration with an interclass correlation coefficient of 0.71. Baumrind et al.[9] tested the reliability of head film measurements for landmark identification and their results reflected intra- as well as inter-observer reliability. According to our reliability test, the majority of the registrations (87.71%) showed an interclass correlation coefficient equal to or greater than 0.91, the highest being Gonio and Condylion in the X plane. 12.29% of the ICC were below 0.91. Baumrind et al.[9] stated that the perceptual task involved in identifying landmarks varies from point to point. If the operator estimates the position of a point on an edge, the precision with which this operation is carried out is a function of how sharply the edge folds in the region of the point being estimated. However, where the edge is a gradual curve like the inferior orbital rim in the X plane, the errors tend to be proportionately larger

and distributed along the edge itself. This condition also appears to hold true in our case for Pogonion and Orbitale in the X plane and Condylion in the Z plane. In the future, the envelopes of errors of different landmarks in 3-D should be compared to the 2-D envelopes of error found in the past. This will allow us to evaluate if the third dimension limits the envelope of error in the two other planes, which we would expect or, on the contrary, increases the chance of error of registration.

The highest associations found in the antero-posterior change were between 1) the maxillary and mandibular canines on the Class I side with the maxillary and mandibular molars on the same side, respectively, the maxillary molars of the Class I and Class II sides, 3) the mandibular molars of the Class I and Class II sides. These can be explained by the Class II mechanics used that were in general bilateral: the whole arch was treated and not only the side of the malocclusion, which is why the changes of both sides correlate. It is interesting to note the negative but non-significant correlation between both mandibular molar and Condylion with Gonion on the Class II side and between mandibular molar and Gonion on the Class I side. If bony apposition occurred in our sample over the course of treatment and the general tendency of Gonion was to move backward unlike all other measurements, the correlation will be negative. Even if no correlation was found between the change of the incisors contact point and the change in molar and canine, the maxillary central incisor contact point showed a strong tendency to move transversally toward the Class II side with the correction as shown in Table 6.

Conclusion

The coordinate system proved to be reliable for the longitudinal study of Class II subdivision malocclusion treatment changes. The results of this study suggest that

1) All planes combined, the maxillary molar on the Class II side is the only bilateral landmark that showed a significant difference in change, which can be explained by the type of bone found in the posterior maxilla and that skeletal change accounted for the major part of the antero-posterior gross change in molar position. Both maxillary and mandibular molars on the Class II side displayed significantly different changes from the Class I side when distinction of planes is made.

2) The transverse measurements never showed a significant change in any dento-skeletal landmarks.

3) There was no association between the transverse movement of maxillary incisors contact points with the antero-posterior movement of the maxillary canines and molars, neither was there one between the mandibular incisor contact point and the mandibular canines and molars.

4) There was a negative but non-significant correlation between both mandibular molar and Condylion with Gonion on the Class II side and only between mandibular molar and Gonion on the Class I side.

5) PNS and Gonion showed the tendency to move posteriorly and the maxillary central incisors contact point showed a marked tendency to move toward the Class II side.

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APPENDICES

Appendix 1: IRB Approval

Case Western Reserve University
Institutional Review Board
NOTICE OF APPROVAL

Responsible Investigator: **J. Martin Palomo**
Department: **DENT - School of Dentistry**
IRB Protocol #: **20120301**
Title: ***A 3D Evaluation of Class II Subdivision Malocclusion Correction***
Co-Investigator: **Cyrine Cachecho**

Approval Date: **March 22, 2012**
Continuing Review Deadline: **March 7, 2013**
Expiration Date: **March 21, 2013**

The Institutional Review Board (IRB) has APPROVED the above new protocol through the expedited review process.
It has been determined that this study involves minimal risk, and that the following vulnerable populations will be involved: minors.
As an investigator of human subjects, your responsibilities include the following (see full description of responsibilities at our website):

1. Report all adverse events and unanticipated problems involving human subjects to the IRB Office, located in the Office of Research Compliance (ORC), within three (3) business days of your knowledge of the occurrence.
2. Provide the IRB with a complete Continuing Review form (available at the CWRU IRB Web Pages, or from the ORC) by the continuing review deadline noted above, and when the study is terminated.
3. Submit all proposed changes to the protocol to the IRB, and receive approval from the IRB, before implementation of the change.
4. Keep all research data and original consent documents in your possession for at least three (3) years after the study is terminated.
5. Note that completely de-identified data can be kept and used for research indefinitely. Note that all master and/or coded lists should be destroyed at this point.
6. ***Discontinue all work pertaining to this protocol if a continuing review approval is NOT finalized by the expiration date noted above.*** No further work on this protocol is allowable until the proper continuing review materials or required revisions are approved by the Case SBER IRB.

    a. If the study is discontinued, please complete the continuing review materials to close-out the study and to retain IRB privileges. The IRB forms can be found at the CWRU IRB web page.

    b. Please note that, if the continuing review materials or required revisions are not received by the expiration date, the RI and this study would be automatically placed on Administrative Hold for 30 days. This means that the RI loses their IRB privileges and research from this study must cease.

    c. If after 30 days, the Case IRB still does not have the protocol for processing, this protocol will be administratively terminated and your IRB privileges will be revoked for all your protocols.

Thank you for your attention to this matter.

Appendix 2: American Association of Orthodontists, patient Informed Consent p.1

INFORMED CONSENT

for the Orthodontic Patient

Risks and Limitations of Orthodontic Treatment

Successful orthodontic treatment is a partnership between the orthodontist and the patient. The doctor and staff are dedicated to achieving the best possible result for each patient. As a general rule, informed and cooperative patients can achieve positive orthodontic results. While recognizing the benefits of a beautiful healthy smile, you should also be aware that, as with all healing arts, orthodontic treatment has limitations and potential risks. These are seldom serious enough to indicate that you should not have treatment; however, all patients should seriously consider the option of no orthodontic treatment at all by accepting their present oral condition. Alternatives to orthodontic treatment vary with the individual's specific problem, and prosthetic solutions or limited orthodontic treatment may be considerations. You are encouraged to discuss alternatives with the doctor prior to beginning treatment.

Orthodontics and Dentofacial Orthopedics is the dental specialty that includes the diagnosis, prevention, interception and correction of malocclusion, as well as neuromuscular and skeletal abnormalities of the developing or mature orofacial structures.

An orthodontist is a dental specialist who has completed at least two additional years of graduate training in orthodontics at an accredited program after graduation from dental school.

American Association of Orthodontists

Appendix 3: American Association of Orthodontists, patient Informed Consent p.3, Consent to Use of Records

Patient _____ Date _____

Allergies

Occasionally, patients can be allergic to some of the component materials of their orthodontic appliances. This may require a change in treatment plan or discontinuance of treatment prior to completion. Although very uncommon, medical management of dental material allergies may be necessary.

General Health Problems

General health problems such as bone, blood or endocrine disorders, and many prescription and non-prescription drugs (including bisphosphonates) can affect your orthodontic treatment. It is imperative that you inform your orthodontist of any changes in your general health status.

Use of Tobacco Products

Smoking or chewing tobacco has been shown to increase the risk of gum disease and interferes with healing after oral surgery. Tobacco users are also more prone to oral cancer, gum recession, and delayed tooth movement during orthodontic treatment. If you use tobacco, you must carefully consider the possibility of a compromised orthodontic result.

Temporary Anchorage Devices

Your treatment may include the use of a temporary anchorage device(s) (i.e. metal screw or plate attached to the bone.) There are specific risks associated with them.

It is possible that the screw(s) could become loose which would require its/their removal and possibly relocation or replacement with a larger screw. The screw and related material may be accidentally swallowed. If the device cannot be stabilized for an adequate length of time, an alternate treatment plan may be necessary.

It is possible that the tissue around the device could become inflamed or infected, or the soft tissue could grow over the device, which could also require its removal, surgical excision of the tissue and/or the use of antibiotics or antimicrobial rinses.

It is possible that the screws could break (i.e. upon insertion or removal.) If this occurs, the broken piece may be left in your mouth or may be surgically removed. This may require referral to another dental specialist.

When inserting the device(s), it is possible to damage the root of a tooth, a nerve, or to perforate the maxillary sinus. Usually these problems are not significant; however, additional dental or medical treatment may be necessary.

Local anesthetic may be used when these devices are inserted or removed, which also has risks. Please advise the doctor placing the device if you have had any difficulties with dental anesthetics in the past.

If any of the complications mentioned above do occur, a referral may be necessary to your family dentist or another dental or medical specialist for further treatment. Fees for these services are not included in the cost for orthodontic treatment.

Patient or Parent/Guardian Initials _____

ACKNOWLEDGEMENT

I hereby acknowledge that I have read and fully understand the treatment considerations and risks presented in this form. I also understand that there may be other problems that occur less frequently than those presented, and that actual results may differ from the anticipated results. I also acknowledge that I have discussed this form with the undersigned orthodontist(s) and have been given the opportunity to ask any questions. I have been asked to make a choice about my treatment. I hereby consent to the treatment proposed and authorize the orthodontist(s) indicated below to provide the treatment. I also authorize the orthodontist(s) to provide my health care information to my other health care providers. I understand that my treatment fee covers only treatment provided by the orthodontist(s), and that treatment provided by other dental or medical professionals is not included in the fee for my orthodontic treatment.

Signature of Patient/Parent/Guardian Date

Signature of Orthodontist/Group Name Date

Witness Date

CONSENT TO UNDERGO ORTHODONTIC TREATMENT

I hereby consent to the making of diagnostic records, including x-rays, before, during and following orthodontic treatment, and to the above doctor(s) and, where appropriate, staff providing orthodontic treatment prescribed by the above doctor(s) for the above individual. I fully understand all of the risks associated with the treatment.

AUTHORIZATION FOR RELEASE OF PATIENT INFORMATION

I hereby authorize the above doctor(s) to provide other health care providers with information regarding the above individual's orthodontic care as deemed appropriate. I understand that once released, the above doctor(s) and staff has(have) no responsibility for any further release by the individual receiving this information.

CONSENT TO USE OF RECORDS

I hereby give my permission for the use of orthodontic records, including photographs, made in the process of examinations, treatment, and retention for purposes of professional consultations, research, education, or publication in professional journals.

Signature Date

Witness Date

I have the legal authority to sign this on behalf of

Name of Patient

Relationship to Patient

Notes

Fig 1: Axial plane setting according to the Optical Foramina in the coronal view

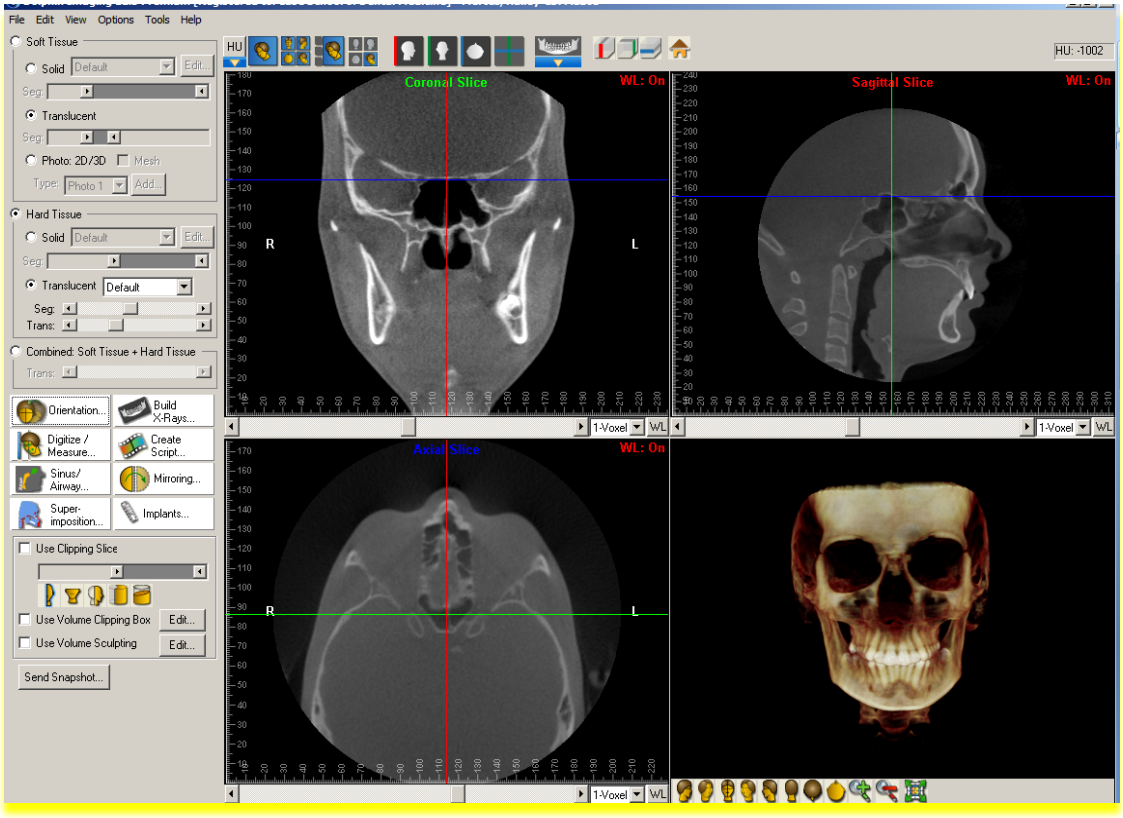


Fig 2: Coronal plane setting according to the Foramina Ovale in the axial plane

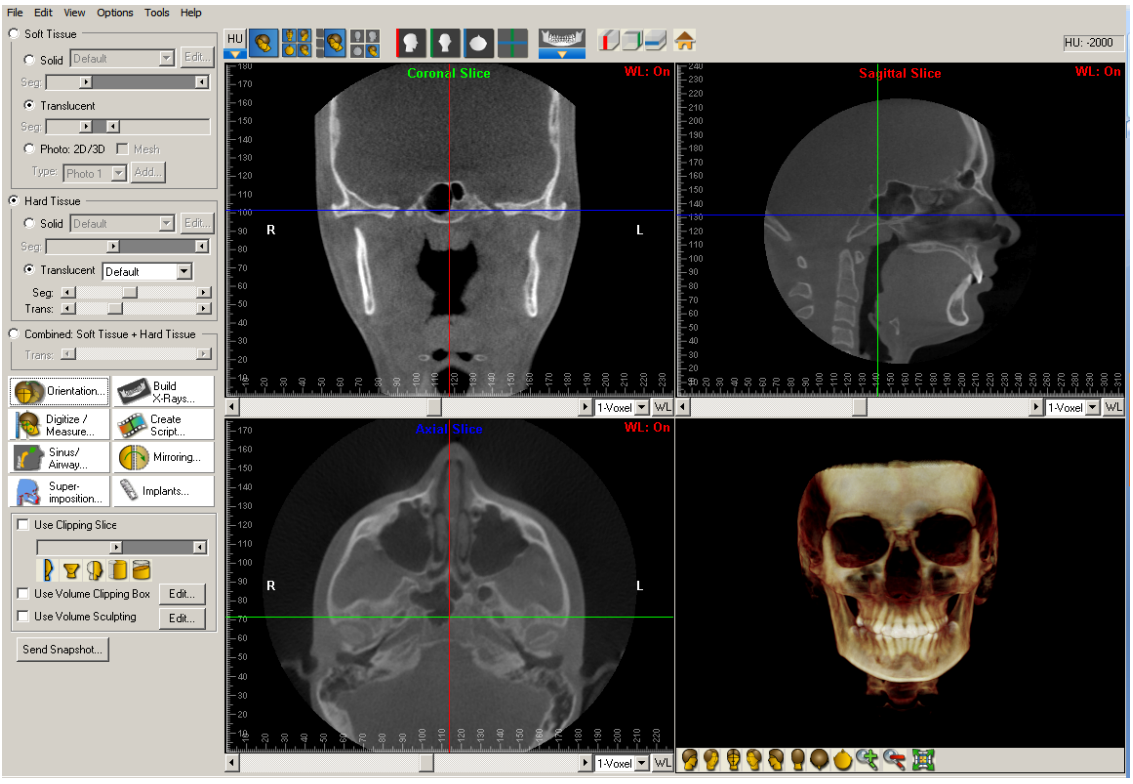


Fig 3: Axial plane setting using Foramen Cecum and McRae's line in the sagittal plane

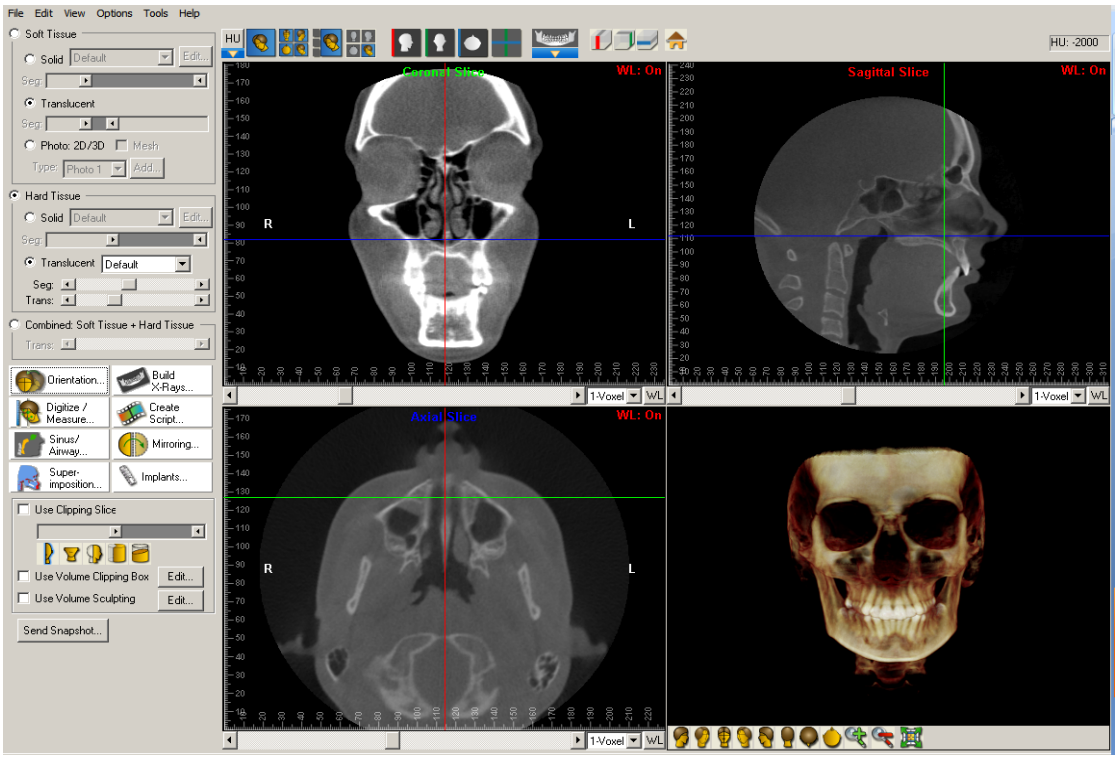


Fig 4: Setting coronal plane at Basion and saving as default orientation.

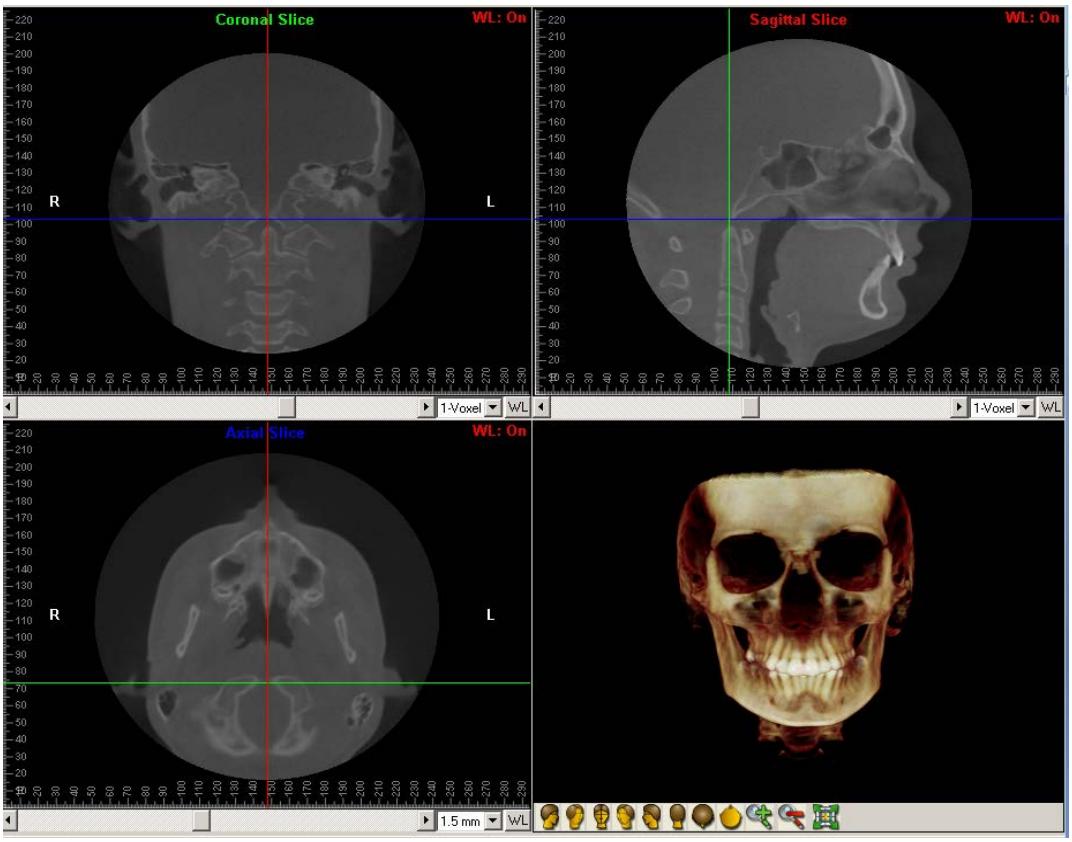


Table 1: Descriptive statistics of the sample: age, gender and Class II distribution, treatment duration (N=25)

		Age at T1 (years,months)					Class II side		Treatment time (months)				
	N	Mean	SD	Min	Max	Range	Right	Left	Mean	SD	Min	Max	Range
Males	13	13.6	2.2	11.4	17.0	6.8	7	6	24.4	5.7	20	42	22
Females	12	13.5	1.7	11.2	15.0	3.10	7	5	22.4	4.9	13	27	14

Table 2: Descriptive statistics of the absolute value of the bilateral landmarks: Canines, molars, Gonion and Condylion at T1, T2 and in the 3 planes.

	N	Range	Minimum	Maximum	Mean	Std. Deviation
Mx3Cl1T1x	25	9.6	13	22.6	17.52	2.79
Mx3Cl1T1y	25	37	12.4	49.4	30.21	9.46
Mx3Cl1T1z	25	27.3	67.1	94.4	84.00	5.91
Mx3Cl1T2x	25	8.8	13	21.8	17.46	2.58
Mx3Cl1T2y	25	40.7	11.5	52.2	32.62	10.31
Mx3Cl1T2z	25	31.1	68.1	99.2	85.92	6.79
Mx3Cl2T1x	25	9.6	11.3	20.9	16.48	3.11
Mx3Cl2T1y	25	38.6	11.9	50.5	29.66	10.13
Mx3Cl2T1z	25	30.3	68.2	98.5	85.24	6.02
Mx3Cl2T2x	25	10	10.5	20.5	16.86	2.62
Mx3Cl2T2y	25	39.8	13.5	53.3	32.57	10.31
Mx3Cl2T2z	25	33.4	68.2	101.6	85.76	6.77
Md3Cl1T1x	25	10.3	7.9	18.2	12.50	2.84
Md3Cl1T1y	25	40.7	7.7	48.4	27.71	9.63
Md3Cl1T1z	25	25.1	68.9	94	84.14	5.43
Md3Cl1T2x	25	8.9	8.3	17.2	13.16	2.39
Md3Cl1T2y	25	40	9.9	49.9	30.89	10.36
Md3Cl1T2z	25	30.1	70.3	100.4	87.00	6.50
Md3Cl2T1x	25	9.3	8.3	17.6	12.92	3.13
Md3Cl2T1y	25	41.3	9	50.3	27.70	9.85
Md3Cl2T1z	25	26.9	67.4	94.3	83.64	5.45
Md3Cl2T2x	25	10	7.3	17.3	12.99	2.84
Md3Cl2T2y	25	41.5	10.2	51.7	30.98	10.45

Md3Cl2T2z	25	33	68.9	101.9	86.72	6.77
Mx6Cl1T1x	25	11.2	20.8	32	25.66	2.95
Mx6Cl1T1y	25	32.1	9.1	41.2	25.64	7.71
Mx6Cl1T1z	25	26.7	48.2	74.9	63.82	5.77
Mx6Cl1T2x	25	10	21.4	31.4	26.12	2.77
Mx6Cl1T2y	25	33.4	10.4	43.8	27.64	8.24
Mx6Cl1T2z	25	29.2	49.9	79.1	66.08	6.49
Mx6Cl2T1x	25	9.9	19.5	29.4	24.62	3.06
Mx6Cl2T1y	25	30.6	12.8	43.4	26.28	7.87
Mx6Cl2T1z	25	28.5	48.9	77.4	64.93	5.92
Mx6Cl2T2x	25	9	20.9	29.9	25.58	2.37
Mx6Cl2T2y	25	31.8	13.4	45.2	27.62	8.08
Mx6Cl2T2z	25	32.8	49.5	82.3	65.96	6.59
Md6Cl1T1x	25	11.6	15	26.6	20.40	2.88
Md6Cl1T1y	25	31.4	10.4	41.8	26.62	7.58
Md6Cl1T1z	25	25.5	45.9	71.4	61.18	5.91
Md6Cl1T2x	25	9.9	16	25.9	20.72	2.64
Md6Cl1T2y	25	32.5	12.2	44.7	29.01	8.05
Md6Cl1T2z	25	28.7	48.4	77.1	64.07	6.50
Md6Cl2T1x	25	11.7	14.3	26	19.81	3.33
Md6Cl2T1y	25	30.6	13.2	43.8	26.88	7.63
Md6Cl2T1z	25	28	44.2	72.2	60.28	5.86
Md6Cl2T2x	25	8.7	15.4	24.1	20.28	2.38
Md6Cl2T2y	25	31.8	14.4	46.2	29.04	7.92
Md6Cl2T2z	25	33	46.7	79.7	63.74	6.73
GoCl1T1x	25	15.4	34.3	49.7	42.04	4.45
GoCl1T1y	25	20.4	23.9	44.3	34.26	4.89
GoCl1T1z	25	19.1	10.4	29.5	20.36	5.79
GoCl1T2x	25	16.5	35	51.5	43.48	4.45
GoCl1T2y	25	20.9	26.8	47.7	36.74	4.81
GoCl1T2z	25	24.9	8.2	33.1	19.30	6.29
GoCl2T1x	25	14.1	35.9	50	41.07	3.19
GoCl2T1y	25	20	27.3	47.3	35.40	5.77
GoCl2T1z	25	21	10.3	31.3	19.70	5.06
GoCl2T2x	25	14.3	37.3	51.6	42.13	3.28
GoCl2T2y	25	19.6	29	48.6	37.84	5.39
GoCl2T2z	25	22.5	10.5	33	18.84	5.78
CdCl1T1x	25	14.6	39	53.6	47.35	3.89
CdCl1T1y	25	14.7	12.4	27.1	19.53	3.61
CdCl1T1z	25	10.4	9.3	19.7	14.61	2.73
CdCl1T2x	25	14.5	40.1	54.6	47.92	3.72
CdCl1T2y	25	14.8	13.4	28.2	19.79	3.34
CdCl1T2z	25	10	10.6	20.6	15.29	2.86
CdCl2T1x	25	13.3	38.1	51.4	47.45	3.01

CdCl2T1y	25	16.2	9.6	25.8	18.37	3.58
CdCl2T1z	25	11	9	20	14.94	2.45
CdCl2T2x	25	16.6	38.4	55	47.79	3.35
CdCl2T2y	25	16.4	9.5	25.9	19.00	3.71
CdCl2T2z	25	13.9	9.1	23	15.26	2.93

Table 3: Descriptive statistics of the parasagittal landmarks: maxillary and mandibular contact point, right Orbitale, ANS, PNS, Pogonion and Menton at T1 and T2 in the 3 planes.

	N	Range	Minimum	Maximum	Mean	Std. Deviation
MxCT1x	25	11.5	-5.6	5.9	1.50	2.64
MxCT1y	25	39.7	-52.8	-13.1	-32.31	10.56
MxCT1z	25	29.2	76.9	106.1	92.88	6.29
MxCT2x	25	10.1	-4.9	5.2	1.28	2.29
MxCT2y	25	43.4	-54.4	-11	-33.67	11.30
MxCT2z	25	31.6	77.3	108.9	94.52	6.82
MdCT1x	25	10.8	-5.7	5.1	1.18	2.67
MdCT1y	25	42.3	-50.9	-8.6	-28.75	10.14
MdCT1z	25	28.6	72.7	101.3	88.76	5.90
MdCT2x	25	9.7	-4.8	4.9	1.15	2.29
MdCT2y	25	42.3	-52.9	-10.6	-32.45	10.97
MdCT2z	25	31.6	74.8	106.4	91.90	6.73
OrRT1x	25	7.2	-35.4	-28.2	-32.33	1.99
OrRT1y	25	29.4	-1.3	28.1	14.49	7.82
OrRT1z	25	14	71	85	78.03	3.56
OrRT2x	25	7.7	-36.2	-28.5	-32.11	1.96
OrRT2y	25	32.7	-1.8	30.9	14.78	8.36
OrRT2z	25	17	74.2	91.2	80.14	4.42
ANST1x	25	11	-5.1	5.9	0.92	2.09
ANST1y	25	37.3	-28.3	9	-7.03	9.44
ANST1z	25	18.5	82.7	101.2	92.91	4.32
ANST2x	25	8.4	-4.6	3.8	0.89	1.79
ANST2y	25	37.2	-27.9	9.3	-7.59	10.10
ANST2z	25	20.8	84.4	105.2	95.34	5.05
PNST1x	25	6.6	-4	2.6	0.28	1.73
PNST1y	25	20.7	-16.4	4.3	-4.07	5.56
PNST1z	25	10.3	37.9	48.2	44.04	2.83
PNST2x	25	6.3	-3.7	2.6	0.04	1.58
PNST2y	25	20.6	-16.7	3.9	-4.44	5.40

PNST2z	25	16.7	34.8	51.5	44.14	3.71
PogT1x	25	15.9	-7.2	8.7	2.00	3.84
PogT1y	25	44.9	-81.1	-36.2	-57.20	10.63
PogT1z	25	34.7	63.3	98	83.22	8.55
PogT2x	25	14.3	-5.5	8.8	1.80	3.12
PogT2y	25	45.7	-84.7	-39	-61.04	11.37
PogT2z	25	41.5	61.8	103.3	84.94	10.17
MeT1x	25	16.5	-7.3	9.2	2.20	3.86
MeT1y	25	41.2	-84.7	-43.5	-63.24	9.91
MeT1z	25	38.2	55.4	93.6	77.01	9.04
MeT2x	25	13.6	-5.6	8	1.98	3.34
MeT2y	25	42.1	-89.6	-47.5	-67.48	10.77
MeT2z	25	42.7	54.4	97.1	79.00	10.27

Table 4: Descriptive Statistics of the changes (absolute value of the difference T2-T1) for all landmarks in the 3 planes

	N	Range	Minimum	Maximum	Mean	Std. Deviation
MX3CL1X	25	3.7	0	3.7	1.37	0.74
MX3CL1Y	25	12.5	0.2	12.7	2.78	2.62
MX3CL1Z	25	7.4	0	7.4	2.55	2.17
MXCL2X	25	3.3	0.1	3.4	1.47	0.95
MX3CL2Y	25	9.7	0.3	10	3.34	2.42
MX3CL2Z	25	5.2	0	5.2	1.90	1.54
MD3CL1X	25	3.6	0.2	3.8	1.62	0.99
MD3CL1Y	25	11.5	0.1	11.6	3.26	2.75
MD3CL1Z	25	8.6	0.1	8.7	2.94	2.48
MD3CL2X	25	3	0.4	3.4	1.47	0.74
MD3CL2Y	25	10.2	0.1	10.3	3.39	2.58
MD3CL2Z	25	9.6	0.4	10	3.43	2.59
MX6CL1X	25	3.9	0	3.9	1.20	1.01
MX6CL1Y	25	8.8	0	8.8	2.14	2.15
MX6CL1Z	25	7	0.1	7.1	2.42	2.08
MX6CL2X	25	3.8	0	3.8	1.29	0.97
MX6CL2Y	25	7.8	0.1	7.9	1.88	1.79
MX6CL2Z	25	4.7	0.2	4.9	1.67	1.49
MD6CL1X	25	2.8	0.1	2.9	1.32	0.76
MD6CL1Y	25	9.2	0	9.2	2.42	2.29
MD6CL1Z	25	6.4	0.3	6.7	2.94	2.02
MD6CL2X	25	3.4	0	3.4	1.25	0.96

MD6CL2Y	25	8.5	0	8.5	2.33	2.15
MD6CL2Z	25	8.3	0	8.3	3.56	2.25
GOCL1X	25	4.9	0.2	5.1	1.66	1.57
GOCL1Y	25	7.8	0	7.8	3.05	2.21
GOCL1Z	25	5.8	0	5.8	1.86	1.32
GOCL2X	25	4.6	0.2	4.8	1.52	1.14
GOCL2Y	25	6.9	0.2	7.1	2.78	1.97
GOCL2Z	25	5.3	0	5.3	1.88	1.50
CDCL1X	25	4.6	0.1	4.7	1.50	1.23
CDCL1Y	25	2.7	0	2.7	1.02	0.66
CDCL1Z	25	4	0	4	1.15	0.98
CDCL2X	25	5.3	0	5.3	1.19	1.17
CDCL2Y	25	3.3	0	3.3	1.00	0.95
CDCL2Z	25	3.9	0.1	4	1.38	1.00
MxCx	25	3.4	0	3.4	1.42	0.96
MxCy	25	7.8	0.3	8.1	2.29	1.77
MxCz	25	6.7	0.1	6.8	2.52	2.00
MdCx	25	2.9	0.1	3	1.26	0.83
MdCy	25	11.7	0.2	11.9	3.85	2.76
MdCz	25	8.4	0	8.4	3.19	2.40
OrRx	25	6.1	0.1	6.2	1.29	1.30
OrRy	25	3.9	0	3.9	1.45	1.17
OrRz	25	7.8	0	7.8	2.28	1.94
ANSx	25	3	0	3	0.77	0.73
ANSy	25	6.4	0	6.4	1.76	1.53
ANSz	25	7.2	0	7.2	2.64	1.95
PNSx	25	2.8	0	2.8	0.76	0.64
PNSy	25	2.8	0.2	3	0.85	0.67
PNSz	25	5.9	0.2	6.1	1.52	1.36
Pogx	25	4	0.1	4.1	1.27	1.04
Pogy	25	12.1	0.2	12.3	3.88	3.08
Pogz	25	7.5	0.4	7.9	2.89	2.04
Mex	25	3.5	0	3.5	1.47	0.91
Mey	25	12.1	0.4	12.5	4.27	3.30
Mez	25	8.6	0.1	8.7	2.83	2.16

Table 5: Subjects distribution according to the direction of change for bilateral landmarks (N=25)

	X						Y						Z					
	Class I			Class II			Class I			Class II			Class I			Class II		
	out	in	NC	out	in	NC	down	up	NC	down	up	NC	forward	back	NC	forward	back	NC
Mx3	12	12	1	14	11	0	21	4	0	21	4	0	18	7	1	13	11	1
Md3	15	10	0	14	11	0	24	1	0	23	2	0	23	2	0	23	2	0
Mx6	16	7	2	18	5	2	21	3	1	18	7	0	22	3	0	17	8	0
Md6	16	9	0	17	7	1	21	2	2	20	4	1	23	2	0	23	1	1
Go	21	4	0	18	7	0	20	4	1	20	5	0	7	17	1	10	14	1
Cd	18	7	0	14	10	1	14	10	1	15	8	2	15	8	2	14	11	0

N C: No change

Table 6: Subjects distribution according to the direction of change for unilateral landmarks (N=25)

	X			Aw.Cl II	Tow. Cl II	Y			Z			Same direction		
	Left	Right	NC			Up	Down	NC	Anterior	Posterior	NC	X	Y	Z
MxC	12	12	1	7	16	8	17	0	16	9	0	18	19	18
MdC	12	13	0	13	12	4	21	0	22	2	1			
OrR	16	9	0	13	12	13	11	1	21	3	1	-	-	-
ANS	12	12	1	11	13	9	15	1	21	3	1	15	18	15
PNS	11	12	2	10	14	7	18	0	12	13	0			
Pog	13	12	0	12	13	1	24	0	16	9	0	17	23	23
Me	12	12	1	12	12	1	24	0	18	7	0			

Aw.Cl II: moved away from the Class II side
Tow.Cl II: moved toward the Class II side

Table 7: Intra-observer reliability for the bilateral landmarks registration, Interclass Correlation Coefficient (r^2)

Variables	Class 1			Class 2		
	X	Y	Z	X	Y	Z
Mx3	1.00	0.97	0.98	1.00	0.98	0.98
Md3	0.99	0.97	0.98	1.00	0.98	0.97
Mx6	1.00	0.97	0.99	1.00	0.97	0.97
Md6	1.00	0.97	0.98	1.00	0.97	0.98
Go	1.00	0.95	0.94	1.00	0.95	0.93
Cd	1.00	0.95	0.94	1.00	0.98	0.86

Table 8: Intra-observer reliability for the parasagittal landmarks registration, Interclass Correlation Coefficient (r^2)

	Class 1		
	X	Y	Z
MxC	0.89	0.98	0.98
MdC	0.88	0.98	0.99
OrR	0.71	0.97	0.95
ANS	0.88	0.98	0.96
PNS	0.89	0.96	0.97
Pog	0.89	0.98	0.99
Me	0.91	0.98	0.98

Table 9: Side comparison of the spatial position at T1

		Paired Differences		Sig. (2-tailed)
		Mean	Std. Deviation	
Pair 1	Mx3Cl1T1x - Mx3Cl2T1x	1.04	5.51	0.36
Pair 2	Mx3Cl1T1y - Mx3Cl2T1y	0.55	1.91	0.16
Pair 3	Mx3Cl1T1z - Mx3Cl2T1z	-1.24	2.02	.**01***
Pair 4	Md3Cl1T1x - Md3Cl2T1x	-0.42	5.67	0.71
Pair 5	Md3Cl1T1y - Md3Cl2T1y	0.01	1.49	0.98
Pair 6	Md3Cl1T1z - Md3Cl2T1z	0.50	1.65	0.14
Pair 7	Mx6Cl1T1x - Mx6Cl2T1x	1.04	5.22	0.33
Pair 8	Mx6Cl1T1y - Mx6Cl2T1y	-0.64	2.00	0.12
Pair 9	Mx6Cl1T1z - Mx6Cl2T1z	-1.11	2.01	**.01***
Pair 10	Md6Cl1T1x - Md6Cl2T1x	0.59	5.56	0.60
Pair 11	Md6Cl1T1y - Md6Cl2T1y	-0.26	1.72	0.45
Pair 12	Md6Cl1T1z - Md6Cl2T1z	0.90	1.86	**.02***
Pair 13	GoCl1T1x - GoCl2T1x	0.97	6.15	0.44
Pair 14	GoCl1T1y - GoCl2T1y	-1.14	3.68	0.14
Pair 15	GoCl1T1z - GoCl2T1z	0.66	3.14	0.30
Pair 16	CdCl1T1x - CdCl2T1x	-0.10	4.45	0.92
Pair 17	CdCl1T1y - CdCl2T1y	1.16	3.26	0.09
Pair 18	CdCl1T1z - CdCl2T1z	-0.33	2.66	0.54

*significance at the 0.05 level for Paired t-test

Table 10: Side comparison of the spatial position at T2

		Paired Differences		Sig. (2-tailed)
		Mean	Std. Deviation	
Pair 1	Mx3Cl1T2x - Mx3Cl2T2x	0.60	4.85	0.54
Pair 2	Mx3Cl1T2y - Mx3Cl2T2y	0.04	1.19	0.86
Pair 3	Mx3Cl1T2z - Mx3Cl2T2z	0.15	1.36	0.58
Pair 4	Md3Cl1T2x - Md3Cl2T2x	0.17	5.03	0.87
Pair 5	Md3Cl1T2y - Md3Cl2T2y	-0.09	1.01	0.65
Pair 6	Md3Cl1T2z - Md3Cl2T2z	0.29	0.99	0.16
Pair 7	Mx6Cl1T2x - Mx6Cl2T2x	0.54	4.35	0.54
Pair 8	Mx6Cl1T2y - Mx6Cl2T2y	0.02	1.85	0.97
Pair 9	Mx6Cl1T2z - Mx6Cl2T2z	0.13	1.71	0.71
Pair 10	Md6Cl1T2x - Md6Cl2T2x	0.45	4.36	0.61
Pair 11	Md6Cl1T2y - Md6Cl2T2y	-0.03	1.53	0.92
Pair 12	Md6Cl1T2z - Md6Cl2T2z	0.34	1.60	0.31

Pair 13	GoCl1T2x - GoCl2T2x	1.36	5.51	0.23
Pair 14	GoCl1T2y - GoCl2T2y	-1.10	4.03	0.19
Pair 15	GoCl1T2z - GoCl2T2z	0.46	3.44	0.51
Pair 16	CdCl1T2x - CdCl2T2x	0.12	4.68	0.90
Pair 17	CdCl1T2y - CdCl2T2y	0.79	2.49	0.12
Pair 18	CdCl1T2z - CdCl2T2z	0.03	2.53	0.96

*significance at the 0.05 level for Paired t-test

Table 11: Side comparison of the treatment effects on maxillary canines in the 3 planes

		Paired Differences		Sig. (2-tailed)
		Mean	Std. Deviation	
Pair 1	Mx3Cl1T1x - Mx3Cl1T2x	0.23	1.56	0.46
Pair 2	Mx3Cl1T1y - Mx3Cl1T2y	2.41	2.98	**.00***
Pair 3	Mx3Cl1T1z - Mx3Cl1T2z	-1.92	2.77	**.00***
Pair 4	Mx3Cl2T1x - Mx3Cl2T2x	0.12	1.77	0.73
Pair 5	Mx3Cl2T1y - Mx3Cl2T2y	2.91	2.94	**.00***
Pair 6	Mx3Cl2T1z - Mx3Cl2T2z	-0.53	2.41	0.29

*significance at the 0.05 level for the paired t-test

Table 12: Side comparison of the treatment effects on mandibular canines in the 3 planes

		Paired Differences		Sig. (2-tailed)
		Mean	Std. Deviation	
Pair 1	Md3Cl1T1x - Md3Cl1T2x	-0.06	1.93	0.87
Pair 2	Md3Cl1T1y - Md3Cl1T2y	3.18	2.85	**.00***
Pair 3	Md3Cl1T1z - Md3Cl1T2z	-2.86	2.58	**.00***
Pair 4	Md3Cl2T1x - Md3Cl2T2x	0.13	1.67	0.70
Pair 5	Md3Cl2T1y - Md3Cl2T2y	3.28	2.72	**.00***
Pair 6	Md3Cl2T1z - Md3Cl2T2z	-3.08	3.02	**.00***

*significance at the 0.05 level for the paired t-test

Table 13: Side comparison of the treatment effects on maxillary molars in the 3 planes

		Paired Differences		Sig. (2-tailed)
		Mean	Std. Deviation	
Pair 1	Mx6Cl1T1x - Mx6Cl1T2x	0.04	1.59	0.89
Pair 2	Mx6Cl1T1y - Mx6Cl1T2y	2.00	2.28	**.00***
Pair 3	Mx6Cl1T1z - Mx6Cl1T2z	-2.26	2.26	**.00***
Pair 4	Mx6Cl2T1x - Mx6Cl2T2x	0.43	1.58	0.19
Pair 5	Mx6Cl2T1y - Mx6Cl2T2y	1.34	2.24	**.01***
Pair 6	Mx6Cl2T1z - Mx6Cl2T2z	-1.02	2.01	**.02***

*significance at the 0.05 level for the paired t-test

Table 14: Side comparison of the treatment effects on mandibular molars in the 3 planes

		Paired Differences		Sig. (2-tailed)
		Mean	Std. Deviation	
Pair 1	Md6Cl1T1x - Md6Cl1T2x	0.12	1.55	0.69
Pair 2	Md6Cl1T1y - Md6Cl1T2y	2.40	2.32	**.00***
Pair 3	Md6Cl1T1z - Md6Cl1T2z	-2.89	2.09	**.00***
Pair 4	Md6Cl2T1x - Md6Cl2T2x	0.37	1.55	0.25
Pair 5	Md6Cl2T1y - Md6Cl2T2y	2.16	2.32	**.00***
Pair 6	Md6Cl2T1z - Md6Cl2T2z	-3.46	2.42	**.00***

*significance at the 0.05 level for the paired t-test

Table 15: Side comparison of the treatment effects on Gonion in the 3 planes

		Paired Differences		Sig. (2-tailed)
		Mean	Std. Deviation	
Pair 1	GoCl1T1x - GoCl1T2x	0.01	2.31	0.99
Pair 2	GoCl1T1y - GoCl1T2y	2.48	2.86	**.00***
Pair 3	GoCl1T1z - GoCl1T2z	1.06	2.04	**.02***
Pair 4	GoCl2T1x - GoCl2T2x	-0.09	1.93	0.81
Pair 5	GoCl2T1y - GoCl2T2y	2.44	2.39	**.00***
Pair 6	GoCl2T1z - GoCl2T2z	0.85	2.27	0.07

*significance at the 0.05 level for the paired t-test

Table 16: Side comparison of the treatment effects on Condylion in the 3 planes

		Paired Differences		Sig. (2-tailed)
		Mean	Std. Deviation	
Pair 1	CdCl1T1x - CdCl1T2x	.4520	1.9086	.248
Pair 2	CdCl1T1y - CdCl1T2y	-.2600	1.2059	.292
Pair 3	CdCl1T1z - CdCl1T2z	-.6760	1.3633	**.021***
Pair 4	CdCl2T1x - CdCl2T2x	-.1120	1.6809	.742
Pair 5	CdCl2T1y - CdCl2T2y	-.6240	1.2380	**.019***
Pair 6	CdCl2T1z - CdCl2T2z	-.3160	1.6992	.362

*significance at the 0.05 level for the paired t-test

Table 17: Side comparison of the treatment effects all planes combined

		Paired Differences		Sig. (2-tailed)
		Mean	Std. Deviation	
Pair 1	Mx3CL1 - Mx3CL2	-0.01	2.94	0.99
Pair 2	MD3CL1 - MD3CL2	-0.47	2.43	0.34
Pair 3	MX6CL1 - MX6CL2	0.92	1.76	**.02***
Pair 4	MD6CL1 - MD6CL2	-0.46	1.76	0.20
Pair 5	GOCL1 - GOCL2	0.38	2.35	0.42
Pair 6	CDCL1 - CDCL2	0.10	2.31	0.84

*significance at the 0.05 level for the Paired t-test

Table 18: Side comparison of the treatment effects with plane distinction

	Mean	Std. Deviation	Sig. (2-tailed)
MX3CL1X – MX3CL2X	.10	1.04	.64
MX3CL2Y - MX3CL1Y	.56	1.76	.13
MX3CL1Z - MX3CL2Z	.65	1.95	.11
MD3CL1X - MD3CL2X	.15	1.17	.53
MD3CL2Y - MD3CL1Y	.13	1.29	.61
MD3CL1Z - MD3CL2Z	.49	1.35	.08

MX6CL1X - MX6CL2X	.09	1.23	.72
MX6CL1Y - MX6CL2Y	.26	.86	.15
MX6CL1Z - MX6CL2Z	.75	1.13	.003**
MD6CL1X - MD6CL2X	.08	1.09	.73
MD6CL1Y - MD6CL2Y	.09	.73	.55
MD6CL1Z - MD6CL2Z	.62	1.04	.006**
GOCL1X - GOCL2X	.13	1.74	.71
GOCL1Y - GOCL2Y	.27	1.38	.33
GOCL1Z - GOCL2Z	-.02	1.67	.95
CDCL1X - CDCL2X	.31	1.75	.39
CDCL1Y - CDCL2Y	.02	1.22	.94
CDCL1Z - CDCL2Z	.23	1.22	.35

**significance at the 0.01 level for the Paired t-test

Table 19: Treatment effects on the maxillary central incisors contact point in the 3 planes

		Paired Differences		Sig. (2-tailed)
		Mean	Std. Deviation	
Pair 1	MxCT1x - MxCT2x	0.22	1.72	0.52
Pair 2	MxCT1y - MxCT2y	1.36	2.58	**.01***
Pair 3	MxCT1z - MxCT2z	-1.64	2.79	**.01***

*significance at the 0.05 level for the paired t-test

Table 20: Treatment effects on the mandibular central incisors contact point in the 3 planes

		Paired Differences		Sig. (2-tailed)
		Mean	Std. Deviation	
Pair 1	MdCT1x - MdCT2x	0.02	1.54	0.94
Pair 2	MdCT1y - MdCT2y	3.70	2.96	**.00***
Pair 3	MdCT1z - MdCT2z	-3.13	2.48	**.00***

*significance at the 0.05 level for the paired t-test

Table 21: Treatment effects on the right Orbitale, ANS, PNS, Pogonion and Menton in the 3 planes

		Paired Differences		Sig. (2-tailed)
		Mean	Std. Deviation	
Pair 1	OrRT1x – OrRT2x	-0.22	1.83	0.55
Pair 2	OrRT1y – OrRT2y	-0.28	1.87	0.46
Pair 3	OrRT1z – OrRT2z	-2.11	2.14	**.00***
Pair 4	ANST1x - ANST2x	0.03	1.07	0.90
Pair 5	ANST1y - ANST2y	0.56	2.29	0.23
Pair 6	ANST1z - ANST2z	-2.43	2.22	**.00***
Pair 7	PNST1x – PNST2x	0.25	0.97	0.22
Pair 8	PNST1y – PNST2y	0.36	1.03	0.09
Pair 9	PNST1z – PNST2z	-0.10	2.06	0.80
Pair 10	PogT1x – PogT2x	0.20	1.65	0.56
Pair 11	PogT1y – PogT2y	3.84	3.13	**.00***
Pair 12	PogT1z - PogT2z	-1.71	3.13	**.01***
Pair 13	MeT1x - MeT2x	0.23	1.74	0.52
Pair 14	MeT1y - MeT2y	4.24	3.34	**.00***
Pair 15	MeT1z - MeT2z	-1.99	2.98	**.00***

*significance at the 0.05 level for the paired t-test

Table 22: Association between changes of the maxillary incisors contact point and the maxillary canines and molars

		MX3CL1Z	MX3CL2Z	MX6CL1Z	MX6CL2Z	DeltaMxCx
MX3CL1T2-T1Z	Pearson Correlation	-	**.49***	**.86****	**.71****	.09
	Sig. (2-tailed)		.01	.00	.00	.66
MX3CL2T2-T1Z	Pearson Correlation	**.49***	-	**.47***	**.63****	.16
	Sig. (2-tailed)	.01		.02	.00	.45
MX6CL1T2-T1Z	Pearson Correlation	**.86****	**.47***	-	**.85****	.13
	Sig. (2-tailed)	.00	.019		.00	.54
MX6CL2T2-T1Z	Pearson Correlation	**.71****	**.63****	**.85****	-	.11
	Sig. (2-tailed)	.00	.00	.00		.60
MxCT2-T1X	Pearson Correlation	.09	.16	.13	.11	-
	Sig. (2-tailed)	.66	.45	.54	.60	

*. Correlation is significant at the 0.05 level (2-tailed).

**. Correlation is significant at the 0.01 level (2-tailed).

Table 23: Association between changes of the mandibular central incisors contact point and the mandibular canines and molars

		MD3CL1T1-T1Z	MD3CL2T2-T1Z	MD6CL1T2-T1Z	MD6CL2T2-T1Z	MdCT2-T1X
MD3CL1T2-T1Z	PearsonCorrelation	-	**.86****	**.91****	**.84****	.12
	Sig. (2-tailed)		.00	.00	.00	.57
MD3CL2T2-T1Z	Pearson Correlation	**.86****	-	**.71****	**.84****	.20
	Sig. (2-tailed)	.00		.00	.00	.34
MD6CL1T2-T1Z	Pearson Correlation	**.91****	**.71****	-	**.89****	.24
	Sig. (2-tailed)	.00	.00		.00	.26
MD6CL2T2-T1Z	Pearson Correlation	**.84****	**.84****	**.89****	-	**.43***
	Sig. (2-tailed)	.00	.00	.00		.03
MdCT2-T1X	Pearson Correlation	.12	.20	.24	**.43***	-
	Sig. (2-tailed)	.57	.34	.26	.03	

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

Table 24: Association between the changes of the mandibular molar, Gonion and Condylion on the Class I side

		MD6CL1Z	GOCL1Z	CDCL1Z
MD6CL1Z	Pearson Correlation	-	-.11	.16
	Sig. (2-tailed)		.60	.46
GOCL1Z	Pearson Correlation	-.11	-	.00
	Sig. (2-tailed)	.60		.10
CDCL1Z	Pearson Correlation	.16	.00	-
	Sig. (2-tailed)	.46	.10	

Table 25: Association between the changes of the mandibular molar, Gonion and Condylion on the Class II side

		MD6CL2Z	GOCL2Z	CDCL2Z
MD6CL2Z	Pearson Correlation	-	-.10	.08
	Sig. (2-tailed)		.63	.713
GOCL2Z	Pearson Correlation	-.10	-	-.14
	Sig. (2-tailed)	.63		.51
CDCL2Z	Pearson Correlation	.08	-.14	-
	Sig. (2-tailed)	.71	.51	

Fig. 5: Frontal picture and frontal view of the oriented image of patient HE100



Fig. 6: Frontal view of the oriented pre- (left) and post-treatment (right) images of patient HE100

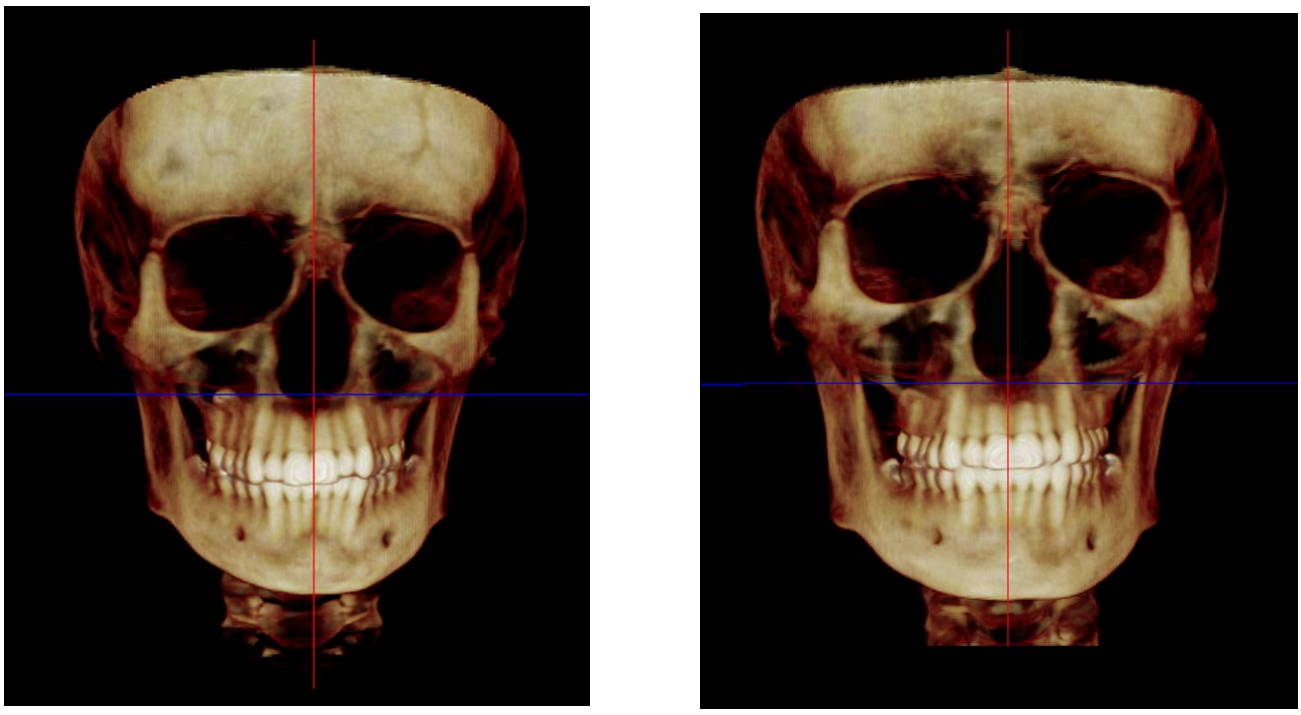


Fig. : Frontal picture and frontal view of the oriented image of patient LO87

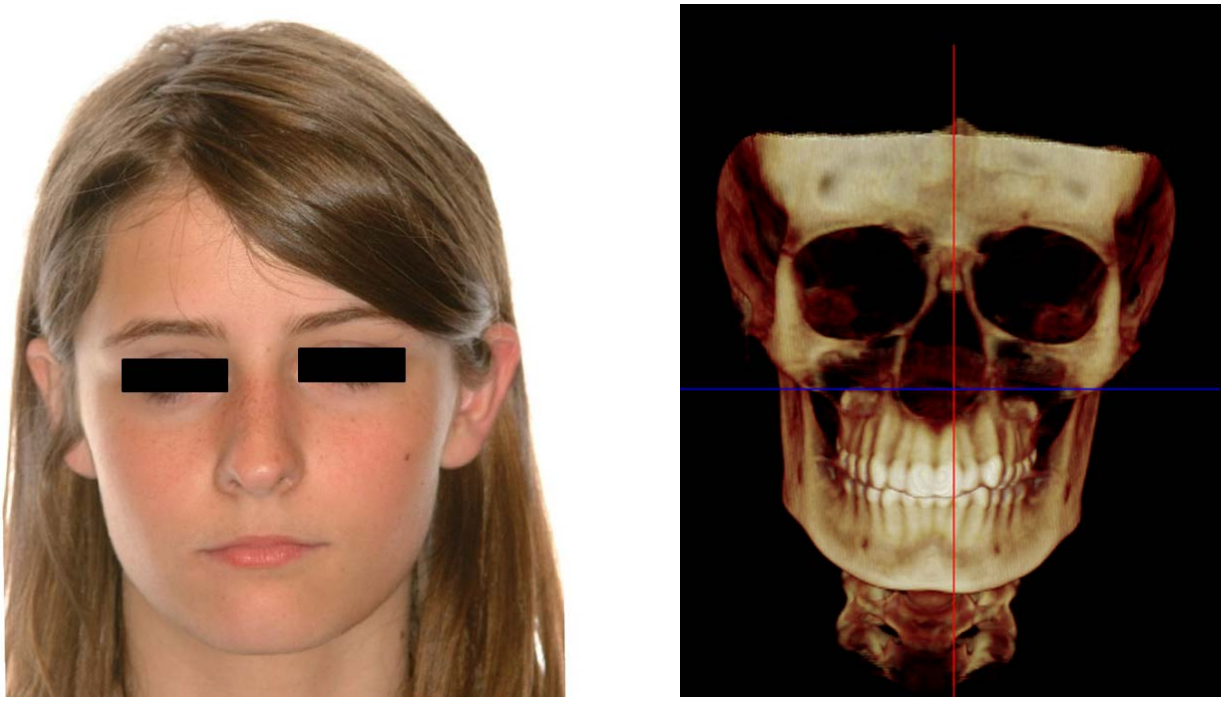


Fig. : Frontal picture and frontal view of the oriented image of patient LO87

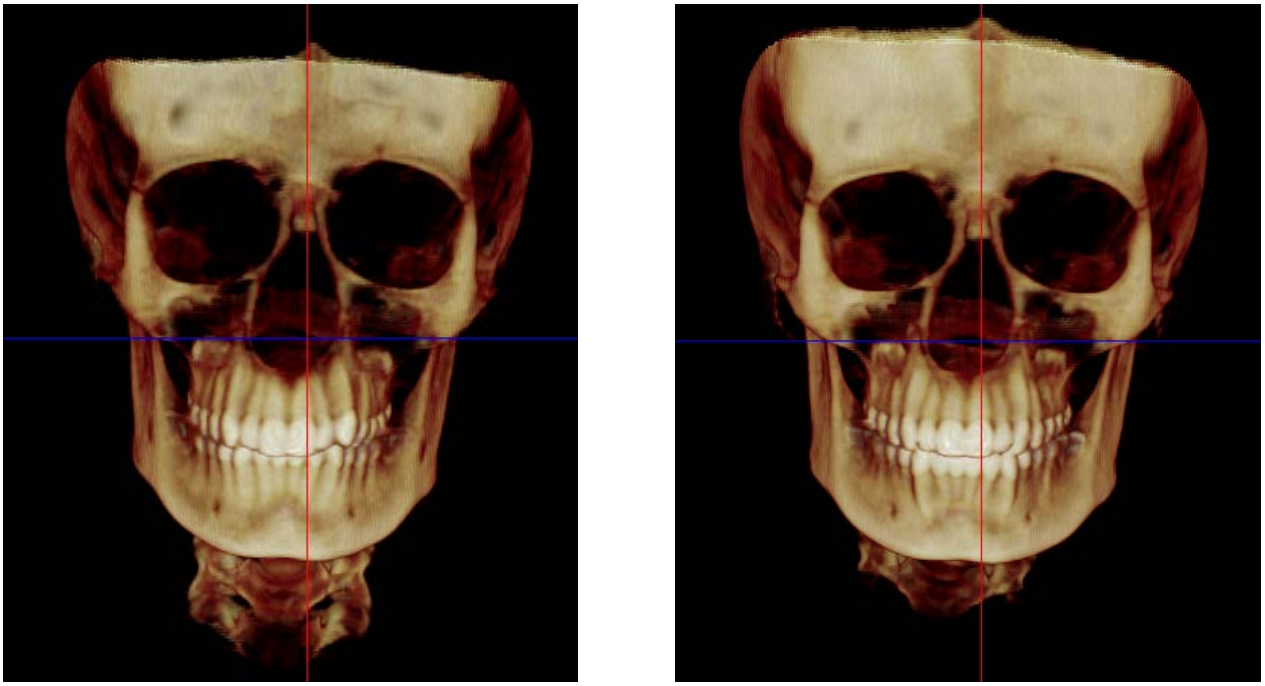


Fig. : Frontal picture and frontal view of the oriented image of patient TO65

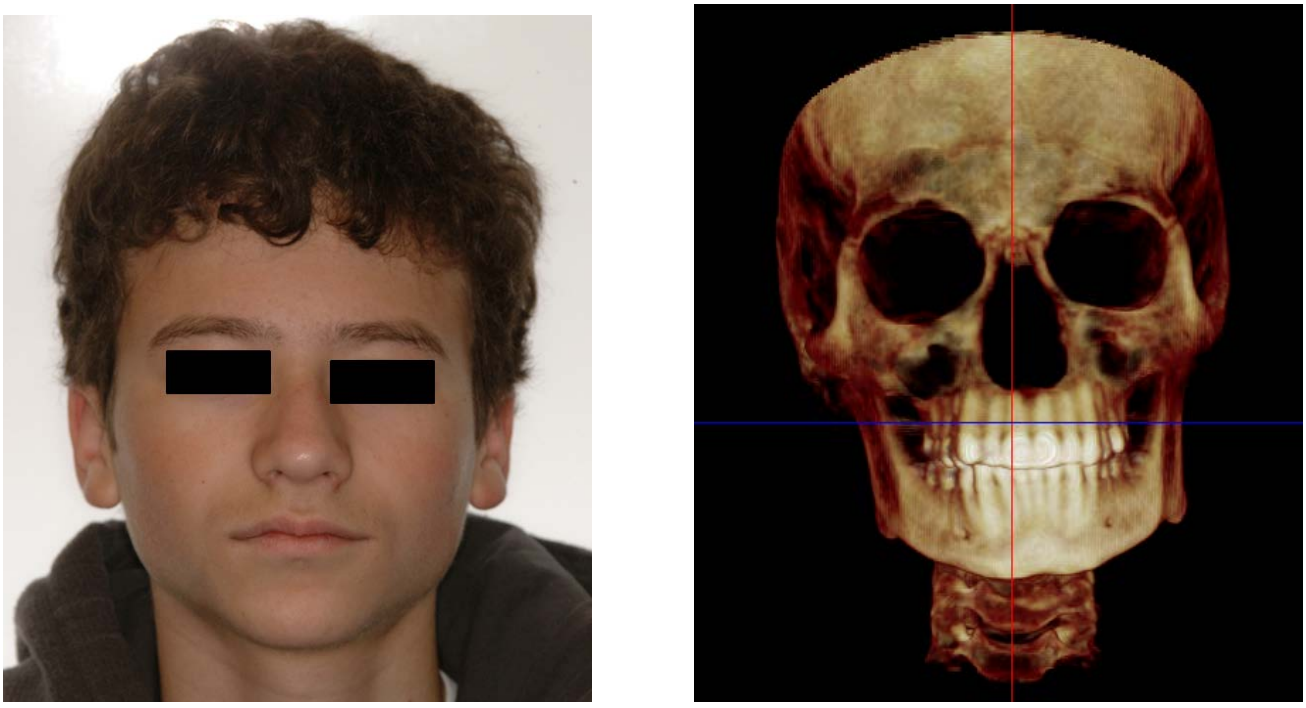


Fig. : Frontal view of the oriented pre- (left) and post-treatment (right) images of patient TO65

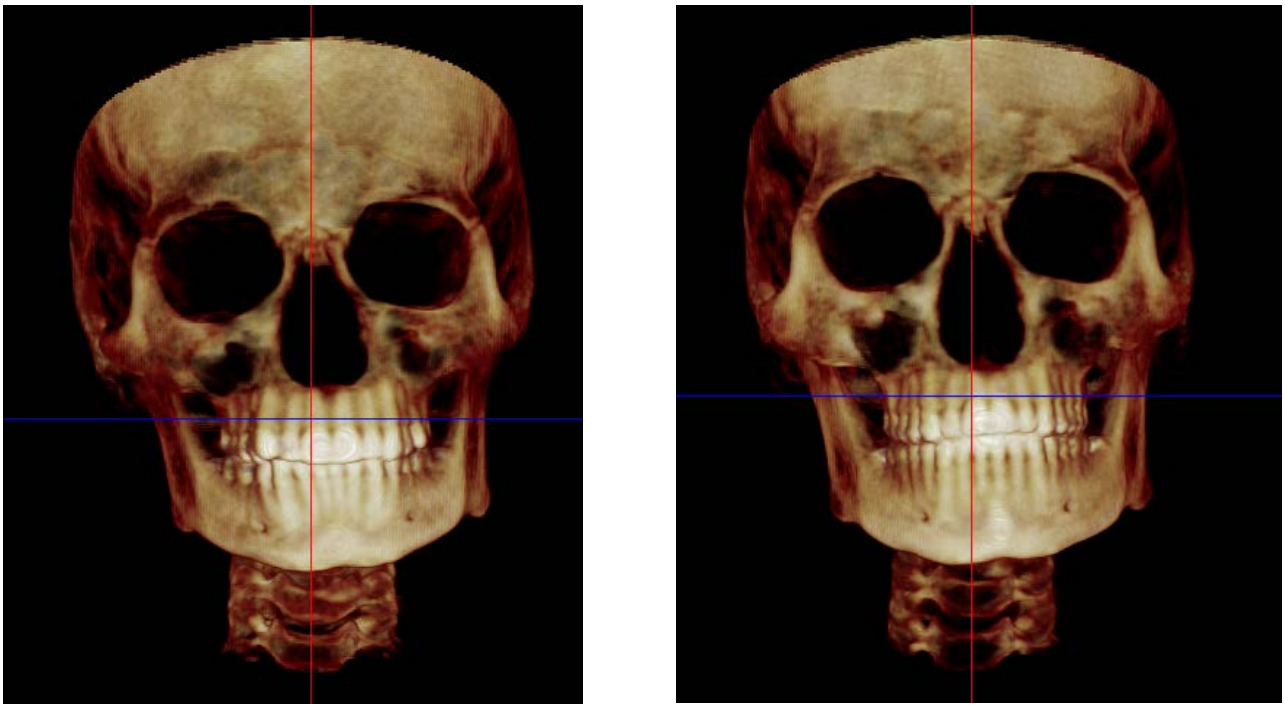


Fig. : Frontal picture and frontal view of the oriented image of patient NO45

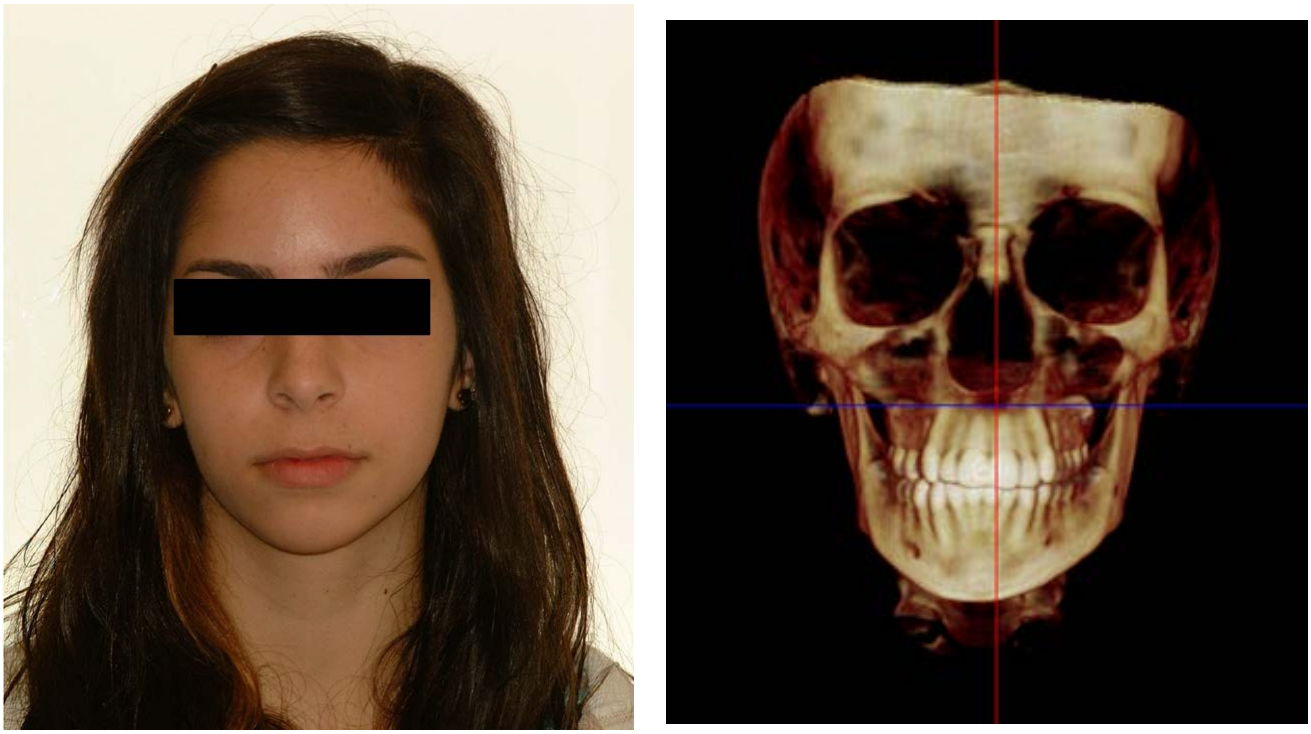


Fig. : Frontal view of the oriented pre- (left) and post-treatment (right) images of patient NO45

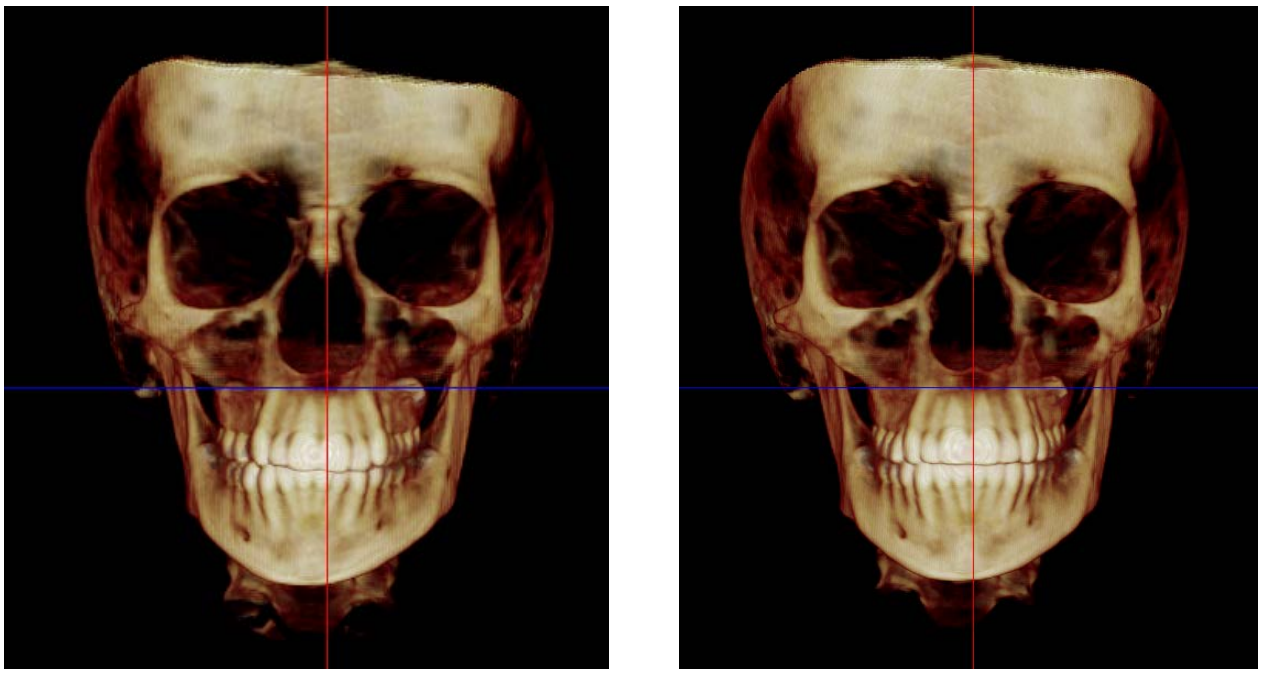


Fig. : Frontal picture and frontal view of the oriented image of patient FL43



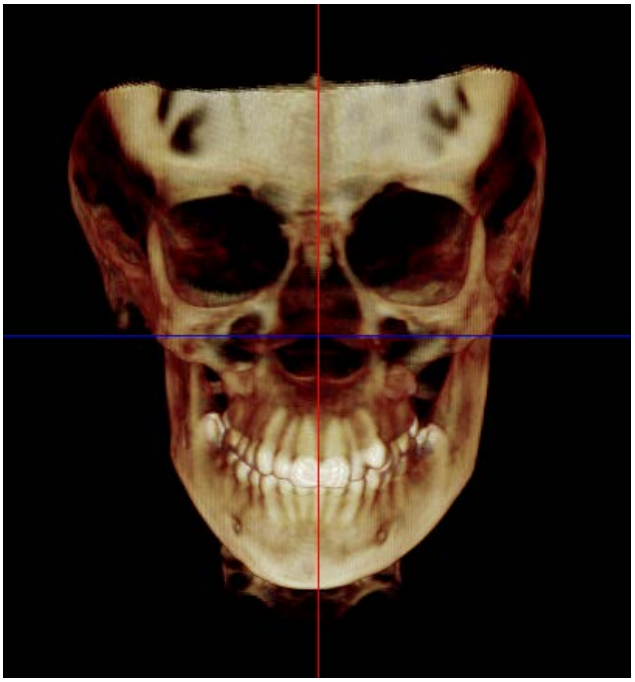
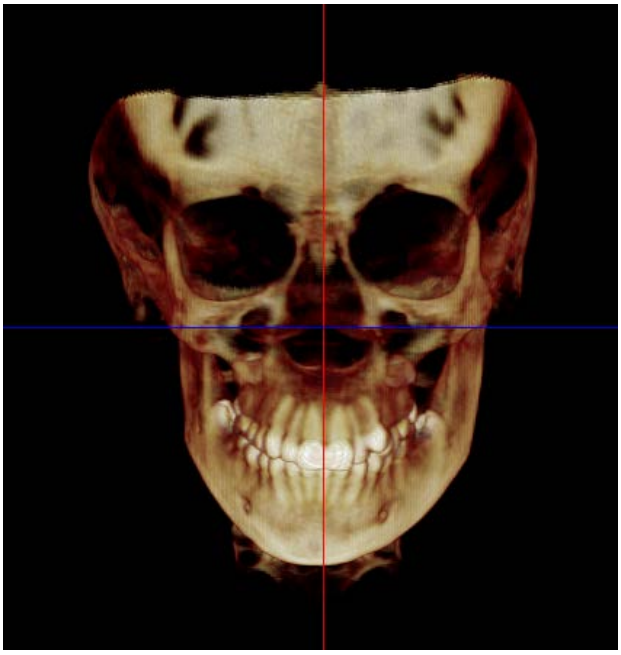
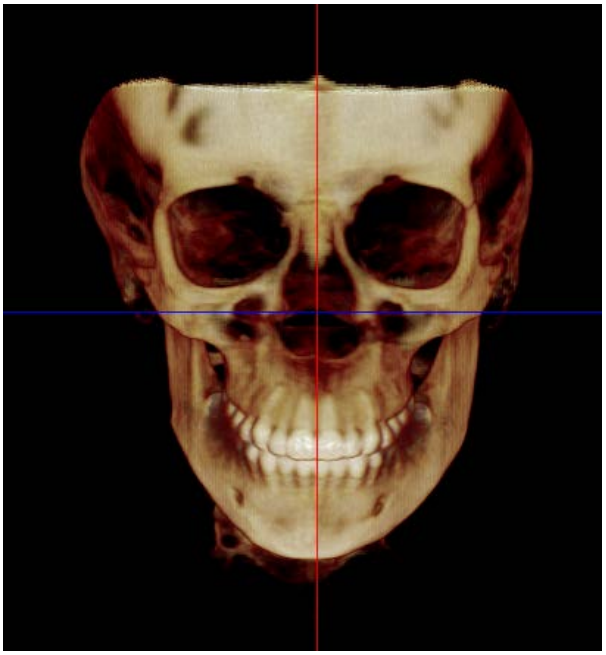


Fig. : Frontal view of the oriented pre- (left) and post-treatment (right) images of patient FL43





Appendix 4: Raw Data for Mx3

	Mx3											
	CL I						Cl II					
	T1			T2			T1			T2		
	X	Y	Z	X	Y	Z	X	Y	Z	X	Y	Z
BE182	-16.00	-25.40	82.20	-17.30	-24.10	88.60	16.20	-25.40	81.50	16.70	-23.30	86.70
BR264	20.40	-38.10	76.20	19.50	-41.40	75.70	-15.50	-38.60	78.90	-14.10	-42.40	76.40
CA232	-14.50	-34.10	94.40	-16.50	-35.50	94.90	20.60	-31.90	93.20	18.70	-34.90	95.10
CA253	-13.00	-32.60	91.50	-13.00	-33.90	91.50	19.10	-31.90	90.90	20.50	-33.20	90.70
FL43	17.70	-39.30	80.30	15.90	-45.00	75.50	-16.00	-41.30	76.90	-16.80	-43.00	75.50
FR98	15.40	-16.70	85.80	16.50	-17.30	89.70	-16.50	-15.30	88.20	-17.40	-17.30	88.70
HE100	-17.60	-26.70	89.10	-15.90	-24.50	96.50	15.20	-24.80	89.40	17.80	-22.90	94.50
KO8	-13.90	-19.70	87.20	-13.00	-32.40	86.80	17.40	-20.50	87.80	18.40	-30.50	84.50
LO87	-22.40	-30.20	86.80	-20.40	-31.30	85.80	11.40	-29.80	89.10	10.50	-32.60	84.40
NI44	20.40	-23.80	94.20	21.80	-26.60	99.20	-14.90	-21.20	98.50	-14.50	-26.30	101.60
NO45	14.90	-22.60	88.00	16.00	-22.40	88.70	-19.30	-22.80	88.60	-18.50	-23.10	88.40
OR23	18.70	-31.00	80.30	20.00	-32.10	80.00	-20.50	-30.40	83.00	-17.40	-34.30	81.20
PA162	20.60	-35.50	86.90	18.40	-37.10	88.20	-11.30	-38.70	88.40	-14.70	-38.30	88.70
PR78	-15.30	-44.20	67.10	-16.40	-48.50	68.10	19.70	-43.30	68.20	19.60	-47.60	68.20
SA115	-15.20	-34.80	82.40	-13.10	-37.00	85.50	19.30	-33.80	81.90	20.40	-36.10	84.00
SP65	16.60	-25.00	80.50	17.40	-25.70	82.30	-17.40	-23.00	82.90	-17.70	-26.10	82.70
SP60	-15.60	-27.90	82.20	-19.30	-31.40	84.90	20.10	-22.10	82.90	17.70	-30.40	85.30
TE47	19.70	-49.40	78.20	20.30	-52.20	81.90	-18.00	-49.80	83.40	-16.70	-53.30	84.50
TO65	22.60	-12.40	86.20	21.80	-11.50	91.70	-12.40	-11.90	91.20	-11.90	-13.50	92.40
VI34	19.40	-47.50	85.60	18.30	-50.00	85.40	-11.80	-50.50	84.20	-13.60	-51.60	84.10
WE141	16.70	-29.40	83.20	15.70	-35.60	84.80	-15.40	-29.00	83.40	-18.40	-35.80	82.40
WI235	21.60	-18.30	86.70	21.10	-18.80	89.20	-13.40	-20.00	88.50	-15.30	-19.10	90.40
YA24	17.90	-38.70	76.80	16.30	-40.80	80.90	-17.60	-37.20	79.60	-19.30	-39.90	82.10
ZD5	-17.90	-21.30	85.30	-16.70	-25.40	84.60	12.00	-20.10	86.40	14.70	-24.40	84.70
ZO9	-13.90	-30.60	82.90	-15.90	-34.90	87.50	20.90	-28.20	83.90	20.10	-34.40	86.90

Appendix 5: Raw Data for Md3

	Md3											
	CL I						Cl II					
	T1			T2			T1			T2		
	X	Y	Z	X	Y	Z	X	Y	Z	X	Y	Z
BE182	-10.00	-22.10	83.90	-11.20	-21.10	89.70	12.00	-22.10	82.00	13.10	-21.90	88.10
BR264	14.60	-35.80	77.60	15.60	-40.90	77.70	-9.20	-36.40	77.30	-10.80	-41.50	78.10
CA232	-10.00	-30.50	93.10	-11.40	-32.90	95.10	16.70	-28.80	91.60	14.90	-33.60	95.70
CA253	-9.20	-29.60	89.90	-9.40	-31.20	91.80	16.30	-29.10	87.50	16.90	-32.00	92.20
FL43	10.70	-38.10	76.90	12.40	-45.20	77.90	-13.00	-38.50	75.70	-14.30	-43.20	76.30
FR98	12.30	-15.90	85.30	11.70	-16.50	90.70	-11.00	-16.10	87.10	-13.10	-16.50	90.50
HE100	-12.60	-22.60	89.30	-12.10	-22.70	98.00	13.20	-21.30	86.00	14.90	-21.90	96.00
KO8	-7.90	-19.70	86.20	-10.60	-31.30	87.10	16.00	-19.30	83.70	15.50	-29.60	85.60
LO87	-18.20	-26.80	86.70	-17.20	-29.40	85.80	8.30	-27.00	86.80	7.30	-30.40	85.20
NI44	14.20	-20.50	94.00	16.70	-25.00	100.40	-13.40	-19.30	94.30	-10.00	-25.00	101.90
NO45	8.30	-19.90	88.80	12.10	-21.10	89.00	-16.00	-21.20	88.50	-14.40	-21.30	89.60
OR23	12.00	-26.50	82.10	14.60	-28.90	82.00	-15.10	-27.90	83.90	-12.80	-30.50	81.10
PA162	15.90	-32.80	88.60	13.90	-35.50	89.60	-8.60	-35.20	87.50	-10.10	-36.40	89.50
PR78	-10.90	-41.00	68.90	-11.60	-46.80	70.30	16.80	-40.40	67.40	16.20	-45.60	68.90
SA115	-11.20	-33.20	81.50	-8.30	-34.60	85.60	16.20	-31.60	79.90	17.30	-35.00	85.50
SP65	12.80	-23.50	81.60	14.00	-24.90	83.20	-11.00	-22.10	81.80	-11.40	-23.90	83.40
SP60	-11.70	-26.20	82.80	-14.60	-29.20	86.40	15.00	-22.40	81.40	13.80	-28.30	86.30
TE47	13.60	-48.40	81.20	15.50	-49.90	84.40	-14.90	-50.30	83.60	-12.30	-51.70	85.50
TO65	16.30	-7.70	86.90	17.20	-9.90	93.50	-8.80	-9.00	87.40	-7.80	-10.20	93.00
VI34	15.10	-46.10	84.10	14.10	-48.50	85.30	-8.30	-46.80	82.30	-10.10	-49.80	84.10
WE141	11.40	-25.30	81.60	11.90	-34.30	86.40	-13.60	-27.00	80.20	-16.40	-35.30	84.50
WI235	18.20	-16.50	87.50	16.40	-16.90	90.50	-9.60	-18.40	88.60	-10.50	-17.20	90.40
YA24	13.40	-35.10	78.70	11.80	-38.60	81.60	-13.70	-36.00	82.20	-14.70	-38.00	82.60
ZD5	-13.20	-20.00	84.40	-12.70	-23.80	84.60	8.80	-19.40	83.50	10.10	-23.40	85.00
ZO9	-8.80	-28.90	81.90	-12.10	-33.10	88.50	17.60	-26.90	80.70	16.10	-32.30	88.90

Appendix 6: Raw Data for Mx6

	Mx6											
	CL I						Cl II					
	T1			T2			T1			T2		
	X	Y	Z	X	Y	Z	X	Y	Z	X	Y	Z
BE182	-26.30	-20.80	63.80	-25.80	-20.10	68.90	24.10	-21.00	60.80	24.00	-20.10	65.50
BR264	25.10	-31.10	55.90	26.30	-33.30	56.40	-20.30	-34.30	58.50	-24.10	-36.10	57.20
CA232	-24.70	-31.90	74.90	-26.00	-32.70	74.40	29.40	-28.90	73.10	27.50	-30.40	74.00
CA253	-20.80	-29.50	68.80	-21.40	-30.10	69.00	26.80	-27.90	69.10	27.30	-28.90	68.30
FL43	23.90	-34.80	58.70	23.90	-37.00	58.10	-23.10	-34.40	57.30	-24.80	-34.60	57.50
FR98	24.30	-16.00	66.40	22.90	-15.50	69.60	-21.70	-16.50	68.90	-24.70	-15.50	69.30
HE100	-28.00	-22.60	71.90	-25.40	-23.10	78.40	22.50	-22.70	70.50	24.40	-20.70	75.20
KO8	-22.70	-20.50	66.50	-22.30	-29.30	68.10	26.80	-19.40	67.40	26.90	-27.30	66.50
LO87	-31.00	-24.40	65.70	-31.00	-25.40	66.00	19.50	-27.00	67.10	20.90	-27.60	66.20
NI44	28.30	-21.00	72.00	28.80	-23.00	79.10	-23.80	-20.60	77.40	-24.40	-23.00	82.30
NO45	21.40	-20.70	67.90	23.70	-20.20	68.00	-27.40	-20.80	69.10	-27.40	-20.20	68.60
OR23	26.30	-25.30	60.10	28.60	-26.80	59.20	-28.20	-27.50	61.20	-26.90	-28.50	59.60
PA162	27.80	-29.90	67.10	25.30	-31.10	68.50	-20.70	-34.60	68.30	-23.20	-33.40	69.50
PR78	-23.00	-36.10	48.20	-23.90	-40.50	49.90	27.40	-35.90	48.90	26.60	-38.80	49.50
SA115	-24.40	-30.20	61.00	-23.10	-31.00	63.70	28.30	-28.60	60.60	29.90	-28.30	63.00
SP65	25.60	-20.40	61.70	26.20	-20.40	63.20	-25.00	-21.40	63.70	-26.80	-21.50	64.20
SP60	-26.50	-21.40	60.50	-29.50	-27.30	62.80	26.70	-20.00	62.40	27.80	-25.20	62.60
TE47	26.70	-41.20	57.40	27.30	-43.80	61.60	-26.90	-43.40	61.00	-26.80	-45.20	64.60
TO65	30.30	-9.10	67.30	31.10	-10.40	72.10	-19.80	-12.80	71.20	-22.10	-13.40	72.90
VI34	27.40	-40.70	63.80	27.70	-41.50	64.80	-22.10	-43.30	62.90	-22.10	-43.90	63.30
WE141	26.60	-23.30	62.60	27.00	-28.10	64.60	-24.90	-25.40	61.80	-26.50	-28.50	60.80
WI235	32.00	-16.20	66.20	31.40	-16.60	68.40	-24.40	-19.10	68.40	-25.20	-18.40	69.40
YA24	24.10	-27.50	57.40	24.80	-32.90	62.30	-28.20	-27.90	61.30	-28.80	-31.70	64.10
ZD5	-23.60	-20.70	65.80	-25.00	-22.40	66.30	20.60	-20.00	67.70	21.90	-22.30	66.60
ZO9	-20.80	-25.60	63.90	-24.70	-28.40	68.70	27.00	-23.50	64.70	28.50	-27.00	68.20

Appendix 7: Raw Data for Md6

	Md6											
	CL I						Cl II					
	T1			T2			T1			T2		
	X	Y	Z	X	Y	Z	X	Y	Z	X	Y	Z
BE182	-20.20	-22.10	60.60	-21.20	-21.90	66.50	18.00	-22.60	57.60	19.80	-21.90	62.90
BR264	20.30	-32.50	53.80	21.10	-34.10	54.40	-17.30	-35.20	53.80	-18.90	-37.10	55.00
CA232	-19.80	-33.10	70.70	-21.10	-33.80	71.80	25.10	-30.70	67.60	22.00	-32.00	70.70
CA253	-15.00	-29.50	65.60	-16.00	-31.90	67.50	21.40	-28.60	63.00	20.90	-30.90	67.30
FL43	19.30	-35.30	54.70	19.10	-37.60	55.90	-18.60	-34.10	54.70	-19.50	-35.60	54.70
FR98	20.40	-17.20	64.90	18.10	-17.20	69.90	-16.80	-18.00	65.50	-19.30	-17.10	69.50
HE100	-22.00	-23.60	68.50	-19.30	-24.10	75.20	17.20	-22.70	63.90	18.90	-22.60	72.20
KO8	-16.80	-21.30	63.20	-17.40	-30.50	65.40	21.30	-20.80	59.90	21.90	-29.30	63.30
LO87	-26.50	-25.90	64.10	-24.90	-27.00	64.40	14.50	-27.40	63.30	15.40	-28.20	63.60
NI44	21.90	-21.40	71.40	23.30	-24.70	77.10	-19.40	-21.20	72.20	-19.20	-24.00	79.70
NO45	15.40	-21.10	65.60	17.30	-21.10	66.60	-22.10	-22.00	64.80	-22.10	-22.00	67.30
OR23	20.40	-25.60	57.70	22.70	-27.60	57.10	-22.90	-27.70	58.60	-21.50	-29.20	57.30
PA162	21.50	-31.60	65.10	19.40	-32.70	67.10	-14.30	-35.20	65.20	-17.70	-34.80	68.00
PR78	-18.20	-37.30	45.90	-19.70	-41.60	48.40	23.70	-36.20	44.20	23.80	-40.70	46.70
SA115	-18.40	-29.60	57.60	-16.80	-32.10	61.30	23.20	-27.70	55.40	24.10	-29.20	60.80
SP65	20.00	-21.90	58.80	20.20	-21.80	60.70	-19.30	-22.10	60.20	-20.50	-22.60	62.30
SP60	-20.60	-22.60	57.30	-23.50	-28.70	60.30	21.90	-21.10	54.40	22.60	-27.00	59.30
TE47	21.40	-41.80	54.40	21.30	-44.70	60.40	-22.10	-43.80	56.50	-21.10	-46.20	62.80
TO65	25.10	-10.40	66.50	25.90	-12.20	71.20	-14.70	-13.20	67.30	-16.20	-14.40	71.70
VI34	21.70	-41.80	61.30	22.20	-43.30	62.90	-16.90	-43.30	60.00	-16.50	-44.40	60.80
WE141	22.40	-24.40	58.00	21.70	-29.60	61.30	-20.70	-24.90	55.00	-21.90	-30.00	59.00
WI235	26.60	-17.70	63.40	25.40	-18.80	65.80	-18.30	-19.40	64.10	-19.30	-20.50	66.00
YA24	18.40	-27.60	55.60	19.60	-34.20	59.50	-23.00	-27.90	57.70	-23.10	-33.30	61.30
ZD5	-19.90	-22.70	64.50	-21.60	-24.30	64.90	16.60	-22.00	63.70	17.90	-24.20	65.50
ZO9	-17.80	-27.40	60.40	-19.30	-29.80	66.20	26.00	-24.20	58.40	22.80	-28.90	65.70

Appendix 8: Raw Data for Go

	Go											
	CL I						Cl II					
	T1			T2			T1			T2		
	X	Y	Z	X	Y	Z	X	Y	Z	X	Y	Z
BE182	-42.00	-32.30	24.40	-45.60	-32.20	22.00	35.90	-30.90	16.40	37.90	-32.30	16.00
BR264	45.10	-34.70	12.80	44.90	-37.20	10.50	-42.00	-43.20	13.40	-41.10	-46.50	10.50
CA232	-41.10	-44.30	25.10	-42.10	-47.70	25.80	45.70	-40.00	24.50	44.90	-44.00	26.30
CA253	-34.80	-36.20	26.40	-35.20	-40.70	27.80	40.50	-33.60	25.70	41.40	-36.40	26.60
FL43	42.90	-35.40	14.90	42.10	-35.70	11.90	-40.30	-33.00	12.30	-41.20	-34.80	11.60
FR98	42.50	-29.10	22.70	42.70	-31.60	23.20	-40.70	-32.40	22.70	-42.80	-33.30	24.40
HE100	-47.00	-31.70	28.40	-47.40	-38.30	33.10	37.30	-30.30	19.80	42.10	-35.50	23.60
KO8	-41.00	-33.90	22.90	-42.00	-39.70	21.90	43.00	-31.80	21.20	42.80	-36.30	17.30
LO87	-47.90	-33.00	28.40	-48.10	-35.20	25.40	36.10	-38.40	25.20	38.20	-37.90	20.20
NI44	44.00	-34.60	29.50	48.20	-37.70	28.00	-43.50	-37.80	31.30	-45.40	-42.50	33.00
NO45	34.30	-33.70	28.70	35.20	-30.90	22.90	-37.90	-34.30	25.50	-37.30	-34.10	24.20
OR23	39.60	-38.10	14.80	43.10	-35.50	12.20	-40.40	-38.30	15.30	-37.80	-39.50	13.70
PA162	49.70	-38.20	22.10	48.30	-39.40	21.40	-40.50	-46.60	23.20	-44.90	-45.20	23.20
PR78	-41.50	-38.10	16.90	-43.20	-41.20	15.20	46.30	-39.90	18.70	46.90	-39.70	13.40
SA115	-35.20	-36.00	15.50	-35.00	-37.40	14.20	41.10	-35.10	14.30	42.50	-36.90	14.50
SP65	39.10	-30.50	18.40	39.30	-32.30	19.50	-41.10	-30.90	18.90	-41.90	-29.00	19.10
SP60	-41.50	-30.70	18.80	-45.80	-36.80	16.40	41.50	-29.20	15.40	43.70	-33.80	12.70
TE47	39.50	-42.70	10.40	42.00	-41.10	8.20	-42.80	-46.30	10.30	-44.00	-48.60	12.00
TO65	47.90	-23.90	18.60	51.50	-26.80	18.60	-37.30	-29.40	22.30	-39.10	-33.00	22.80
VI34	46.70	-43.00	12.50	47.10	-43.00	13.60	-38.00	-47.30	14.50	-37.50	-48.30	13.50
WE141	47.40	-28.60	19.30	48.70	-33.20	17.90	-41.80	-31.30	18.70	-42.50	-35.30	15.60
WI235	45.80	-26.40	15.60	46.30	-28.00	16.10	-40.70	-30.30	20.60	-41.90	-31.40	19.80
YA24	35.00	-33.30	14.00	38.10	-41.10	11.90	-41.50	-34.30	17.20	-43.20	-41.30	14.40
ZD5	-40.60	-35.60	26.90	-41.30	-36.30	24.60	40.80	-33.10	25.10	40.60	-36.10	22.50
ZO9	-38.80	-32.50	20.90	-43.90	-39.60	20.20	50.00	-27.30	19.90	51.60	-34.40	20.20

Appendix 9: Raw Data for Cd

	Cd											
	CL I						Cl II					
	T1			T2			T1			T2		
	X	Y	Z	X	Y	Z	X	Y	Z	X	Y	Z
BE182	-53.00	19.30	15.20	-53.80	20.70	14.40	44.80	21.20	11.50	45.30	22.80	10.60
BR264	43.60	18.00	9.30	46.10	17.20	10.60	-47.30	18.30	13.40	-48.80	18.20	13.50
CA232	-47.80	15.50	19.70	-48.00	16.80	19.70	46.40	18.50	14.20	46.70	17.50	16.80
CA253	-46.60	12.40	19.30	-46.80	13.40	20.20	44.20	17.10	18.40	45.60	17.80	19.00
FL43	46.90	19.10	13.60	46.60	18.30	13.20	-44.80	15.70	12.30	-44.70	17.70	13.20
FR98	44.60	21.50	11.80	43.90	22.10	13.60	-46.00	19.00	13.60	-44.80	21.90	14.00
HE100	-53.60	21.80	18.60	-54.60	22.40	20.60	47.30	19.40	14.60	46.50	22.70	14.80
KO8	-47.40	20.40	15.60	-49.90	20.10	18.00	46.40	23.20	16.60	47.00	21.80	18.10
LO87	-50.10	21.10	16.20	-48.70	19.60	14.00	43.20	14.10	14.10	44.10	14.00	12.40
NI44	39.00	18.50	11.90	40.10	19.60	15.90	-48.50	14.80	15.20	-48.10	14.80	19.20
NO45	46.40	22.20	13.60	44.40	23.60	13.40	-51.10	20.30	15.30	-50.50	20.90	17.00
OR23	50.00	18.60	13.70	51.10	19.10	13.20	-50.60	19.40	16.00	-48.00	18.20	13.90
PA162	49.80	24.80	13.40	47.30	22.20	13.40	-46.10	16.20	12.30	-47.20	18.20	14.10
PR78	-44.90	16.10	13.50	-49.10	16.10	14.90	49.30	15.00	13.90	47.80	15.30	12.70
SA115	-41.80	19.00	15.40	-41.70	20.00	16.00	48.20	19.10	16.30	48.20	21.30	16.20
SP65	53.00	21.90	11.30	48.30	21.00	12.70	-51.20	21.50	13.20	-51.80	20.80	15.70
SP60	-51.00	14.50	12.90	-52.30	15.40	11.40	46.30	16.10	9.00	49.40	16.20	9.10
TE47	46.60	16.60	18.10	46.70	18.30	19.50	-49.70	13.70	20.00	-55.00	14.30	23.00
TO65	48.70	26.30	12.20	49.70	24.70	12.30	-49.00	21.30	16.20	-48.30	22.60	14.90
VI34	39.60	13.60	15.20	42.40	14.30	17.00	-38.10	9.60	15.50	-38.40	9.50	14.80
WE141	51.60	27.10	17.00	53.20	28.20	16.90	-49.20	25.80	18.40	-49.80	25.90	18.30
WI235	49.10	21.00	10.70	49.80	20.60	12.90	-49.20	18.20	15.00	-47.90	19.00	13.20
YA24	43.80	20.10	16.30	44.50	19.90	16.40	-50.40	18.60	18.30	-50.80	20.40	16.60
ZD5	-47.90	18.60	16.90	-49.10	18.20	18.30	47.50	18.90	16.60	46.10	18.80	14.90
ZO9	-47.00	20.20	13.90	-49.80	22.90	13.70	51.40	24.30	13.70	54.00	24.30	15.50

Appendix 10: Raw Data for MxC and MdC

	MxC						MdC					
	T1			T2			T1			T2		
	X	Y	Z	X	Y	Z	X	Y	Z	X	Y	Z
BE182	0.00	-25.50	90.50	0.90	-24.30	95.80	1.40	-24.00	87.90	1.50	-24.20	93.40
BR264	3.30	-41.20	85.20	2.90	-43.90	84.70	2.00	-38.60	81.40	2.60	-43.70	81.90
CA232	3.30	-33.10	104.10	1.60	-35.70	105.00	3.70	-29.90	99.00	1.30	-33.50	101.10
CA253	3.60	-32.50	101.60	3.70	-34.20	100.00	4.20	-29.50	95.30	3.50	-32.40	97.00
FL43	0.50	-44.80	86.00	-0.70	-46.80	84.10	-1.70	-40.00	82.10	-1.50	-46.00	81.50
FR98	0.80	-15.00	94.30	0.10	-17.50	97.50	0.80	-17.50	88.90	-0.40	-17.30	94.60
HE100	-1.00	-27.00	97.30	1.80	-23.80	103.70	1.20	-24.10	93.20	2.10	-23.30	101.60
KO8	1.20	-24.30	96.80	3.00	-32.40	93.10	3.50	-19.40	90.40	2.90	-31.30	90.80
LO87	-5.60	-31.70	94.20	-4.90	-32.60	93.90	-5.70	-27.10	90.30	-4.80	-31.40	91.00
NI44	2.80	-24.00	106.10	3.70	-26.40	108.90	1.90	-21.50	101.30	3.70	-26.20	106.40
NO45	-2.80	-23.70	98.60	-1.30	-23.20	97.50	-3.70	-22.00	95.00	-1.50	-21.70	95.00
OR23	0.20	-33.90	87.90	2.00	-34.70	89.80	-1.10	-26.10	84.40	0.90	-31.50	87.40
PA162	5.40	-40.20	95.80	2.00	-38.60	96.80	3.30	-34.30	90.90	1.80	-37.00	94.30
PR78	2.40	-47.50	76.90	2.40	-51.30	77.30	3.60	-42.80	72.70	2.60	-49.30	74.80
SA115	2.00	-37.70	88.90	4.00	-37.40	93.30	2.30	-32.60	84.40	4.30	-36.60	91.00
SP65	-0.30	-26.90	86.70	0.20	-26.20	89.70	1.50	-23.10	83.90	1.00	-26.00	88.00
SP60	2.20	-27.10	94.40	-0.20	-32.00	95.70	1.80	-23.60	90.00	-0.10	-30.00	93.40
TE47	2.10	-52.80	89.80	2.50	-54.40	93.70	-0.50	-50.90	86.80	2.40	-52.90	91.10
TO65	5.90	-13.10	94.10	5.20	-11.00	100.90	4.00	-8.60	91.30	4.90	-10.60	98.50
VI34	3.70	-52.10	93.20	2.20	-53.40	93.10	2.00	-48.50	87.90	1.80	-51.50	90.40
WE141	1.40	-32.70	93.10	-1.90	-38.40	92.80	-1.70	-27.90	87.20	-2.20	-36.70	90.30
WI235	3.70	-20.00	95.40	3.10	-18.00	98.80	3.30	-17.30	93.10	2.50	-16.80	95.20
YA24	1.20	-41.30	88.00	-1.40	-43.40	89.60	0.40	-38.10	85.80	-1.40	-41.80	86.90
ZD5	-2.60	-24.70	92.10	-1.10	-25.90	90.70	-2.20	-20.70	88.00	-1.20	-25.00	87.90
ZO9	4.20	-34.90	90.90	2.20	-36.30	96.60	5.10	-30.60	87.90	2.10	-34.60	93.90

Appendix 11: Raw Data for OrR

	OrR					
	T1			T2		
	X	Y	Z	X	Y	Z
BE182	-31.10	16.10	76.40	-30.70	20.00	79.30
BR264	-31.60	10.50	74.20	-30.50	9.40	74.20
CA232	-32.80	15.00	81.60	-33.30	13.80	82.30
CA253	-34.70	6.30	81.70	-28.50	6.70	83.20
FL43	-33.10	8.70	71.00	-31.90	7.60	74.40
FR98	-30.20	22.10	77.30	-31.50	23.90	79.70
HE100	-32.30	18.70	77.70	-32.50	22.30	85.50
KO8	-33.80	23.20	77.70	-32.50	19.30	80.50
LO87	-34.10	15.00	81.80	-31.90	14.40	81.10
NI44	-35.00	20.10	85.00	-34.90	20.10	91.20
NO45	-35.20	23.00	76.80	-33.50	23.60	75.80
OR23	-35.40	15.20	76.70	-34.70	13.00	76.20
PA162	-32.00	9.40	81.40	-35.30	11.10	82.50
PR78	-33.80	2.60	72.60	-32.30	1.60	74.70
SA115	-31.40	10.10	76.90	-30.40	10.40	80.90
SP65	-32.40	22.50	74.20	-31.90	23.20	76.30
SP60	-29.90	16.20	76.10	-32.30	15.70	77.20
TE47	-30.10	-0.20	83.60	-31.00	0.20	88.70
TO65	-30.20	28.10	74.60	-29.90	30.90	75.60
VI34	-29.20	-1.30	83.20	-29.10	-1.80	83.30
WE141	-32.80	16.70	80.20	-34.50	15.30	84.10
WI235	-28.20	23.40	76.50	-29.80	25.10	76.90
YA24	-32.40	5.70	79.50	-32.00	6.30	81.10
ZD5	-31.80	19.60	75.70	-31.60	18.50	77.50
ZO9	-34.80	15.60	78.40	-36.20	18.80	81.30

Appendix 12: Raw Data for ANS and PNS

	ANS						PNS					
	T1			T2			T1			T2		
	X	Y	Z	X	Y	Z	X	Y	Z	X	Y	Z
BE182	-0.20	-0.70	90.50	0.30	1.80	94.90	-2.60	-1.50	42.40	-2.20	-1.00	44.90
BR264	2.90	-14.00	86.50	2.10	-15.80	86.50	0.60	-10.00	37.90	0.10	-10.60	37.30
CA232	1.20	-7.60	100.60	-0.20	-9.90	101.00	1.40	-7.00	46.40	0.30	-7.40	47.20
CA253	2.30	-9.50	96.50	2.10	-10.00	96.00	1.00	-11.90	48.20	1.40	-11.30	47.10
FL43	-0.30	-13.90	85.80	-0.10	-16.20	86.50	0.50	-10.30	37.90	-0.40	-10.60	38.60
FR98	0.20	5.70	93.20	0.20	5.70	95.50	2.00	2.10	44.50	-0.80	1.70	46.80
HE100	-1.00	-2.90	95.60	2.00	1.20	100.50	-1.80	-1.80	46.90	-1.60	0.50	49.90
KO8	1.10	3.60	91.40	1.30	-2.80	94.10	0.20	3.00	46.50	0.60	0.00	46.70
LO87	-5.10	-9.40	97.80	-4.60	-10.20	96.10	-4.00	-5.60	44.20	-3.70	-6.20	43.50
NI44	2.70	-1.30	98.00	3.30	-1.10	105.20	0.10	1.00	47.90	-1.00	1.30	51.50
NO45	-1.60	3.10	91.80	-0.60	4.70	95.60	-2.20	-1.30	41.20	-1.20	-0.10	41.90
OR23	0.30	-6.50	93.00	1.80	-8.00	92.50	-1.00	-3.80	43.40	0.50	-4.60	42.60
PA162	2.80	-10.70	101.20	1.60	-11.30	103.70	1.90	-6.50	46.90	0.80	-7.20	46.10
PR78	1.40	-21.90	82.70	1.10	-24.50	84.40	1.90	-11.80	40.90	0.10	-12.10	34.80
SA115	1.80	-11.10	90.70	2.60	-10.00	93.50	1.80	-4.00	46.50	2.60	-3.80	46.30
SP65	0.50	-3.10	89.70	-0.10	-3.20	92.00	-1.10	2.60	41.50	-1.20	1.70	42.70
SP60	1.20	-3.70	93.80	0.90	-5.90	94.70	0.30	-4.90	43.40	0.30	-5.70	41.10
TE47	1.00	-23.50	92.60	1.40	-23.80	97.30	-0.30	-11.50	42.30	-1.70	-10.50	45.60
TO65	5.90	9.00	94.90	3.40	9.30	96.40	2.50	4.30	45.20	1.50	3.90	45.60
VI34	2.00	-28.30	90.10	1.80	-27.90	91.20	2.00	-16.40	44.10	2.40	-16.70	43.60
WE141	0.60	-4.60	95.80	0.00	-8.60	99.50	1.10	3.10	44.40	1.70	2.30	43.20
WI235	3.30	4.00	92.90	3.80	7.50	96.40	1.40	-0.70	45.00	1.80	-2.60	43.80
YA24	0.50	-19.70	90.70	0.00	-21.50	93.70	-1.50	-5.10	42.20	-1.50	-6.00	41.50
ZD5	-2.10	-3.30	92.40	-2.00	-5.10	94.50	0.30	-2.20	47.70	-0.10	-3.20	46.20
ZO9	1.50	-5.50	94.50	0.10	-4.20	101.70	2.60	-1.60	43.50	2.20	-2.70	45.10

Appendix 13: Raw Data for Pog and Me

	Pog						Me					
	T1			T2			T1			T2		
	X	Y	Z	X	Y	Z	X	Y	Z	X	Y	Z
BE182	-0.20	-50.70	83.20	0.90	-50.20	90.10	1.00	-56.10	75.90	-0.30	-56.90	83.40
BR264	5.90	-66.00	72.90	5.10	-69.80	70.40	5.60	-71.70	66.10	6.80	-76.00	63.60
CA232	4.60	-60.20	96.80	2.80	-63.50	96.30	5.80	-68.50	88.90	3.30	-71.50	88.50
CA253	4.70	-56.50	87.50	4.50	-59.10	90.00	4.30	-62.10	81.70	4.60	-65.10	84.40
FL43	-2.00	-69.00	70.90	-1.90	-72.10	67.50	-2.80	-74.90	65.10	-3.30	-78.20	61.60
FR98	1.40	-45.90	88.80	-1.00	-46.20	93.60	1.80	-52.70	84.70	-1.00	-52.30	89.10
HE100	0.60	-51.40	89.50	2.30	-54.10	97.40	0.60	-59.60	81.90	1.70	-61.50	90.60
KO8	5.50	-51.30	86.80	4.30	-63.60	84.90	4.40	-55.40	79.60	4.40	-67.90	80.00
LO87	-7.20	-53.80	86.90	-5.50	-56.60	86.00	-7.30	-60.20	81.80	-5.60	-62.60	80.80
NI44	2.40	-52.10	98.00	3.60	-58.20	103.30	1.90	-57.40	93.60	2.60	-64.40	97.10
NO45	-4.10	-51.30	87.20	-1.80	-51.60	88.70	-4.60	-57.20	81.40	-1.80	-58.00	83.00
OR23	0.00	-57.10	81.10	1.90	-59.50	78.30	0.00	-62.60	75.10	2.20	-64.60	73.10
PA162	6.40	-67.70	84.60	2.30	-69.90	87.00	6.40	-74.10	79.00	2.90	-76.20	81.40
PR78	3.40	-71.90	63.30	3.80	-78.40	61.80	3.40	-74.70	55.40	4.20	-82.60	54.40
SA115	3.20	-61.80	76.30	3.90	-63.50	79.20	3.20	-66.50	70.90	4.40	-69.80	74.10
SP65	0.30	-48.30	83.10	0.00	-49.50	84.30	0.90	-59.00	77.00	0.50	-59.90	78.90
SP60	1.70	-51.00	84.10	0.50	-60.20	86.10	3.50	-57.90	77.80	0.60	-67.60	79.40
TE47	0.00	-81.10	74.90	1.50	-84.70	78.70	0.00	-84.70	67.60	1.70	-89.60	73.30
TO65	8.70	-36.20	93.10	8.80	-39.00	98.60	9.20	-43.50	87.40	8.00	-47.50	92.30
VI34	4.20	-75.30	78.80	3.90	-77.40	79.20	4.60	-81.60	69.50	5.30	-84.30	70.70
WE141	-0.70	-56.10	79.70	-0.30	-63.10	79.00	1.60	-62.40	73.20	0.00	-70.50	73.70
WI235	6.30	-44.70	90.10	5.10	-44.90	92.40	6.60	-52.40	83.50	5.60	-52.90	86.40
YA24	-1.20	-63.80	68.40	-2.30	-70.60	71.20	-0.90	-68.10	62.10	-2.30	-76.80	65.80
ZD5	-1.80	-45.00	89.80	-1.50	-50.30	89.30	-1.50	-50.80	85.40	-0.40	-55.00	85.30
ZO9	7.80	-61.70	84.80	4.10	-69.90	90.10	7.40	-67.00	80.60	5.30	-75.40	84.00