9-25-2020

OROPHARYNGEAL AIRWAY CHANGES FOLLOWING ORTHODONTIC TREATMENT OF ANTERIOR OPEN BITE IN GROWING VS NON-GROWING PATIENTS

Mona Awadi
m_awadi@u.pacific.edu

Heeyeon Suh
hsuh1@pacific.edu

Joorok Park
jpark3@pacific.edu

Heesoo Oh
hoh@pacific.edu

OROPHARYNGEAL AIRWAY CHANGES FOLLOWING ORTHODONTIC TREATMENT OF ANTERIOR OPEN BITE IN GROWING VS NON-GROWING PATIENTS

by

Mona Awadi

A Thesis submitted to the

Graduate Orthodontic Program

In partial Fulfillment of the

Requirements for the Degree of

MASTER OF SCIENCE IN

DENTISTRY

Arthur A. Dugoni School of Dentistry

University of the Pacific
Arthur A. Dugoni School of Dentistry
San Francisco, California

2020

OROPHARYNGEAL AIRWAY CHANGES FOLLOWING ORTHODONTIC TREATMENT OF ANTERIOR OPEN BITE IN GROWING VS NON-GROWING PATIENTS

by

Mona Awadi

APPROVED BY:

Thesis Advisor: Heesoo Oh, DDS, MSD, Ph.D.

Thesis Committee: Joorok Park, DDS, MSD.

Program Director and Chair: Heesoo Oh, DDS, MSD, Ph.D.

ABSTRACT

Introduction: Orthodontic treatment of anterior open bite can result in a counter-clockwise rotation of the mandible and a more ideal forward position of the tongue. Usually this movement is thought to increase the oropharyngeal airway. The primary aim of the present study was to evaluate changes in vertical dimension and airway in AOB patients following orthodontic treatment.

Methods: 52 subjects were included in this retrospective study of anterior open bite malocclusion treated in the graduate orthodontics clinic at the University of the Pacific, Arthur A. Dugoni School of Dentistry between 2006 – 2019. Cephalometric and airway measurements were done by 2 judges. Intraclass correlation coefficient (ICC) was used to evaluate inter-judge reliability for evaluating airway volume and MCA measurements. Chi-square tests were used to compare proportions. Unpaired t-tests were used to compare mean differences and paired *t*-tests were used to compare pre- and post-treatment changes.

Results: More vertical control and intrusion of molars was seen in non-growing (NG) subjects. There was more successful open bite correction in NG subjects. Even though there was a reduction in FMA, LFA, improved incisor position and open bite correction, there was not much influence on airway dimensions. There was no statistically significant change in airway in growing (G) and NG subjects when looking at the whole sample.

Conclusion: With correction of an anterior open; intrusion of molars and a more forward mandibular position result. However, these changes did not result in an increase in oropharyngeal airway in our study.

INTRODUCTION

Anterior open bite (AOB) is defined as a lack of vertical overlap between upper and lower incisors. The vertical separation between the two quantifies its severity. It is estimated in around 16% of the black population in the US and 4% in the white population. Patients with open bite usually complain about the inability to incise food or unappealing facial esthetics[1].

The etiology can be dental, skeletal, or multifactorial (respiratory, neuromuscular, etc.)[2] There are various treatment modalities including: extractions, fixed appliances, clear aligners, temporary anchorage devices (TADs), habit devices, myofunctional therapy, occlusal equilibration, and orthognathic surgery. Traditionally, habit appliances and fixed appliances only have been used to treat OB in children and adolescents. And orthognathic surgery has been used to treat adult OB cases[2].

It has been reported that Md advancement increases the oropharyngeal airway way due to tightening of muscles and tendons, while Md setback decrease the airway. It was also observed that many patients with obstructive sleep apnea (OSA) have retrognathic mandibles and high occlusal and mandibular planes. Due to Md retrognathism, the tongue may appear large and posteriorly positioned as a result of the decreased oral cavity volume[3]. Surgical correction of high Md plane angle and OB usually involves a counterclockwise (CCW) rotation of the maxillomandibular complex to decrease the high angle. A CCW rotation of the complex will result in forward movement of the genial tubercles which will also cause forward movement of the hyoid bone, base of the tongue, and associated soft tissues[3]. All these movements would theoretically increase the pharyngeal airway. This same concept of CCW rotation of the maxillomandibular complex is applied to orthodontic correction of an AOB. If open bite is corrected by posterior teeth intrusion, the mandibular plane is decreased which results in a CCW rotation. Currently there are no studies that have analyzed changes in mandibular plane and its affect on the airway dimensions.

The primary aim of the present study was to evaluate changes in vertical dimension and airway in AOB patients following orthodontic treatment. We specifically compared differences between growing (G) and non-growing (NG) patients. The hypothesis was that there will be no significant differences in changes in vertical dimension and airway dimension between growing and non-growing patients. A secondary question was to identify the contributing factors in correcting open bite.

MATERIALS AND METHODS

This retrospective study was approved by the Institutional Review Board (IRB) prior to starting the study (IRB # 18-26). The treated sample comprised 52 consecutive patients with anterior open bite malocclusion treated in the graduate orthodontics clinic at the University of the Pacific, Arthur A. Dugoni School of Dentistry between 2006 - 2019. The initial search consisted of 195 OB patients at T1 using Dolphin imaging cephalometric analysis. Inclusion criteria included: 1) pre-treatment (T1) and post-treatment (T2) CBCTs; 2) an open bite of 0.5mm or more (measured from dolphin 2D tracing). Patients who completed treatment resulted in 81 patients.

Exclusion criteria included: 1) patients who underwent orthognathic surgery (n=24); 2) patients with craniofacial anomalies/syndromes (n=4); 3) poor quality CBCT (n=1). Once the exclusion criteria was applied, the final sample consisted of 52 subjects.

All CBCT ((i-CATTM, Hatfield, PA) scans were 23 x 17 cm FOV and 0.3 mm voxel size. No specific instructions were given to the patient during the scans. DICOM files were imported into Invivo6 3D Imaging Software (Anatomage, San Jose, California). Before tracing, all scans were oriented: axial plane adjusted to line up the inferior borders of the right and left orbits, coronal plane adjusted at Frankfort horizontal (right porion and right orbitale), and the sagittal plane was adjusted to line up the lateral borders of the right and left orbital rims. A total of 31 landmarks (Table 1) and 12 measurements were made on the CBCT (Table 2 and Figure 1). Three calibrated judges digitized cephalometric landmarks independently, outliers were excluded, and the average values were used for further analyses. Airway volume renderings were also generated for each patient and traced by 2 examiners (MA and HS). Each examiner was calibrated by generating airway volumes and MCA, the average values of both were used. The airway was measured at 2 areas: upper oropharynx (palatal plane to base of soft palate at the anterior most point), and lower oropharynx (soft palate to vallecula of epiglottis). Palatal plane was defined as the line connecting ANS to PNS. In both areas the following measurements were made: volume (VOL) in cm^3 and minimum cross-sectional area (MCA) in mm^2 (Figures 2-A & B). The sample was divided into G and NG groups. The growing subjects were defined as females under 15 years and males under 18 years. The growing sample was 24 (46%) and the non-growing was 28 (54%).

Statistical Analysis

Descriptive statistics were used to report the mean, standard deviation (SD), and range. Intraclass correlation coefficient (ICC) was used to evaluate inter-judge reliability for evaluating airway volume and MCA measurements. Inter-rater reliability was excellent with an ICC of greater than 0.92 for all airway measurements. Chi-square tests were used to compare proportions. Unpaired t-tests were used to compare mean differences and paired *t*-tests were used to compare pre- and post-treatment changes. In addition, Pearson correlation coefficient was used to measure the strength of association of statistically significant findings. A multiple regression was carried out to further evaluate which cephalometric changes significantly contributed to overbite correction. P-values less than 0.05 were considered statistically significant. IBM SPSS Statistics for Windows (version 24.0; IBM Corp) and the language R (version 3.6.1; R Foundation for Statistical Computing) were used to analyze the data.

RESULTS

The total sample consisted of 52 subjects, 29 females (55%) and 23 males (45%). The mean age was 20 years (range: 10-43 years). Total extraction cases were 16 (32%) and 36 non-extraction (68%). The average total treatment time was 34 months (2.9 years). The sample included 44 (85%) fixed appliance treatment and 9 (15%) Invisalign treatment. The sample characteristics among G and NG are summarized in Table 3. The number of AOB at different age groups is shown in Figure 3.

Cephalometric measurement changes

At T1, the following were statistically significant measurements between G and NG subjects: LFH, U6-PP, L6-MP, and L1-MP. All of the above values were greater in the NG subjects at T1 (Table 4).

At T2 the following measurements were statistically significant between G and NG subjects: FMA, IMPA, and OB. FMA and IMPA were greater at T2 for G subjects and OB was greater for NG subjects (Table 4).

For changes between T2-T1, the following measurements were statistically for G subjects: LFH, IIA, OB, OJ, U6-PP, U1-PP, L6-MP, L1-MP. LFH increased, most probably due to growth. IIA increased due to uprighting of the upper incisors. Overbite increased after open bite correction, while OJ decreased. Upper molars seem to have erupted less than 1mm, which means that during treatment the molar vertical position was either held or intruded (accounting for approximately 1mm eruption per year). However, lower molar vertical control was not seen as they seem to have erupted approximately 2.4mm on average. Upper incisors extruded which could have been a combination of growth and orthodontic extrusion. And lower incisors showed extrusion as well (Table 5).

Measurements that were statistically significant between T2-T1 for NG subjects were: FMA, IIA, IMPA, OB, U6-PP, U1-PP, and L1-MP. FMA decreased in the NG group. IIA increased due to uprighting of both upper and lower incisors. Overbite increased due to OB correction. Upper molars were intruded ~0.8mm. Upper and lower incisors were extruded, with greater extrusion seen in the upper incisors (Table 5).

The following measurements were significant between the groups from T2-T1: LFH, IMPA, U6-PP, L6-MP, and L1-MP. There was a greater increase in LFH, L6-MP and L1-MP in the G group probably due to normal growth. Changes in IMPA in the G group show less incisors uprighting after treatment. That might have happened because more extrusion of lower incisors was observed in the G group. Upper and lower molars in the NG group exhibited more vertical control than G group (Table 5).

Changes in various skeletal and dental measurements were also analyzed using regression analysis. We found that for every 1mm of L1 extrusion, there was 0.86mm of overbite increase. For every 1mm U1 extrusion, there was a 0.62mm overbite increase. Also, for every 1 degree increase in IIA, there was a 0.07mm increase in overbite. When FMA increases by 1 degree then overbite will decrease by 0.39mm. As LFH increased by 1 mm, overbite decreased by 0.68mm. All changes were statistically significant. However, the clinical significance of some of these changes is questionable.

Airway Dimension Changes

Airway changes were also analyzed through scatter plots by age. It seems that growing patients exhibit more airway changes (Figure 7), however, there was no statistically significant differences found in airway changes between G and NG groups (Table 6).

Airway Dimensional Changes and Cephalometric Measurements Changes

In the G group, mandibular length showed a positive correlation with U.VOL, L.VOL, L.MCA. Mandibular ramus length showed a positive correlation with L.VOL and L.MCA. ANB showed a negative correlation with U.VOL and U.MCA. B point and Pg position change showed a positive correlation with U.VOL and L.MCA. Upper incisor position positively correlated with U.VOL and L.MCA. Lower incisor position positively correlated with U.VOL, U.MCA, and L.VOL (Table 7).

In the NG group there was a positive correlation with L.VOL and FMA (Table 8). Therefore, there was only a positive correlation between FMA and L.VOL in NG individuals. Also, there was a statistically significant, and positive moderate correlation between mandibular growth and changes in upper and lower oropharynx.

DISCUSSION

Open bites can be caused by dental factors, skeletal factors or both. It can be accompanied by several clinical characteristics such as: excessive anterior face height (AFH), lip incompetence, mandibular deficiency/retrognathism, crowding in the lower arch, narrow maxilla and a posterior crossbite. Some of the radiographic characteristics include: steep palatal plane, increased lower face height, excessive eruption of maxillary posterior teeth, down and back rotation of the mandible, and excessive eruption of maxillary and mandibular incisors. Usually the lower face is the cause of disproportionate vertical facial relationships. Also, an open bite can exist with normal or long facial morphology. (Ngan et al).

The presence of overjet and OB forces the patient to place the tongue against the anterior teeth in order to create a seal when swallowing to prevent the escape of food or liquids. Also, this tongue tip protrusion during swallowing is at times associated with a forward position of the tongue. Patients with upper airway obstruction also experience a change in tongue and jaw position. To be able to breathe through the mouth, they lower the mandible and tongue, position the tongue forward, and extend the head. The lowered mandibular position causes eruption of posterior teeth, which results in a down and back rotation of the mandible[4]. It is therefore assumed that once the OB is corrected, the tongue will be in a more favorable position on the roof of the mouth. And the mandible with be in a more forward position, which theoretically could increase the upper airway volume.

A study conducted by Chen et al looked at airway changes after open bite closure using TADs in adult patients. They found that 2D measurements revealed an increase in the retroglossal area after treatment. 3D and MRI measurements revealed an increase in total airway, retropalatal and retroglossal volumes. However, the retroglossal volume was the only significant measurement. Their reasoning for airway increase were the changes in tongue and mandibular position. Another finding was mandibular counterclockwise rotation and more forward position of the mandible[5]. These findings contrast the current study as we did not find significant changes in airway morphology following treatment in adult patients. This difference can be attributed to the amount of open bite closure and the fact that they used TADs to intrude all maxillary posterior teeth and hold the mandibular teeth from extruding. While our sample consisted of only 40% TADs and had less vertical control on the lower molars.

Furaya et al looked at the effects in changes in mandibular position (intercuspal vs. bite-raised vs. mandibular advanced positions) on 3D shape of the oropharynx in adult subjects.

They found that the oropharyngeal volume and cross sectional area increased with a mandibular advancement device. This increase was mostly due to increased volume in the inferior oropharynx with forward movement of the tongue root. As the mandible moves forward it pulls the hyoid bone and tongue root which is how the inferior oropharynx increases in volume. (Furaya et al)[6]. Again this finding was not found in our current study probably due to the significantly greater mandibular advancement achieved in the Furaya study.

In a recent article by Vidal-Manyari et al, they looked at various upper airway measurements in OB and non-OB subjects using CBCT to determine whether there is a causal relationship between upper airway morphology and OB. They only looked at non-growing subjects to eliminate growth as a factor for airway changes. They found no differences in the linear measurements (AP) or volumes between OB and non-OB subjects. However, they did find a larger pharyngeal area in OB subjects than non-OB. This finding should be considered carefully as area is not an accurate measurement of airway size. Area represents only a small section of the total volume evaluated. Also, there could be anatomical variation that can skew the results. They reported that FMA was higher and overbite was less in the OB group. In addition, the oropharyngeal and total volumes were negatively correlated with ANB angle[7].

It is also important to look at the skeletal/dental characteristics that contribute to open bite and how their correction affects airway dimensions. Laranjo et al conducted a study to evaluate differences in upper airway dimensions and dentoalveolar heights in adult OB subjects vs. non-OB using lateral cephalogram. Their findings showed an increase in anterior facial and dentoalveolar heights and a decreases in PFH/AFH ratio in OB subjects. They found a lower value of oropharyngeal space OB subjects, increase in vertical airway dimension, and downward and forward movement of the hyoid bone. Vertical airway length was considered a good cephalometric indicator of OB tendency. The higher the vertical length, the greater the dentoalveolar height of upper first molar, and an increased tendency to vertical facial growth[8].

Pae et al sought to determine morphologic features that contribute to lack of overbite, an association between vertical upper airway length and lack of overbite, and whether pharyngeal length can determine an actual open bite from an open bite tendency. Their sample consisted of only growing subjects. They found vertical upper airway length is significantly related to lack of overbite. Vertical airway length distinguished between subjects lacking overbite and non-open bite. Also, measurements indicating a large MP might not necessarily mean the subject will have an actual OB. LFH plays a significant role in discriminating lack of overbite group and non-open bite group[9].

Some claim that airway dimensional changes occur due to abnormal function (mouth breathing). As demonstrated by Kerr et al in their study looking at non-mouth breathing male subjects at 5, 10 and 15 years of age using cephalometrics. They found no changes in nasopharyngeal airway accompanied by face height or overbite changes. Confirming that when function is normal, the relationship between nasopharyngeal morphology and anterior facial and dental dimensions are weak. It is more likely that posture due to mouth breathing will have a stronger association with changes in facial form[10].

Looking at the effects of orthognathic surgery on airway might give insight on similar movements done with TAD intrusion of posterior teeth and CCW rotation of the mandible, even though the effects are much greater in surgery. Several studies have reported an increase in pharyngeal airway after maxillomandibular advancement. Maxillomandibular advancement surgery increases the pharyngeal airway space and strengthens the suprahyoid and palatopharyngeal musculature to alter its bone fixations. This morphological change interrupts the repetitive collapse and consequently reduces hypopnea and apnea, normalizing the cardio-respiratory functions. (Prado et al)[11].

Mehra et al conducted a pilot study to assess the effect of double jaw orthognathic surgery with CCW rotation of the mandible on the pharyngeal airway. Their results show that this type of surgery increases the pharyngeal airway space at the base of the tongue and soft palate tip. With the increase at the base of the tongue being greater than the soft palate. This happens because the suprahyoid musculature of the mandible is maintained with CCW rotation of the maxillomandibular complex and it increases the oral cavity volume and anteriorly repositions the tongue and hyoid bone. They also found that the soft palate followed the anterior movement of the tongue[3].

No studies were found that look at the difference in airway morphology, specifically between G and NG groups, after OB correction. However, one study by Isidor et al aimed to determine whether functional appliance therapy in Cl II G subjects influences upper airway volume using CBCT. This is a similar concept to looking at airway changes after open bite correction in growing subjects if we expect more anterior mandibular position. They compared the Cl II functional appliance group to a Cl I control. They found a significant increase in oropharyngeal airway volume in the functional appliance group and hypothesized it might be due to dentoalveolar modifications that guide the tongue in a more forward position, enlarging the posterior airway space[12]. Therefore, in OB correction as well we expect the tongue to be in a more forward and superior position, theoretically enlarging the oropharyngeal airway volume as well. The results of the current study shows increases in oropharyngeal airway volume as well. However, these changes can also be attributed to normal growth as we saw no significant airway volume changes in the NG group.

CONCLUSION

Between T2-T1, the following cephalometric measurements were significant for G subjects: LFH, IIA, OB, OJ, U6-PP, U1-PP, L6-MP, L1-MP. And in the NG subjects the following measurements were significant: FMA, IIA, IMPA, OB, U6-PP, U1-PP, and L1-MP.

There was no statistically significant change in airway in G and NG subjects when looking at the whole sample. However, after analyzing the non-extraction G group there was a significant increase U.VOL, U.MCA and L.VOL.

There was a statistically significant correlation between airway dimensions and mandibular/ramus length, ANB, and L1 position changes in the full sample. In the G group, mandibular length showed a positive correlation with U.VOL, L.VOL, L.MCA.   Mandibular ramus length showed a positive correlation with L.VOL and L.MCA. ANB showed a negative correlation with U.VOL and U.MCA. B point and Pg position change showed a positive correlation with U.VOL and L.MCA. Upper incisor position positively correlated with U.VOL and L.MCA. Lower incisor position positively correlated with U.VOL, U.MCA, and L.VOL. There was no correlation with airway dimensions and any of the measurements after treatment in the NG group.

REFERENCES

1) Ngan P, Fields HW. Open bite: a review of etiology and management. *Pediatr Dent*. 1997;19(2):91-98.
2) Huang G, Baltuck C, Funkhouser E, et al. The National Dental Practice-Based Research Network Adult Anterior Open Bite Study: Treatment recommendations and their association with patient and practitioner characteristics. *Am J Orthod Dentofacial Orthop*. 2019;156(3):312-325. doi:10.1016/j.ajodo.2019.05.005
3) Mehra P, Downie M, Pita MC, Wolford LM. Pharyngeal airway space changes after counterclockwise rotation of the maxillomandibular complex. *Am J Orthod Dentofacial Orthop*. 2001;120(2):154-159. doi:10.1067/mod.2001.114647
4) Karacay S, Akin E, Ortakoglu K, Bengi AO. Dynamic MRI evaluation of tongue posture and deglutitive movements in a surgically corrected open bite. *Angle Orthod*. 2006;76(6):1057-1065. doi:10.2319/112005-405
5) Chen Y, Hong L, Wang CL, et al. Effect of large incisor retraction on upper airway morphology in adult bimaxillary protrusion patients. *Angle Orthod*. 2012;82(6):964-970. doi:10.2319/110211-675.1
6) Furuya J, Tamada Y, Suzuki T. Effect of mandibular position on three-dimensional shape of the oropharynx in seated posture. *J Oral Rehabil*. 2012;39(4):277-284. doi:10.1111/j.1365-2842.2011.02263.x
7) Patricia Aurora Vidal-Manyari, Luis Ernesto Arriola-Guillén, Ludy Marileidy Jimenez-Valdivia, Heraldo Luis Dias-Da Silveira, Mariana Boessio-Vizzotto. Upper airways evaluation in young adults with an anterior open bite: A CBCT retrospective controlled and cross-sectional study. *International Orthodontics*. 2020;18(2): 276-285. doi.org/10.1016/j.ortho.2020.02.007.
8) Laranjo F, Pinho T. Cephalometric study of the upper airways and dentoalveolar height in open bite patients. *Int Orthod*. 2014;12(4):467-482. doi:10.1016/j.ortho.2014.10.005
9) Pae EK, Kuhlberg A, Nanda R. Role of pharyngeal length in patients with a lack of overbite. *Am J Orthod Dentofacial Orthop*. 1997;112(2):179-186. doi:10.1016/s0889-5406(97)70244-0
10) Kerr WJ. The nasopharynx, face height, and overbite. *Angle Orthod*. 1985;55(1):31-36. doi:10.1043/0003-3219(1985)055<0031:TNFHAO>2.0.CO;2
11) Prado FB, Rossi AC, Freire AR, Groppo FC, De Moraes M, Caria PH. Pharyngeal airway space and frontal and sphenoid sinus changes after maxillomandibular advancement with counterclockwise rotation for Class II anterior open bite malocclusions. *Dentomaxillofac Radiol*. 2012;41(2):103-109. doi:10.1259/dmfr/22419253
12) Isidor S, Di Carlo G, Cornelis MA, Isidor F, Cattaneo PM. Three-dimensional evaluation of changes in upper airway volume in growing skeletal Class II patients following mandibular advancement treatment with functional orthopedic appliances. *Angle Orthod*. 2018;88(5):552-559. doi:10.2319/083117-587.1

Figures and Tables

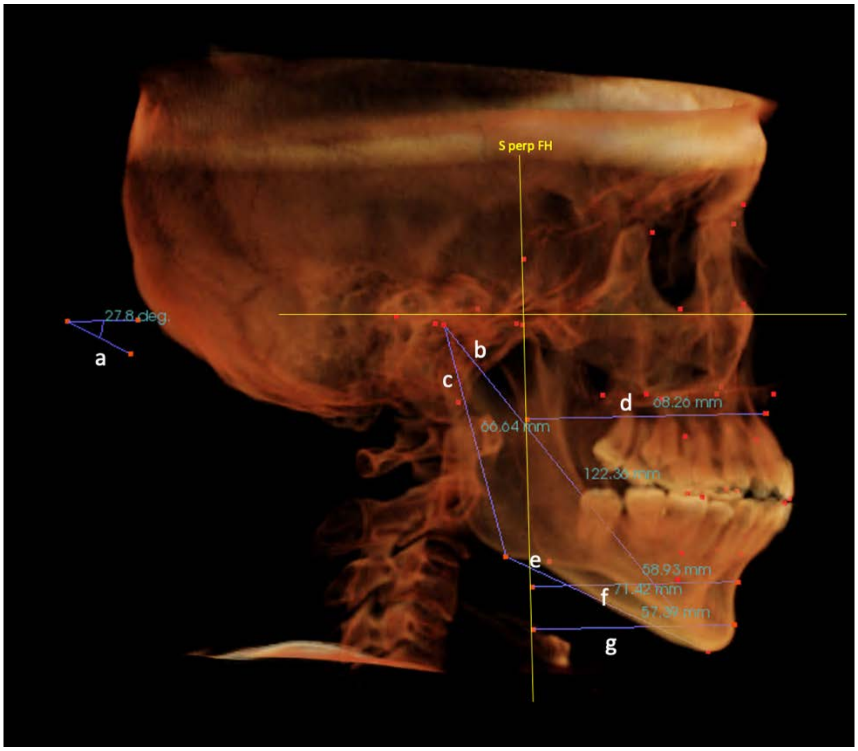

Figure 1-A. CBCT Measurements: **a,** FMA; **b,** Mandibular length; **c,** Mandibular ramus length; **d,** Sella perpendicular A; **e,** Mandibular body length; **f,** Sella perpendicular B; **g,** Sella perpendicular Pogonion.

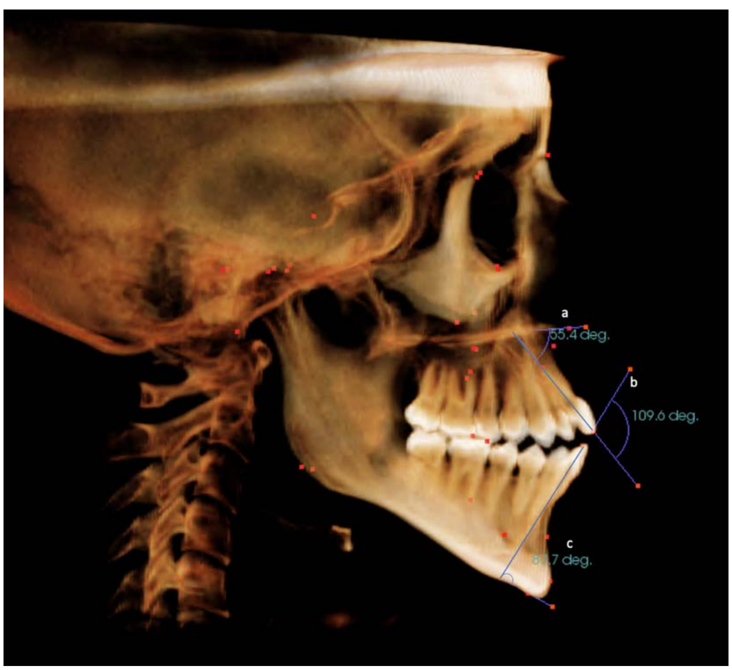

Figure 1-B. CBCT Measurements. **a,** U1PPA (upper incisor to palatal plane); **b,** IIA (interincisal angle); **c,** IMPA (lower incisors to MP).

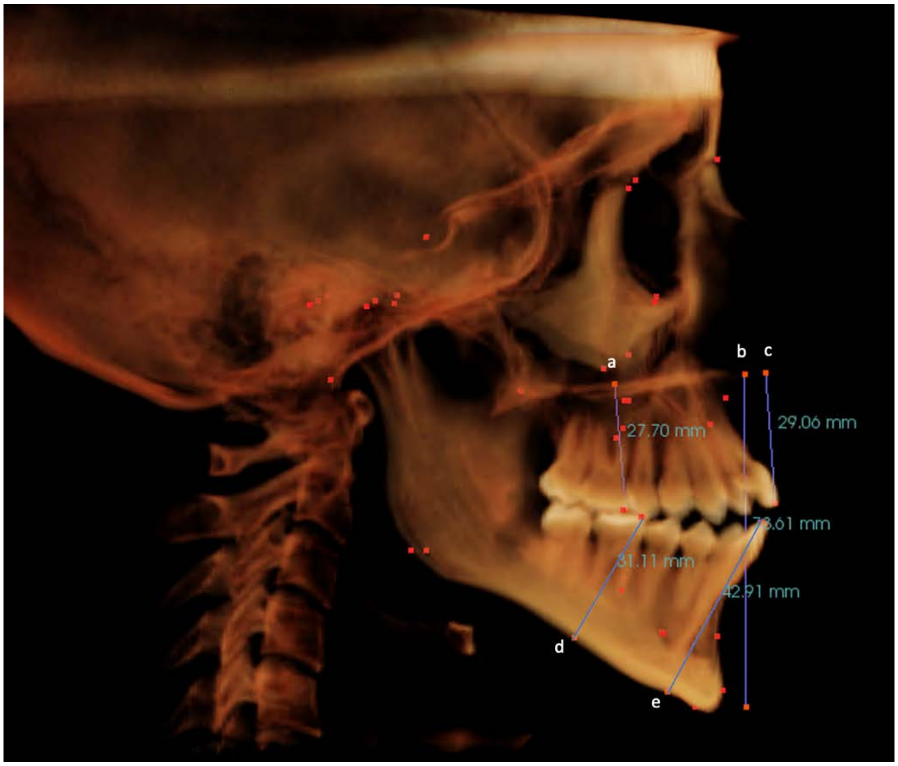

Figure 1-C. CBCT Measurements. **a,** U6-PP (mm); **b,** LFH (ANS-Me); **c,** U1-PP (mm); **d,** L6-MP (mm); **e,** L1-MP (mm).

Figure **2-A.** Volume measured from upper (1) and lower (2) oropharyngeal airway; **2-B.** MCA measured from upper (1) and lower (2) oropharyngeal airway

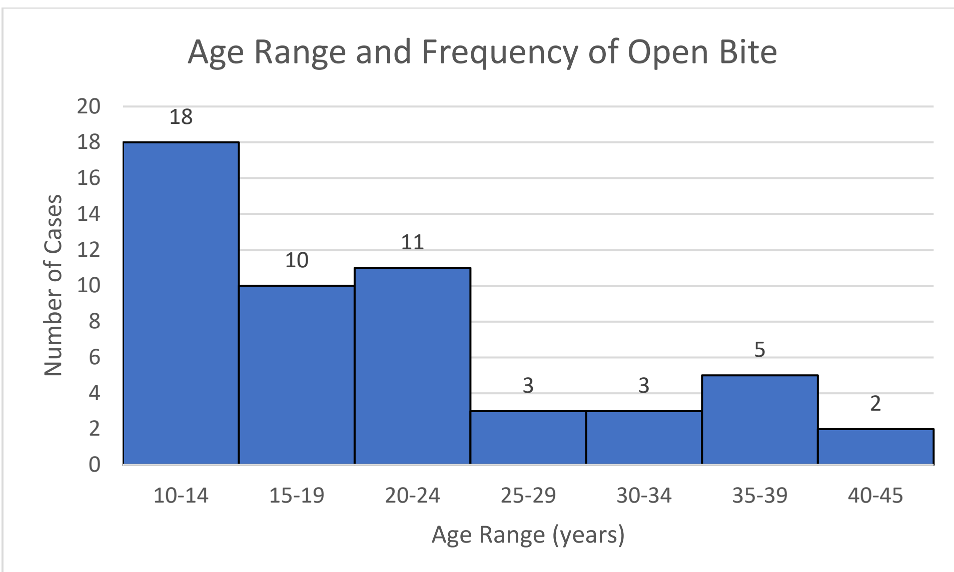

Figure 3. The number of AOB at different age groups.

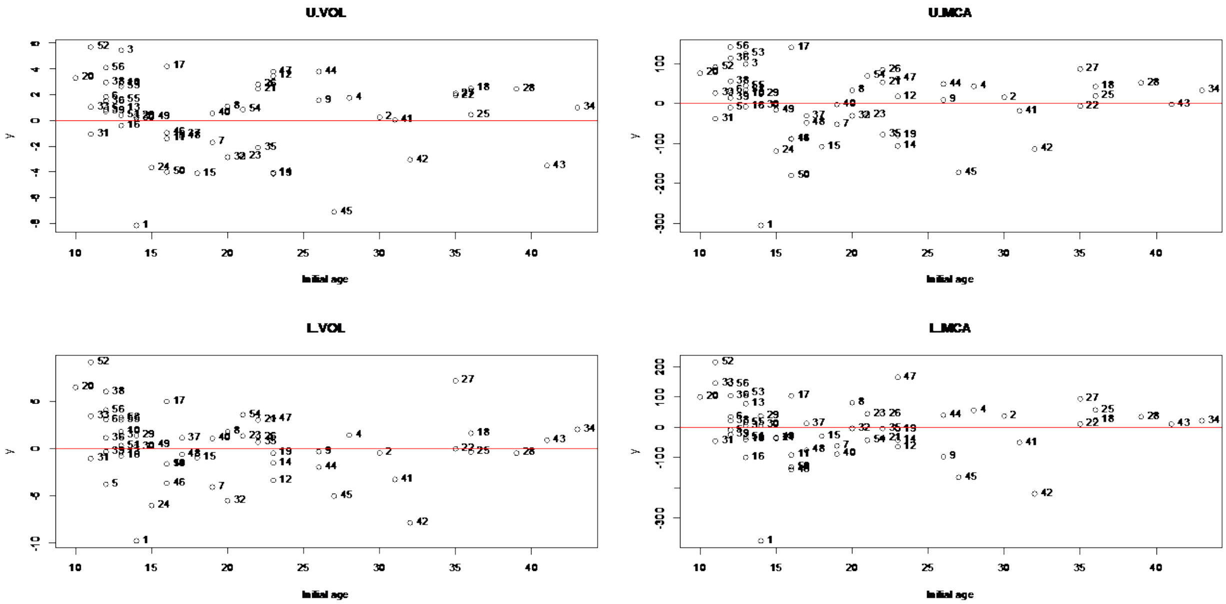

Figure 4. Scatter plot of airway changes vs age.

Table 1. Skeletal and dental landmarks identified on CBCT

Landmarks	
Skeletal :	**Dental:**
• Nasion	• Upper Right Central Incisor Mesio-incisal corner
• Orbitale (R & L)	• Upper Right Central Incisor Apex
• Porion (R & L)	• Lower Right Central Incisor Mesio-incisal corner
• Basion	• Lower Right Central Incisor Apex
• Sella	• Upper First Molar Mesiobuccal cusp (R & L)
• Nasal Bone Point	• Upper First Molar Distobuccal cusp (R & L)
• Frontozygomatic suture (R & L)	• Upper First Molar Mesiolingual cusp (R & L)
• Pogonion	• Upper First Molar Distolingual cusp (R & L)
• Temporal Fossa Point (R & L)	• Lower First Molar Mesiobuccal cusp (R & L)
• A point	• Lower First Molar Distobuccal cusp (R & L)
• Key Ridge (R & L)	• Lower First Premolar Buccal cusp (R & L)
• Jugale (R & L)	• Upper First Premolar Buccal cusp (R & L)
• Anterior Nasal Spine	
• Posterior Nasal Spine	
• B point	
• Menton	
• Gonion (R & L)	
• Condylion (R & L)	
• Mental Foramen (R & L)	

Table 2. Measurements calculated from CBCT landmarks

Measurements
Mandibular length
Mandibular ramus length
Mandibular body length
Mandibular plane angle
ANB
SNA
SNB
Sella perp A
Sella perp B
Sella perp Pog
Sella perp U1 (y coordinate of landmark U1)
Sella perp L1 (y coordinate of landmark L1)

Table 3. Sample characteristics of growing and non-growing open bite patients

	Growing patients (n=24)	Non-growing (n=28)	*p**
	Number (%)	Number (%)	
Sex (Male)	10 (42%)	14 (50%)	NS
Appliance type			
Fixed appliance	24 (100%)	19 (68%)	0.002
Clear aligner	0	9 (32%)	
TAD	10 (42%)	11 (39%)	NS
Extraction	12 (50%)	5 (18%)	0.02
Skeletal openbite (FMA>30°)	8 (33%)	7 (25%)	NS

*, Chi-square test

Table 4. Comparison of cephalometric measurements between growing and non-growing open bite patients at T1 and T2.

	T1				T2		
	Growing Patients (n=24)	Non-growing (n=28)	P*		Growing Patients (n=24)	Non-growing (n=28)	P*
	Mean ± SD	Mean ± SD			Mean ± SD	Mean ± SD	
Age (years)	13.25 ±1.92	26.79 ± 7.6	**<.0001*** **		16.29 ± 2.03	29.64 ± 8	**<.0001*** **
SNA (°)	**80.9 ± 4.32**	**81.5 ± 5.8**	**0.6**		**80.58 ± 4.41**	**81.6 ± 5.68**	**0.4799**
SNB (°)	76.27 ± 5.21	78.03 ± 4.9	0.2142		76.3 ± 5.42	78.23 ± 4.66	0.1734
ANB (°)	**4.65 ± 2.35**	**3.66 ± 2.56**	**0.1526**		**4.48 ± 2.53**	**3.61 ± 2.28**	**0.1964**
FMA (°)	29.39 ± 5.48	26.55 ± 5.81	0.0772		28.94 ± 5.45	25.39 ± 5.08	**0.0188***
LFH (mm)	**65.9 ± 6.44**	**69.81 ± 6.67**	**0.0374***		**68.16 ± 6.96**	**69.14 ± 6.5**	**0.6020**
IIA (°)	115.69 ± 8.38	119.04 ± 13.14	0.2875		122.92 ± 9.57	127.85 ± 9.33	0.0659
U1PPA (°)	**117.72 ± 6.47**	**118.02 ± 9.35**	**0.8977**		**113.61 ± 9.69**	**114.35 ± 7.81**	**0.7623**
IMPA (°)	98.94 ± 5.4	99.76 ± 6.47	0.6225		100.17 ± 5.99	96.37 ± 4.9	**0.0151***
OB (mm)	**-2.22 ± 1.4**	**-2.54 ± 2.24**	**0.5440**		**0.64 ± 0.78**	**1.19 ± 1.1**	**0.0464***
OJ (mm)	3.74 ± 2.74	2.7 ± 2.4	0.1508		2.42 ± 0.62	2.68 ± 0.66	0.1560
U6-PP (mm)	**23.41 ± 2.87**	**25.13 ± 2.73**	**0.0315**		**24.05 ± 3**	**24.36 ± 2.88**	**0.7071**
U1-PP (mm)	27.24 ± 4.16	27.38 ± 4.8	0.9064		29.56 ± 4.13	28.91 ± 3.92	0.5605
L6-MP (mm)	**30.9 ± 3.37**	**33.53 ± 3.35**	**0.0069****		**33.27 ± 2.65**	**33.9 ± 3.24**	**0.4521**
L1-MP (mm)	38.61 ± 3	41.02 ± 3.73	**0.0143***		40.44 ± 2.85	41.97 ± 3.74	0.1082

*** Independent t test**

Table 5. Table IV. Comparison of treatment time and cephalometric changes during treatment (T1-T2) between growing and non-growing OB subjects

Measurements		Changes (T2-T1) Growing (n=24) Mean± SD	Non-growing (n=28) Mean± SD	*P* ‡
Treatment time		3.04 ± 1.33	2.86 ± 1.04	0.58
Skeletal-AP	**SNA (°)**	-0.31 ± 1.1	0.06 ± 0.81	0.17
	SNB (°)	0.02 ± 1.53	0.19 ± 1.2	0.64
	ANB (°)	-0.18 ± 1.24	-0.05 ± 0.96	0.68
Skeletal-vertical	**FMA (°)**	-0.46 ± 1.4	-1.16 ± 1.58***	0.10
	LFH (mm)	2.25 ± 2.32***	-0.66 ± 2.24	**<0.0001**
Incisor inclination	**IIA (°)**	7.21 ± 11.41**	8.81 ± 15.22**	0.67
	U1PPA (°)	-4.11 ±10.13	-3.67 ± 10.19	0.88
	IMPA (°)	1.23 ± 6.68	-3.4 ± 5.74**	**0.01**
Dental linear measurements	**OB (mm)**	2.86 ± 1.51***	3.73 ± 2.43***	0.13
	OJ (mm)	-1.32 ± 2.88*	-0.03 ± 2.31	0.08
	U6-PP (mm)	0.64 ± 1.3*	-0.77 ± 1.16**	**<0.0001**
	U1-PP (mm)	2.32 ± 1.68***	1.52 ± 1.98***	0.13
	L6-MP (mm)	2.38 ± 1.67***	0.37 ± 0.97	**<0.0001**
	L1-MP (mm)	1.85 ± 1.28***	0.94 ± 1.28***	**0.01**

Table 6. Airway Dimensional Changes (T1-T2) in Growing and Nongrowing Subjects

Airway dimension	Growing patients (n=24)				Non-growing patients (n=28)				$P^{‡}$
	T1	T2	T2-T1		T1	T2	T2-T1		
	Mean ± SD	Mean ± SD	Mean ± SD	$P^{§}$	Mean ± SD	Mean ± SD	Mean ± SD	$P^{§}$	
U.VOL	6.79 ± 3.18	7.615 ± 2.55	0.825 ± 2.36	NS	8.782 ± 3.87	8.911 ± 4.56	0.1291 ± 2.58	NS	NS
U.MCA	175.82 ± 81.41	185.8 ± 65.42	9.952 ± 72.19	NS	187.3 ± 96.03	185.56 ± 96.22	-1.75 ± 60.65	NS	NS
L.VOL	6.535 ± 4.11	7.638 ± 3.34	1.1021 ± 3.25	NS	6.991 ± 4.45	6.821 ± 3.57	-0.1696 ± 3.06	NS	NS
L.MCA	163.32 ± 89.99	174.7 ± 78.04	11.335 ± 82.26	NS	167.4 ± 119.75	161.5 ± 92.34	-5.852 ± 76.58	NS	NS

§ Intragroup comparison of T2-T1 difference (paired-sample *t* test; siginificance at *P*<.05);

* P<.05; ** P<.01; *** P<.001; NS, not significant.

‡ Independent *t* test

Table 7. Correlation between airway dimensions and cephalometric changes in the growing sample (n=24).

	Growing patients (n=24)							
	U.VOL		U.MCA		L.VOL		L.MCA	
	r	$P^{§}$	r	$P^{§}$	r	$P^{§}$	r	$P^{§}$
Mn length	0.42*	0.04	0.33	NS	0.52	0.01	0.51*	0.01
Mn ramus length	0.3	NS	0.25	NS	0.47	0.02	0.48*	0.02
Mn body length	0.45*	0.03	0.37	NS	0.36	0.09	0.37	NS
FMA	-0.33	NS	-0.33	NS	-0.06	NS	-0.24	NS
SNB	0.34	NS	0.27	NS	0.29	NS	0.35	NS
ANB	-0.42*	0.04	-0.43*	0.03	-0.29	NS	-0.34	NS
SNA	0.11	NS	0	NS	0.14	NS	0.26	NS
S perp A	0.25	NS	0.09	NS	0.32	NS	0.27	NS
S perp B	0.48*	0.02	0.38	NS	0.38	NS	0.44*	0.03
S perp Pog	0.45*	0.03	0.36	NS	0.34	NS	0.42*	0.04
S perp U1	0.41	0.05	0.37	NS	0.29	NS	0.42*	0.04
S perp L1	0.46*	0.02	0.42*	0.04	0.51*	0.01	0.37	NS

r= correlation coefficient

* P<.05; ** P<.01; *** P<.001; NS, not significant.

Table 8. Correlation between airway dimensions and cephalometric changes in the non-growing sample

	Non-growing group (n=28)							
	U.VOL		U.MCA		L.VOL		L.MCA	
	r	p	r	p	r	p	r	p
Mn length	0.03	NS	0.22	NS	0.06	NS	0.12	NS
Mn ramus length	0.07	NS	0.04	NS	0.21	NS	-0.05	NS
Mn body length	-0.15	NS	0.03	NS	0.07	NS	0.17	NS
FMA	0.02	NS	0.06	NS	0.43	0.02	0.05	NS
SNB	0.01	NS	0.13	NS	-0.24	NS	0.16	NS
ANB	-0.24	NS	-0.22	NS	-0.22	NS	-0.15	NS
SNA	0.04	NS	0.09	NS	-0.32	NS	0.11	NS
S perp A	-0.1	NS	-0.08	NS	-0.17	NS	-0.19	NS
S perp B	-0.08	NS	0	NS	-0.27	NS	-0.01	NS
S perp Pog	-0.06	NS	-0.01	NS	-0.29	NS	-0.06	NS
S perp U1	0.03	NS	-0.01	NS	-0.25	NS	-0.03	NS
S perp L1	0.11	NS	0.13	NS	-0.21	NS	0.08	NS

r= correlation coefficient; NS, not significant.