Skeletal, Dental, and Nasal Airway Changes After Treatment with Quad-helix Appliance as Evaluated by CBCT

by

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A thesis submitted in partial fulfillment of the requirements for the degree of

Master of Science

Medical Sciences – Dentistry

University of Alberta

Abstract

Introduction: Transverse maxillary deficiency has been associated with a variety of malocclusions, occlusion instability, and breathing problems. Managing this condition at an early stage is recommended to ensure normal dental and skeletal relationships and to improve oral health and aesthetics. Slow maxillary expansion using Wilson quad-helix is one treatment modality for transverse maxillary deficiency. The purpose of this study was to evaluate skeletal, dental, and nasal airway changes after treatment with the Wilson quad-helix appliance through CBCT.

Method: Pre- and post-treatment CBCT images for a group of patients who received maxillary expansion treatment with a Wilson quad-helix appliance were retrospectively collected. The Wilson group consisted of 12 patients (nine males and three females). The pre-treatment age range was 10 to 13 years with a mean age of 11.4 ± 1.2 years. The period between pre-treatment (T1) and post-treatment (T2) CBCTs ranged from 1 to 2 years with a mean of 1.6 ± 0.4 years. The comparison group included 12 patients (eight males and four females) with an age range at the study's onset of 10 to 13 years (age mean of 11.7 ± 0.7 years). The period between T1 and T2 CBCTs ranged from 1 to 2 years with a mean of 1.6 ± 0.3 years. The patients in the comparison group did not have maxillary expansion treatment. They had Class II elastics and fixed orthodontic appliances (braces). AVIZO software was used to locate specific anatomical skeletal and dental landmarks to measure skeletal and dental distances. Mimics software was used to segment the nasal airway and to reconstruct 3D models. Nasal volume, surface area, and part analysis (point-based analysis) were used to analyze 3D nasal models. ICC was used to test intra-examiner reliability. One-way ANOVA was applied to the linear skeletal and dental distances to identify differences between groups. Independent t-tests were conducted to compare the mean difference of nasal volume, surface area, and part analysis between the Wilson group and the comparison group.

Results: There was statistically significant difference in the maxillary inter-molar width change from T1 to T2 between the Wilson group and the comparison group. The distance between upper first molars significantly (difference between groups) increased (mean 3.6 mm) at the pulp chamber and at the root apex (mean 3.5 mm). The distance between upper first premolars significantly increased (mean 3 mm) at the pulp chambers. There was no statistically significant difference in the nasal volume, surface area, and part analysis between the Wilson group and the comparison group.

Conclusion: Maxillary inter-molar and inter-premolar widths increased as a result of the Wilson quad-helix treatment. Buccal translation movement of upper first molars was observed after Wilson quad-helix treatment. Dental changes were greater

than skeletal changes. There was no statistically significant difference in nasal airway volume or surface area between the Wilson group and the control group.

Preface

This thesis is an original work by Rabia Njie. Research project, which is this thesis is apart of, received ethical approval from the University of Alberta Health Ethics Review Board, project name “ Retrospective Cephalometric evaluation of patients treated with Wilson and Bio-progressive orthodontic treatment”, Number: Pro 00047506. Date: February 17th, 2017 (Approval renewal Date)

Acknowledgement

I would like to thank my supervisor, Dr. El. Bialy for his guidance and continues support. I also thank my committee for their support. Dr. Major, Dr. Lagravere, Dr. Alsufyani, and Dr. Lai. I really appreciate your time and valuable advice all of you.

I would like to thank my husband for his endless support. His encouragement and inspiration helped me to overcome all challenges. I wish I have words to thank him.

I thank my parents and all my family in Libya. I am especially grateful for my father for his generous giving and support from early stages of my studies and life.

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Chapter 1: Introduction

Statement of The Problem

A narrow upper jaw is a common problem in orthodontic practice. A large percentage of children with narrow upper jaw suffer from transverse maxillary deficiency and teeth crowding.[1,2] Transverse maxillary deficiency is also called maxillary constriction. The etiology of this condition has been reported to be associated with multiple factors, for example, abnormal oral/myofunctional habits such as thumb sucking and mouth breathing.[3] The clinical features of a narrow upper arch frequently include moderately to severely crowded upper arches which may or may not be associated with posterior crossbites.[4]

Posterior crossbite is a transversal discrepancy of the relationship between upper and lower posterior teeth due to a narrowing of the upper dental arch in comparison to the lower dental arch that might be also wider than normal. It is an abnormal buccolingual relationship between upper and lower molars and/or premolars. In this condition, upper teeth occlude more palately to opposing lower posterior teeth.[5,6] Posterior crossbite can be either bilateral or unilateral and its origin can be skeletal (due to constricted maxillary basal bone) or dentoalveolar (due to palatal tipping of maxillary posterior teeth). Unilateral posterior crossbite can cause tilting of the lower dental arch to the affected side, resulting in a deviation of the midline which could be due to functional shift of the mandible.[7,8]

Crossbite is not self-corrected and early treatment is desirable in order to achieve stable and normal occlusion, balanced condyle growth, and overall growth in the lower jaw.[8,9] Untreated unilateral posterior crossbite can lead to negative long-term effects/consequences on the development of jaws and teeth, such as disturbance of the muscle activity of the temporalis and masseter muscle in children and uneven normal growth on both temporomandibular joints and fossae.[10–12]

One approach to correct transverse maxillary deficiency is slow maxillary expansion (SME) using quad-helix appliance. Skeletal versus dental changes after SME using quad-helix are still controversial. Most studies that have tried to address this topic were performed on dental casts or using two-dimensional (2D) radiographs. Dental models are susceptible to distortion resulting from impression material or procedure and can be connected to measurement errors, while 2D imaging is subject to projection and landmark identification errors.[13,14] Cone Beam Computed Tomography (CBCT), on the other hand, provides more information and is considered more reliable than traditional 2D radiographs. In addition, CBCT has made the assessment of nasomaxillary regions and nasal airway segmentation feasible.[15]

To the best of our knowledge, only one study has used CBCT to assess dentoalveolar changes after quad-helix ; however, that study did not have a comparison group.[16] No studies have investigated the effects of SME using the quad-helix on nasal airways. This is the first study to investigate nasal airway changes after Wilson quad-helix appliance assessed through CBCT.

Study Objectives

1- To determine maxillary skeletal and dental changes after expanding the upper dental arch using Wilson quad-helix appliance as evaluated by CBCT, and to compare the results of using Wilson appliance to a non-Wilson appliance-treated comparison group to eliminate possible changes due to growth.

2- To determine the possible three-dimensional (3D) changes in the nasal airway after maxillary arch expansion using Wilson quad-helix appliance and to compare the results of using Wilson appliance to a non-Wilson appliance-treated comparison group.

Hypotheses

1- Maxillary skeletal and dental transverse dimensions increase after using slow maxillary expansion using Wilson quad-helix appliance.

2- Nasal airway volume and nasal surface area increase after slow maxillary expansion using Wilson quad-helix appliance.

Literature Review

Maxillary Expansion Treatment

The concept of transverse maxillary deficiency correction was first explained by Angell in 1860, and in 1961 Haas reemphasized the concept through expansion appliances.[17]

Three approaches are available to expand the maxilla: rapid maxillary expansion (RME), slow maxillary expansion (SME), and surgically assisted rapid maxillary expansion (SARME). Each treatment modality has its respective advantages and disadvantages. Selection of any of these approaches depends upon practitioners' preference, malocclusion, and patients' age. SARME is used for individuals who have an increased or a totally fused palatal suture, while RME and SME are used for younger individuals who are still growing.[18–20]Although SARME is relatively successful in expanding the maxilla by splitting the palatal suture, the procedure is expensive, aggressive, and may be associated with bleeding, pain, and infection.[21]

Most clinicians prefer RME or SME (if possible) as more conservative alternatives. RME applies heavy force (15 to 50 newtons) to gain more skeletal orthopedic effects. The rate of expansion with RME varies from 0.25 to 0.5 mm (1 or 2 turns of the jackscrew) per day,[19] whereas SME delivers lighter force (5 to 20 newtons). The rate of expansion is 0.25 mm every other day with appliances such as Haas and Hyrax, or SME can be done through 1-molar-width activation of a quad-helix appliance.[19,20]

Studies have reported certain RME drawbacks, for example incisal diastema, pain, edema, and tissue irritation and ulceration.[22] Root resorption and microtrauma to the temporomandibular joint (TMJ) and midpalate suture have also been associated with RME.[23–26] In addition, Gurel et al.[27] reported a significant amount of relapse after RME.[27] It has been reported that pain, resistance, and relapse caused by RME are related to the rigidity of facial bones and circummaxillary structures.[28]

Slower expansion rate with lighter force may be considered more physiological than RME, giving the opportunity for the tissues to adjust and to prevent accumulation of excessive residual force in maxillary complex.[29,30]

SME procedure creates less tissue resistance throughout circummaxillary structures. As a result, it enhances bone formation in intermaxillary structures which theoretically decreases RME limitations.[19,30,31]SME can be designed to produce continuous physiological force until required expansion is achieved. If sufficient retention is applied after the active expansion period, SME procedure shows great stability.[29,30,32]

Appliances Applied in SME

SME can be done using different appliances either by slow rate activation of jackscrew of tooth-borne or tooth-tissue-borne appliances (e.g. Hyrax and Haas) or by the following appliances:

- Coffin appliance
- Magnets
- Removable expansion plate
- Minne expander
- W-Arch
- Quad-helix[20]

Quad-helix, one of the most popular orthodontic appliances to correct posterior crossbite,[32–36] is a modification of W-Arch which was explained by Ricketts.[37] The appliance is attached to the first upper molars by two bands. Four helix springs are incorporated to the W spring that assists by improving the flexibility and range of the appliance's activation.[20,38] The length of two palatal arms can be changed based on the position of the teeth in the crossbite.[20]

Wilson 3D quad-helix

Wilson 3D quad-helix is a type of quad-helix expansion appliance.[39] The inserting/removing system makes insertion and removal of quad-helix considerably easier. The inserting/removing system is composed of stamped two posts laser soldered to the quad-helix and a vertical insertion tube,[37] orthodontists can easily remove the appliance for activation without needing to remove the bands.[37]

Moreover, prefabrication of Wilson appliances in different sizes saves time by eliminating impression procedures.

Clinical Management

The recommended force level of 10 to 20 newtons can be obtained by activating (expanding) the quad-helix for 8 mm which is almost equal to one molar width.[30,40] Wearing a Wilson quad-helix includes an activation period of approximately six months followed by a retention period of three months or more depending on the amount of expansion that is needed. The expansion should continue until correction of crossbite (palatal cusps of upper molars contact with buccal cusps of lower molars) has been achieved. Patients should be seen every six to eight weeks for activation and monitoring of the expansion.[20,41]

Studies that have investigated the effectiveness of the quad-helix treatment in the correction of a posterior crossbite used orthodontic models and cephalograms (lateral and anteroposterior) to assess dental effects and skeletal changes.[33–36,42–44] Some of these studies compared expansion outcomes between a quad-helix treatment and a removable expansion plate and reported greater expansion gained after the quad-helix compared to the expansion plate.[33–35,44] On the other hand, Bjerklin found similar effects produced by the two treatments.[43]

Another study assessed treatment effects of quad-helix in comparison to Haas and hyrax and found no differences between the three appliances.[32]

Boysen et al.[33] found the expressed expansion by quad-helix in posterior areas mostly resulted from buccal translation of upper molars, whereas Erdinc et al.[35] reported considerable buccal tipping at the end of the quad-helix treatment despite the short period of treatment. Surprisingly, a later study documented lingual tipping of maxillary first molars and mesiobuccal rotation due to quad-helix activation.[45]

In addition, Boysen et al[33] reported that the basal expansion resulting from quad-helix was relatively less than dental expansion, however, Sandikcioglu et al[36] found equal skeletal and dental effects after the quad-helix treatment.

Skeletal versus dental effects after SME (for example using quad-helix) are still controversial. A recently published systematic review demonstrated that the evidence for SME in correcting crossbite by increasing the transverse width is low because of the low number and low quality of studies addressing this topic. The skeletal outcomes were presented but reported to be lower than dental changes. Therefore, more studies are required to confirm this finding.[46]

The effects of RME on the nasal cavity and breathing have been reported in the literature. Cordasco et al[47] reported that RME increased the nasal cavity size, specifically the lower area of the nose. Felippe et al[48] reported an increase in total nasal volume and nasal valve area (the minimum cross sectional area in the nose) with a decrease in nasal airway resistance and improvement in breathing in subjects treated with RME. Moreover, Moreira et al[49]compared the immediate effects of RME using Hyrax and Haas appliance on the nasal cavity and found significant increase in nasal cavity dimensions produced by both appliances, although Hyrax created a greater increase on transverse dimensions of the nasal airway.

Cone Beam Computed Tomography (CBCT)

Two-dimensional (2D) imaging for example cephalograms (lateral, anteroposterior) and panoramic radiographs have been used in daily orthodontic practice as a diagnostic tool. Analyzing 3D structures on a 2D view is considered inaccurate and potentially associated with landmark identification and measurement errors.[13,14] A parallel relationship between the image plane and the object to be scanned is required. However, as x-ray beams are not parallel with all points in the examined object, they can cause magnification and distortion. In addition, 2D imaging is often connected with superimposition of adjacent anatomical structures.[13,14,50]

In order to address the drawbacks of 2D imaging, 3D technology has been developed. Although conventional computed tomographic radiography (CT) is an accurate method, it has limited accessibility, a high cost, and a high radiation dose.[51]

Cone-beam geometry provides an alternative to either fan-beam or spiral-scan geometries used in conventional CT providing more rapid acquisition of a data set of the entire field of view. CBCT has become more popular in orthodontic practice because of its availability, lower radiation exposure, and relatively low cost in comparison to conventional CT.[52] A significant advantage is reduced examination time, which in turn reduces image blurriness due to patient translation and minimizing image distortion caused by internal patient movement. [53] In addition, the volumetric nature of CBCT provides an opportunity to produce images in different orientations (coronal, sagittal and panoramic) without distortion or magnification in shape or size[54,55]

Because of its adequate resolution and accuracy of images produced, CBCT has been recommended in cases where conventional radiographs are unable to provide sufficient information such as assessment of root morphology and resorption, as well as upper airway evaluation[56–58]. In addition, using 3D digital markers with three dimensional coordinates (x, y, z) can be useful in the evaluation of craniofacial structures in three dimensions. This has expanded the use of CBCT from its restricted role as a diagnostic tool to a research tool for assessing structural changes over time.[51,53,56]

Chapter 2: Materials and Methods

Sample Information

This retrospective study was approved by the University of Alberta, Health Ethics Review Board (Pro 00047506). Before and after the treatment CBCT sets were retrieved from Orthodontic Graduate Clinic database at the University of Alberta and from a private clinic for patients with a constricted maxilla who were treated with slow maxillary expansion using the Wilson quad-helix appliance.

Inclusion Criteria:

1-Male and female children between the ages of 10 to 13 years old who had diagnosed with a constricted maxilla and posterior cross bite.

2- Patients who had Wilson quad-helix phase 1 expansion treatment.

3-Patients who had CBCTs before the insertion of the appliance and after the removal the appliance (before their phase 2 treatment).

Exclusion criteria:

1-Patients with craniofacial abnormalities.

2-Patients who had undergone to any other orthodontic treatment or surgery for the maxilla prior to Wilsons quad-helix expansion treatment.

T1 CBCTs were taken directly before the insertion of the Wilson quad-helix appliance. T2 CBCTs were taken following the removal of the appliance and before entering phase 2 of the treatment (full fixed bonding). Patients were treated with the Wilson quad-helix for an active period of six months on average. The retention period with the Wilson quad-helix lasted for one year on average. T2 CBCTs were taken directly after the retention period. The Wilson quad-helix (Rocky Mountain Orthodontics, Denver, CO, USA) manufactured of a 0.038 Blue Elgiloy wire is attached to the bands on the upper first molars through vertical spurs that are inserted into vertical palatal tubes. The appliance has been activated by the orthodontist 2 mm every visit (every eight weeks) until the needed expansion was reached (i.e. when the palatal cusps of the upper first molars contacted the buccal cusps of the lower first molars). CBCTs were taken by classic ICAT (Imaging Sciences International, Hatfield, PA). CBCT protocol used a medium-large field of view (16 cm width x 13 cm height, 120 kVp, 24 mAs, 8.9 seconds scan time). Images were transferred into a DICOM file (0.3 mm voxel size).

To account for changes due to growth, a group without maxillary expansion treatment was needed. CBCT sets from 18 age matched patients who did not have maxillary expansion appliances were obtained from the University of the Pacific. However, the patients in this group had class II elastic treatment and fixed orthodontic appliances. CBCT images were taken as part of their prescribed treatment protocol. The images were generated by a second generation I-CAT machine (Imaging Sciences International, Hatfield, PA) with 8.9 second scan time and 16 x 13 cm field of view at a resolution of 0.4 mm voxels. I-CAT software was used to reconstruct and export the raw data into DICOM file.

In order to have an equal number of cases in both groups, 12 cases from the group without expansion were randomly chosen for inclusion in the study.

Sample Size Calculation

Calculation of sample size in each group was based on significance level (α)5%, power 80%, and inter maxillary molar width difference of 2.5 mm ± 2mm. Sample size calculation showed that a minimum of 11 cases in each group was required.

Determination of Skeletal and Dental Changes

Skeletal and dental specific anatomical landmarks were chosen based on previous studies[59 60] to measure transverse dental and skeletal distances. These landmarks and their definitions are shown in Table 2.1 and Appendix Figures 1-6. DICOM format files were converted to volumetric images in AVIZO software (version 9.1). AVIZO software was used to locate the landmarks on each CBCT. Determination of the landmarks' locations was done by the investigator using axial, coronal, and sagittal slices in addition to 3D reconstruction of the images (Figure 2.1).

Intra-examiner reliability of the landmarks' identification was performed on 10 randomly selected cases. Each landmark was measured three times with one week apart between trials. Mean error for each landmark was assessed and mean differences of intra-examiner reliability greater than 1 mm were considered clinically significant based on Lagravere study [60]. To control bias, blinding was done by asking a person who was not involved in the study to code the cases.

By clicking on the "create object" option followed by the "create landmarks" option, the examiner started placing 0.5 mm 3D digit markers in the centre of each landmark in the same order for all cases. After finishing the landmark placement, the landmark files were saved and then opened in Excel to calculate distances. Each landmark had three coordinates (X, Y, Z). The distance between each landmark and its contra-lateral counterpart was measured. The measured distances and their definitions are displayed in Table 2.2

To measure the distances between the landmarks, the following formula was used:

$$D=\sqrt{(x1-x2)^2+(y1-y2)^2+(z1-z2)^2}$$

Where D is the distance between the landmarks. Next, the statistical analysis was accomplished.

Table 2.1: Dental and skeletal landmarks and their definitions

Landmark	Definition
Upper first molars pulp chambers (L&R)	Center of the largest cross-sectional pulp chamber area
Upper first molars root apex (L&R)	The root apex of mesiobuccal root of the upper first molars
Upper first molars alveolar bone (L&R)	The outer cortex of alveolar bone at the level of the root apex
Upper first premolars pulp chambers (L&R)	Center of the largest cross-sectional pulp chamber area
Upper first premolars root apex (L&R)	The root apex of buccal root of the first premolars
Upper first premolars alveolar bone (L&R)	The outer cortex of alveolar bone at the level of the root apex
Infraorbital foramen (L&R)	Center of the infraorbital foramen outer lower border viewed in 3D
Greater palatine foramen (L&R)	Center of the smallest area with well defined border viewed in axial view on greater palatine foramen

(L&R) = Left& Right

Table 2.1: Measured dental and skeletal distances and their definitions

Distance measured	Definition
Dental	
Inter-molars (pulp chamber)	Distance between right and left upper first molars pulp chambers
Inter-molars (root apex)	Distance between right and left upper first molars mesiobuccal root apexes
Inter-molars (alveolar bone)	Distance between the outer cortexes of the alveolar bone of right and left upper first molars at the level of the mesiobuccal root apexes
Inter-premolars (pulp chamber)	Distance between right and left upper first premolars pulp chambers
Inter-premolars (root apex)	Distance between right and left upper first premolars buccal root apexes
Inter-premolars (alveolar bone)	Distance between the outer cortexes of the alveolar bone of the right and left upper first premolars at the vertical level of the buccal root apexes
Skeletal	
Inter-infraorbital	Distance between right and left infraorbital foramina
Inter-greater palatine	Distance between right and left greater-palatine foramina

Figure 2. 1: 3 D reconstruction, axial, coronal, and sagittal slices of the CBCT images. Upper first molar pulp chamber landmark

Determination of Nasal Airway Changes

Determination of the nasal changes was from the CBCTs of both groups. One CBCT in the Wilson group and one CBCT in the comparison group were excluded because the two CBCT scans did not open in the Mimics software due to a technical issue.

To evaluate 3-dimensional changes of the nasal airway, segmentation of the nasal airway from the CBCT images was required. Mimics software [Mimics 19.0, Materialise NV, Leuven, Belgium] was used for segmentation and building of 3D models of the nasal cavity.

The region of interest extended from the anterior nasal nares anteriorly to the last coronal slice before the nasal septum fuses with the posterior wall of the pharynx posteriorly and from the hard palate inferiorly to the superior nasal meatus superiorly. This region of interest included the inferior and middle nasal meatus and the limit of segmentation superiorly was the superior nasal meatus. The operator stopped the segmentation at an imaginary line extended from a point bisecting the line formed between the nasion and the tip of the nasal bone anteriorly and right and left sphenopalatine foramina posteriorly [15].The maxillary sinus and the ethmoid cells were not included in the region of interest.

Segmentation of the Nasal Airway and Building 3D Models

Mask tool in Mimics was applied to manually select the grey level threshold by the investigator for each axial slice in the region of the interest. Region of interest in each CBCTs contained 400 to 440 slices. The grey threshold varied between slices (900 to 300) according to their positions and quality of the image. Adjustment was required by the investigator to add or erase on each slice to accurately fill the highlighted airway.

After editing the segmentation and creating 3D models. of the nasal airway, the models were saved in ASCII STL format to prepare for the smoothing and wrapping stages. For smoothing the 3D models, factor 0.7 (standard smoothing factor) [15]in Mimics was used and then their surfaces were wrapped and saved after measuring the total volume and surface area for each model. Smoothing factor is an automatic filter used to smoothen the rough edges of the 3D models for better superimposition and comparison without affecting their measurements. A radiologist and radiology expert (N.A.) then checked the segmentation of all cases before analysis of the 3D model.

3D Nasal Airway Models Analysis

In addition to using volume and surface area in analyzing and comparing 3D models, a point-based analysis and color mapping were applied. The point-based analysis was performed using "Part comparison tool", a tool in 3-matic software used to measure the distance (in mm) between each triangular node forming the 3D mesh from one airway model to the surface of the reference airway model.[15]

To assess intra-examiner reliability of the segmentation, five random cases were selected. The nasal airways were segmented three times for each CBCT image by the same investigator in one-week intervals between the three trials. Next, volume, surface area, and part comparison with color mapping were used to identify the differences between the three trials.

To compare pre-treatment (T1) and post-treatment (T2) 3D models, T1 and T2 CBCTs for each patient were superimposed (image registration stage). Next, Mimics software automatically superimposed (T1, T2) 3D model pairs for each patient (Figure 2.2). Superimposition of T1 and T2 CBCT pairs was done by using specific anatomical landmarks which were validated in a previous study.[61] These landmarks are shown in Figure 2.3.

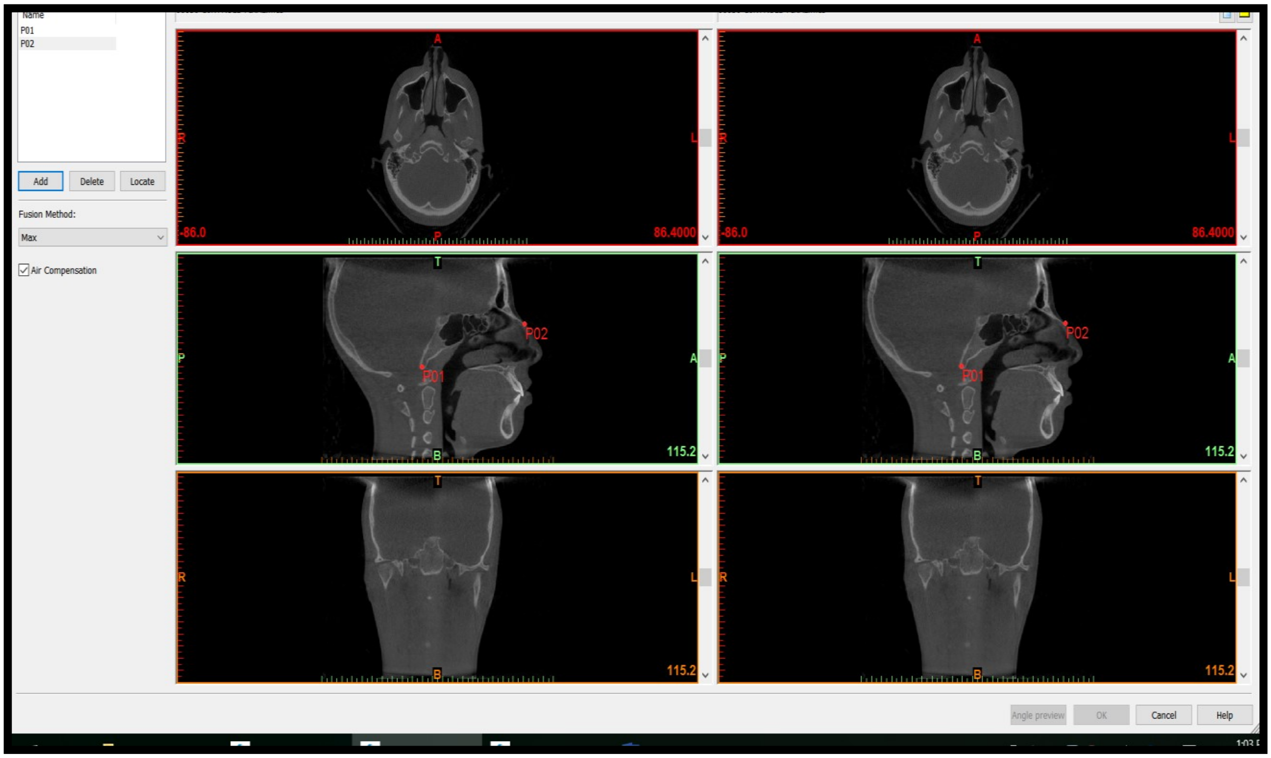

Figure 2. 2: Superimposing T1 and T2 CBCTs (image registration) in Mimics software using the landmarks.

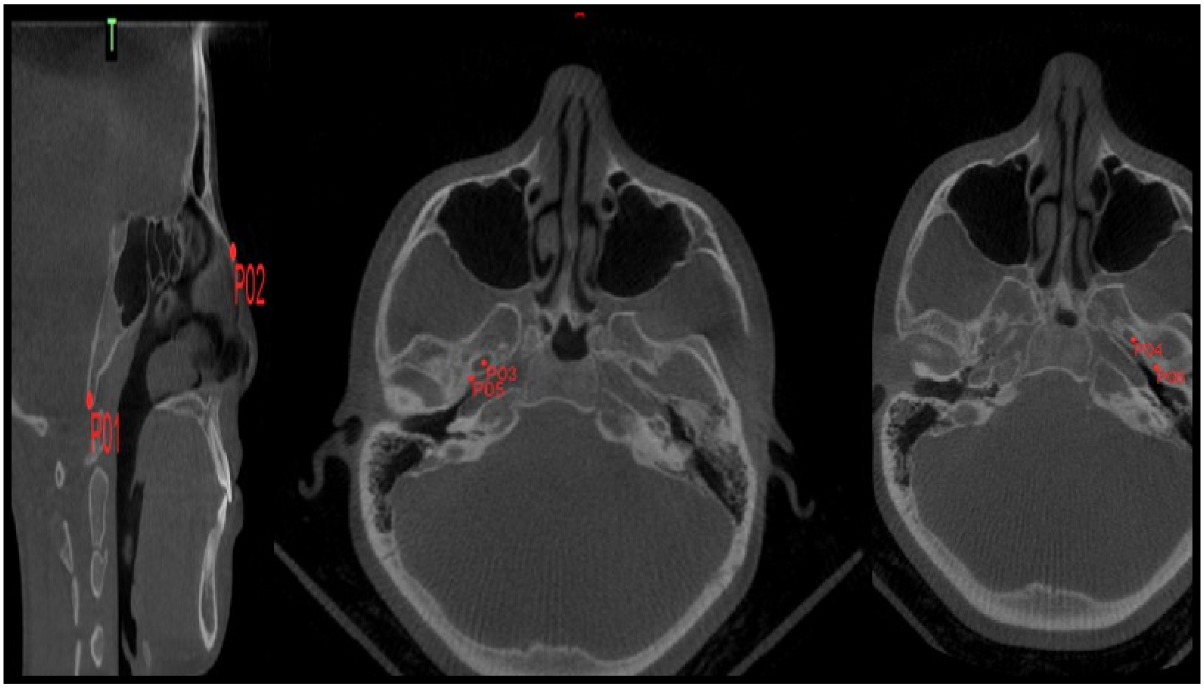

Figure 2. 3: Anatomical landmarks used in CBCTs superimposition (image registration) as appearing in Mimics software: P01. Tip of clivus. P02. Tip of the nasal bone. P03. Right foramen ovale. P04. Left foramen ovale. P05. Right foramen spinosum. P06. Left foramen spinosum.

The superimposed 3D models were then saved and exported to 3-matic software (version 9.0; Materialise) to start point-based analysis and color mapping using part comparison tool (Figures 2.4 and 2.5). The threshold of part comparison was set at 5 mm based on discussion with a radiology expert (N.A.) of what is considered clinically significant based on Alsufyani study[62]. In color mapping, triangular nodes which travelled distances within threshold boundaries would be seen as green, distances less than -5 mm would appear as blue (minimum part comparison), and distances of more than 5 mm would be seen as red (maximum part comparison).

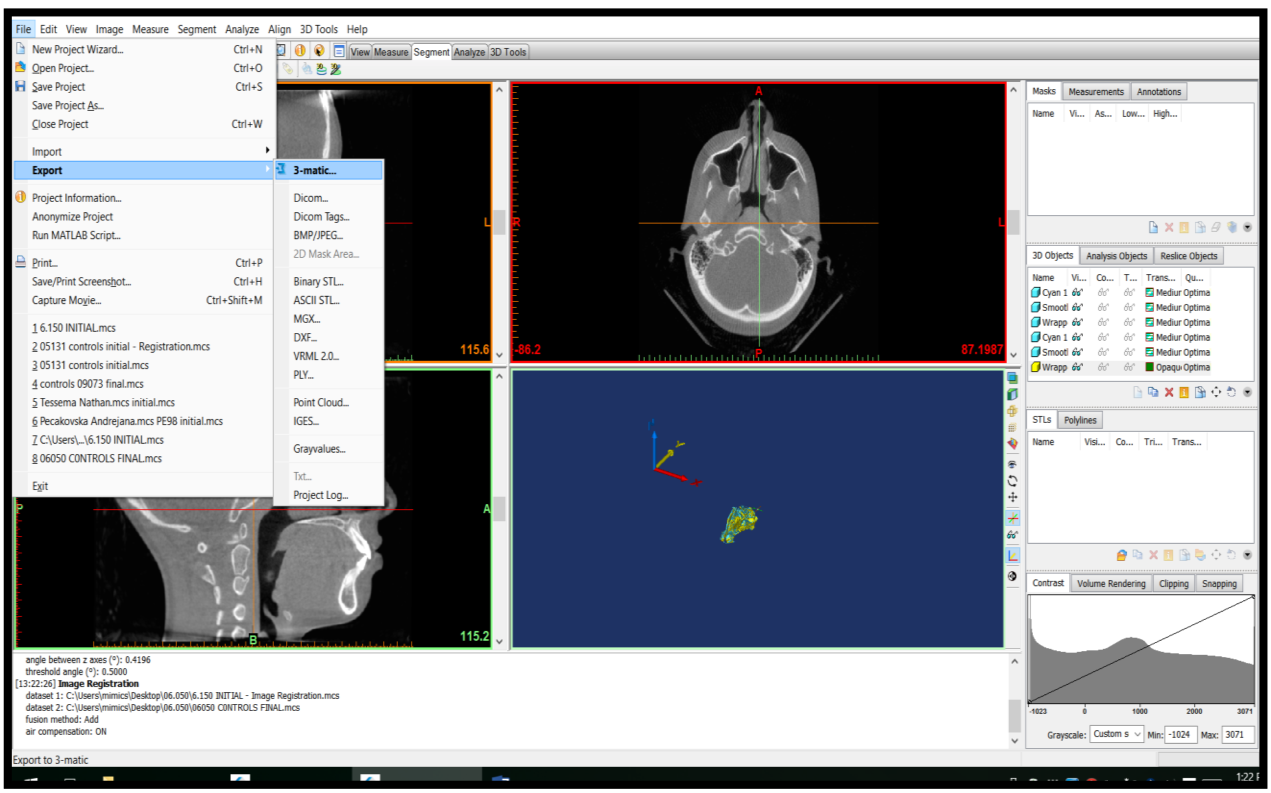

Figure 2. 4: Exporting superimposed (T1, T2) 3D models to 3-matic

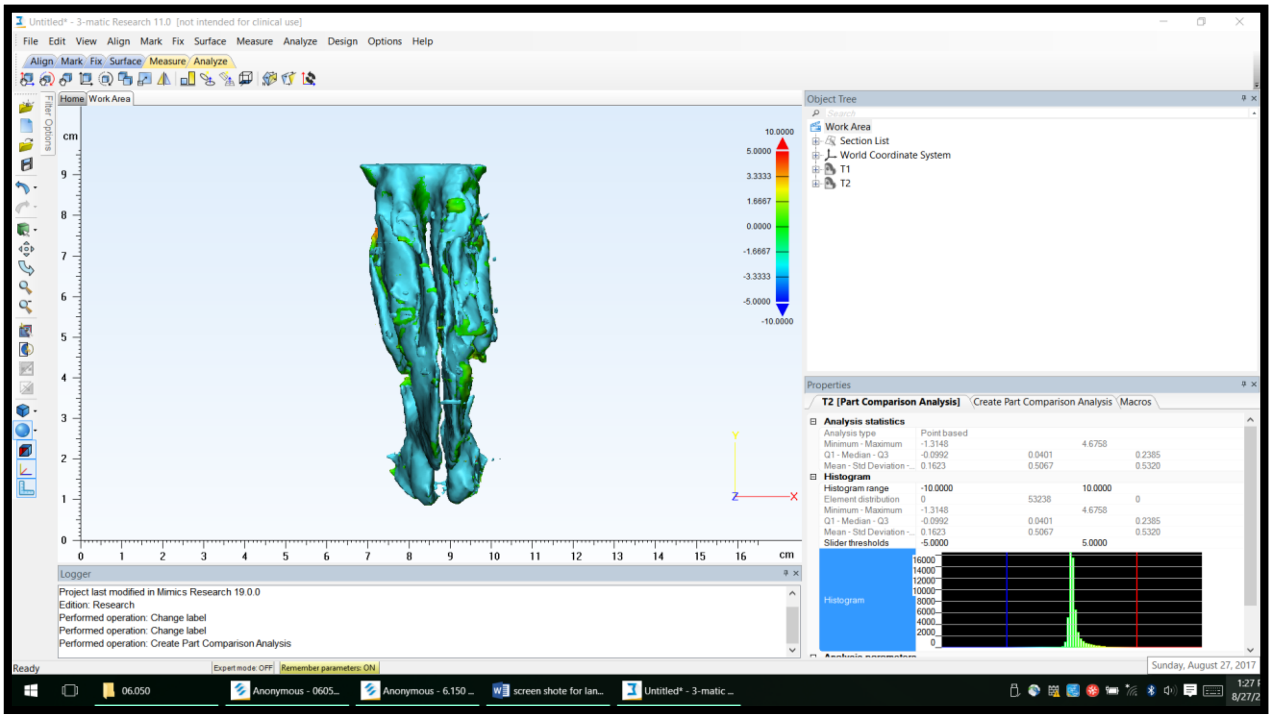

Figure 2. 5: Part comparison analysis and color mapping of superimposed (T1, T2) 3D models

Statistical Analysis

Independent t-tests were conducted on the T1 age and the T1 to T2 time interval to evaluate differences between the Wilson group and the comparison group at baseline. Intra-Class Correlation Coefficient (ICC) and the descriptive statistics were used to test intra-examiner reliability of dental and skeletal landmarks. One-way analysis of variance (ANOVA) was used to the dental and skeletal linear transverse distances to evaluate differences between groups. Paired t-test was used to assess differences within groups. Regarding the second part of the study, the Intra-Class Correlation Coefficient (ICC) of volume and surface area was used to test the intra-examiner reliability of the nasal airway segmentation. Independent t-tests were conducted to compare the three parameters of the Wilson group and the comparison group (nasal volume, nasal surface area, and part comparison).

Chapter 3: Results

There was no statistically significant difference between the Wilson group and the comparison group in age at T1 (P= 0.46) or in the time interval from T1 to T2 (P= 0.95). The Wilson Group consisted of 12 patients (nine males and three females). The age range at the beginning of the study was 10 to 13 years with a mean age of 11.4 ± 1.2 years. The period between pre-treatment (T1) and post-treatment (T2) CBCTs ranged from 1 to 2 years with a mean of 1.6 ± 0.4 years. The comparison group included 12 patients (eight males and four females) with an age range at the start of the study of 10 to 13 years (age mean of 11.7 ± 0.7 years). The period between T1 and T2 CBCTs ranged from 1 to 2 years with a mean of 1.6 ± 0.3 years.

Skeletal and Dental Changes

The intra-examiner reliability was excellent for all landmarks in all axes (X, Y, and Z). The Intra-reliability Correlation Coefficient (ICC) values were more than 0.99 (95% confidence interval, 0.99-1.00). For the three trials, the mean difference in the X, Y, and Z coordinates was less than 1.2 mm. The largest mean difference value was for the right infraorbital foramen in the Z axis (1.2 ± 1.1). Ninety-seven per cent of the landmarks had a mean difference of less than 1 mm. The mean difference and standard deviation of the landmarks for the three coordinates are shown in Table 3.1.

Table 3.1: Intra-examiner absolute mean difference (mm) of the three coordinates of the landmarks based on three trials

Landmark	X		Y		Z	
	Mean	**S.D.**	**Mean**	**S.D.**	**Mean**	**S.D**
Pulp chamber of the right upper first molar	0.31	0.15	0.75	0.31	0.94	0.26
Right upper first molar mesiobuccal root apex	0.36	0.26	0.62	0.42	0.55	0.32
Alveolar bone of the right upper first molar	0.74	0.32	1.17	0.58	0.75	0.68
Pulp chamber of the left upper first molar	0.35	0.17	0.47	0.37	0.47	0.25
Left upper first molar mesiobuccal root apex	0.42	0.27	0.46	0.23	0.42	0.19
Alveolar bone of the left upper first molar	0.92	0.47	0.72	0.44	0.53	0.33
Pulp chamber of the right upper first premolar	0.46	0.19	0.34	0.20	0.84	0.81
Pulp chamber of the left upper first premolar	0.71	0.74	0.58	0.53	0.93	0.71
Right upper first premolar buccal root apex	0.99	0.94	0.93	0.58	0.92	0.62
Alveolar bone of the right upper first premolar	0.88	0.39	0.81	0.40	0.86	0.77
Left upper first premolar buccal root apex	1.03	0.64	0.62	0.30	0.80	0.62
Alveolar bone of the left upper first premolar	0.67	0.43	0.53	0.46	0.73	0.55
Right infraorbital foramen	1.05	0.58	0.96	0.70	1.22	1.16
Left infraorbital foramen	1.02	0.52	0.97	0.42	1.21	1.13
Right greater palatine foramen	0.68	0.56	0.78	0.68	0.59	0.87
Left greater palatine foramen	0.41	0.17	0.94	1.02	0.77	1.07

Table 3.2 displays the mean expansion in the transverse dimension for the

Wilson group and the comparison group (dental and skeletal distances). There was a statistically significant difference in the inter-molar width of the maxilla between the Wilson group and the comparison group. The distance between the upper first molars increased by 3.6 mm on average at the pulp chamber and by 3.5 mm on average at the root apex in the Wilson group. The increase for the comparison group was less than 1 mm on average at the pulp chamber and the root apex. In addition, the Wilson treatment group presented a statistically significant increase in the inter-premolar width at the pulp chamber (3 mm). The change at the premolar apex was not significant. The changes at the alveolar bone at the molar and premolar areas were not statistically significant either within groups or between groups. There was a statistically significant increase in the distance between the right and left infraorbital foramina and in the distance between right and left palatine foramina in the Wilson group, however, the difference was not statistically significant between groups (Table 3.2).

Table 3.2: The mean expansion in the transverse dimension for the

Wilson group and the comparison group (dental and skeletal distances)

Distance measured	Wilson Group			Comparison Group			P value (between groups) =
Dental	**Mean**	**SD**	**P =**	**Mean**	**SD**	**P =**	
Inter-molars (pulp chamber)	3.61	2.41	**<0.01**	0.88	2.2	0.203	**0.008**
Inter-molars (root apex)	3.51	2.29	**<0.01**	0.86	2.18	0.187	**0.008**
Inter-molars (alveolar bone)	0.75	2.64	0.346	-0.48	2.28	0.477	0.233
Inter-premolars (pulp chamber)	3.01	2.21	**0.001**	0.48	1.77	0.362	**0.006**
Inter-premolars (root apex)	0.64	3.19	0.585	-0.29	1.84	0.613	0.429
Inter-premolars (alveolar bone)	0.41	2.17	0.967	-0.71	1.2	0.072	0.413
Skeletal							
Inter-infraorbital	1.01	1.01	**0.004**	0.64	2.4	0.376	0.503
Inter-greater palatine	1.48	1.94	**0.023**	0.89	1.19	0.026	0.379

Nasal Airway Changes

The intra-examiner reliability of the nasal airway segmentation was excellent. The Intra-reliability Correlation Coefficient values among the three trials were 0.99 (95% confidence interval, 0.96-0.99) for the nasal volume and 0.97 (95% confidence interval, 0.89-0.99) for the nasal surface area. The mean intra-examiner differences obtained from the three trials for the volume and surface area were 0.04 ± 0.08 cm^3, and 0.1 ± 0.1 cm^2, respectively. In the median part analysis, the mean difference was 0.03 ± 0.06 mm. The part comparison analysis and colour mapping of the intra-examiner reliability of the three trials (for the five cases) are demonstrated in Figures 3.1 and 3.2.

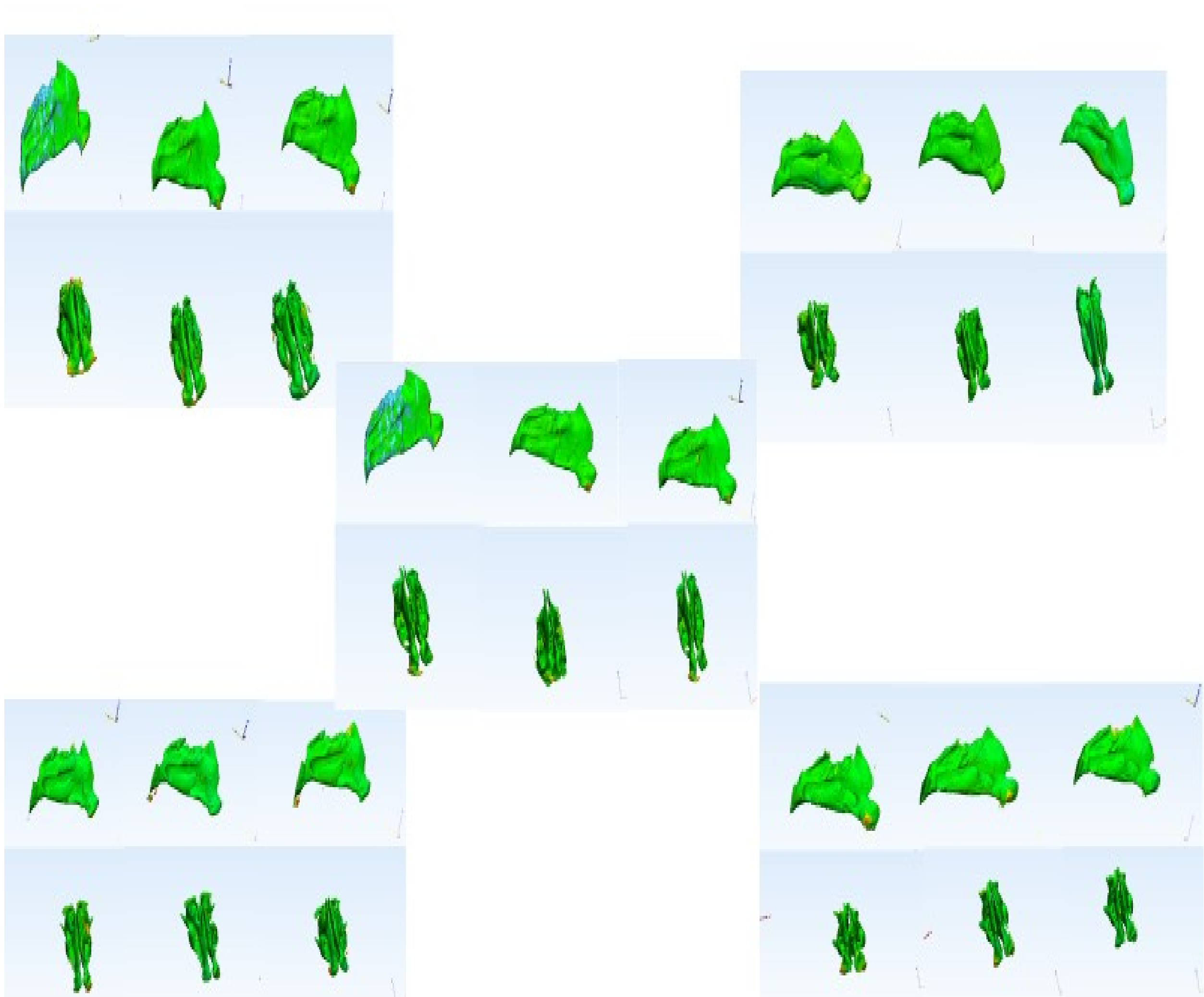

Figure3. 1: The part comparison analysis and colour mapping of the intra-examiner three trials of the five cases (3D nasal airway models lateral and frontal views)

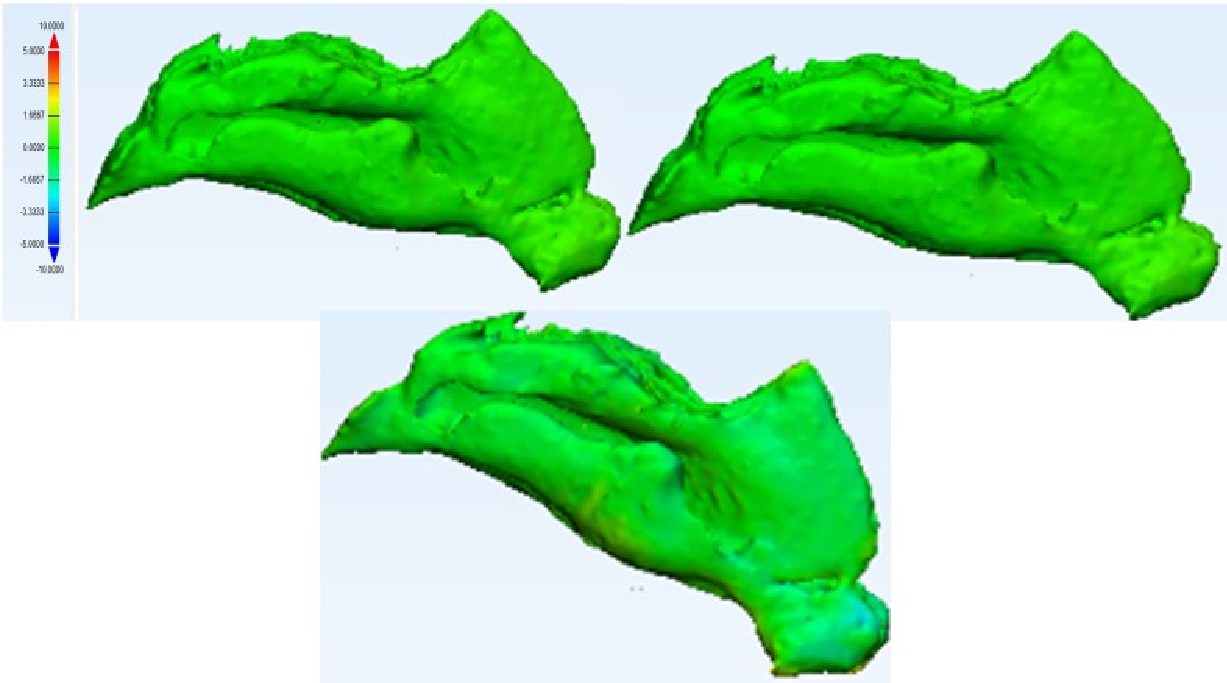

Figure3. 2: The part comparison analysis and colour mapping of the intra-examiner three trials of the first case (3D nasal airway models lateral views)

Based on the independent t-tests that were conducted to compare the mean differences of the nasal volume, nasal surface area, and part analysis of the two groups, there was no statistically significant difference in the three parameters between the Wilson group and the comparison group. The nasal volume and nasal surface area of the Wilson group increased on average by 2.4 ± 4 cm^3 (13% ± 22%) and 1.9 ± 1.8 cm^2 (12% ±12%), respectively. The nasal volume and the surface area of the comparison group increased on average by 1.2 ± 3 cm^3 (6% ± 16%) and 1.00 ± 1.5 cm^2 (6% ± 10%), respectively. The average mean part analysis for the Wilson group was 0.8 mm, and 0.5mm for the comparison group. The mean differences of the nasal airway volume, nasal airway surface area, and part analysis of the two groups are shown in Table 3.3. The part comparison analysis and colour mapping of the Wilson group and the comparison group are shown in Figures 3.3 and 3.4.

Table 3.3: The mean differences of the nasal airway volume, nasal airway surface area, and part analysis of the Wilson group and the comparison group

Parameter measured	Wilson Group			Comparison Group			P value
	Mean± SD	**Min.**	**Max.**	**Mean± SD**	**Min.**	**Max.**	
Average Volume Difference (cm^3)	2.4± 4.1	-5.8	8.7	1.2± 3.0	-6.5	5.2	0.25
Average Surface Area Difference (cm^2)	1.9± 1.8	-2.1	4	1.0± 1.5	-2.6	2.8	0.43
Average Mean Part Analysis (mm)	0.8± 0.3	0.3	1.3	0.5± 0.3	-0.04	1.3	0.3

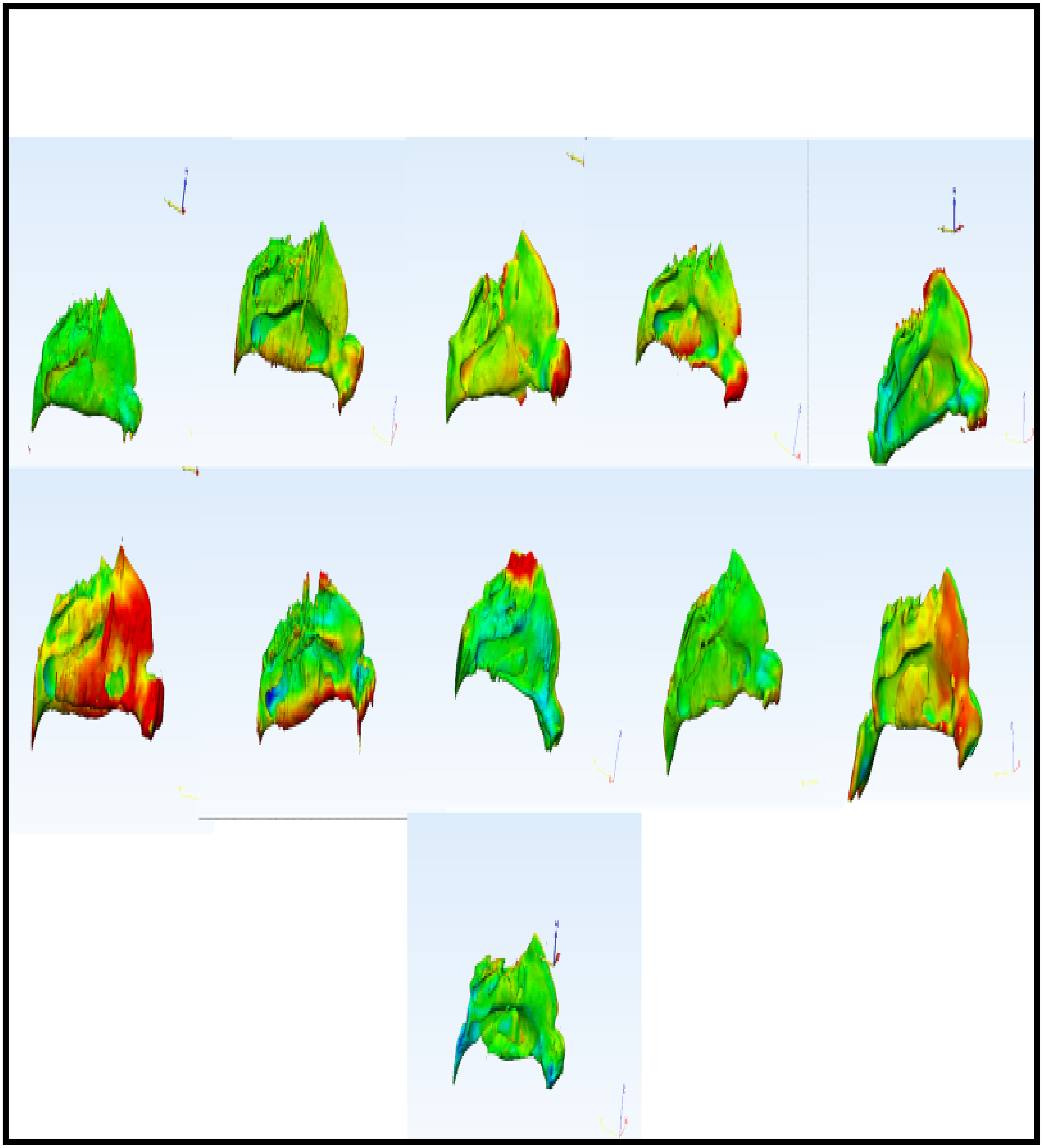

Figure3. 3: Part comparison analysis and color mapping of the Wilson group

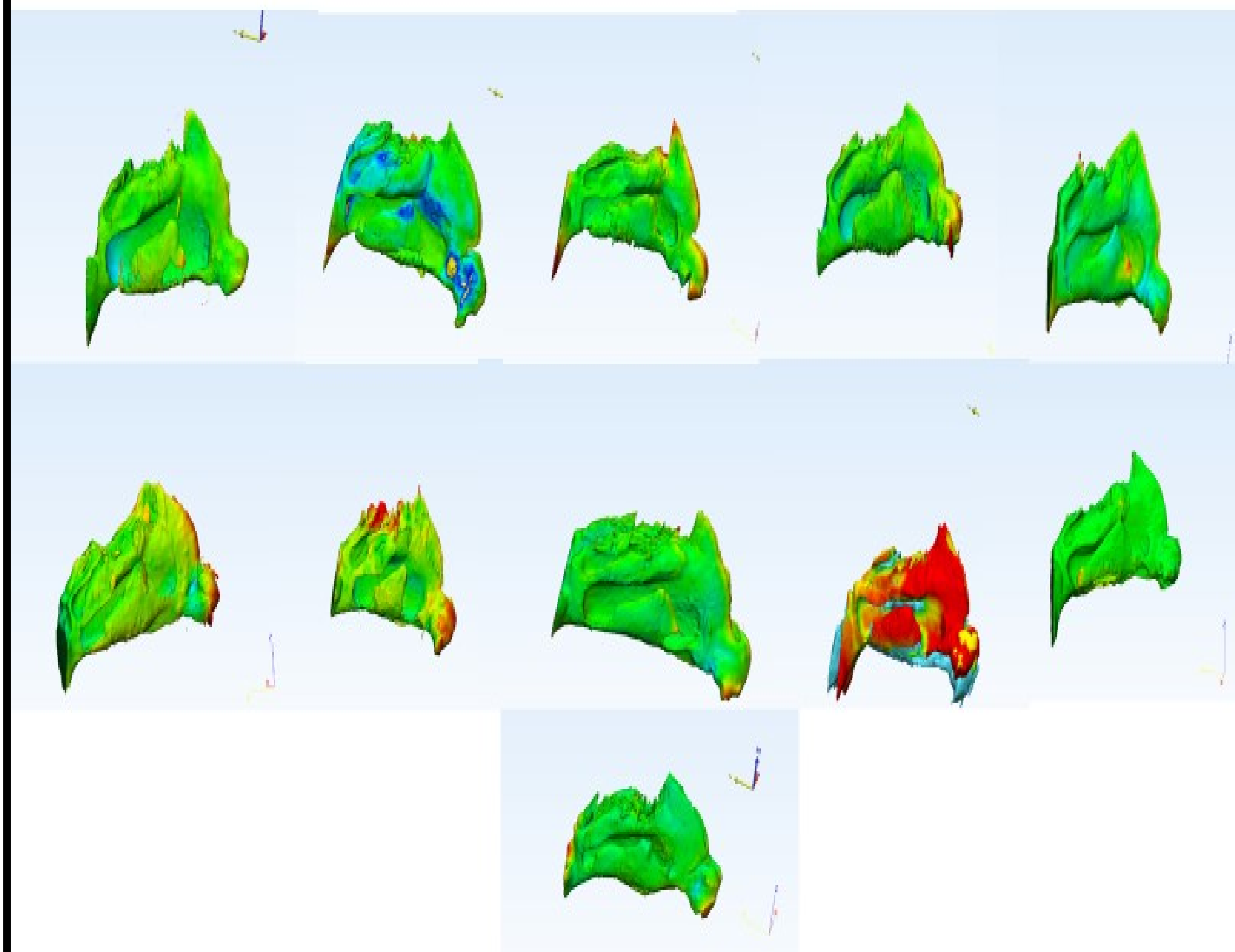

Figure3. 4: Part comparison analysis and color mapping of the comparison group

Chapter 4: Discussion

Skeletal and dental effects of slow maxillary expansion using quad-helix have been investigated by many studies. The investigation materials in the majority of these studies were dental casts or 2D imaging.[33–36,44] One study used 3D imaging to measure dentoalveolar changes after quad-helix.[16] CBCT enables practitioners to measure landmarks with greater accuracy.[63]

Skeletal and Dental Outcomes

The greatest transverse dental expansion observed in the Wilson quad-helix group was mostly seen in the posterior region of the maxilla at the level of the upper first molars pulp chambers and roots. The increased posterior dental expansion in comparison to anterior expansion may be due to the fact that Wilson quad-helix appliance is attached to the upper first molars bands through palatal tubes while the anterior part of the quad-helix appliance wire only touches the teeth in the anterior region in a one-point contact which can tip these only with lighter forces. In addition, quad-helix allows the clinician to choose where to expand more either anteriorly or posteriorly depending on the need by choosing which helix is opened.

Shundo et al.[45] used dental casts and cephalograms to evaluate the effects of quad-helix treatment. The authors reported that maxillary inter-molar width increased by 3.32 mm, which is similar to our results.[45] However, Corbridge et al.[16] who used CBCT in their study documented an increase in the maxillary inter molar width of up to 6 mm. The method of analysis was different between Corbridge et al. study and the present study. Corbridge et al. study measured linear distances on the CBCT slices while in our study the three cartesian coordinate landmarks system was used. The sample also was different and the mean age at T1 was 2 years younger in Corbridge et al. study. The authors found a slight increase in the alveolar width (0.5 mm) which positively correlated to the increase in intermolar width.[16] However, our study did not identify significant alveolar expansion in the Wilson quad-helix group.

A previous meta-analysis conducted to assess and compare the effectiveness of SME and RME reported that the mean difference of maxillary inter-molar width between the time before treatment and after retention for SME using quad-helix was 2.4 mm which is less than the findings of this study. However, the studies that were included in the meta-analysis used dental models and cephalograms.[64]

The amount of crown expansion from the Wilson quad-helix was approximately the same as the root expansion of the maxillary first molars which could be interpreted as bodily movement of the teeth. This result is inconsistent with the findings of Erdinc et al.[35] who reported buccal tipping after quad-helix treatment. Boysen et al.,[33] on the other hand, reported buccal translation movement of the upper first molars resulting from the quad-helix treatment which was similar to the finding in the present study. Buccal tipping reported in Erdinc et al. study might be due to the rate of appliance activation which was every month, whereas in the present study the appliance was activated every two months which allowed time for the torque effect on the buccal roots of the upper first molars. However, In Erdinc et al. study, the time frame (0.6 year) and the T1 age (9.7 years on average) were different from those in our study. Erdinc used stain steel wire placed in the right and left upper first molars tubes to determine upper first molars inclination during analysis of posteroanterior cephalograms. This is different from the method used in the present study where the distances between the root apexes and pulp chambers landmarks from CBCT images were measured and amount of crown and apical change was then compared. In the present study the amount of crown expansion and apical expansion at the upper first molars was about the same suggesting translation movement. However, the present study investigated only 2 time points (before appliance insertion and after the retention period). Therefore, it is not clear if the movement was tipping and then translation or the whole movement was translation.

Luebbert et al. assessed the dental and skeletal effects of RME through CBCT, used the same software (AVIZO) that was used in the present study, and utilized similar landmarks.[59] Their study compared two samples for different populations with different activation protocols and retention periods. The first sample was from University of Alberta and the second sample was from the University of Al-Azhar. The daily expansion of the University of Alberta sample (Edmonton, Alberta, Canada population) was 0.5 mm and the Hyrax appliance was left passive for a retention period of six months. In comparison, the daily expansion of the University of Al-Azhar sample (Cairo, Egypt population) was 0.8 mm and the retention period was three months. The age range of the patients of the groups in Luebbert et al study was 11 to 17 years.

Luebbert et al study reported that the transverse expansion occurring at the level of the pulp chamber of the upper first molars was 4.3 mm for the first sample and 3.7 mm for the second sample. These results are similar to the results in the present study. However, the amount of crown expansion of the upper first molars obtained from using RME in Alberta and Al-Azhar samples in Luebbert et al study was greater than the apical expansion, thereby suggesting tipping movement. This is different than the present study results where the crown and apical expansion were approximately equal for the upper first molars. This could be due to the fact that the Wilson quad-helix appliance allows the clinicians to apply buccal root torque at any time to correct for any upper first molars tipping due to the expansion force alone.

The expansion of the alveolar bone at the level of the root apexes of the mesiobuccal roots of the upper first molars resulting from RME treatment in Luebbert et al. study and from the Wilson quad-helix in the present study was similarly small (0.7 mm). Both the Luebbert et al. (RME) and the present study (SME) did not identify significant alveolar changes. Based on this finding since the alveolus did not expand, the bone could be thinner and may in fact have root apex perforation. However, we did not measure the buccal bone thickness to confirm this. It is recommended in future study to mesure the buccal bone thickness (the distance between the buccal alveolar bone and the tooth root). Some researchers [16]may suggest that with dental expansion there is compensatory subperiosteal bone apposition to maintain bone thickness. This might be not the case in this study and may have long term implications.

Based on the results of the present study, the overall amount of dental expansion was greater in the Wilson group than the comparison group. Our study showed statistically significant increase in the distance between the right and left greater palatine foramina within the Wilson group. The skeletal expansion at the greater palatine foramen area was smaller than dental expansion between upper first molars (ratio about 1:3). however, the skeletal expansion at the greater palatine foramen area was not statistically significance between groups. These results are in agreement with Vizzotto et al[65] study which reported smaller skeletal outcomes than dental outcomes with quad-helix treatment (ratio1:10).[65] Vizzotto et al investigated how much mid palatal suture was opened using occlusal radiographs which was different analysis method from our study. Sandikcioglu et al.[36] concluded that equal skeletal and dental effects were observed after quad-helix treatment, and Corbridge et al.[16] found that 50% of overall expansion resulted from dental movements.[16] The percentage of skeletal changes observed in our study related to dental changes is more than the percentages reported by Vizzotto et al.[65] and Frank et al.[66] (1:10 and 1:6, respectively) and closer to the percentages reported by Sandikcioglu et al.[36] and Corbridge et al.[16] (1:2).

Nasal Airway Changes

Mimics software was used to manually segment the nasal airway from the CBCT sets in the present study. Manual segmentation is the standard approach in the segmentation of the nasal airway from CBCT. To manually segment the airway, the operator needs to trace the boundaries of the entire region of interest. Although manual segmentation is time-consuming (2 to 3.5 hours to precisely segment one nasal airway from one CBCT image) due to the complex anatomy of the nasal airway, it is considered accurate providing 3D rendering of the nasal airway.[15] Two studies used manual segmentation to test the validity of their new introduced softwares.[15,67]

It has been shown that the upper airway volume can change depending on the stage of breathing.[68–70] The nasal airway also can be affected with many factors that can change the nasal airway volume .The nasal cycle is complex and changes during the day. Allergy and inflammation also can impact the nasal airway size. This was also appeared in our study where the standard deviation was large. Two cases in the

Wilson group and two cases in the comparison group had negative nasal cavity volume differences which in fact means that the nasal airway volume decreased.

In addition, nasal volume and nasal surface area are non-specific parameters and do not show the location and distribution of the change. Therefore, part comparison analysis (point-based analysis) was used in this study in addition to nasal volume and surface area. Part comparison analysis was used in a previous study to test the reliability and validity of semi-automatic segmentation of pharyngeal and nasal airways.[15] Cevidanes et al. [71,72] used a similar analysis method to evaluate 3D surface growth in the craniofacial area.

Although there was no statistically significant difference in the three nasal airway parameters between the Wilson group and the comparison group. The colour mapping showed more red areas (differences of 5 mm or more) in the Wilson group than in the comparison group (Figure 3.2). In the comparison group, only one 3D model appeared with red generalized areas (Figure 3.3). In this particular 3D model, the mucosal thickening was evident in the patient's nasal cavity which might affect the segmentation. Despite the fact that theses red areas were more in the Wilson group cases, it is not confirmed that these differences resulted because of Wilson quad-helix treatment since most red areas appear in the superior part of the nasal cavity and the anterior part. These changes could be due to the segmentation error because it has been shown that these two areas are difficult to segment first because of complexity of the anatomy at the superior nasal meatus and the operator might unintentionally included some of the ethmoid cells especially with the fact lacking cutting plane. Anterior area of the nasal cavity is also challenging area for segmentation because of low resolution in this area. It is recommended for future study having cutting plane to correctly exclude the superior nasal meatus.

In the present study, voxel size of the CBCT images of the study groups was different. Vieira[73] investigated the influence of different voxel sizes on accuracy of measurements on CBCT images and reported no difference .Venskutonis et al.[74] also explored the influence of voxel size on the diagnostic ability of CBCT to evaluate simulated root perforations and the study reported no difference between voxel sizes 0.3 and 0.4 mm which were the same voxel sizes used in this study.

Limitations

In this retrospective study, we aimed to have a control group to factor out changes due to normal growth. However, due to ethical issues, it was not possible to obtain a group without treatment having two-time frames of CBCT. Therefore, while the comparison group in this study did not have maxillary expansion appliances, it did have class II elastic and fixed orthodontic therapy. It is possible that there was expansion from the arch wires. Furthermore, the small sample size of the study may affect the ability to detect a statistically significant difference in the nasal airway outcome due to the variability. The variability and standard deviation are high in most variables. In addition, some confounding factors that might affect changes on the nasal airways were not controlled, for example, not standardizing time of day and for season of year as well as of not using steroid nasal spray prior to imaging.

Conclusion

1- Maxillary inter-molar and inter-premolar widths increased as a result of the treatment using Wilson quad-helix.

2- Buccal translation movement of the upper first molars was observed after the Wilson quad-helix treatment.

3- There was no significant transverse alveolar maxillary expansion with Wilson quad-helix treatment.

4- There was no significant difference in nasal airway volume or surface area between the Wilson group and the comparison group.

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Appendix

Figure 1: Pulp chamber of upper first molar (Center of the largest cross-sectional area)

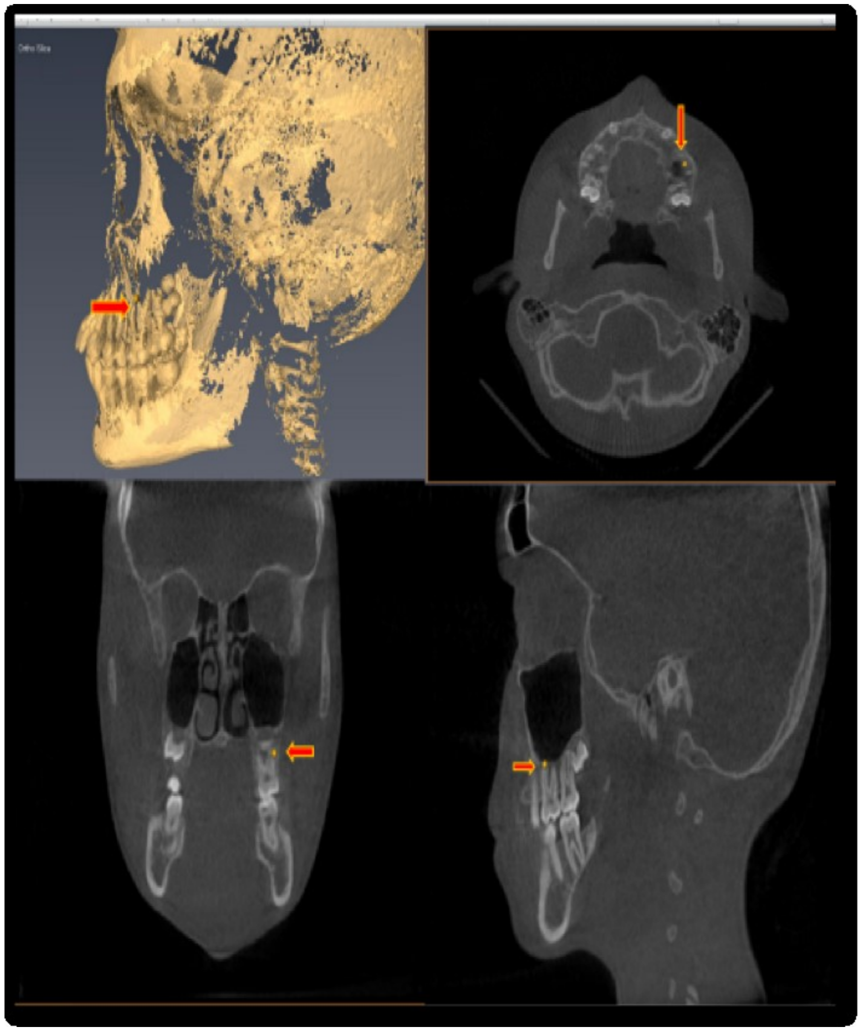

Figure 2: Mesiobuccal root apex of upper first molar

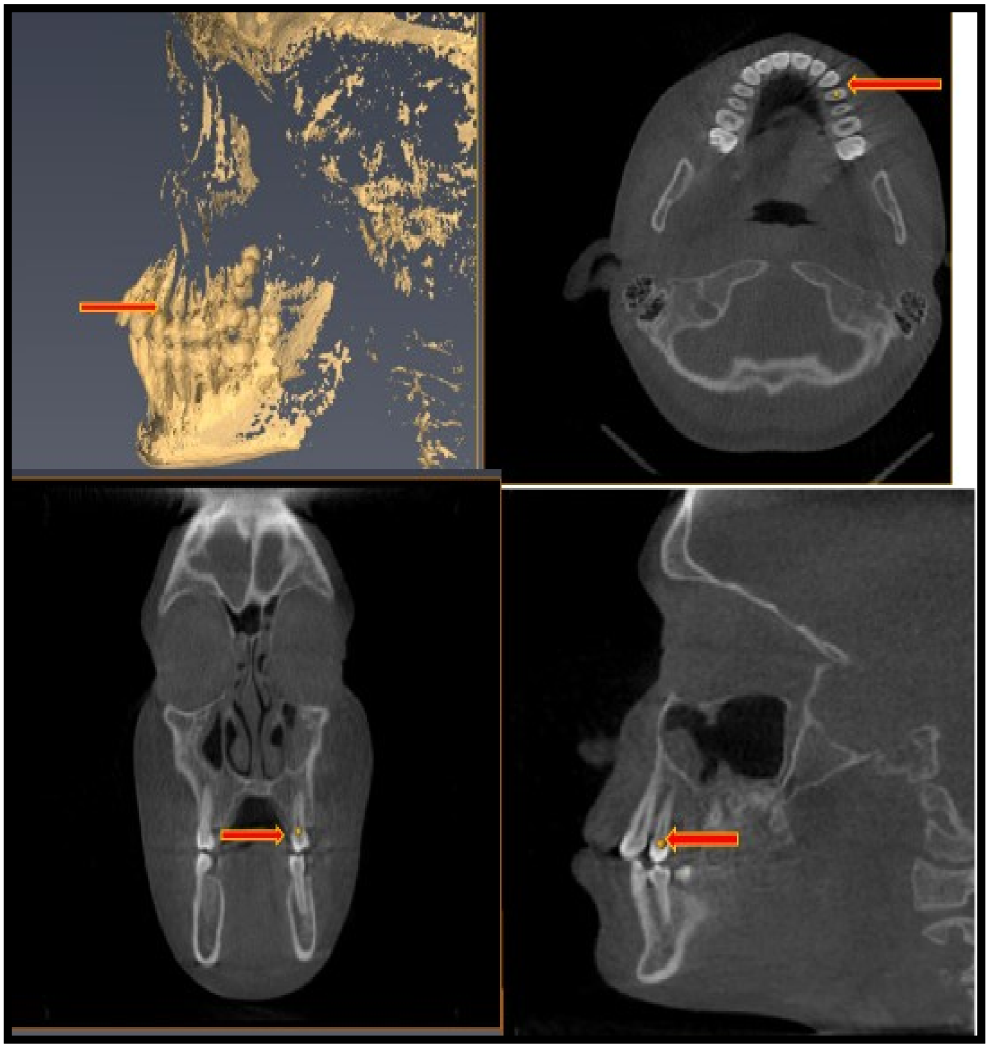

Figure 3: Pulp chamber of upper first premolar.

Figure 4:Buccal root apex of upper first premolar

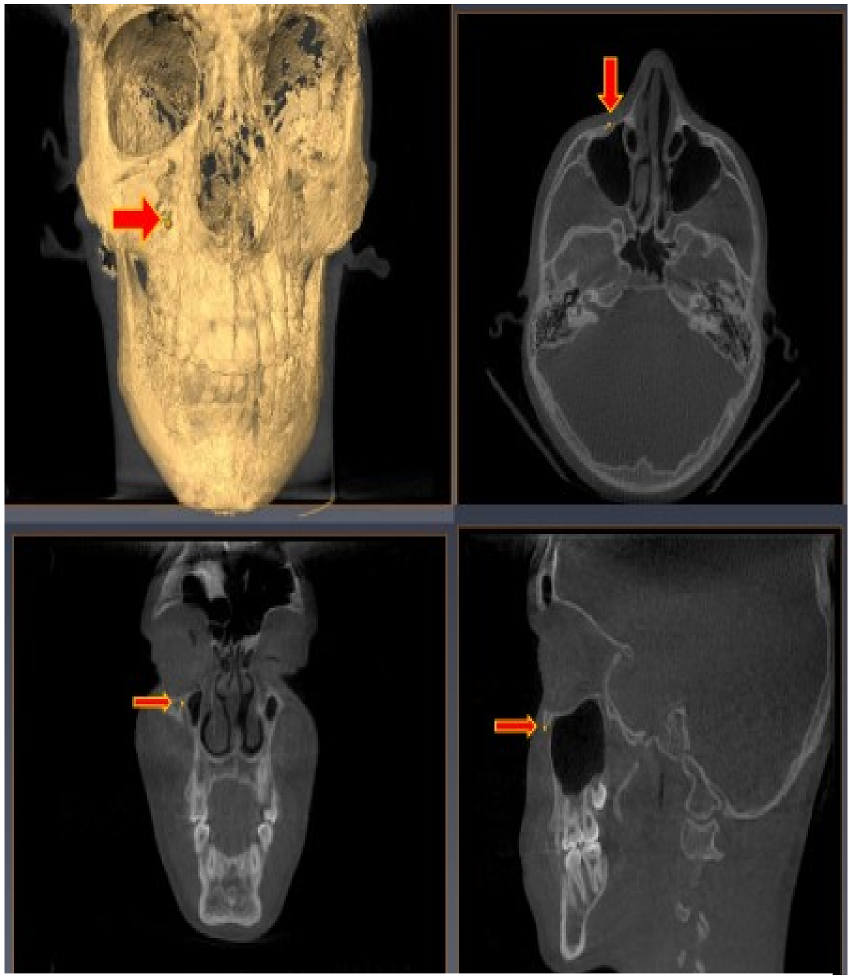

Figure 5: Infra orbital foramen

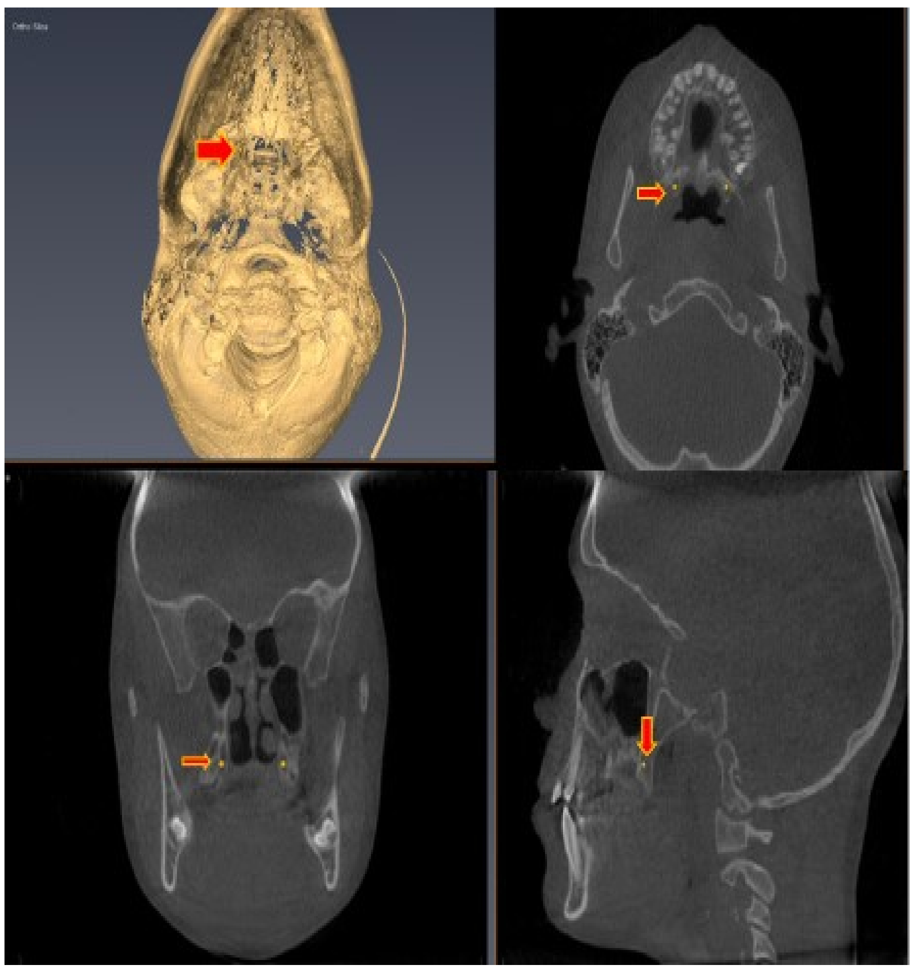

Figure 6: Greater palatine foramen (**Center of the smallest sectional area with complete defined borders)**