THE ANTEROPOSTERIOR EFFECT OF RAPID MAXILLARY EXPANSION USING BONE-BORNE VERSUS TOOTH-BORNE EXPANDER: A COMPARATIVE STUDY

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ABSTRACT

The anteroposterior effect of rapid maxillary expansion using bone-borne VERSUS tooth-borne expander: A comparative study

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Background: In orthodontics, slow, rapid, and surgically assisted maxillary expansions are commonly performed to correct maxillary constriction, posterior crossbite, and crowding. Ideally, this treatment approach is recommended in growing (i.e., pediatric and adolescent) patients, as it requires a mid-palatal suture that is not fully fused. There is limited understanding on the relative efficacy of bone- and tooth-borne expanders for maxillary expansion.

Aim: To assess and compare dentoskeletal changes in maxilla and mandible after RME using bone- and tooth-borne expanders in adolescent patients.

Materials and Methods: This study compares 18 subjects (10 females and 8 males, with an average age of 14.4±1.3 years) who received tooth-borne RME; and 18 subjects (12 females and 6 males, with an average age of 14.7±1.4 years) who received bone-borne RME. Specific three-dimensional landmarks were used in order to compare skeletal and dental changes in tooth-borne and bone-borne expanders. Data was analyzed using Shapiro-Wilk, Paired t, Wilcoxon, and Mann-Whitney tests, in addition to Pearson correlation. A P-value of less than 0.05 was considered significant in all statistical analyses.

Results: In the tooth-borne group the following parameters showed a significant difference after expansion ($P<0.05$): molar width, intermolar width, molar buccal tipping in the transverse plane, and Pog-FH in the vertical plane. In the bone-borne group, a significant difference after expansion ($P<0.05$) was recorded for the following parameters: linear intermolar relation, palatal bone width, intermolar width, and interpremolar width. Comparison of the post-expansion results of both groups revealed that the bone-borne group exhibited less molar buccal tipping.

Conclusion: There was significant transverse change reported after expansion in both the bone-borne and tooth-borne groups, with less significant of dental tipping in the former. Nevertheless, both groups displayed limited sagittal and vertical changes when correlated to the transverse changes.

DEDICATION

I dedicate my dissertation to my family and friends. A special feeling of gratitude to my loving parents, May AlBloushi and Qais AlNashmi, for their words of encouragement and motivation. My sisters Nashami and Aisha and my brother Hamad, who have never left my side, pushing me to my absolute best and always being there for me whenever I needed them. A special dedication to my aunt, Ghanema AlBloushi, who has been a source of constant support and joy in my life. I also dedicate this dissertation to my friends who have supported me throughout this journey. I will always appreciate all that they have done, especially Hashem AlAwadhi, Yousif AlAbdullah, and Mohammed Bohindi.

DECLARATION

I declare that all the content of this thesis is my own work. There is no conflict of interest with any other entity or organization

Name: Nashmi AlNashmi

Signature

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1. INTRODUCTION

1.1. History of maxillary expansion

Maxillary expansion is a therapy done to correct maxillary constriction, posterior cross-bite, crowding, and jaw misalignment. This treatment approach is recommended in growing (pre-adult) patients, because it requires a mid-palatal suture that is not fully fused (1, 2). Maxillary expansion was first noted in 1859 by a dental practitioner known as Westcott, who reported applying mechanical forces to the upper jaw, and the following year the first paper on dental expansion was written by Emerson C. Angeli in *Dental Cosmos*, which prompted the first reported case. In 1877, Walter Coffin developed a “Coffin spring” to expand the upper arch, but the procedure received strong opposition in 1889 from McQuillen, the then President of the American Dental Association (3).

The idea was later revitalized by Goddard in 1890 and Landsberger in 1910 (3). Goddard made a significant contribution by standardizing the expansion protocol, stating that adjusting the expander two times a day for three weeks for effective arch expansion was necessary. Dr. Andrew J. (4) reintroduced Haas expander in the US, which was subsequently utilized extensively as an expansion device (1). Additionally, (4) described the lowering of the mandible with bite opening, and his accomplishments included increasing the arch perimeter and expanding the nasal width using expansion procedures.

In 1968 Biederman introduced the hyrax expander, which was used to expand the tooth bone, and in 1973 Silverman and Cohen introduced the bonded type of expander. From its initial description in the 19^{th} century to the pioneering research by (4), rapid maxillary expansion continues to seek to optimally correct the narrowness of the maxillary arch relative to its significant effect on the bone structure supporting the head and face (3, 5).

1.2. Types of dental expansions

Three common types of maxillary expansions have been widely utilized over the years, which include slow maxillary expansion, rapid maxillary expansion, and surgically assisted maxillary expansion (6-8).

1.2.1. Rapid maxillary expansion (RME)

Rapid maxillary expansion (RME) uses heavy forces which are transferred to the sutures when applied, in the context of there being insufficient time for tooth movement. The magnitude of the forces needed to separate the mid palatal sutures is different from that required to move the tooth; the sutures consequently open while the teeth move only minimally. This procedure compresses the periodontal ligaments, bends the alveolar bone, tips the anchored teeth, and opens the mid-palatal suture (1). The theoretical principle behind the differential force application is the disarticulation of the circum-maxillary suture, with a resultant orthopedic expansion before the teeth respond (7).

Various clinical considerations and indications exist for RME. The optimum therapy window for expansion treatment is believed to be around 10-14 years of age. When the procedure is carried out in older patients, the amount of expansion is limited, and its overall stability is decreased (9). Maxillary expansion can be used to provide relief from crowding (10), and to treat patients with palatal impacted canines (11). Moreover, in Class III malocclusions in growing patients, it can be used in conjunction with appliances for maxillary protraction to disarticulate the circum-maxillary sutures, using an element of anterior maxilla displacement. The latter is caused by the pivoting impact of the pterygoid plates during the separation of the palatal and correction of associated crossbite (12). Furthermore, the procedure can help improve the nasal airflow in patients with nasal obstruction (7). Patients of optimum age who report to dental clinics with 4-6 mm bilateral or unilateral posterior crossbite are prime candidates for RME (9).

RME appliances can either be tooth-borne, such as Isaacson and Biederman/Hyrax appliances; tooth-tissue-borne, like Derichsweiler and Haas appliances (10) or the bone-borne anchored appliances, such as the Miniscrew assisted rapid palatal expansion (13), and Dresden distractor (14). The Haas design has a palatal plate, connecting bars, and an expansion crew. The connecting bars can be soldered to every band pair's palatal and buccal surfaces, or be embedded in a capping component (10). Studies have suggested that the palatal plate enables the appliance to be tooth-tissue-borne with numerous parallel expansion forces exerted on the alveolar component (15-17).

Derichsweller appliances, unlike Haas, have no buccal connectors. The Hyrax appliance is a tooth-borne rapid maxillary expander that consists of an expansion screw that is welded to the cemented bands of the abutment teeth. The design keeps it clean compared to other appliances. The Isaacson design resembles a Hyrax expander, but its expansion screw is replaced with a coil spring, which can be compressed through nut turning. One of its main limitations is an accumulation of kinetic energy in the spring, leading to continuous expansion forces that may continue even during the passive phase (18).

The limitations of tooth-borne RME include limited skeletal movement, unwanted tooth movement, tipping of the tooth, root resorption, dehiscence, and relapse (19, 20). To address these limitations, bonded rapid maxillary appliances have been created as an alternative. For maximum anchorage, minicrews have been incorporated in the palate, providing skeletal rather than dental movement, leading towards more physiological sutural expansion, used with capping limited to the occlusal surface, resulting in minimal tipping of the abutment teeth (18). Bone-borne expanders can overcome the drawbacks associated with the tooth-borne RPE, including periodontal damage and tipping of the anchor teeth (21, 22). Hybrid hyrax is bonded using an occlusal cap to the abutment teeth and anchored by an anchorage device. The device reduces the anchor tipping while enhancing the tooth-borne and orthopedic appliances (23).

1.2.2. Slow maxillary expansion (SME)

Slow maxillary expansion (SME) procedures are known to produce minimal tissue resistance around the circum-maxillary structures. As a result, they improve the formation of bone in the intermaxillary suture, leading to improved post-expansion stability, given a sufficient retention period (18). The maxillary slow expansion encompasses the delivery of a constant physiological force until the desired maxillary expansion is obtained (1). This mode of force delivery could be one of the reasons that SME might overcome some of the limitations of RME mentioned in the literature (24). In SME, the recommended force (pressure) is around 10-20 Newtons ($kg \cdot m/s^2$), which might be insufficient to allow for the separation of the progressively mature suture (8, 9, 15, 25).

There are various appliances in SME. The Coffin appliance can achieve slow dentoalveolar expansion, and consists of an omega-shaped wire of 1.25 mm thickness, positioned in the mid-palatal area, with its free ends engaged in acrylic covering the plate slopes. The Coffin spring is activated manually, pulling the two sides apart (26). SME could also be achieved using the forces of repulsive magnets; the main limitation of this method is that the magnets tend to be oxidized in the oral environment, due to the potential formation of corrosive materials and compounds in the mouth (27). Moreover, the magnets used for expansion tend to be very bulky and thus uncomfortable for patients. On the other hand, the main advantage of magnets is that their effect exerts a continuous force over a duration of time, thus reducing the likelihood of external root resorption (1).

W-arch is another appliance that was historically used to treat cleft palate patients (28). The W-arch is a fixed appliance made using 0.9 millimeters of steel wire soldered to the molar bands. The appliance is activated by opening the apices of the W-arch. It is easily adjusted to allow more anterior than posterior expansion or vice-versa, depending on the effect desired. It delivers proper levels of force when it is opened 3-4 mm wider than the passive molar width.

It is recommended that the expansion should continue at the rate of 2 mm every month, until a slight overcorrection of the crossbite is achieved (1, 28).

The Quad-helix is another SME appliance which is a modification of the Coffin W-spring. Four helixes are incorporated into the W-spring to help increase the range of activation and flexibility. The length of the appliance's palatal arms can be adjusted based on the teeth in crossbite (29). Recent prefabricated appliances have been constructed from nickel, invented by Wendell (30). The resultant effect of using nickel is to produce more physiologic tooth movement with an enhanced and faster correction of crossbites. This quad-helix appliance works by combining skeletal expansion and buccal tipping at a ratio of 1:6 in prepubertal children. When the appliance is activated by 8 mm (equivalent to around one molar width), a desirable force level of 400 g is produced.

The recommended period of patient review using the appliance is 6 weeks. Its chief advantages are good retention, differential expansion, compliance, cost-effectiveness, incorporation of fixed appliances, and habit breaking (29). Studies indicate that 350 g of force are exerted by a 3 mm expansion increment in the appliance. The alloy component allows for relatively uniform force levels as the deactivation of the expander occurs (31).

1.2.3. Surgically assisted maxillary expansion techniques

The surgical techniques available for maxillary expansion can overcome the limitations of age, including segmental maxillary surgery and surgically assisted rapid palatal expansion, which has become a popular option for correcting a maxillary transverse deficiency in adults (32). The orthopedic treatment involves moving the maxillary central incisors apart to improve surgical access to the site where osteotomy will be carried out. This is a procedure of choice in patients requiring expansion. It is also appropriate in patients with co-existing vertical and sagittal maxillary discrepancies of both (1).

1.3. Dental and skeletal effects of maxillary expansion

Various studies reported the effects of dental and skeletal expansion on patients (3, 4, 33-35). RME leads to an increase in all arch dimensions in different planes, as well as increases in the intermolar width (2). It also affects the frontonasal, fronto-maxillary, maxillonasal, internasal, and intermaxillary sutures (36), and has an effect on the sagittal occlusal relationship in patients with early mixed dentition. Improvements in molar relation have been reported among various patient types, including 49% in class II patients, 29% in end-to-end patients, and 23% in class I patients (37, 38). It also causes an increase in nasopharynx and nasal cavity volume (2, 7).

1.4. Methods of assessing dental expansions

Various diagnostic tools can be used to assess maxillary expansion, including radiography (39, 40), dental cast analysis (35, 41), and clinical evaluations. Posteroanterior cephalograms are considered one of the best modalities to evaluate the impact of maxillary expansion on the posterior skeletal structures (42), but the two-dimensional imaging of skeletal structures is highly limiting (43). 3D imaging is becoming a feasible diagnostic modality that can be utilized to assess maxillary expansions, such as cone-beam computed tomography (CBCT) (44, 45). This medical imaging technique consists of X-ray computed tomography, whereby divergent x-rays form a cone.

Evaluation of the palate area after and before RME using a cone-beam computed tomography confirmed that the imaging study allowed minimal distortion, greater resolution, low radiation dose, and real size (46). The imaging allowed for visualization of the surface area of the palate, and depicted an increased intermolar width. Novel angular measurement can also be used in the assessment of dental expansion. The angular measurement from certain arbitrary points can be used. Angular measurement is more accurate if a true fulcrum can be located. In maxillary expansion assessment, angular measurement can be used to calculate the fulcrum locations and then apply novel angular measurement systems (47).

2. AIM

The aim of this study is to assess and compare the dentoskeletal changes in maxilla and mandible after RME using bone- and tooth-borne expanders in adolescent patients (aged 11-15 years).

3. MATERIALS AND METHODS

3.1. Overview

3.1.1. Ethics

The research data were obtained from the Faculty of Medicine and Dentistry, University of Alberta, Edmonton, Canada. The data was used retrospectively, and had published previously under the ethical approval and supervision of the Health Research Ethics Board, University of Alberta (Pro#13379). The same data used in this study thus required no further ethical approval from the MBRU-IRB Committee.

3.1.2. Participant inclusion criteria

- Patients aged between 11 and 15 years old.
- No orthodontic treatment.
- No temporomandibular joint issues.
- No complaints of adenoid and tonsil issues.
- No signs of caries.
- Healthy periodontium.
- Systemic disease-free.
- Normal craniofacial configuration.

Initially, 40 subjects (20 subjects in the BB and 20 subjects in the TB expansion groups) were included in the study; however, three subjects (one in the BB and two in the TB group) were excluded due to motion artifacts in the CBCT images. In addition, one subject was excluded from the BB group, due to showing excessive opacification of the maxillary sinuses and nasal cavity in the T2 CBCT image. As a result, 18 subjects (10 females: eight males; average age: 14.4±1.3 years) who received TB RME, and 18 subjects (12 females: six males; average age: 14.7±1.4 years) who received BB RME were included in the final analyses.

3.1.3. Intervention

Two types of expanders were used in the study, tooth-borne (TB) and bone-borne (BB) RME. Patients (n = 36) were equally and randomly allocated to the TB (n = 18) or BB (n = 18) groups.

The randomization resulted in the establishment of two groups of patients with no significant differences in their initial conditions. Bilateral maxillary crossbite was the main characteristic feature in all the patients involved, and bone-anchored RME and tooth anchored RME were delivered to them as part of the comprehensive treatment. Hyrax appliance was used for the TB expander, where the bands were placed on the first molars and first premolars. If the first premolars were not yet erupted, then the band was placed on the deciduous molars.

Expansion with miniscrews was used for the BB RME group, two miniscrews (length: 12 mm; diameter: 1.5 mm; Straumann GBR System, Andover, MA) were placed in the palate area right and left between the permanent first molar and second premolar and were connected between each other by jackscrew. Both TB and BB groups have the same activation rate of the jackscrew which is (0.25 mm/turn), both groups were asked to do 2 turns per day (equal to 0.5 mm/day). Patients kept activating until the mesiopalatal cusps of the maxillary first molar got in contact with the buccal cusp of the mandibular first molar.

Two low-dose CBCTs were undertaken for the subjects: the first one before the expansion (T1) and the second one after a 3-months-retention period (T2). All patients were scanned with the iCAT CBCT Unit (Imaging Sciences International, Hartfield, PA) and the same setting protocol: 0.3 voxels, 8.9 seconds, large field of view at 120 kV and 20 mA.

Dolphin Imaging Software, version 11.0 (Dolphin Imaging, Chatsworth, CA), was used for image analyses. Analysis was performed using the same computer monitor and light settings (24-in. monitor; Dell, Round Rock, TX; 1920 3 1200 pixels).

To confirm the accuracy of the position of the landmarks, the reseacher undertook a radiology course to facilitate the reading and positioning the landmarks. Later on, an intra reliability test was performed. Additionally, the researcher (N.N.) traced and analyzed 10 randomly selected images. The primary researcher (N.N.) repeated the same tracing and analysis after 3 weeks to determine the intra reliability of the different anatomical landmarks. Intra-examiner reliability (ICC) for all landmarks was greater than 0.99, with an average 95% CI of 1.00. Mean measurement differences obtained from the principal researcher's trials in all angular parameter's measurements were less than 0.7 degrees and 0.53 mm for all linear parameter's measurements. All CBCT images were adjusted and oriented based on the skeletal midline in the front view, with Frankfort representing the horizontal line, and a line passing through the deepest point of the key ridge, representing the vertical line in the sagittal view. The 3D linear and angular landmarks for analysis shown in Table 1 were selected to achieve the study aim.

Table 1: 3D linear and angular landmarks for analysis

Code	Definition
1. IMW	Intermolar width "Line connecting the centroid of the upper right first molar and upper left first molar" (axial view) (Fig. 1)
2. IPW	Interpremolar width "Line connecting the centroid of the upper right first premolar and upper left first premolar" (axial view) (Fig. 2)
3. MA	Molar angulation "Angle formed between a line from the mesiobuccal cusp of the upper first molar to the palatal root of the first molar and a line from the palatal root of the first molar to the Frankfort horizontal line" (coronal view) (Fig. 3)
4. ABA	Alveolar bone angulation "Angle formed from the buccal bone of the molar to the A' and A' to Z" (coronal view) (Fig. 3)
5. MW	Molar width "Distance between the cemento-enamel junction of the upper first right molar to the cemento-enamel junction of the upper first left molar" (coronal view) (Fig. 4)
6. BW	Buccal width "Distance between the A' point on the right side to the A' point on the left side" (coronal view) (Fig. 4)
7. MR	Molar relation "Line between the upper mesiobuccal cusp of the first molar to the mesiobuccal cusp of the lower first molar" (sagittal view) (Fig. 5)
8. OJ	Overjet "distance from the most prominent point on the incisal edge of the upper central incisors to the labial surface of the lower central incisors" (sagittal view) (Fig. 6)
9. OB	Overbite "distance from the most prominent point on the incisal edge of the upper central incisors to the most prominent point of the incisal edge of the lower central incisors" (sagittal view) (Fig. 7)
10. SNA	"Angle between Sella-Nasion and Nasion-A point" (sagittal view) (Fig. 8)
11. SNB	"Angle between Sella-Nasion and Nasion-B point" (sagittal view) (Fig. 9)
12. ANB	"Angle formed between A point-Nasion and Nasion to B point" (sagittal view) (Fig. 10)
13. ANS-PNS	"Line connecting the Anterior nasal spine to Posterior nasal spine" (sagittal view) (Fig. 11)
14. ANS-V	"Line from the ANS to the Vertical plane" (sagittal view) (Fig. 12)
15. ANS-FH	"Line from the ANS to the Frankfort horizontal plane" (sagittal view) (Fig. 13)
16. Pog-V	"Line from the Pogonion point to the Vertical plane A" (sagittal view) (Fig. 12)
17. Pog-FH	"Line from the Pogonion point to the Frankfort horizontal plane" (sagittal view) (Fig. 13)

A': mid zygomatic the deepest point

Z': base of the zygomatic point

3.2. Outcomes measured

Outcomes measures were divided into skeletal and dental changes, both of which were measured using linear and angular measurements in the transverse, sagittal, and vertical planes.

3.2.1. Transverse measurements

To measure the effect of expansion, the skeletal and dental transverse changes were measured linearly and angularly. For the skeletal measurements, the transverse width of the palate was measured in terms of molar width (MW) (Table 1, Fig. 4), which is the line between the cemento-enamel junction of the upper first right molar to the cemento-enamel junction of the upper first left molar.

Buccal width (BW) (Fig. 4) was measured as the distance between the A’ point on the right side to the A’ point on the left side.

Alveolar bone angulation is measured as the angle formed from the buccal bone of the molar to the A’ and from A’ to Z’ on both sides (ABA) (Fig. 3).

For the dental transverse changes, inter-molar width (IMW) and inter-premolar (IPW) (Fig. 1, Fig. 2) width change were measured by the intermolar width line connecting the centroid of the upper right first molar and upper left first molar.

The interpremolar width line connects the centroid of the upper right first premolar and upper left first premolar.

Furthermore, molar angulation (MA) (Fig. 3), was measured from the angle formed between two lines; one from the mesiobuccal cusp of the upper first molar to the palatal root of the first molar, and the other from the palatal root of the first molar to the Frankfort horizontal line.

3.2.2. Sagittal measurements

Several points were considered to assess the skeletal and dental changes in the maxilla and mandible. Skeletal changes were measured with the following linear measurements:

- ANS-PNS: the line connecting the anterior to the posterior nasal spine (Fig. 11).
- ANS-vertical: the line from the ANS to the vertical plane (Fig. 12).

- Pogonion vertical (Pog-V): the line from the Pogonion point to the vertical plane (Fig. 12).

The angular measurements were as follows:

- SNA: the angle between Sella-Nasion and Nasion-A point (Fig. 8).
- SNB: the angle between Sella-Nasion and Nasion-B point (Fig. 9).
- ANB: the angle formed between A point-Nasion and Nasion to B point (Fig. 10).

For the dental changes, the linear measurements were:

Molar relation (MR): the line between the upper mesiobuccal cusp of the first molar to the mesiobuccal cusp of the lower first molar (Fig. 5).

Overjet (OJ): the distance from the most prominent point on the incisal edge of the upper central incisors to the labial surface of the lower central incisors (Fig. 6).

3.2.3. Vertical measurements

For the vertical dimension, a point from ANS to the Frankfort horizontal plane (ANS-FH) (Fig. 13) and a point from Pogonion to Frankfort horizontal line (Pog-FH) (Fig. 13) were measured as linear skeletal points, while the OB (Fig. 7) is the distance from the most prominent point on the incisal edge of the upper central incisors to the most prominent point of the incisal edge of the lower central incisors; the latter was used as the point to measure linear dental vertical changes.

3.3. Statistical analysis

Data was entered into the computer using IBM-SPSS for Windows version 28.0 (SPSS Inc., Chicago, IL). Continuous variables were described by measure of tendency and measure of dispersion Shapiro-Wilk was used to test the normality of continuous variables. Pair-t-test was used to compare means between two dependent variables (intra-comparison); when variables were not normally distributed Wilcoxon was used. For normally distributed variables, *t*-test was used to compare between the two studied groups (TB and BB); if the data was not normal, Mann-Whitney test was used to compare the two groups' mean values. A P-value of less than

0.05 was considered significant in all statistical analyses. Pearson's correlation coefficient test was applied to study if there is a significant correlation between the transverse changes and any sagittal or vertical changes.

4. RESULTS

4.1. Descriptive statistics

Descriptive statistics for each parameter measure and the data distribution are reported in Tables 2-4. Pairwise comparison was done between the TB anchored and BB anchored expansion groups. Comparisons were made between the transverse, sagittal, and vertical planes, to assess any significant changes at the end of expansion, considering the angular and linear measurements. Table 2 displays the descriptive data of the mean and standard deviation (SD) values of all parameters recorded in T1 and T2 in the TB and BB groups.

Table 2: Descriptive data of the mean and SD of all parameters recorded in T1 and T2 in TB & BB groups

	TB		BB	
Items	**No.**	**Mean (SD)**	**No.**	**Mean (SD)**
Sagittal-Skeletal-Linear T1 ANS - PNSL	13	50.2 (2.8)	21	51.27 (3.11)
Sagittal-Skeletal-Linear T2 ANS - PNSL	13	50.25 (3.1)	19	51.26 (2.83)
Sagittal-Skeletal-Linear T1 ANS - VLIN	13	28.49 (4)	21	28.2 (3.68)
Sagittal-Skeletal-Linear T2 ANS -VLIN	13	28.02 (4)	19	28.06 (3.09)
Sagittal-Skeletal-Linear T1 Pog-VL	13	21.47 (6.28)	21	22.78 (5.9)
Sagittal-Skeletal-Linear T2 Pog-VL	13	20.85 (5.87)	19	22.72 (5.93)
Sagittal-Skeletal-Angular T1 SNA	13	79.6 (3.35)	21	81.21 (4)
Sagittal-Skeletal-Angular T2 SNA	13	80.03 (3.45)	19	80.98 (3.55)
Sagittal-Skeletal-Angular T1 SNB	13	77.05 (2.99)	21	78.80 (3.59)
Sagittal-Skeletal-Angular T2 SNB	13	77.09 (2.76)	19	78.74 (3.13)
Sagittal-Skeletal-Angular T1 ANB	13	2.62 (2.51)	21	1.79 (3.71)
Sagittal-Skeletal-Angular T2 ANB	13	2.94 (2.14)	19	2.3 (3.33)
Sagittal-Dental-Linear T1 MRR	13	3.1 (1.4)	21	4.21 (2.68)
Sagittal-Dental-Linear T2 MRR	13	3.31 (1.29)	19	4.29 (2.81)
Sagittal-Dental-Linear T1 MRL	13	3.26 (1.73)	21	3.81 (1.62)
Sagittal-Dental-Linear T2 MRL	13	3.76 (1.94)	19	3.75 (1.66)
Sagittal-Dental-Linear T1 OJ	13	2.66 (1.68)	21	2.44 (1.66)
Sagittal-Dental-Linear T2 OJ	13	2.58 (1.78)	19	2.23 (1.77)
Transverse-Skeletal-Linear T1 MW	13	28.92 (2.84)	21	60.64 (3.97)
Transverse-Skeletal-Linear T2 MW	13	32.79 (3.49)	19	62.43 (4.25)
Transverse-Skeletal-Linear T1 BW	13	60.22 (3.77)	21	30.17 (3.13)
Transverse-Skeletal-Linear T2 BW	13	61.1 (4.15)	19	34.21 (2.96)
Transverse-Skeletal-Angular T1 ABR	13	133.45 (7.56)	21	132.27 (10.45)
Transverse-Skeletal-Angular T2 ABR	13	132.37 (6.98)	19	128.21 (9.45)
Transverse-Skeletal-Angular T1 ABRL	13	132.93 (6.65)	21	134.86 (11.7)
Transverse-Skeletal-Angular T2 ABRL	13	131.88 (6.28)	19	129.49 (10.54)
Transverse-Dental-Linear T1 IMW	13	40.54 (2.72)	21	41.37 (2.41)
Transverse-Dental-Linear T2 IMW	13	45.59 (2.9)	19	45.51 (2.91)
Transverse-Dental-Linear T1 IPW	13	30.92 (2.07)	21	32.58 (2.97)
Transverse-Dental-Linear T2 IPW	13	35.62 (1.97)	19	34.64 (3.71)
Transverse-Dental-Angular T1 MAR	13	63.41 (4.93)	21	64.66 (6.37)
Transverse-Dental-Angular T2 MAR	13	60.42 (5.96)	19	61.4 (5.29)

Table 2: Descriptive data of the mean and SD of all parameters recorded in T1 and T2 in TB & BB groups

	TB		**BB**	
Items	**No.**	**Mean (SD)**	**No.**	**Mean (SD)**
Transverse-Dental-Angular T1 MAL	13	61.81 (3.78)	21	65.05 (5.31)
Transverse-Dental-Angular T2 MAR	13	59.06 (4.4)	19	61.04 (5.47)
Vertical-Skeletal-Linear T1 ANS-FH	13	19.11 (3.12	21	19.75 (2.46)
Vertical-Skeletal-Linear T2 ANS-FH	13	19.6 (2.9)	19	20.10 (2.11)
Vertical-Skeletal-Linear T1 Pog-FH	13	79.34 (5.29)	21	79.32 (5.03)
Vertical-Skeletal-Linear T2 Pog-FH	13	80.58 (5.35)	19	79.75 (5.39)
Vertical-Dental-Linear T1 OB	13	4.03 (1.69)	21	4 (1.94)
Vertical-Dental-Linear T2 OB	13	4.07 (1.44)	19	3.79 (2.06)

Table 3: Shapiro-Wilk normality testing for TB measurements

Items	Statistic	df	P-value
Sagittal-Skeletal-Linear T1 ANS-PNSL	0.968	13	0.863
Sagittal-Skeletal-Linear T2 ANS-PNSL	0.987	13	0.998
Sagittal-Skeletal-Linear T1 ANS-VLIN	0.938	13	0.426
Sagittal-Skeletal-Linear T2 ANS-VLIN	0.91	13	0.182
Sagittal-Skeletal-Linear T1 Pog-VL	0.962	13	0.791
Sagittal-Skeletal-Linear T2 Pog-VL	0.946	13	0.545
Sagittal-Skeletal-Angular T1 SNA	0.914	13	0.207
Sagittal-Skeletal-Angular T2 SNA	0.922	13	0.268
Sagittal-Skeletal-Angular T1 SNB	0.934	13	0.38
Sagittal-Skeletal-Angular T2 SNB	0.965	13	0.824
Sagittal-Skeletal-Angular T1 ANB	0.965	13	0.828
Sagittal-Skeletal-Angular T2 ANB	0.956	13	0.686
Sagittal-Dental-Linear T1 MRR	0.968	13	0.864
Sagittal-Dental-Linear T2 MRR	0.931	13	0.349
Sagittal-Dental-Linear T1 MRL	0.926	13	0.3
Sagittal-Dental-Linear T2 MRL	0.93	13	0.341
Sagittal-Dental-Linear T1 OJ	0.782	13	0.004
Sagittal-Dental-Linear T2 OJ	0.807	13	0.008
Transverse-Skeletal-Linear T1 MW	0.944	13	0.508
Transverse-Skeletal-Linear T2 MW	0.941	13	0.47
Transverse-Skeletal-Linear T1 BW	0.944	13	0.505
Transverse-Skeletal-Linear T2 BW	0.951	13	0.612
Transverse-Skeletal-Angular T1 ABR	0.985	13	0.996
Transverse-Skeletal-Angular T2 ABR	0.984	13	0.994
Transverse-Skeletal-Angular T1 ABRL	0.981	13	0.985
Transverse-Skeletal-Angular T2 ABRL	0.934	13	0.381
Transverse-Dental-Linear T1 IMW	0.94	13	0.459
Transverse-Dental-Linear T2 IMW	0.975	13	0.943
Transverse-Dental-Linear T1 IPW	0.938	13	0.428
Transverse-Dental-Linear T2 IPW	0.975	13	0.942
Transverse-Dental-Angular T1 MAR	0.91	13	0.182
Transverse-Dental-Angular T2 MAR	0.934	13	0.387
Transverse-Dental-Angular T1 MAL	0.964	13	0.809
Transverse-Dental-Angular T2 MAR	0.941	13	0.464

Table 3: Shapiro-Wilk normality testing for TB measurements

Items	Statistic	df	P-value
Vertical-Skeletal-Linear T1 ANS-FH	0.962	13	0.781
Vertical-Skeletal-Linear T2 ANS-FH	0.923	13	0.273
Vertical-Skeletal-Linear T1 Pog-FH	0.96	13	0.748
Vertical-Skeletal-Linear T2 Pog-FH	0.956	13	0.698
Vertical-Dental-Linear T1 OB	0.945	13	0.526
Vertical-Dental-Linear T2 OB	0.859	13	0.038

Table 4: Shapiro-Wilk normality testing for BB measurements

Items	Statistic	df	P-value
Sagittal-Skeletal-Linear T1 ANS-PNSL	0.971	19	0.793
Sagittal-Skeletal-Linear T2 ANS-PNSL	0.966	19	0.7
Sagittal-Skeletal-Linear T1 ANS-VLIN	0.962	19	0.616
Sagittal-Skeletal-Linear T2 ANS-VLIN	0.952	19	0.43
Sagittal-Skeletal-Linear T1 Pog-VL	0.953	19	0.437
Sagittal-Skeletal-Linear T2 Pog-VL	0.956	19	0.499
Sagittal-Skeletal-Angular T1 SNA	0.951	19	0.41
Sagittal-Skeletal-Angular T2 SNA	0.926	19	0.147
Sagittal-Skeletal-Angular T1 SNB	0.927	19	0.152
Sagittal-Skeletal-Angular T2 SNB	0.959	19	0.544
Sagittal-Skeletal-Angular T1 ANB	0.914	19	0.088
Sagittal-Skeletal-Angular T2 ANB	0.921	19	0.12
Sagittal-Dental-Linear T1 MRR	0.836	19	0.004
Sagittal-Dental-Linear T2 MRR	0.864	19	0.011
Sagittal-Dental-Linear T1 MRL	0.952	19	0.43
Sagittal-Dental-Linear T2 MRL	0.942	19	0.289
Sagittal-Dental-Linear T1 OJ	0.858	19	0.009
Sagittal-Dental-Linear T2 OJ	0.865	19	0.012
Transverse-Skeletal-Linear T1 MW	0.95	19	0.399
Transverse-Skeletal-Linear T2 MW	0.983	19	0.969
Transverse-Skeletal-Linear T1 BW	0.926	19	0.144
Transverse-Skeletal-Linear T2 BW	0.94	19	0.263
Transverse-Skeletal-Angular T1 ABR	0.956	19	0.489
Transverse-Skeletal-Angular T2 ABR	0.946	19	0.334
Transverse-Skeletal-Angular T1 ABRL	0.976	19	0.884
Transverse-Skeletal-Angular T2 ABRL	0.953	19	0.445
Transverse-Dental-Linear T1 IMW	0.955	19	0.47
Transverse-Dental-Linear T2 IMW	0.962	19	0.617
Transverse-Dental-Linear T1 IPW	0.925	19	0.138
Transverse-Dental-Linear T2 IPW	0.96	19	0.578
Transverse-Dental-Angular T1 MAR	0.675	19	<.001
Transverse-Dental-Angular T2 MAR	0.827	19	0.003
Transverse-Dental-Angular T1 MAL	0.904	19	0.058
Transverse-Dental-Angular T2 MAR	0.93	19	0.171

Table 4: Shapiro-Wilk normality testing for BB measurements

Items	Statistic	df	P-value
Vertical-Skeletal-Linear T1 ANS-FH	0.941	19	0.274
Vertical-Skeletal-Linear T2 ANS-FH	0.969	19	0.746
Vertical-Skeletal-Linear T1 Pog-FH	0.955	19	0.48
Vertical-Skeletal-Linear T2 Pog-FH	0.965	19	0.668
Vertical-Dental-Linear T1 OB	0.967	19	0.708
Vertical-Dental-Linear T2 OB	0.955	19	0.472

4.2. TB group

4.2.1. Transverse plane

There were several significant points which showed P-values <0.01 between the T1 group and T2 group in the TB anchored, as it divided into skeletal and dental with furthermore linear and angular. The points which showed significant difference were the Transverse-Skeletal-Linear MW with -3.88 (-5.12 to -2.63), Transverse-Dental-Linear Inter Molar Width (IMW) -5.05 (-5.89 to -4.22), Transverse-Dental-Linear Inter Premolar Width -4.71 (-5.87 to -3.55), Transverse-Dental-Angular Molar Angulation Right side (MA-R) 2.99 (1.13 to 4.85), and Transverse-Dental-Angular Molar Angulation Left side (MA-L) 2.75 (1.1 to 4.39) (Table 5).

4.2.2. Sagittal plane

All the sagittal landmarks, either skeletal or dental and linear or angular, show no significant differences between the T1 and T2 groups (Table 5).

4.2.3. Vertical plane

In the TB anchored, there was only one landmark which showed a significant difference in both skeletal and dental, when comparing the results between the T1 group and T2 group: the Vertical-Skeletal-Linear, namely Pogonion to Frankfort Horizontal Plane (Pog-FH) (-1.24 (-2.3 to -0.18)) (Table 5).

4.3. BB group

4.3.1. Transverse plane

Many points show significant differences in the transverse dimension with P-value <0.01, between the T1 and T2 groups. These measurements were Transverse-Skeletal-Linear MW -1.88 (-3.13 to -0.64), Transverse-Skeletal-Linear BW -4.16 (-5.05 to -3.25), Transverse-Skeletal-Angular Alveolar Bone Angulation Right side (ABA-R) 4.45 (1.76 to 7.13), Transverse-Skeletal-Angular Alveolar Bone Angulation Left side (ABA-L) 6.01 (3.37 to 8.65), Transverse-Dental-Linear Inter Molar Width (IMW) -4.19 (-5.05 to -3.33), Transverse-Dental-Linear Inter Premolar Width (IPW) -2.19 (-2.93 to -1.45), Transverse-Dental-Angular Molar Angulation right side (MA-R) 3.61 (1.65 to 5.65), Transverse-Dental-Angulation Molar Angulation left side (MA-L) 4.32 (2.42 to 6.22) (Table 5).

4.3.2. Sagittal plane

In the sagittal plane, there were no significant differences between the 2 groups T1 and T2 (Table 5).

4.3.3. Vertical plane

No significant differences in the vertical plane were observed when comparing the T1 and T2 groups (Table 5).

Table 5: Within TB and BB measurements

	TB	BB
Pairwise comparison	**Difference (95%CI)**	
Sagittal-Skeletal-Linear T1 ANS-PNSL, T2	-0.05 (-0.48 to 37)	-0.41 (-0.94 to 0.12)
Sagittal-Skeletal-Linear T1 ANS-VLIN - T2	0.48 (-0.42 to 1.38)	-0.3 (-0.82 to 0.22)
Sagittal-Skeletal-Linear T1 Pog-VL - T2	0.62 (-0.63 to 1.87)	-0.16 (-0.69 to 0.36)
Sagittal-Skeletal-Angular T1 SNA, T2	-0.43 (-0.87 to 0)	-0.25 (-0.64 to 0.15)
Sagittal-Skeletal-Angular T1 SNB, T2	-0.04 (-0.63 to 0.55)	-0.21 (-0.67 to 0.26)
Sagittal-Skeletal-Angular T1 ANB, T2	-0.32 (-1.02 -0.39)	-0.16 (-0.64 to 0.32)
Sagittal-Dental-Linear T1 MRR, T2	-0.21 (-0.78 to 0.37)	0.08 (-0.37 to 0.53)
Sagittal-Dental-Linear T1 MRL, T2	-0.5 (-1.18 to 0.18)	0.16 (-0.3 to 0.61)
Sagittal-Dental-Linear T1 OJ, T2 OJ	0.08 (-0.77 to 0.94)	0.13 (-0.25 to 0.5)
Transverse-Skeletal-Linear T1 MW, T2	-3.88 (-5.12 to -2.63) *	-1.88 (-3.13 to -0.64) *
Transverse-Skeletal-Linear T1 BW, T2	-0.88 (-2.26 to 0.49)	-4.16 (-5.05 to -3.25) *
Transverse-Skeletal-Angular T1 ABR, T2	1.08 (-0.55 to 2.7)	4.45 (1.76 to 7.13) *
Transverse-Skeletal-Angular T1 ABRL, T2	1.05 (-0.83 to 2.92)	6.01 (3.37 to 8.65) *
Transverse-Dental-Linear T1 IMW, T2	-5.05 (-5.89 to -4.22) *	-4.19 (-5.05 to -3.33) *
Transverse-Dental-Linear T1 IPW, T2	-4.71 (-5.87 to -3.55) *	-2.19 (-2.93 to -1.45) *
Transverse-Dental-Angular T1 MAR, T2	2.99 (1.13 to 4.85) *	3.61 (1.65 to 5.65) *
Transverse-Dental-Angular T1 MAL, T2	2.75 (1.1 to 4.39) *	4.32 (2.42 to 6.22) *
Vertical-Skeletal-Linear T1 ANS-FH, T2	-0.49 (-1.02 to 0.04)	-0.19 (-0.64 to 0.27)
Vertical-Skeletal-Linear T1 Pog-FH, T2	-1.24 (-2.3 to -0.18) *	-0.34 (-0.8 to 0.13)
Vertical-Dental-Linear T1 OB, T2OB	-0.04 (-0.98 -0.9)	0.13 (-4.8-0.74)

*Indicates that the pairwise is significant for p-value < 0.01

4.4. Combined TB and BB groups

Another Pairwise t-test was done to compare TB and BB expansion results in three dimensions.

4.4.1. Transverse dimension

All of the dental linear and angular, and skeletal linear and angular analyses revealed no significant difference except in the Transverse Skeletal Linear, namely MW in T1 and T2 and the BW in T1 and T2, with P-values of less than 0.001 (Table 6).

4.4.2. Sagittal dimension

The comparison between skeletal and dental data showed no significant differences between TB anchored and BB anchored in both T1 and T2 groups (Table 6).

4.4.3. Vertical dimension

No significant differences were detected when analyzing vertical dimensions between the T1 and T2 groups in terms of both skeletal linear and angular, and dental linear and angular data (Table 6).

Table 6: Comparison of TB and BB measurements

	TB		BB		p-value
	No.	Mean (SD)	No.	Mean (SD)	
Sagittal-Skeletal-Linear T1 AnS-PNSL	13	50.20 (2.8)		51.27 (3.11)	0.310
Sagittal-Skeletal-Linear T2 AnS-PNSL	13	50.25 (3.1)		51.26 (2.83)	0.350
Sagittal-Skeletal-Linear T1 AnS-VLIN	13	28.49 (4)		28.2 (3.68)	0.360
Sagittal-Skeletal-Linear T2 AnS-VLIN	13	28.02 (4)		28.06 (3.09)	0.826
Sagittal-Skeletal-Linear T1 PogVLin	13	21.47 (6.28)		22.78 (5.9)	0.970
Sagittal-Skeletal-Linear T2 PogVLin	13	20.85 (5.87)	19	22.72 (5.93)	0.545
Sagittal-Skeletal-Angular T1 SNA	13	79.6 (3.35)	21	81.21 (4)	0.552
Sagittal-Skeletal-Angular T2 SNA	13	80.03 (3.45)	19	80.98 (3.55)	0.386
Sagittal-Skeletal-Angular T1 SNB	13	77.05 (2.99)	21	78.8 (3.59)	0.217
Sagittal-Skeletal-Angular T2 SNB	13	77.09 (7.76)	19	78.74 (3.13)	0.457
Sagittal-Skeletal-Angular T1 ANB	13	2.62 (2.51)	21	1.79 (3.71)	0.137
Sagittal-Skeletal-Angular T2 ANB	13	2.94 (2.14)	19	2.3 (3.33)	0.128
Sagittal-Dental-Linear T1 MRR	13	3.1 (1.4)	21	4.21 (2.68)	0.441
Sagittal-Dental-Linear T2 MRR	13	3.31 (1.29)	19	4.29 (2.81)	0.515
Sagittal-Dental-Linear T1 MRL	13	3.26 (1.73)	21	3.81 (1.62)	0.124
Sagittal-Dental-Linear T2 MRL	13	3.76 (1.94)	19	3.75 (1.66)	0.192
Sagittal-Dental-Linear T1 OJ	13	2.66 (1.68)	21	2.44 (1.66)	0.356
Sagittal-Dental-Linear T2 OJ	13	2.58 (1.78)	19	2.23 (1.77)	0.587
Transverse-Skeletal-Linear T1 MW	13	28.92 (2.84)	21	60.64 (3.97)	< 0.001
Transverse-Skeletal-Linear T2 MW	13	32.79 (3.49)	19	62.43 (4.25)	< 0.001
Transverse-Skeletal-Linear T1 BW	13	60.22 (3.77)	21	30.17 (3.13)	< 0.001
Transverse-Skeletal-Linear T2 BW	13	61.10 (4.15)	19	34.21 (2.96)	< 0.001
Transverse-Skeletal-Angular T1 ABR	13	133.45 (7.56)	21	132.27 (10.45)	0.726
Transverse-Skeletal-Angular T2 ABR	13	132.37 (6.98)	19	128.21 (9.45)	0.163
Transverse-Skeletal-Angular T1 ABRL	13	132.93 (6.65)	21	134.86 (11.7)	0.545
Transverse-Skeletal-Angular T2 ABRL	13	131.88 (6.28)	19	129.49 (10.54)	0.429
Transverse-Dental-Linear T1 IMW	13	40.54 (2.72)	21	41.37 (2.41)	0.377
Transverse-Dental-Linear T2 IMW	13	45.59 (2.9)	19	45.51 (2.91)	0.934
Transverse-Dental-Linear T1 IPW	13	30.92 (2.07)	21	32.58 (2.97)	0.063
Transverse-Dental-Linear T2 IPW	13	35.62 (1.97)	19	34.64 (3.71)	0.337
Transverse-Dental-Angular T1 MAR	13	63.41 (4.93)	21	64.66 (6.37)	0.526
Transverse-Dental-Angular T2 MAR	13	60.42 (5.96)	19	61.4 (5.29)	0.635
Transverse-Dental-Angular T1 MAL	13	61.81 (3.78)	21	65.05 (5.31)	0.064

Table 6: Comparison of TB and BB measurements

	TB		BB		p-value
	No.	Mean (SD)	No.	Mean (SD)	
Transverse-Dental-Angular T2 MAR	13	59.06 (4.4)	19	61.04 (5.47)	0.267
Vertical-Skeletal-Linear T1 ANS-FH	13	19.11 (3.12)	21	19.75 (2.46)	0.537
Vertical-Skeletal-Linear T2 ANS-FH	13	19.6 (2.9)	19	20.1 (2.11)	0.600
Vertical-Skeletal-Linear T1 Pog-FH	13	79.34 (5.29)	21	79.32 (5.03)	0.992
Vertical-Skeletal-Linear T2 Pog-FH	13	80.58 (5.35)	19	79.75 (5.39)	0.671
Vertical-Dental-Linear T1 OB	13	4.03 (1.69)	21	4 (1.94)	0.967
Vertical-Dental-Linear T2 OB	13	4.07 (1.44)	19	3.79 (2.06)	0.654

4.4.4. Interaction between transverse and sagittal dimensions

To investigate if the sagittal and vertical changes are correlated with the changes in the transverse dimension, Pearson correlation was performed involving transverse parameters (skeletal, dental, and linear, angular) with sagittal and vertical (skeletal, dental, and linear, angular) dimensions. The following changes in the transverse dimension T2 showed either positive or negative correlations with specific sagittal and vertical data for both TB and BB anchorage.

In the TB anchorage expansion group, the transverse change in the MW was positively correlated with the sagittal skeletal angular values of SNA ($P < 0.05$), whereas it was negatively correlated with the change in the sagittal dental linear molar relation on the right side (MRR) ($P < 0.01$). The change in the BW was negatively correlated with the sagittal dental linear molar relation on the left side ($P < 0.01$). The change in the transverse alveolar bone angle and molar angle on the left side (MA-L) both were positively correlated with the change in molar relation on the left side as well ($P < 0.05$). Changes in the inter premolar width (IPW) were negatively correlated with the sagittal dental molar relation ($P < 0.05$). Vertically, the overbite change was positively correlated with the change in the transverse skeletal angular dimension changes ($P < 0.05$) (Tables 7-8).

Table 7: TB transverse parameters' correlation with sagittal parameters

		Sagittal-Skeletal-Angular T2 SNA
Transverse-Skeletal-Linear T2 MW	Pearson Correlation	.576*
		Sagittal-Dental-Linear T2 MRL
Transverse-Skeletal-Linear T2 BW	Pearson Correlation	-.732**
		Sagittal-Dental-Linear T2 MRL
Transverse-Skeletal-Angular T2 ABRL	Pearson Correlation	.576*
		Sagittal-Dental-Linear T2 MRL
Transverse-Dental-Linear T2 IPW	Pearson Correlation	-.604*
		Sagittal-Dental-Linear T2 MRL
Transverse-Dental-Angular T2 MAL	Pearson Correlation	.670*
		Sagittal-Dental-Linear T2 MRR
		-.764**

Table 8: TB transverse parameters' correlation with vertical parameters

		Vertical-Dental-Linear T3 OB
Transverse-Skeletal-Angular T3 ABRL	Pearson Correlation	.593*

In the BB anchorage expansion group, the change in the transverse skeletal linear MW was positively correlated with the change in the sagittal skeletal linear Pog-V parameter ($P < 0.05$). The changes in the transverse IMW were positively correlated with the sagittal linear molar relation left MRL ($P < 0.05$). The transverse inter premolar width changes were positively correlated with the changes in the sagittal Pog-V parameter ($P < 0.05$). The changes in the transverse molar angle on the right (MA-R) and left (MA-L) were negatively correlated with the in the sagittal skeletal angular ANB angle ($P < 0.05$). Vertically, the changes in the transverse BW and IMW were negatively correlated with the OB ($P < 0.05$). BB correlation of transverse with sagittal and vertical as well (Tables 9-10).

Table 9: BB transverse parameters' correlation with sagittal parameters

		Sagittal-Skeletal-Linear T2 PogVLin
Transverse-Skeletal-Linear T2 MW	Pearson Correlation	.527*
		Sagittal-Dental-Linear T2 MRL
Transverse-Dental-Linear T2 IMW	Pearson Correlation	.506*
		Sagittal-Skeletal-Linear T2 PogVLin
Transverse-Dental-Linear T2 IPW	Pearson Correlation	.495*
		Sagittal-Skeletal-Angular T2 ANB
Transverse-Dental-Angular T2 MAR	Pearson Correlation	-.559*
		Sagittal-Skeletal-Angular T2 ANB
Transverse-Dental-Angular T2 MAL	Pearson Correlation	-.520*

Table 10: BB transverse parameters' correlation with vertical parameters

		Vertical-Dental-Linear T3 OB
Transverse-Skeletal-Linear T3 BW	Pearson Correlation	-.506*
		Vertical-Dental-Linear T3 OB
Transverse-Dental-Linear T3 IMW	Pearson Correlation	-.483*

5. DISCUSSION

The indication to use the RME as a modality to treat a constricted maxilla is well-documented in the literature. The procedure is achieved through an orthodontic appliance that opens laterally, with a screw that is activated daily (33). Previous investigations on the effects of RME treatment were carried out through 2D radiographic examination, which was limited because it did not allow for an accurate assessment of all structures. Structure overlapping is eliminated with the 3D examination, and higher accuracy is achieved (48). Computer tomography (CT) and CBCT facilitated the 3D examinations undertaken in this study. They provide a scanning technique of an excellent resolution, allowing 3D analysis of treatment-related bony structural changes without overlapping (49).

5.1. Transverse effect

The RME affects the transverse dimension, whether tooth- or BB. Patients treated with tooth-tissue-borne RME before puberty portray a more significant increase in the skeletal transverse dimension than those treated post-puberty (34). Comparison of the effects of bone-anchored with tooth-anchored rapid expanders in adolescents indicated that both TB and BB RME procedures indicate significant skeletal maxillary expansion of about 1.27 mm and 1.31 mm, respectively; bone RME shows a lower dental to skeletal expansion ratio than tooth RME procedure, whereby the molar crown expands by 1.84 mm more than the implant side (33). Similarly, it has been established that the hyrax group reported more buccal tipping of the alveolar bone and tooth axes except in the second molar, with the bone anchored expander showing more significant skeletal expansion (34).

Our findings affirm the abovementioned studies, reporting a significant change before and after expansion in the molar width (MW) of -3.88 (-5.12 to -2.63) in the tooth-borne anchored, and -1.88 (-3.13 to -0.64) in the BB anchored, while BW showed a -4.16 (-5.05 to -3.25) change in BB anchored. Hyrax expander was found to exert the most significant transverse tooth-borne change in intermolar width (36), which seems to be the consensus in this field (33, 35, 37).

BB expansion resulted in twice the level of skeletal expansion, with more symmetrical expansion on both sides than tooth-borne expansion (34). However, this expansion was accompanied by significant dental tipping, as reported by many researchers (14, 33, 34). Molar tipping after expansion was compared between skeletal borne and tooth-borne expanders, revealing that more tipping was recorded in the tooth-borne expander groups. Some researchers measured molar tipping by drawing a palatal root axis to a line tangential to the nasal floor at a most inferior level (34); others measured the distance between root apices and the pulp chambers to measure the extent of tipping of the molars after expansion (45). used A Dresden distractor revealed less tipping of teeth (about 6-9 degrees) among a skeletal expansion group (14).

In this study, dental tipping of the molars was measured after expansion in both groups by reporting the parameter (MA) angle formed between a line from the mesiobuccal cusp of the upper first molar to the palatal root of the first molar, and a line from the palatal root of the first molar to the Frankfort horizontal line (Fig. 3). The results confirm previous studied in concluding that there is less tipping of the molars in the BB group than in the tooth-borne group (7, 33, 34).

5.2. Effects of expansion on dental and skeletal sagittal relation and dimensions

RME significantly affects the sagittal dimension, either with the use of tooth-borne or BB expanders. Examination of maxillary and mandibular responses to rapid palatal expansion in transverse, sagittal, and vertical dimensions using a Haas-type expander appliance, measuring changes with imaging techniques, revealed that the maxillary and mandibular incisors inclination did not change significantly for all patients after the procedure (41). The SNA moved slightly forward after the RME, with a reported increase of 0.35 degrees. On the other hand, SNA values in our results increased among all patients, but no statistically significant change was detected before and after expansion, with a mean increase of 0.43 degrees (0.87 to 0) and 0.25 degrees (0.46 to 0.15) for the tooth-borne and BB groups, respectively. The anteroposterior skeletal effect increases molar width by 1.8 mm and increases mandibular length but reduces the overjet (37). The overjet values in our results reported negligible changes within each expansion group: 0.08 (-0.77 to 0.94) in tooth-borne, and 0.13 (-0.25 to 0.5) in BB. Upon expanding the constricted maxillary arch, the transverse increase in maxillary width at the molar level and premolar level influences the sagittal dimension of the maxillary arch, thereby relieving crowding in the arch to a certain extent. Consequently, the expansion releases the mandible forward to attain a better sagittal position (50, 51, 52). Studies have debated the magnitude and limitation of the mandibular movement (14, 53, 54), but our results agree with those displaying some forward positioning of the mandible. The sagittal skeletal parameters display the changes in SNB values 0.04 degrees (0.63 to 0.55) in the tooth-borne, 0.21 degrees (-0.67 to 0.26) in the BB, along with the Pog. Vertical 0.62 mm (-0.63 to 1.87) in tooth-borne and -0.16 mm (-0.69 to 0.36) in BB. However, these values were not statistically or clinically significant.

Dentally, the molar relation did not change among most patients in both groups; for those for whom it did, the molar moved forward. In the tooth-borne group, the molar relation changes were 0.21 mm (-0.78 to 0.37) to the right, and 0.5 mm (-1.18 to 0.18) to the left. In the BB group, the molar relation changes were 0.08 mm (-0.37 to -0.53) to the right, and 0.16 mm (-0.3 to 0.61) to the left. It is imperative to mention that the patients were not grouped initially according to their molar or skeletal relation, thus the interpretation of the results is sensitive, given the impacts that different molar/skeletal relation would have on the final mandibular position, reducing in the sagittal skeletal angular ANB, corresponding to the molar angulation in both sides.

5.3. Effects of expansion on vertical relation and dimensions

RME also significantly affects the vertical dimensions of either tooth-borne or BB treatment. A recent study concluded that tooth-borne RME led to a vertical molar extrusion of about 1.8 mm, but the BB RME procedure generated no significant tooth vertical changes (33). Although we did not measure the vertical molar changes, the significant change reported in the above study explains the decrease in the overbite that we measured in our results. In addition to the reported decrease in the overbite before and after in tooth-borne and BB expansion groups, there was a negative correlation between the change in molar width and overbite change in the BB group ($P<0.05$).

Among children, the maxilla was reportedly displaced slightly forward and downward, with the mandible rotated downward and backward, leading to anterior facial height increase (41). We measured the vertical skeletal linear displacement of the mandible by measuring the Pog to FH vertical distance (Fig. 13). There was a statistically significant increase ($P < 0.01$), in agreement with the previously reported vertical change after expansion. It is of importance to note that the change in vertical height is not a permanent change; it is affected by type and amount of remaining growth, in addition to the amount of relapse after the expansion. As this is not a longitudinal study, no long-term follow-up measurements are available to draw conclusions about this, but the finding of an increase in the vertical dimension being prone to change again corroborates previous studies (2, 35, 55).

6. CONCLUSION

6.1. Main findings

There was significant change reported before and after expansion at the molar width in the tooth-borne anchored and in the bone-borne anchored groups. There was less tipping of the molars in the bone-borne group than in the tooth-borne group. Some forward positioning of the mandible was reported, but the values were not statistically or clinically significant. There was a statistically significant increase in the mandibular vertical height, along with a decrease in the overbite, correlated with the change in the transverse dimensions.

6.2. Study limitations

The main limitations in this study included variability in the parameters of the baseline readings, some subjects being excluded due to the sub-par CBCT resolution, and the lack of a control group. It would be advisable to address these shortcomings in future research concerning bone-borne and tooth-borne treatment for adolescents, and to conduct a longitudinal study to explore possible long-term impacts. It is also advisable to study younger (child) patients, to see the extent to which their responses to these therapies differ from the adolescents studied in this research.

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8. APPENDIX: ILLUSTRATIONS OF LANDMARKS USED

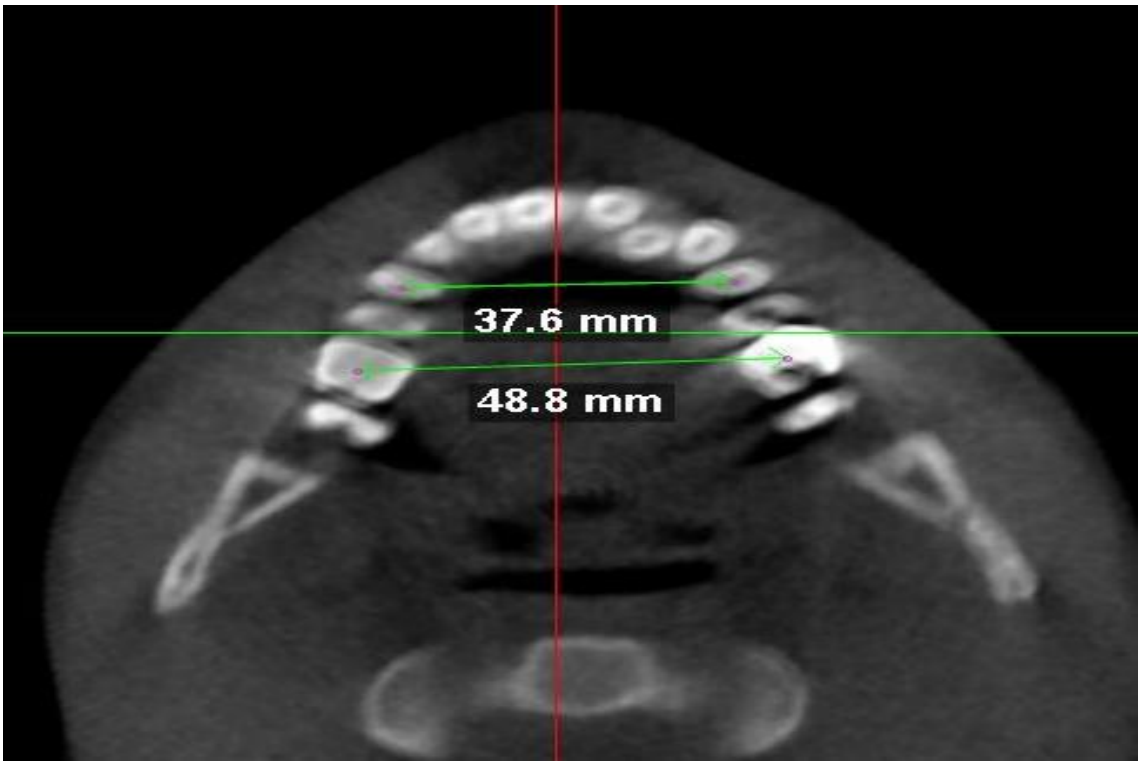

Figure 1: Inter-molar width and inter premolars width (axial slice)

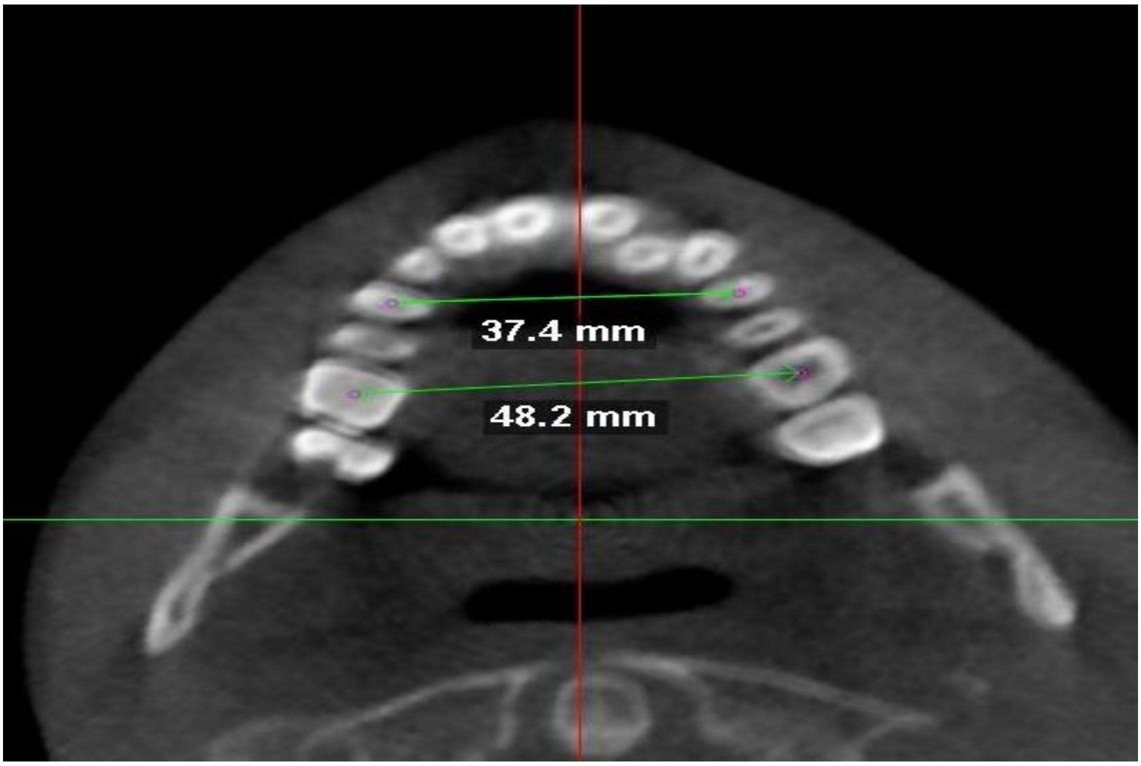

Figure 2: Inter-molar width and inter-premolar width (axial slice)

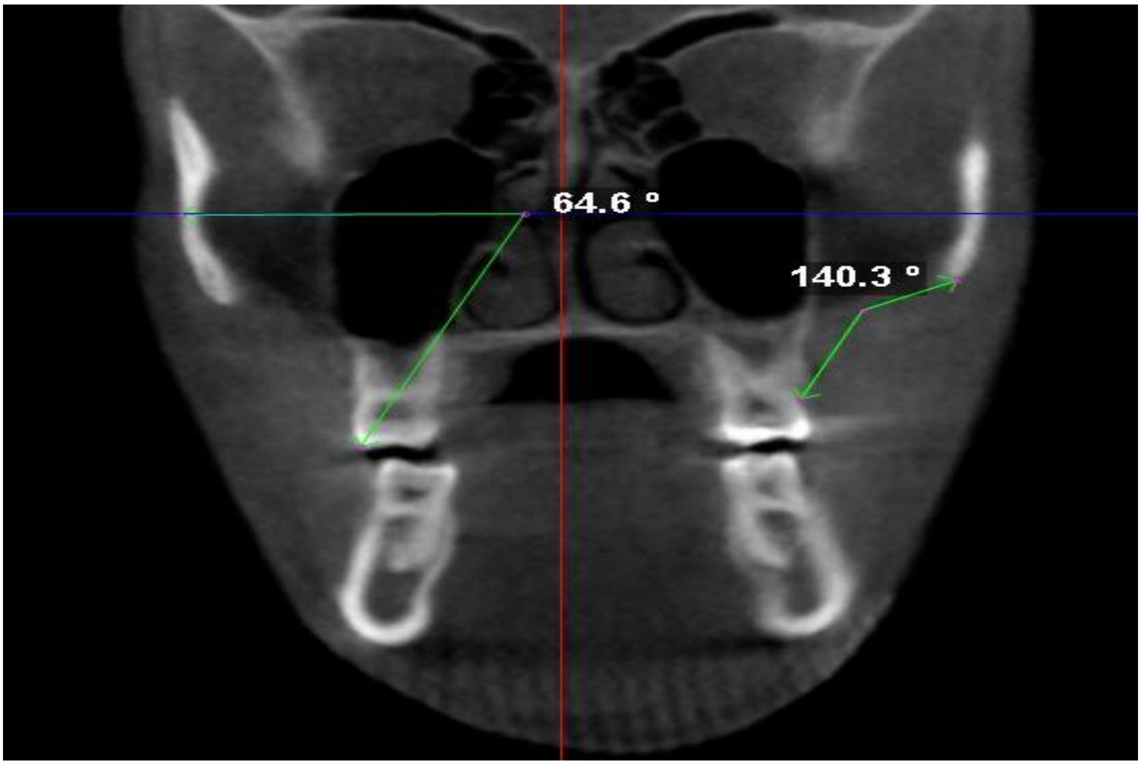

Figure 3: Molar angle and alveolar bone angle (coronal slice)

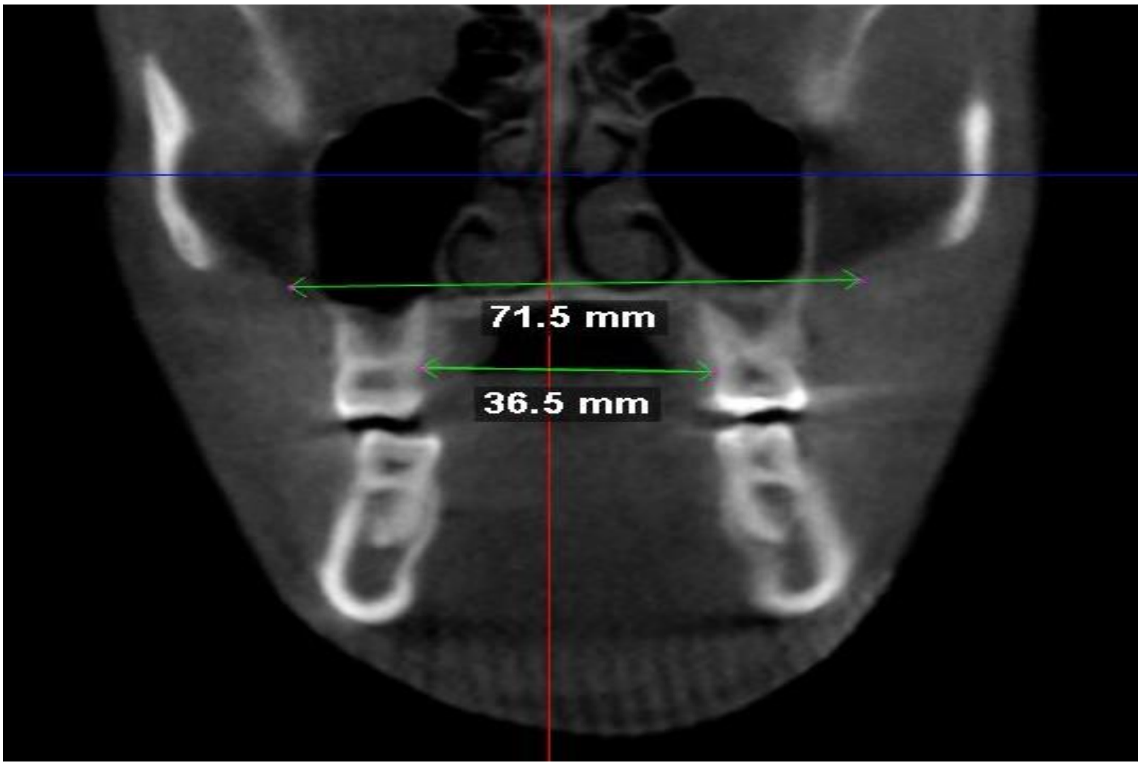

Figure 4: Molar width and buccal width (coronal slice)

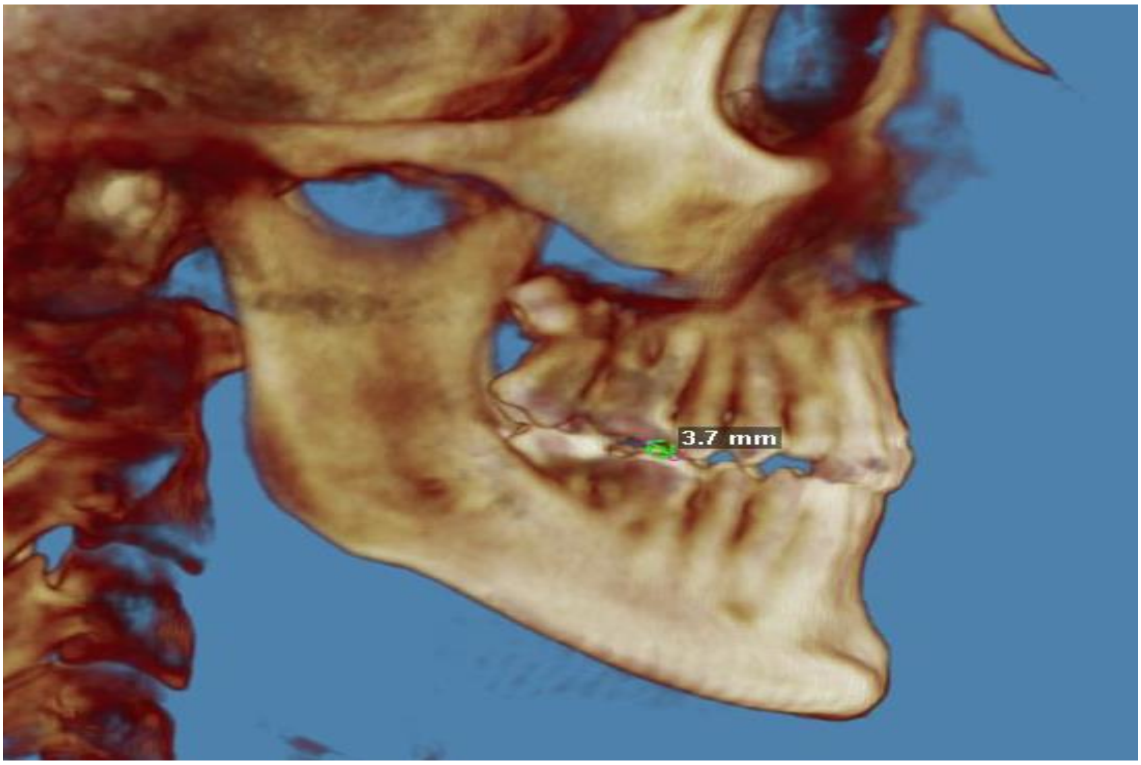

Figure 5: Molar relation

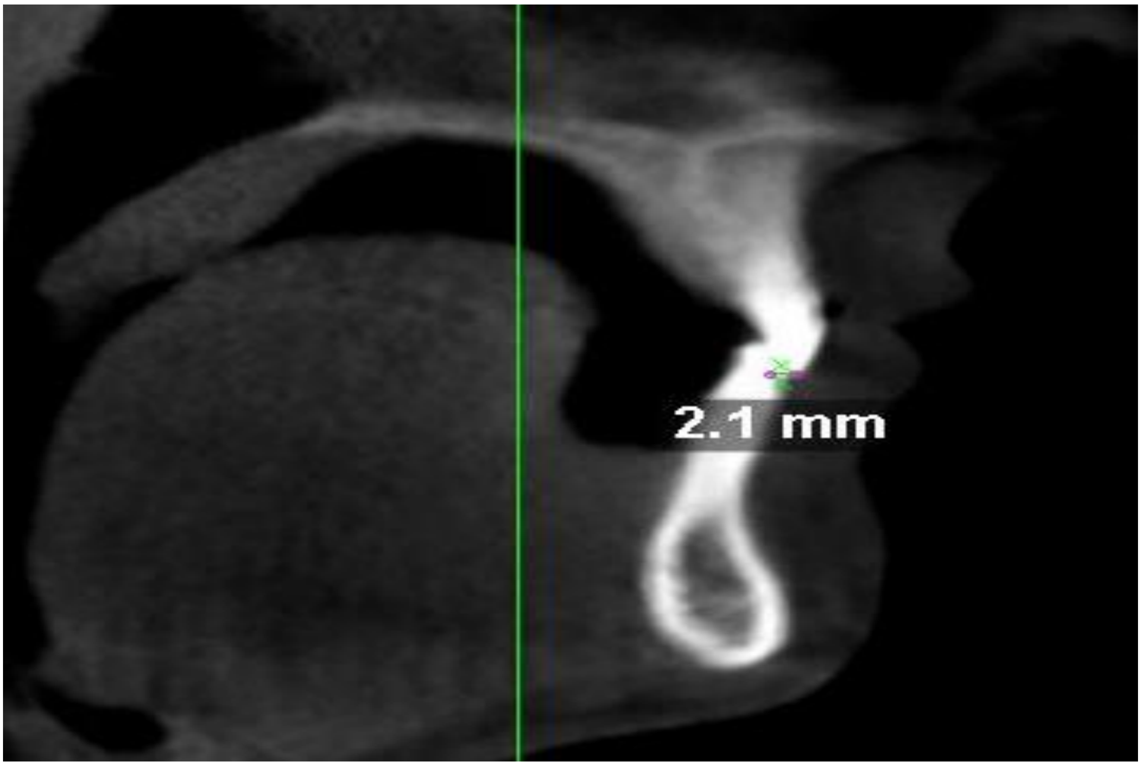

Figure 6: Overjet (sagittal slice)

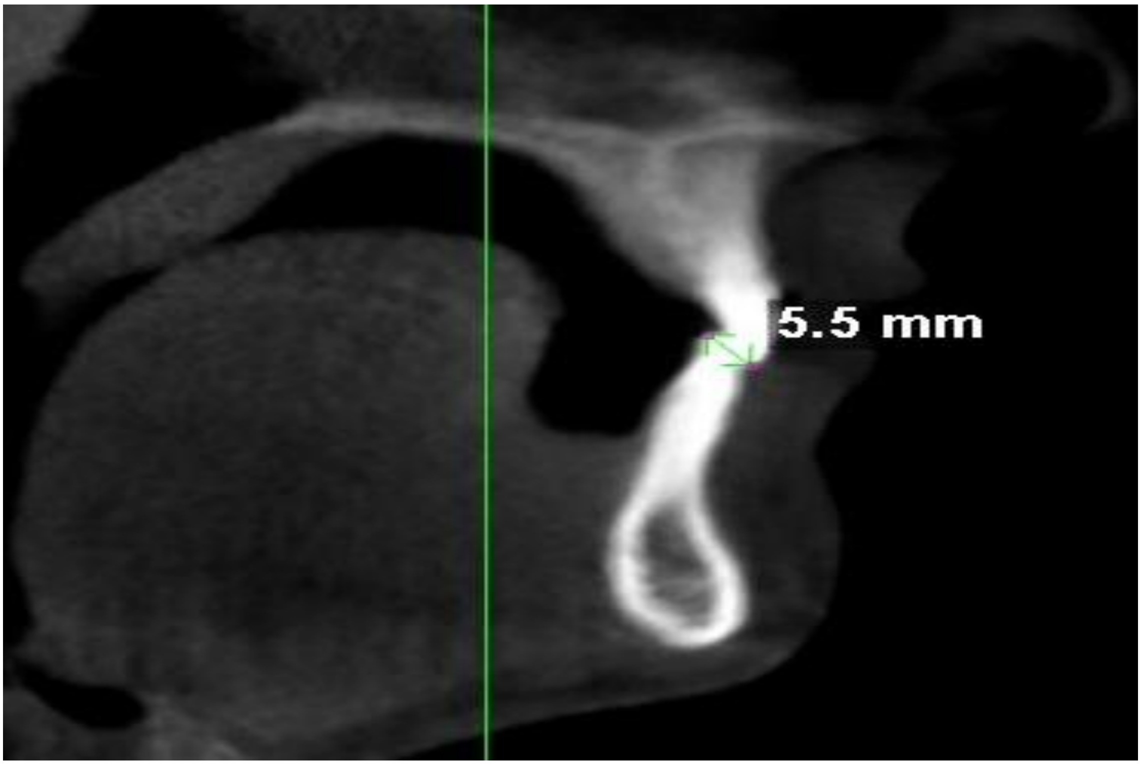

Figure 7: Overbite (sagittal slice)

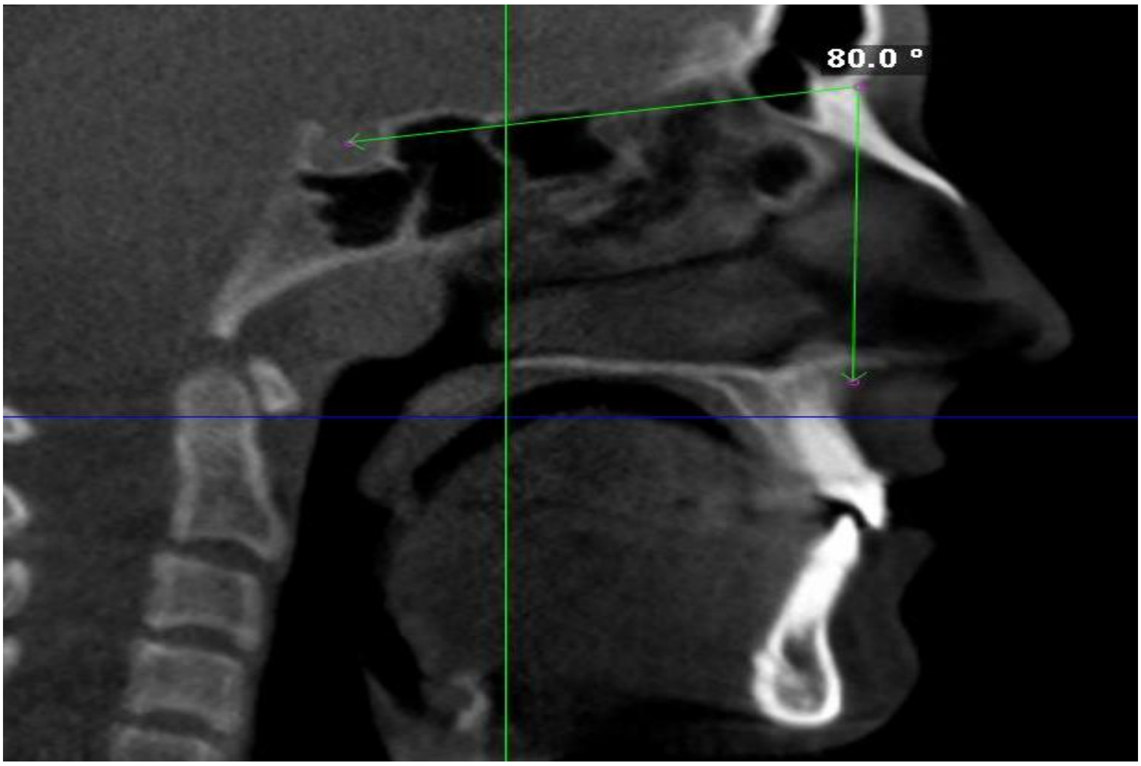

Figure 8: SNA angulation (sagittal slice)

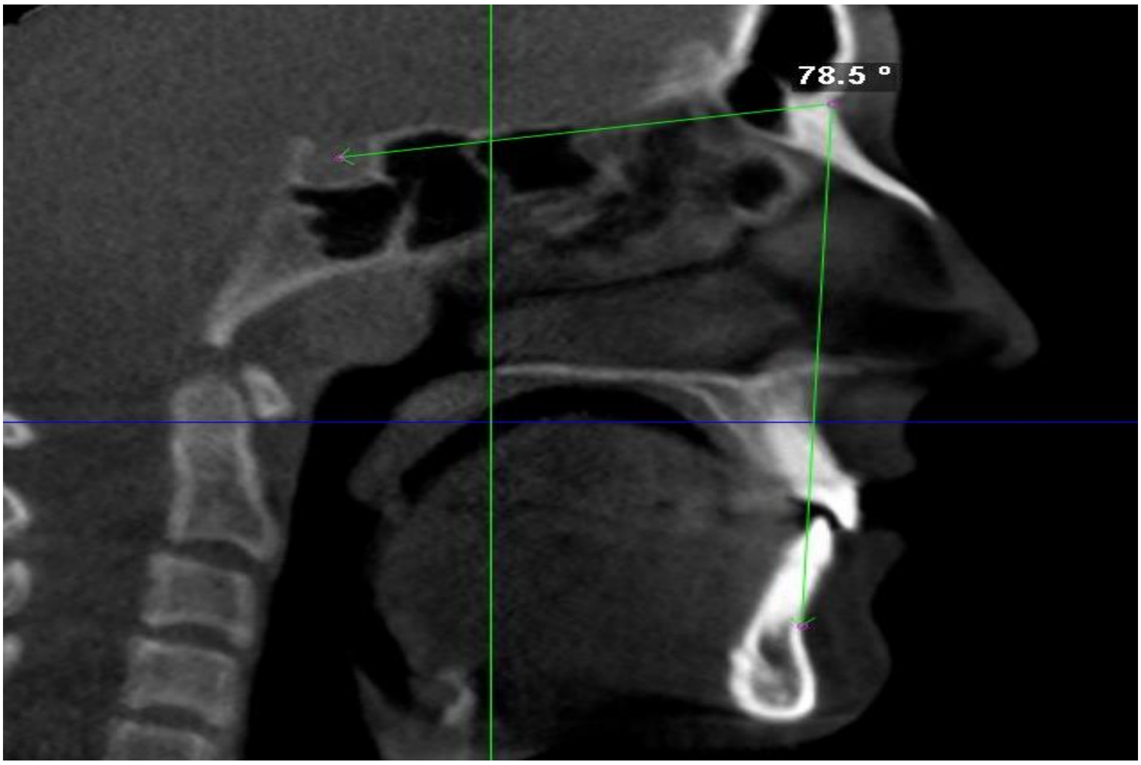

Figure 9: SNB angulation (sagittal slice)

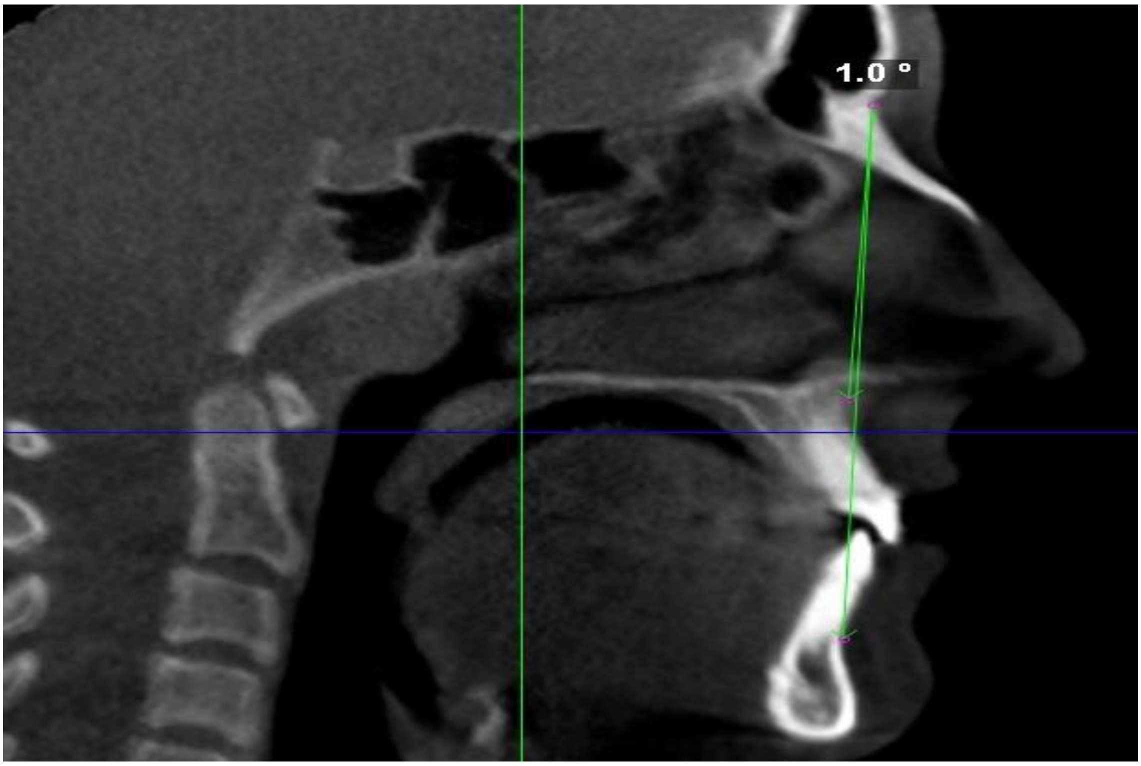

Figure 10: ANB angulation (sagittal slice)

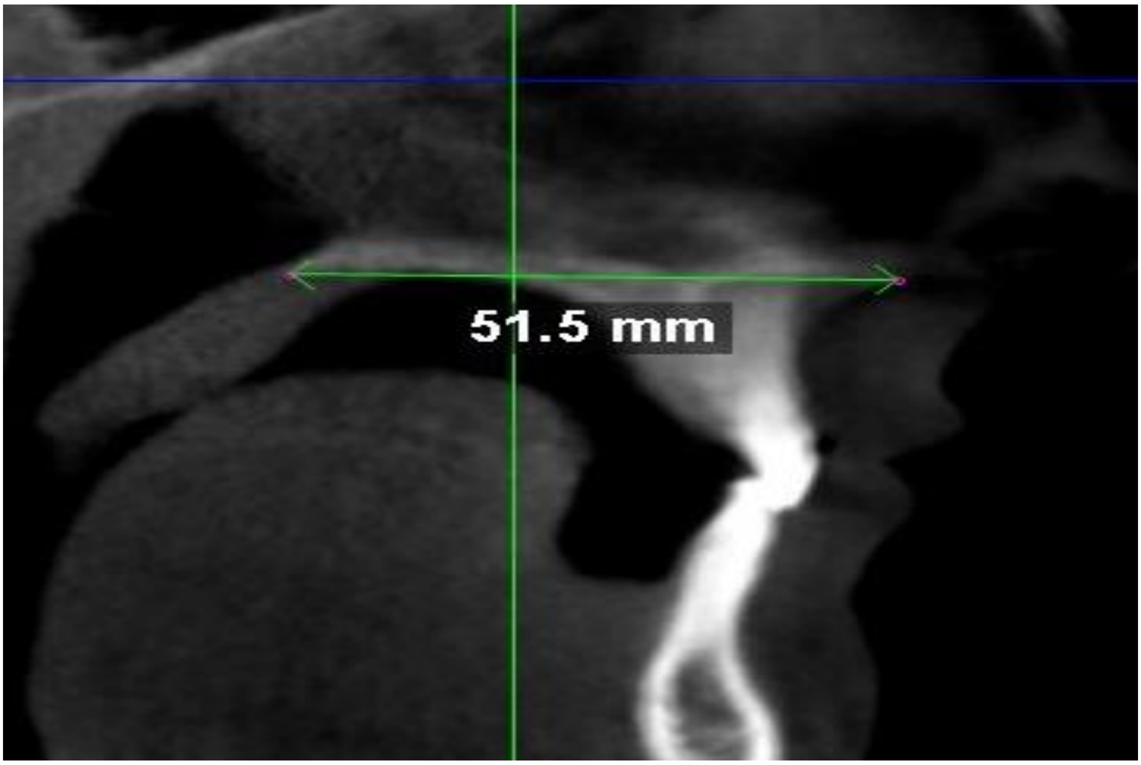

Figure 11: ANS to PNS length (sagittal slice)

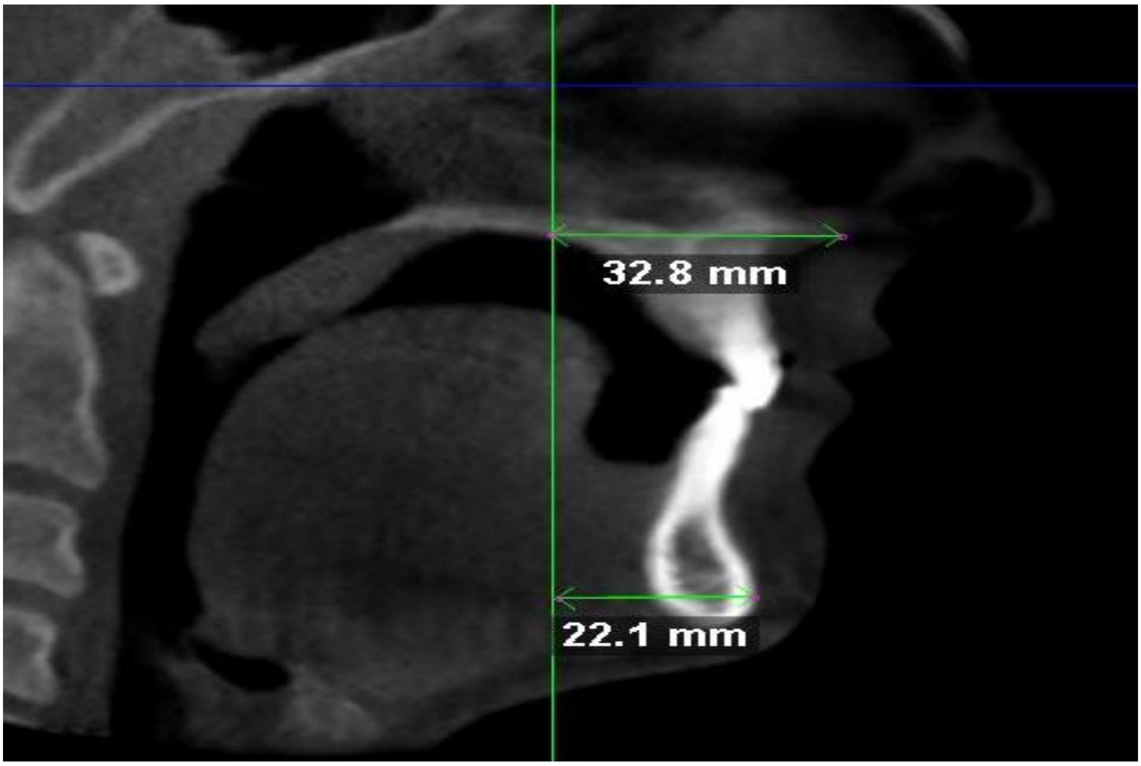

Figure 12: ANS and Pogonion to vertical plane length (sagittal slice)

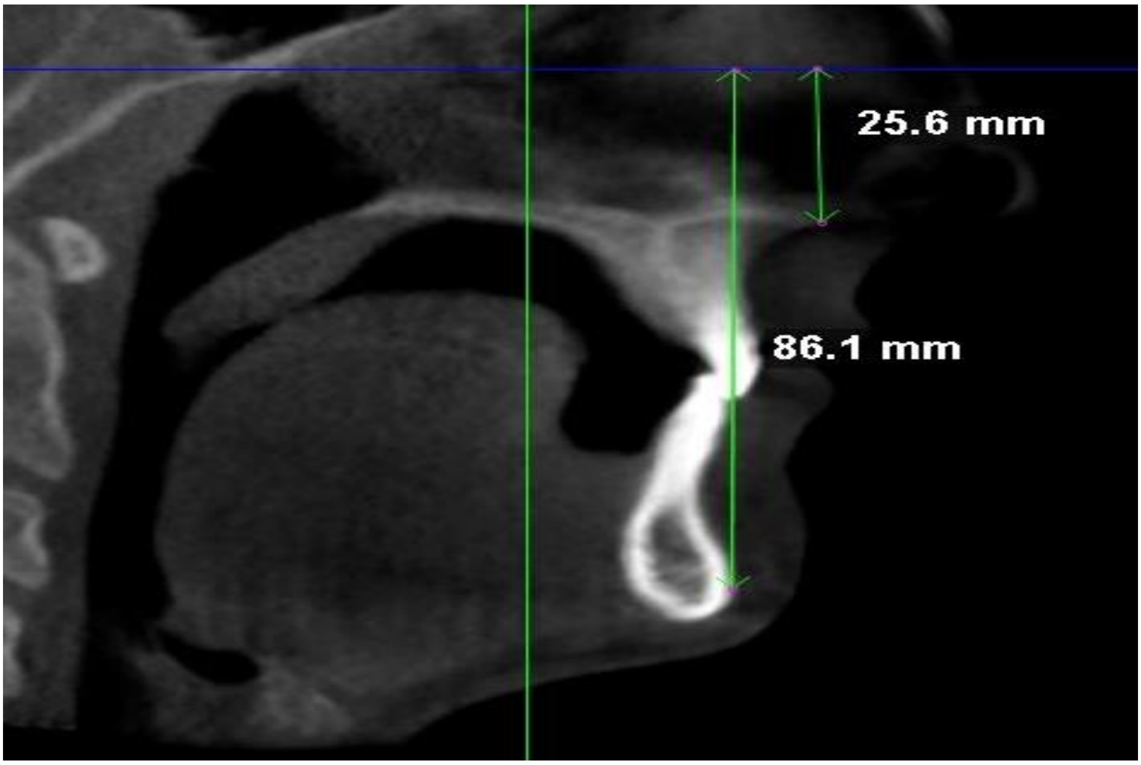

Figure 13: ANS and Pogonion to Frankfort horizontal plane length (sagittal slice)

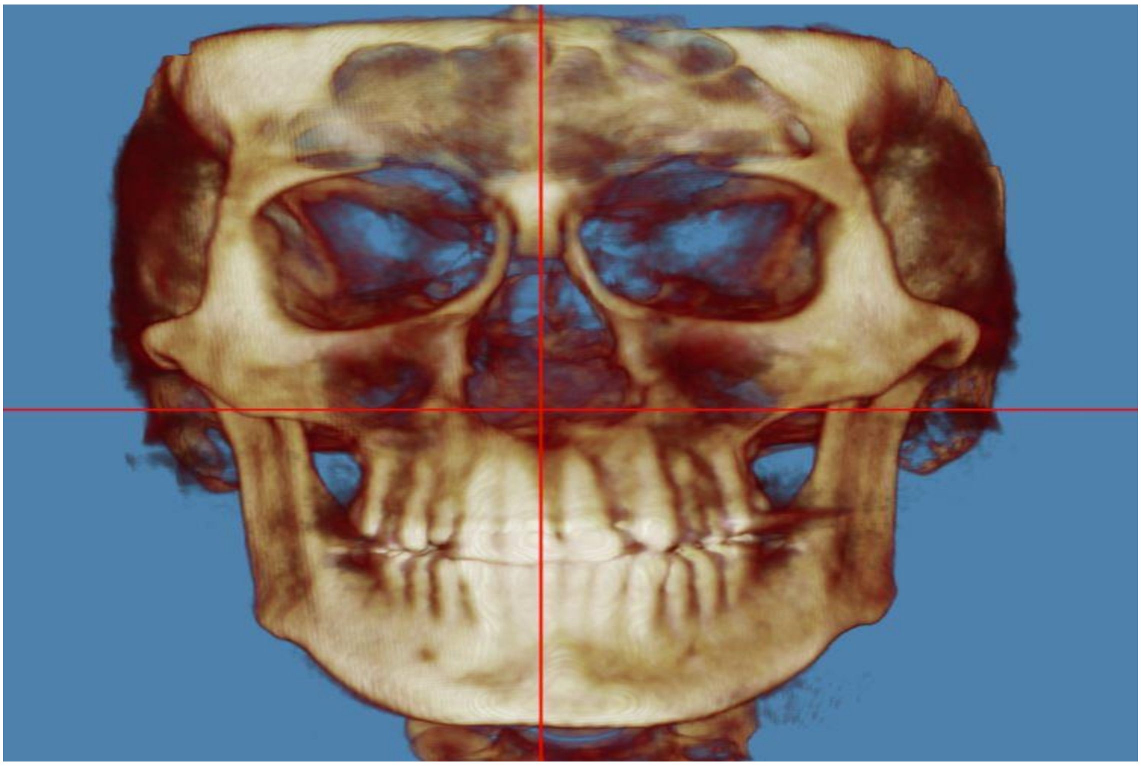

Figure 14: Skeletal midline

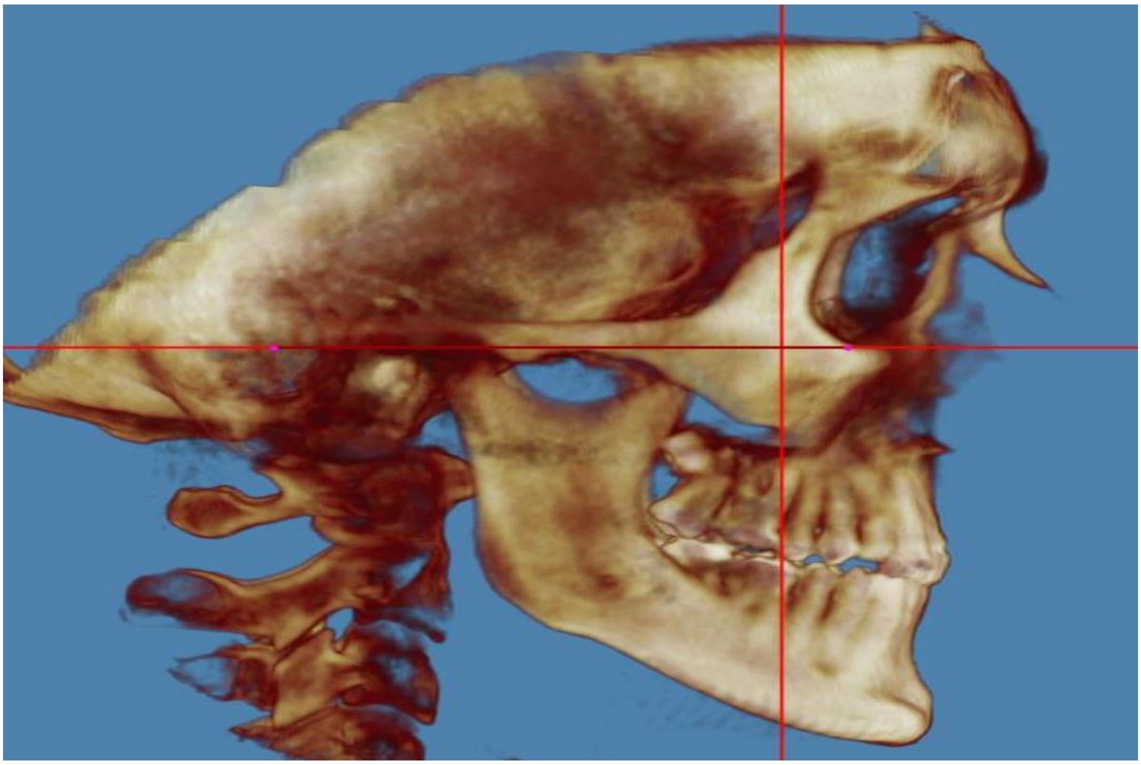

Figure 15: Frankfort horizontal and vertical line