Department of Orthodontics

A 3D AIRWAY ASSESSMENT OF 12-13 YEAR OLD SUBJECTS.

by

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Abstract

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The main objective of this study was to develop a method to measure the nasal passage and oropharyngeal airway three-dimensionally using Cone Beam CT, and to report the volumes for 12 and 13 year old individuals seeking orthodontic treatment. The Hitachi CB Mercuray (Hitachi Medical Systems America Co. - Twinsburg, OH) was used to scan 200 individuals seeking orthodontic treatment during "records week" at Case Western Reserve School of Dental Medicine as part of routine diagnostic records. Using the View Point software (Ortho Computer Systems, Inc. - Ames, Iowa), a list was compiled of all active patients ages 12-13 who had records taken during "records week 2006". The first 100 individuals from this list were selected for this study. A custom program named Ortho CT Dent Application was used to measure airway volume from the CBCT images. All other data was collected from the patient's record and View Point software. The oropharyngeal and nasal passage airways were measured by painting the pre-defined area slice-by-slice. The Ortho

Segment feature of the Ortho CT Dent Application program then automatically calculated the volume of the painted airway.

The average volume of the oropharynx was 8183.25 mm^3 for 12 year olds and 7818.84 mm^3 for 13 year olds. The average volume of the nasal passage was 4753.48 mm^3 for 12 year olds and 4368.50 mm^3 for 13 year olds. The average oropharyngeal airway volumes ranged from 2040 mm^3 to 18505.81 mm^3 for 12 year olds and from 3126.42 mm^3 to 17581.86 mm^3 for 13 year olds. The nasal passage volume ranged from 522.32 mm^3 to 15601.01 mm^3 for 12 year olds and from 1035.23 mm^3 to 10632.72 mm^3 for 13 year olds. Intraoperator analysis of the CBCT measurements showed good correlation for both oropharyngeal volume ($r > .97$) and nasal passage volume ($r > .96$). No statistically significant difference was found between oropharyngeal airway or nasal passage volume in 12 and 13 year old individuals.

DEDICATION

This thesis is dedicated to:

My husband Daniel, I can't imagine life without you. Thank you for your unwavering support and for constantly reminding me to enjoy life in the present rather than getting lost in continually focusing on the future.

My parents, Veta, Wendell and Marilyn, thank you for always believing in me and encouraging me to aim high. I owe all that I am to you.

My in-laws "'rents", Catherine and Robert, you have always treated me like one of your own, supported me like one of your own, and believed in me like one of your own. I am so lucky to have a mother and father-in-law like you.

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Thank you to Dr. Martin Palomo for your guidance during not only this thesis process but also in my training in orthodontics. I have learned so much from you and am so grateful to have you as my advisor.

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Thank you to my "big sister" Alika and my "big brother" Boyd. I would not be the same without the two of you. Thank you for always being there for me when I needed help even after you two graduated from the program.

To my classmates, Kurt, Cynthia and Vandy, you've always been there to listen when I needed someone to talk to. I wish you all nothing but the best in the future and hope that graduation is not the last time we will all be together.

To my little sisters and brothers, Monica, Lisa, Nikos, David, and John, thanks for being so cool and making this past year of residency fun. I've had a great time being a student teacher and hope that you've all enjoyed having me as a big sister.

To the entire full-time and part-time orthodontic faculty, thank you so much for all of your time and effort. You are an amazing group of people and I have had a great time learning from you.

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LITERATURE REVIEW

Airway and Craniofacial Morphology:

Previous literature has shown that there is a significant relationship between pharyngeal structures and craniofacial morphology (Drummond, 1968). It has been hypothesized that chronic nasal obstruction causes mouth breathing which leads to "long face syndrome" in which a patient exhibits with an increased lower facial height, lip incompetency, maxillary transverse deficiency and vertical maxillary excess, suggesting that the oropharyngeal airway has an effect on the growth of craniofacial structures (Drummond, 1968). It has also been shown that patients with obstructive sleep apnea tend to have retrusive anterior cranial bases with retrognathic maxillas and mandibles which are believed to be the result of an enlargement of soft tissue structures surrounding the airway thus leading to a reduced airway space (Drummond, 1968). As a result, the most common treatment for individuals with obstructive sleep apnea is mandibular advancement, either by surgery or with a mandibular protrusion appliance. All of these issues

suggest that a relationship exists between reduced airway capacity and dentofacial pattern (Drummond, 1968).

Due to this close relationship between uvulo-glossal-pharyngeal structures and the facial-skeleton, Allhaija and Al-Khateeb studied ninety subjects (forty-five males and forty-five females) aged 14-17 years to determine if a difference in hard and soft tissue structures of the upper airway existed in different anteroposterior skeletal patterns. The subjects were divided into three groups (skeletal CL I, skeletal CL II and skeletal CL III) based on an ANB angle of 1-5, ANB >5, and ANB <1 respectively. These groups were then further divided into two subgroups of male and female for a total of six groups and different dimensions in the upper airway were measured on lateral cephalograms. Allhaija and Al-Khateeb found that vertical airway length was significantly reduced in CL II male subjects compared with CL I and CL III male subjects. They also found that for the total group, there was a significantly reduced vertical airway length in CL II subjects compared with CL III subjects. Thus, the investigators concluded that uvulo-glosspharyngeal dimensions are affected by anterorposterior skeletal pattern (Allhaija et al, 2005). Width of the upper airway was measured for the superior,

middle and inferior airway spaces in addition to total airway length, however no attempt at calculating an area for the airway space was made. As a result the variables were calculated as linear one dimensional (1D) entities rather than in three dimensions (3D). Studying the airway in the anteroposterior skeletal pattern may yield a completely different result. This is a major limitation of this study.

It has been shown that mouth-breathing is associated with CL II malocclusions and increased lower facial height implying that there is an anatomical factor for these malocclusion characteristics. As a result, de Freitas and coworkers (2006) assessed the upper and lower pharyngeal airways of four groups of untreated subjects; CL I malocclusions with normal growth patterns, CL I malocclusions with vertical growth patterns, CL II malocclusions with normal growth patterns, and CL II malocclusions with vertical growth patterns. Each group contained twenty subjects seeking orthodontic treatment with a mean age of 11.64 years, no previous history of tonsillectomy, no pharyngeal pathology, no clinical signs and symptoms, and no complaints of nasal obstruction at the initial visit. The eighty total cephalograms were analyzed using McNamara's airways analysis. The

investigators found that the upper pharyngeal width in the subjects with CL I and CL II malocclusions and vertical growth patterns was statistically significantly narrower than in the normal growth-pattern groups. However, the malocclusion type did not influence the upper airway width and neither malocclusion type nor vertical growth pattern had an influence on lower airway width (de Freitas, et al, 2006). As with the previous study, a linear rather than a 3D assessment of the airway space was made. In addition the sample was selected based on malocclusion (CL I and full-step CL II) rather than anteroposterior skeletal relationship. Other studies have used A-P skeletal relationships rather than molar classification to define their sample. This may be a limitation of this study since it did not demonstrate a correlation between molar classification and airway width. The small sample size may also be a study limitation.

With a similar objective in mind, Joseph and coworkers (1988) performed a study to compare nasopharyngeal, oropharyngeal, and hypopharyngeal dimensions on individuals with hyperdivergent and normodivergent facial types to determine whether a difference exists. Lateral cephalograms of twenty-seven

hyperdivergent and twenty-three normodivergent patients were analyzed and used to compare soft tissue airway dimensions. The hyperdivergent group consisted of persons with a FMA >33° and a lip incompetence of 4mm or more, while the normodivergent group was comprised of persons with FMA <33° but no lower than 17°. The groups were also matched for age, sex and racial characteristics. The investigators found that overall, the hyperdivergent group had narrower anteroposterior pharyngeal dimensions statistically significant in nasopharynx at the level of the hard palate and the oropharynx at the level of the tip of the soft palate and the mandible. The also found that the hyperdivergent group had a more retruded maxilla and mandible (as determined by SNA and SNB) and a higher CL II skeletal discrepancy (as determined by ANB) than the normodivergent group. They thus concluded that the narrower anteroposterior dimension of the airway may contribute to the skeletal features usually seen in hyperdivergent individuals (Joseph, Elbaum, Cisneros, and Eisig). In this study, airway dimensions were reported as widths rather than area, thus the same limitation mentioned previously applies to this investigation as well.

The previous literature provides studies regarding the anteroposterior craniofacial pattern and airway dimension. However, many use the 2D cephalogram to make comparisons. In the studies reviewed for this project, the majority of the investigators reported linear measures for lengths and widths, but only one study done by Martin et al reported nasopharyngeal area measures (Martin et al, 2006), and none of these studies reported area measures for the oropharynx. Schwab et al used magnetic resonance imaging (MRI) to measure volumes of soft tissue structures surrounding the upper airway (defined as the area from the tip of the soft palate to the base of the epiglottis), however did not measure the volume of the actual upper airway. Because there are a great number of studies that attempt to associate airway dimensions with anteroposterior craniofacial pattern in 2D, it would be interesting to view airway three-dimensionally to determine if conclusions drawn from the previous literature still apply.

Airway and Function:

Paul and Nanda (1973) observed one hundred male individuals ages 15-20 years to determine if any morphologic differences in dental occlusal existed

between mouth breathers and nasal breathers. A "cotton wisp" test was used to separate the individuals into the two groups. The experimental group (mouth breathers) was selected on the basis that no other abnormal habit or local cause could be responsible for their malocclusion. All individuals in the control group (nasal breathers) were determined to have excellent occlusion. Dental casts were made of each of the subjects to measure intermolar, intercanine and interpremolar widths, overbite, overjet, and palatal vault height. Paul and Nanda found that the experimental group had a smaller mean intermolar width, and the mean values of maxillary arch length, overbite and overjet were greater by 3.26mm, 1.10mm and 5.48mm respectively. In addition, seventy-four percent of the mouth breathers had a CL II malocclusion and the association between mouth breathing and this malocclusion was found to be statistically significant. None of the measures in the mandibular arch were found to be statistically significant and thus the authors concluded that mouth breathing does not affect the mandibular arch (Paul and Nanda, 1973). In this study, the selected sample is not adequately defined. There is no statement of where the subjects under study came from and how they were selected. It appears that the

one hundred males were selected and then equally divided into a control group and experimental group which seems highly unlikely unless the group was selected based on some unstated selection criteria. In addition, the sample was divided based on a "cotton wisp" test to determine if airflow was coming from an individual's mouth or nose, however no assessment of allergies, colds, etc. was mentioned. The fact that the individuals knew their respiration was being tested may have altered their breathing patterns thus placing them in the incorrect group. Lastly, an error study was not conducted in this study. As a result, the findings of this study are questionable.

In an attempt to address the question "does nasorepiratory function exert an effect on the dentofacial complex?" O'Ryan and her colleagues (1982) conducted a critical review of the most frequently cited literature currently written at the time. The literature was divided into two major groups, those dealing with cross-sectional studies and those dealing with longitudinal studies. In the cross-sectional studies she found that respiratory patterns were evaluated subjectively rather than quantitatively, age at onset and duration of nasal obstruction were not assessed,

investigators made assumptions about nasal resistance without actually measuring individuals' actual physiologic breathing patterns, lack of data to support an association between nasal resistance and the amount of air passing through the nose or dentofacial morphology. O'Ryan et al. had similar criticisms for the longitudinal study. The authors do not dispute the fact that there is a possible causal relationship between nasorespiratory function and function and development of dentofacial complex, they are simply calling for more well-controlled studies that quantitatively assess nasorespiratory function (O'Ryan, Gallagher, LaBanc, and Epker, 1982).

Similarly, Nancy Ung et al (1990), stated that the effects of breathing pattern on craniofacial morphology were a subject of debate because many studies had been based on subjective opinions (an individual's perception of his or her breathing pattern). As a result, Ung and coworkers set out to quantify the proportions of oral and nasal breathing at repeating intervals to access the effects on facial form. Forty-nine individuals ages 10-16 years, were subjected to a head-out body plethysomograph technique two separate times to measure oral, nasal, and total airflow. Each individual, along with his or her parent were also asked about their

subjective perceptions of their breathing modes. These perceptions were then compared to the airflow values and the breathing pattern measurements were also compared to nasal airway resistance and nasal power. Cephalometric radiographs were also accessed so that possible associations between dentofacial form and respiration could be made. The cephalometric analysis included ten anteroposterior measurements and nine vertical measurements. The investigators found a weak tendency among mouth breathers toward a Class II skeletal pattern and retroclined maxillary and mandibular incisors. They also found that the subjective perception of mouth breathing was associated with an increased anterior facial height and greater mandibular plane angle. There was no correlation of nasal power and resistance with either dental or skeletal variables. They also found no notable threshold level at which nasal resistance was associated with quantitatively assessed mouthbreathing (Ung, Koenig, Shapiro, Shapiro, and Trask). Although forty-nine children initially participated in the study, only thirty-six returned for a second measurement of breathing patterns. This reduced sample size may be a reason for the non-significant findings in this study. In addition, the investigators noted that there was

notable variation in the two breathing pattern assessments for each individual which they attributed to the "nasal breathing cycle" in which there are inherent fluctuations in respiratory activity (nasal vs. oral vs. oronasal breathing) throughout the day. In conclusion, the investigators state that more study is needed before casual relationships between both objective and subject assessments of respiratory patterns and dentofacial variables can be made (Ung, Koenig, Shapiro, Shapiro, and Trask).

Age, Sex, Obesity and Airway:

The relationship between ages, sex, obesity and airway is also a widely researched topic especially in snorers and individuals with obstructive sleep apnea (OSA). Mayer et al (1996) investigated a large population of snorers with and without OSA to determine if there is a relationship between BMI, age and upper airway morphology. Cephalometric radiographs and computed tomography (CT) scans were taken on one hundred forty consecutively referred patients from a regional University Sleep Laboratory in France. Patients were stratified based on their age (<52, 52-63, >63 yrs), BMI (<27, 27-30, >30), and apnoea/hypopnoea index (AHI) (<15,

≥15). Lateral cephalograms were used to make anatomical measures such as soft palate length and position of hyoid bone. CT scans were used to assess airway shape. Most of the differences in the overall population were found in the lean (BMI <27) and younger (age<52 years) group. The leaner, younger OSA patients had increased soft palate length and a hyoid bone placed more inferiorly and posteriorly than the snorers. They also had a significantly different shaped upper airway; shape of the pharyngeal lumen was measured as a ratio of the anteroposterior and transverse measures (AP/T). There was no mention of an error study in this investigation, and the differences found were quite small (2-4mm) for the cephalometric measures and a 6% for upper airway shape (AP/T). However, this study does suggest that there may be a relationship between BMI, age and upper airway measures (Mayer, Pèpin, Bettega, Veale, Ferretti, Deschauz, and Levy, 1996).

3-Dimensional Airway Imaging:

According to Schwab (1998), cephalometry provides valuable information skeletal information for upper airway surgery but cannot provide volumetric data, 3D information about soft tissue structures, and provides no information about lateral structures in the upper airway.

Hseuh-Yu Li (2003) and his coworkers investigated the correlation between upper airway 3D CT measurements and polysomnography data in patients with sleep-disorder breathing to determine if it could be a valuable tool to evaluate upper airway patency. 194 subjects (33 were diagnosed as simple snorers and 161 were diagnosed with OSA) underwent CT scans and polysomnography. The CT scans were used to measure retropalatal space (RP), AP and lateral dimensions of the retropalatal space, retroglossal space (RG), RP/RG and volume of the upper airway (defined as the space from the hard palate to the base of the epiglottis). Polysomnography was used to calculate the respiratory disturbance index (RDI), snoring index (DI) and lowest arterial O_2 saturation (LSAT). There was negative correlation between RP and RDI as well as between the RP/RG ratio and RDI. The investigators concluded that 3-D CT scan measurements can be valuable in evaluating upper airway patency in patients with sleep-disordered breathing (Hseuh-Yu, Ning-Hung, Chao-Ran, Yu-Hsiang, and Pa-Chun, 2003).

In a study involving ten obstructive sleep apnea (OSA) patients and ten control subjects, Owaga et al (2007) used the New Tom cone-beam CT to study 3D images if the oropharynx. The investigators segmented the

airway and manually traced the area using a software segmentation tool and were able to measure total airway volume of the oropharynx, the smallest cross-sectional area, the anteroposterior (AP) and lateral (L) dimensions of the smallest cross-sectional area, the relationship between AP and L (AP/L), the location of the smallest cross-sectional area in relation to the occlusal plane, and the configuration of the smallest cross-sectional area as rounded, elliptical, square or concave. Ogawa et al found that the smallest cross-sectional area was found below the occlusal plane in OSA patients 70% of time, where as in non-OSA patients it was equally found in both locations (50% above and 50% below the occlusal plane). There was no correlation between BMI and airway volume or BMI and AP dimension; however there was a negative correlation between BMI and minimum cross-sectional area and a positive correlation between BMI and lateral dimension (Ogawa, Enciso, Shintaku, Clark, 2007). No error study was conducted in this investigation, so the reliability of the method used is questionable. However, this study is one the first to report mean airway volumes although it was in adults whereas in orthodontics, teenage patients may be of more interest.

After a review of the literature, recent studies aimed at measuring 3-D airway volumes are limited to populations diagnosed with some form of sleep-disorder breathing ranging from snoring to OSA. It also appears that there is still some debate about whether there is a correlation between airway and craniofacial morphology and dentofacial morphology. Most studies to date were conducted using lateral cephalograms and hence were limited to 1-D and 2-D airway measures. No study was found that actually used 3-D computed tomography to measure airway volume in an attempt to find a correlation with craniofacial and dentofacial morphology. With the advent of Cone Beam CT, we are able to obtain 3-D images and expose our patient to less radiation than traditional CT (Ogawa et al, 2007).

If in fact an association is found between craniofacial and dentofacial pattern and 3D airway measures, a number of questions may be raised, most importantly, can those measures somehow be altered in a growing patient to produce a normal mandibular growth pattern? First and foremost, a method for measuring airway volume as well as reporting airway volumes in the general orthodontic population needs to be developed.

This would be a crucial step in addressing this gap in knowledge.

STATEMENT OF THESIS

The objective of this study was to develop a method to measure the nasal passage and oropharyngeal airway three-dimensionally using cone beam computed tomography and reconstruction software, and to report the volumes for 12 and 13 year old individuals seeking orthodontic treatment. A chosen segment of the airway was measured slice-by-slice to compute a volume.

Thirty subjects were re-measured in the same manner and compared with the initial measurements to determine the reliability of the method developed. It was also hypothesized that there is no difference between airway volume in 12 and 13 year old individuals. If rejected, one group will have a tendency for smaller airway volume in either the nasal passage and/or the oropharynx.

METHODS AND MATERIALS

The Case Western Reserve University Institutional Review Board (IRB) approved the experimental protocol. This investigation was a cross-sectional study involving orthodontic patients from Case Western Reserve University Department of Orthodontics. Using the View Point software (Ortho Computer Systems, Inc. - Ames, Iowa), a list was compiled of all active patients ages 12-13 who had records taken between 2006 and 2007. A Cone Beam CT (CBCT) scan obtained using the Hitachi CB Mercuray (Hitachi Medical Systems America Co. - Twinsburg, OH) is a routine part of initial diagnostic records for all orthodontic patients in Case Orthodontic department. All records are standardized to a 2mA, 120 kVp, and a 9 inch field of view.

These patients' initial CBCT records were then selected from the Cone Beam CT database at the Case Western Reserve University Department of Orthodontics. Each patient had a signed consent form allowing the use of their orthodontic records. The variables under study were obtained from the patient's record, CBCT and View Point software. Initially, we planned to exclude

individuals with increased lower facial height (FMA >33) were excluded from the study due to findings from a previous study in which differences in airway dimensions in persons with hyperdivergent and normodivergent facial patterns were detected (Joseph, et al), however non of our subjects had FMA 33°. Initially, any scans in which the defined airway was not clear or fully contained within the image were to be excluded from the study. However, all individuals selected had a clear and fully visible airway.

A sample size calculation was estimated using a formula for reporting a mean using data of airway volumes in non-OSA patients (Ogawa, et al. 2007). A 95% confidence interval and an 80% power were used to calculate a sample size of ten per group. However, because the difference found in the study was not statistically significant, this study included fifty subjects in each group.

A custom program named Ortho CT Dent Application was used to reconstruct the data from the Cone Beam CT. In accordance with Ogawa et al, oropharyngeal airway was defined as the area inferior to a plane drawn parallel to the Frankfort plane and going through the most distal point of the bony hard palate and superior to a plane

drawn parallel to Frankfort plane and going through the most anterior-inferior point of the second cervical vertebrate. The inferior limit of the nasal passage airway was defined as the area superior to the oropharyngeal airway; it's superior limit was defined as the last slice before the nasal septum fused with the posterior wall of the pharynx. The airway was painted in the Ortho Segment feature of the Ortho CT Dent Application program slice-by-slice and the program rendered the total volume by calculating the number of pixels painted. The volumes were then entered into Microsoft excel spreedsheets (Microsoft Corporation - Redmond, WA) manually.

Ten explanatory variables describing skeletal relationships, socio-demographic variables and functional/soft tissue factors were also studied. Lip competence was judged by viewing frontal photographs, molar classification and posterior crossbite (unilateral, bilateral, not present) were determined from diagnostic models, history of mouth breathing, snoring, adenoidectomy and tonsillectomy, as well as height and weight were obtained from the patient's record. Body mass index (BMI) was calculated using the patient's height and weight.

Descriptive statistics were calculated using an Excel spreadsheet. Sample size was calculated using previously published means and standard deviations. Data were entered into SPSS 16.0 (SPSS Inc., Chicago, IL) for further data analysis. Nasal passage and oropharyngeal airway mean volumes were reported along with a standard deviation and range. To determine if there was an interaction between male and female averages, or 12 and 13 year old averages independent T-Tests were used. ANOVA and independent T-tests were used for the ten potential explanatory variables.

A reliability study was completed two weeks after initial data collection. Thirty individuals were randomly selected (using the table of random digit numbers) and nasal passage and oropharyngeal airway volumes were re-measured. Intraclass correlation values were calculated using SPSS 16.0.

A 3D AIRWAY ASSESSMENT OF 12 AND 13 YEAR OLD SUBJECTS

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Objectives: to develop a method to measure the nasal passage and oropharyngeal airway three-dimensionally using cone beam computed tomography, and to report the volumes for 12 and 13 year old individuals seeking orthodontic treatment. **Methods:** The sample consisted of forty-seven 12 year olds (mean age 12.36 $\pm$ .3 years) and fifty-three 13 year olds (mean age 13.42 $\pm$ .32 years). Nasal passage and oropharyngeal airway volumes were measured on each individual using reconstructed data from cone beam CT images taken at initial records. Lip competence was judged by viewing frontal photographs, molar classification and posterior crossbite (unilateral, bilateral, not present) were determined from diagnostic models, history of mouth breathing, snoring, adenoidectomy and tonsillectomy, as well as height and weight were obtained from the patient's record. Body mass index (BMI) was calculated using the patient's height and weight. **Results:** The average volume of the oropharynx was 8183.25 mm^3 for 12 year olds and 7818.84 mm^3 for 13 year olds. The average volume of the nasal passage was 4753.48 mm^3 for 12 year olds and 4368.50 mm^3 for 13 year olds. The average oropharyngeal airway volumes ranged from 2040 mm^3 to 18505.81 mm^3 for 12 year olds and from 3126.42 mm^3 to 17581.86 mm^3 for 13 year olds. The nasal passage volume ranged from 522.32 mm^3 to 15601.01 mm^3 for 12 year olds and from 1035.23 mm^3 to 10632.72 mm^3 for 13 year olds. Intraoperator analysis of the CBCT measurements showed good correlation for both oropharyngeal volume ($r > .97$) and nasal passage volume ($r > .96$). No statistically significant difference was found between oropharyngeal airway or nasal passage volume in 12 and 13 year old individuals. Individuals with a history of mouth breathing had statistically significant smaller nasal passage volumes than individual who did not. In addition, individuals with CL II molar relationship had statistically significant smaller nasal passage volumes than individuals with CL III molar relationships. No differences were found in the oropharyngeal airway volumes. **Conclusions:** The method developed to measure airway volume is very accurate. No age or gender differences in airway volume were found in this study.

INTRODUCTION:

Previous literature has shown that there is a significant relationship between pharyngeal structures and craniofacial morphology[1]. It has been hypothesized that chronic nasal obstruction causes mouth breathing which leads to "long face syndrome" in which a patient exhibits with an increased lower facial height, lip

incompetency, maxillary transverse deficiency and vertical maxillary excess, suggesting that the oropharyngeal airway has an effect on the growth of craniofacial structures[1]. It has also been shown that patients with obstructive sleep apnea tend to have retrusive anterior cranial bases with retrognathic maxillas and mandibles which are believed to be the result of an enlargement of soft tissue structures surrounding the airway thus leading to a reduced airway space[1]. As a result, the most common treatment for individuals with obstructive sleep apnea is mandibular advancement, either by surgery or with a mandibular protrusion appliance. All of these issues suggest that a relationship exists between reduced airway capacity and dentofacial pattern[1].

Due to this close relationship between uvulo-glossal-pharyngeal structures and the facial-skeleton, Allhaija and Al-Khateeb studied ninety subjects (45 males and 45 females) aged 14-17 years to determine if a difference in hard and soft tissue structures of the upper airway existed in different anteroposterior skeletal patterns. The subjects were divided into three groups (skeletal CL I, skeletal CL II and skeletal CL III) based on an ANB angle of 1-5, ANB >5, and ANB <1 respectively. These groups were then further divided into two subgroups of male and female for a total of 6 groups and different dimensions in the upper airway were measured on lateral cephalograms. Allhaija and Al-Khateeb found that vertical airway length was significantly reduced in CL II male subjects compared with CL I and CL III male subjects. They also found that for the total group, there was a significantly reduced vertical airway length in CL II subjects compared with CL III subjects. Thus, the investigators concluded that uvulo-glosspharyngeal dimensions are affected by anterorposterior skeletal pattern[2]. Width of the upper airway was measured for the

superior, middle and inferior airway spaces in addition to total airway length, however no attempt at calculating an area for the airway space was made. As a result the variables were calculated as linear one dimensional (1D) entities rather than in three dimensions (3D). Studying the airway in the anteroposterior skeletal pattern may yield a completely different result. This is a major limitation of this study.

It has been shown that mouth-breathing is associated with CL II malocclusions and increased lower facial height implying that there is an anatomical factor for these malocclusion characteristics. As a result, de Freitas and coworkers (2006) assessed the upper and lower pharyngeal airways of four groups of untreated subjects; CL I malocclusions with normal growth patterns, CL I malocclusions with vertical growth patterns, CL II malocclusions with normal growth patterns, and CL II malocclusions with vertical growth patterns. Each group contained 20 subjects seeking orthodontic treatment with a mean age of 11.64 years, no previous history of tonsillectomy, no pharyngeal pathology, no clinical signs and symptoms, and no complaints of nasal obstruction at the initial visit. The eighty total cephalograms were analyzed using McNamara's airways analysis. The investigators found that the upper pharyngeal width in the subjects with CL I and CL II malocclusions and vertical growth patterns was statistically significantly narrower than in the normal growth-pattern groups. However, the malocclusion type did not influence the upper airway width and neither malocclusion type nor vertical growth pattern had an influence on lower airway width[3]. As with the previous study, a linear rather than a 3D assessment of the airway space was made. In addition the sample was selected based on malocclusion (CL I and full-step CL II) rather than anteroposterior skeletal relationship. Other studies have used A-P skeletal relationships rather than molar

classification to define their sample. This may be a limitation of this study since it did not demonstrate a correlation between molar classification and airway width. The small sample size may also be a study limitation.

With a similar objective in mind, Joseph and coworkers (1988) performed a study to compare nasopharyngeal, oropharyngeal, and hypopharyngeal dimensions on individuals with hyperdivergent and normodivergent facial types to determine whether a difference exists. Lateral cephalograms of twenty-seven hyperdivergent and twenty-three normodivergent patients were analyzed and used to compare soft tissue airway dimensions. The hyperdivergent group consisted of persons with a FMA >33° and a lip incompetence of 4mm or more, while the normodivergent group was comprised of persons with FMA <33° but no lower than 17°. The groups were also matched for age, sex and racial characteristics. The investigators found that overall, the hyperdivergent group had narrower anteroposterior pharyngeal dimensions statistically significant in nasopharynx at the level of the hard palate and the oropharynx at the level of the tip of the soft palate and the mandible. The also found that the hyperdivergent group had a more retruded maxilla and mandible (as determined by SNA and SNB) and a higher CL II skeletal discrepancy (as determined by ANB) than the normodivergent group. They thus concluded that the narrower anteroposterior dimension of the airway may contribute to the skeletal features usually seen in hyperdivergent individuals[4]. In this study, airway dimensions were reported as widths rather than area, thus the same limitation mentioned previously applies to this investigation as well.

The previous literature provides studies regarding the anteroposterior craniofacial pattern and airway dimension. However, many use the 2D cephalogram

to make comparisons. In the studies reviewed for this project, the majority of the investigators reported linear measures for lengths and widths, but only one study done by Martin et al reported nasopharyngeal area measures[5], and none of these studies reported area measures for the oropharynx. Schwab et al used magnetic resonance imaging (MRI) to measure volumes of soft tissue structures surrounding the upper airway (defined as the area from the tip of the soft palate to the base of the epiglottis), however did not measure the volume of the actual upper airway[6].

Because there are a great number of studies that attempt to associate airway dimensions with anteroposterior craniofacial pattern in 2D, it would be interesting to view airway three-dimensionally to determine if conclusions draw from the previous literature still apply. If in fact an association is found between craniofacial and dentofacial pattern and 3D airway measures, a number of questions may be raised, most importantly, can those measures somehow be altered in a growing patient to produce a normal mandibular growth pattern? First and foremost, a method for measuring airway volume as well as reporting airway volumes in the general orthodontic population needs to be developed. This would be a crucial step in addressing this gap in knowledge.

The objective of this study was to develop a method to measure the nasopharyngeal and oropharyngeal airway three-dimensionally using cone beam computed tomography and reconstruction software, and to report the volumes for 12 and 13 year old individuals seeking orthodontic treatment. A chosen segment of the airway was measured slice-by-slice to compute a volume.

METHODS AND MATERIALS:

The Case Western Reserve University Institutional Review Board (IRB) approved the experimental protocol. This investigation was a case-control study involving orthodontic patients from Case Western Reserve University Department of Orthodontics. Using the View Point software (Ortho Computer Systems, Inc. – Ames, Iowa), a list was compiled of all active patients ages 12-13 who had records taken between 2006 and 2007. A Cone Beam CT (CBCT) scan obtained using the Hitachi CB Mercuray (Hitachi Medical Systems America Co. – Twinsburg, OH) is a routine part of initial diagnostic records for all orthodontic patients in Case Orthodontic department. All records are standardized to a 2mA, 120 kVp, and a 9 inch field of view.

These patients' initial CBCT records were then selected from the Cone Beam CT database at the Case Western Reserve University Department of Orthodontics. Each patient had a signed consent form allowing the use of their orthodontic records. The variables under study were obtained from the patient's record, CBCT and View Point software. Individuals with increased lower facial height (FMA >33) were excluded from the study due to findings from a previous study in which differences in airway dimensions in persons with hyperdivergent and normodivergent facial patterns were detected (Joseph, et al). Initially, any scans in which the defined airway was not clear or fully contained within the image were to be excluded from the study. However, all individuals selected had a clear and fully visible airway. The first 100 eligible subjects, forty-seven 12 year olds (mean age 12.36 $\pm$ .3 years) and fifty-three 13 year olds (mean age 13.42 $\pm$ .32 years) were selected for the study.

A custom program named Archive Manager was used to reconstruct the data from the Cone Beam CT. In accordance with Ogawa et al, oropharyngeal airway was

defined as the area inferior to a plane drawn parallel to the Frankfort plane and going through the most distal point of the bony hard palate and superior to a plane drawn parallel to Frankfort plane and going through the most anterior-inferior point of the second cervical vertebrate[7] (Figure 1). The inferior limit of the nasal passage airway was defined as the area superior to the oropharyngeal airway; it's superior limit was defined as the last slice before the nasal septum fused with the posterior wall of the pharynx (Figure 2). The airway was painted in Archive manager slice-by-slice (Figure 3) and the program rendered the total volume by calculating the number of pixels painted. In addition, the total volume was rendered for viewing (Figures 4-7). The volumes were then entered into Microsoft excel spreedsheets (Microsoft Corporation – Redmond, WA) manually.

Ten explanatory variables describing skeletal relationships, socio-demographic variables and functional/soft tissue factors were also studied. Lip competence was judged by viewing frontal photographs, molar classification and posterior crossbite (unilateral, bilateral, not present) were determined from diagnostic models, history of mouth breathing, snoring, adenoidectomy and tonsillectomy, as well as height and weight were obtained from the patient's record. Body mass index (BMI) was calculated using the patient's height and weight.

DATA ANALYSIS AND STATISTICAL METHODS:

Descriptive statistics were calculated using an Excel spreadsheet. Sample size was calculated using previously published means and standard deviations. Data were entered into SPSS 16.0 (SPSS Inc., Chicago, IL) for further data analysis. Nasal

passage and oropharyngeal airway mean volumes were reported along with a standard deviation and range. To determine if there was an interaction between male and female averages, or 12 and 13 year old averages independent T-Tests were used. X^2, ANOVA, and independent T-tests were used for the ten potential explanatory variables. Normal distribution of the sample was tested using SPSS 16.0, all means were skewed to the left of the mean.

A reliability study was completed two weeks after initial data collection. Thirty individuals were randomly selected (using the table of random digit numbers) and nasal passage and oropharyngeal airway volumes were re-measured. Interaclass correlation values were calculated using SPSS 14.0. Intraoperator analysis of the CBCT measurements showed good correlation for both oropharyngeal volume ($r > .97$) and nasal passage volume ($r > .96$).

RESULTS:

Tables 1 and 2 summarize the descriptive characteristics of the study population. The average oropharyngeal airway volumes (OPV) were 7811.03 mm^3 for 12 year old males, 8571.67mm^3 for 12 year old females, 7779.47mm^3 for 13 year old males, and 7950.63mm^3 for 13 year old females. The average nasal passage (NPV) volumes were 4782.54mm^3 for 12 year old males, 4723.16mm^3 for 12 year old females, 4471.30mm^3 for 13 year old males, and 4161.01mm^3 for 13 year old females. No gender differences were found in either OPV or NPV for the 12 and 13 year old population (Table 3) so the groups were combined into a 12 year old group and a 13 year old group.

The average OPV for the combined gender groups are 8183.26mm^3 for 12 year olds and 7818.84mm^3 for 13 year olds. The average NPV for the combined

gender groups are 4753.48mm^3 for 12 year olds and 4368.50mm^3 for 13 year olds. The average oropharyngeal airway volumes ranged from 2040 mm^3 to 18505.81 mm^3 for 12 year olds and from 3126.42 mm^3 to 17581.86 mm^3 for 13 year olds. The nasal passage volume ranged from 522.32 mm^3 to 15601.01 mm^3 for 12 year olds and from 1035.23 mm^3 to 10632.72 mm^3 for 13 year olds. No difference between 12 and 13 year olds or between males and females for either OPV or NPV (Table 4).

Independent T-tests and ANOVA were used to test differences in OPV and NPV for each of the potential explanatory variables (Table 5). Non-mouth breathers were found to have a statistically significant larger NPV (4831.72mm^3) than mouth breathers (3381.01mm^3). ANOVA was used to test mean differences in the molar classification groups and returned a *P* value that was not significant, however, because the means for CL II and CL III individuals appeared to have a great different, an individual T-test was used to compare the two groups. As a result, individuals with CL III molar classification were found to have a statistically significantly larger NPV (6688.81mm^3) than individuals with CL II molar classification (4042.65mm^3). No differences were found in the OPV for any of the potential explanatory variables.

T-tests were not conducted to test differences in mean airway volumes for the tonsillectomy and adenoidectomy variables because the difference in the number of subjects in each group was so large. Attempts were made to match a sample of seven subjects with no history of adenoidectomy and eight subjects with no history of tonsillectomy for weight and height to compare their mean airway volumes with the patients who had a history of adenoidectomy and tonsillectomy respectively, however this was unsuccessful because the attempt at matching was done after the original

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sample was selected and appropriate matches were not found within the selected sample.

Since no differences were found between 12 and 13 year old subjects, the age groups were combined and an independent T-test was used to test a difference in OPV and NPV (table 6). NPV was found to be significantly smaller than OPV in our sample.

The standard deviations calculated in this sample were very high. In many cases they were one-third to one-half of the mean. In an attempt to address this, the sample was stratified into 12 and 13 year olds for each potential explanatory variable and new means and standard deviations were calculated to rule out the possibility that our 12 and 13 year olds were inherently different. Each potential explanatory variable was equally distributed among the 12 and 13 year old groups, in addition the standard deviations remained just as high and thus this data has not been included in this study.

DISCUSSION:

The main objective of this study was to develop a method for reliably measuring airway volume using cone beam CT and reporting average airway volumes for 12 and 13 year old individuals seeking orthodontic treatment. As shown by the error study conducted, the method developed was very reliable for both the oropharyngeal airway and the nasal passage airway volumes. No age or gender differences were found in either airway volume measured which may be due to the large variability of sample. This is demonstrated in the large standard deviations found for each mean and may be remedied by and increase in sample size. It is also

possible that even with an increased sample size, an age difference may not be found because the two samples were only separated by one year.

De Freitas and coworkers (2006) found that malocclusion type did not influence the upper and lower airway width[3]. However in this study, individuals with CL II molar were found to have a significantly smaller nasal passage volume than individuals with CL III molar. The sample size of the CL III molar group was very small, so this finding may be due to chance. Allhaija and Al-Khateeb[2] found a significantly reduced vertical airway length in CL II subjects compared with CL III subjects, however the authors used skeletal AP relationships rather than molar classification to define their groups so their findings may not be comparable to this study.

Subjects with lip incompetence were found to have statistically significant smaller nasal passage volumes than those with lip competence. This finding does seem likely due to the fact that lip incompetence is a feature of "long face syndrome"[1] which is believed to be caused by nasal obstruction; or in this case small nasal airway volume. A limitation of this study is that lip incompetence was measured using photos of each subject rather than a clinical exam. Further study may be needed to verify that lip incompetence really is related to a smaller nasal volume.

Martin et al. found a correlation between BMI and upper airway size in adult men and women (45-50yrs)[8]. Their findings are not comparable to this study because their subjects were much older than the subjects in this study, however their sample size for each group was much larger than ours. It is possible that a difference in airway volume may be found in teenagers based on BMI if a larger sample size is used.

When viewing a center slice of the Cone Beam CT in the sagittal view, it appears as though the area we called NPV is much larger than the area we designated as OPV, but in fact, our study shows that in our sample the NPV is significantly smaller than OPV.

CONCLUSIONS:

- We can use CBCT to reliably measure airway volume.
- Airway volume in 12 and 13 year old individuals is highly variable.
- Subjects with CL III molar occlusion have significantly larger NPV than subjects with CL II molar occlusion.
- Mouth breathers have a significantly reduced NPV compared to non-mouth breathers.
- NPV is significantly smaller than OPV in 12 and 13 year old individuals.

This study was meant to be a pilot study in which a reliable method for measuring airway volume would be developed and using that method, mean airway volume for teenage patients could be reported. Many studies have been conducted investigating airway measures and craniofacial morphology. Now that a reliable method for measuring airway volume has been developed, further study is needed to determine if airway volume is correlated with dentofacial and craniofacial morphology.

Table 1: Descriptive summary of socio-demographic factors, molar classification and presence/absence of posterior crossbite. (T=100) Categorical Variables

Variables	N
Age	
12-0 – 12-11	47
13-0 – 13-11	53
Gender	
Male	54
Female	46
Molar Classification	
CL I	61
CL II	33
CL III	6
History of snoring	
Often	2
Sometimes	21
Never	31
Rarely	42
Adenoidectomy	
No	87
Yes	8
Tonsillectomy	
No	87
Yes	8
Mouth Breather	
No	79
Yes	16
Lip competence	
No	81
Yes	9

Table 2: Descriptive summary of socio-demographic factors (continuous variables).

	12 year old males N=24 mean SD	12 year old females N=23 mean SD	13 year old males N=30 mean SD	13 year old females N=23 mean SD
Age	13.04 ± .73	12.38± .35	13.33 ± .57	12.38 ± .31
Height	61.58 ± 4.1	60.61 ± 3.2	63.09 ± 3.73	62.72 ± 4.2
Weight	106.53± 26.2	111.11±23.9	121.52±29.7	103.21±32.3
BMI	19.84 ± 4.47	21.17 ± 4.09	21.90 ± 4.50	18.36 ± 3.39

Table 3: Means, standard deviations and P values gender differences in airway volume.

	12 year old males mean SD N= 24	12 year old females mean SD N= 23	*P*	13 year old males mean SD N= 30	13 year old females mean SD N= 23	*P*
OPV (mm^3)	7811.03±2975.00	8571.67±4582.38	*.50*	7779.47±3639.11	7950.63±3916.03	*.87*
NPV (mm^3)	4782.54±3177.04	4723.16±2390.12	*.55*	4471.30±1990.52	4161.01±2283.97	*.86*

OPV indicates oropharyngeal volume; NPV, nasal passage volume.

Table 4: Means, standard deviations and P values for age and gender differences in airway volume (gender groups combined).

	Age			Gender		
	12.0-12.9 (n = 47) Mean SD	13.0-13.99 (n = 53) Mean SD	Age Difference *P* value	Males (n = 54) Mean SD	Females (n = 46) Mean SD	Sex Difference *P* value
OPV	8183.26± 3823.05	7818.84± 3728.80	.63	7793.50± 3329.76	8229.87± 4243.71	.57
NPV	4753.48± 2789.24	4368.50± 2114.95	.44	4609.63± 2563.71	4481.23± 2339.89	.80

OPV indicates oropharyngeal volume; NPV, nasal passage volume.

Table 5: Means, standard deviations and *P* values for potential explanatory variable differences in airway volume.

	OP volume			NP Volume		
	Mean	SD	*P* value	Mean	SD	*P* value
Posterior crossbite						
No	7772.21	± 3781.86		4567.94	± 2452.82	
Yes	8717.60	± 3669.51	.29	4496.19	± 2507.62	.90
Unilateral	8502.96	± 4111.81		4614.08	± 3088.37	
Bilateral	8951.75	± 3303.08	.78	4367.59	± 1818.57	.82
Molar classification						
CL I	8098.51	± 4010.08	.54	4651.21	± 2498.98	.07
CL II	7567.18	± 3471.77		4042.65	± 2217.18	.02* (vs. *CL III*)
CL III	9493.28	± 2014.81		6688.81	± 2532.80	
Lip competence						
Yes	7083.59	± 3468.12		3666.30	± 1704.06	
No	8207.56	± 3813.37	.24	4761.45	± 2563.57	.08
BMI						
<18.5	8410.28	± 3729.63	.46	4443.32	± 1910.09	.91
18.5-24.9	8159.87	± 3804.09		4581.59	± 2205.26	
25-29.9	6297.30	± 2524.41		4240.18	± 3084.55	
Snoring						
Sometimes/often	8223.20	±3467.84		3960.87	±2187.38	
Rarely/never	7865.96	± 3886.10	.97	4786.93	± 2529.71	.11
Mouth breathing						
Yes	7754.14	± 3520.81		3381.01	± 1271.99	
No	8026.18	± 3880.99	.08	4831.72	± 2595.97	.03*

*** denotes *P<.05***

Table 6: OPV vs. NPV (12 and 13 year old subjects combined).

	Mean SD	*P* value
OPV	8008.62± 3743.66	
NPV	4532.56± 2447.67	<.0001

Figure 1. Inferior and superior limit of oropharynx.



Figure 2. Superior limit of nasal passage.



The nasal septum has fused with the posterior wall of the pharynx. The slice inferior to this marks the superior limit of the nasal passage.

Figure 3. Painting of the airway slice-by-slice.

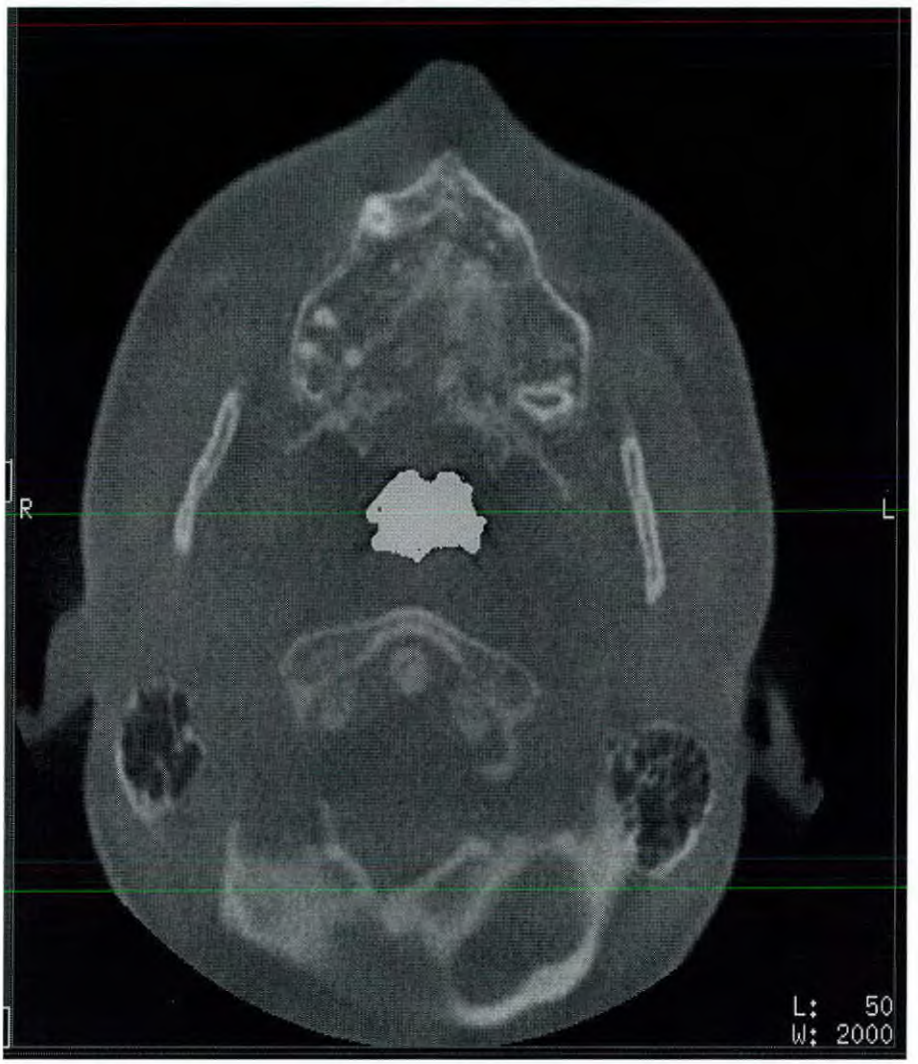


Figure 4: Volume rendered of the oropharynx (sagittal view).

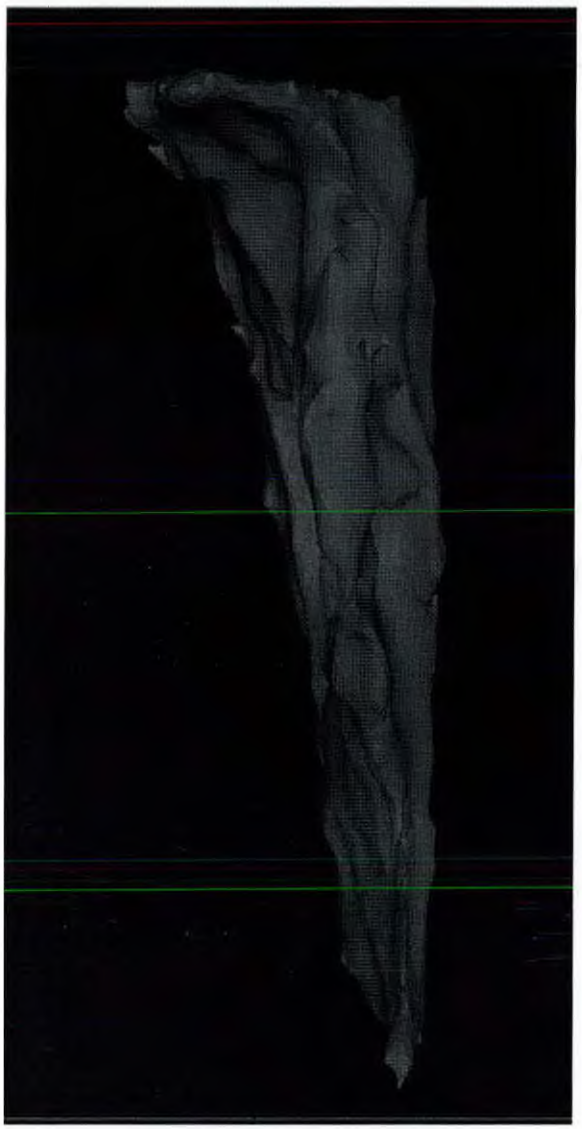


Figure 5: Volume rendered of the oropharynx (coronal view).

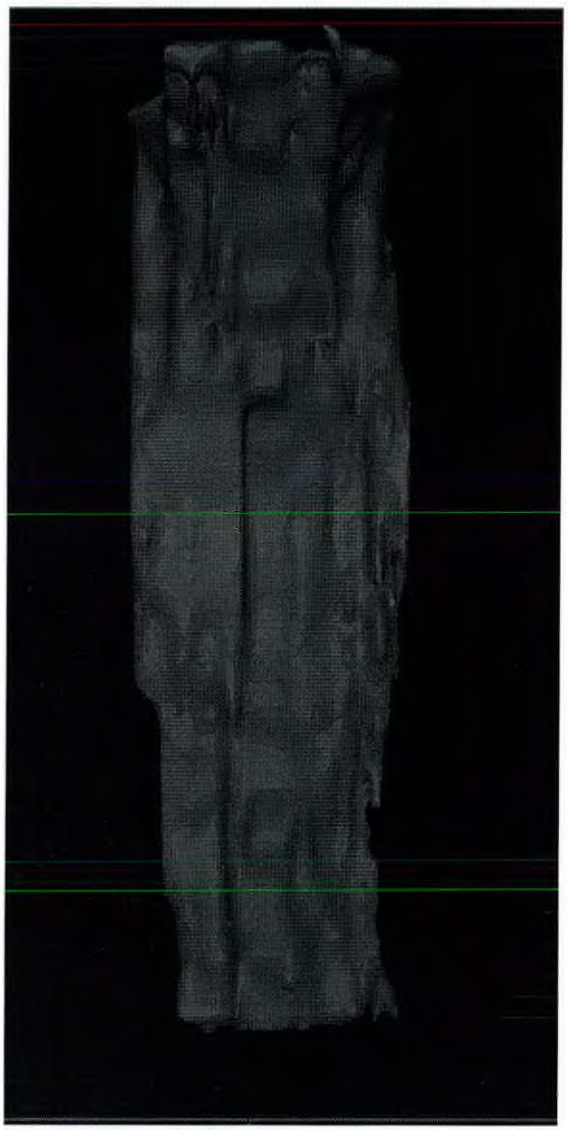


Figure 6: Volume rendered of the nasal passage (sagittal view).

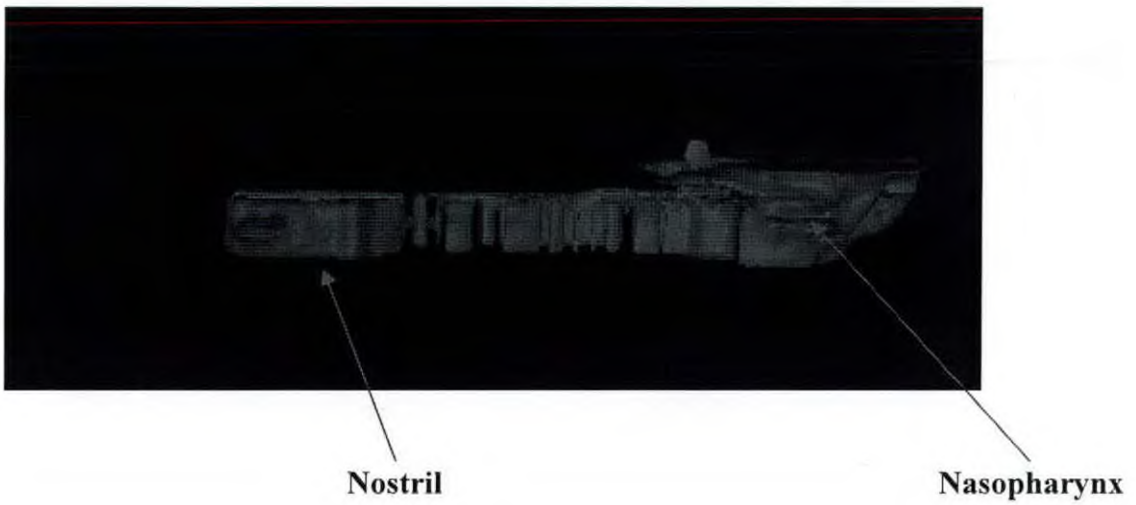
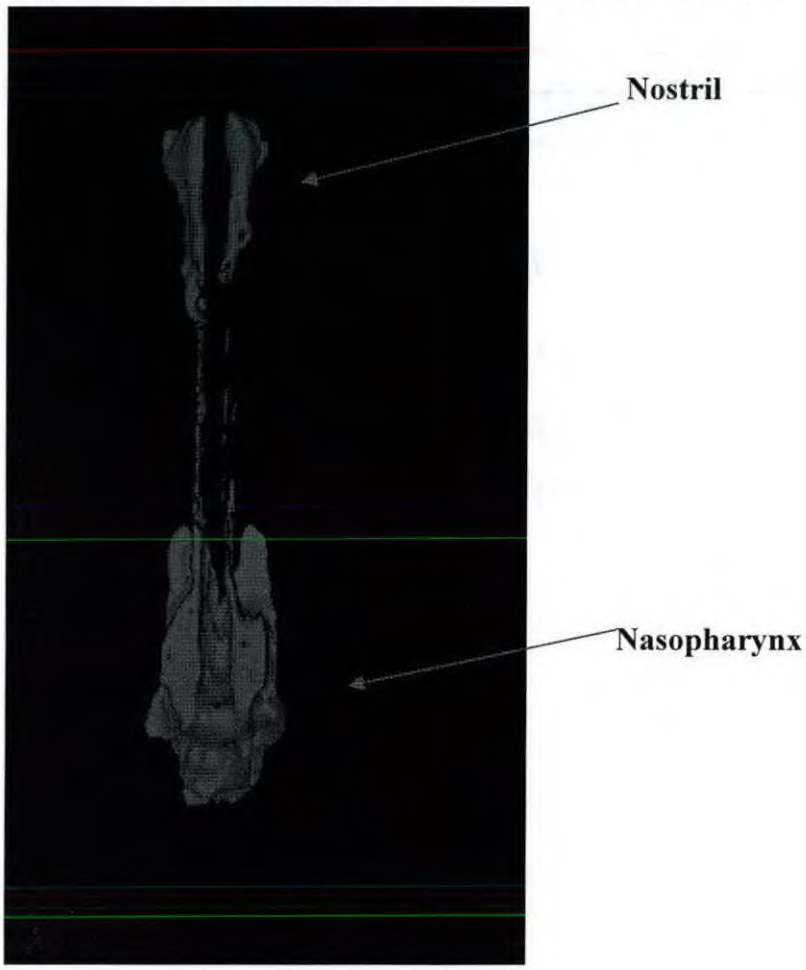


Figure 7: Volume rendered of the nasal passage (axial view).



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APPENDIX 1

IRB Approval

Case Western Reserve University
Institutional Review Board

NOTICE OF EXEMPTION (#4)

Research involving the collection or study of existing data, documents, records, pathological specimens, or diagnostic specimens, if these sources are publicly available or if the information is recorded by the investigator in such a manner that subjects cannot be identified, directly or through identifiers linked to the subjects.

This protocol is exempt under the #4 category because this involves existing retrospective de-identified data.

Please note that this only applies to existing data.

Prospective data is NOT included in this exemption – i.e., De-identified pre-existing data to be collected on

08/09/2007 and after are NOT covered by this exemption.

Responsible Investigator: **J. Martin Palomo**
Department: **Dental Clinic**
IRB Protocol Number: **20070717**
Title: ***A Descriptive Study of Airway Dimensions in 12 and 13 Year Olds Using the Cone Beam CT***
Co-Investigator: **Breyn Peters**

Exemption Date: August 8, 2007

The Institutional Review Board (IRB) has deemed the above protocol EXEMPT under 45 Code of Federal Regulations (CFR) part 46.101(b)(4). The IRB will not conduct subsequent reviews of this protocol.

Any changes to the protocol that put it under the purview of the IRB would require a formal application to, and approval of, the IRB prior to implementation of the change IRB applications are available at the CWRU IRB Pages, or from the Office of Research Compliance (ORC) at Sears Library Building, #657.

OR
contact our administrative office…

Isabel Sanchez, IRB Director
216.368.6993
Maureen Dore-Arshenovitz, IRB Assistant
216.368.6925
Fax: 216.368.3737

CASE Institutional Review Board
Office of Research Compliance
Sears Building 657
Cleveland, OH 44106-7230

APPENDIX 2

Raw Data: Demographic and potential explanatory variables.

Table 1.-- Demographic and potential explanatory variables data subjects 1-31.

1			Start		inches	lbs	kg/m^2	N/R/S/O	(8)yes/no(89)	yes/no	yes/no	0/1/2		
2	Gender	B Date	Date	Chart Age	Height	Weight	BMI	Snorer	Tonsillectomy	Adenoidectomy	Mouth breather	Post x-bite	Lip comp.	Molar CL
3														
4	F	4/5/1994	10/19/06	12.00	56.00	70	15.692	s	n	n	n	0	y	1
5	F	4/10/1994	10/26/06	12.00	64.00	125	21.454	r	n	n	n	0	y	1
6	F	4/11/1995	09/05/07	12.04	54.00	78	18.805	n	n	n	n	0	y	2
7	F	3/2/1994	08/31/06	12.10				n	n	n	n	0	y	1
8	F	3/15/1994	10/09/06	12.10	60.00	131	25.581	s	n	n	y	0	y	1
9	F	6/9/1993	08/16/06	12.10	60.00	139	27.144	r	n	n	n	0	y	1
10	F	6/19/1993	12/04/06	12.10	63.00	105	18.598	r	n	n	n	0	y	3
11	F	5/10/1994		12.11	59.00	120	24.234	r	n	n	n	0	y	1
12	F	11/23/1993	11/29/06	12.11	65.00	130	21.631	o	n	n	n	0	y	1
13	F	2/12/1994	09/13/06	12.20	58.00	82	17.136	n	n	n	n	2	y	1
14	F	2/2/1994	10/09/06	12.20	60.00	138	26.948	n	n	n	n	0	y	2
15	F	1/28/1994	07/12/06	12.25				n	n	n	y	0	y	1
16	F	12/31/1993	08/06/06	12.30	62.00	110	20.117		n	n	n	0	n	2
17	F	10/31/1994	09/24/07	12.47	62.00	101	18.471	s	n	n	y	2	y	1
18	F	11/18/1993	08/10/06	12.50	64.00	100	17.163	r	n	n	y	0	y	1
19	F	10/27/1993	09/07/06	12.50				n	n	n	n	2	n	1
20	F	11/13/1993	10/25/06	12.50				r	n	n	n	0	y	1
21	F	11/15/1993	11/27/06	12.50	66.00	121	19.528	n	n	n	n	0	n	1
22	F	8/12/1994	07/17/07	12.67	62.00	136	25.238	n	n	n	n	0	y	1
23	F	7/18/1993	08/02/06	12.90	59.00	140	28.273	r	n	n	y	0	y	1
24	F	8/20/1993	10/04/06	13.00	57.00	72	15.579	n	n	n	n	0	y	1
25	F	4/20/1993	10/04/06	13.00				n	n	n	n	1	n	2
26	F	9/30/1992	10/02/06	13.10	60.00	100	19.528	n	n	n	n	2	n	1
27	F	6/13/1992	08/31/06	13.10	59.00	100	20.195	s	n	n	n	1	n	2
28	F	7/20/1993	11/20/06	13.20	70.00	96	13.773	r	n	n	n	0	y	1
29	F	2/7/1993	08/09/06	13.20	59.00	110	22.215	n	n	n	n	0	y	1
30	F	7/16/1993	10/23/06	13.30	60.00	90	17.575	r	n	n	n	0	n	2
31	F	2/18/1993	07/20/06	13.30	59.00	96	19.388	r	n	n	n	1	y	2
32	F	4/12/1993	10/25/06	13.30	57.00	90	19.474	r	n	n	n	0	y	1
33	F	11/22/1993	8/21/2007	13.50	66.00			s	n	n	n	0	y	1
34	F	11/4/1992	09/13/06	13.50	58.00	110	22.988	n	n	n	y	0	n	2

Table 2.-- Demographic and potential explanatory variables data subjects 32-65.

	C	D	F	I	J	K	N	O	P	Q	R	S	T	U
35	F	10/31/1992	12/11/2006	13.50	65	185	30.782	n	n	n	n	2	y	3
36	F	8/31/1992	10/18/06	13.70	60.00	110	21.481	n	n	n	n	0	y	1
37	F	7/29/1992	01/02/07	13.80	63.00	105	18.598	n	n	n	n	0	y	2
38	F	8/25/1992	07/13/06	13.90				n	n	n	n	0	y	1
39	F	7/14/1992	08/30/06	13.90				n	n	n	n	1	y	1
40	F	7/22/1992	10/02/06	13.90				n	n	n	n	1	y	1
41	F	7/1/1992	01/09/07	13.90	66.00	130	20.98	n	n	n	n	0	n	1
42	M	3/22/1995	10/18/07	12.10	58.00	65	13.584	r	n	n	y	0	y	1
43	M	5/20/1994	03/29/07	12.10	63.00	110	19.483	r	n	n	n	0	n	2
44	M	6/9/1993	10/18/06	12.10	57.00	124	26.83	r	n	n	n	0	y	2
45	M	6/16/1993	11/13/06	12.10	70.00	110	15.782	n	n	n	n	1	n	2
46	M	5/19/1993	09/12/06	12.11	59.00			n	n	n	n	1	y	1
47	M	5/7/1993	10/09/06	12.11	62.00	110	20.117	r	n	n	n	2	y	2
48	M	5/19/1993	11/30/06	12.11	59.00	70	14.137	r	n	n	n	0	y	2
49	M	2/26/1994	10/16/06	12.20				s	n	n	n	2	y	2
50	M	12/14/1994	08/15/07	12.20		82		r	n	n	n	0	n	2
51	M	2/9/1994	10/17/06	12.20	59.00	100	20.195	s	n	n	y	0	y	2
52	M	1/25/1995	08/30/07	12.25	68.00	80	12.163	s	n	n	n	0	y	1
53	M	1/20/1994	11/30/06	12.30	63.00	110	19.483	n	n	n	n	0	y	2
54	M	11/15/1993	10/30/06	12.50	63.00	113	20.015	n	n	n	n	0	y	1
55	M	1/10/1994	10/31/06	12.70	63.00	100	17.712	r	n	n	n	0	y	1
56	M	11/30/1993	08/03/06	12.80	62.00	115	21.031	s	n	n	n	1	y	1
57	M	8/6/1993	11/14/06	12.80	60.00	99	19.333	r	n	n	n	0	y	1
58	M	7/1/1993	10/18/06	12.80	56.00	75	16.813	n	n	n	n	1	y	3
59	M	9/12/1993	07/12/06	12.90	62.00	85	15.545	s	n	n	y	0	n	2
60	M	7/7/1993	10/31/06	12.90	59.00	82	16.56	s	n	n	n	1	y	1
61	M	7/2/1993	11/13/06	12.90				s	n	n	y	0	y	1
62	M	7/7/1993	11/22/06	12.90				n	n	n	n	0	y	1
63	M	4/23/1993	07/13/06	13.00				n	n	n	n	2	y	2
64	M	4/29/1994	08/13/07	13.00	65.00	120	19.967	n	n	n	y	2	y	1
65	M	4/9/1993	08/23/06	13.00	65.00	120	19.967	r	n	n	n	0	y	2
66	M	4/16/1993	10/25/06	13.00	64.00	90	15.447	n	n	n	n	0	y	1
67	M	7/13/1993	01/23/07	13.00	67.00	135	21.142	s	n	n	n	0	y	2
68	M	9/20/1992	10/18/06	13.10				s	n	n	n	0	y	1
69	M	5/3/1992	07/10/06	13.11	74.00	215	27.601	r	n	n	n	0	y	1

Table 3.-- Demographic and potential explanatory variables data subjects 66-100.

70	M	4/24/1993	08/02/07	13.11	59.00	82	16.56	n	n	n	n	0	y	1
71	M	5/19/1992	08/31/06	13.11	62.00	83	15.179	n	n	n	n	0	y	1
72	M	4/30/1992	10/02/06	13.11				r	n	n	y	0	y	1
73	M	11/27/1993	03/07/07	13.20	58.00	75	15.673	n	n	n	n	0	y	1
74	M	4/1/1994	08/21/07	13.20	67.00	122	19.106	s	n	n	n	1	n	2
75	M	12/22/1992	10/24/06	13.40	63.00	97	17.181	n	n	n	n	0	n	1
76	M	11/20/1993	08/27/07	13.47	62.00	128	23.409	r	n	n	y	0	n	1
77	M	10/28/1992	11/06/06	13.50				n	n	n		0	y	2
78	M	10/17/1992	08/07/06	13.60	65.00	129	21.464	n	n	n	n	2	n	3
79	M	10/12/1992	07/11/06	13.70	62.00	120	21.946	r	n	n	n	0	y	1
80	M	9/9/1993	08/29/07	13.70		105		r	n	n	n	0	y	1
81	M	5/27/1993	03/01/07	13.80	66.00	115.5	18.64	n	n	n	n	0	y	2
82	M	8/13/1992	08/22/06	13.80	68.00	180	27.366	n	n	n	n	0	y	2
83	M	8/14/1992	08/29/06	13.80		75		n	n	n	n	0	y	1
84	M	8/1/1992	10/09/06	13.80	67.00	125	19.576	s	n	n	n	0	y	1
85	M	8/3/1992	11/27/06	13.80				r	n	n	n	0	y	2
86	M	7/17/1992	08/28/06	13.90	62.00	95	17.374	s	n	n	n	0	y	2
87	M	7/27/1992	10/05/06	13.90	67.00	109	17.07	n	n	n	n	0	y	2
88	M	7/12/1992	11/27/06	13.90	71.00	168	23.429	n	n	n	n	1	y	3
89	F	3/23/1995	08/23/07	12.20	58.00	101	21.107	n	y	n	n	0	y	1
90	F	8/30/1992	09/07/06	12.70	60.00	106	20.699	n	y	n	n	0	y	1
91	F	4/21/1994	10/26/06	13.30	56.00	74	16.589	o	n	y	y	2	y	1
92	M	6/9/1993	08/30/06	12.10	57.00	128	27.696	r	n	y	n	0	y	2
93	F	10/13/1993	11/06/06	12.11	65.00	110	18.303	r	y	y	n	0	y	2
94	M	3/8/1994	07/11/06	12.10	64.00	155	26.603	r	y	y	n	0	y	1
95	M	3/21/1993	07/17/06	13.10	63.00	175	30.996	s	y	y	y	0	n	1
96	M	2/15/1993	10/05/06	13.20					y	y	y	2	y	1
97	M	7/23/1993	04/03/07	13.70	62.00	110	20.117	s	y	y	n	0	y	3
98	M	6/4/1992	07/12/06	13.10	62.00	174	31.822	s	y		n	0	y	1
99	F	1/24/1993	10/02/06	13.30	60.00	120	23.433	s				0	y	2
100	F	11/19/1993	09/04/07	13.50	61.00	95	17.948	r				0	y	1
101	F	12/21/1992	09/14/06	13.60								0	y	1
102	F	9/14/1993	08/20/07	13.64								0	y	2
103	M	6/4/1993	07/10/06	12.90				r			n	0	n	1

APPENDIX 2

Raw Data: Oropharyngeal and Nasopharyngeal Volumes

Table 4.-- Oropharyngeal and Nasopharyngeal volumes subjects 1-31.

2	OP Volume	NP Volume
3		
4	16599.86	5605.55
5	5007.57	4527.44
6	3215.81	3380.82
7	5629.43	4495.69
8	4147.00	522.32
9	6763.85	8767.96
10	11616.02	6083.93
11	5409.80	5458.95
12	7893.40	1580.99
13	13248.42	7437.16
14	4706.49	1275.20
15	4818.79	3876.11
16	6850.61	5691.97
17	11879.48	6019.26
18	13939.04	2260.16
19	3095.03	2218.86
20	10919.41	5247.78
21	15768.04	8468.22
22	7067.22	2861.31
23	3842.37	2087.07
24	5557.78	1665.34
25	4575.69	3049.76
26	8427.77	4991.18
27	3374.63	1141.17
28	13749.73	6920.2
29	7197.75	2946.91
30	10546.03	1749.22
31	5890.95	6727.89
32	4560.45	3085.94
33	6233.05	8838.37
34	8763.15	3998.40

Table 5.-- Oropharyngeal and Nasopharyngeal volumes subjects 32-65.

35	9668.95	2680.48
36	8111.23	5073.16
37	16000.04	10071.40
38	3927.62	3249.63
39	16893.07	2461.45
40	4263.15	5194.84
41	5666.20	4604.25
42	4522.48	4533.47
43	3706.31	2946.72
44	6206.84	6345.35
45	9668.95	2680.48
46	11623.58	8657.39
47	8542.72	3090.43
48	6437.17	3451.00
49	12387.20	1669.50
50	2040.59	3409.27
51	8944.03	3805.37
52	9698.4	8262.82
53	4148.00	1705.10
54	9923.48	5606.08
55	6195.98	3974.30
56	4857.35	1667.61
57	5112.67	5238.52
58	8789.33	7579.11
59	9120.19	2973.74
60	12589.44	3297.84
61	12323.96	2169.98
62	9998.95	15601.01
63	10375.31	6575.71
64	5927.85	4158.49
65	9401.31	3273.29
66	4798.52	3594.86
67	8070.12	5821.66
68	7973.89	6608.28
69	11717.18	7259.48

Table 6.-- Oropharyngeal and Nasopharyngeal volumes subjects 66-100.

69	11717.18	7259.48
70	5442.66	3361.72
71	3849.14	4019.44
72	5426.10	4008.36
73	3269.41	2934.12
74	8212.29	2278.66
75	5588.80	2926.68
76	11163.56	3359.52
77	6108.92	6769.17
78	9063.07	4531.75
79	7167.35	3175.57
80	3475.21	1497.71
81	17581.86	2260.16
82	3126.42	2834.36
83	15783.98	7624.54
84	4802.20	5748.16
85	6821.55	3692.88
86	4304.81	4219.99
87	10290.84	6278.67
88	11297.10	10632.72
89	7756.62	8035.95
90	18505.81	5763.17
91	4481.91	4417.41
92	7722.31	8267.15
93	8468.30	6966.90
94	7673.31	2181.62
95	3725.82	2972.82
96	11040.45	2933.75
97	6700.88	4616.52
98	10877.60	4170.10
99	7277.19	3970.76
100	7220.42	3953.54
101	13647.34	3876.60
102	6830.47	1035.23
103	5231.40	5667.06

APPENDIX 4

Raw Data: Distribution

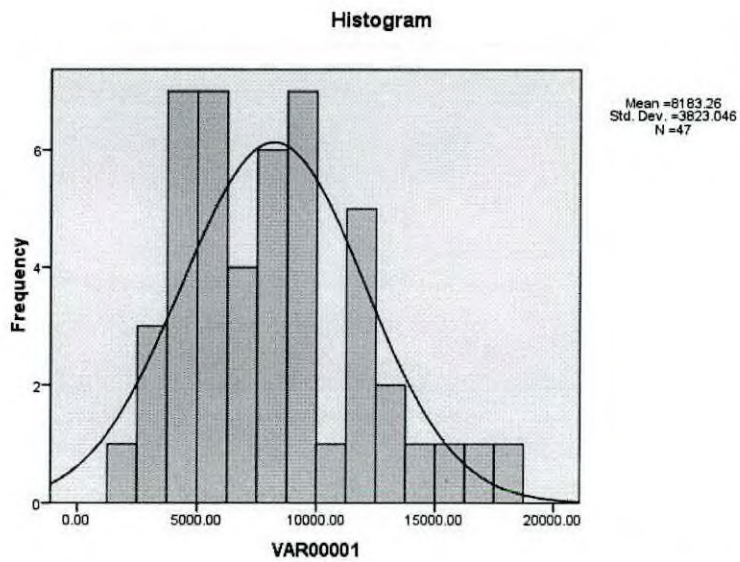


Figure 8: Oropharyngeal volume of 12 year olds

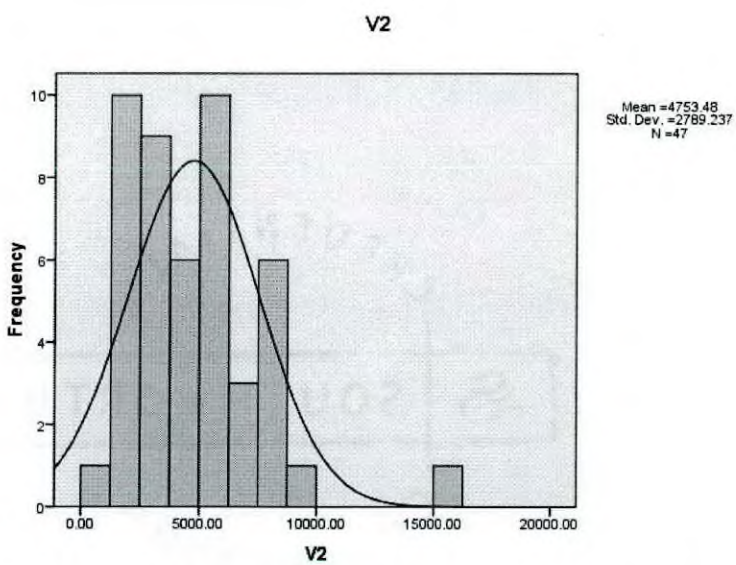


Figure 9: Nasopharyngeal volume of 12 year olds

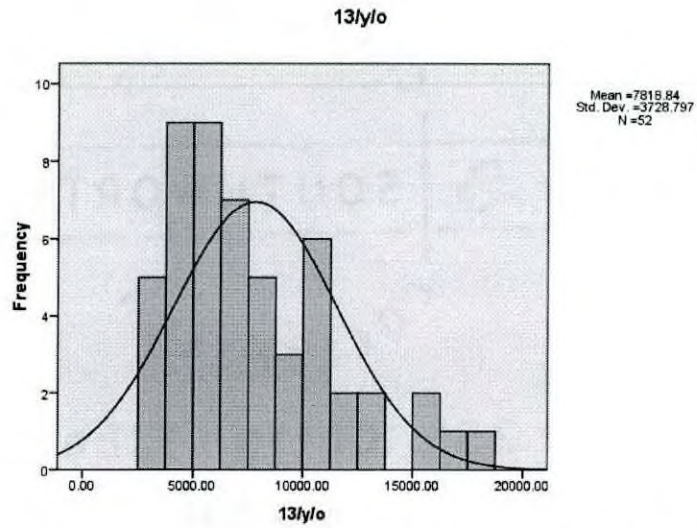


Figure 10: Oropharyngeal volume of 13 year olds

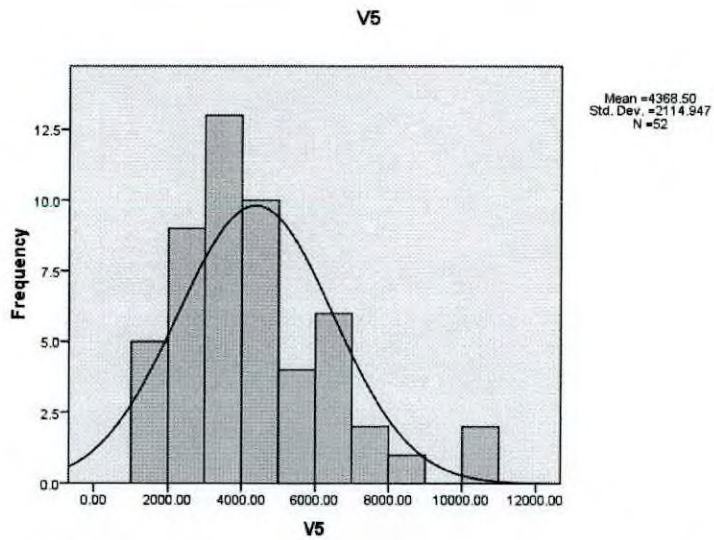


Figure 11: Nasopharyngeal volume of 13 year olds

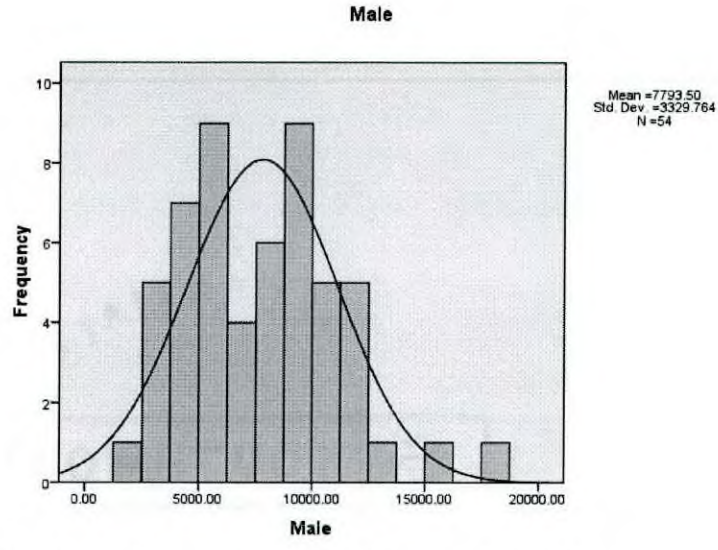


Figure 12: Oropharyngeal volume of males

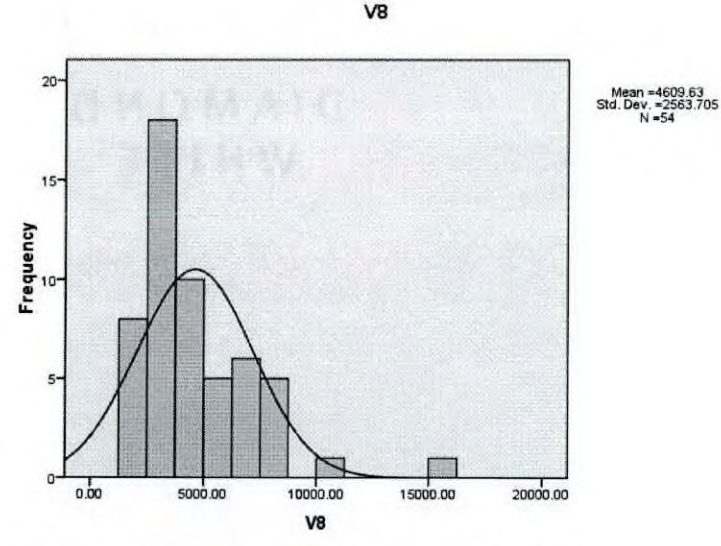


Figure 13: Nasopharyngeal volume of males

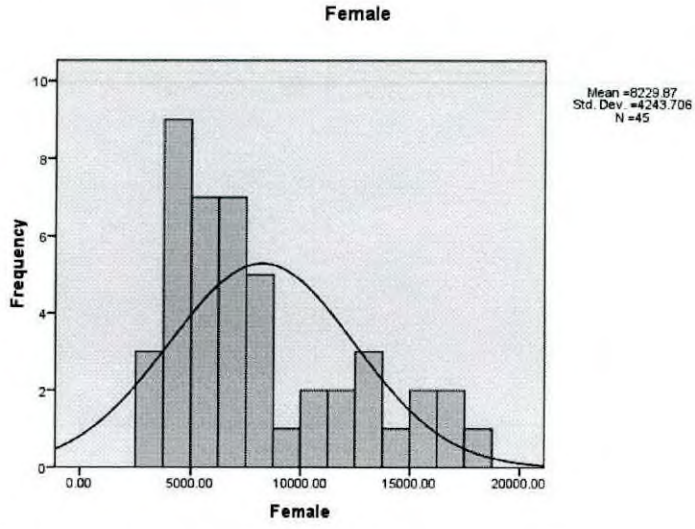


Figure 14: Oropharyngeal volume of females

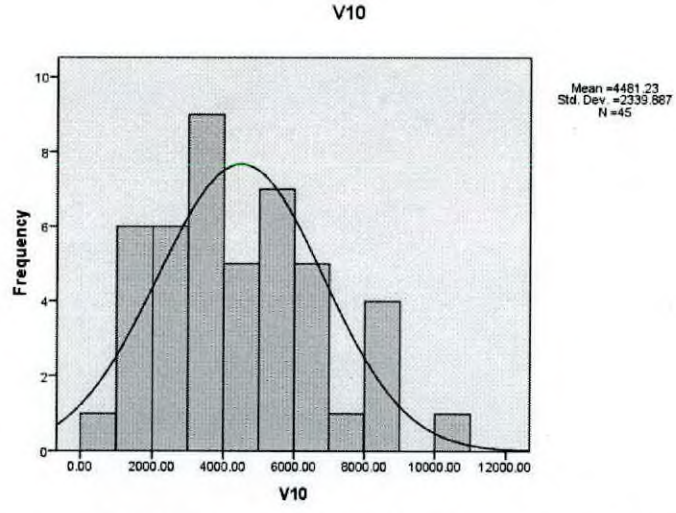


Figure 15: Nasopharyngeal volume of females

Appendix 5:

Raw Data: Intra examiner reliability

Table 7.—Error study, oropharyngeal and nasal passage airway volumes.

1	OP T1	OP T2	NP T1	NP T2
2	16893.07	15335.34	2461.45	2886.89
3	6233.05	5841.26	8838.37	7103.45
4	7893.40	6216.6	1580.99	2067.58
5	4481.91	4507.05	4417.41	3625.03
6	5666.20	5845.49	4604.25	4103.52
7	6437.17	6079.07	3451.00	3620.71
8	9998.95	10109.06	15601.01	14170.6
9	8944.03	8215.24	3805.37	3147.94
10	8111.23	8491.24	5073.16	3489.94
11	4802.20	4829.84	5748.16	4754.22
12	13248.42	12026.44	7437.16	5211.63
13	12323.96	11228.61	2169.98	2128.11
14	5557.78	5290.11	1665.34	1321.09
15	16599.86	15352.44	5605.55	5270.02
16	5112.67	4833.99	5238.52	4675.92
17	8763.15	8017.11	3998.40	3395.91
18	11616.02	9085.31	6083.93	7001.34
19	6763.85	9389.71	8767.96	4448.76
20	12589.44	11384.14	3297.84	3548.53
21	7167.35	6526.95	3175.57	3409.6
22	11623.58	8597.74	8657.39	7143.72
23	6108.92	6121.4	6769.17	5882.06
24	6821.55	7417.84	3692.88	3576.57
25	8789.33	8529.36	7579.11	6732.56
26	11040.45	9963.58	2933.75	3146.23
27	8070.12	7673.26	5821.66	4625.21
28	10919.41	10111.2	5247.78	4785.36
29	5588.80	4987.26	2926.68	2723.69
30	16000.04	14936.75	10071.40	9736.44
31	3374.63	3576.25	1141.17	1523.58
32				

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