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3-D Oropharyngeal Airway Analysis of Different Antero-Posterior and Vertical Craniofacial Skeletal Patterns in Children and Adolescents

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3-D OROPHARYNGEAL AIRWAY ANALYSIS OF DIFFERENT ANTERO-POSTERIOR AND VERTICAL CRANIOFACIAL SKELETAL PATTERNS IN CHILDREN AND ADOLESCENTS

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ABSTRACT

3-D Oropharyngeal Airway Analysis of Different Antero-Posterior and Vertical Craniofacial Skeletal Patterns in Children and Adolescents

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Sleep apnea disorder has recently emerged as a significant public health issue. While the prevalence of obesity is on the rise among children, it is one of the main risk factors associated with apnea. Upper airway dimensions and morphology seem to be major components of obstructive sleep apnea (OSA) and can be affected by different craniofacial patterns. The purpose of this retrospective, cross-sectional pilot study is to correlate gender, Body Mass Index, risk for OSA, neck circumference, and 3-D oropharyngeal airway dimensions in children and adolescents with different antero-posterior (AP) and vertical craniofacial skeletal patterns. A total of 86 pre-orthodontic treatment records in the age group of 8-16 years were analyzed. 3-D volumetric skeletal tracing and oropharyngeal airway measurements were completed for each scan. Each subject was classified into AP Classes I, II, and III groups; vertical Normodivergent, Hypodivergent, and Hyperdivergent groups; and combined AP-vertical subgroups. Oropharyngeal airway measurements included the total oropharyngeal airway volume, minimum cross-section area, depth, width, and perimeter. Mean, standard deviation, and Pearson's correlation coefficient were performed to evaluate the relationships among

variables. There were one or more correlations, but not all, between gender, Body Mass Index, risk for OSA, neck circumference, and 3-D oropharyngeal airway dimensions in children and adolescents among the AP groups, vertical groups, and nine craniofacial subgroups ($P < 0.05$ and $P < 0.01$). This investigation aimed to determine whether patients with certain skeletal deficiencies are predisposed to upper airway obstruction. Early identification and management of airway problems in children and adolescents may prevent or minimize the sequelae and adverse dental implications of obstructive sleep apnea. Our small, young groups of sample were mainly in the healthy weight category with normal size neck circumference. Therefore, this limited our overall findings. Currently, sleep disorders are not well researched and understood. Long-term goal of our study is to further investigate this study in larger sample size taken into considerations predisposing factors (i.e. abnormal neural regulation and intrinsic muscle weakness) and pathologic conditions (allergies, polyps, and tumors). The physiology of the airway, influenced by these confounding factors, has an essential role in determining whether patients with certain skeletal deficiencies are predisposed to upper airway obstruction. Sleep apnea is a complex phenomenon that warrants further research regarding the physiology and anatomy of the airway and craniofacial structures.

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CHAPTER 1 INTRODUCTION

BACKGROUND

Sleep apnea disorder has recently emerged as a significant public health issue, trailing only behind cancer and heart disease as leading causes of mortality (National Heart Lung and Blood Institute, 2010). Estimates of 18 million Americans are affected by sleep apnea (National Heart Lung and Blood Institute, 2010). Obesity is one of the main risk factors associated with apnea. Based on data from 2007-2008, 68 percent of U.S. adults (approximately 127 million) and 32 percent of school-aged U.S. children and adolescents are overweight or obese (Flegal, Carroll, Ogden, & Curtin, 2010; Ogden, Carroll, Curtin, Lamb, & Flegal, 2010). Sleep apnea affects an estimated 2% of all U.S. children (American Academy of Pediatrics, 2003). Sleep apnea is defined as having one or more pauses in breathing or shallow breaths while sleeping. Individuals with sleep apnea can stop breathing, often for a minute or longer, as many as 30 times or more each night (National Heart Lung and Blood Institute, 2010). If remain undiagnosed and consequently untreated, sleep apnea can lead other health problems. Complications of untreated sleep apnea can include: cardiovascular disease, headaches, high blood pressure, stroke, impotence, memory problems, obesity, fatigue, poor quality of life, work-related impairment , drowsy driving/accidents, and increased mortality (Peeke, Hershberger, & Marriner, 2006; McCrillis *et. al*., 2009). In children, it can lead to cardiac, behavior, learning, and growth problems (American Academy of Pediatrics, 2003). Obstructive sleep apnea (OSA) is the most common type. Upper airway morphology and dimensions seem to be major components of OSA. In general histories of snoring and daytime somnolence are useful markers of OSA (Davies, Ali, & Stradling, 1992). Obstructive sleep apnea patients have significantly higher body mass index (BMI) and neck circumference than the controls (Hoffstein & Mateika, 1992). Neck circumference may be a more powerful and useful clinical predictor of OSA than BMI or other indexes of obesity (Davies *et al.*, 1992).

Traditionally, upper airway morphological and dimensional studies in orthodontics are based on 2-Dimensional (2-D) lateral cephalometric headfilms (Hibbert & Whitehouse, 1978; Holmberg & Linder-Aronson, 1979; Poole, Engel, Chaconas, 1980; Vig, Spalding, & Lints, 1991; Kemaloglu, Goksu, Inal, & Akyildiz, 1999). However, there are inherent limitations with this methodology (Vig & Hall, 1980; Major, Flores-Mir, & Major, 2005). The information is oversimplified because the data are gathered from a 2-D image of a complex 3-dimensional (3-D) structure. Recent technological advancement termed cone-beam computed tomography (CBCT) offers researchers and clinicians the ability to view the patient's anatomical structures in 3-D. Evaluations of airway dimensions and morphology can now be conducted more accurately, effectively, and efficiently through all dimensions (McCrillis *et. al*., 2009). A better understanding of upper airway morphology, its dimensions and variations among patients, better treatment modalities can be optimized for patients diagnosed with obstructive sleep apnea.

STATEMENT OF THE PROBLEM

Comprehensive medical or dental evaluation of patients should include an analysis of the airway. Traditional dental examinations most often do not include airway evaluation despite the proximity of the anatomic regions of the jaws and teeth to the airway. Airways have not been commonly evaluated likely due to a lack of screening and evaluation methods available in dentistry. However, rather infrequently, orthodontists have assessed upper airways using traditional lateral cephalograms in patients undergoing orthognathic surgery. Upper airway morphology and dimensions are major components of OSA. Evaluation of the airway is an essential and powerful diagnostic step to offer the clinicians accurate information for appropriate diagnosis, treatment planning, and management.

With the use of cone beam technology and increased availability of CBCT data, there has been much research regarding 3-dimensional upper airway morphology and sleep apnea as well as diagnosis and treatment planning for orthodontics and orthognathic surgery (Aboudara, Hatcher, Nielsen, & Miller, 2003; Ogawa, Enciso, Memon, Mah, & Clark, 2005; Ogawa, Enciso, Shintaku, & Clark, 2007; Shigeta, Enciso, Ogawa, Shintaku, & Clark, 2008; Ghoneima & Kula, 2011). Despite this research, there are few studies focused on the upper airway evaluation in adult patients with different craniofacial patterns. There is even more limited research in evaluating 3-D upper airway morphology and dimensions of children with different craniofacial patterns, especially combined with the vertical dimensions of the face and risk assessments for obstructive sleep apnea. Additionally, there is lack of correlation of Body Mass Index and neck circumference among children and adolescents with different craniofacial patterns.

SIGNIFICANCE OF THE PROBLEM

While sleep apnea disorders are typically associated with the elderly adult male population, its presence in the pediatric population has recently become a matter of concern (Peeke *et al.*, 2006). In particular, the sequelae of OSA in children is known to associate with excessive daytime sleepiness, hyperactivity, attention deficit disorder, poor hearing, physical debilitation, and failure to thrive (Iwasaki, Hayasaki, Takemoto, Kanomi, & Yamasaki, 2009; O'Brien *et al.*, 2003). The association between mouth breathing and craniofacial development in children has long been established (Brusse 1935, Linder-Aronson, 1970, 1979; Woodside, Linder-Aronson, Lundstrom, & McWilliam, 1991; McNamara, 1981). The adverse dental implications for children with an obstructed airway, especially during their period of rapid dentofacial growth, include narrow and high vaulted maxillary arch, posterior crossbite, anterior open bite, retroclined maxillary and mandibular incisors, short retrognathic mandible, increased anterior face height, lower tongue posture, and increased mandibular plane angles (Angle, 1907; Linder-Aronson, 1970, 1979).

To date, true upper airway volume, minimum cross-sectional area and its dimensions are not well established. Secondly, the correlation of upper airway dimensions to their respective craniofacial patterns is not well known. Thirdly, the association between these variables with BMI and neck circumference is of importance when evaluating children and adolescents clinically. Evaluation of the upper airway is an essential and powerful diagnostic step for the clinician in appropriate diagnosis, treatment planning, and management of airway abnormalities. Early identification and management of airway problems in children may prevent or minimize the sequelae and adverse dental implications of obstructive sleep apnea.

PURPOSE OF THE STUDY

The purpose of this retrospective, cross-sectional pilot study is to correlate the 3-D oropharyngeal airway dimensions, BMI, neck circumference, risk for OSA, and gender in children and adolescents with different antero-posterior and vertical craniofacial skeletal patterns. This investigation aims to determine whether patients with certain skeletal deficiencies are predisposed to upper airway obstruction. Ultimately, this investigation intends to contribute to the current knowledge about upper airway.

RESEARCH QUESTION 1

Are there correlations between gender, Body Mass Index, risk for obstructive sleep apnea, neck circumference, and oropharyngeal airway dimensions in children and adolescents with antero-posterior craniofacial Class I, II, and III? **Hypothesis**: There are correlations between gender, Body Mass Index, risk for obstructive sleep apnea, neck circumference, and oropharyngeal airway dimensions in children and adolescents with antero-posterior craniofacial Class I, II, and III. **Null hypothesis**: There are no correlations between gender, Body Mass Index, risk for obstructive sleep apnea, neck circumference, and oropharyngeal airway dimensions in children and adolescents with antero-posterior craniofacial Class I, II, and III.

RESEARCH QUESTION 2

Are there correlations between gender, Body Mass Index, risk for obstructive sleep apnea, neck circumference, and oropharyngeal airway dimensions in children and adolescents with Normodivergent, Hypodivergent, and Hyperdivergent craniofacial groups? **Hypothesis**: There are correlations between gender, Body Mass Index, risk for obstructive sleep apnea, neck circumference, and oropharyngeal airway dimensions in children and adolescents with Normodivergent, Hypodivergent, and Hyperdivergent craniofacial groups. **Null hypothesis**: There are no correlations between gender, Body Mass Index, risk for obstructive sleep apnea, neck circumference, and oropharyngeal airway dimensions in children and adolescents with Normodivergent, Hypodivergent, and Hyperdivergent craniofacial patterns.

RESEARCH QUESTION 3

Are there correlations between gender, Body Mass Index, risk for obstructive sleep apnea, neck circumference, and oropharyngeal airway dimensions in children and adolescents among nine craniofacial subgroups? **Hypothesis**: There are correlations between gender, Body Mass Index, risk for obstructive sleep apnea, neck circumference, and oropharyngeal airway dimensions in children and adolescents among nine craniofacial subgroups. **Null hypothesis**: There are no correlations between gender, Body Mass Index, risk for obstructive sleep apnea, neck circumference, and oropharyngeal airway dimensions in children and adolescents among nine craniofacial subgroups.

DEFINITION OF TERMINOLOGY

2-Dimensional (2-D)

- Referring to objects that are projected on film, paper, or screen in two planes (width and height; X and Y).

3-Dimension (3-D)

- Referring to objects that are projected on film, paper, or screen in three planes (width, height, and depth: X, Y, and Z).

Antero-posterior (AP)

- Describing a relative position along a direction from front to back.

Body mass index (BMI)

- A screening tool that provides a measure of general body fat based on ratio between height and weight; measured in kg/mm^2 unit. The percentile indicates the relative position of the child's BMI value among children of the same sex and age (Appendices A and B). There are four categories of BMI (Table 1).

Table 1

BMI Categories

BMI percentiles	Categories
< 5^{th}	Underweight
5^{th} to < 85^{th}	Healthy weight
85^{th} to <95^{th}	Overweight
> 95^{th}	Obese

Deep bite

- An occlusal relationship where there is excessive overlap of maxillary and mandibular anterior teeth.

Frankfort Horizontal Plane

- A horizontal plane represented in profile by a line between the most inferior point on the margin of the orbit and the most superior point on the margin of the auditory meatus.

Landmark

- A fixed, reproducible or anatomical point of reference on a radiograph.

Lateral

- Relating to or situated on the side, right and left

Mandibular Plane

- A plane constructed from the most anterior inferior point of the mandible termed menton, and the most inferior posterior point of the mandible termed gonion.

Hyperdivergent

- An orthodontic term describing a patient as having a high mandibular plane angle; usually longer lower facial height, clockwise growth pattern, and/or vertical open bite pattern.

Hypodivergent

- An orthodontic term describing a patient as having a low mandibular plane angle; usually normal to short lower facial height, counterclockwise growth pattern, and/or horizontal deep bite pattern.

Macrognathia

- Abnormal enlargement of one or both jaws.

Micrognathia

- Abnormal smallness of one or both jaws.

Normodivergent

- An orthodontic term describing a patient as having normal vertical skeletal pattern; usually normal lower facial height.

Open bite

- An occlusal relationship where maxillary and mandibular teeth are not touching, either in anterior or posterior region.

Oropharynx

- Oral part of the pharynx extending from the uvula to the level of the hyhoid bone. Anteriorly it opens into the mouth; laterally bounded by the palatine tonsils.

Prognathia

- Condition referring to abnormal anterior positioning of maxilla or mandible relative to facial skeleton and soft tissues.

Retrognathia

- Condition referring to abnormal posterior positioning of maxilla or mandible relative to facial skeleton and soft tissues.

Segmentation

- The construction of 3D virtual surface model by separating a specific structure of interest and remove all other non-interest structures for better visualization and analysis.

Skeletal Class I

- An orthodontic term describing a type of skeletal pattern in which the maxilla and mandible are balanced and in good harmonious position relative to each other.

Skeletal Class II

- An orthodontic term describing a type of skeletal discrepancy in which the mandible is retrusive (behind), relative to the maxilla.

Skeletal Class III

- An orthodontic term describing a type of skeletal discrepancy in which the mandible is protrusive (forward), relative to the maxilla.

EXCLUSION CRITERIA

1. Patients < 8 and > 18 years of age
2. Cleft Palate, Cleft Lip, and all craniofacial syndrome patients
3. CBCT field of view is cut off where landmarks are not visible
4. CBCT scans of patients with teeth not in full centric occlusion
5. Inadequate image quality (e.g. patient movement during image acquisition)

INCLUSION CRITERIA

1. Patients in the age range 8-16 years
2. Complete pre-treatment orthodontic records
3. CBCT scans were taken prior to initiation of any type of orthodontic or orthopedic treatment

CHAPTER 2 REVIEW OF THE LITERATURE

ANATOMY OF THE UPPER AIRWAY

The upper airway functions in swallowing, ventilation, and speech. There exist dynamic biomechanical relationships among the upper airway muscles that allow these functions to occur. The upper airway is divided into three regions, from superior to inferior based on sagittal imaging: nasopharynx, oropharynx, and hypopharynx as shown in Figure 1. The nasopharynx begins at the nares, extends back to hard palate, and includes the nasal septum and nasal turbinates. The oropharynx is subdivided into retropalatal and retroglossal areas. The retropalatal region extends from hard palate to the inferior tip of soft palate, including the uvula and superior posterior pharyngeal wall. The major muscles in the retropalatal region are the tensor palatine, levator pallatini, and musculus uvulae. The retroglossal region extends from the inferior tip of soft palate to the base of the epiglottis (which is the base of the tongue). The pharyngeal tonsils are located in this retroglossal region along with many extrinsic and intrinsic muscles that control tongue posture, such as the genioglossus, palatoglossus, superior longitudinal and transverse muscles. The hypopharynx extends from base of tongue to the larynx (Schwab & Goldberg, 1998; McCrillis *et. al*., 2009).

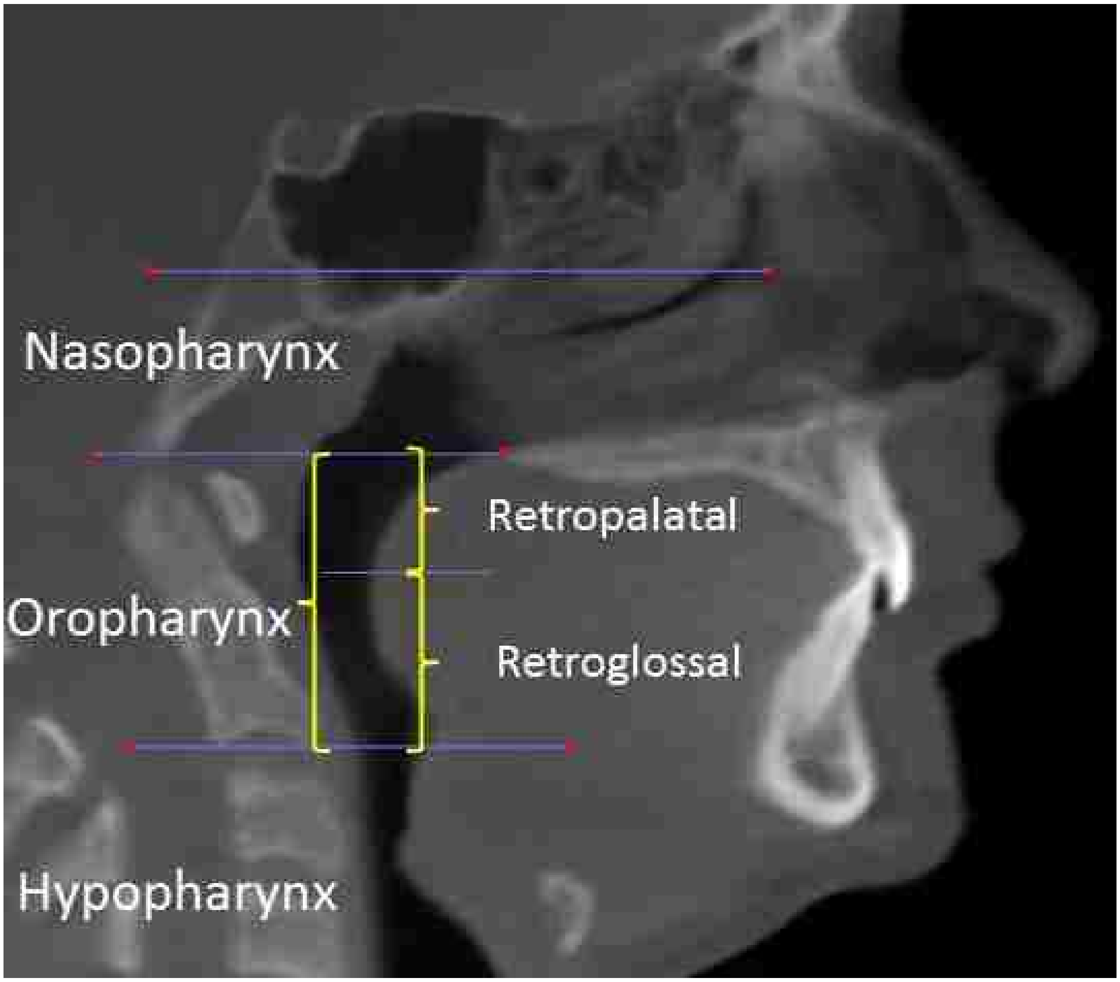


Figure 1. Three regions of the upper airway.

The anterior, posterior and lateral walls of the oropharynx are composed of a number of soft tissue structures. The anterior wall is formed by the soft palate, tongue, and lingual tonsils (Schwab, 1998). The posterior wall is formed by the superior, middle, and inferior constrictor muscles, which are in front of the cervical spine. These muscles also make up part of the lateral walls. The lateral walls are formed by the palatine tonsils, parapharyngeal fat pads, and many other muscles with varying functions (Schwab, 1998; Schwab & Goldberg, 1998). Currently, the biomechanical relationships among these muscles that make up the lateral walls and their interactions with soft palate, tongue, and mandible are not well understood (Schwab, 1998). Knowledge of the morphology and mechanical behavior of bony and soft tissue structures is essential to understand the physiology and pathogenesis of upper airway obstruction (Schwab & Goldberg, 1998).

OBSTRUCTIVE SLEEP APNEA

Sleep apnea is defined as having one or more pauses in breathing or cessation of air flow while sleeping (Cataletto, Lipton, & Murphy, 2011). In contrast, hypopnea is shallow breathing with decreased air flow by at least 50% (Cataletto *et al.*, 2011). There are three types of sleep apnea, obstructive, central, or mixed. Airway obstruction may be considered complete or partial. Complete obstruction is when the airway is completely blocked not allowing any air to flow through. This is called apnea. On the contrary, partial obstruction is when the airway narrows and some air may pass through causing snoring (NHBLI, 2010). Obstructive sleep apnea is the most common type. Obstructive sleep apnea was described more than 100 years ago, but in children it was initially described in the 1970s. It is a common but under diagnosed condition in children that may ultimately lead to substantial morbidity if left untreated. Central sleep apnea is due to the central nervous system failing to send a signal to the muscles to enact breathing (Cataletto *et al.*, 2011). The causes of this type of sleep apnea include head trauma, stroke, and tumor (Cataletto *et al.*, 2011). Mixed sleep apnea is a combination of obstructive and central sleep apnea (Cataletto *et al.*, 2011).

Individuals with sleep apnea can stop breathing as many as 30 times or more each night (NHLBI, 2010). In adults, apnea occurs when breathing stops for 10 seconds or more or at least 4% drop in oxygen in the blood (called oxygen desaturation) occurs due to lack of adequate oxygen/carbon dioxide exchange in the lungs. In children, if obstruction occurs with 2 or more consecutive breaths, it is considered apnea, even if it lasts less than 10seconds (Cataletto *et al.*, 2011). This is due to less functional residual capacity resulting in rapid oxygen desaturation whenever airflow is interrupted.

Complications of untreated sleep apnea can include: cardiovascular disease, headaches, high blood pressure, stroke, impotence, memory problems, obesity, fatigue, poor quality of life, work-related impairment, drowsy driving/accidents, and increased mortality (Peeke *et. al*., 2006; McCrillis *et. al*., 2009). In children, it can lead to heart, behavior, learning, and growth problems (American Academy of Pediatrics, 2003). Incidents of sleep fragmentation, intermittent hypoxemia, and hypercapnia from OSA contribute to dysfunction in the prefrontal areas of the brain, which impairs cognitive abilities and learning (Beebe & Gozal, 2002). The sequelae of OSA in children is known to associate with excessive daytime sleepiness, hyperactivity, attention deficit disorder, poor hearing, physical debilitation, and failure to thrive (Iwasaki *et al.*, 2009; O'Brien *et al.*, 2003).

The adverse dental implications for children with an obstructed airway, especially during their period of rapid dentofacial growth, include narrow and high vaulted maxillary arch, posterior crossbite, anterior open bite, retroclined maxillary and mandibular incisors, short retrognathic mandible, increased anterior face height, lower tongue posture, and increased mandibular plane angles (Angle, 1907; Linder-Aronson, 1970, 1979). This is due to the fact that these children alter their mode of breathing from nasal to oral route. The association between mouth breathing and craniofacial development in children has long been established (Brusse, 1935; Linder-Aronson, 1970, 1979; Woodside, Linder-Aronson, Lundstrom, & McWilliam, 1991; McNamara, 1981).

PATHOPHYSIOLOGY

The patency of the pharynx is vital to the respiratory function. The contribution of various anatomical structures and the interaction of these structures lead to upper airway patency or obstruction during sleep. During wakefulness, the muscle tensions keep the airway lumen patent. On the contrary, during sleep, the muscles relax making the pharyngeal walls become more flexible and more collapsible. Additionally, the supine position while sleeping allows gravity to distort the pharyngeal walls and pulls the tongue back resulting in a reduction of the airway lumen (McCrillis *et. al*., 2009). Air flow through this narrowed airway is turbulent and creates vibration of the flexible pharyngeal walls and soft palate; thus, produce snoring (McCrillis *et. al*., 2009). At a certain critical point, the airway lumen becomes even narrower, air flows at a faster rate and the intraluminal pressure is lowered leading to an occluded airway. There is silence at this point. Continued breathing involves contraction of the diaphragm and chest wall but air flow stops. As the individual is aroused and gasping for air, muscle tension regains and the pharyngeal airway is opened once again (McCrillis *et. al*., 2009). The oxygen/carbon dioxide ratio then returns to normal, allowing the individual to fall back asleep. This cycle may repeat a few times or up to hundreds of times per night.

It is clear that airway dimensions and morphology are major components of OSA. Airway obstruction is caused by multiple predisposing factors. These include anatomic narrowing, abnormal anatomic arrangement between airway dilating muscles and airway walls, abnormal neural regulation, and intrinsic muscle weakness (Cataletto *et al.*, 2011).

In particular, the anatomic narrowing of the upper airway is due to hypertrophic tonsils and adenoids, obesity, chronic and allergic rhinitis, environmental irritants, infections, congenital nasal deformities, or nasal traumas (Schlenker, Jennings, Jeiroudi, & Caruso, 2000). Obesity and enlargement of the tonsils and/or adenoids play significant etiological roles for most cases of OSA in children (Cataletto *et al.*, 2011). Additionally, craniofacial anomalies are also the causes in certain cases (Cataletto *et al.*, 2011). In addition to predisposing factors, there are pathologic conditions of the nose, nasopharynx, oropharynx and larynx that also contribute to airway obstruction, such as polyps and tumors (Cataletto *et al.*, 2011).

It has been reported that head posture influences the size of the pharyngeal airway space. Previous research using lateral cephalograms indicated that a change of 10 degrees in craniocervical angulation leads to a change of about 4millimeters (mm) in the pharyngeal airway space (Muto *et al.*, 2002). Therefore, head positioned at different degrees of extension and flexion clearly affect airway dimension.

There are differences in upper airway morphology and dimensions among normal, snorer, and apneic groups. In an MRI study, apneic patients exhibit significant airway luminal reduction in the lateral dimension and occurred in the retropalatal region, and no significant difference in the antero-posterior airway dimension between subject groups (Schwab *et al.*, 1995). At the minimum airway area, thicker lateral pharyngeal muscular walls rather than enlargement of the parapharyngeal fat pads was the predominant anatomic factor causing airway narrowing in apneic group (Schwab *et al.*, 1995).

EPIDEMIOLOGY OF CHILDHOOD OBSTRUCTIVE SLEEP APNEA

Most children with OSA are at the age of 2-10 years. This coincides with the adenotonsillar lymphatic tissue growth period (Cataletto *et al.*, 2011). Up to 16 years of age, the lymphoid growth based on Scammon's curve and the adenoids have reached their maximum size at this age (Scammon *et. al.*, 1930). The gender distribution of childhood OSA is 1:1 male to female ratio. At puberty, this male to female ratio begins to increase. By adulthood, this ratio reaches 2:1 or more, respectively (Cataletto *et al.*, 2011). OSA occurs more commonly among Black and Hispanic than white children. In the 18 years or younger age group, Black children are 3.5 times more likely to develop OSA than Whites (Cataletto *et al.*, 2011). Pediatricians now recommend that all children should be regularly screened for snoring (American Academy of Otolaryngology-Head and Neck Surgery, n.d.).

DIAGNOSIS OF OBSTRUCTIVE SLEEP APNEA

The patient's medical history and chief complaint are always taken into consideration in the evaluation of sleep apnea. The gold standard for diagnosis is by a sleep study, also known as a polysomnogram. It is during this overnight sleep study that apnea and hypopnea are determined through various stages of sleep. The apnea index (AI) is an estimate of severity of apnea, calculated by dividing the number of apneas by the number of hours of sleep. It is labeled as apneas per hour; a greater value indicates more severe of an apnea. Hypopnea is defined as a decrease or shallow breathing of which airflow is decreased by at least 50% (Cataletto *et al.*, 2011).

Clinical presentations of OSA are easily recognized in advanced cases, but cases with less of a classical presentation are more difficult. Signs and symptoms of OSA can be evaluated via general appearances such as obesity, fatigue, poor quality of life, work-related impairment and hypersomnolence (Peeke *et. al*., 2006; McCrillis *et. al*., 2009). For the general population a history of snoring and daytime somnolence are useful markers of OSA (Davies *et al.,* 1992). Specifically, neck circumference is a helpful clinical predictor than other clinical indices for signs of OSA (Hoffstein & Mateika, 1992). In addition, the signs for OSA can be examined via facial characteristics, including micrognathia, retrognathia, short and thick neck, long-face syndrome, anterior open bite.

RELATIONSHIP OF OBESITY TO OBSTRUCTIVE SLEEP APNEA

Most patients with OSA are obese and this characteristic is considered to be a major risk factor for developing OSA. Obesity is an epidemic in the U.S. Based on data from 2007-2008, 68 percent of U.S. adults and 32 percent of school-aged U.S. children and adolescents are overweight and obese combined (Flegal *et al.*, 2010; Ogden *et al.*, 2010). Among children and adolescents aged 2 through 19 years, 11.9% were at or above the 97th percentile (morbidly obese), 16.9% were at or above 95th percentile (obese), and 31.7% were at or above 85th percentile (overweight) of BMI-for-age chart (Ogden *et al.*, 2010). See Appendices A and B for BMI-for-age charts for Boys and Girls, respectively.

General obesity is measured by body mass index. It is an inexpensive and easy-to-perform method of screening for weight categories. The BMI number is plotted on the Centers for Disease Control and Prevention (CDC) BMI-for-age growth charts, specifically for either girls or boys, to obtain a percentile ranking (Appendices A and B). The percentile on this chart indicates the relative position of the child's BMI number among children of the same sex and age. There exists a high correlation between OSA and obesity as measured by BMI. It has been shown that OSA patients have significantly higher BMI than the control group (Hoffstein and Mateika, 1992; Ogawa, Enciso, Memon, Mah, & Clark, 2005). MRI study showed larger tongue, parapharyngeal-fat pads and lateral pharyngeal walls in apneic patients with high body mass index ($32.5kg/m^2$) (Schwab, 1998).

Regional obesity is measured by neck circumference (Ferguson, Ono, Lowe, Ryan, & Fleetham, 1995; Rajala *et al.*, 1991; Dancey *et al.*, 2003). Neck circumference is a simple clinical measurement that reflects obesity in the region of the upper airway. Neck circumference may actually be a more powerful and useful clinical predictor for presence of OSA than BMI or other indexes of obesity, but not when used alone (Davies *et al.*, 1992). Since most patients with OSA are overweight and typically have a short, thick neck, a neck circumference greater than 16 inches in a female adult or greater than 18 inches in a male adult correlates with an increased risk for the disorder (Davies & Stradling, 1990). This may be due to fat tissue deposition in the neck causing narrowing of the airway (Hoffstein & Mateika, 1992). A cephalometric study showed that patients with larger neck circumference have larger tongues and soft palate (Ferguson *et al.*, 1995). Larger neck circumference is seen in obese apneic patients but not in obese non-apneic patients (Hoffstein and Mateika, 1992). The increase in weight means having an increased adipose tissue surrounding the upper airway; however, the thickness of lateral pharyngeal muscular walls, not enlarged parapharyngeal fat pads, was the main anatomic factor causing airway narrowing in apneic patients (Schwab &Goldberg, 1998). Thus, the mechanism that obesity predisposes to sleep apnea remains questionable.

Obesity and enlargement of the tonsils and/or adenoids play significant etiological roles for most cases of OSA in children. Obesity contributes 4-5 times the risk for sleep disordered breathing, not just sleep apnea alone (Cataletto *et al.*, 2011). CT studies have shown that obese patients with sleep apnea have narrowed retropalatal region, smaller upper airway, and increase size of upper airway soft tissue structures including tongue, soft palate, and lateral pharyngeal walls (Schwab, 1998). However, some non-obese apneic patients may have craniofacial abnormalities that contribute to their apnea, such as small retrognathic mandible (reduced mandibular body length), retrognathic maxilla, narrow posterior airway space, and inferiorly positioned hyoid bone (Hoffstein & Mateika, 1992; Ferguson *et al.*, 1995; Schwab 1998).

EPWORTH SLEEPINESS SCALE

The gold standard assessment for excessive daytime sleepiness is the mean sleep latency (MSL) on serial daytime naps of the multiple sleep latency test, an objective assessment (Chervin & Aldrich, 1999). It is a laboratory-based assessment that is monitored by a technician resulting in significant costs and time to perform the test. The Epworth Sleepiness Scale (ESS), on the other hand, provides a quick and inexpensive alternative method. The Epworth Sleepiness Scale, proposed in 1991 by Johns MW, who was from Epworth Hospital in Melbourne Australia, is an alternative method to screen for the manifestations of obstructive sleep apnea. Excessive daytime sleepiness is a frequent and impairing consequence but may be perceived poorly by the patients. This subjective scale measures the patient's probability of falling asleep in a variety of daily situations. It has been shown that ESS score is closely related to the frequency of apneas (Johns, 1991). It is widely accepted and used to evaluate a patient's level of habitual sleepiness during the day. It comprises eight items addressing typical day-to-day situations. Each item can be rated from 0-3 points by the patients; with final score ranging from 0-24.

The cutoff scores to determine sleepiness have changed over time. Originally, a cutoff score of 16 was suggested to determine “a high level of daytime sleepiness” (Johns, 1991). Later, the cutoff score of greater than 9 was suggested (Johns, 1992). Currently, the cutoff score of 10 has been suggested and in most widespread use (Johns, 1993, 1994, 2000). Despite its popular use as part of the clinical assessment, there are concerns or limitations to this method. Sleepiness is potentially due to physiologic need and/or a manifestation of a pathological condition (Rosenthal & Dolan, 2008). The relative weakness of the relationship between ESS and multiple sleep latency test has been reported (Chervin & Aldrich, 1999). Therefore, ESS score cannot be the sole determinant of OSA. Additional objective measures, such as polysomnograms, are needed to confirm diagnosis of OSA.

TREATMENTS FOR OBSTRUCTIVE SLEEP APNEA

A multitude of treatments exist for obstructive sleep apnea. Non-surgical approaches to treat sleep apnea consist of weight loss, continuous positive airway pressure, and dental appliances. Despite the inconclusive mechanism between obesity and sleep apnea, weight reduction is a way to change the upper airway compliance or mechanical action of upper airway muscles including those of lateral pharyngeal wall (Thorton & Roberts, 1996; Schwab, 1998). Additionally, it has been shown that with weight reduction, the lateral pharyngeal walls decreased in size (Thorton & Roberts, 1996; Schwab, 1998). This presumably allows an increase in the airway lumen. However, it is a challenge to achieve and maintain the weight reduction in patients with sleep apnea. The alternative or rather next option is continuous positive airway pressure (CPAP). This treatment method involves wearing a nasal and/or oral mask of which is attached to a machine that provides constant air pressure during inhalation and exhalation (Waite, 1998). The benefits of CPAP are anterior displacement of the tongue and soft palate as well as significant increase lateral dimension of the airway with concomitantly thinning of the lateral pharyngeal muscular walls as airway is expanded with positive airway pressure (Schwab, 1998). Treatment with CPAP is effective but patient must be compliant, which is sometimes difficult to achieve. Another treatment method is the use of oral/dental appliances such as mandibular repositioning device and tongue retaining device. Mandibular repositioning devices attach onto the upper and lower teeth, pulling the mandible downward and forward. The airway enlargement occurs in antero-posterior as well as lateral dimensions resulting from the extension of the genioglossus muscle which pulls the base of the tongue forward (Thorton & Roberts, 1996; Schwab, 1998). These appliances are effective in non-obese apeic patients with retrognathia and micrognathia (Schwab, 1998). The mechanism of action of dental appliances involves complex interactions among the tongue, soft palate, lateral pharyngeal walls, and mandible to alter airway lumen. Dental appliances are usually fabricated and delivered by dentists or orthodontists. Side effects from dental appliances include tooth discomfort, occlusal changes, temporomandibular discomfort, changes in face height, position of mandible, over eruption of teeth and proclination of mandibular incisors (Robertson, Herbison,, & Harkness, 2003) . All are most often adapted to and accepted by patients when comparing with the life-threatening consequences of OSA (Chen, Lowe, de Almeida, Fleetham, & Wang). With long term therapy, dental changes may result in favorable reduction in overjet and or overbite particularly in Dental Class II patients (Chen *et al.*, 2008; de Almeida *et al.*, 2005). Since dental appliance therapy requires the mandible being held in forward position, this result in more discomfort and pain of the temporomandibular joint (TMJ) compared to CPAP therapy. However, the intensity of these TMJ symptoms decreases significantly throughout treatment among patients who are able to continue use of the dental appliance (Doff *et al.*, 2012).

In cases where patients are intolerable or unsuccessful via non-surgical intervention, surgery of the upper airway is considered. Surgical treatments include adenotonsillectomy, uvulopalatopharyngoplasty (UPPP), and maxillomandibular advancement (Schwab, 1998). UPPP is the most common soft-tissue surgery for OSA patients. The procedure primarily involves removal of antero-posterior upper airway structures including tonsils, the uvula, the distal margin of soft palate, and excess pharyngeal tissue. Soft tissues in the lateral pharyngeal walls are also removed and reshaped (Schwab, 1998). The success of UPPP is dependent on the site of obstruction which is identified by 3-dimensional imaging. Obstruction of the retropalatal region has better outcomes than retroglossal obstruction. Maxillomandibular advancement is highly effective in treating sleep apnea patients with craniofacial abnormalities (Schwab, 1998). This surgery increases the airway lumen in the antero-posterior dimension as the maxilla and mandible are repositioned more anteriorly (Schwab, 1998).

CLASSIFICATION OF OCCLUSION AND MALOCCLUSION

In order to understand how obstructive sleep apnea relates to malocclusion and or craniofacial skeletal patterns, it is important to understand the classification of malocclusion. Dr. Edward Angle, the father of modern orthodontics, first described the four classifications of occlusion in the 1890s based on the position of the maxillary first molar relative to position of the mandibular first molar (Angle, 1907). This system is still currently used in dentistry and orthodontics.

- Normal occlusion: the mesiobuccal cusp of maxillary first molar occludes in the buccal groove of mandibular first molar, with all teeth arranged on a smoothly curving line of occlusion.
- Class I malocclusion: is the normal relationship of molars, with discrepancy in line of occlusion due to malposed teeth.
- Class II malocclusion: the mesiobuccal cusp of the maxillary first molar is mesially positioned relative to the buccal groove of mandibular molar, regardless of line of occlusion.
- Class III malocclusion: the mesiobuccal cusp of maxillary first molar is distally positioned relative to the buccal groove of the mandibular molar, regardless of line of occlusion.

RELATIONSHIPS OF AIRWAY PROBLEMS TO CRANIOFACIAL MORPHOLOGY AND MALOCCLUSION

There has been suggestion that craniofacial growth and development is closely affected by the anatomy and function of the upper airway (Angle, 1907). Thus, any deviations from normal airway function, such as airway obstruction or restriction during active craniofacial growth period can lead to abnormal speech, abnormal craniofacial development, and dental malocclusion (Angle, 1907). These children are likely to change their respiratory pattern toward mouth breathing. The association between mouth breathing and craniofacial development in children has long been established (Ricketts, 1968; Linder-Aronson, 1970, 1979; Woodside, Linder-Aronson, Lundstrom, &

McWilliam, 1991; McNamara, 1981). The classical clinical example is the type of patient described as having “adenoid facies” (Meyer, 1872). This type of patient usually presents mouth-open posture, small nose with small and poorly developed nostrils, short upper lip, prominent upper incisors, pouting lower lip, and an expressionless face (Angle 1907; Ricketts, 1968; McNamara, 1981). Although these features are typical, patients may not express all of them and some features may be expressed more or less prominently. The adverse dental implications for children with an obstructed airway, especially during their period of rapid dentofacial growth, include a narrow and high vaulted maxillary arch, posterior crossbite(s), anterior open bite, proclined maxillary and mandibular incisors, short retrognathic mandible, increased anterior face height, lower tongue posture, and increased mandibular plane angle (Angle, 1907; Linder-Aronson, 1970, 1979; McNamara, 1981). The increase in anterior facial height is mostly due to a corresponding increase in the vertical development of the lower anterior face (Tourne, 1990). Thus, the relationship between obstructive sleep apnea with craniofacial morphology illustrates the correlation between function and form, obstruction and aberrant facial growth (McNamara, 1981).

An association has been made between airway problems and different types of dental and skeletal malocclusions. Nasal obstruction seems to be a major factor in dentofacial anomalies (Angle, 1907; Linder-Aronson, 1979). Class II division 1 malocclusion is associated with obstruction of the upper airway and mouth breathing (Angle, 1907). Several studies have analyzed the morphology of upper airway from lateral cephalograms. Class II dental malocclusion children are associated with narrower upper airway structure even without a retrognathic mandible (Kirjavainen & Kirjavainen, 2007). The lower pharyngeal width in girls with prognathism is significantly larger than normal group, whereas no difference exists in upper pharyngeal width (Takemoto *et al.*, 2011). The prognathic mandible is positioned more anteriorly, resulting in a wider lower pharyngeal airway (Takemoto *et al.*, 2011). The upper airway width is significantly narrower in Class I or Class II dental malocclusions with vertical growth patterns than Class I and Class II dental malocclusions with normal growth patterns (de Freitas *et al.*, 2006). Additionally, this group concluded that dental malocclusion type does not influence upper airway width. This finding may not be surprising as airway problems and mode of respiration seem to primarily manifest in the vertical dimension, such as the "Adenoid face" relationship with mouth breathing, which is the result of upper airway obstruction due to infection and inflammation of the adenoids (Linder-Aronson, 1970). These studies were conducted with 2-dimensional records, thereby limiting their measurements and the subsequent interpretation.

Although some apneic patients may not be obese, they may have craniofacial abnormalities that contribute to their apnea (Hoffstein & Mateika, 1992). Numerous studies using lateral cephalometric radiographs have shown craniofacial abnormalities in patients with OSA compared to control group. OSA patients commonly present with a small retrognathic mandible (reduced mandibular body length), retrognathic maxilla, narrow posterior airway space, enlarged tongue and soft palate, and an inferiorly positioned hyoid bone (Schwab, 1998). Mandibular body length (Gonion-Gnathion) is a single cephalometric variable with clinically significant association in OSA patients (Schwab, 1998).

METHODS OF AIRWAY ASSESSMENT

Evaluation of the airway is an essential and powerful diagnostic step in the appropriate diagnosis, treatment planning, and management of airway abnormalities. The ideal upper airway imaging modality should be inexpensive, noninvasive, and allow for supine imaging position of patient. Moreover, the image should provide high resolution anatomical representation of the airway structure while capable of rendering dynamic images during alertness and sleep (Schwab & Goldberg, 1998). However, such an ideal modality does not exist. Airway evaluation is currently accomplished with physiologic and morphometric airway studies. Physiologic studies involve full polysomnogram in a sleep center. Morphometric studies generally quantify upper airway size, shape and function by functional or anatomic measurements with the use of acoustic reflection, fluoroscopy, nasopharyngoscopy, 2-D lateral cephalometry, Computerized Tomography (CT), endoscopic analysis with optical coherence tomography (OCT), or Magnetic Resonance Imaging (MRI) and CBCT (Schwab & Golberg, 1998; Schwab, 1998; Linder-Aronson, 1973; Arens *et al.*, 2001; Armstrong *et al.*, 2006; Donnelly *et al.*, 2003; Bhattacharyya, Blake, & Fried, 2000; Tipton & Metz, 2007; Osorio *et al.*, 2008).

CT and MRI provide excellent representation of the upper airway, soft tissue, and bony structures. The patients are imaged in a supine position which closely simulates sleeping position. Three dimensional reconstruction, visualization and evaluation of structures are possible. Both provide accurate assessment of upper airway cross-sectional area and volume during wakefulness and sleep (Schwab, 1998). Studies using these techniques have improved our knowledge and understanding of the pathogenesis of sleep apnea and the related upper airway morphological and dimensional changes.

Although CT and MRI offer excellent and detailed visualization they are accompanied with high cost, high degree of complexity, higher radiation dose involved with CT only, and limited availability and accessibility. As a result, many airway assessments have been primarily performed with cephalometry (Osorio, Perilla, Doyle, & Palomo, 2008; de Freitas *et al.*, 2006; Ghoneima & Kula, 2011). By comparison, lateral cephalometry (Figure 2) is widely available, easily performed, non-invasive, and much less costly (Schwab, 1998). The imaging technique is acquired in standardized fashion, with patient in sitting position, head stabilized, and the radiograph obtained at the end of expiration (Schwab, 1998). It is routinely used as diagnostic tool in orthodontics to assess bony and soft tissue structures prior to orthodontic treatment, in patients with facial abnormalities and prior to orthognathic surgery. In addition, it is also routinely used in evaluating the efficacy and outcomes of orthodontic treatment.

One of the airway analyses commonly use in orthodontics measures the possibility of airway impairment on lateral cephalogram (McNamara, 1984). The antero-posterior width of the upper pharynx is measured from a point on the posterior outline of the soft palate to the closest point on the posterior pharyngeal wall. A distance of 5 mm or less indicates possible airway impairment. The antero-posterior width of the lower pharynx is measured from the intersection of the posterior border of the tongue and inferior border of the mandible to the closest point on the posterior pharyngeal wall. The average value for the lower pharynx is 10-12 mm. Hyperdivergent patients have narrower antero-posterior dimension of the airway compared to normodivergent patients (Joseph *et al.*, 1998). This might be due the skeletal features of maxillary and mandibular retrusion and vertical maxillary excess. These patients also exhibit thin posterior pharyngeal wall (Joseph *et al.*, 1998).

However, there are inherent limitations with the cephalometric modality. Because it is a 2-D evaluation of a complex 3-D structure and is unable to provide volumetric data, therefore it can only provide limited information of the antero-posterior structures without identifying soft tissue structures in the lateral dimension. It is also not capable of providing visualization of structure in the axial plane. The axial plane is physiologically pertinent in airway assessment because it is perpendicular to the direction of airflow (Abramson, Susarla, Tagoni, & Kaban 2010; Schwab, 1998). Another shortcoming of the cephalometric radiograph includes differences in magnification. The radiographic film is positioned paralleled to the patient's midsagittal plane on the patient's left side. The x-ray source produces an x-ray beam 5 feet away from the patient's midsagittal plane on the right side. Thus, those structures located closest to the film will be magnified less than those located nearest the x-ray source (Broadbent, 1937). Additional limitations of lateral cephalometric radiograph include superimposition of bilateral craniofacial structures and low reproducibility resulting from difficulties in landmark identification (Baumrind & Frantz, 1971). Collectively, these issues limit the validity of data using lateral cephalometry to assess airway dimensions and morphology (Vig & Hall, 1980; Aboudara *et al.*, 2003; Lenza *et al.*, 2010; Baumrind & Frantz, 1971).

Figure 2. Example of a lateral cephalogram. A profile x-ray of the skull and soft tissues.

CONE-BEAM COMPUTED TOMOGRAPHY TECHNOLOGY

Radiographs are indispensable tools for evaluation, diagnosis and treatment planning in the fields of endodontics, oral surgery, oral medicine, periodontology, restorative dentistry, and orthodontics. In particular to the orthodontic specialty, x-ray records traditionally include panoramic and lateral cephalometric radiographs. These radiographs are useful in analyzing the airway, TMJ, and other craniofacial structures within the skull. However, due to the many limitations of these image views, there has been a shift toward a new imaging modality within the last decade (Mah & Hatcher, 2005).

The introduction of cone-beam computed tomography (CBCT) to dentistry in the 2000's has made 3-dimensional assessment of the patient's dental and maxillofacial structures more accessible and practical. The advantages with CBCT are modest cost, less scan time, less effective radiation exposure and the upright sitting position of the patient. In addition, it provides more accurate, reliable and high definition images compared to conventional multidetector CT (MDCT), MRI, and lateral cephalometric headfilms (El & Palomo, 2010; Palomo, Rao, & Hans, 2008; Mah, Danforth, Bumann, & Hatcher, 2003; Ludlow, Davies-Ludlow, Brooks, & Howerton, 2006; Ghoneima & Kula, 2011). MDCT is used in medicine, but not as a routine method for airway analysis because of its high cost, high level of radiation exposure and restricted access, despite its superior soft tissue rendering capability. CBCT data are used to obtain a wide range of facial skeletal measurements including cervical spine, mandibular corpus length, and esthetic facial proportions. Additionally, CBCT data provide accurate depictions of volumetric soft tissue structures, such as the tongue and soft palate, as it readily defines the boundaries between soft tissues and air spaces (Osorio *et al.*, 2008; Guijarro-Martinez & Swennen, 2011). Other applications of CBCT data include airway analyses for sleep apnea, virtual laryngoscopy, evaluation of sinus anatomy and pathology, diagnosis and treatment planning for the combined orthodontic and orthognathic surgery, TMJ structure visualization, inferior alveolar nerve location, impactions, odontogenic lesion visualization, dental implant placement, and alveolar bone structure (Huang, Bumann, & Mah, 2005). Upper airway analysis in particular has become increasingly relevant to orthodontics mainly due to the relationship between morphological airway characteristics and craniofacial growth, maxillofacial and dental pathology and OSA (Guijarro-Martinez & Swennen, 2011). The emergence of CBCT technology as the potential alternative for obtaining a thorough evaluation of the upper airway is obvious.

In brief, the technology behind CBCT involves a pulsed, conical x-ray beam centered on x-ray tube detector, which rotates 360 degrees around the patient's head, producing series of exposures at one degree intervals. The cone-shaped x-ray beam pulses on and off capturing a large volume of area thus requiring minimal amount of generated radiation, which is lower radiation exposure than conventional medical CTs (Mozzo, Procacci, Tacconi, Tinazzi Martini, & Bergamo Andreis, 1998). In addition, the x-ray generator with CBCT devices operates at much lower energy relative to MDCT devices. The X-ray tube detector may be an image intensifier coupled with a charge-coupled device sensor or more recently an amorphous silicon flat panel or CMOS sensor to capture the image data. Digital radiographs are generally acquired in 512x512 pixel format or higher resolution. Digital image files are exported in digital imaging and communications in medicine (DICOM) format for analysis with DICOM viewer software (Mozzo *et al.*, 1998). DICOM viewers allow for visualization, measuring, segmenting, and complete analysis of a CBCT scan in 3-D volumetric structure in all dimensions, sagittal, coronal, and axial as shown in Figure 3.

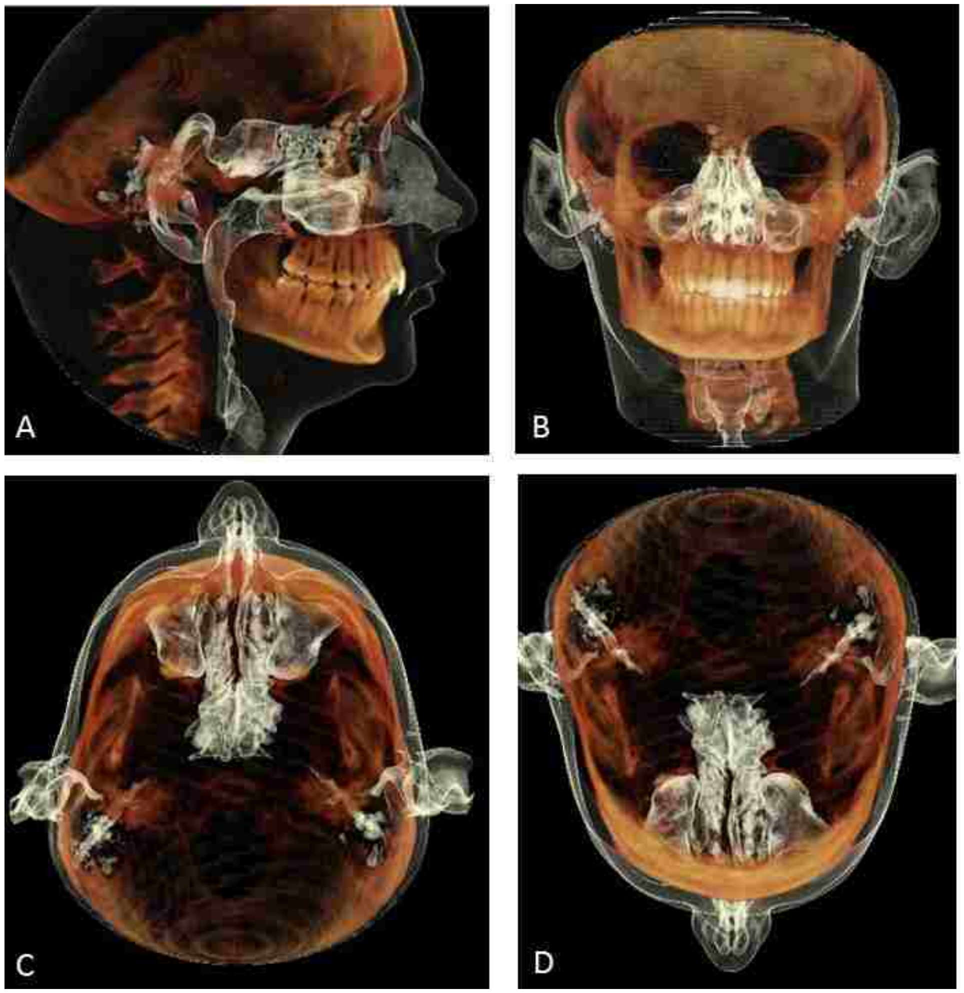


Figure 3. Example of CBCT images. A, Sagittal view. B, Coronal view. C, Axial view from bottom. D, Axial view from top.

Patient positioning during CBCT imaging is most often very different from that of MDCT. In conventional MDCT devices the patient is scanned in a supine position. Only a few CBCT devices, the NewTom 9000 and the Newtom 3G image the patient in the supine position. Other CBCT devices, such as the iCAT and CB Mercuray, require patients to be in the sitting position (Guijarro-Martinez & Swennen, 2011). The supine position provides incomplete representation of the upper airway, but may be more closely related to the sleeping position, as OSA normally occurs during sleep. The position of oropharyngeal structures change in response to gravity. The locations of key anatomical landmarks changed in patients sitting upright (from CBCT scans) versus the supine position (from MDCT) (Sutthiprapaporn *et al.*, 2008). The soft palate, epiglottis, and opening of esophagus all moved caudally (downward) when changed from supine to upright position, and posteriorly when changed from upright to supine position. Additionally the hyoid bone moved downward when changed from supine to upright position only. These authors also found that the cross-sectional area in the upright position was larger than in the supine position. These findings imply that changes in airway and related soft tissues are due to gravity and posture (Sutthiprapaporn *et al.*, 2008). A strong correlation exists between the posterior airway space and head posture as defined by craniocervical angulation. A change of 10 degrees in craniocervical angulation can produce a 4 mm change in posterior airway space (Muto *et al.*, 2002).

CBCT ACCURACY IN AIRWAY MEASUREMENTS

CBCT is more advantageous over 2-D radiography because it is a much more accurate representation of anatomic structures in 3-D. This ultimately gives the clinician a clear and better understanding of the structures being evaluated. Therefore, it has been widely accepted for use in clinical orthodontics. The need to determine its accuracy is essential to justify its application. Evaluation of the accuracy and reliability of airway volume measurements from CBCTs was compared to manual measurements made on an airway model (Ghoneima & Kula, 2011). No statistically significant differences were found between total and internal airway volumes as well as the minimal cross-sectional airway area measured on CBCTs compared with the manual measurements. Those measured from CBCTs were reliable and accurate compared to the manual measurements. The use of CBCT imaging for the assessment of the airway can provide clinically useful information in orthodontics (Ghoneima & Kula, 2011). Similar findings were found in another study that compared airway measurements from CBCT and those from manual measurements (Schendel & Hatcher, 2010). The measurements from CBCTs are accurate, reliable, and fast. Comparison of the airway size between lateral cephalograms and CBCTs revealed that CBCT scan is simple and effective method to accurately analyze the airway (Aboudara *et al.*, 2009). Airway volume acquired from CBCT showed moderate variability compared with the airway area measured from corresponding lateral cephalograms, indicating that airway information is not accurately represented from lateral cephalogram (Aboudara *et al.* 2009).

CBCT DOSIMETRY

The topic of patient radiation exposure is critical to discussion. The American Dental Association Council on Scientific Affairs recommends the use of dental radiographic techniques that would reduce the amount of radiation exposure. This is known as the ALARA (As Low As Reasonably Achievable) principle. It includes taking radiographs based on patient's needs, lowest kVp (voltage) and mA (current) setting, collimating beam to smallest size possible (small field of view), and using leaded aprons and thyroid shields (Palomo, Rao, & Hans, 2008). Increasing use of CBCT as a substitute for medical CT will benefit patient from radiation exposure reduction. However, using CBCT in replacement of panoramic and lateral cephalometric imagings possibly may increase radiation exposure risk to patient, although recent CBCT devices, Next-Generation i-CAT® machine, report dose levels to be lower than that of traditional panoramic imaging (Carlson, n.d.). Radiation exposure is particularly a concern for children as they may retain the effects of radiation in their body longer than adults and their developing organs are more sensitive to radiation induced damage (Ludlow *et al.*, 2006). The benefits of gaining substantial diagnostic information against the expense and risk of the imaging procedure are determined by the clinician. A vast amount of information can be obtained from CBCTs and its numerous clinical applications are invaluable to formulating appropriate diagnosis and treatment plans. Dosimetry was examined of 3 CBCT devices for oral and maxillofacial radiology: CB Mercuray, NewTom 3G, and i-CAT (Ludlow *et al.*, 2006). Report of varying exposure levels depends on device, field of view, and exposure setting. The effective dose is many times higher than conventional panoramic imaging, but less than doses for medical CT. Another study assessed the effective dose of the NewTom 9000 CBCT device and found that it is significantly less than those with traditional CT imaging methods and comparably within the range of traditional dental panoramic imaging (Mah *et al.*, 2003). Most of the CBCT dosimetry studies operate the device at the default or highest possible settings, although most devices allow for variable operational settings and collimation of the field of view. Quantification of the changes in radiation dose when using different settings on the CB MercuRay CBCT device showed a reduction in radiation exposure can be attained by using lowest settings and narrow collimation (Palomo, Rao, and Hans, 2008). The field of view is selected based on the region of interest, which is choosing the smallest field that would include the entire region of interest.

ACCURACY OF DICOM VIEWERS

Evaluating the accuracy and reliability of the DICOM viewer is also important. Different imaging software programs have different tools and approaches to segment, compute and analyze the upper airway. Thus, advantages and disadvantages inherently exist in each imaging software program. In one study, three commercially available DICOM imaging software programs were compared for measuring nasopharyngeal and oropharyngeal volumes: Dohphin3D, InVivo Dental, and OnDemand3D (El & Palomo, 2010). These three software programs are highly reliable in airway volume calculation and high correlation of the results but their accuracy was poor which may be due to systematic error. The high correlation suggests that all programs behaved similarly, but when a value was chosen it was not the same among the programs (El & Palomo, 2010). A recent study compared the precision and accuracy of 6 imaging software programs for measuring oropharynx volume: Mimics, ITK-Snap, OsiriX, Dolphin3D, InVivo Dental, and OnDemand3D (Weissheimer *et al.*, 2012). The reliability was high for all 6 programs, but had variability in volume segmentations of the oropharynx. Mimics, ITK-Snap, OsiriX, and Dolphin3D had less than 2% errors, whereas InVivo Dental and OnDemand3D had more than 5% errors compared with the gold standard (Weissheimer *et al.*, 2012). Another study analyzed the accuracy and precision of one DICOM viewer, 3dMD Vultus. The software proved to be accurate, reliable, and fast method to evaluate the airway (Schendel & Hatcher, 2010).

CBCT AIRWAY STUDIES IN ORTHODONTICS

Airway analyses have been conventionally conducted using lateral cephalometric radiographs. Comparison of adolescents' airway evaluation between lateral cephalometric radiograph and CBCT scan of the same region was performed (Aboudara, *et al.*, 2003). The upper airway volume acquired from CBCT scan showed more variability than the airway area acquired from corresponding lateral cephalometric radiograph. This indicates that more accurate information is gained from CBCT. Using only lateral cephalometric radiograph, it is impossible to identify any possible airway constriction in the lateral dimension. By using CBCT image, the airway can be segmented at different level of the airway and volumetrically in all dimensions. One recent study using CBCT scan in adults analyzed airway shapes and found that greatest variability occurred in the hypopharynx, in region below the epiglottis, and above the vocal folds. There was moderate variation at the nares, behind soft palate, and at base of the tongue. Uniform shape was found at the central portion of the nasal airway surrounding the inferior turbinate. The authors concluded that it is possible to compare airway shape among patients (Stratemann *et al.*, 2011). The correlation of upper airway linear measurements in sagittal and transverse dimensions, cross-sectional areas, with volumetric measures from CBCT images was assessed (Lenza *et al.*, 2010). They found weak correlation between most linear measurements with volumes. Because airway is extremely variable depending on head posture, breathing stage, craniofacial morphology and airway muscle tension, airway volume alone does not accurately depict true airway morphology (Lenza *et al.*, 2010). It seems best to analyze using linear measurements, area and volume together.

With increased utilization of cone beam technology, there has been a rise in research regarding airway morphology with association of sleep apnea. More studies are becoming available on the upper airway evaluation in adult and children patients with different facial patterns. Volumetric analysis of the upper airway in normal adults reveals the area of maximum cross-sectional constriction most frequently locates in the oropharyngeal level (Tso *et al.*, 2009). Assessment of the upper airway volume and shape in adolescents and adults with different facial patterns shows that both airway volume and shape vary amongst different antero-posterior jaw relationships, whereas airway shape differs with various vertical jaw relationships (Grauer, Cevidanes, Styner, Ackerman, and Proffit, 2009). These type of volumetric studies show that skeletal Class III malocclusion adults have greater airway volume relative to skeletal Class I controls (Hong, Oh, Kim, Kim, & Park, 2011).

There are few studies evaluating airway morphology and dimensions based on patients' dental patterns. Specifically, the healthy Asian children with dental Class III malocclusion group had a flat and larger oropharyngeal airway, larger area and larger width compared with the dental Class I malocclusion group (Iwasaki *et al.*, 2009). The dental Class III group also exhibited lower tongue position and reduced oropharyngeal airway size which is in contrast to the study in adults (Hong *et al.*, 2011).

Various researchers have published on the relationship of the narrowest cross-section airway configuration between OSA and non-OSA groups. OSA adult patients present with higher BMI, lower total upper airway volume, and the narrowest cross-section segment having significantly smaller antero-posterior dimension and smaller minimum cross-section area (Ogawa, Enciso, Shintaku, Clark, 2007). Quantitative evaluation of the adults' retroglossal airway configuration defined the relationship between BMI and airway configuration showed only the airway cross-section area/square area ratio in OSA group had 8.8% statistically significant smaller than normal non-OSA group (Shigeta, Enciso, Ogawa, Shintaku, & Clark, 2008). The smallest cross-sectional area of the upper airway and its lateral dimension were significantly smaller in the adult OSA group as compared to the snorer group (Enciso *et al.*, 2010). On the other hand, significant group differences in total airway volume and antero-posterior dimension of the smallest cross-sectional area between OSA and non-OSA adult group, and no differences with respect to the smallest cross-sectional area and lateral dimension (Ogawa *et al.*, 2005).

At this time, there are few CBCT studies on pharyngeal airway characterization of children and adolescents in relation to their craniofacial patterns. Assessment of upper airway volume, minimum cross-section area, and morphology of lower pharyngeal portion, in adolescents, and relating them to their craniofacial patterns was done by stratifying the patients into three groups according to the ANB angles only, all with normodivergent vertical craniofacial pattern. The skeletal Class II group had significantly smaller minimum cross-sectional areas in the lower pharyngeal portion than the skeletal Class III and Class I groups (Claudino, Mattos, Ruella, & Anna, 2013). AP Skeletal Class II adolescents have smaller volumes than AP skeletal Class I and Class III, with the observation that mandibular position with respect to cranial base has an effect on the upper airway volume (El and Palomo, 2011). In preadolescent, healthy, Asian children with AP skeletal Class I and Class II groups, there was no significant difference in the minimum cross-section area and volumetric measurements of different parts of the upper airway, except for the total volume. The mean total airway volume, extending from the anterior nasal cavity to the epiglottis, in skeletal Class II group was significantly smaller than skeletal Class I group (Kim, Hong, Hwang, & Park, 2010). Together the prior research shows variation in methodologies but obtained similar result with regards to total airway volume, but different outcomes for minimum cross-section area. This is perhaps because of the different population in these studies and different imaging software used. Up to date there is limited research in three-dimensional airway analysis and its association to BMI, neck circumference, risk for OSA of children and adolescents with different vertical craniofacial patterns.

CHAPTER 3 METHODOLOGY

SUBJECTS

A total of 86 pre-treatment orthodontic records were obtained from the UNLV School of Dental Medicine's archival dental records from June 2012 through June 2013. The sample comprised of individuals ranging from 8-16 years. This age range was chosen largely to coincide with Scammon's lymphoid development curve (Scammon, 1930). During this growth curve the adenoid tissues enlarge and reach their maximum size. This in turn influences airway function and morphology. The pre-treatment orthodontic records include: CBCT scan; BMI; neck circumference measurement and a modified Epworth Sleepiness Scale. All subject information was de-identified by UNLV SDM IT technician. A UNLV Institutional Review Board approval for use of archival dental records was approved (Protocol # 1204-4115M, Appendix C).

ANTHROPOMETRIC AND DEMOGRAPHIC MEASUREMENTS

Anthropometric data including: age; gender; BMI; and neck circumference (NC) were collected. These measures and all subsequent variables were recorded in Excel 2007 (Microsoft, Redmond, WA). BMI values were provided from a BMI digital machine (Health O Meter Professional 500KL, Pelstar LLC, McCook, IL). Neck circumferences were measured in inches using a flexible inelastic tape at the level of the cricothyroid membrane. In this study, BMI values were categorized in percentiles relative to children of the same sex and age (Table 1, Appendices A and B).

MODIFIED EPWORTH SLEEPINESS QUESTIONNAIRE

The Epworth Sleepiness Questionnaire was previously modified for UNLV School of Dental Medicine clinical use. Modifications were made to clarify and rephrase questions (Appendices D and E). Data from the modified sleep disorder questionnaire (Appendix E) were also recorded in Excel 2007 (Microsoft, Redmond, WA). The current Epworth Sleepiness Scale (ESS) score of 10 or higher indicates "a high level of daytime sleepiness" (Johns, 2000). In our study, a score of 10 or more indicated the possibility of a sleep disorder breathing with risk for OSA.

CBCT IMAGING PROTOCOL

All CBCT scans were taken by one radiology technician trained in the technique and operation of the CBCT machine. The CBCT machine (CB MercuRay, Hitachi Medical Corp) was operated at 100 kV, 10 mA, and exposure time of 10-seconds. Each patient was seated in a chair with Frankfort Horizontal Plane paralleled to the floor. Imaging was performed at the end of expiration, without swallowing and in centric occlusion to obtain a standardized position of the oropharyngeal structures. Centric occlusion was utilized to minimize variability in mandibular and soft tissue measurements (Pracharktam *et al*., 1996). The data were in Digital Imaging and Communications in Medicine (DICOM) format.

3-D VOLUMETRIC SKELETAL MEASUREMENTS

Volumetric renderings of subjects' CBCT scans were visualized using InVivo Dental software version 5.2 (Anatomage, San Jose, CA). The principal investigator performed 3-D volumetric skeletal tracings to classify subjects by AP and vertical dimensions. The following reference points, lines, and planes were utilized.

Reference points (Jacobson, A. & Jacobson, R.L., 2006):

1. A-point (A) — a midline point on the innermost curvature from the maxillary anterior nasal spine to the crest of the maxillary alveolar process.

2. Articulare (Ar) — a point at the junction of posterior border of the ramus and inferior border of the occipital bone.
3. Basion (Ba) — the anterior margin of the foramen magnum.
4. B-point (B) —the midline point in the innermost curvature from chin to alveolar junction.
5. Gonion (Go) — the most inferior posterior point of the mandible.
6. Menton (Me) — the lowest point on the symphysis of the mandible.
7. Nasion (Na) — the junction of the nasal and frontal bones at the most posterior point on the curvature of the bridge of the nose.
8. Orbitale (Or) — a lowest point on the inferior margin of the orbit.
9. Pogonion (Pog) — the most anterior point on the contour of the chin.
10. Porion (Po) — the midpoint of the upper contour of the external auditory canal.
11. Posterior Nasal Spine (PNS) — the tip of the posterior nasal spine of the palatine bone, at the junction of the soft and hard palate.
12. Sella (S) — the geometric center of the pituitary fossa.

Reference Planes or Lines (Jacobson, A. & Jacobson, R.L., 2006):

1. Facial Plane (FP) — a plane connecting N to Pog.
2. Frankfort Horizontal (FH) — a line connecting Po to Or.
3. Mandibular Plane (MP) — a plane connecting Go to Me.
4. Occlusal Plane (OP) — a plane going through the mesial cusps of the permanent maxillary and mandibular first molars and incisal edges of maxillary and mandibular central incisors.
5. Sella-Nasion (S-N) — a line connecting S to Na.

The AP craniofacial skeletal class was determined from five lateral cephalometric measurements. All measurements determine the relative position of the maxilla to mandible in the AP dimension. Each subject was classified into one of three AP Classes (I, II, and III) by having at least three out of five measurements based on the standard values (Table 2).

1. **ANB** – The ANB angle is determined by subtracting the SNB angle from the SNA angle (SNA-SNB=ANB) (Figure 4). A positive ANB angle generally indicates that the maxilla is positioned anteriorly relative to the mandible (Class I or Class II malocclusion cases). A negative ANB angle indicates that the maxilla is positioned posteriorly relative to the mandible (Class III malocclusion cases).

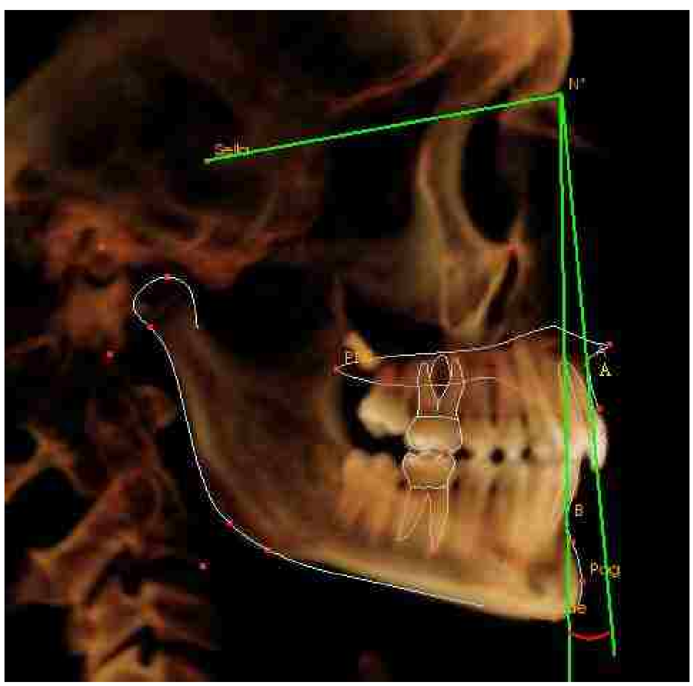


Figure 4. ANB angle (red line).

2. **WITS** – the linear distance difference between Point A perpendicular to occlusal plane and Point B perpendicular to occlusal plane (Figure 5). If Point A is in front of Point B, WITS is a positive value. If Point B is in front of Point A, WITS is a negative value.

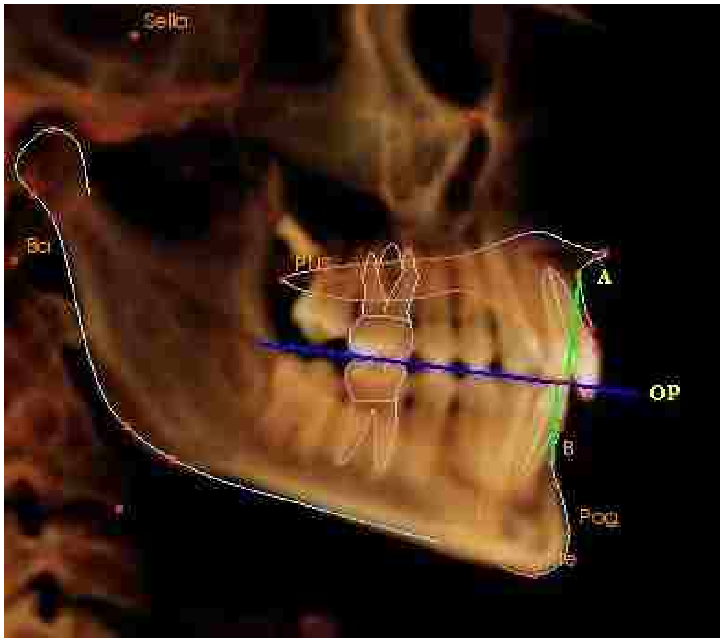


Figure 5. WITS (red line).

3. **A-point to N-perp** – the linear distance from Point A to the line Nasion perpendicular to Frankfort Horizontal plane (Figure 6).

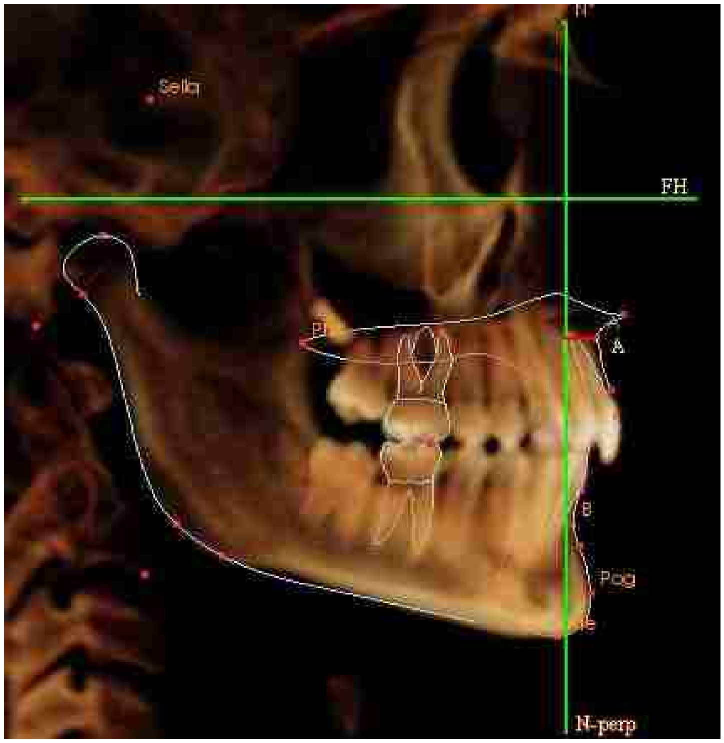


Figure 6. A-point to N-Perp (red line).

4. **Pog to N-perp** – the linear distance from Pogonion to the line Nasion perpendicular to Frankfort Horizontal plane (Figure 7).

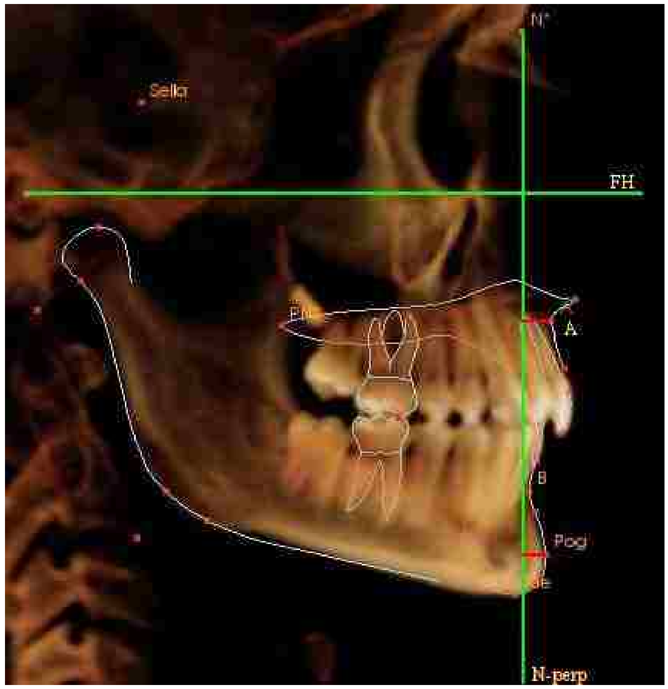


Figure 7. Pog to N-Perp (red line).

5. **Facial convexity** – the linear distance from Point A to Facial Plane (Figure 8).

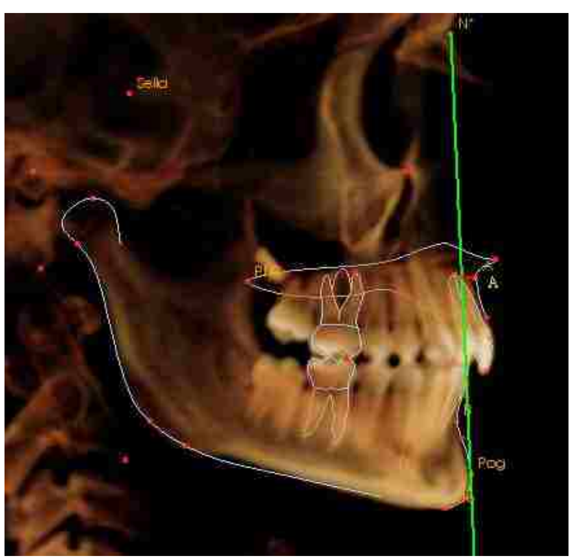


Figure 8. Facial convexity (red line).

Table 2

AP Skeletal Measurement Norms

	Class I	Class II	Class III
ANB*	0-5	>5	<0
WITS**	2 to -4	>2	<-4
A-Nperp**	3 to -3	>3	<-3
Pog-Nperp**	4 to -6	<-6	>4
Facial Convex**	2.5 to -1.5	>2.5	<-1.5

* Measurement units are in degrees.
**All measurement units are in millimeters (mm).
(Jacobson, A, 1975 ; Jacobson, A. & Jacobson, R.L., 2006).

The vertical skeletal class was determined from five lateral cephalometric measurements. Each subject was classified into one of three vertical classes (Normodivergence, Hypodivergence, and Hyperdivergence) by having at least three out of five measurements based on the standard values (Table 3). Overall, nine subgroups, combined both AP and vertical craniofacial groups, are possible (Figure 14).

1. **FMA** – the angle formed by Frankfort Horizontal plane to Mandibular plane (Figure 9).

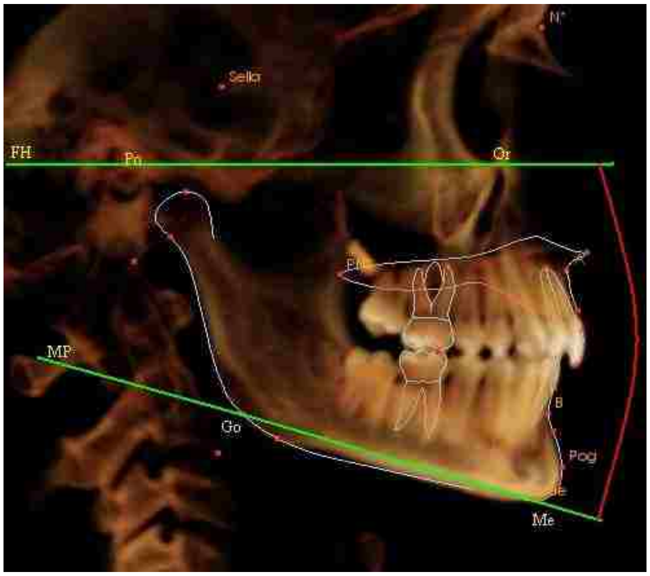


Figure 9. FMA (red line).

2. **AFH** – Anterior Facial Height which is the linear distance between Nasion and Menton (Figure 10).

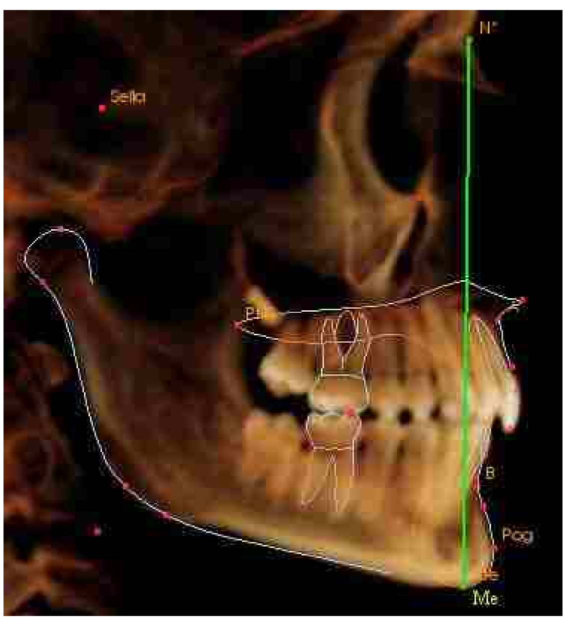


Figure 10. AFH (green line).

3. **PFH** – Posterior Facial Height which is the linear distance between Sella and Gonion (Figure 11).

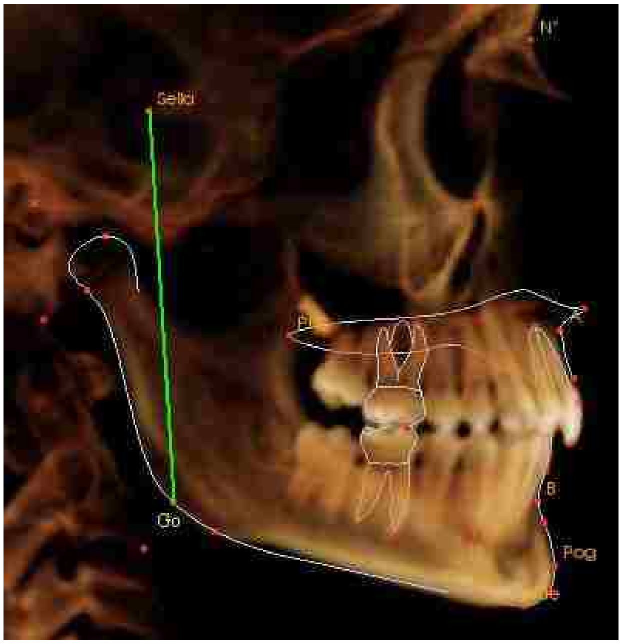


Figure 11. PFH (green line).

4. **Facial Height ratio** (FHR) – ratio of PFH to AHF (Figure 12).

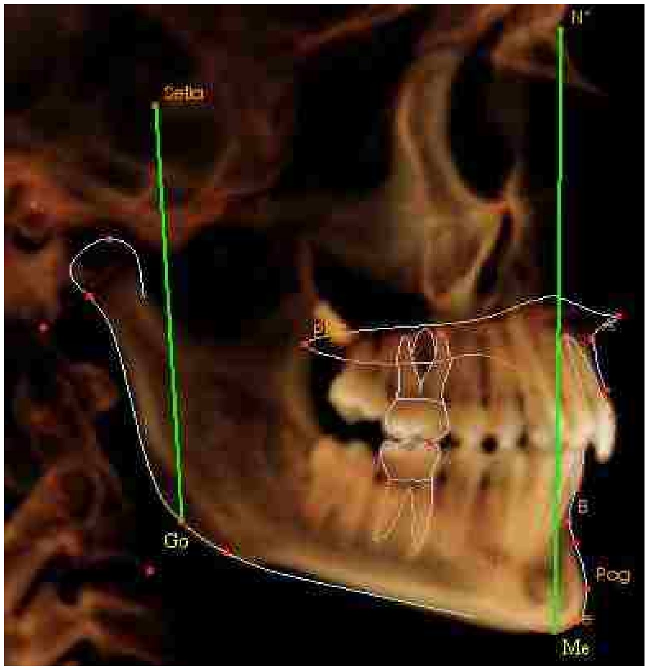


Figure 12. FHR (green lines).

5. **Gonial angle** – the angle formed by the junction of the posterior and lower borders of the mandible (Articulare-Gonion-Menton) (Figure 13).

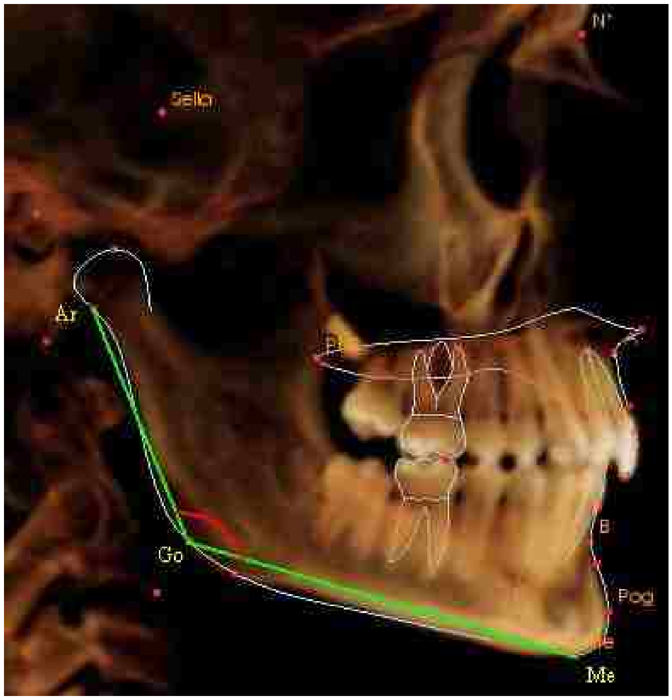


Figure 13. Gonial angle (red line).

Table 3

Vertical Skeletal Measurement Norms

	Normodivergence	Hypodivergence	Hyperdivergence
FMA*	21-27	<21	>27
AFH**	105-120	<105	>120
PFH**	70-85	>85	<70
FHR	62-65	>65	<62
Gonial Angle*	123-137	<123	>137

*Measurement units are in degrees.
**All measurement units are in millimeters (mm).
(Jarabak J.R. & Fizzel J.A., 1972; Jacobson, A. & Jacobson, R.L., 2006)

SUBGROUPS	AP Skeletal Measurements					Vertical Skeletal Measurements				
	ANB	WITS	A-Nperp	Pog-Nperp	Facial Convex	FMA	AFH	PFH	FHR	Gonial angle
Class I, Normodivergent										
Class I, Hypodivergent										
Class I, Hyperdivergent										
Class II, Normodivergent										
Class II, Hypodivergent										
Class II, Hyperdivergent										
Class III, Normodivergent										
Class III, Hypodivergent										
Class III, Hyperdivergent										

Figure 14. Excel format for determination of nine subgroups.

OROPHARYNGEAL AIRWAY MEASUREMENTS

Following, oropharyngeal airway measurements were performed. Volumetric region of interest (VROI) was defined from two planes based on sagittal view of image (Figure 15a): (1) upper border is the plane drawn parallel to Frankfort plane and going through most distal point of bony hard palate, (2) lower border is the plane drawn parallel to Frankfort plane and going through most anterior-inferior point of the second cervical vertebrae (Ogawa *et al.*, 2007). This location is a reproducible anatomic landmark (Shigeta *et al.*, 2008). The volumetric tracing landmarks were visible only within the 3-D analysis view. Therefore, the Frankfort plane, upper border plane of VROI, and lower border plane of VROI were transferred from 3-D Analysis view to the volume render view. From the volume render view, the volume image was reoriented in order for the three planes to be parallel. This was accomplished by using the grid and patient orientation tools. The orientation tool has the option to click and drag the red wheel to visually align all three planes to be parallel to the grid lines (Figure 15b-c). Threshold values were adjusted within the range of -400 to -480 Hounsfield units to eliminate imaging artifacts and refine the selected airway region.

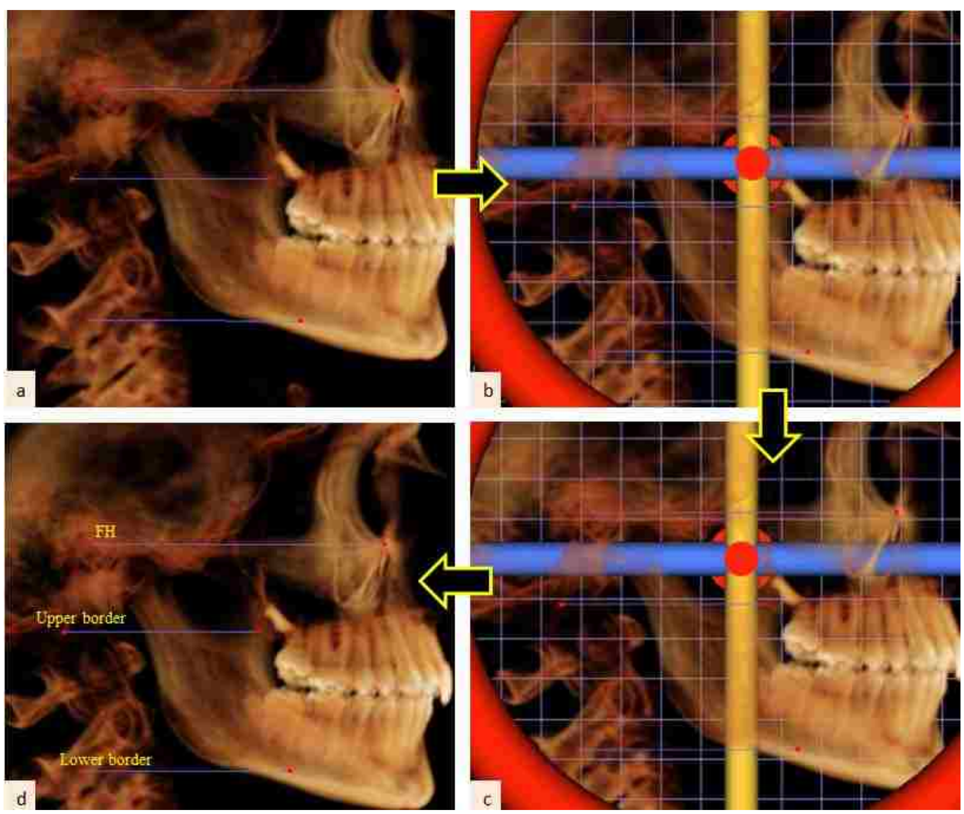


Figure 15. Determination of upper airway volumetric region of interest.

Once all planes are parallel (Figure 15d, 16a-b), airway measurement tool was selected and points were chosen along the airway path starting from the upper border to the lower border of VROI. The points demarcating the upper and lower borders were individually reoriented in order to be parallel and coincident with the upper and lower border planes (Figure 16c). Following, the software automatically rendered the airway within the VROI. The total airway volume in cubic millimeters (mm^3) and the minimum cross-section slice with its total surface area (minCSA) in squared millimeters (mm^2) were given (Figure 16d).

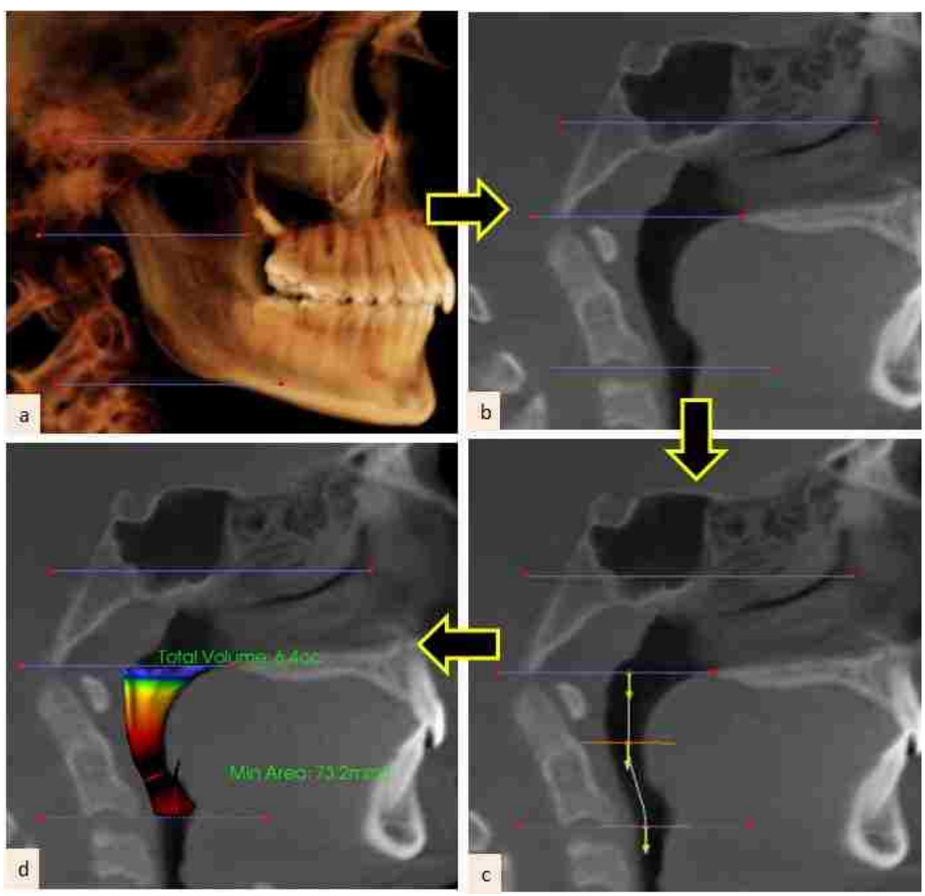


Figure 16. Analysis of upper airway within VROI. d. Red line, minimum cross-section slice.

Due to the tortuous nature of the airway, the location of the minimum cross-section slice varies along the VROI. In order to view the minimum cross-section slice in its axial dimension, it was re-oriented horizontally by using the grid and patient orientation tool (Figure17). Next, the volume image was selected to display under grayscale view control and clipped axially to the level of the minimum cross-section slice (Figure 18a-b). At this point, the airway volume was deleted from visual and the axial bottom view was selected in order to view and perform measurements of the cross-section dimensions of this slice (Figure 18c). Opacity, brightness, and contrast can be adjusted to maximize the visual outline of the airway cross-section. The perimeter of the minimum cross-section was measured in millimeters (mm) using the polygonal measurement tool (Figure 18e). The largest antero-posterior depth and largest lateral width of the minimum cross-section slice were measured in mm using the distance measurement tool (Figure 18e).

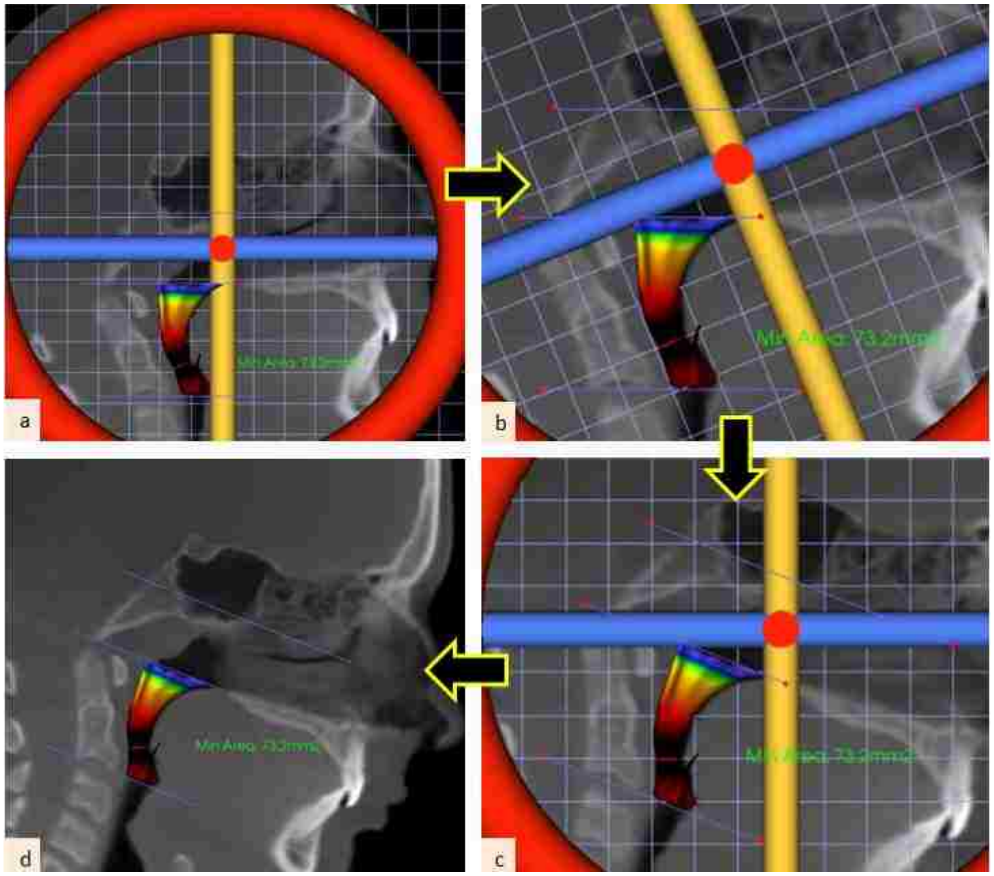


Figure 17. Reorientation of upper airway within VROI.

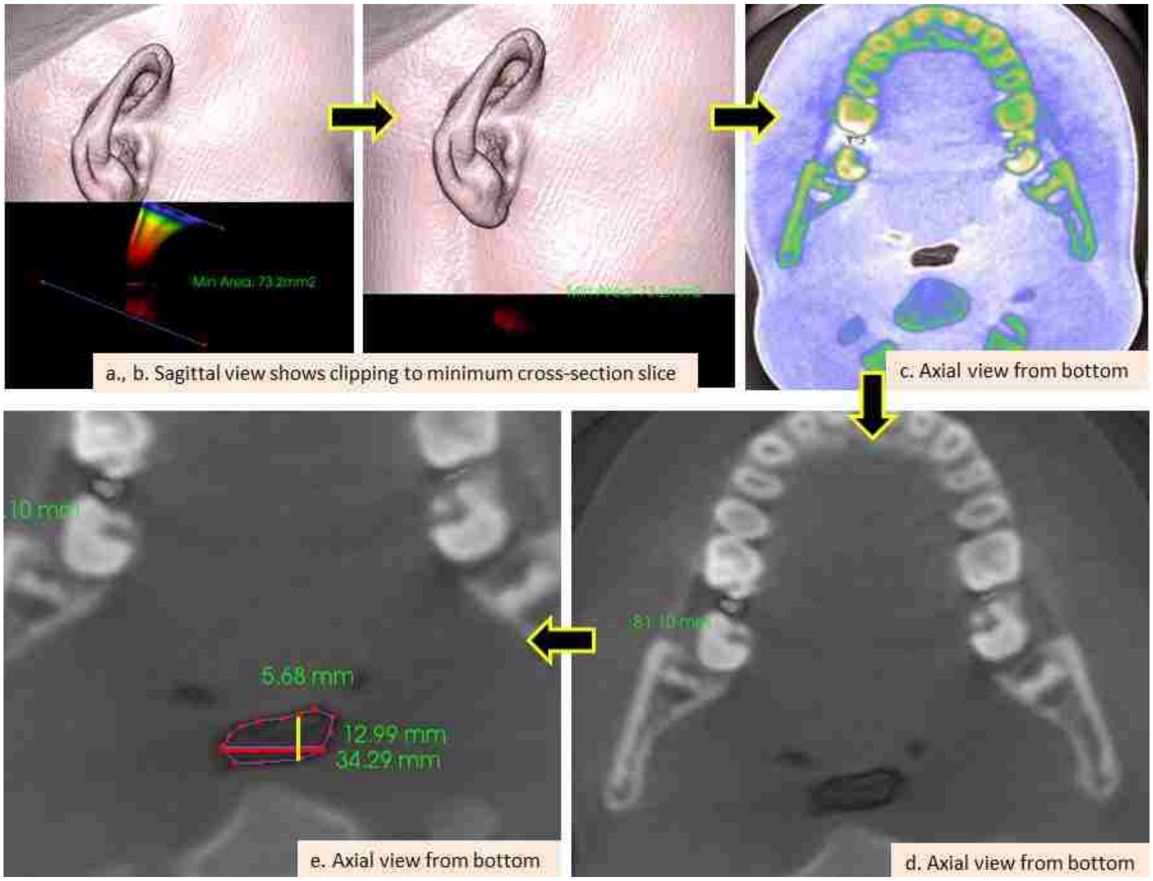


Figure 18. Analysis of airway dimensions at the minimum cross-section slice. e. blue outline, perimeter; yellow line, AP depth; red line, lateral width.

CRANIOFACIAL GROUPS		VARIABLES								
		Gender	BMI category	Risk for OSA	NC	Total Vol	MinCSA	Perimeter	Depth	Width
AP	Class I									
	Class II									
	Class III									
Vertical	Normodivergent									
	Hypodivergent									
	Hyperdivergent									
Combined	Class I Normodivergent									
	Class I Hypodivergent									
	Class I Hyperdivergent									
	Class II Normodivergent									
	Class II Hypodivergent									
	Class II Hyperdivergent									
	Class III Normodivergent									
	Class III Hypodivergent									
	Class II Hyperdivergent									

Figure 19. Excel format for all data input. NC = neck circumference; Total Vol = total volume; minCSA = minimum cross-section area.

METHOD ERROR

All measurements were performed by the principal investigator. The reliability of 3-D volumetric tracing for skeletal measurements and oropharyngeal airway measurements was tested by investigating the error in locating landmarks and measuring airway dimensions. Measurements were repeated for thirty randomly selected subjects two weeks after the first round of measurements. The degree of reliability was determined using Dahlberg's formula, $\sqrt{((\Sigma d^2)/2n)}$ for each AP and vertical skeletal measurement and airway measurement (Dahlberg, 1940).

STATISTICAL ANALYSIS

Data from Excel was transferred into SPSS software version 20.0 (SPSS, Chicago, IL) for statistical analysis. Mean, standard deviation, and Pearson's correlation coefficient were performed to evaluate the relationships among variables. *P* value of < 0.05 and < 0.01 were used to determine statistical significance. When evaluating the correlation, the following classification was used: a strong correlation when $r \geq 0.8$, moderate correlation if $0.5 < r < 0.8$, and weak correlation if $r \leq 0.5$.

CHAPTER 4 RESULTS

METHOD ERROR RESULTS

The degree of reliability for each linear, angular, ratio, and airway measurement was calculated according to Dalhberg's method (Table 4). According to all repeated measurements, the method error was considered negligible.

Table 4

Results of Method Error

Variables	Measurements	d
AP Skeletal measurements	ANB (°)	0.12
	WITS (mm)	0.31
	A-Nperp (mm)	0.31
	Pog-Nperp (mm)	0.43
	Facial convexity	0.17
Vertical Skeletal measurements	FMA (°)	0.53
	AFH (mm)	0.57
	PFH (mm)	0.63
	AFH/PFH	0.01
	Gonial Angle (°)	0.85
Oropharyngeal airway measurements	Total Vol (cc)	0.21
	MinCSA (mm^2)	1.49
	Depth (mm)	0.55
	Width (mm)	0.22
	Perimeter (mm)	0.35

d = amount of error.

RESEARCH QUESTION 1

Are there correlations between gender, Body Mass Index, risk for obstructive sleep apnea, neck circumference, and oropharyngeal airway dimensions in dimensions in children and adolescents with antero-posterior craniofacial Class I, II, and III? Hypothesis: There are correlations between gender, Body Mass Index, risk for obstructive sleep apnea, neck circumference, and oropharyngeal airway dimensions in children and adolescents with antero-posterior craniofacial Class I, II, and III. Null hypothesis: There are no correlations between gender, Body Mass Index, risk for obstructive sleep apnea, neck circumference, and oropharyngeal airway dimensions in children and adolescents with antero-posterior craniofacial Class I, II, and III. Null hypothesis was rejected. The significant correlations found in this study are described below.

CORRELATIONS IN AP CLASS I GROUP

A Pearson's correlation coefficient was computed to assess the relationship between variables within the AP Class I group ($n = 38$) (Table 5). There was a weak negative correlation between neck circumference and gender ($r = -0.41$, $p < 0.05$). Increases in neck circumference were moderately related in male. There was a moderate positive correlation between neck circumference and BMI ($r = 0.77$, $p < 0.01$). Increases in BMI were correlated with increases in neck circumference. There was a weak positive correlation between neck circumference and minimum cross-section airway depth ($r = 0.37$, $p < 0.05$). There were strong positive correlations between total oropharyngeal airway volume with minimum cross-section area ($r = 0.82$, $p < 0.01$), width ($r = 0.81$, $p < 0.01$), perimeter ($r = 0.83$, $p < 0.01$), and weak positive correlation between total oropharyngeal airway volume with depth ($r = 0.44$, $p < 0.01$). Increases in total airway volume were correlated with increases in minimum cross-section area, width, perimeter and depth. There were moderate positive correlations between minimum cross-section area with minimum cross-section depth ($r = 0.73$, $p < 0.01$), strong positive correlations with width ($r = 0.85$, $p < 0.01$), and perimeter ($r = 0.94$, $p < 0.01$). Increases in minimum cross-section area were correlated with increases in minimum cross-section depth, width, and perimeter. There were weak positive correlation between minimum cross-section depth with minimum cross-section width ($r = 0.41$, $p < 0.01$) and moderate positive correlation with minimum cross-section perimeter ($r = 0.64$, $p < 0.01$). There were strong positive correlations between minimum cross-section width and minimum cross-section perimeter ($r = 0.88$, $p < 0.01$). Increases in minimum cross-section width were strongly correlated with increases in minimum cross-section perimeter. There were no statistically significant correlations between gender with BMI, risk for OSA, and oropharyngeal airway dimensions. There were no statistically significant correlations between BMI with risk for OSA and oropharyngeal airway dimensions. There were no statistically significant correlations between risk for OSA with neck circumference and all oropharyngeal airway dimensions. There were no statistically significant correlations between neck circumference with total oropharyngeal airway volume, minimum cross-section area, width and perimeter.

Table 5

Correlations Among and Descriptive Statistics for Variables in AP Class I Group

	M (*SD*)	Gender	BMI Cat	Risk for OSA	NC (in)	Total Vol (cc)	MinCSA (mm^2)	Depth (mm)	Width (mm)	Perimeter (mm)
Gender	1.58 (.50)	___								
BMI Cat	2.42 (.76)	-.233	___							
Risk for OSA	1.11 (.31)	-.055	-.193	___						
NC (in)	12.76 (1.47)	-.406*	.765**	.130	___					
Total Vol (cc)	7.52 (2.85)	.132	-.015	.104	.032	___				
MinCSA (mm^2)	139.13 (72.99)	.050	.036	.101	.079	.821**	___			
Depth (mm)	9.05 (2.66)	-.067	.290	.105	.374*	.436**	.733**	___		
Width (mm)	19.64 (6.06)	.079	-.134	.145	-.100	.813**	.850**	.413**	___	
Perimeter (mm)	50.90 (14.47)	.111	.032	.063	.027	.834**	.936**	.638**	.876**	___

Notes. n = 38. Male=16, Female=22. BMI cat = Body Mass Index Categories. NC = neck circumference. Total Vol = total airway volume. MinCSA = minimum cross-section area. * $p < 0.05$. ** $p < 0.01$.

CORRELATIONS IN AP CLASS II GROUP

A Pearson's correlation coefficient was computed to assess the relationship between variables within the AP Class II group (n = 35) (Table 6). There was a weak positive correlation between BMI and neck circumference ($r = 0.44$, $p < 0.01$). Increases in BMI were weakly correlated with increases in neck circumference. There were moderate correlations between total oropharyngeal airway volume with minimum cross-section area ($r = 0.79$, $p < 0.01$), depth ($r = 0.54$, $p < 0.01$), width ($r = 0.71$, $p < 0.01$) and strong correlation with perimeter ($r = 0.82$, $p < 0.01$). Increases in total oropharyngeal airway volume were correlated with increases in minimum cross-section area, depth, width, and perimeter. There were moderate positive correlation between minimum cross-section area with minimum cross-section depth ($r = 0.56$, $p < 0.01$), strong correlations with width ($r = 0.82$, $p < 0.01$), and perimeter ($r = 0.89$, $p < 0.01$). Increases in minimum cross-section area were correlated with increases in minimum cross-section depth, width, and perimeter. There was weak positive correlation between minimum cross-section depth and perimeter ($r = 0.49$, $p < 0.01$). Increases in minimum cross-section depth were correlated with increases in minimum cross-section perimeter. There was strong positive correlation between minimum cross-section width and perimeter ($r = 0.95$, $p < 0.01$). Increases in minimum cross-section depth were strongly correlated with increases in minimum cross-section perimeter. There were no statistically significant correlations between gender with BMI, risk for OSA, neck circumference, and oropharyngeal airway dimensions. There were no statistically significant correlations between BMI and risk for OSA and oropharyngeal airway dimensions. There were no statistically significant correlations between risk for OSA with neck circumference and all oropharyngeal airway dimensions. There were no statistically significant correlations between neck circumference and all oropharyngeal airway dimensions. There were no statistically significant correlations between minimum cross-section depth and width.

Table 6

Correlations Among and Descriptive Statistics for Variables in AP Class II Group

	M (*SD*)	Gender	BMI Cat	Risk for OSA	NC (in)	Total Vol (cc)	MinCSA (mm^2)	Depth (mm)	Width (mm)	Perimeter (mm)
Gender	1.43 (.50)	___								
BMI Cat	2.11 (.72)	.023	___							
Risk for OSA	1.20 (.41)	.144	.222	___						
NC (in)	12.56 (1.09)	.002	.440**	.086	___					
Total Vol (cc)	6.52 (2.45)	-.185	-.028	-.144	.263	___				
MinCSA (mm^2)	119.70 (55.89)	-.076	.052	-.180	.061	.790**	___			
Depth (mm)	8.31 (2.57)	-.165	.201	-.093	.024	.539**	.557**	___		
Width (mm)	18.22 (6.10)	.160	-.018	-.210	.109	.714**	.821**	.273	___	
Perimeter (mm)	46.75 (11.72)	.039	-.016	-.182	.064	.817**	.886**	.492**	.946**	___

Notes. n = 35. Male = 20, Female = 15. BMI cat = Body Mass Index Categories. NC = neck circumference. Total Vol = total airway volume. MinCSA = minimum cross-section area. ** $p < 0.01$.

CORRELATIONS IN AP CLASS III GROUP

A Pearson's correlation coefficient was computed to assess the relationship between variables within the AP Class III group (n = 13) (Table 7). There was a moderate positive correlation between BMI and neck circumference ($r = 0.67$, $p < 0.01$). Increases in BMI were moderately correlated with increases in neck circumference. There were strong correlation between total oropharyngeal airway volume with minimum cross-section area ($r = 0.80$, $p < 0.01$), moderate correlations with depth ($r = 0.65$, $p < 0.01$), width ($r = 0.77$, $p < 0.01$) and perimeter ($r = 0.75$, $p < 0.01$). Increases in total oropharyngeal airway volume were correlated with increases in minimum cross-section area, depth, width, and perimeter. There were strong positive correlations between minimum cross-section area with minimum cross-section depth ($r = 0.86$, $p < 0.01$), width ($r = 0.83$, $p < 0.01$), and perimeter ($r = 0.91$, $p < 0.01$). Increases in minimum cross-section area were strongly correlated with increases in minimum cross-section depth, width, and perimeter. There were moderate positive correlations between minimum cross-section depth with minimum cross-section width ($r = 0.58$, $p < 0.01$) and perimeter ($r = 0.64$, $p < 0.01$). Increases in minimum cross-section depth were moderately correlated with increases in minimum cross-section width and perimeter. There was strong positive correlation between minimum cross-section width and perimeter ($r = 0.88$, $p < 0.01$). Increases in minimum cross-section depth were strongly correlated with increases in minimum cross-section perimeter. There were no statistically significant correlations between gender with BMI, risk for OSA, neck circumference, and oropharyngeal airway dimensions. There were no statistically significant correlations between BMI with risk for OSA and oropharyngeal airway dimensions. There were no statistically significant correlations between risk for OSA with neck circumference and all oropharyngeal airway dimensions. There were no statistically significant correlations between neck circumference and all oropharyngeal airway dimensions.

Table 7

Correlations Among and Descriptive Statistics for Variables in AP Class III Group

	M (*SD*)	Gender	BMI Cat	Risk for OSA	NC (in)	Total Vol (cc)	MinCSA (mm^2)	Depth (mm)	Width (mm)	Perimeter (mm)
Gender	1.62 (.51)	___								
BMI Cat	2.46 (.97)	.222	___							
Risk for OSA	1.15 (.38)	-.101	.247	___						
NC (in)	12.56 (1.28)	-.027	.669*	-.020	___					
Total Vol (cc)	7.23 (2.48)	-.089	-.170	-.453	.103	___				
MinCSA (mm^2)	137.76 (59.51)	.191	-.090	-.267	.256	.797**	___			
Depth (mm)	9.32 (2.73)	.301	.123	-.237	.361	.653*	.856**	___		
Width (mm)	19.95 (5.51)	.208	-.365	-.348	-.017	.770**	.832**	.580*	___	
Perimeter (mm)	51.62 (13.52)	.277	-.137	-.224	.101	.748**	.913**	.644*	.884**	___

Notes. n = 13. Male = 5, Female = 8. BMI cat = Body Mass Index Categories. NC = neck circumference. Total Vol = total airway volume. MinCSA = minimum cross-section area. * $p < 0.05$. ** $p < 0.01$.

RESEARCH QUESTION 2

Are there correlations between gender, Body Mass Index, risk for obstructive sleep apnea, neck circumference, and oropharyngeal airway dimensions in children and among Normodivergent, Hypodivergent, and Hyperdivergent craniofacial groups? Hypothesis: There are one or more correlations, but not all, between gender, Body Mass Index, risk for obstructive sleep apnea, neck circumference, and oropharyngeal airway dimensions in children and adolescents with among Normodivergent, Hypodivergent, and Hyperdivergent craniofacial groups. Null hypothesis: There are no correlations between gender, Body Mass Index, risk for obstructive sleep apnea, neck circumference, and oropharyngeal airway dimensions in children and adolescents among Normodivergent, Hypodivergent, and Hyperdivergent craniofacial groups. Null hypothesis was rejected. The significant correlations found in this study are described below.

CORRELATIONS OF VARIABLES IN VERTICAL NORMODIVERGENT GROUP

A Pearson's correlation coefficient was computed to assess the relationship between variables within the vertical Normodivergent group ($n = 50$) (Table 8). There was a moderate positive correlation between BMI and neck circumference ($r = 0.73$, $p < 0.01$). Increases in BMI were correlated with increases in neck circumference. There were strong correlations between total oropharyngeal airway volume with minimum cross-section area ($r = 0.84$, $p < 0.01$), perimeter ($r = 0.85$, $p < 0.01$), moderate correlations with depth ($r = 0.67$, $p < 0.01$), and width ($r = 0.74$, $p < 0.01$). Increases in total oropharyngeal airway volume were correlated with increases in minimum cross-section area, depth, width, and perimeter. There were moderate positive correlation between minimum cross-section area with minimum cross-section depth (r = 0.75, p <

0.01), strong correlations with width ($r = 0.83$, $p < 0.01$), and perimeter ($r = 0.93$, $p < 0.01$). Increases in minimum cross-section area were correlated with increases in minimum cross-section depth, width, and perimeter. There were weak positive correlation between minimum cross-section depth with minimum cross-section width ($r = 0.45$, $p < 0.01$) and moderate positive correlation with perimeter ($r = 0.65$, $p < 0.01$). Increases in minimum cross-section depth were correlated with increases in minimum cross-section width and increases in minimum cross-section perimeter. There was strong positive correlation between minimum cross-section width and perimeter ($r = 0.89$, $p < 0.01$). Increases in minimum cross-section width were strongly correlated with increases in minimum cross-section perimeter. There were no statistically significant correlations between gender with BMI, risk for OSA, neck circumference, and oropharyngeal airway dimensions. There were no statistically significant correlations between BMI with risk for OSA and all oropharyngeal airway dimensions. There were no statistically significant correlations between risk for OSA with neck circumference and all oropharyngeal airway dimensions. There were no statistically significant correlations between neck circumference and oropharyngeal airway dimensions.

Table 8

Correlations Among and Descriptive Statistics for Variables in Vertical Normodivergent Group

	M (*SD*)	Gender	BMI Cat	Risk for OSA	NC (in)	Total Vol (cc)	MinCSA (mm^2)	Depth (mm)	Width (mm)	Perimeter (mm)
Gender	1.56 (.50)	___								
BMI Cat	2.40 (.83)	-.205	___							
Risk for OSA	1.12 (.33)	-.045	.045	___						
NC (in)	12.76 (1.40)	-.237	.726**	.099	___					
Total Vol (cc)	7.32 (2.69)	-.026	-.067	-.040	.060	___				
MinCSA (mm^2)	138.20 (69.88)	.085	-.076	-.096	.006	.835**	___			
Depth (mm)	9.17 (2.76)	-.059	.144	-.004	.221	.669**	.745**	___		
Width (mm)	19.50 (6.08)	.213	-.242	-.098	-.143	.743**	.828**	.446**	___	
Perimeter (mm)	50.40 (14.19)	.185	-.112	-.137	-.049	.845**	.925**	.648**	.887**	___

Notes. n = 50. Male = 22, Female = 28. BMI cat = Body Mass Index Categories. NC = neck circumference. Total Vol = total airway volume. MinCSA = minimum cross-section area. ** $p < 0.01$.

CORRELATIONS IN VERTICAL HYPODIVERGENT GROUP

A Pearson's correlation coefficient was computed to assess the relationship between variables within the vertical Hypodivergent group (n = 10) (Table 9). There was a moderate positive correlation between gender and BMI ($r = 0.74$, $p < 0.05$) and minimum cross-section depth ($r = 0.63$, $p < 0.05$). Higher BMI were correlated in males. Increases in minimum cross-section depth were correlated in males. There was a moderate positive correlation between BMI and risk for OSA ($r = 0.74$, $p < 0.05$) and minimum cross-section depth ($r = 0.64$, $p < 0.05$). Increases in BMI were correlated with increases in risk for OSA and minimum cross-section depth. There were moderate positive correlations between total oropharyngeal airway volume and minimum cross-section width ($r = 0.74$, $p < 0.05$). Increases in total oropharyngeal airway volume were correlated with increases in minimum cross-section width. There were moderate positive correlation between minimum cross-section area with minimum cross-section depth ($r = 0.66$, $p < 0.05$), and strong correlations with width ($r = 0.85$, $p < 0.01$), and perimeter ($r = 0.93$, $p < 0.01$). Increases in minimum cross-section area were correlated with increases in minimum cross-section depth, width, and perimeter. There was strong positive correlation between minimum cross-section width and perimeter ($r = 0.89$, $p < 0.01$). Increases in minimum cross-section width were strongly correlated with increases in minimum cross-section perimeter. There were no statistically significant correlations between gender with risk for OSA, neck circumference, total oropharyngeal airway volume, minimum cross-section area, width, and perimeter. There were no statistically significant correlations between BMI with neck circumference, total oropharyngeal airway volume, minimum cross-section area, width, and perimeter. There were no statistically significant correlations between risk for OSA with neck circumference and all oropharyngeal airway dimensions. There were no statistically significant correlations between neck circumference and all oropharyngeal airway dimensions. There were no statistically significant correlations between total oropharyngeal airway volume with minimum cross-section area, depth and perimeter. There were no statistically significant correlations between minimum cross-section depth with width and perimeter.

Table 9

Correlations Among and Descriptive Statistics for Variables in Vertical Hypodivergent Group

	M (*SD*)	Gender	BMI Cat	Risk for OSA	NC (in)	Total Vol (cc)	MinCSA (mm^2)	Depth (mm)	Width (mm)	Perimeter (mm)
Gender	1.40 (.52)	___								
BMI Cat	1.90 (.99)	.736*	___							
Risk for OSA	1.10 (.32)	.408	.742*	___						
NC (in)	12.83 (.76)	-.084	.413	.540	___					
Total Vol (cc)	7.06 (1.89)	-.084	-.316	-.197	.100	___				
MinCSA (mm^2)	123.49 (48.60)	.300	.108	.333	-.129	.553	___			
Depth (mm)	8.12 (2.03)	.633*	.638*	.461	.173	.202	.663*	___		
Width (mm)	20.46 (4.91)	.102	-.199	.001	-.288	.736*	.854**	.374	___	
Perimeter (mm)	50.76 (10.64)	.301	.164	.443	.029	.618	.931**	.598	.888**	___

Notes. n = 10. Male = 6, Female = 4. BMI cat = Body Mass Index Categories. NC = neck circumference. Total Vol = total airway volume. MinCSA = minimum cross-section area. * $p < 0.05$. ** $p < 0.01$.

CORRELATIONS IN VERTICAL HYPERDIVERGENT GROUP

A Pearson's correlation coefficient was computed to assess the relationship between variables within the vertical Hyperdivergent group (n = 26) (Table 10). There was a moderate positive correlation between BMI and neck circumference ($r = 0.60$, $p < 0.01$) and weak positive correlation with minimum cross-section width ($r = 0.39$, $p < 0.05$). Increases in BMI were moderately correlated with increases in neck circumference and weakly correlated with increases minimum cross-section width. There were strong positive correlations between total oropharyngeal airway volume and minimum cross-section area ($r = 0.82$, $p < 0.01$), width ($r = 0.83$, $p < 0.01$), and perimeter ($r = 0.81$, $p < 0.01$). Increases in total oropharyngeal airway volume were strongly correlated with increases in minimum cross-section area, width, and perimeter. There were moderate positive correlation between minimum cross-section area with minimum cross-section depth ($r = 0.54$, $p < 0.01$), strong correlations with width ($r = 0.87$, $p < 0.01$), and perimeter ($r = 0.90$, $p < 0.01$). Increases in minimum cross-section area were correlated with increases in minimum cross-section depth, width, and perimeter. There was strong positive correlation between minimum cross-section width and perimeter ($r = 0.93$, $p < 0.01$). Increases in minimum cross-section width were strongly correlated with increases in minimum cross-section perimeter. There were no statistically significant correlations between gender with BMI, risk for OSA, neck circumference, all oropharyngeal airway dimensions. There were no statistically significant correlations between BMI with risk for OSA, total oropharyngeal airway volume, minimum cross-section area, depth, and perimeter. There were no statistically significant correlations between risk for OSA with neck circumference and all oropharyngeal airway dimensions. There were no statistically significant correlations between neck circumference and all oropharyngeal airway dimensions. There was no statistically significant correlation between total oropharyngeal airway volume with minimum cross-section depth. There was no statistically significant correlation between minimum cross-section depth with width.

Table 10

Correlations Among and Descriptive Statistics for Variables in Vertical Hyperdivergent Group

	M (*SD*)	Gender	BMI Cat	Risk for OSA	NC (in)	Total Vol (cc)	MinCSA (mm^2)	Depth (mm)	Width (mm)	Perimeter (mm)
Gender	1.50 (.51)	___								
BMI Cat	2.27 (.53)	-.074	___							
Risk for OSA	1.23 (.43)	.000	-.282	___						
NC (in)	12.38 (1.22)	-.161	.602**	.034	___					
Total Vol (cc)	6.60 (2.84)	.069	.243	-.134	.224	___				
MinCSA (mm^2)	120.10 (58.86)	-.155	.384	-.107	.361	.817**	___			
Depth (mm)	8.31 (2.54)	-.204	.315	-.200	.323	.247	.538**	___		
Width (mm)	17.85 (6.15)	.045	.394*	-.078	.268	.826**	.867**	.276	___	
Perimeter (mm)	46.68 (12.43)	-.040	.383	-.104	.265	.810**	.904**	.466*	.932**	___

Notes. n = 26. Male = 13, Female = 13. BMI cat = Body Mass Index Categories. NC = neck circumference. Total Vol = total airway volume. MinCSA = minimum cross-section area. * $p < 0.05$. ** $p < 0.01$.

RESEARCH QUESTION 3

Are there correlations between gender, Body Mass Index, risk for obstructive sleep apnea, neck circumference, and oropharyngeal airway dimensions in children and adolescents among the nine craniofacial subgroups? Hypothesis: There are one or more correlations, but not all, between gender, Body Mass Index, risk for obstructive sleep apnea, neck circumference, and oropharyngeal airway dimensions in children and adolescents among the nine craniofacial subgroups. Null hypothesis: There are no correlations between gender, Body Mass Index, risk for obstructive sleep apnea, neck circumference, and oropharyngeal airway dimensions in children and adolescents among the nine craniofacial subgroups. Null hypothesis was rejected. The significant correlations found in this study are described below.

CORRELATIONS IN CLASS I-NORMODIVERGENT SUBGROUP

A Pearson's correlation coefficient was computed to assess the relationship between variables within the Class I-Normodivergent group ($n = 23$) (Table 11). There was a weak negative correlation between neck circumference and gender ($r = -0.45$, $p < 0.05$). Increases in neck circumference were weakly related in male. There was a strong positive correlation between neck circumference and BMI ($r = 0.81$, $p < 0.01$). Increases in BMI were strongly correlated with increases in neck circumference. There were strong positive correlations between total oropharyngeal airway volume with minimum cross-section area ($r = 0.87$, $p < 0.01$), width ($r = 0.81$, $p < 0.01$), perimeter ($r = 0.89$, $p < 0.01$), and moderate correlation with depth ($r = 0.60$, $p < 0.01$). Increases in total airway volume were correlated with increases in minimum cross-section area, depth, width, and perimeter. There were strong positive correlations between minimum cross-section area with minimum cross-section depth ($r = 0.80$, $p < 0.01$), width ($r = 0.83$, $p < 0.01$), and perimeter ($r = 0.94$, $p < 0.01$). Increases in minimum cross-section area were strongly correlated with increases in minimum cross-section depth, width, and perimeter. There were weak positive correlation between minimum cross-section depth with minimum cross-section width ($r = 0.46$, $p < 0.05$) and moderate-positive correlation with minimum cross-section perimeter ($r = 0.66$, $p < 0.01$). There were strong positive correlations between minimum cross-section width and minimum cross-section perimeter ($r = 0.85$, $p < 0.01$). Increases in minimum cross-section width were strongly correlated with increases in minimum cross-section perimeter. There were no statistically significant correlations between gender with BMI, risk for OSA, and all oropharyngeal airway dimensions. There were no statistically significant correlations between BMI with risk for OSA and all oropharyngeal airway dimensions. There were no statistically significant correlations between risk for OSA with neck circumference and all oropharyngeal airway dimensions. There were no statistically significant correlations between neck circumference with all oropharyngeal airway dimensions.

Table 11

Correlations Among and Descriptive Statistics for Variables in Class I-Normodivergent Subgroup

	M (*SD*)	Gender	BMI Cat	Risk for OSA	NC (in)	Total Vol (cc)	MinCSA (mm^2)	Depth (mm)	Width (mm)	Perimeter (mm)
Gender	1.57 (.51)	___								
BMI Cat	2.48 (.85)	-.341	___							
Risk for OSA	1.09 (.29)	-.041	-.178	___						
NC (in)	12.84 (1.63)	-.446*	.807**	.201	___					
Total Vol (cc)	7.61 (2.75)	.244	-.178	.183	-.072	___				
MinCSA (mm^2)	150.51 (77.41)	.238	-.120	.132	-.087	.866**	___			
Depth (mm)	9.43 (2.92)	.078	.240	.202	.266	.599**	.804**	___		
Width (mm)	20.08 (6.10)	.238	-.409	.155	-.335	.805**	.833**	.462*	___	
Perimeter (mm)	52.87 (15.73)	.336	-.148	.060	-.153	.890**	.939**	.663**	.852**	___

Notes. n = 23. Male = 10, Female = 13. BMI cat = Body Mass Index Categories. NC = neck circumference. Total Vol = total airway volume. MinCSA = minimum cross-section area. * $p < 0.05$. ** $p < 0.01$.

CORRELATIONS IN CLASS I-HYPERDIVERGENT SUBGROUP

A Pearson's correlation coefficient was computed to assess the relationship between variables within the Class I-Hyperdivergent group ($n = 12$) (Table 12). There were moderate positive correlations between BMI with neck circumference ($r = 0.67$, $p < 0.05$) and minimum cross-section perimeter ($r = 0.60$, $p < 0.05$). Increases in BMI were moderately correlated with increases in neck circumference and minimum cross-section perimeter. There were moderate positive correlations between neck circumference and minimum cross-section depth ($r = 0.66$, $p < 0.05$). Increases in neck circumference moderately correlated with increases in minimum cross-section depth. There were strong positive correlations between total oropharyngeal airway volume with minimum cross-section area ($r = 0.80$, $p < 0.01$), width ($r = 0.84$, $p < 0.01$), perimeter ($r = 0.79$, $p < 0.01$). Increases in total airway volume were strongly correlated with increases in minimum cross-section area, width, and perimeter. There were moderate positive correlation between minimum cross-section area with minimum cross-section depth ($r = 0.58$, $p < 0.05$), strong correlations with width ($r = 0.91$, $p < 0.01$), and perimeter ($r = 0.93$, $p < 0.01$). Increases in minimum cross-section area were moderately correlated with increases in minimum cross-section depth, and strongly correlated with minimum cross-section width, and perimeter. There were strong positive correlations between minimum cross-section width and minimum cross-section perimeter ($r = 0.95$, $p < 0.01$). Increases in minimum cross-section width were strongly correlated with increases in minimum cross-section perimeter. There were no statistically significant correlations between gender with BMI, risk for OSA, neck circumference, and all oropharyngeal airway dimensions. There were no statistically significant correlations between BMI with risk for OSA and all oropharyngeal airway dimensions. There were no statistically significant correlations between risk for OSA with neck circumference and all oropharyngeal airway dimensions. There were no statistically significant correlations between risk for OSA with neck circumference and all oropharyngeal airway dimensions. There were no statistically significant correlations between neck circumference with total oropharyngeal airway volume, minimum cross-section area, width, and perimeter.

Table 12

Correlations Among and Descriptive Statistics for Variables in Class I-Hyperdivergent Subgroup

	M (*SD*)	Gender	BMI Cat	Risk for OSA	NC (in)	Total Vol (cc)	MinCSA (mm^2)	Depth (mm)	Width (mm)	Perimeter (mm)
Gender	1.58 (.52)	___								
BMI Cat	2.33 (.65)	-.090	___							
Risk for OSA	1.17 (.39)	-.076	-.239	___						
NC (in)	12.63 (1.35)	-.310	.672*	.043	___					
Total Vol (cc)	7.27 (3.45)	-.034	.341	.038	.244	___				
MinCSA (mm^2)	120.89 (69.81)	-.317	.511	.112	.528	.800**	___			
Depth (mm)	8.37 (2.39)	-.401	.388	.009	.662*	.164	.580*	___		
Width (mm)	18.42 (6.59)	-.196	.560	.203	.425	.835**	.905**	.334	___	
Perimeter (mm)	47.14 (13.29)	-.377	.597*	.142	.534	.785**	.925**	.570	.946**	___

Notes. n = 12. Male = 5, Female = 7. BMI cat = Body Mass Index Categories. NC = neck circumference. Total Vol = total airway volume. MinCSA = minimum cross-section area. * $p < 0.05$. ** $p < 0.01$.

CORRELATIONS IN CLASS II-NORMODIVERGENT SUBGROUP

A Pearson's correlation coefficient was computed to assess the relationship between variables within the Class II-Normordivergent group (n = 20) (Table 13). There were weak positive correlations between BMI and risk for OSA ($r = 0.45$, $p < 0.05$) and moderate positive correlations with neck circumference ($r = 0.60$, $p < 0.01$). Increases in BMI were weakly correlated with increases in risk for OSA, while moderately correlated with increases in neck circumference. There were moderate positive correlations between total oropharyngeal airway volume with minimum cross-section area ($r = 0.79$, $p < 0.01$), depth ($r = 0.68$, $p < 0.01$), width ($r = 0.66$, $p < 0.01$), perimeter ($r = 0.79$, $p < 0.01$). Increases in total airway volume were moderately correlated with increases in minimum cross-section area, depth, width, and perimeter. There were moderate positive correlation between minimum cross-section area with minimum cross-section depth ($r = 0.59$, $p < 0.01$), strong correlations with width ($r = 0.82$, $p < 0.01$), and perimeter ($r = 0.88$, $p < 0.01$). Increases in minimum cross-section area were moderately correlated with increases in minimum cross-section depth, and strongly correlated with width, and perimeter. There were moderate positive correlations between minimum cross-section depth and perimeter ($r = 0.55$, $p < 0.05$). Increases in minimum cross-section depth moderately correlated with increases minimum cross-section perimeter. There were strong positive correlations between minimum cross-section width and minimum cross-section perimeter ($r = 0.94$, $p < 0.01$). Increases in minimum cross-section width were strongly correlated with increases in minimum cross-section perimeter. There were no statistically significant correlations between gender with BMI, risk for OSA, neck circumference, and all oropharyngeal airway dimensions. There were no statistically significant correlations between BMI with all oropharyngeal airway dimensions. There were no statistically significant correlations between risk for OSA with neck circumference and all oropharyngeal airway dimensions. There were no statistically significant correlations between neck circumference with all oropharyngeal airway dimensions. There were no statistically significant correlations between minimum cross-section depth and width.

Table 13

Correlations Among and Descriptive Statistics for Variables in Class II-Normodivergent Subgroup

	M (*SD*)	Gender	BMI Cat	Risk for OSA	NC (in)	Total Vol (cc)	MinCSA (mm^2)	Depth (mm)	Width (mm)	Perimeter (mm)
Gender	1.55 (.51)	—								
BMI Cat	2.20 (.77)	-.161	—							
Risk for OSA	1.15 (.37)	.099	.449*	—						
NC (in)	12.69 (1.11)	-.098	.600**	.250	—					
Total Vol (cc)	6.92 (2.66)	-.334	-.005	-.019	.198	—				
MinCSA (mm^2)	126.22 (62.50)	-.147	-.071	-.131	.005	.790**	—			
Depth (mm)	8.74 (2.61)	-.386	-.005	.060	.041	.680**	.589**	—		
Width (mm)	18.78 (6.25)	.164	-.028	-.135	.082	.658**	.816**	.288	—	
Perimeter (mm)	48.32 (12.40)	-.007	-.073	-.127	-.002	.788**	.882**	.545*	.936**	—

Notes. n = 20. Male = 9, Female = 11. BMI cat = Body Mass Index Categories. NC = neck circumference. Total Vol = total airway volume. MinCSA = minimum cross-section area. * $p < 0.05$. ** $p < 0.01$.

CORRELATIONS IN CLASS II-HYPERDIVERGENT SUBGROUP

A Pearson's correlation coefficient was computed to assess the relationship between variables within the Class II-Hyperdivergent group (n= 12) (Table 14). There were strong positive correlations between total oropharyngeal airway volume with minimum cross-section area ($r = 0.93$, $p < 0.01$), width ($r = 0.87$, $p < 0.01$), perimeter ($r = 0.91$, $p < 0.01$). Increases in total airway volume were strongly correlated with increases in minimum cross-section area, width, and perimeter. There were strong positive correlations between minimum cross-section area with minimum cross-section width ($r = 0.92$, $p < 0.01$) and perimeter ($r = 0.95$, $p < 0.01$). Increases in minimum cross-section area were strongly correlated with increases in minimum cross-section width and perimeter. There were strong positive correlations between minimum cross-section width and minimum cross-section perimeter ($r = 0.97$, $p < 0.01$). Increases in minimum cross-section width were strongly correlated with increases in minimum cross-section perimeter. There were no statistically significant correlations between gender with BMI, risk for OSA, neck circumference, and all oropharyngeal airway dimensions. There were no statistically significant correlations between BMI with risk for OSA, neck circumference, and all oropharyngeal airway dimensions. There were no statistically significant correlations between risk for OSA with neck circumference and all oropharyngeal airway dimensions. There were no statistically significant correlations between neck circumference with all oropharyngeal airway dimensions. There were no statistically significant correlations between total oropharyngeal airway volume and minimum cross-section depth. There were no statistically significant correlations between minimum cross-section area and depth. There were no statistically significant correlations between minimum cross-section depth with width and perimeter.

Table 14

Correlations Among and Descriptive Statistics for Variables in Class II-Hyperdivergent Subgroup

	M (*SD*)	Gender	BMI Cat	Risk for OSA	NC (in)	Total Vol (cc)	MinCSA (mm^2)	Depth (mm)	Width (mm)	Perimeter (mm)
Gender	1.33 (.49)	—								
BMI Cat	2.25 (.45)	.000	—							
Risk for OSA	1.33 (.49)	.250	-.408	—						
NC (in)	12.33 (1.12)	.110	.449	-.014	—					
Total Vol (cc)	5.74 (2.22)	-.031	.061	-.214	.254	—				
MinCSA (mm^2)	114.33 (50.41)	-.122	.240	-.292	.232	.931**	—			
Depth (mm)	8.20 (2.56)	-.125	.323	-.377	.007	.410	.458	—		
Width (mm)	16.88 (6.28)	.173	.210	-.238	.166	.868**	.916**	.341	—	
Perimeter (mm)	43.97 (11.52)	.042	.226	-.192	.161	.914**	.952**	.477	.967**	—

Notes. n = 12. Male = 8, Female = 4. BMI cat = Body Mass Index Categories. NC = neck circumference. Total Vol = total airway volume. MinCSA = minimum cross-section area. ** $p < 0.01$.

ELIMINATION OF SUBGROUPS

The total sample sizes for Class I-Hypodivergent group (n = 3) (Table 15), Class II-Hypodivergent group (n = 3) (Table 16), Class III-Normodivergent group (n = 7) (Table 17), Class III-Hypodivergent group (n = 4) (Table 18), Class III-Hyperdivergent group (n = 2) (Table 19) were too low, therefore Pearson's correlation coefficients yielded no significant correlation (Appendix F). These five subgroups were excluded in the analysis.

CHAPTER 5 DISCUSSIONS AND CONCLUSION

INTRODUCTION

Evaluation of the airway is an essential and powerful diagnostic step in the appropriate diagnosis, treatment planning, and management of airway abnormalities. Multiple 2-D and 3-D studies have performed to demonstrate the relationships between upper airway structures and different dentofacial patterns (El & Palomo, 2011; Joseph *et al.*, 1998; Freitas *et al.*, 2006; Tso *et al.*, 2009; Aboudara, *et al.*, 2003; Aboudara *et al.* 2009; Lenza *et al.*, 2010; Grauer *et al.*, 2009; Hong *et al.*, 2011). CBCT is more advantageous over 2-D radiography because it is a much more accurate representation of anatomic structures in 3-D. This ultimately gives the clinician a clear and better understanding of the structures being evaluated. Accordingly CBCT has been widely accepted for use in clinical orthodontics. Measurements from CBCTs are reliable and accurate compared to manual measurements (Ghoneima & Kula, 2011). The use of CBCT imaging for the assessment of the airway can provide clinically useful information in orthodontics (Ghoneima & Kula, 2011).

To date, true upper airway volume, minimum cross-sectional area and its dimensions are not well established. Secondly, the correlation of upper airway dimensions to their respective craniofacial patterns is not well known. Thirdly, the association between these variables with BMI and neck circumference is of importance when evaluating children and adolescents clinically. Early identification and management of airway problems in children may prevent or minimize the sequelae and adverse dental implications of obstructive sleep apnea. The purpose of this retrospective, cross-sectional pilot study is to correlate the 3-D oropharyngeal airway dimensions, BMI, neck circumference, risk for OSA, and gender in children and adolescents with different antero-posterior and vertical craniofacial patterns. This investigation aims to determine whether patients with certain craniofacial skeletal patterns are predisposed to upper airway obstruction.

DISCUSSIONS

Our study was limited to a total of 86 pre-treatment orthodontic records obtained from the UNLV School of Dental Medicine's archival dental records from June 2012 through June 2013. Cephalometric tracings were used to classify subjects into one of three AP Classes (I, II, and III) by having at least three out of five AP cephalometric parameters based on the standard values. Additionally, each subject was classified into one of three vertical classes (Normodivergence, Hypodivergence, and Hyperdivergence) by having at least three out of five vertical cephalometric parameters based on the standard values. Three parameters were used to minimize misclassification.

Most children with OSA are at the age of 2-10 years. This coincides with the adenotonsillar lymphatic tissue growth period (Scammon *et. al.*, 1930; Cataletto *et al.*, 2011). Lymphoid and adenoid have reached their maximum size by age 16 (Scammon *et. al.*, 1930). Many orthodontic patients are of this age group.

When treating OSA, improving the most constrictive point in the airway is more equally important as improving the overall total volume (Lenza *et al.*, 2010). Since the airway is extremely variable depending on head posture, breathing stage, craniofacial morphology and airway muscle tension, airway volume alone does not accurately depict true airway morphology (Lenza *et al.*, 2010). It seems best to analyze the airway using linear measurements, area and volume together. From our results there are general consistent patterns of strong positive correlations among the 3-D oropharyngeal airway dimensions for most AP groups, vertical groups, and AP-vertical subgroups. For all three AP groups, there were statistically significant correlations between all five oropharyngeal airway dimensions. This is anticipated as we expect increases in total airway volume there would be increases in minimum cross-section area, depth, width, and perimeter. This finding is similar to that of a previous study that found high correlation between total oropharyngeal airway volume and minimum cross-section area in normal Class I adults (*Tso et al.*, 2009). Our study showed strong correlations between total volume and minimum cross-section area, depth, width, and perimeter in all AP classes and Normodivergent group, but not in Hypodivergent and Hyperdivergent groups. The Hypodivergent group showed only strong correlation between total volume with minimum cross-section width while the Hyperdivergent group has strong correlations between total volume with minimum cross-section area, width and perimeter. These findings are in contrast to another study, where weak correlations exist between total oropharyngeal airway volume and minimum cross-section area, depth, and width (Lenza *et al.*, 2010). We found a trend with higher positive correlation between minimum cross-section area with lateral width than with AP depth. This is in support by a study where they found significant correlation between minimum cross-section areas with airway width, suggesting lateral width is more important than AP depth (Iwasaki *et al.*, 2009). But this is in contrast for Class III group and Class III-Normodivergent subgroup, which have higher correlation in depth than width. This may be due to the more anteriorly positioned mandible in Class III craniofacial patterns. Detailed knowledge of the airway dimensions gives a better understanding of the anatomical characteristics of the upper airway. This knowledge could lead to an improvement of diagnosis and treatment (McNamara, 1981; Lenza *et al.*, 2010; McCrillis *et al.*, 2009).

The relationship of the narrowest cross-section airway configuration between OSA and non-OSA groups has been previously described. OSA adult patients present with higher BMI, lower total upper airway volume, and the minimum cross-section segment is significantly smaller in depth and minimum cross-section area (Ogawa *et al*., 2007). However, another study found no difference in minimum cross-section airway dimensions between OSA and control groups (Shigeta *et al.*, 2008). It has also been shown that OSA patients have significantly higher BMI and thicker neck size than the control group independent of their craniofacial pattern (Hoffstein and Mateika, 1992; Ogawa *et al.*, 2005; Ogawa *et al.*, 2007). In contrast, our study failed to demonstrate any strong relationships between risk for OSA and neck circumference, risk for OSA and all oropharyngeal airway dimensions in different craniofacial patterns. The only exceptions were the vertical Hypodivergent group which showed moderate positive correlation between risk for OSA and BMI with the sample size of ten, and a weak correlation within the II-Normodivergent subgroup with the sample size of twenty. We evaluated the risk for OSA using the modified Epworth Sleepiness scale (Rosenthal & Dolan, 2008). This sleep questionnaire is a self-reported assessment to screen for the manifestations of OSA and has often been used routinely in adult patients (Rosenthal & Dolan, 2008). However, a prior study found that the Epworth Sleepiness Scale does not significantly reflect the levels of sleepiness in patients suspected or confirmed to have sleep-disordered breathing and that the scale should be interpreted cautiously (Chervin & Aldrich, 1999). Perhaps the lack of correlation in this study may be in part due to this young group of patients not accurately responding to the sleep questionnaire because they did not understand the questions. The lack of any relationships between risk for OSA and neck circumference, risk for OSA and all oropharyngeal airway dimensions in different craniofacial patterns could be due to the small sample size in each group, therefore did not give adequate power in our analysis. Additionally, our sample comprised of only children and adolescents in the healthy weight category. There was inadequate sample size of large neck circumference and high BMI category. Further investigation with risk for OSA is warranted with larger sample size, larger neck circumference, and higher BMI category; in addition to implementing one investigator to conduct the modified Epworth Sleepiness Scale.

We found moderate to strong correlation between BMI and neck circumference among different craniofacial patterns except for the Hypodivergent group. This finding is anticipated since a higher BMI value generally corresponds to an increase in neck circumference. Previous study found that neck circumference is an important factor along with higher BMI and the male sex in OSA patients (Enciso *et al.,* 2010). We found moderate to strong correlations between BMI and neck circumference among some but not all groups. Our data may not correlate well because patients were young children and adolescents with average BMI within the healthy weight category. There was no large sample of patients in the obese category. Thus, further investigation is necessary with larger scale of sample size in the higher BMI category.

It has been reported that no correlation exist between BMI and upper airway size, BMI and airway volume, BMI and minimum cross-section depth; while significant correlations exist between BMI and minimum cross-section area, and BMI and minimum cross-section width (Ferguson *et al.*, 1995; Ogawa *et al.*, 2007). This is consistent with our general findings, except for the Hypodivergent group which demonstrated moderate correlation between BMI and minimum cross-section depth, but no correlation with width. In addition, there was a weak positive correlation between BMI and minimum cross-section width in the Hyperdivergent group; this is a similar finding to prior studies (Ferguson *et al.*, 1995; Ogawa *et al.*, 2007). MRI studies showed larger tongue, parapharyngeal-fat pads and lateral pharyngeal walls in apneic patients with high body mass index (Schwab, 1998). This indicates that apneic patients with high BMI have narrower lateral airway width. However our finding of a weak positive correlation between BMI and minimum cross-section width in the Hyperdivergent group is in contrast to this report. However, some non-obese apneic patients may have craniofacial abnormalities that contribute to their apnea, such as small retrognathic mandible (reduced mandibular body length), retrognathic maxilla, narrow posterior airway space, and inferiorly positioned hyoid bone (Hoffstein & Mateika, 1992; Ferguson *et al.*, 1995; Schwab, 1998). While these studies only assessed the antero-posterior craniofacial dimensions, our study found a variation in the Hypodivergent group which has not shown in previous studies. This suggests that further analysis is needed in these groups with larger sample size in higher BMI category.

Overall, there were no statistically significant correlations between gender and risk for OSA, gender and neck circumference, and gender and airway dimensions in most groups; with the exception of the Hypodivergent group which showed moderate correlation between gender and BMI categories, and gender and minimum cross-section depth. These moderate relationships indicate higher BMI and larger minimum cross-section depth in males, which are in contrast to prior studies that showed correlation between BMI and airway minimum cross-section width (Ferguson *et al.*, 1995; Ogawa *et al.*, 2007). Our lack of correlation between gender and airway dimensions is inconsistent with a previous study which observed larger airway volume associated with males compared to females (Grauer *et al.*, 2009). Additionally, we found a weak negative correlation between gender and neck circumference in AP Class I group and Class I-Normodivergent subgroup, indicating larger neck circumference are found in males. This is consistent partly with previous study showing OSA patients were mainly older male, larger neck circumference and higher BMI than snorers (Enciso *et al.*, 2010). Our findings must be taken with caution due to the small sample size. Further investigation with larger sample is indicated prior to formulating definitive conclusions. However, some non-obese apneic patients may have craniofacial abnormalities that contribute to their apnea, such as small retrognathic mandible (reduced mandibular body length), retrognathic maxilla, narrow posterior airway space, and inferiorly positioned hyoid bone (Hoffstein & Mateika, 1992; Ferguson *et al.*, 1995; Schwab, 1998).

It is surprising that we did not find strong correlations between neck circumference and airway dimensions in most groups. Since most patients with OSA are overweight and typically have a short, thick neck, a neck circumference greater than 16 inches in a female adult or greater than 18 inches in a male adult correlates with an increased risk for the disorder (Davies & Stradling, 1990). This may be due to fat tissue deposition in the neck causing narrowing of the airway (Hoffstein & Mateika, 1992). There was a weak positive correlation between neck circumference and minimum cross-section depth only within the AP Class I group and a moderate positive correlation within the Class I-Hyperdivergent subgroup. Since our sample comprised of young children and adolescents with small neck size, it is not surprising to have no or weak correlation of neck circumference with airway dimensions. A larger sample size of patients with larger neck circumference is needed to further investigate this relationship.

The location of the minimum cross-section area actually varies within the selected region of interest. This approach differs from a method that uses a single axial slice at the specific level of the anterior-inferior corner of the second cervical vertebra. The justification of using this level is that it is readily reproducible. Therefore, the software identifies the specific slice with the smallest cross-section area, which could be at any level within the selected region of interest. Although this smallest cross-section area is an inconsistent anatomic landmark, this method actually gives more accurate representation as airway variability is common, especially in diseases or positional changes of the tongue (Shigeta *et al.*, 2008). Therefore, more relevant assessments and relationships can be determined.

LIMITATIONS

In addition to what have been discussed in previous section, there are additional notable limitations. BMI and Epworth Sleepiness Scale are both crude tools to measure a complex physiologic problem. Polysomnogram and MRI studies are more accurate airway assessments. Our study has limited sample with high BMI category and large neck circumference, which may have contributed to inadequate correlations between variables. Moreover, there may be possible unknown mechanisms related between the variables. Subjects are limited to patients in the dental records archive from UNLV School of Dental Medicine, which are not representative of the entire population at large.

Therefore, our finding cannot be assumed to be true for entire population. CBCT scans are taken with patients sitting upright instead of in supine position. This depends on the CBCT device as certain model requires patient to be in supine position as it is closely resemble sleeping position. The supine position provides incomplete representation of the upper airway, but may be more closely related to the sleeping position, as OSA normally occurs during sleep. The position of oropharyngeal structures change in response to gravity. The locations of key anatomical landmarks changed in patients sitting upright (from CBCT scans) versus the supine position (from MDCT) (Sutthiprapaporn *et al.*, 2008). The soft palate, epiglottis, and opening of esophagus all moved caudally (downward) when changed from supine to upright position, and posteriorly when changed from upright to supine position. Additionally the hyoid bone moved downward when changed from supine to upright position only. These authors found that the cross-sectional area in the upright position was larger than in the supine position. These findings imply that changes in airway and related soft tissues are due to gravity and posture (Sutthiprapaporn *et al.*, 2008). CBCT scans may have artifacts depending on machine calibration. This possibly contributes to error in performing 3-D cephalometric measurements and airway measurements.

FUTURE STUDIES

Assessment of the upper airway volume and shape in adolescents and adults with different facial patterns shows that both airway volume and shape vary amongst different antero-posterior jaw relationships, whereas airway shape differs with various vertical jaw relationships (Grauer *et al.*, 2009). This indicates a correlational study between airway shapes with various vertical jaw dimensions. The correlation of airway dimensions with sleep study in children and adolescents is warranted since physiology of the airway has an important role. Furthermore, correlation of the upper airway dimensions and cross-section area measured specifically at the level of the second cervical vertebrae in children and adolescents is another possible future study. This is considered to be a relatively consistent anatomic location that will not change with time; therefore, it is readily reproducible. Additionally, it is possible to conduct a correlational study like our but the older age group as there is still limited knowledge for this age group with different craniofacial patterns. Anatomic changes occur from supine to sitting upright position, such as the hyoid bone moved downward when changed from supine to upright position only (Sutthiprapaporn *et al.*, 2008). Thus, it is possible to determine the correlation of airway dimensions, cross-sectional shapes, position of the hyhoid bone, and position of the larynx in different craniofacial skeletal patterns of children and adolescents. Gastro-esophageal reflux disorder (GERD) is also known to associate with obstructive sleep apnea in adults (Orr, n.d.). Another possible study is correlating airway dimensions with GERD in children and adolescents.

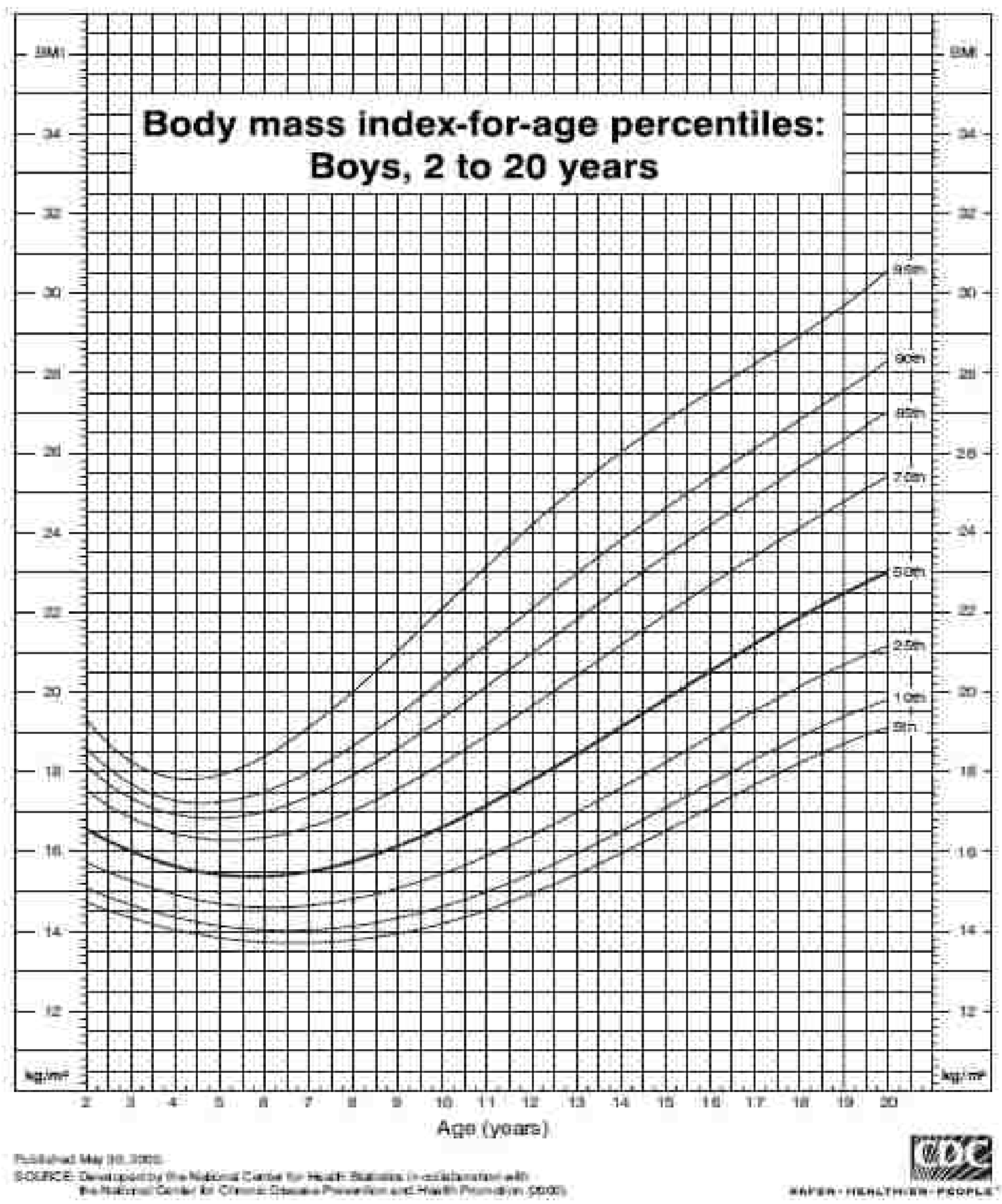
CONCLUSION

The purpose of our retrospective, cross-sectional pilot study was to correlate the 3-D oropharyngeal airway dimensions, BMI, neck circumference, risk for OSA, and gender in children and adolescents with different antero-posterior and vertical craniofacial patterns. This investigation aimed to determine whether patients with certain skeletal deficiencies are predisposed to upper airway obstruction. Early identification and management of airway problems in children and adolescents may prevent or minimize the sequelae and adverse dental implications of obstructive sleep apnea. Our small, young groups of sample were mainly in the healthy weight category with normal size neck circumference. Therefore, this limited our overall findings. Currently, sleep disorders are not well researched and understood. Long-term goal of our study is to further investigate this study in larger sample size taken into considerations predisposing factors (i.e. abnormal neural regulation and intrinsic muscle weakness) and pathologic conditions (allergies, polyps, and tumors). The physiology of the airway, influenced by these confounding factors, has an essential role in determining whether patients with certain skeletal deficiencies are predisposed to upper airway obstruction. Sleep apnea is a complex phenomenon that warrants further research regarding the physiology and anatomy of the airway and craniofacial structures.

APPENDIX A

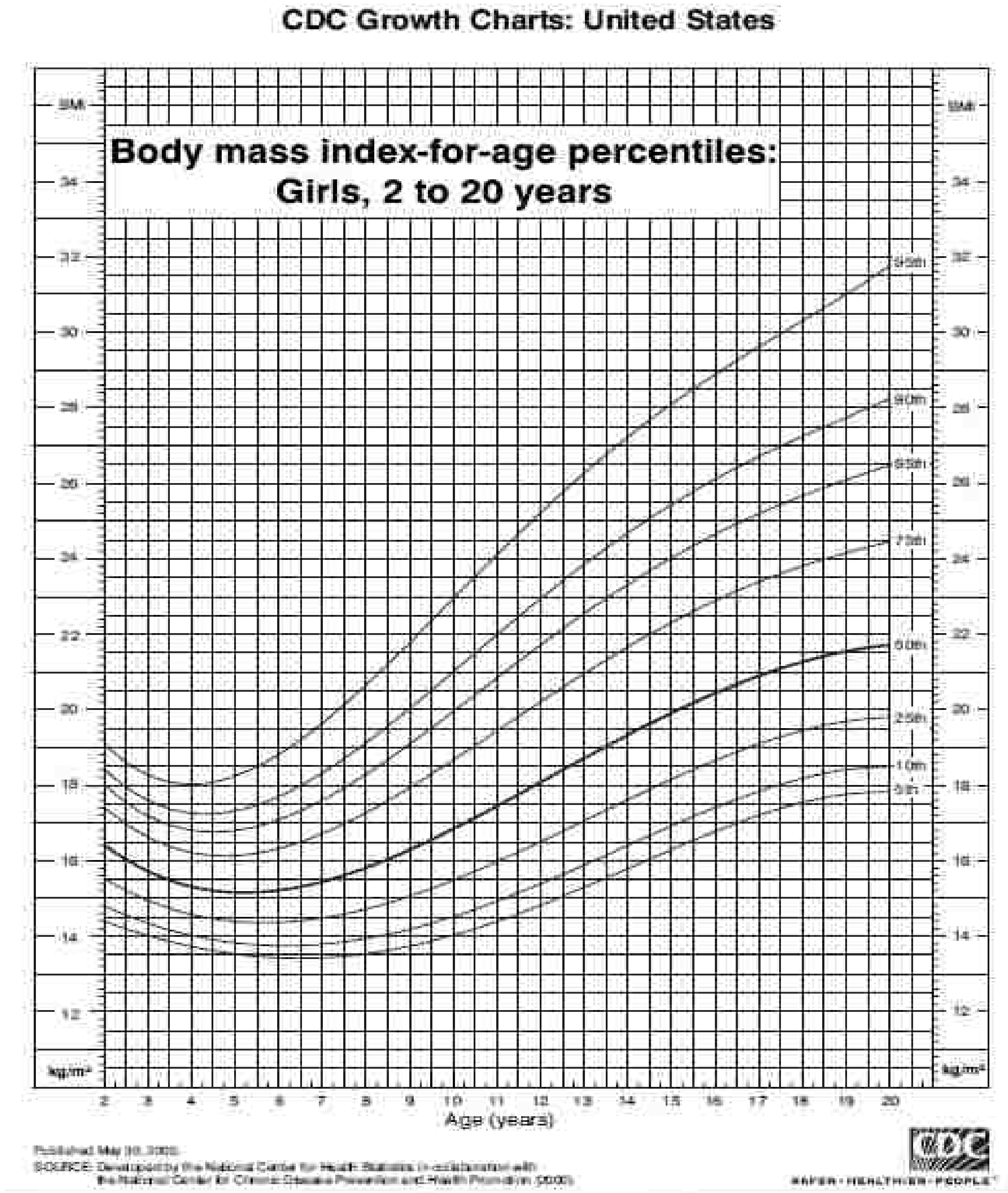
BOYS CDC BMI-FOR-AGE CHART

CDC Growth Charts: United States



APPENDIX B

GIRLS CDC BMI-FOR-AGE CHART



APPENDIX C

UNLV INSTITUTIONAL REVIEW BOARD APPROVAL

UNLV
UNIVERSITY OF NEVADA LAS VEGAS

Biomedical IRB – Exempt Review
Deemed Exempt

DATE: June 19, 2012

TO: **Dr. James Mah,** School of Dental Medicine

FROM: Office of Research Integrity – Human Subjects

RE: Notification of IRB Action
Protocol Title: Airway Analysis of Archival Dental Records
Protocol# 1204-4115M

This memorandum is notification that the project referenced above has been reviewed as indicated in Federal regulatory statutes 45CFR46 and deemed exempt under 45 CFR 46.101(b)4.

Any changes to the application may cause this project to require a different level of IRB review. Should any changes need to be made, please submit a **Modification Form**. When the above-referenced project has been completed, please submit a **Continuing Review/Progress Completion report** to notify ORI – HS of its closure.

If you have questions or require any assistance, please contact the Office of Research Integrity - Human Subjects at IRB@unlv.edu or call 895-2794.

APPENDIX D

THE EPWORTH SLEEPINESS SCALE

Name: ______________________________
Today's date: ______________ Your age (years): ________
Your sex (male = M; female = F): ______________

How likely are you to doze off or fall asleep in the following situations, in contrast to feeling just tired? This refers to your usual way of life in recent times. Even if you have not done some of these things recently try to work out how they would have affected you. Use the following scale to choose the *most appropriate number* for each situation:

0 = would *never* doze
1 = *slight* chance of dozing
2 = *moderate* change of dozing
3 = *high* chance of dozing

Situation	**Chance of dozing**
Sitting and reading	______
Watching TV	______
Sitting, inactive in a public place (e.g. a theater or a meeting)	______
As a passenger in a car for an hour without a break	______
Lying down to rest in the afternoon when circumstances permit	______
Sitting and talking to someone	______
Sitting quietly after a lunch without alcohol	______
In a car, while stopped for a few minutes in the traffic	______

Thank you for your cooperation

(Johns, 2000)

APPENDIX E

THE MODIFIED EPWORTH SLEEPINESS SCALE

Please Answer the following questions concerning your health:

Y N I have recently gained weight.
Y N I was told I have high blood pressure.
Y N I use high blood pressure medications.
Y N I take anti-depressants.
Y N I use sleep medications.
Y N I use oxygen at night.
Y N I use medications to help me breathe.
Y N I have a regular sleep/wake pattern.

The following questions are designed to identify a sleep problem. Choose the most appropriate number for each situation. A score of 10 or more indicates the possibility of a sleep disorder and should be discussed with your physician or dentist.

Epworth Scale

0= Never 2= Moderate Chance
1= Slight Chance 3=Regularly

In contrast to feeling tired, are you likely to doze or fall asleep in the following situations?

_____ Sitting & Reading?
_____ Watching Television?
_____ Sitting inactive in a public place (i.e. theater)?
_____ Passenger in a car for an hour without a break?
_____ Lying down to rest in the afternoon?
_____ Sitting and talking to someone?
_____ Sitting quietly after lunch?
_____ In a car while stopped for a few minutes in traffic?

_______ **Total Score**

APPENDIX F

ELIMINATION OF FIVE SUBGROUPS

Table 15

Correlations Among and Descriptive Statistics for Variables in Class I-Hypodivergent Subgroup

	M (*SD*)	Gender	BMI Cat	Risk for OSA	NC (in)	Total Vol (cc)	MinCSA (mm^2)	Depth (mm)	Width (mm)	Perimeter (mm)
Gender	1.67 (.58)	___								
BMI Cat	2.33 (.58)	.500	___							
Risk for OSA	1.00 (.00)	.a	.a	___						
NC (in)	12.75 (.66)	-.655	.327	.a	___					
Total Vol (cc)	7.87 (.90)	.064	-.832	.a	-.796	___				
MinCSA (mm^2)	124.87 (45.24)	-.093	-.909	.a	-.692	.988	___			
Depth (mm)	8.88 (.77)	-.220	.735	.a	.881	-.988	-.951	___		
Width (mm)	21.22 (4.15)	-.058	-.894	.a	-.716	.992	.999*	-.961	___	
Perimeter (mm)	50.85 (7.11)	.006	-.863	.a	-.760	.998*	.995	-.977	.998*	___

Notes. n = 3. Male = 1, Female = 2. BMI cat = Body Mass Index Categories. NC = neck circumference. Total Vol = total airway volume. MinCSA = minimum cross-section area. * $p < 0.05$. a. Cannot be computed because at least one of the variables is constant.

Table 16

Correlations Among and Descriptive Statistics for Variables in Class II-Hypodivergent Subgroup

	M (*SD*)	Gender	BMI Cat	Risk for OSA	NC (in)	Total Vol (cc)	MinCSA (mm^2)	Depth (mm)	Width (mm)	Perimeter (mm)
Gender	1.00 (.00)	___								
BMI Cat	1.00 (.00)	.[a]	___							
Risk for OSA	1.00 (.00)	.[a]	.[a]	___						
NC (in)	12.67 (1.04)	.[a]	.[a]	.[a]	___					
Total Vol (cc)	7.00 (1.49)	.[a]	.[a]	.[a]	.804	___				
MinCSA (mm^2)	97.7 (26.28)	.[a]	.[a]	.[a]	-.888	-.440	___			
Depth (mm)	5.89 (.42)	.[a]	.[a]	.[a]	-.959	-.940	.720	___		
Width (mm)	19.86 (5.24)	.[a]	.[a]	.[a]	-.437	.184	.802	.163	___	
Perimeter (mm)	47.48 (8.38)	.[a]	.[a]	.[a]	-.351	.274	.743	.071	.996	___

Notes. n = 3. Male = 3, Female = 0. BMI cat = Body Mass Index Categories. NC = neck circumference. Total Vol = total airway volume. MinCSA = minimum cross-section area. [a]. Cannot be computed because at least one of the variables is constant.

Table 17

Correlations Among and Descriptive Statistics for Variables in Class III-Normodivergent Subgroup

	M (*SD*)	Gender	BMI Cat	Risk for OSA	NC (in)	Total Vol (cc)	MinCSA (mm^2)	Depth (mm)	Width (mm)	Perimeter (mm)
Gender	1.57 (.54)	___								
BMI Cat	2.71 (.95)	.047	___							
Risk for OSA	1.14 (.38)	-.471	-.331	___						
NC (in)	12.68 (1.48)	.219	.813*	-.501	___					
Total Vol (cc)	7.50 (2.81)	-.078	-.037	-.643	.237	___				
MinCSA (mm^2)	131.97 (66.62)	.123	-.091	-.647	.376	.851*	___			
Depth (mm)	9.57 (2.83)	.343	.021	-.723	.426	.866*	.922**	___		
Width (mm)	19.64 (6.20)	.274	-.432	-.629	.019	.759*	.885**	.812*	___	
Perimeter (mm)	48.28 (14.35)	.129	-.204	-.702	.245	.848*	.958**	.853*	.953**	___

Notes. n = 7. Male = 3, Female = 4. BMI cat = Body Mass Index Categories. NC = neck circumference. Total Vol = total airway volume. MinCSA = minimum cross-section area. * $p < 0.05$. ** $p < 0.01$.

Table 18

Correlations Among and Descriptive Statistics for Variables in Class III-Hypodivergent Subgroup

	M (*SD*)	Gender	BMI Cat	Risk for OSA	NC (in)	Total Vol (cc)	MinCSA (mm^2)	Depth (mm)	Width (mm)	Perimeter (mm)
Gender	1.50 (.57)	—								
BMI Cat	2.25 (1.26)	.688	—							
Risk for OSA	1.25 (.50)	.577	.927	—						
NC (in)	13.00 (.82)	.000	.649	.816	—					
Total Vol (cc)	6.50 (2.76)	-.272	-.470	-.121	.044	—				
MinCSA (mm^2)	141.80 (64.39)	.299	-.010	.287	.140	.833	—			
Depth (mm)	9.23 (2.16)	.653	.291	.482	.128	.545	.917	—		
Width (mm)	20.33 (6.45)	.120	-.282	.014	-.067	.917	.962*	.809	—	
Perimeter (mm)	53.15 (15.51)	.367	.177	.474	.320	.754	.979*	.933	.888	—

Notes. n = 4. Male = 2, Female = 2. BMI cat = Body Mass Index Categories. NC = neck circumference. Total Vol = total airway volume. MinCSA = minimum cross-section area. * $p < 0.05$.

Table 19

Correlations Among and Descriptive Statistics for Variables in Class III-Hyperdivergent Subgroup

	M (*SD*)	Gender	BMI Cat	Risk for OSA	NC (in)	Total Vol (cc)	MinCSA (mm^2)	Depth (mm)	Width (mm)	Perimeter (mm)
Gender	2.00 (.00)	___								
BMI Cat	2.00 (.00)	.[a]	___							
Risk for OSA	1.00 (.00)	.[a]	.[a]	___						
NC (in)	11.25 (.35)	.[a]	.[a]	.[a]	___					
Total Vol (cc)	7.75 (.35)	.[a]	.[a]	.[a]	1.000**	___				
MinCSA (mm^2)	149.95 (53.39)	.[a]	.[a]	.[a]	1.000**	1.000**	___			
Depth (mm)	8.61 (5.06)	.[a]	.[a]	.[a]	1.000**	1.000**	1.000**	___		
Width (mm)	20.31 (2.68)	.[a]	.[a]	.[a]	-1.000**	-1.000**	-1.000**	-1.000**	___	
Perimeter (mm)	60.23 (.33)	.[a]	.[a]	.[a]	1.000**	1.000**	1.000**	1.000**	-1.000**	___

Notes. n = 2. Male = 0, Female = 2. BMI cat = Body Mass Index Categories. NC = neck circumference. Total Vol = total airway volume. MinCSA = minimum cross-section area. ** $p < 0.01$. [a]. Cannot be computed because at least one of the variables is constant.

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