University of Alberta

Cone-Beam Computed Tomography Evaluation of Oropharyngeal Airway Dimensions in Adolescents with Maxillary Transverse Deficiency

by

Brent Yaremko

A thesis submitted to the Faculty of Graduate Studies and Research in partial fulfillment of the requirements for the degree of

Master of Science

in

Medical Sciences - Orthodontics

Fall 2012
Edmonton, Alberta

Dedication

I would like to dedicate this thesis first and foremost to my wife Sarah, for all her love and understanding, and her belief in me as a student, as a husband, and as a father. For the countless hours of help, and the many unspoken tasks completed to help me achieve my goals, I cannot thank you enough.

To my kids, Jordan and Benjamin, for their understanding that daddy has to go to work tonight, and their trust in me to return to play another day.

And to my parents, Terry and Pamela, who encouraged me to achieve more than what I thought was possible, and who have loved and supported me through everything.

Abstract

Objectives: The objective of this study is to analyze cone-beam computed tomography (CBCT) images to measure changes in oropharyngeal airway (OPA) dimensions after treatment with rapid maxillary expansion (RME), and compare these changes with those from a matched control group.

Methods: This randomized controlled clinical trial included an untreated matched control group of 38 subjects, and a treatment group of 37 subjects with maxillary transverse deficiency that received RME with a hyrax appliance. CBCT scans were taken at baseline and after 6 months and were analyzed for changes in OPA volume and cross-sectional area measurements.

Results: A MANOVA revealed no significant changes in OPA volume and cross-sectional area measurements between subjects treated with RME compared to an untreated group over a 6 month time period.

Conclusion: Treatment with a hyrax appliance did not yield a significant effect in changing OPA dimensions.

Table of Contents:

List of Tables

List of Figures

Chapter 1 – Introduction and Literature Review

1.1 Introduction- Statement of the problem

The upper airway and the maxillofacial structures have been understood to interrelate due to their anatomical proximity.[1,2,3,4] An appreciation for the effect of a compromised airway on the growth and development of the skeletal and dental structures has been demonstrated through the development of the characteristic adenoid faces associated with a constricted maxilla, posterior crossbite, open bite tendencies, long lower face height, and high mandibular plane angle.[5,6] The reciprocal relationship of the orofacial structures on the airway has also been studied, but less conclusive results have been identified to support this correlation. More specifically, the interrelationship of the oropharynx and maxillary expansion has been studied in recent years. [7,8,9,10,11,12] It has been hypothesized that by expanding the maxilla with an orthodontic appliance, additional space is created for the tongue to be positioned more superiorly and anteriorly, thus increasing the oropharyngeal airway (OPA) space posteriorly.[13,14,15] This may have implications in the research of sleep disordered breathing therapies.[14,15]

Cone-beam computed tomography (CBCT) offers three-dimensional (3D) cross-sectional and volumetric analysis of the complex anatomy of the upper airway.[16] Its popularity over other 3D imaging tools is its accessibility, low cost, and remarkably reduced radiation exposure compared to conventional CT.[17,18,19,20]

With the increase in usage of CBCT technology becoming more widely spread in orthodontic private practices, more information is being offered than ever before to the clinician in these scans.[17,20] A desire for utilizing measurements such as airway dimensions from these scans thus exists.[16,21] The purpose of this study is to measure OPA dimensions on CBCT scans to help better understand the relationship of the OPA with the maxilla when the maxilla is expanded for orthodontic purposes.

1.2 Significance of the Study

The upper airway, and the OPA in particular, have been a research interest in the orthodontic literature as of late due to the increased awareness of obstructive sleep apnea (OSA).[14,15,22,23] Because the lumen of the OPA is the most prone to collapse in patients susceptible to OSA, the focus of treatment has been to maintain patency at this site.[24] Due to their education in facial growth and development as well as craniofacial and dentofacial anomalies, orthodontists are capable to assist in screening for and having a role in the treatment of OSA.[25] This study may provide insight for future sleep studies as to the role orthodontic appliances, specifically maxillary expansion, may play in assisting individuals with sleep apnea.

1.3 Research question

Do OPA dimensions of volume and minimum cross-sectional areas measured on CBCT images differ before and after expansion of the maxilla with a rapid maxillary expander compared to an untreated matched control group?

1.4 Hypothesis

This study tested a hypothesis interested in assessing whether 4 airway dimensions, volume (vol), cross-sectional area at the inferior level of the soft palate (SP), cross-sectional area at a midway point up the soft palate (MP), and minimum cross-sectional area (MCA), changed over time due to expansion therapy:

H_o: Mean Vol, SP, MP, and MCA are the same between time points for treatment and control groups.

1.5 Literature Review

1.5.1 Airway in Orthodontics- Introduction

The upper airway has been studied in orthodontics for over half of a century due to its close approximation to the maxillofacial structures.[4] Historically, airway studies in orthodontics have been aimed at assessing the role of airway obstruction on the growth and development of the skeletal and soft tissue structures of the head and neck.[6,26] More recently, studies have shifted focus to the use of various interventions, such as intraoral appliances [27,28,29,30] and orthognathic surgeries[31,32,33] in relieving airway obstructions and the potential effect on sleep disordered breathing.

1.5.2 Anatomic Boundaries of the Upper Airway

The boundaries of the upper airway have been defined with slight variations throughout the literature.[11,12,33] For instance, in Ribeiro et al,[12] the retroglossal area is categorized as part of the nasopharynx whereas Schwab[33] describes the retroglossal area as part of the oropharynx. For the purposes of this study the upper airway shall be characterized as follows: The three main subsections of the upper airway are made up of the nasal cavity, the nasopharynx, and the oropharynx. The nasal cavity begins at the entrance of the external nares and proceeds through to the posterior border of the nasal turbinates. The nasopharynx then begins at the distal border of the nasal cavity and is separated from the oropharynx by the most posterior border of the hard palate. The oropharynx is then divided into two parts; the retropalatal area from the most posterior and inferior surface of the hard palate to the inferior border of the soft palate, and the retroglossal portion from the inferior border of the soft palate to the level of the epiglottis. Inferior to the epiglottis is the laryngopharyngeal space, also referred to as the hypopharynx. The focus of this study is the OPA and its dimensions as it relates to changes in the oral cavity.

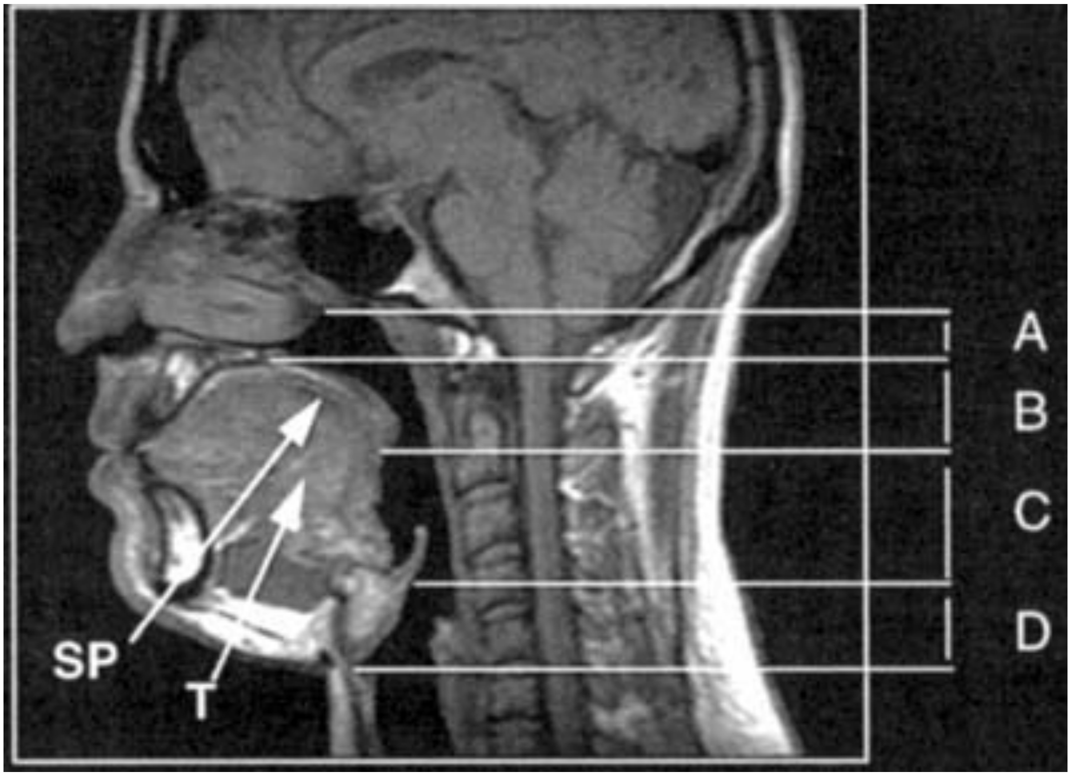

Figure 1-1: Boundaries of the Upper Airway: A=Nasopharynx, B=Retropalatal region of the Oropharynx, C=Retroglossal region of the Oropharynx, D=Laryngopharynx.[33]

1.5.3 – Interrelationship Between Upper Airway and Craniofacial Structures

A mutual relationship is understood to exist between the upper airway and the dentofacial structures due to their close anatomical location in relation to each other. [1,2,3] Early airway studies in orthodontics utilized two-dimensional (2D) measurements on lateral and anterior-posterior (AP) cephalograms, and demonstrated certain skeletal factors, such as a reduced cranial base angle and short mandibular length, are associated with a narrowing of the airway dimensions.[34,35,36] Joseph et al[37] also concluded that individuals with bimaxillary retrusion showed a marked decrease in AP airway dimension. In addition, the vertical maxillary excess that is common to hyperdivergent individuals leads to downward rotation of the mandible causing the tongue to be positioned more posteriorly and inferiorly, thus invading the OPA.[37,38] The limitation of such studies is the 2D nature of lateral cephalograms representing a 3D structure in missing key information about the complex nature of the upper airway.[39] The introduction of 3D imaging has allowed researchers to study the upper airway dimensions in greater detail.

Alves et al[19] was one of the first to study the upper airway in 3D using computed tomography. Their results indicated that the transverse measurements of the nasopharynx showed a greater variation between craniofacial types than the AP dimensions of the airway, with Class II subjects displaying a significantly greater reduction in transverse dimension. Another 3D study by Kim et al[40] examined the upper airway in Class I and Class II facial types and found the Class II retrognathic pattern to have a smaller total airway volume. However, when the airway was divided into subsections, all cross-sectional and volume measurements were similar between craniofacial types. When examining the shape of the upper airway among various facial patterns, Grauer et al[41] found that Class II subjects showed a more forward inclination of the airway volume, whereas a more vertically oriented airway shape was found in the Class III group. They found volume differences existed between the various AP jaw relationships, but were not significantly different between the various vertical jaw relationships. Although the use of 3D imaging has greatly enhanced the ability to measure the complexities of the upper airway, new challenges have arose with respect to consistency of measurements. The previously mentioned studies demonstrate the variation of results present within the literature, and indicate a need for further investigation and consensus on the correlation between airway form and craniofacial structures.

In 2D studies the narrowing of the upper airway is shown to be associated with AP and vertical discrepancies in jaw position whereas in 3D studies, the transverse dimension seems to also impact pharyngeal changes. The position of the hyoid bone has a role in securing the pharyngeal airway due to the attached musculature that influences the tonicity of surrounding soft tissues.[42] Battagel et al[43] found the hyoid bone to be posteriorly positioned in Class II individuals which resulted in a narrow upper airway, while Adamidis et al[44] showed the hyoid bone to lie more anteriorly in Class III patients allowing for normal OPA dimensions. The influence of change in AP position of the mandible on hyoid bone position and the OPA space has been repeatedly verified in the literature.[43,44,45,46] Surgical advancement of the mandible has been shown to result in anterior repositioning of the hyoid and is critical in the surgical treatment of sleep apnea to increase the pharyngeal space.[45] The opposite effect on the airway is seen in mandibular set back procedures as a result of the repositioning of the hyoid bone superiorly during healing, resulting in a reduction in the pharyngeal airway space.[46]

1.5.4 Respiratory Obstruction and Facial Morphology

It has long been assumed that respiratory function has an effect on dentofacial development due in part to their close anatomical relationship.[3,6] Obstruction of the airway may be caused by a multitude of factors; these include hypertrophic adenoids and tonsils, chronic and allergic rhinitis, environmental irritants, infections, congenital nasal deformities, nasal trauma, polyps and tumors, and an excessively narrow airway.[3,6,47] Obstruction of the nasal airway inevitably leads to mouth breathing, which, when it becomes a common habit, can have a deleterious effect on the dentition and supporting facial structures as a result of altering tongue posture and mandibular position.[6,26]

To demonstrate the effect of airway obstruction on craniofacial structures, a number of studies were published by Harvold, Miller, and Vargervik, that involved artificially occluding the nasal airway of monkeys to study their neuromuscular adaptation.[48,49,50] It was discovered with these primate experiments that in blocking the nasal passage way and forcing the monkeys to become mouth breathers, a number of physiological patterns developed including a lowered mandibular posture, forward rest position of the tongue, and eruption of the posterior dentition. The lowered mandibular posture promoted changes to the shape of the mandible, particularly a relative shortening of the ramus and an increase in gonial angle, and led to a downward displacement of the maxilla. These findings provide a basis for understanding the influence of neuromuscular adaptation to an obstructed airway;

namely that the similar physiological responses to mouth breathing as seen in monkeys would also be occurring in humans.[48,49,50]

The term "adenoid facies" has been used to describe the general appearance of an individual who presents with a combination of such features as open mouth posture, hypotonia, mouth breathing, low tongue posture, constricted pharyngeal airway, narrow base of the nose and nares, narrow maxilla, high palate, increased lower anterior facial height, steep angle of the mandible, retrognathic mandible and retroclined mandibular incisors.[5,6] The etiology of adenoid facies, as the name suggests, originally was considered to be due to adenoid hypertrophy, [5] but in fact any number of other airway disturbances may be at fault, making the name a bit of a misnomer. Another term, the "long face syndrome" describes a similar characteristic growth pattern and may in some cases have the same etiology as the adenoid facies.[47,51] Lack of muscle balance is a major factor in why these symptoms occur. For example, mouth breathing results in low tongue posture which leads to constriction of the maxilla as the low tongue position is not able to balance the force of the cheek against the maxillary alveolus. This in turn forces the mandible open and extends the posture of the head, leading to the dentofacial changes previously described.[34]

Adenoidectomy and tonsillectomy studies have shown positive results in "reversing" the unfavorable growth pattern in patients exhibiting airway obstruction from enlarged adenoids and tonsils.[5,49,50,52] The main outcome was found to be an increase in the corpus length of the mandible by anterior advancement of the symphysis,[52] and change in the mandibular plane angle.[52,53] This reversal effect strengthens the causative effect obstruction of the airway plays on craniofacial development.[26] However, a large variation in results occurred in these studies in the changes to the pattern of growth, thus the cause and effect interaction between airway obstruction and craniofacial form seems to be multifactorial in nature.[54]

1.5.5 Obstructive sleep apnea in Orthodontics

Obstructive sleep apnea (OSA) is characterized by repetitive episodes of upper airway obstruction that occur during sleep, resulting in reduced blood oxygen saturation. A study by Lowe et al[23] demonstrated a common pattern among sleep apnea subjects to include a posteriorly positioned maxilla and mandible, a steep occlusal plane, overerupted maxillary and mandibular teeth, proclined incisors, a steep mandibular plane, a large gonial angle, high upper and lower facial heights, and an anterior open bite in association with a large tongue and a posteriorly placed pharyngeal wall. These craniofacial features of OSA resemble those of children with adenoid facies.[55] As such, these alterations in craniofacial form may reduce the upper airway dimensions and subsequently impair upper airway stability.[23]

Among the different types of apnea, obstruction of the oropharynx is due to the collapse of soft tissues structures such as the base of the tongue, soft palate with uvula, tonsils, epiglottis and pyriform sinuses.[22,56,57] A correlation has been shown to exist between minimum cross-sectional area of the OPA and oxygen saturation in addition to length of apneic episodes.[56] Furthermore, in patients who suffer from OSA, it is the retroglossal and retropalatal sites that are most susceptible to collapse and therefore changes in the dimension of these sites are of particular importance.[24] Several dental specialties have focused on enlarging the OPA by way of surgical intervention or oral appliance therapy.[8,25]

The rationale behind orthognatic surgical advancement of both the maxilla and mandible is to enlarge all levels of the upper airway anterior-posteriorly as well as laterally, and reduce the collapsibility of the surrounding soft tissue and musculature.[31,32,33] Mandibular repositioning appliances have been shown to enlarge the OPA by protruding the mandible and repositioning the tongue more anteriorly to prevent collapse of soft tissues during sleep.[27,28,29,30] These appliances are meant for mild to moderate OSA sufferers who are not compliant with other medical devices such as the Continuous Positive Airway Pressure device.[32] Another appliance therapy involving maxillary expansion has gained popularity in the literature due not only to its direct effects on the nasal cavity, but by indirectly affecting the OPA by providing more room in the oral cavity for the tongue to be positioned anteriorly.[13,58]

1.5.6 Maxillary Expansion and Airway

Studies examining orthodontic treatment to improve airway have focused on expansion of the maxilla and its effect on the nasal cavity since they share a common border of the palate and nasal floor.[59,60,61] Maxillary expansion is commonly performed in orthodontics for the purpose of treating maxillary transverse deficiency for the correction of posterior crossbites, and to introduce space into the dental arch to aid in the relief of crowding.[62,63] Maxillary expansion can either be completed orthopedically with a slow or rapid maxillary expander, or with a surgical technique of either a surgically assisted rapid palatal expansion (SARPE) or transverse segmental osteotomy in non-growing adults once the palatal suture has been fused.[64,65,66] The non-surgical techniques rely on the palatal suture being open, allowing for separation of the palatal halves, thus expanding the arch perimeter of the dentition.[65,66,67,68]

It is expected that the nasal cavity will be affected by this separation of the palatal suture, resulting in expansion of the nasal floor.[66,68,69] Though it is now generally acknowledged that an anatomical change happens in the nasal cavity following maxillary expansion, the literature is unclear as to whether this change is clinically significant.[69,70] Thus far, improvement in respiratory function as a result of maxillary expansion has not consistently been proven.[68,69,70] Individual variation exists in the improvement of respiratory function after maxillary expansion since increasing nasal cavity dimensions does not improve the other multitude of potential obstructing factors such as nasal concha hyperplasia, nasal polyps, adenoid hypertrophy, and septal deviations.[71] Thus, justification for the use of maxillary expansion for the sole purpose of improving nasal airway dimensions has not been recommended.[69,70,71]

More recently maxillary expansion has been studied in the literature to assess its impact on relieving OSA.[14,72,73] In a preliminary study by Cistulli et al,[14] an improvement in 9 out of 10 young adult patients with constricted maxillas suffering from mild to moderate OSA was shown. This was demonstrated by a reduction in their apnea/hypopnea index from 19 apneas and hypopneas per hour of sleep to 7 events per hour after maxillary expansion. This same improvement was demonstrated in a study by Pirelli et al[72] in which 31 growing children with OSA and maxillary constriction showed a reduction in apnea/hypopnea index from 12.2 events per hour to less than one. Villa et al[73] also showed a marked decrease in OSA symptoms in 14 treated patients with maxillary expansion, suggesting maxillary expanders as a effective appliance for treating OSA in growing individuals. Johal et al[74] emphasizes that maxillary expansion however should not be used to treat OSA without the presence of maxillary constriction as it is not the sole etiological factor in this disorder.

1.5.7 Maxillary expansion and the Oropharyngeal Airway

The effect of maxillary expansion on OSA in the aforementioned studies was suggested to improve due to enhanced airflow in an expanded nasal cavity, better soft palate function, expanding the nasopharyx, as well as improving tongue posture.[14,72,73] It is hypothesized that the increase in oral cavity dimensions from maxillary expansion allows the tongue to be positioned more anteriorly and superiorly, thus relieving narrow retroglossal and retropalatal dimensions.[14,72,73] Villa et al[73] suggested that when the tongue is repositioned in the oral cavity, it promotes a return to normal lingual tone with proper swallowing. This in turn reduces the hypotonia that causes the tongue to fall back during the hypotonic stage of sleep.[73]

In the last few years, the OPA has been studied to determine whether in fact changes in the dimensions of the lumen occur after maxillary expansion. Early studies have used lateral cephalograms to measure the AP changes in the OPA post-expansion.[7,8] Kilic et al[7] studied the effects of expansion and protraction headgear on 18 patients with Class III malocclusion. Increases in linear sagittal dimensions of the oropharynx were found, however, increases in total area were not statistically significant. In contrast, Mucedero et al[8] did not find changes in sagittal OPA dimensions in their treatment group of patients with Class III malocclusion. It should be noted that both studies were limited by the inadequacies of 2D cephalometrics in measuring the complex nature of the OPA.

More recently, airway studies have utilized CBCT technology to analyze the 3D changes to gain a more accurate picture of the changes to the lumen of the oropharynx. Zhao et al[9] found no changes in OPA volume or cross-sectional area dimensions using CBCT images from 24 treated patients with maxillary expansion.

Conversely Ribeiro et al[12] showed changes in retroglossal volume and area within their treatment group of 15, although the increase noted was attributed to a lack of standardized tongue positioning. Studies by Pangrazio-Kulbersh et al[10] and Smith et al[11] also failed to show a difference in OPA volume after expansion. Thus the dimensional change in OPA after maxillary expansion is still uncertain and requires further investigation to rationalize any improvement in airway patency suggested previously.

1.5.8 Assessment of the Oropharyngeal Airway

The OPA and surrounding structures, both bony and soft tissue, have been measured and analyzed using a variety of modalities. The most common techniques include: acoustic reflection, fluoroscopy, nasopharyngoscopy, cephalometrics, magnetic resonance imaging (MRI), and computed tomography (CT).[33] For each approach, Schwab[33] outlines various distinct strengths and limitations:

Acoustic Reflection:

Acoustic reflection is a non-invasive, inexpensive, and efficient technique that uses reflected sound waves from the respiratory system to provide a graphic display of the desired cross-section area versus distance curve. It can be used repeatedly to provide a dynamic study of the airway. Acoustic reflection of the oropharynx requires the mouth to be open which distorts the pharyngeal dimensions. This makes acoustic reflection less accurate as it does not allow comparisons to other imaging modalities that measure the oropharynx in a more natural closed mouth state.

Fluoroscopy:

Fluoroscopy utilizes radiation and a fluorescent detector screen to image internal structures in real time, thus providing dynamic evaluation during wakefulness or sleep. The disadvantages include significant radiation exposure, inadequate sensitivity and inability to produce cross-sectional images.

Nasopharyngoscopy:

Nasopharyngoscopy is an invasive clinical technique that allows direct observation of the pharynx in wakeful or sleeping patients to assess for pathologies, obstructions, and physiologic changes to therapies. It does not provide information about the surrounding soft tissues, and is difficult to quantify airway area measurements.

Cephalometry:

Lateral cephalograms have been used extensively in the orthodontic literature for research purposes as they are widely used in the clinical environment. A comparatively lower dose of radiation is required for a single static image compared to CT imaging, as cephalometry provides an abundance of hard tissue dimensions along soft tissue positions in patients with craniofacial abnormalities and known airway disturbances. Due to the nature of the 2D image, only sagittal measurements can be made on a single image. Consequently changes in the transverse dimension cannot be visualized and volumetric data on critical 3D airway structures is not possible.

Magnetic Resonance Imaging (MRI):

The main advantages of MRI's are the detailed airway and soft tissue resolution in 3D as well as dynamic imaging capabilities during wakefulness or sleep in the absence of radiation. Nonetheless scans take a long time and can therefore be distorted with even the slightest movement. Accessibility to MRI technology is limited, as well very expensive which makes it impractical for routine screening purposes.

Computed Tomography (CT):

Traditionally, CT scans provide axial plane images of soft tissues, hard tissues, and airway space in the supine position, but can be reconstructed for volumetric analysis. Though hard tissue image quality is exceptional, the radiation dose is relatively high.[18] Advances in CT technology include helical CT, which allow for direct volumetric acquisition of images, as well as electron beam CT for functional dynamic airway imaging. With the introduction of CBCT for oral and maxillofacial imaging, volumetric and cross-sectional airway dimensions can be presented in any plane at a fraction of the radiation dose required for traditional medical CT scans (Figure 2).[18,75] CBCT scanners also allow for patients to be imaged in the upright position, thus providing a more accurate visualization of the state of the airway during wakefulness.

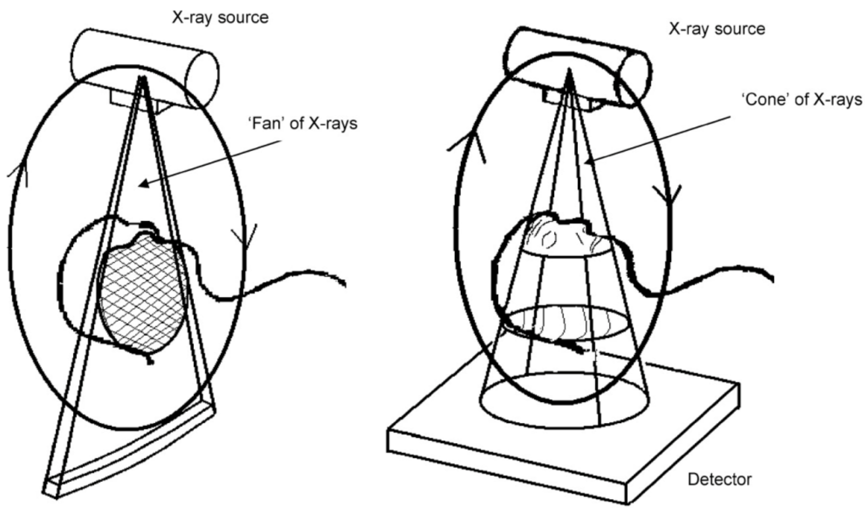

Figure 1-2: Image Capture Technique of CT and CBCT Devices.[75]

Limitations of CBCT scans compared to traditional CT scans include a reduction in clarity due to artifacts, noise, and poor soft tissue contrast. These can be a result of the inherent nature of the geometry of the cone-beam projection, as well as limitations related to detector sensitivity and contrast resolution. Artifacts are errors or distortions of the image that can present for a full host of reasons ranging from beam hardening around metallic restorations due to differential absorption, to unwanted subject motion during the scan. Partial volume averaging is the automatic averaging of CT values of the boundary of tissues caused by a discrepancy in the voxel resolution of the scan being greater than the contrast resolution of the imaged object. This not only produces artifacts, but it can also contribute to noise and inaccurate soft tissue contrast. Detected scattered radiation is a major contributor to not only an increase in image noise, but also to the reduction in image contrast. Finally, the divergence of the x-ray beam over the detector screen also hinders image contrast due to a variation in x-ray beam and ultimately absorption levels.[76]

1.5.9 Cone Beam Computed Tomography Evaluation of Airway in Orthodontics

New 3D technologies have emerged that provide an accurate, simple, and effective solution for airway research.[16,39] When analyzing the upper airway, Tso et al[77] argue that the minimum cross-sectional area and the extent of this restriction should be noted and compared with volumetric images. These criteria cannot be accomplished with lateral cephalograms since they do not provide the appropriate detail, such as visualization in the transverse dimension, to analyze the complex 3D parameters of the upper airway.[18,39] When comparing to other 3D technologies such as MRI and conventional CT, CBCT may be a preferred 3D technology in providing information about airway shape and volume as well as cross sectional areas due to its lower cost, accessibility, availability to dentists, and considerably reduced radiation dose compared to conventional CT.[20,21]

The major weakness of CBCT technology in airway analysis as cited by Tso et al,[77] is "determining whether a static evaluation of the airway will provide a threshold of size or shape predictive of potential clinical problems". Future studies are required to perform functional tests to compare anatomic airway dimensions with airway dynamics and airflow.[78]

1.6 Conclusion

The reciprocal effects of airway and the maxillofacial structures have been suggested. Understanding the response the OPA has to maxillary expansion may aid the research into OSA therapies. The recent advances in imaging technology, particularly the availability of 3D CBCT, have enhanced the study of the OPA in the orthodontic literature.

1.7 References

1. Harvold EP, Tomer BS, Vargervik K, Chierici G. Primate experiments on oral respiration. Am J Orthod. 1981 Apr;79(4):359-72.

2. Yamada T, Tanne K, Miyamoto K, Yamauchi K. Influences of nasal respiratory obstruction on craniofacial growth in young Macaca fuscata monkeys. Am J Orthod Dentofacial Orthop. 1997 Jan;111(1):38-43.

3. Tourne LP. Growth of the pharynx and its physiologic implications. Am J Orthod Dentofacial Orthop. 1991 Feb;99(2):129-39.

4. Subtelny JD, The Significance of Adenoid Tissue in Orthodontia. The Angle Orthodontist. 1954 April;24(2):59-69.

5. Linder-Aronson S. Adenoids. Their effect on mode of breathing and nasal airflow and their relationship to characteristics of the facial skeleton and the denition. A biometric, rhino-manometric and cephalometro-radiographic study on children with and without adenoids. Acta Otolaryngol Suppl. 1970;265:1-132.

6. Stellzig-Eisenhauer A. Meyer-Marcotty P. Interaction between otorhinolaryngology and orthodontics: correlation between the nasopharyngeal airway and the craniofacial complex. Gms Current Topics in Otorhinolaryngology Head & Neck Surgery. 9:Doc04, 2010.

7. Kilinç AS, Arslan SG, Kama JD, Ozer T, Dari O. Effects on the sagittal pharyngeal dimensions of protraction and rapid palatal expansion in Class III malocclusion subjects. Eur J Orthod. 2008 Feb;30(1):61-6. Epub 2007 Sep 28.

8. Mucedero M, Baccetti T, Franchi L, Cozza P. Effects of maxillary protraction with or without expansion on the sagittal pharyngeal dimensions in Class III subjects. Am J Orthod Dentofacial Orthop. 2009 Jun;135(6):777-81.

9. Zhao Y, Nguyen M, Gohl E, Mah JK, Sameshima G, Enciso R. Oropharyngeal airway changes after rapid palatal expansion evaluated with cone-beam computed tomography. Am J Orthod Dentofacial Orthop. 2010 Apr;137(4 Suppl):S71-8.

10. Pangrazio-Kulbersh V, Wine P, Haughey M, Pajtas B, Kaczynski R. Cone beam computed tomography evaluation of changes in the naso-maxillary complex associated with two types of maxillary expanders. Angle Orthod. 2012 May;82(3):448-57. Epub 2011 Oct 27.

11. Smith T, Ghoneima A, Stewart K, Liu S, Eckert G, Halum S, Kula K. Three-dimensional computed tomography analysis of airway volume changes after rapid maxillary expansion. Am J Orthod Dentofacial Orthop. 2012 May;141(5):618-26.

12. Ribeiro AN, de Paiva JB, Rino-Neto J, Illipronti-Filho E, Trivino T, Fantini SM. Upper airway expansion after rapid maxillary expansion evaluated with cone beam computed tomography. Angle Orthod. 2011 Oct 17.

13. Ozbek MM, Memikoglu UT, Altug-Atac AT, Lowe AA. Stability of maxillary expansion and tongue posture. Angle Orthod. 2009 Mar;79(2):214-20.

14. Cistulli PA, Palmisano RG, Poole MD. Treatment of obstructive sleep apnea syndrome by rapid maxillary expansion. Sleep. 1998 Dec 15;21(8):831-5.

15. Praud JP. Dorion D. Obstructive sleep disordered breathing in children: beyond adenotonsillectomy. [Review], Pediatric Pulmonology. 43(9):837-43, 2008 Sep.

16. Aboudara C, Nielsen I, Huang JC, Maki K, Miller AJ, Hatcher D. Comparison of airway space with conventional lateral headfilms and 3-dimensional reconstruction from cone-beam computed tomography. Am J Orthod Dentofacial Orthop. 2009 Apr;135(4):468-79.

17. Holmberg H, Linder-Aronson S. Cephalometric radiographs as a means of evaluating the capacity of the nasal and nasopharyngeal airway. Am J Orthod. 1979 Nov;76(5):479-90.

18. Shi H., Scarfe WC., Farman AG. Upper airway segmentation and dimensions estimation from cone-beam CT image datasets. Int J CARS. 2006 Oct 1(3):177-186

19. Alves PV, Zhao L, O'Gara M, Patel PK, Bolognese AM. Three-dimensional cephalometric study of upper airway space in skeletal class II and III healthy patients. J Craniofac Surg. 2008 Nov;19(6):1497-507.

20. Mah JK, Danforth RA, Bumann A, Hatcher D. Radiation absorbed in maxillofacial imaging with a new dental computed tomography device. Oral Surg Oral Med Oral Pathol Oral Radiol Endod. 2003 Oct;96(4):508-13.

21. Ogawa T, Enciso R, Shintaku WH, Clark GT. Evaluation of cross-section airway configuration of obstructive sleep apnea. Oral Surg Oral Med Oral Pathol Oral Radiol Endod. 2007 Jan;103(1):102-8. Epub 2006 Sep 1.

22. Sunitha C, Aravindkumar S. Obstructive sleep apnea: clinical and diagnostic features. Indian J Dent Res. 2009 Oct-Dec;20(4):487-91.

23. Lowe AA, Santamaria JD, Fleetham JA, Price C. Facial morphology and obstructive sleep apnea. Am J Orthod Dentofacial Orthop. 1986 Dec;90(6):484-91.

24. Ono T, Otsuka R, Kuroda T, Honda E, Sasaki T. Effects of head and body position on two- and three-dimensional configurations of the upper airway. J Dent Res. 2000 Nov;79(11):1879-84.

25. Conley RS. Evidence for dental and dental specialty treatment of obstructive sleep apnoea. Part 1: the adult OSA patient and Part 2: the paediatric and adolescent patient. J Oral Rehabil. 2011 Feb;38(2):136-56. doi: 10.1111/j.1365-2842.2010.02136.x. Epub 2010 Aug 15.

26. McNamara JA. Influence of respiratory pattern on craniofacial growth. Angle Orthod. 1981 Oct;51(4):269-300.

27. Ng AT, Gotsopoulos H, Qian J, Cistulli PA. Effect of oral appliance therapy on upper airway collapsibility in obstructive sleep apnea. Am J Respir Crit Care Med. 2003 Jul 15;168(2):238-41. Epub 2003 Apr 30.

28. Pack AI. Obstructive sleep apnea. Adv Intern Med. 1994;39:517-67.

29. Schmidt-Nowara W, Lowe A, Wiegand L, Cartwright R, Perez-Guerra F, Menn S. Oral appliances for the treatment of snoring and obstructive sleep apnea: a review. Sleep. 1995 Jul;18(6):501-10.

30. Strollo PJ Jr, Rogers RM. Obstructive sleep apnea. N Engl J Med. 1996 Jan 11;334(2):99-104.

31. Fairburn SC, Waite PD, Vilos G, Harding SM, Bernreuter W, Cure J, Cherala S. Three-dimensional changes in upper airways of patients with obstructive sleep apnea following maxillomandibular advancement. J Oral Maxillofac Surg. 2007 Jan;65(1):6-12.

32. Fleisher KE, Krieger AC. Current trends in the treatment of obstructive sleep apnea. J Oral Maxillofac Surg. 2007 Oct;65(10):2056-68.

33. Schwab RJ. Upper airway imaging. Clin Chest Med. 1998 Mar;19(1):33-54.

34. Solow B, Siersbaek-Nielsen S, Greve E. Airway adequacy, head posture, and craniofacial morphology. Am J Orthod. 1984 Sep;86(3):214-23.

35. Trenouth MJ, Timms DJ. Relationship of the functional oropharynx to craniofacial morphology. Angle Orthod. 1999 Oct;69(5):419-23.

36. Battagel JM, Johal A, Kotecha B. A cephalometric comparison of subjects with snoring and obstructive sleep apnoea. Eur J Orthod. 2000 Aug;22(4):353-65.

37. Joseph AA, Elbaum J, Cisneros GJ, Eisig SB. A cephalometric comparative study of the soft tissue airway dimensions in persons with hyperdivergent and normodivergent facial patterns. J Oral Maxillofac Surg. 1998 Feb;56(2):135-9.

38. Memon S, Fida M, Shaikh A. Comparison of different craniofacial patterns with pharyngeal widths. J Coll Physicians Surg Pak. 2012 May;22(5):302-6.

39. Lenza MG, Lenza MM, Dalstra M, Melsen B, Cattaneo PM., An analysis of different approaches to the assessment of upper airway morphology: a CBCT study., Orthod Craniofac Res. 2010 May;13(2):96-105.

40. Kim YJ, Hong JS, Hwang YI, Park YH. Three-dimensional analysis of pharyngeal airway in preadolescent children with different anteroposterior skeletal patterns. Am J Orthod Dentofacial Orthop. 2010 Mar;137(3):306.e1-11; discussion 306-7.

41. Grauer D, Cevidanes LS, Styner MA, Ackerman JL, Proffit WR. Pharyngeal airway volume and shape from cone-beam computed tomography: relationship to facial morphology. Am J Orthod Dentofacial Orthop. 2009 Dec;136(6):805-14.

42. Eggensperger N, Smolka K, Johner A, Rahal A, Thüer U, Iizuka T. Long-term changes of hyoid bone and pharyngeal airway size following advancement of the mandible. Oral Surg Oral Med Oral Pathol Oral Radiol Endod. 2005 Apr;99(4):404-10.

43. Battagel JM, Johal A, L'Estrange PR, Croft CB, Kotecha B. Changes in airway and hyoid position in response to mandibular protrusion in subjects with obstructive sleep apnoea (OSA). Eur J Orthod. 1999 Aug;21(4):363-76.

44. Adamidis IP, Spyropoulos MN. Hyoid bone position and orientation in Class I and Class III malocclusions. Am J Orthod Dentofacial Orthop. 1992 Apr;101(4):308-12.

45. Achilleos S, Krogstad O, Lyberg T. Surgical mandibular advancement and changes in uvuloglossopharyngeal morphology and head posture: a short- and long-term cephalometric study in males. Eur J Orthod. 2000 Aug;22(4):367-81.

46. Kawakami M, Yamamoto K, Fujimoto M, Ohgi K, Inoue M, Kirita T. Changes in tongue and hyoid positions, and posterior airway space following mandibular setback surgery. J Craniomaxillofac Surg. 2005 Apr;33(2):107-10.

47. Schlenker WL, Jennings BD, Jeiroudi MT, Caruso JM. The effects of chronic absence of active nasal respiration on the growth of the skull: a pilot study. Am J Orthod Dentofacial Orthop. 2000 Jun;117(6):706-13.

48. Harvold EP, Vargervik K, Chierici G. Primate experiments on oral sensation and dental malocclusions. Am J Orthod. 1973 May;63(5):494-508.

49. Miller AJ, Vargervik K, Chierici G. Experimentally induced neuromuscular changes during and after nasal airway obstruction. Am J Orthod. 1984 May;85(5):385-92.

50. Vargervik K, Miller AJ, Chierici G, Harvold E, Tomer BS. Morphologic response to changes in neuromuscular patterns experimentally induced by altered modes of respiration. Am J Orthod. 1984 Feb;85(2):115-24.

51.Tourne LP. The long face syndrome and impairment of the nasopharyngeal airway. Angle Orthod. 1990 Fall;60(3):167-76.

52. Kerr WJ, McWilliam JS, Linder-Aronson S. Mandibular form and position related to changed mode of breathing--a five-year longitudinal study. Angle Orthod. 1989 Summer;59(2):91-6.

53. Linder-Aronson S, Woodside DG, Lundström A. Mandibular growth direction following adenoidectomy. Am J Orthod. 1986 Apr;89(4):273-84.

54. Vig KW. Nasal obstruction and facial growth: the strength of evidence for clinical assumptions. Am J Orthod Dentofacial Orthop. 1998 Jun;113(6):603-11.

55. Zettergren-Wijk L, Forsberg CM, Linder-Aronson S. Changes in dentofacial morphology after adeno-/tonsillectomy in young children with obstructive sleep apnoea--a 5-year follow-up study. Eur J Orthod. 2006 Aug;28(4):319-26. Epub 2006 Apr 28.

56. Avrahami E, Englender M. Relation between CT axial cross-sectional area of the oropharynx and obstructive sleep apnea syndrome in adults. AJNR Am J Neuroradiol. 1995 Jan;16(1):135-40.

57. Bradley TD, Brown IG, Grossman RF, Zamel N, Martinez D, Phillipson EA, Hoffstein V., Pharyngeal size in snorers, nonsnorers, and patients with obstructive sleep apnea., N Engl J Med. 1986 Nov 20;315(21):1327-31.

58. Pirelli P, Saponara M, Attanasio G. Obstructive Sleep Apnoea Syndrome (OSAS) and rhino-tubaric disfunction in children: therapeutic effects of RME therapy. Prog Orthod. 2005;6(1):48-61.

59. Ceroni Compadretti G, Tasca I, Alessandri-Bonetti G, Peri S, D'Addario A. Acoustic rhinometric measurements in children undergoing rapid maxillary expansion. International Journal of Pediatric Otorhinolaryngology 2006;70:27-34.

60. Babacan H, Sokucu O, Doruk C, Ay S. Rapid maxillary expansion and surgically assisted rapid maxillary expansion effects on nasal volume. Angle Orthod. 2006 Jan;76(1):66-71.

61. Enoki C, Valera FC, Lessa FC, Elias AM, Matsumoto MA, Anselmo-Lima WT. Effect of rapid maxillary expansion on the dimension of the nasal cavity and on nasal air resistance. Int J Pediatr Otorhinolaryngol. 2006 Jul;70(7):1225-30. Epub 2006 Feb 23.

62. McNamara JA., Maxillary transverse deficiency., Am J Orthod Dentofacial Orthop. 2000 May;117(5):567-70.

63. Bishara SE, Staley RN. Maxillary expansion: clinical implications. Am J Orthod Dentofacial Orthop. 1987 Jan;91(1):3-14.

64. Haas AJ. Long-term posttreatment evaluation of rapid palatal expansion. Angle Orthod. 1980 Jul;50(3):189-217.

65. Haas AJ. Palatal expansion: just the beginning of dentofacial orthopedics. Am J Orthod. 1970 Mar;57(3):219-55.

66. Moss JP. Rapid expansion of the maxillary arch. II. Indications for rapid expansion. JPO J Pract Orthod. 1968 May;2(5):215-23.

67. Proffit W, Fields H, Sarver D. Contemporary Orthodontics. St. Louis, MO: Mosby; 2007: 498-502.

68. Gray LP. Results of 310 cases of rapid maxillary expansion selected for medical reasons. J Laryngol Otol. 1975 Jun;89(6):601-14.

69. Baratieri C, Alves M Jr, de Souza MM, de Souza Araújo MT, Maia LC. Does rapid maxillary expansion have long-term effects on airway dimensions and breathing? Am J Orthod Dentofacial Orthop. 2011 Aug;140(2):146-56.

70. Gordon JM, Rosenblatt M, Witmans M, Carey JP, Heo G, Major PW, Flores-Mir C. Rapid palatal expansion effects on nasal airway dimensions as measured by acoustic rhinometry. A systematic review. Angle Orthod. 2009 Sep;79(5):1000-7. Review.

71. Warren DW, Hershey HG, Turvey TA, Hinton VA, Hairfield WM. The nasal airway following maxillary expansion. Am J Orthod Dentofacial Orthop. 1987 Feb;91(2):111-6.

72. Pirelli P, Saponara M, Guilleminault C. Rapid maxillary expansion in children with obstructive sleep apnea syndrome. Sleep. 2004 Jun 15;27(4):761-6.

73. Villa MP, Malagola C, Pagani J, Montesano M, Rizzoli A, Guilleminault C, Ronchetti R. Rapid maxillary expansion in children with obstructive sleep apnea syndrome: 12-month follow-up. Sleep Med. 2007 Mar;8(2):128-34. Epub 2007 Jan 18.

74. Johal A, Conaghan C. Maxillary morphology in obstructive sleep apnea: a cephalometric and model study. Angle Orthod. 2004 Oct;74(5):648-56.

75. Kau CH, Richmond S, Palomo JM, Hans MG. Three-dimensional cone beam computerized tomography in orthodontics. J Orthod. 2005 Dec;32(4):282-93.

76. Scarfe WC, Farman AG. What is cone-beam CT and how does it work? Dent Clin North Am. 2008 Oct;52(4):707-30, v.

77. Tso HH, Lee JS, Huang JC, Maki K, Hatcher D, Miller AJ. Evaluation of the human airway using cone-beam computerized tomography. Oral Surg Oral Med Oral Pathol Oral Radiol Endod. 2009 Nov;108(5):768-76. Epub 2009 Aug 28.

78. Aboudara CA, Hatcher D, Nielsen IL, Miller A. A three-dimensional evaluation of the upper airway in adolescents. Orthod Craniofac Res 2003; 6 Suppl 1:173–175.

Chapter 2- Effects of Maxillary Expansion on Oropharyngeal Airway Dimensions: A Systematic Review

2.1 Introduction

Due to the close anatomical location of the upper airway to the dentofacial structures, a reciprocal relationship is perceived to exist between them.[1,2,3] The influence of impaired breathing on facial development has been proposed through the description of the long face growth pattern due to such variables as adenoid and tonsil hypertrophy, chronic and allergic rhinitis, and narrow external nares.[3,4]

Maxillary transverse deficiency, which can be characterized by a combination of posterior crossbite, high palatal vault, buccally flared maxillary posterior dentition, crowding, and dark spaces in the "buccal corridors",[5] has also been shown to be a result of obstructed breathing.[4,6] More recently, the inverse effect of maxillary transverse deficiency on airway has been described. It is proposed that a narrowing of the oropharyngeal airway (OPA) space exists from the tongue being forced posteriorly due to a reduced oral cavity space in subjects with maxillary transverse deficiency.[7,8,9] Narrowing of the OPA lumen has been demonstrated to play a role in the symptoms of obstructive sleep apnea (OSA).[10,11,12]

Rapid maxillary expansion (RME) is commonly used for correction of crossbite. It has recently been suggested to be a useful tool to aid in improvement of sleep disordered breathing.[13,14] One possible explanation for RME's effect on OSA is due to a concurrent change in OPA dimension. With expansion of the constricted maxilla and increase in the oral cavity dimension, resting tongue posture has been shown to improve,[15] potentially increasing OPA space.[7,16]

Lateral cephalometric imaging has been the most extensively used tool in the orthodontic literature for studying airway changes in growing and non-growing surgical patients,[17,18,19] The major limitation of lateral cephalometrics is the inability to visualize transverse dimensional changes[20] which can account for a large variation in airway dimensions.[21] Other imaging methods available for assessing the OPA are not practical due to anatomical distortion of the oropharynx with acoustic reflection, excessive radiation exposure with fluoroscopy and conventional computed tomography (CT), and limited accessibility and high cost of magnetic resonance imaging (MRI).[22,23] More recently, the availability of cone-beam computed tomography (CBCT) has become more widely accepted for accurate three-dimensional cross-sectional and volumetric analysis of the complex anatomy of the upper airway, at a fraction of the radiation dose of conventional CT.[19,22-24]

Although the effects of maxillary expansion on the nasal cavity have been investigated for years,[25,26] only recently an interest has risen to investigate the effects of maxillary expansion on the OPA.[7,9,14,27,28] The aim of this systematic review was to assemble the available evidence to clarify the existence of a relationship between maxillary expansion and the OPA dimensions. The potential effect could have implications on the treatment of such airway disorders as obstructive sleep apnea.

2.2 Materials and Methods

An electronic database search was conducted using the following databases: Medline (1948 to week 2 of June 2012), PubMed (1966 to week 2 of June 2012), EMBASE (1980 to week 23 2012), and EBM Reviews Full Text (Cochrane DSR[1], ACP[2] Journal Club and DARE[3]) (to the second quarter of 2012). The computerized search was completed with the help of a senior librarian specialized in Health Sciences databases. Specific search terms and combinations used in the electronic database search are shown in Table 1. No language limitation was set.

---

[1] Database of Systematic Reviews
[2] American College of Physicians
[3] Database of Abstracts of Reviews of Effects

Table 2-1: Database Search Results

Database	Keywords/Search Strategy	Results	Selected
MEDLINE (1950- week 2, June 2012)	1) exp Cone-Beam Computed Tomography/ or CBCT or exp Imaging, Three-Dimensional, OR exp Magnetic Resonance Imaging/ or MRI; 2) (airway OR oropharyn* OR retroglossal OR retropalatal; 3) crossbite* OR maxillary constriction OR maxillary transverse deficienc* OR narrow maxilla OR exp Palatal Expansions Technique/ or rapid maxillary expansion OR exp Palatal Expansion Technique/ or rapid palatal expansion; 1 AND 2 AND 3	10	2 (repeat)
PubMed (1966- week 2, June 2012)	1) crossbite OR maxillary constriction OR maxillary transverse deficienc* OR narrow maxilla OR palatal expansion OR rapid maxillary expansion; 2) airway OR oropharyn* OR retroglossal OR retropalatal; 3) cone-beam computed tomography OR CBCT OR imaging OR Three-Dimensional OR magnetic resonance imaging OR MRI 1 AND 2 AND 3	49	4
EMBASE (1980- week 23 of 2012)	1) exp Cone-Beam Computed Tomography/ or CBCT or exp Imaging, Three-Dimensional, OR exp Magnetic Resonance Imaging/ or MRI; 2) (airway OR oropharyn* OR retroglossal OR retropalatal; 3) crossbite* OR maxillary constriction OR maxillary transverse deficienc* OR narrow maxilla OR exp Palatal Expansions Technique/ or rapid maxillary expansion OR exp Palatal Expansion Technique/ or rapid palatal expansion; 1 AND 2 AND 3	18	1 (repeat)
All EBM Reviews (to the 2nd quarter of 2012)	1) exp Cone-Beam Computed Tomography/ or CBCT or exp Imaging, Three-Dimensional, OR exp Magnetic Resonance Imaging/ or MRI; 2) (airway OR oropharyn* OR retroglossal OR retropalatal; 3) crossbite* OR maxillary constriction OR maxillary transverse deficienc* OR narrow maxilla OR exp Palatal Expansions Technique/ or rapid maxillary expansion OR exp Palatal Expansion Technique/ or rapid palatal expansion; 1 AND 2 AND 3	0	0
Hand-search		0	0

Articles were initially selected after applying the following inclusion criteria to the titles/abstracts:

- cohort, case control or RCT study design,

- measurement of the OPA space using 3D technology,
- presence of MTD or use of RME, and
- absence of congenital anomalies.

If the abstract or the title was unclear, the entire article was obtained and reviewed to assess its eligibility. Two researchers completed the article selection individually. Any discrepancies in the selection were addressed through discussion and consensus. If the abstract fulfilled the inclusion criteria, the full article was collected. Reference lists from selected articles were also hand-searched for additional publications that may not have appeared in the electronic database searches.

2.3 Results

Only four articles met the initial inclusion criteria from the total number of abstracts identified in Table 1. The majority of articles from the initial search were excluded because they did not measure the OPA specifically, or were simply review articles. Of the four selected articles, three studies did not have control groups to differentiate normal growth from measureable airway changes due to maxillary expansion.

Table 2 provides a summary of the key methodologies from the selected articles. The results obtained from each article shown in Table 3 demonstrate the similarity in findings between the 4 articles.

Table 2-2: Descriptive Statistics for Final Articles

Author	Year	Group	*n*	Gender	Age	Imaging Machine	Subject Positioning	T1-T2 Interval	Retention	Imaging Software
Zhao et al[9]	2010	RME	24	6♂, 18♀	12.8 ±1.88	NewTom[b] CBCT	Supine	15 months*	3 months minimum	Vwork[e]
		Control[a]	24	6♂, 18♀	12.8 ±1.85	NewTom[b] CBCT	Supine	15 months*	3 months minimum	Vwork[e]
Pangrazio -Kulbersh et al[34]	2012	Banded RME	13	7♂, 6♀	12.6 ±1.8	ICAT[c] CBCT	Upright	7-7.5 months	6 months	Dolphin[f]
		Bonded RME	10	5♂, 5♀	13.8 ±2.1	ICAT[c] CBCT	Upright	7-7.5 months	6 months	Dolphin[f]
Smith et al[35]	2012	RME	20	8♂, 12♀	12.3 ±1.9	Xvision EX[d] Spiral CT	Supine	3 months	NR	Dolphin[f]
Ribeiro et al[36]	2012	RME	15	7♂, 8♀	7.5	ICAT[c] CBCT	Upright	4 months	NR	Dolphin[f]

RME: rapid maxillary expander
[a]Ortho treatment without RME
[b]NewTom 3G, QA S.R.L., Verona, Italy
CBCT: Cone-Beam Computed Tomography
[c]ICAT technology (Imaging Sciences International, Hatfield, Pa)
[d]Xvision EX; Toshiba Medical Systems, Otawara-Shi, Japan
CT: computed tomography
NR: Not reported
* range of 8-24 months reported
[e]version 5.0, Cybermed USA, Torrance, Calif
[f]version 11.0; Dolphin Imaging, Chatsworth, Calif

Table 2-3: Mean Measurements, Standard Deviations, and Percentage Change (%) of OPA Dimensions Between T1 and T2.

	Zhao et al[9]		Pangrazio-Kulbersh et al[34]		Smith et al[35]	Ribeiro et al[36]
	RME	Control[a]	Bonded RME	Banded RME	RME	RME
Oropharyngeal Vol (cm^3)	0.1 ± 2.37 (4.6% ±31.10)	-1.0 ± 3.45 (4.1% ±33.21)	0.095[b] (0.8%)	7.42[b] (38.4%)	-0.18 ± 4.34 (1.7%)	
Retropalatal vol (cm^3)	0.1 ± 1.30 (7.3% ±32.47)	-0.3 ± 1.08 (1.7% ±30.94)				0.88 ± 2.63 (10.3%)
Retroglossal vol (cm^3)	0.0 ± 1.36 (16.0% ±91.36)	-0.7 ± 2.05 (3.1% ±45.31)				0.24 ± 0.53* (14.0%)
Oropharyngeal Length (mm)	1.1 ± 4.15 (3.1% ±11.29)	1.3 ± 3.41 (3.2% ±8.46)				
Retropalatal Length (mm)	0.9 ± 2.78 (3.6% ±11.10)	1.0 ± 2.21 (3.7% ±8.66)				
Retroglossal Length (mm)	0.2 ± 3.01 (11.3% ±48.56)	0.3 ± 2.11 (3.5% ±15.12)				
Oropharyngeal MCA (mm^2)	-7.0 ± 48.46 (23.9% ±76.01)	-18.2 ± 55.59 (29.5% ±50.24)				
Retropalatal MCA (mm^2)						5.79 ± 40.44 (7.3%)
Retroglossal MCA (mm^2)						30.83 ± 62.49** (33.4%)
Median sagittal area (mm^2)						
Retropalatal (mm^2)						-9.87 ± 87.65 (2.4%)
Retroglossal (mm^2)						16.87 ± 26.73 ** (14.9%)

RME: rapid maxillary expander
[a]Ortho treatment without RME
MCA: minimum cross-sectional area
Vol: Volume
[b]Standard deviation of mean difference not reported
* indicates $p = 0.05$
** indicates $p < 0.05$

2.4 Discussion

To date, the relationship between maxillary expansion and the OPA dimensions has not been adequately supported in the literature. Just as the potential interaction of the two is difficult to define, the necessity and applicability of corrective therapy for such disturbances as OSA has not been empirically determined.

For the present systematic review, it was imperative to only include studies that employed 3D imaging of the oropharynx due to the complex nature of the anatomy of this structure. Many airway studies have utilized linear measurements from lateral cephalograms,[6,27,29,30] however, the validity of this 2D technology in airway studies is inadequate.[31] Lateral cephalograms analyses experience major limitations when representing a 3D structure as a 2D image such as image distortion, magnification error, superimposition, and low reproducibility.[32] More specific to the imaging of the OPA, lateral cephalograms are unable to capture the non-cylindrical shape of the lumen since the transverse dimension is not observable.[33,] If the purpose of analyzing the OPA is to detect area of constriction that may be prone to collapse, then cross-sectional area measurements are required which are not evident on lateral cephalograms.[31] The introduction of 3D imaging with such technologies as CBCT, have allowed researchers to accurately depict the complex structures of the upper airway[24] and define the critical dimensions required for analyzing and potentially diagnosing airway concerns.[31] Consequently inclusion criteria for the purpose of this review was restricted to studies with 3D analyses.

The data available regarding the 3D analysis of the OPA was limited. This systematic review revealed only four articles that met the initial inclusion criteria. Within those four studies chosen, only one study included a control group for comparison, though it was matched solely on age and gender, not on need for maxillary expansion. The remaining three articles, despite providing a lower level of evidence with no control, still contribute to the overall understanding of the use of maxillary expansion interventions for OPA change.

Zhao et al[9] retrospectively studied 24 adolescents who received maxillary expansion as part of their orthodontic correction along with 24 age and gender matched normal controls. Linear, cross-sectional, and volumetric measurements were taken of the OPA, which was then subdivided into retropalatal and retroglossal regions. Despite the trend of OPA enlargement in most dimensions after 4-6 weeks of maxillary expansion, none of the measurements of change were statistically significant. Contrary to expectation, the minimum cross-sectional area showed a reduction in area, though not statistically significant. The presence of a large standard deviation negatively impacted the significance of change noted between treatment and control groups.

Similar expansion studies were performed by Prangrazio-Kulbersh et al,[34] Smith et al,[35] and Ribeiro et al.[36] The study by Prangrazio-Kulbersh et al[34] examined the difference between banded and bonded RPE appliances. Specifically, the researchers measured the impact of these expanders on a variety of parameters within the naso-maxillary complex. While the OPA volume showed more expansion with the banded RPE appliance than the bonded, the difference was not statistically significant. This lack of statistical significance could also be attributed to the large standard deviation within the groups as previously noted with the Zhao et al[9] study.

The non-significant change in OPA volume was also reported by Smith et al.[35] They examined 20 patients using RPE and even found a reduction in OPA volume after expansion. This was attributed to the lowering of the palatal plane after expansion, which affected the superior border of the area of interest. Soft-tissue thicknesses within the oropharynx were also examined post expansion by measuring the horizontal distance from the edge of each of the first four cervical vertebrae to the posterior wall of the oropharynx; no significant differences were found.

Contrary to the aforementioned studies, Ribeiro et al[36] reported a significant change in retroglossal volume, median sagittal area, and minimum cross-sectional area. There was however no change observed in the retropalatal airway, which Ribeiro et al[36] labels the nasopharynx, for any of the same parameters. Ribeiro et al[36] suggested that the difference in retroglossal airway could be due to repositioning of the tongue as a consequence of maxillary expansion. Other explanations put forth were inconsistency with tongue posture, head inclination, and breathing and swallowing movements between CBCT scans. It should be noted that a distinguishing finding in this study that separates it from the studies by Zhao et al,[9] Prangrazio-Kulbersh et al,[34] and Smith et al,[35] is the younger age of the subjects. The mean age of 7.5 in the study by Ribeiro et al,[36] compared to the range of 12.3-13.8 of the other studies, could suggest the difference in response to maxillary expansion may be due to the difference in physiology in the preadolescent subjects. Further investigation into this matter could prompt new research questions regarding appropriate ages for maxillary expansion and airway response.

One of the major limitations shared by all three of the latter studies outlined is the lack of control group. This omission of a comparison group brings into question the causal relationship between maxillary expansion and a change in airway dimension. It is possible that any difference observed could be a result of another physiological occurrence not otherwise determined. While the study by Zhao et al[9] was the only 3D OPA study to have a control group, it was matched solely by age and gender. The specific condition being corrected, maxillary transverse deficiency, was only present in the experimental group. Consequently, the control group may be inappropriate for direct comparison. It should be noted that the control and experimental groups statistically differed in retropalatal airway volume at baseline. This underscores the inadequacy of the match-controls as well as highlights the potential relation between a restricted maxilla and a smaller retropalatal airway. It is not likely this difference was clinically significant as no history of respiratory concerns was present for either group in this study.

Research into the effect of maxillary expansion on the OPA with 3D imaging is still in its infancy. Together the four studies outlined in this review do not present a clear understanding of this relationship. The large amount of variance within the measurements, both within and between studies, as well as a lack of adequate control groups hinders the ability to draw causal inferences. Future investigation can improve the lack of clarity by enhancing investigative methodology.

2.5 Conclusion:

- There is little evidence to show a statistically significant difference in OPA dimensions after maxillary expansion

2.6 References

1. Harvold EP, Tomer BS, Vargervik K, Chierici G. Primate experiments on oral respiration. Am J Orthod. 1981 Apr;79(4):359-72.

2. Yamada T, Tanne K, Miyamoto K, Yamauchi K. Influences of nasal respiratory obstruction on craniofacial growth in young Macaca fuscata monkeys. Am J Orthod Dentofacial Orthop. 1997 Jan;111(1):38-43.

3. Tourne LP. Growth of the pharynx and its physiologic implications. Am J Orthod Dentofacial Orthop. 1991 Feb;99(2):129-39.

4. Schlenker WL, Jennings BD, Jeiroudi MT, Caruso JM. The effects of chronic absence of active nasal respiration on the growth of the skull: a pilot study. Am J Orthod Dentofacial Orthop. 2000 Jun;117(6):706-13.

5. McNamara JA., Maxillary transverse deficiency. Am J Orthod Dentofacial Orthop. 2000 May;117(5):567-70.

6. Johal A, Conaghan C. Maxillary morphology in obstructive sleep apnea: a cephalometric and model study. Angle Orthod. 2004 Oct;74(5):648-56.

7. Cistulli PA, Palmisano RG, Poole MD. Treatment of obstructive sleep apnea syndrome by rapid maxillary expansion. Sleep. 1998 Dec 15;21(8):831-5.

8. Kushida CA, Efron B, Guilleminault C. A predictive morphometric model for the obstructive sleep apnea syndrome. Ann Intern Med. 1997 Oct 15;127(8 Pt 1):581-7.

9. Zhao Y, Nguyen M, Gohl E, Mah JK, Sameshima G, Enciso R. Oropharyngeal airway changes after rapid palatal expansion evaluated with cone-beam computed tomography. Am J Orthod Dentofacial Orthop. 2010 Apr;137(4 Suppl):S71-8.

10. Bradley TD, Brown IG, Grossman RF, Zamel N, Martinez D, Phillipson EA,

Hoffstein V., Pharyngeal size in snorers, nonsnorers, and patients with obstructive sleep apnea., N Engl J Med. 1986 Nov 20;315(21):1327-31.

11. Sunitha C, Aravindkumar S., Obstructive sleep apnea: clinical and diagnostic features., Indian J Dent Res. 2009 Oct-Dec;20(4):487-91.

12. Avrahami E, Englender M., Relation between CT axial cross-sectional area of the oropharynx and obstructive sleep apnea syndrome in adults., AJNR Am J Neuroradiol. 1995 Jan;16(1):135-40.

13. Schmidt-Nowara W, Lowe A, Wiegand L, Cartwright R, Perez-Guerra F, Menn S. Oral appliances for the treatment of snoring and obstructive sleep apnea: a review. Sleep. 1995 Jul;18(6):501-10.

14. Pirelli P, Saponara M, Attanasio G. Obstructive Sleep Apnoea Syndrome (OSAS) and rhino-tubaric disfunction in children: therapeutic effects of RME therapy. Prog Orthod. 2005;6(1):48-61.

15. Ozbek MM, Memikoglu UT, Altug-Atac AT, Lowe AA., Stability of maxillary expansion and tongue posture., Angle Orthod. 2009 Mar;79(2):214-20.

16. Praud JP. Dorion D. Obstructive sleep disordered breathing in children: beyond adenotonsillectomy. [Review], Pediatric Pulmonology. 43(9):837-43, 2008 Sep.

17. Holmberg H, Linder-Aronson S. Cephalometric radiographs as a means of evaluating the capacity of the nasal and nasopharyngeal airway. Am J Orthod. 1979 Nov;76(5):479-90.

18. Muto T, Yamazaki A, Takeda S. A cephalometric evaluation of the pharyngeal airway space in patients with mandibular retrognathia and prognathia, and normal subjects. Int J Oral Maxillofac Surg. 2008 Mar;37(3):228-31

19. Kau CH, Richmond S, Palomo JM, Hans MG. Three-dimensional cone beam computerized tomography in orthodontics. J Orthod. 2005 Dec;32(4):282-93.
20. Shi H., Scarfe WC., Farman AG., Upper airway segmentation and dimensions estimation from cone-beam CT image datasets., Int J CARS. 2006 Oct 1(3):177-186
21. Alves PV, Zhao L, O'Gara M, Patel PK, Bolognese AM., Three-dimensional cephalometric study of upper airway space in skeletal class II and III healthy patients., J Craniofac Surg. 2008 Nov;19(6):1497-507.
22. Mah JK, Danforth RA, Bumann A, Hatcher D., Radiation absorbed in maxillofacial imaging with a new dental computed tomography device., Oral Surg Oral Med Oral Pathol Oral Radiol Endod. 2003 Oct;96(4):508-13.
23. Ogawa T, Enciso R, Shintaku WH, Clark GT., Evaluation of cross-section airway configuration of obstructive sleep apnea., Oral Surg Oral Med Oral Pathol Oral Radiol Endod. 2007 Jan;103(1):102-8. Epub 2006 Sep 1.
24. Aboudara C, Nielsen I, Huang JC, Maki K, Miller AJ, Hatcher D. Comparison of airway space with conventional lateral headfilms and 3-dimensional reconstruction from cone-beam computed tomography. Am J Orthod Dentofacial Orthop. 2009 Apr;135(4):468-79.
25. Gordon JM, Rosenblatt M, Witmans M, Carey JP, Heo G, Major PW, Flores-Mir C. Rapid palatal expansion effects on nasal airway dimensions as measured by acoustic rhinometry. A systematic review. Angle Orthod. 2009 Sep;79(5):1000-7. Review.
26. Baratieri C, Alves M Jr, de Souza MM, de Souza Araújo MT, Maia LC., Does rapid maxillary expansion have long-term effects on airway dimensions and breathing?, Am J Orthod Dentofacial Orthop. 2011 Aug;140(2):146-56. Review.

27. Kilinç AS, Arslan SG, Kama JD, Ozer T, Dari O. Effects on the sagittal pharyngeal dimensions of protraction and rapid palatal expansion in Class III malocclusion subjects. Eur J Orthod. 2008 Feb;30(1):61-6. Epub 2007 Sep 28.

28. Villa MP, Malagola C, Pagani J, Montesano M, Rizzoli A, Guilleminault C, Ronchetti R., Rapid maxillary expansion in children with obstructive sleep apnea syndrome: 12-month follow-up., Sleep Med. 2007 Mar;8(2):128-34. Epub 2007 Jan 18.

29. Joseph AA, Elbaum J, Cisneros GJ, Eisig SB. A cephalometric comparative study of the soft tissue airway dimensions in persons with hyperdivergent and normodivergent facial patterns. J Oral Maxillofac Surg. 1998 Feb;56(2):135-9.

30. Mucedero M. Baccetti T. Franchi L. Cozza P. Effects of maxillary protraction with or without expansion on the sagittal pharyngeal dimensions in Class III subjects. Am J Orthod Dentofacial Orthop. 135(6):777-81, 2009 Jun.

31. Lenza MG, Lenza MM, Dalstra M, Melsen B, Cattaneo PM., An analysis of different approaches to the assessment of upper airway morphology: a CBCT study. Orthod Craniofac Res. 2010 May;13(2):96-105.

32. Ahlqvist J, Eliasson S, Welander U., The effect of projection errors on cephalometric length measurements., Eur J Orthod. 1986 Aug;8(3):141-8.

33. Vig PS, Hall DJ., The inadequacy of cephalometric radiographs for airway assessment., Am J Orthod. 1980 Feb;77(2):230-3.

34. Pangrazio-Kulbersh V, Wine P, Haughey M, Pajtas B, Kaczynski R., Cone beam computed tomography evaluation of changes in the naso-maxillary complex associated with two types of maxillary expanders., Angle Orthod. 2012 May;82(3):448-57. Epub 2011 Oct 27.

35. Smith T, Ghoneima A, Stewart K, Liu S, Eckert G, Halum S, Kula K., Three-dimensional computed tomography analysis of airway volume changes after rapid maxillary expansion., Am J Orthod Dentofacial Orthop. 2012 May;141(5):618-26.

36. Ribeiro AN, de Paiva JB, Rino-Neto J, Illipronti-Filho E, Trivino T, Fantini SM., Upper airway expansion after rapid maxillary expansion evaluated with cone beam computed tomography., Angle Orthod. 2012 May;82(3):458-63. Epub 2011 Oct 17.

Chapter 3- Cone-Beam Computed Tomography Evaluation of Oropharyngeal Airway Dimensions in Adolescents with Maxillary Transverse Deficiency

3.1 Introduction

A dynamic relationship is understood to exist between the upper airway and the dentofacial structure due to their close anatomical location.[1,2,3] The influence of impaired nasal breathing on facial development has been demonstrated to exist through the characteristics of the long face growth pattern.[3,4] Maxillary transverse deficiency (MTD), which can be characterized by posterior crossbite,[5] has also been shown to be related to impaired nasal breathing.[4,6] More recently, the reciprocal effect of MTD on airway has been described. It is proposed that a narrowing of the oropharyngeal airway (OPA) exists from the tongue being forced posteriorly due to a reduced oral cavity space in subjects with MTD.[7,8,9] This potentially narrowing of the lumen of the OPA has been hypothesized to play a role in the symptoms of obstructive sleep apnea (OSA).[6,7,10,11]

Rapid maxillary expansion (RME) is commonly used for correction of crossbite. It has been suggested to be a useful tool to aid in improvement of sleep disordered breathing.[10,12] One possible explanation for RME's effect on OSA is due to a concurrent change in OPA dimension. With expansion of the constricted maxilla and increase in the oral cavity dimension, resting tongue posture has been shown to improve,[13] potentially increasing OPA space.[7,14] Lateral and frontal cephalometric imaging have been the most extensively used tools in the orthodontic literature for studying airway dimensions in growing patients.[15,16] The availability of cone-beam computed tomography (CBCT) has become more widely accepted for 3-dimensional cross-sectional and volumetric analysis of the naso- and OPA.[17,18]

Four studies have been found that specifically have examined the relationship between maxillary expansion with OPA change using CBCT technology.[9,19,20,21] Zhao et al,[9] Prangrazio-Kulbersh et al,[19] Smith et al.,[20] and Ribeiro et al,[21] have not shown consistency in demonstrating a change in OPA after expansion as Ribeiro et al[21] was the only study to reveal a statistically significant change in preadolescent subjects. Only Zhao et al[9] utilized a control group, though this group was not matched for preexisting MTD. Lack of inadequate controls across these studies generates uncertainty as to whether any change recorded is actually a result of appliance therapy.

Although the relationship between MTD and airway has been investigated, only recently an interest has risen to relate MTD and OPA dimensions. Regarding a potential impact on the OPA, only a few studies have described the relationship between the morphology of the OPA and MTD.[6,9,21,22,23] The objective of this study is to analyze CBCT images to measure changes in OPA dimensions after treatment with RME, and compare these changes with those from a matched control group.

3.2 Materials and Methods

This retrospective study utilized CBCT images from two previous randomized clinical trials. For both trials, subjects were recruited from the University of Alberta Orthodontic Clinic patient pool during an 18 month period. Subjects with permanent dentition erupted from first molar to first molar requiring maxillary expansion treatment, were selected and randomly assigned to either a treatment or control group. It is unknown whether any of the subjects suffered from any airway symptoms as this information was not collected at the time of the initial trial. All available subjects available from these studies were included with the exceptions of subjects who received maxillary expansion therapy with a bone borne appliance (1/3 of sample), and an additional 7 subject who did not receive scans from the same machine. The resulting 75 subjects included 37 in the treatment group, and 38 matched controls. This study was approved by the Health Ethics Research Board under the study ID Pro00019986 (Appendix A).

The treatment group received RME by twice daily activation of a tooth borne Hyrax appliance for up to 1 month followed by 6 months retention with the Hyrax appliance. The total expansion varied based on the need of each subject. The control group had treatment delayed for the study period after which time they received the same necessary treatment with RME. CBCT images were obtained for both groups at a baseline time point (T1), then repeated 6 months after the expansion appliance was inserted (T2) for the treatment group. CBCT images were taken on either a

NewTom 3G (64 subjects) or ICAT machine (11 subjects). Neither tongue position nor respiration were controlled for during the time of the scan, rather subjects were asked to bite normally and remain still.

Raw data from the CBCT machine were exported as DICOM files and imported into the Mimics software program (Materialise Interactive Medical Image Control System, Leuven Belgium). A grey level threshold was then defined for each scan independently by controlling the contrast to optimally differentiate the soft tissues from the airway space. To define the volumetric region of interest, OPA borders were traced using a line drawn parallel to a standard plane (designated at the level of the most inferior borders of both orbits and the most superior border of the right auditory meatus) between the hard and soft palate at the posterior nasal spine, and a second line parallel to the first plane through the superior margin of the epiglottis (Fig 1). Auto-segmentation was then completed within the Mimics software to digitally excised the highlighted voxels which were below the grey level threshold ranges for soft tissue and bone. Cross-sectional area and volumetric measurements were obtained from the axial plane reconstructions and generated 3D rendering.

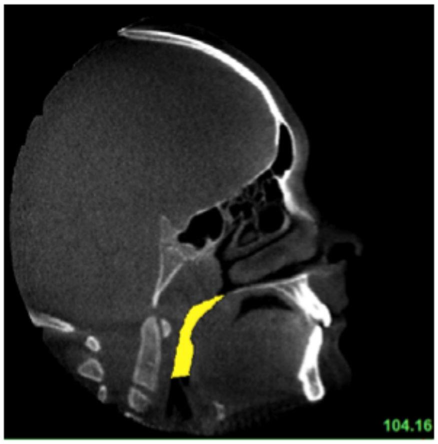

Figure 3-1: Example of the OPA Borders at a Single Sagittal Slice.

OPA measurements obtained from the CBCT scans were divided into 4 separate variables: total airway volume (Vol) measured in cm^3, cross-sectional areas at the most inferior point of the soft palate (SP) and middle of the soft palate (MP) measured in mm^2, and smallest cross-sectional area (MCA) measured in mm^2. Cross-sectional area measurements were made on segmented axial slices of 1mm to define area, and maximum constriction was evaluated by determining the narrowest cross-sectional area. Finally, volume was calculated from the 3D rendering automatically using the volume rendering software.

All data was coded for blinding purposes. The principal investigator was not aware of the patient group assignment, and treatment was provided by a different orthodontist, thus avoiding bias.

3.3 Statistical Methods

Reliability was assured by measuring the four airway dimensions of interest for 10 randomly selected subjects 3 times over a period of 2 weeks (Appendix B). Recalibrating the orientation and grey level threshold of the CBCT scans were performed prior to redefining the boundaries of the OPA and the autosegmentation step for each round of measurements. Intra-class correlation coefficients (ICC) of these values from the CBCT scans were used to assess intra-rater reliability.

The focus of the study was to measure the change in OPA dimensions before and after expansion treatment, and compare those changes with an untreated control group. Absolute changes in OPA dimensions were calculated by taking the difference between T1 and T2 measurements. Percent change scores were also calculated by dividing the absolute change score by the T1 measurement, and multiplying by 100. A multivariate analysis of variance (MANOVA) was used to assess differences in mean Vol, SP, MP and MCA between treatment and control groups, as well as gender, and to evaluate whether any change in these measurements exist between groups at T1 and T2. Statistical data analyses including all descriptives, reliability tests, model assumptions, and multivariate analyses were performed using SPSS software version 16.0, at a significance level of 5%.

3.4 Results

The intra-class coefficients and corresponding 95% confidence interval (CI) for each of the parameters of interest along with the measurement error of the three trials are shown in Table 1. Though the ICC values indicate a high level of repeatability of the radiologic measures, there is a discrepancy present when considering the relatively high measurement error value in SP measurement in Table 1.

Table 3-1: ICC with 95% Confidence Interval(CI), and Measurement Error (ME).

	ICC	95% CI	Absolute ME	ME stand dev	ME % diff
Vol	0.985	(0.959, 0.996)	0.34 cm^3	0.24 cm^3	5.02
SP	0.945	(0.800, 0.986)	18.33 mm^2	10.54 mm^2	15.71
MP	0.959	(0.887, 0.989)	9.36 mm^2	11.19 mm^2	6.57
MCA	0.998	(0.993, 0.999)	3.11 mm^2	2.40 mm^2	3.18

Gender and age distribution of the 75 subjects are shown in Table 2. Boxplots in Figure 2 and 3 depict the distribution of percentage change in mean OPA measurements made between treatment and control groups, and between genders at T1 and T2. The mean and standard deviations of each OPA measurement change scores for each groups are displayed in Table 4. Despite a large number of outliers skewing the distribution of data, the equal variance and independence assumptions were adequate to fulfill the criteria for MANOVA tests.

Table 3-2: Gender and Age Distribution

Treatment Group	Gender	Frequency	Age (y)	Age Std Deviation
Control	Male	13	13.7	1.6
	Female	25	13.1	1.4
	Total	38	13.3	1.5
Treatment	Male	14	14.4	1.4
	Female	23	13.8	1.4
	Total	37	14.1	1.4

Figure 3-2: Boxplot of Percent Differences of OPA Dimensions Between Treatment and Control Groups

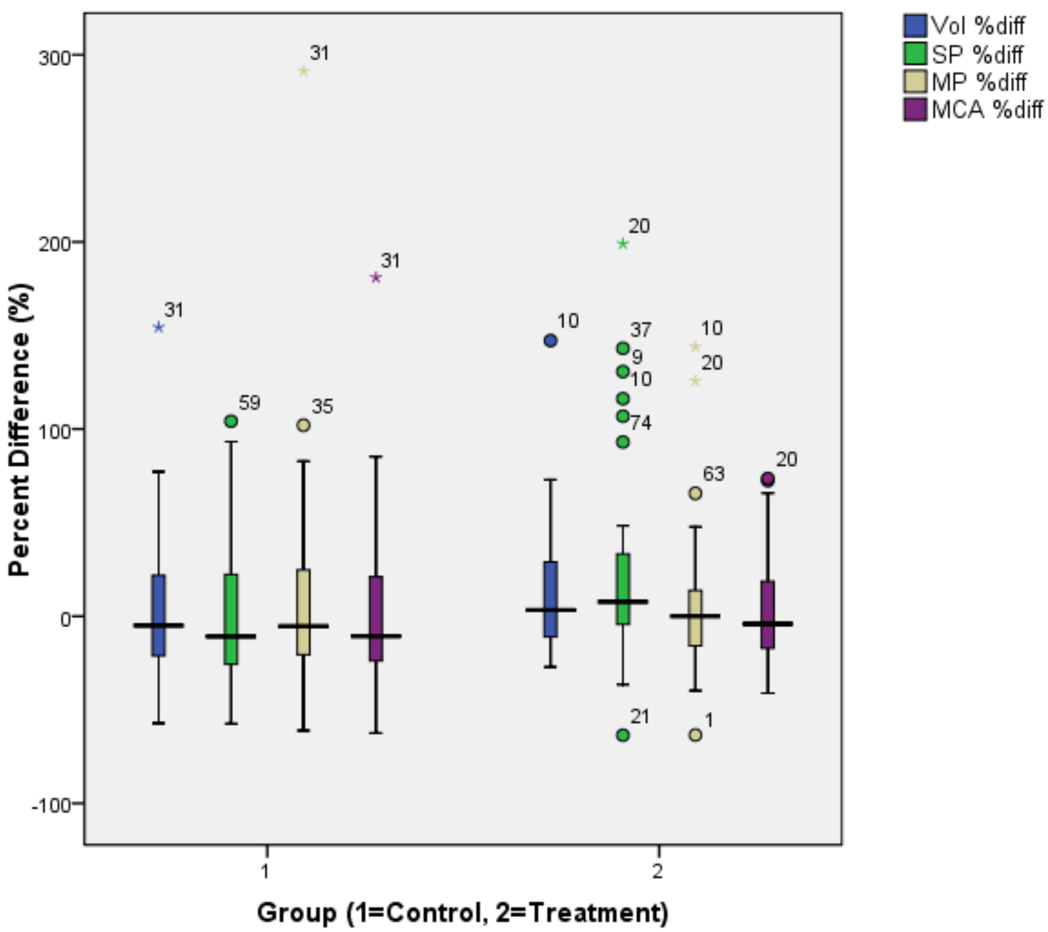

Figure 3-3: Boxplot of Percent Differences of OPA Dimensions Between Gender Groups

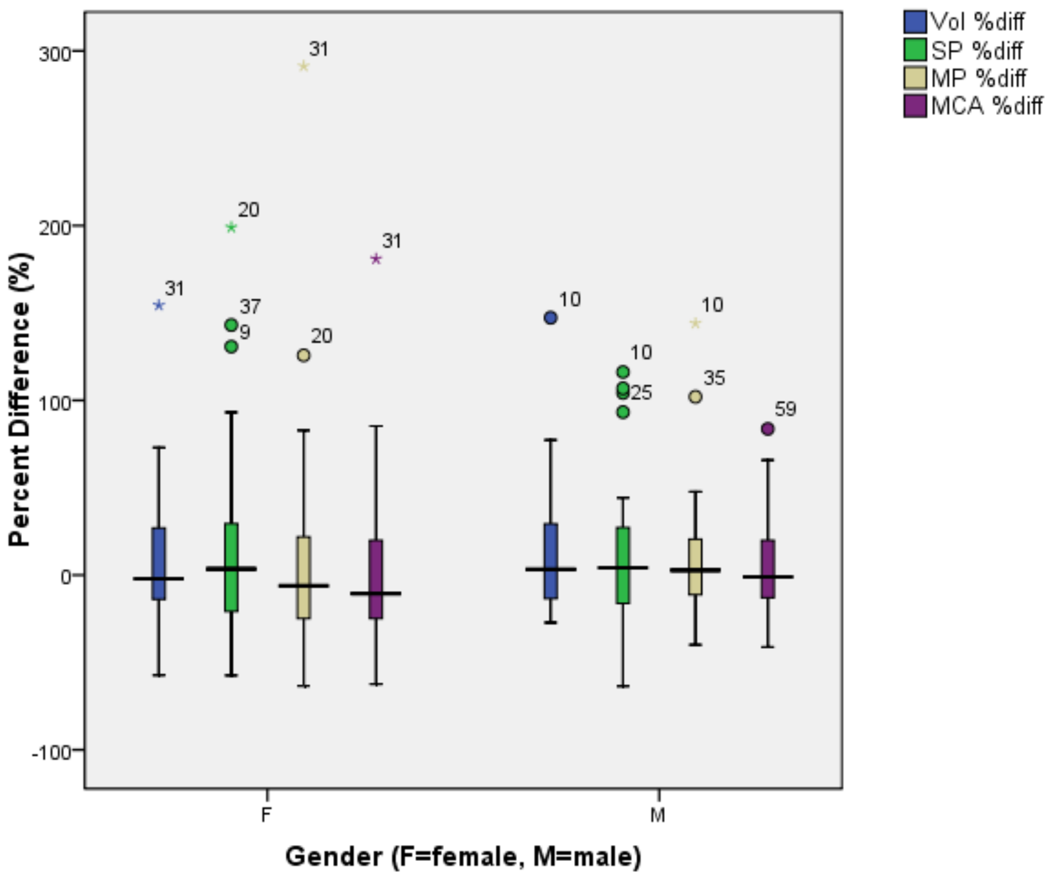

Table 3-3: Mean and Standard Deviation of Absolute and Percentage Change of OPA Dimensions

Parameter	Male				Female			
	Control		Treatment		Control		Treatment	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Absolute Value								
Vol (cm^3)	0.20	2.18	0.99	3.44	-0.43	2.78	0.59	2.05
SP (mm^2)	-5.28	53.71	15.55	77.13	-17.01	62.77	17.21	44.80
MP (mm^2)	11.58	39.03	21.78	81.67	-4.22	80.20	-9.03	44.15
MCA (mm^2)	2.98	23.84	-2.99	28.39	-15.36	48.67	-1.46	23.48
Percent Difference								
Vol (%)	8.33	32.07	14.97	43.99	3.19	45.40	11.03	26.00
SP (%)	8.59	44.90	18.30	47.92	-1.00	35.73	27.75	59.95
MP (%)	10.62	32.28	12.47	43.79	7.94	69.57	2.61	37.21
MCA (%)	10.21	32.63	-0.16	29.86	-2.42	52.15	4.10	30.54

Homogeneity of OPA measurements between treatment groups and between genders at baseline were initially assessed with a MANOVA. These revealed non-significant differences between treatment groups [$F(4,68)=1.058$, $p=0.384$], and similarly differences between genders at baseline were not conclusive [$F(4,68)=1.851$, $p=0.129$].

To investigate whether treatment group type and gender had a main effect on OPA dimensions between timepoints, a MANOVA was performed using first the change scores, then the percent scores. Once removing the interaction between gender and group, which showed a non-significant difference [$F(4,68)=1.339$, $p=0.264$, $\eta^2=0.073$], the final MANOVA model revealed no significant differences in mean change scores due to treatment group type [$F(4,69)=1.756$, $p=0.148$, $\eta^2=0.092$], or due to gender [$F(4,69)=0.638$, $p=0.637$, $\eta^2=0.036$]. The low estimate of effect size revealed the effect of treatment group to account for only 9.2% of the variance in OPA measurements, while gender accounted for 3.6% of the variance in OPA changes. Similar findings were present for the percent scores after removing the non-significant interaction term [$F(4,68)=0.832$, $p=0.510$, $\eta^2=0.047$] for group type [$F(4,69)=2.316$, $p=0.066$, $\eta^2=0.118$] and gender [$F(4,69)=0.130$, $p=0.971$, $\eta^2=0.007$].

3.5 Discussion

This study set out to investigate the treatment efficacy of rapid maxillary expansion on increasing OPA dimensions. Specifically, CBCT images taken pre-expansion and six months post-expansion were compared with a matched control group to assess changes in four specific OPA dimensions; overall volume, cross-sectional area at the soft palate, cross-sectional area at the mid-palate, and the minimum cross-section area. Initial analysis of the data revealed a wide distribution of measurements. The findings were consistent with previous studies[9,19,20] utilizing OPA measurements; the overall changes in OPA dimensions were not statistically significant. However, this study remains the only one to date that compares change in airway dimensions to a randomized control group.

The main finding of this study was that neither rapid maxillary expansion or gender had a statistically significant effect on the change in airway dimensions. However, this outcome needs to be interpreted within the context of this data set. The individual data points for this study were highly scattered and contained a great deal of outliers as shown in Figures 1 and 2. As a result, it is difficult to compare the potential change in measurement between time points. There is a possibility measurement error could be a contributing factor to the large variability within the data as error present at any stage of the isolation of the OPA may result in error compounding throughout the measurement process. The high ICC values (reliability) however provide confidence that the amount of measurement error is statistically acceptable.

There are two possible explanations for the variance observed in the data set. The first includes anatomical variations in head, tongue, and other surrounding structures' positions during the CBCT scan. Lack of standardizing head posture even within the same machine has been shown to affect the airway dimensions.[24] A protocol for positioning subjects in the NewTom machine included centering the head using the lasers of the Newtom, as well instructing the subjects to bite normally while remaining still, however inclination of the head position up or down was not accounted for between subjects or within subjects at different time points, potentially influencing the variance in the results. Additionally, the physical orientation of the patient as a whole also impacts the observable dimensions of the airway; for instance, whether the subject is sitting upright versus laying in the supine position. This positional difference results in sagging of the tongue and other soft tissues into the OPA in a relaxed supine position due simply to gravitational forces.[25,26] For this study, some patients were scanned in the supine position with the NewTom machine while others were scanned in the upright position with the ICAT machine. Consequently, the change in absolute values for each airway parameter may be distorted.

More importantly, the lack of standardizing tongue position is most likely the largest anatomical factor affecting the comparison of scans. As shown in Figure 4, there is a noticeable change in airway dimension when a subject has their tongue pressed up against the palate and when the tongue is more inferiorly postured. Even though the maxillary expander theoretically created an increased oral cavity for the tongue, the tongue can still be artificially positioned by the patient therefore interfering with the observable difference between scans. Thus tongue position protocol needs to be standardized when imaging in order to ascertain any physiological reason for the observed difference between subjects.

Other anatomical variations exist which pose the potential to affect the measurement of the airway. These include transient inflammation and swelling of the tonsils and the adenoids, the transient position of the epiglottis during swallowing, and the change in muscle and soft tissue tension during respiration. Since a CBCT image represents only a “snapshot” in time, a true representation of this dynamic anatomical structure during normal respiration is impossible to achieve with this imaging device. It is therefore difficult to account for all of these potential factors affecting the airway dimensions when measuring and comparing images.

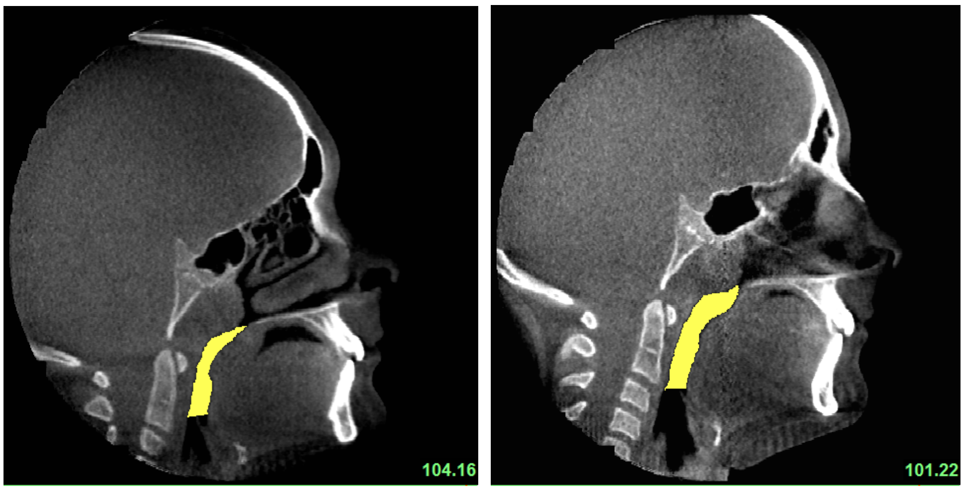

Figure 3-4: Sagittal Views of a Subject in the Control Group Taken at T1 and T2 Demonstrating the Change in Tongue Position Affecting the Airway Dimensions.

The second factor when examining the variance of this study's data set is a lack of sufficient scanning resolution quality when comparing CBCT measurements between subjects and time points. A number of inherent limitations exist with CBCT technology that reduce image clarity compared to conventional CT due to artifacts, partial volume averaging, noise, and poor contrast. High resolution images are preferred in order to differentiate soft tissues from airway space in order to achieve an accurate measurement of the OPA. Measurement error occured when first attempting to isolate the desired airway for analysis by defining a grey level threshold of acceptable OPA boundaries. As shown in the coronal view in Figure 5, a lot of noise exists at the borders of the airway space making it very difficult to discriminate from the surrounding soft tissues. This produces an inaccurate image that is further compounded by any "clean up" provided by the investigator when judging exactly where the airway space extends. It should be noted that the autosegmentation with any software has not been proven to be more accurate Fortunately, with the high intra-rater reliability scores (ICC) shown in Table 1, any inaccuracies due to poor resolution were consistent across all subjects. However, despite the good reliability scores, the image quality does not provide a reliable representation of the change occurring in the OPA. Increasing the radiation dosage to attain higher resolution images, or switching to conventional CT imaging to negate the limitations of CBCT, will consequently expose patients to more radiation. We hope the patient benefit from airway analysis and orthodontic assessment outweighs the harm of extra radiation to keep in accordance with the "as low as reasonably achievable" (ALARA) principal.

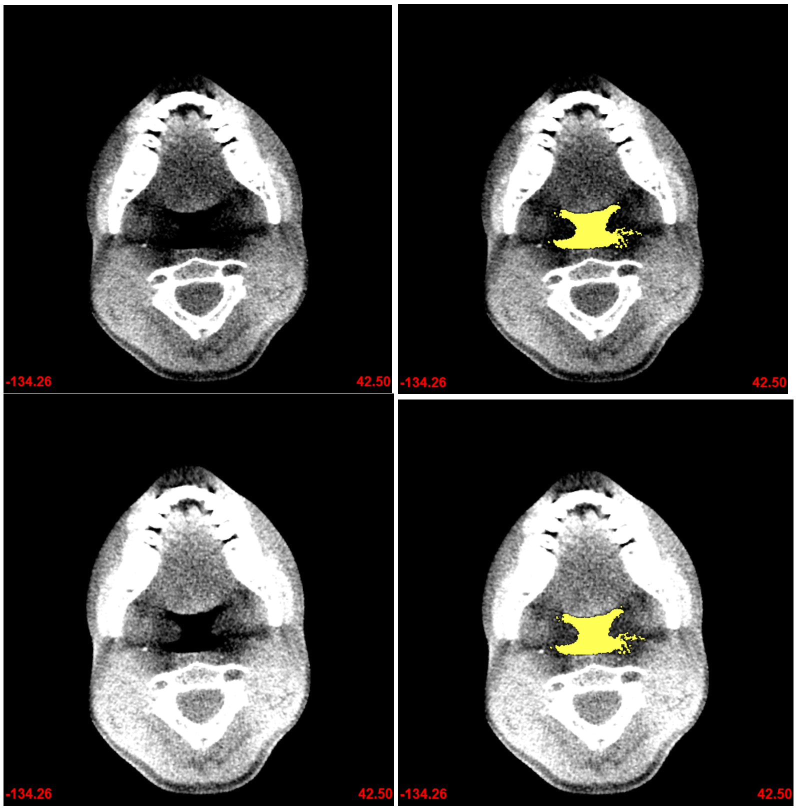

Figure 3-5: Difference in Calibration Settings in the Same Axial Slice to Demonstrate Difficulty in Defining Exact Borders During Thresholding Stage.

Descriptive statistics (Table 3) reveal a potentially clinically relevant change in mean airway dimensional change, however, the large standard deviation reveals an inconsistency of measurements between subjects. The vast majority of the measurements for individual subjects between time points showed a positive or negative change with some differences being quite extreme. In contrast, only a few individuals showed a relatively small alteration between time points. At first glance the data appears to indicate that modifications to the OPA were happening over time. Though upon closer inspection the differences recorded were extremely varied with no predictability for either the control or treatment groups. Overall

MANOVA testing revealed the main effect of treatment to be statistically insignificant in all mean airway dimensions and percentage changes. Gender was also shown to have no effect on OPA dimensions and changes over time. Thus the null hypothesis was supported and the theory of the OPA enlarging after maxillary expansion was rejected.

The results of our study are consistent with previous CBCT studies published that measure change in OPA dimensions. Studies by Zhao et al,[9] Prangrazio-Kulbersh et al,[19] and Smith et al,[20] found no overall change in total OPA dimensions after maxillary expansion. Our study was the next step in the natural progression in the body of literature by being a randomized clinical trial with a matched control. Our results validate and support the non-significant changes noted in these studies.

The collective consensus of non-significant data is in contrast to the study by Ribeiro et al[21] who found slight change in retroglossal volume, minimum cross-sectional and median sagittal area measurements. They justified this change due to the inconsistencies in craniocervical inclination of the subjects, breathing and swallowing movements, as well as a lack of standardized tongue positioning during the scan. In addition, the lack of a matched control in this study weakens the possible inferences of their results. It should be noted that the study by Ribeiro et al[21] also differs from our study by the younger mean age of the subjects (7.5 years). This younger mean age could suggest a physiologically different response to maxillary expansion in adolescent subjects not accounted for in the statistically significant results reported.

One limitation of collecting the data for this study retrospectively from two previous studies was the inability to control for tongue positioning during the CBCT scans. We concur with the recommendations of previous researchers that future prospective airway studies include a standardized tongue positioning protocol. Future studies would also benefit from utilizing individuals with a diagnosed medical airway problem such as sleep apnea in conjunction with a subsequent orthodontic problem; as opposed to attempting to quantify airway dimension change in an already medically healthy individual.

Our study does not provide evidence to support the use of a maxillary expander appliance to increase the OPA. In addition, the consistency with standard positioning, and accuracy in measuring the airway with CBCT was questioned.

3.6 Conclusion

Treatment with a hyrax appliance did not yield a significant effect in changing OPA dimensions.

3.7 References

1. Harvold EP, Tomer BS, Vargervik K, Chierici G. Primate experiments on oral respiration. Am J Orthod. 1981 Apr;79(4):359-72.

2. Yamada T, Tanne K, Miyamoto K, Yamauchi K. Influences of nasal respiratory obstruction on craniofacial growth in young Macaca fuscata monkeys. Am J Orthod Dentofacial Orthop. 1997 Jan;111(1):38-43.

3. Tourne LP. Growth of the pharynx and its physiologic implications. Am J Orthod Dentofacial Orthop. 1991 Feb;99(2):129-39.

4. Schlenker WL, Jennings BD, Jeiroudi MT, Caruso JM. The effects of chronic absence of active nasal respiration on the growth of the skull: a pilot study. Am J Orthod Dentofacial Orthop. 2000 Jun;117(6):706-13.

5. McNamara JA., Maxillary transverse deficiency. Am J Orthod Dentofacial Orthop. 2000 May;117(5):567-70.

6. Johal A, Conaghan C. Maxillary morphology in obstructive sleep apnea: a cephalometric and model study. Angle Orthod. 2004 Oct;74(5):648-56.

7. Cistulli PA, Palmisano RG, Poole MD. Treatment of obstructive sleep apnea syndrome by rapid maxillary expansion. Sleep. 1998 Dec 15;21(8):831-5.

8. Kushida CA, Efron B, Guilleminault C. A predictive morphometric model for the obstructive sleep apnea syndrome. Ann Intern Med. 1997 Oct 15;127(8 Pt 1):581-7.

9. Zhao Y, Nguyen M, Gohl E, Mah JK, Sameshima G, Enciso R. Oropharyngeal airway changes after rapid palatal expansion evaluated with cone-beam computed tomography. Am J Orthod Dentofacial Orthop. 2010 Apr;137(4 Suppl):S71-8.

10. Schmidt-Nowara W, Lowe A, Wiegand L, Cartwright R, Perez-Guerra F, Menn S. Oral appliances for the treatment of snoring and obstructive sleep apnea: a review. Sleep. 1995 Jul;18(6):501-10.

11. Seto BH, Gotsopoulos H, Sims MR, Cistulli PA. Maxillary morphology in obstructive sleep apnoea syndrome. Eur J Orthod. 2001 Dec;23(6):703-14.

12. Pirelli P, Saponara M, Attanasio G. Obstructive Sleep Apnoea Syndrome (OSAS) and rhino-tubaric disfunction in children: therapeutic effects of RME therapy. Prog Orthod. 2005;6(1):48-61.

13. Ozbek MM, Memikoglu UT, Altug-Atac AT, Lowe AA., Stability of maxillary expansion and tongue posture., Angle Orthod. 2009 Mar;79(2):214-20.

14. Praud JP. Dorion D. Obstructive sleep disordered breathing in children: beyond adenotonsillectomy. [Review], Pediatric Pulmonology. 43(9):837-43, 2008 Sep.

15. Holmberg H, Linder-Aronson S. Cephalometric radiographs as a means of evaluating the capacity of the nasal and nasopharyngeal airway. Am J Orthod. 1979 Nov;76(5):479-90.

16. Major MP, Flores-Mir C, Major PW. Assessment of lateral cephalometric diagnosis of adenoid hypertrophy and posterior upper airway obstruction: a systematic review. Am J Orthod Dentofacial Orthop. 2006 Dec;130(6):700-8.

17. Aboudara C, Nielsen I, Huang JC, Maki K, Miller AJ, Hatcher D. Comparison of airway space with conventional lateral headfilms and 3-dimensional reconstruction from cone-beam computed tomography. Am J Orthod Dentofacial Orthop. 2009 Apr;135(4):468-79.

18. Kau CH, Richmond S, Palomo JM, Hans MG. Three-dimensional cone beam computerized tomography in orthodontics. J Orthod. 2005 Dec;32(4):282-93.
19. Pangrazio-Kulbersh V, Wine P, Haughey M, Pajtas B, Kaczynski R., Cone beam computed tomography evaluation of changes in the naso-maxillary complex associated with two types of maxillary expanders., Angle Orthod. 2012 May;82(3):448-57. Epub 2011 Oct 27.
20. Smith T, Ghoneima A, Stewart K, Liu S, Eckert G, Halum S, Kula K., Three-dimensional computed tomography analysis of airway volume changes after rapid maxillary expansion., Am J Orthod Dentofacial Orthop. 2012 May;141(5):618-26.
21. Ribeiro AN, de Paiva JB, Rino-Neto J, Illipronti-Filho E, Trivino T, Fantini SM., Upper airway expansion after rapid maxillary expansion evaluated with cone beam computed tomography., Angle Orthod. 2011 Oct 17.
22. Mucedero M. Baccetti T. Franchi L. Cozza P. Effects of maxillary protraction with or without expansion on the sagittal pharyngeal dimensions in Class III subjects. Am J Orthod Dentofacial Orthop. 135(6):777-81, 2009 Jun.
23. Kilinç AS, Arslan SG, Kama JD, Ozer T, Dari O. Effects on the sagittal pharyngeal dimensions of protraction and rapid palatal expansion in Class III malocclusion subjects. Eur J Orthod. 2008 Feb;30(1):61-6. Epub 2007 Sep 28.
24. Muto T, Takeda S, Kanazawa M, Yamazaki A, Fujiwara Y, Mizoguchi I., The effect of head posture on the pharyngeal airway space (PAS), Int J Oral Maxillofac Surg. 2002 Dec;31(6):579-83.

25. Ingman T, Nieminen T, Hurmerinta K., Cephalometric comparison of pharyngeal changes in subjects with upper airway resistance syndrome or obstructive sleep apnoea in upright and supine positions, Eur J Orthod. 2004 Jun;26(3):321-6.
26. Pae EK, Lowe AA, Sasaki K, Price C, Tsuchiya M, Fleetham JA., A cephalometric and electromyographic study of upper airway structures in the upright and supine positions, Am J Orthod Dentofacial Orthop. 1994 Jul;106(1):52-9.

Chapter 4 – General Discussion

4.1 Final Discussion

This investigation was launched with the goal of attaining a better understanding of oropharyngeal airway (OPA) dimensional changes after maxillary expansion. This study differentiates itself from similar studies in two ways: the addition of a matched control group in this randomized clinical trial study design, and an increase in sample size from 48 which was the largest to date, to 75 combined treatment and control subjects. The present study builds on the previous research and adds to the current collection of knowledge as the next logical step in the natural progression of literature on this topic.

The randomized clinical trial design of this study provides the highest level of research to minimize any bias and confounding factors, while reducing as many sources of variation as possible. Because subjects were randomly allocated to either treatment or control groups, causal inferences can be made from the data allowing comparisons to other individuals with the same characteristics. Population inferences however cannot be made as subjects were not randomly selected from the general population; rather they were chosen based on their posterior crossbite malocclusion from the limited patient pool at the University of Alberta Graduate Orthodontics clinic.

The position of the tongue has been the most frequently cited source of error within the literature.[1,2] Both Zhao et al[1] and Ribeiro et al[2] mentioned the lack of control of tongue position as a potential limitation to understanding the change or lack thereof in the OPA post expansion. Our study also attributed the lack of standardized tongue position to be a major limitation for the non-significant, and highly variable findings. This confuses the hypothesis that maxillary expansion increases oral cavity dimensions allowing for a more anterior and superior tongue position. To test this theory, the ideal tongue posture during scans would have to be at rest and inactive. Patient cooperation during scanning is crucial in order to properly and consistently measure airway dimensional changes. Unfortunately, a natural rest position is extremely difficult to achieve. This leads to a dilemma; do we standardize tongue position, or encourage a relaxed tongue posture, or mention nothing to the subject? Implementing a protocol for tongue positioning could introduce artificial positioning and bias on both the part of the investigator and the subject. Merely verbalizing instruction regarding a relaxed tongue posture, in order to increase standardization, may create a hyper awareness within the patient potentially resulting in more tongue movement overall. What in fact we are looking for is a natural tongue position at rest for each subject as opposed to an artificial standardized position. Theoretically no instruction to the patient regarding tongue posture could provide the best chance for a natural tongue position, however, as seen in this study and depicted in figure 4-1, this natural tongue position is extremely variable and is most likely influenced by the awkward patient experience when having a CBCT scan performed.

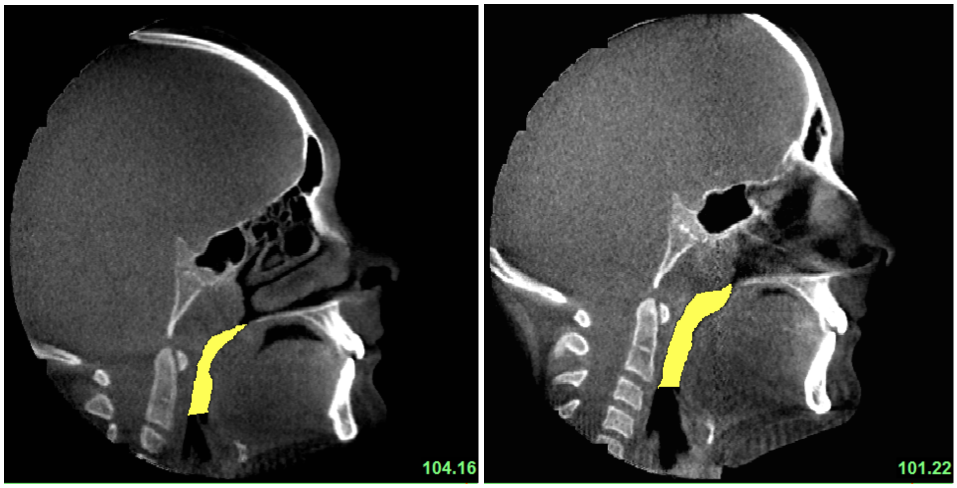

Figure 4-1: Sagittal Views of a Subject in the Control Group Taken at T1 and T2 Demonstrating the Change in Tongue Position Affecting the Airway Dimensions.

The potential for the tongue to influence the OPA dimensions is so great that it makes studying this space a challenge. The dilemma as to whether researchers should standardized tongue position or not leads to the ultimate consideration of whether this line of questioning and inquiry will ever be resolved. Previously, studies were limited by the technology of their time;[3,4,5] namely the lack of visualization of the shape and critical dimensions of the OPA with the 2D imaging. However, with the introduction of 3D imaging, these concerns were virtually eliminated and yet the literature is failing to find statistically significant changes in the OPA post maxillary expansion. Researchers may find it difficult to let go of this type of study as the notion that maxillary expansion leads to OPA enlargement is believed on a clinically intuitive level. Nonetheless studies have repeatedly failed to establish a consistent statistically significant change despite the technological improvements to imaging methodologies. Perhaps more dynamic imaging would reveal a functional process that cannot be seen by the current static imaging. The alternative is the recognition that there is sufficient support that maxillary expansion does not significantly effect changes in OPA dimensions.

4.2 References

1. Zhao Y, Nguyen M, Gohl E, Mah JK, Sameshima G, Enciso R. Oropharyngeal airway changes after rapid palatal expansion evaluated with cone-beam computed tomography. Am J Orthod Dentofacial Orthop. 2010 Apr;137(4 Suppl):S71-8.

2. Ribeiro AN, de Paiva JB, Rino-Neto J, Illipronti-Filho E, Trivino T, Fantini SM., Upper airway expansion after rapid maxillary expansion evaluated with cone beam computed tomography., Angle Orthod. 2012 May;82(3):458-63. Epub 2011 Oct 17.

3. Johal A, Conaghan C. Maxillary morphology in obstructive sleep apnea: a cephalometric and model study. Angle Orthod. 2004 Oct;74(5):648-56.

4. Kilinç AS, Arslan SG, Kama JD, Ozer T, Dari O. Effects on the sagittal pharyngeal dimensions of protraction and rapid palatal expansion in Class III malocclusion subjects. Eur J Orthod. 2008 Feb;30(1):61-6. Epub 2007 Sep 28.

5. Mucedero M. Baccetti T. Franchi L. Cozza P. Effects of maxillary protraction with or without expansion on the sagittal pharyngeal dimensions in Class III subjects. Am J Orthod Dentofacial Orthop. 135(6):777-81, 2009 Jun.

Appendix

Appendix A: Ethics Approval

Approval Form

Date:	January 25, 2011
Principal Investigator:	Paul Major
Study ID:	Pro00019986
Study Title:	Cone-beam computed tomography (CBCT) evaluation of oropharyngeal airway dimensions in adolescents with maxillary transverse deficiency.
Approval Expiry Date:	January 24, 2012

Thank you for submitting the above study to the Health Research Ethics Board - Biomedical Panel. Your application and your response on January 22, 2011 have been reviewed and approved on behalf of the committee.

The Health Research Ethics Board assessed all matters required by section 50(1)(a) of the Health Information Act. It has been determined that the research described in the ethics application is a secondary analysis of previously collected data for which subject consent for access to personally identifiable health information would not be reasonable, feasible or practical. Subject consent therefore is not required for access to personally identifiable health information described in the ethics application. In order to comply with the Health Information Act, a copy of the approval form is being sent to the Office of the Information and Privacy Commissioner.

A renewal report must be submitted next year prior to the expiry of this approval if your study still requires ethics approval. If you do not renew on or before the renewal expiry date (January 24, 2012), you will have to re-submit an ethics application.

Sincerely,

J. Stephen Bamforth, MD

Associate Chair, Health Research Ethics Board - Biomedical Panel

Note: This correspondence includes an electronic signature (validation and approval via an online system).

Appendix B: Reliability Measures

Table 1: Volume (cm^3) (Vol) reliability measures for each subject with average difference between trials

Subject	Vol Trial 1	Vol Trial 2	Vol Trial 3	Mean	SD	Average difference
1	5.53	5.32	5.32	5.39	0.12	0.14
2	3.32	4.20	4.12	3.88	0.49	0.59
3	5.87	5.53	5.29	5.56	0.29	0.39
4	8.28	8.11	8.43	8.27	0.16	0.21
5	2.64	2.86	2.86	2.79	0.13	0.15
6	7.65	7.72	7.87	7.74	0.11	0.15
7	13.33	13.89	14.00	13.74	0.36	0.45
8	9.30	9.08	8.85	9.08	0.22	0.30
9	3.42	4.57	4.75	4.25	0.72	0.89
10	7.65	7.84	7.93	7.81	0.14	0.18

Average difference: the average of the values for trial 1 – trial 2, trial 2 - trial 3, and trial 3 – trial 1

Table 2: Soft Palate (mm^2) (SP) reliability measures along with mean and standard deviation per subject

Subject	SP Trial 1	SP Trial 2	SP Trial 3	Mean	SD	Average difference
1	97.72	97.65	86.61	94.00	6.40	7.41
2	67.56	70.03	52.21	63.27	9.65	11.88
3	121.36	92.61	90.84	101.61	17.13	20.34
4	176.04	203.91	165.46	181.81	19.86	25.64
5	69.44	59.68	53.76	60.96	7.92	10.45
6	113.24	113.24	84.49	103.66	16.60	19.17
7	254.84	293.88	233.90	260.88	30.44	39.98
8	199.62	180.37	156.75	178.92	21.47	28.58
9	50.62	67.38	63.15	60.39	8.71	11.17
10	61.03	68.44	55.38	61.62	6.55	8.70

Average difference: the average of the values for trial 1 – trial 2, trial 2 - trial 3, and trial 3 – trial 1

Table 3: Mid Palate (mm^2) (MP) reliability measures along with mean and standard deviation per subject

Subject	MP Trial 1	MP Trial 2	MP Trial 3	Mean	SD	Average difference
1	126.30	123.66	126.30	125.42	1.53	1.76
2	96.67	99.67	98.61	98.31	1.52	2.00
3	145.53	151.70	148.71	148.65	3.09	4.12
4	178.87	183.10	180.99	180.99	2.12	2.82
5	61.23	69.12	71.04	67.13	5.20	6.54
6	124.89	124.89	128.07	125.95	1.83	2.12
7	294.61	253.31	246.08	264.66	26.18	32.35
8	163.81	164.50	172.81	167.04	5.01	6.00
9	72.68	105.66	114.48	97.61	22.04	27.87
10	146.77	142.53	154.53	147.94	6.08	8.00

Average difference: the average of the values for trial 1 – trial 2, trial 2 - trial 3, and trial 3 – trial 1

Table 4: Minimum Cross Sectional Area (mm^2) (MCA) reliability measures along with mean and standard deviation per subject

Subject	MCA Trial 1	MCA Trial 2	MCA Trial 3	Mean	SD	Average difference
1	87.67	88.55	86.44	87.55	1.06	1.41
2	46.04	48.51	47.45	47.33	1.24	1.65
3	88.73	91.20	86.08	88.67	2.56	3.41
4	158.58	160.35	158.23	159.05	1.13	1.41
5	42.40	47.20	46.24	45.28	2.54	3.20
6	71.27	73.74	77.62	74.21	3.20	4.23
7	225.97	227.38	226.85	226.73	0.71	0.94
8	153.56	148.56	148.25	150.13	2.98	3.54
9	39.16	49.04	52.92	47.04	7.09	9.17
10	48.86	50.98	52.04	50.63	1.62	2.12

Average difference: the average of the values for trial 1 – trial 2, trial 2 - trial 3, and trial 3 – trial 1