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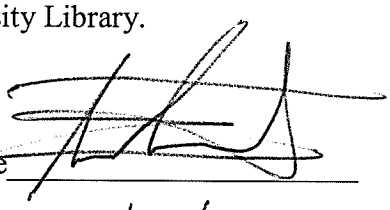
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WHEN STATIC MEETS DYNAMIC: COMPARING CBCT AND ACOUSTIC REFLECTION FOR UPPER AIRWAY ANALYSIS

By

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Submitted in partial fulfillment of the requirements for the degree of

Master of Science in Dentistry

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WHEN STATIC MEETS DYNAMIC: COMPARING CBCT AND ACOUSTIC REFLECTION FOR UPPER AIRWAY ANALYSIS.

Abstract

By

IOANNIS TSOLAKIS, D.M.D.

Objective: The aim of this study is to investigate the differences between cone beam CT and acoustic reflection in calculating airway volume. **Methods:** Subjects from the Orthodontic department at Case Western Reserve University were screened according to the selection criteria. A total of 59 subjects (mean age 15 ± 3.8 years) had their upper airway (5 different areas) measured from existing CBCT images, acoustic rhinometry, and acoustic pharyngometry. Volume and minimal cross section area were extracted and compared using SPSS to analyze the means. **Results:** All measurements showed great reproducibility with high intra-class reliability (>0.77). Data were mostly non-parametric. Means of total nasal volume were significantly different between the two methods (p value = 0.035*), the anterior nasal volume and the minimal cross-sectional area (MCA) had no significant differences (p=0.532 and 0.066 respectively). The pharyngeal volume between the machines had significant differences (p=0.01*) with high correlation (0.755) and the MCA of the pharynx showed no differences (p=0.109). **Conclusions:** Cone Beam Computed Tomography is an accurate method for the measuring of anterior nasal volume, nasal minimal cross sectional area, pharyngeal volume, and pharyngeal minimal cross sectional area. Further research is needed to confirm if it is also accurate when measuring the total nasal volume, since AR is not accurate in that region.

INTRODUCTION

Airway volume has been an area of interest for many physicians and orthodontists alike for over half a century. The upper airway volume measurement can be significantly important for the diagnosis of breathing disorders. Sleep-disordered breathing (SDB) was defined as report of loud snoring, gasping/choking or snorting, awakening with gasping or choking, or momentary periods of stopped or abnormal breathing occurring weekly. More than 20% of the adolescents snore at least a few nights per month, 6% snore every night or nearly every night. Apnea-like symptoms affect from 2.5% to 6.1% of adolescents (Marcus C.L., 2001). SDB affects the health of people or can be fatal in some occasions. A partial or complete collapse of the upper airway (UA) during sleep is the hallmark of sleep apnea. This collapse occurs at a discrete locus, which can be located between the choanae and the epiglottis.

Only until 2 decades ago, we are able to visualize the airways in the dimension that it is meant to be analyzed, by measuring the actual volume. Acoustic reflection (AR), first described over 25 years ago, has been used in many industries and perhaps one of the most important tool in studying the tomographic areas. This non-invasive diagnostic tool is mainly used in airway study by otorhinolaryngologists. It allows researchers to investigate the airway volumes and find minimum cross sectional areas. Its accuracy and reliability has been examined with focus at the anterior passage and the most constricted area in the nasal passage and in the oropharynx. Another benefit of the acoustic reflection is that the function is carried out and can be recorded, rendering real time event of the patients. The reflector does have its flaws that its error increases

as the airway becomes narrower and it does not insure image related to the anatomy of the airway. Twenty years ago we discover another imaging tool was discovered that would forever change the way we view radiographic images. Cone beam computer tomography (CBCT) was discovered by Robles RA in 1982 for angiography purpose (Govila S. and Gundappa M., 2007). This 3-dimensional machine generated hundreds of pictures to stitch the images together to form a 3 dimensional image.

As utilization of CBCT in orthodontic grows, orthodontists have reached out to use the CBCT to investigate the upper airway as well. As patients are screened at a young age, the benefit of detecting a SDB is greatly beneficial to our patients. In the past, one of the most common diagnostic tools for the airway volume is the lateral cephalometric X-ray. However, this machine generates two dimensional images without regarding the width of the anatomy, which raises questions with the use of CBCT regards to 3 dimension information. Comparing the two mentioned tools of airway measurement can enhance the use of the still image that CBCT generate. The question of how accurate is the CBCT airway volume measurement remains because of its static representation.

The aim of this study is to investigate the difference in CBCT and acoustic reflection in the measurement of airway volume. If there are differences between the two methods, quantification of the two methods will be performed.

Objective

1.) To determine the differences between the measurement of acoustic reflection and 3-dimensional imaging of the upper airway.

2.) To determine the correlation between the acoustic reflection and 3 dimensional imaging when measuring the upper airway

Hypotheses:

1.1 Null: There are no differences between the Cone Beam CT and acoustic reflection measurement of the airway volume.

1.2 Alternate: There are significant differences between the Cone Beam CT and Acoustic reflection measurement of the airway volume.

Dimensional information

2.1 Null: There are no differences between the Cone Beam CT and Acoustic reflection measurement of the minimum cross sectional area.

2.2 Alternate: There are significant differences between the Cone Beam CT and Acoustic reflection measurement of the minimum cross sectional area.

3.1 Null: There is a strong correlation between the two methods

3.2 Alternate: There is a weak correlation between the two methods

LITERATURE REVIEW

Upper airway anatomy

The upper airway is a complicated structure that is usually divided into 4 anatomical segments(Figure 1):

1. Nasopharynx: between the nares and hard palate
2. Velopharynx or retropalatal oropharynx: between the hard palate and soft palate
3. Oropharynx: from the soft palate to the epiglottis
4. Hypopharynx: from the base of the tongue to the larynx

This total structure forms a passage for movement of air from the nose to the lungs and also participates in other physiological functions such as phonation and deglutition (Nishino T. and Hiraga K., 1991). The properties of the upper airway are a compromise between these different functions, which variably require maintenance of patency (during breathing) or closure of the airway (as in swallowing).

There are 20 or more upper airway muscles surrounding the airway that actively constrict and dilate the upper airway lumen (Fouke et al., 1986 and Strohl KP and Fouke JM, 1985). They can be classified into four groups:

1. muscles regulating the position of the soft palate: alai nasi, tensor palatini, levator palatine
2. tongue: genioglossus, geniohyoid, hyoglossus styloglossus
3. hyoid apparatus: hyoglossus, genioglossus, digastric, geniohyoid, sternohyoid
4. posterolateral pharyngeal walls: palatoglossus, pharyngeal constrictors

These groups of muscles interact in a complex fashion to determine the patency of the airway. Soft tissue structures form the walls of the upper airway, and include the tonsils, soft palate, uvula, tongue and lateral pharyngeal walls (Schwab RJ et al., 1995). The main craniofacial bony structures that determine the airway size are the mandible (Rivlim J et al., 1984) and the hyoid bone (Lyberg et al, 1989); these presumably act by providing the anchoring structures to which muscles and soft tissue attach. In normal non-obese subjects, the mean minimum cross-sectional area across multiple segments of the upper airway has been measured using several techniques: estimates vary from 320 mm^2 (acoustic reflection, Ayappa and Rapoport 2003), 59mm^2 (fast CT at FRC, Burger et al., 1992) , 64mm^2 (MRI, Schwab et al., 1995), 144mm^2 (Suraat et al, 1983), 188mm^2 (Kuna ST et al., 1988) and 138mm^2 (Shepard JW et al., 1990) (conventional CT). This wide range in size reflects the differences due to individual variability but is also due to differing locations of measurement, positional change (sitting/supine), and differences imposed by the choice of imaging modality (e.g. mouth open is required for acoustic reflection). The minimum caliber of the upper airway in the wake state is primarily in the retropalatal oropharynx (Schwab et al, 1995 and Schwab et al., 1993), which makes it a site of interest as the potential location of collapse during sleep. The anterior wall of the oropharynx is composed primarily of the soft palate, tongue and lingual tonsils; and the posterior wall is bounded by a muscular wall made up of the superior, middle and inferior constrictor muscles that lie in front of the cervical spine. The lateral pharyngeal walls are a complex structure made up of muscles (hypoglossus, styloglossus, stylohyoid, stlylopharyngeus, palatoglossus, palatopharyngeus, and pharyngeal constrictors), lymphoid tissue and pharyngeal mucosa. This complexity of the interactions between these different muscles makes the oropharynx an extremely difficult structure to evaluate.

Upper airway imaging techniques have also been used to visualize the airway lumen and to define the surrounding structures. In awake subjects, Schwab et al., 1993, have shown that the normal upper airway has a longer lateral than AP dimension using MRI techniques.
In addition, by using fast cine CT, they also showed that airway size stays fairly constant during inspiration and reaches a minimum during end expiration, suggesting that muscular stabilization of the airway lumen during inspiration against the negative intraluminal pressure is more important than actual dilatation, as had previously been believed. According to these authors, most respiratory related changes (i.e. end-expiratory loss of diameter) are predominantly in the lateral dimension (Schwab et al., 1993).

The nasal passage

The nasal passages have a complex geometry. The anterior three-quarter of the nose is divided into two parts by the nasal septum. Entrance to these two cavities is through the nostrils, which are slightly slanted with respect to the hard palate about 45°. The nasal vestibule is a funnel-shaped region extending about 1 - 2 cm from the anterior tip of the nose and includes the nostril section. The vestibule leads to the constricted nasal valve region, the posterior boundary of which is roughly presumed to be the anterior limit of the inferior turbinate (Proctor D.F, 1982). The nasal valve, which has been conventionally defined as the site of narrowest cross-sectional area of the nasal passage posterior to the nostril opening, accounts for more than half of the total nasal resistance (Haight, S.J. and Cole, P. 1983). The nasal vestibule and valve region form a flow- limiting structure that is liable to disturb when the pressure difference between the ambient and the respired air in this portion of the airway exceeds a critical value. The nasal airway is, in fact, a dynamically changing structure. Most individuals demonstrate a

coordinated nasal cycle where the nasal passages on one side of the nose are occluded to various degrees due to tissue congestion for a certain period of time (Cole, P. 1982). This physiological effect will lead to dynamically changing differences in the airflow profiles on the two sides of the nose. At the constriction around the nasal valve region, the airway undergoes a right-angled bend toward the nasal floor, with a sudden increase in the coronal cross-sectional area of the passages (Proctor D.F, 1982). As a consequence, airflow in humans has been reported to become turbulent in this region (Cole, P. 1982). The region between the nasal valve region and the nasopharynx is referred to as the main nasal airway.

Pharyngeal airway

The pharyngeal airway is responsible for the physiologic process of swallowing, respiration and vocalization (Schwab RJ, and Goldberg AN., 1998). The pharynx lays posterior to the nasal cavity, the oral cavity and the larynx. The most superior part is posterior to the turbinates and continues inferior until it meets the esophagus. The hard tissue in the superior aspect of the pharynx is the sphenoid and the occipital bone (basilar part). The soft palate, tongue and glottis are also anterior structure of the pharynx as it extends inferiorly. Lymphoid tissues, muscles and adipose tissue forms part of the lateral wall. The pharynx is divided into 3 areas: nasopharynx, oropharynx, and hypopharynx. The nasopharynx is defined as the area posterior to the turbinates to the hard palate. Inferiorly, the oropharynx is divided into 2 sub-sections: retropalatal, which is extends from the hard palate to the tip of the soft palate, and retroglossal, which is the area from the end of the soft palate to the epiglottis. The last section is the hypopharynx, which refers to the cavity from the epiglottis to the esophagus. (Chapter 53: The pharynx and larynxhttps://www.dartmouth.edu/~humananatomy/part_8/chapter_53.html)

Airway and Craniofacial Development

In 1872, Tomes (Tomes CS., 1872) described the concept that facial form can be influenced by enlarged adenoids became accepted as hypothesis. Tomes' view was supported by many leading orthodontists including Todd and Broadbent in 1939 (Todd TW et al., 1939). In 1907, Angle (Angle E.H., 1907) included airway obstruction as an important etiological factor in malocclusion. The concept that postural relationships of the head, jaws, and tongue are established in the first moments after birth as the airway is opened and stabilized, and are altered as necessary thereafter to maintain the airway was published in 1962 by Shelton et al. The respiratory function is well known to have a significant influence on development of orofacial structures. According to Moss's Theory of Functional Matrix in 1969 (Moss ML., 1962), nasal breathing allows proper growth and with the development of the craniofacial complex interacting with other functions such as mastication and swallowing (Prates NS. et al 1997). Later on, Solow and Kreiborg came up with a hypothesis that a change in jaw posture that led to downward-backward rotation of the mandible, or a change in head posture such as head extension, could lead to stretching of the lips, cheeks, and musculature. The result would be upright incisors and narrower dental arches, which often (but not always) are observed in patients with a long-faced and open-bite growth pattern. (Solow B and Kreiborg S, 1977). This hypothesis suggests that the soft tissue in oral and pharyngeal areas is affected by the change of head position or tongue posture. According to Proffit in 1993, Nasal obstruction may lead to mouth breathing, which results in change of the tongue's position and half opened lips. This posture can influence the occlusion and oral cavity. Any obstruction in the upper airways whether due to malformation, nasal mucosa inflammatory reaction (rhinitis) or nasal septum

deviation will result in nasal obstruction forcing the patient to breathe through the mouth (Weckx and Weckx.,1995). The child with chronic mouth breathing, whether due to nasal obstruction or not, develops several morphological disorders during growth phase resulting in unfavorable dentofacial complex development Linder-Aronson S., 1970, Shendal SA., 1976 and Vig KLW., 1998). Abnormalities seen in obstructed airway include retroposition of the mandible and the maxilla, short mandibular body length and long anterior facial heights. At age ten, Behlfelt et al. 1990 reported that children with enlarged tonsils, and consequently different contours of the airway passages, displayed different cranio-facial morphology. The size of the pharyngeal airway space (PAS) has been suggested to be related to facial morphology in normal and diseased subjects. Several investigators (Harris 1959 and Muto T et al., 2006) concluded that head posture should be considered when measuring PAS as this change can significantly changes the PAS volume. In 2006 Muto et al, reported that a change of head posture of 10 degree can change the PAS up to 4 mm. Lessa et al in 2005 found that mandibular plane inclination in mouth breathing children was higher than that of nasal breathing children. Kawashima et al. in 2002 and Kerr et al.1989 reported the same findings in younger children in pre-school age (3 to 6 years): mandible may be retrognathic and posteriorly inclined, particularly if the level of respiratory obstruction ranges from moderate to severe. This condition could determine the increase in anterior facial height due to clockwise mandibular displacement, showing a vertical growth pattern in older children (11 to 14 years) as reported by several authors (Yang at al. 2002, Vig K.,1998 and Fields et al. 1991), however, suggested that causal association between nasal obstruction and facial growth in children seem to be of multi-factorial nature. Lessa et al (2005) also concluded that Mouth breathing children tend to present increased mandibular inclination, vertical growth pattern with changes in normal facial proportions, characterized by increased

anterior lower facial height and decreased posterior facial height in mouth breathing children, therefore evidencing the influence of respiratory function in craniofacial development. Celikoglu et al found different relationship in the nasopharyngeal airway volume and oropharyngeal airway volume in the high-angle group to be lower than that of the low- and normal-angle groups (p value< .01). Total airway volume was highest in the low angle group and lowest in the high-angle group, concluding that airway volume found in pharyngeal area differs among different skeletal vertical patterns (Celikoglu M et al., 2014). El and Palomo, 2010, found differences in the oropharyngeal volume of class II malocclusion subjects when compared to other occlusal types.

The mean OP airway volume of subjects with retruded mandibular positions was statistically significantly smaller when compared with the subjects with higher SNB angles. The area of the most constricted region was suggested to be at the base of the tongue (El and Palomo 2011). The maxilla was more retrognathic in mouth-breathing patients than in patients that primarily breathe through their nose (Ucar et al., 2012). Additionally, the palatal plane had a posterior rotation in mouth-breathing patients. Findings such as shorter maxillary length, more proclined maxillary incisors, thicker and longer soft palate, narrower maxillary arch and higher palatal vault in were present in subjects with reduced airway volume (Indriksone and Jakobsone., 2014). As these research findings concluded that airway volume causes the craniofacial complex to differ in morphology, research suggesting that the craniofacial morphology was the factor determining the airway volume could not be concluded as the results suggest that craniofacial morphology alone does not have a significant influence on upper airway dimensions (Gungor and Turkaharamanb., 2009).

Airway measurements

In modern respiratory medicine, objective measurement of airway patency is a must. In the upper airways, there is need for an equally rigorous standard of measurements. Measurement of nasal cavity geometry has proven to be a great challenge for researchers in modern rhinology. A number of techniques have been used to study the airway including nasal pharyngoscopy, cephalometric radiographs, fluoroscopy, conventional and electron beam computed tomography (CT), acoustic reflection and magnetic resonance imaging (MRI)(Welch. KC et al., 2002). Although MRI is considered to be very accurate in measuring the soft tissue lining, fat pad, surrounding structures of the airway in 3 Dimension, it is not as useful in orthodontics because it emphasize in the soft tissue more. Patel et al in 2006 reported that subjects with fixed orthodontics appliance made from metal can produce artefact and obscure the area of the image. Orthodontists have been taking radiographic x-ray for a century in 2 dimensions. Airway obstruction was assessed in lateral cephalograms and was found useful in adenoid hypertrophy and very constricted airwayFilho D et al., 2001). However, it is an image with incomplete information as it is not a true 3 dimensional structure that is being measured. As obstruction of the airway is a major concern, some studies suggest that nasoendoscopy holds the position of gold standard diagnosis for upper airway obstruction at present. But nasoendoscopy has drawbacks as well; mainly, it allows little opportunity for objective measurement but instead relies on professional opinion, often causing low inter-observer agreement (Major M et al., 2006). Acoustic rhinometry/pharyngometry and CBCT are more widely used in otolaryngology and orthodontic, respectively. Current trends are transitioning to CBCT as it gives a 3 dimensional image and can be used to look at hard tissue structures precisely. However, in upper

airway measurement there is still a difference in what professionals use to measure the volume and the area.

Accoustic rhinometry

The acoustic rhinometry is the most common method used in upper airway measurement. Acoustic rhinometry (AR) was introduced by Hilberg et al., 1989, as an objective method for examining the nasal cavity. This technique is based on the principle that a sound pulse propagating in the nasal cavity is reflected by local changes in acoustic impedance. AR is a simple, noninvasive technique, and as such it became widely accepted in a short period of time. Most previous investigations of living human subjects have demonstrated reasonably good agreement between the cross-sectional areas in the anterior part of the nasal cavity determined by AR and those determined by imaging techniques such as MRI and computed tomography (CT). However, this does not hold true for the posterior part of the nasal cavity and the epipharynx, where AR significantly overestimates cross-sectional areas compared with MRI and CT scans. There have so far been few attempts to validate AR by comparison to other methods, including nasal casting, fluid- displacement and magnetic resonance imaging (MRI). Kaise et al. 1999 estimated that AR only measured 70% of nasal cavity volume in guinea pigs, and have validated acoustic rhinometry post mortem in guinea pigs and rats by comparison to a fluid-displacement-method (FDM). Cakmak and coworkers conducted a clinical study of 25 healthy adults that focused on the nasal valve region in particular (Cakmak O et al, 2003). The results showed that AR is a valuable method for measuring the passage area of the nasal valve. The authors found a significant correlation between the passage areas of the nasal valve determined by AR and CT, when CT imaging was done perpendicular to the curved acoustic axis (Hilberg O

et al. 1989). As reliability is a topic that is currently in question, Numminen and associates used CT volumetry (CTV), which is the one of the best imaging modalities available for evaluating the nasal cavity and paranasal sinus geometry, to compare the measurement attained from AR (Numminen J et al., 2003). CTV has been demonstrated with a phantom test, showing 1% error in segmented volumes when compared with actual volumes. Numminen concluded that AR is a clinically reliable method for measuring the nasal cavity in the anterior and middle parts. However, the question nasal passage is still questionable as reflection and reduced energy is reflected and accurate measurement is not obtainable after waves passes through a smaller area. Wang et al noted that when the MCA is smaller than $0.2cm^2$, a common condition in the early-phase reaction, area-distance measurements beyond this point can be misinterpreted and should be considered with caution (Wang DY et al., 2004).

Rhinometer used in this study is a transient-signal acoustic rhinometer (Ecco Vision, Hood Instruments, Pembroke, MA). A spark generator produces a sound pulse with bandwidth ranging from 100 Hz to 10 kHz. A 10-kHz low-pass filter was used to reduce the errors associated with cross modes in the human nasal cavity. Acoustic rhinometry is based on the physical principle that the impedence of a tube to a pressure wave of sound (over 250Hz) is dependent on local changes in geometry. Hence, by analyzing the amplitude of sound reflected from a 'tube' such as the nasal cavity, an estimate of cavity geometry can be produced by microcomputer software as a plot of cross-sectional area against distance from the nostril (Figure 2,3)(Fisher et al, 1994). This principle is based on the relation:

$$Z = rC/A$$

Where: Z is impedance (resistance), r is the density of gas traversed by the acoustic wave, C is the wave velocity, and A is the diameter of the tube. If we consider r a constant and C equal to 0, we may deduce that the impedance is inversely proportional to the cross-section of the tube:

$$A = 1/Z$$

The amplitude and frequency of reflected waves depend on the airway area, while the time taken for the reflected wave to return is a function of distance. Therefore the relation "pressure/time" may be changed into "cross-sectional area/distance" (Kamal I., 2001). Consequently, reductions in the anatomical space - in particular the diameter, will produce changes in the intensity of the reflected wave and in the time taken for the reflected wave to return from a given anatomical structure to the microphone. Four minimum nasals cross- sectional areas at defined distances and volumes of specified parts of the cavity can be derived by further manipulation of the data. The sound passes into the nasal cavity via a perspex nosepiece which fits snugly in the nostril (but without deformation), and on reflection from the nose the sound is detected by a microphone. After amplification, filtering and digital conversion, the data is analyzed by the NADAR™ program (Nasal Area Distance by Acoustic Reflection) on an mM compatible computer. Three readings are taken from each nostril Sound waves are sent up the nasal passageway and they are reflected back out in such a way that the Eccovision® Acoustic Rhinometer can accurately map out the topography of the nasal airway. This allows us to clearly identify the location and severity of any obstruction in the airway. The acoustic pulse is partially reflected when it encounters an area (impedance) change. The amplitude and temporal changes in the reflected pulse compared with the incident pulse are used to calculate, by computer, the changes in airway cross-sectional area. Acoustic reflection signals from the nose are collected by a microphone, analyzed with an analog to digital

conversion by a computer, and processed to determine the minimal cross-sectional area (MCA) and total volume of the nasal cavity (Zweiman et al., 1997). The test is completely non-invasive and takes 30 seconds to complete. For each subject, a properly fitted nosepiece was selected and a thin layer of ointment was applied to prevent any acoustic leakage from the junction between the nostril and nosepiece. Special care was taken not to distort the nasal valve anatomy and to position the nosepiece such that it was only in light contact with the nostril during the assessment.

In a graph generated by the rhinometry, the x-axis represents the distance into the nasal cavity, and the y-axis represents the 2-dimensional area relative to distance. This shows the cross sectional area as sound travel into the nose. A total volume is calculated by using the area under the graph with a specific distance from the nostrils through the valve and into the nasal turbinate.

Pharyngometry

The acoustic reflection technique has been used to assess pharyngeal cross-sectional area. The technique has been previously applied to study the pharynx, glottis, and trachea in humans in vivo. The technique has been validated against computed tomography scans and experimental models(Wright S et al., 1989). Unlike the nose, the oropharyngeal airway is geometrically more complex and variable and includes mobile structures (soft palate and tongue); therefore establishing a standard operating protocol and understanding of the possible sources of artifacts is of great importance in obtaining reliable results. Of equal importance is testing the repeatability of measurements obtained to ensure validity of both the technique and results.

The Eccovision™ Acoustic Reflection Pharyngometer (Hood Laboratories, Pembroke, MA) provides a non-invasive assessment of the dimensions, structure and physiological behavior of the upper airway from the oral cavity to the hypopharnyx while the patient breathes. Computer processing of the incident and reflected sound waves from the airways provides an area distance curve representing the lumen from which minimal cross-sectional area and volume can be derived(Figure 4). This dynamic test measures the dimensions of the airway through the oral cavity and 25 cm down the pharynx. This device is marketed as a screening method to quickly assess a patient for potential sites of sleep-related upper airway obstruction, and to better determine whether an oral appliance or continuous positive airway pressure is more appropriate for the patient.

In a study to ascertain whether the Eccovision reflectance pharyngometer could assess the anatomical structure of the upper airway in young children, Hatzakis et al (2003) found that the Eccovision pharyngometer does not reliably assess pharyngeal volumes in a pediatric population. However, Gelardi et al (2007) assessed variations of pharyngometric parameters in patients with sleep disorders and established a correlation between morpho-volumetric variations of oropharyngo-laryngeal spaces and the presence and severity of disease. A total of 110 patients, of which 70 with sleep disorders and 40 healthy patients as a control group were analyzed. All patients underwent acoustic pharyngometry to evaluate the mouth and hypopharynx. A significant difference in parameters was observed between sleep disorder patients and the control group, especially in patients with macroglossia. The authors concluded that although not a standardized test, acoustic pharyngometry was proven to be a useful method both in the diagnosis and severity of OSA, and in post-operative monitoring of upper airway surgery in patients with sleep disorders. In 2004, Kamak showed that measurements of pharyngeal

cross-sectional area in different session on the same day did not differ significantly from those obtained in different days. Provided that a standard operating protocol is adopted and maintained, repeatability of acoustic reflection results can be achieved. This adds to the reliability of this technique in assessing the pharyngeal airway in snorers and patients with obstructive sleep apnea. Posture may play an important role in determining the pharyngeal area. Flexion of the neck and back as well as raising the shoulders (which occurs near residual volume) may compress the pharynx and decrease its cross-sectional area; consequently, control of posture is important for proper interpretation (Brown IG et al., 1986). Marshall et al (1993) compared acoustic measurements of the pharyngeal and glottal areas in human volunteers during free breathing with MRI measurements of the same areas and showed that there is no statistically significant difference between measurements taken using either technique. Several studies have validated the accuracy and reproducibility of the acoustic pharyngometry (Brooks LG et al., 1984 and D'Urzo AD. Et al., 1987). Hoffstein and Fredberg reported that using acoustic reflective method can accurately measure the upper airway and is highly reproducible (Hoffstein V and Fredberg J.J., 1991). In 1992, Brooks and Strohl studied 222 normal volunteers and concluded that gender was the most important independent factor contributing to pharyngeal size (3.63 ± 0.1 in males and 3.2 ± 0.09 in females). Some studies (Brown IG. et al., 1986 and Brooks et al., 1989) identified the geometric configuration of the acoustic pharyngogram as the structure extending from the mouthpiece to the minimum area of the curve identified as the glottis. Acoustic pharyngometry can be a clinically useful tool for localizing the narrowed portion of the upper airway and predicting obstructive sleep apnea (Jung DG et al., 2004)

Cone Beam Computed Tomography

Cone Beam CT is a medical imaging modality, which has been applied in different fields of medicine (e.g. cardiac imaging, radiotherapy). The principle behind this technique, as its name implies, is a cone-shaped X-ray bundle, with the X-ray source and detector (Image Intensifier or Flat Panel Detector) rotating around a point (or field) of interest of the patient. The conical shape of the beam distinguishes this technique from helical CT, which used a fan-shaped beam. As a result of the acquisition of two-dimensional projections throughout this rotation, only one rotation or less is needed to acquire a full (three-dimensional) dataset. The images received by the detector are then compiled by the computer into volumetric data (primary reconstruction). During a CBCT scan, the scanner (x-ray source and a rigidly coupled sensor) rotates, usually 360 degrees, around the head to obtain multiple images ranging from approximately 150 to 599 unique radiographic views. The scanning software collects the raw image data and reconstructs them into viewable formats. The scan time can range between five and 40 seconds, depending on the unit and protocol setting. The x-ray source emits a low milliampere and a shaped or divergent beam. The beam size is constrained by a circular or rectangular collimator to match the sensor size, but in some cases it can be constrained (collimated) further to match the anatomical region of interest. After the scan, the resultant image set or raw data are subjected to a reconstruction process that results in the production of a digital volume (a cylindrical or spherical shape that is composed of volume elements called "voxels" that are stacked in rows and columns) of anatomical data that can be visualized with specialized software. Voxels are the smallest subunit of a digital volume. CBCT voxels generally are isotropic (that is, X, Y and Z dimensions are equal) and range in size from approximately 0.07 to 0.40 millimeters per side. Each voxel is assigned a gray-scale value that approximates the attenuation value of the represented tissue or

space. The latest generation of CBCT units produces 12- or 14-bit images in which 12 bits is 2^{12} (4,096) shades of gray and 14 bits is 2^{14} (16,384) shades of gray. Computer monitors used to visualize the 12- or 14-bit digital or voxel volume can display only eight bits (256 shades) of gray at a time. The software uses a technique called "windowing and leveling" that allows the operator to access and visualize all of the data (Hatcher 2010). Windowing allows the data to be scrolled through, thus visualizing eight bits at a time with air and soft tissues (low-attenuation structures) at one end of the spectrum, bone and teeth (high-attenuation structures) at the other end of the spectrum. Once the optimum window level has been achieved, the contrast and brightness (leveling) are adjusted by the clinician for optimal viewing. The small isotropic voxel size along with the large number of gray levels have contributed to accuracy and precision when clinicians measure the dimensions of anatomical structures and visualize anatomical form.(Ludlow JB et al, 2009; Chung et al., 2009 and Honey et al 2007).

The diagnostic value of an imaging study needs to be balanced against the risk to the patient and the cost of service. The trend for CBCT use has been to apply it clinically and then validate its utility scientifically. CBCT technology has several beneficial applications in the clinical setting. In terms of spatial resolution of CBCT, Ballrick et al reported the CBCT had a tendency to underestimate the actual distant of a measurement. This underestimation occurred in 94.4% of the measurements; however, the error is less than 0.1 mm, which may be clinically insignificant. (Ballrick J.W et al. 2008). In 2011, a study found that measurement of CBCT image can be accurate and reproducible with very high inter or intra observers agreement (Kamburoglu K et al. 2011).

CBCT and airway measurement

With the introduction of computed tomography (CT), shortcomings of lateral cephalograms have been prevented. Despite the widespread use of CT examinations in clinical practice, this new technology brought along concerns about the exposure to ionizing radiation and its potential hazards. Therefore, radiation dose and strategies for dose reduction, especially for younger patients, have become an important focus of interest. With the advent of cone beam CT (CBCT), lower radiation doses and faster image acquisition times has become possible. Osorio et al (2008) suggested that CBCT has the potential to eventually emerge as a comprehensive and practical system to evaluate the airway, and should become an excellent research and teaching tool for understanding the normal and abnormal airway. The axial plane, which is not visualized on a lateral cephalogram, is the most physiologically relevant plane because it is perpendicular to the airflow. Three Dimensional imaging considers all planes of space, which is important in airway assessment and volumetric measurement. In 2003, Aboudara et al. reported one of the first studies that tried to measure the volume of the nasopharynx in CBCT. The authors compared the volume of the nasopharynx to its area measured on cephalograms. They concluded that the variability of the airway volume was greater than that of the airway area. The accuracy of airway measurement with CBCT can be achieved by segmentation of the image, which is the evaluation of the size, shape, and volume of the upper airway starts by defining the volume corresponding to the airway passages. In medical imaging, segmentation is defined as the construction of 3D virtual surface models (called segmentations) to match the volumetric data (Grauer D et al., 2009). Upper airway segmentation can be either manual or semiautomatic. In the manual approach, the segmentation is performed slice by slice by the user. The software then combines all slices to form a 3D volume. This method is time-

consuming and almost impractical for clinical application. In contrast, semiautomatic segmentation of the airway is significantly faster than manual segmentation (El and Palomo 2010). In the semiautomatic approach, the computer automatically differentiates the air and the surrounding soft tissues by using the differences in density values (grey levels) of these structures. In some programs, the semiautomatic segmentation includes 2 user-guided interactive steps: placement of initial seed regions in the axial, coronal, and sagittal slices, and selection of an initial threshold. Scendel and Hatcher used 3dMD software that performs semi-assisted metric analysis of the human airway image from CBCT and found that in comparison to a phantom, no significant differences were found between the volumes (calculated by weight) and the software from the CBCT image (Schendel and Hatcher, 2010.) Tso et al suggested that CBCT measurement if the upper airway is a feasible and reliable technique to quantify airway volume and minimal cross section of living human subjects. In this study they reported that subjects can be in supine or up righted position with normal breathing (Tso HH. et al., 2009). They also found that an awake , uprighted and normally breathing subjects had variation in its most constricted region but all located in the oropharynx area. Weissheimer et al (2012) suggested that in the upper airway measurement, InVivo Dental, OnDemand, Mimics, Dolphin3D, ITK-Snap, and OsiriX imaging software programs were reliable but had errors in the volume segmentations of the oropharynx. Mimics™, Dolphin3D™, ITK-Snap™, and OsiriX™ were similar and more accurate than InVivo™ Dental and Ondemand™ 3D for upper airway assessment. This finding was consistent with El and Palomo (2010).

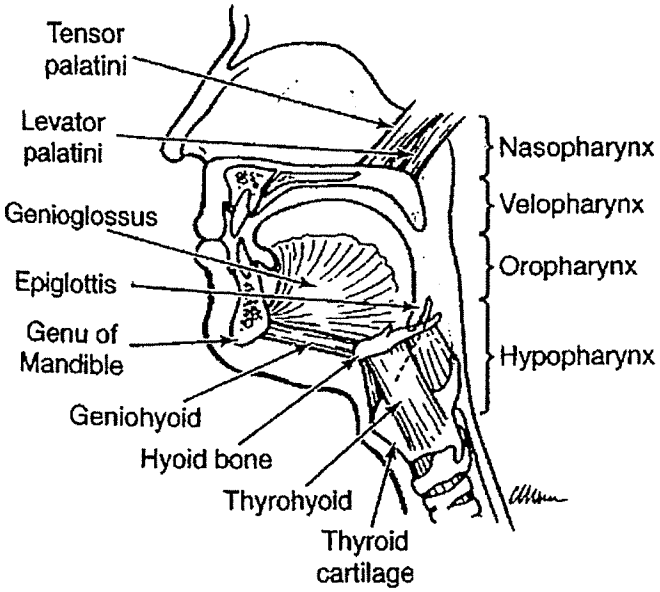


Figure 1. Illustration showing the pharyngeal area and its sections: nasopharynx, velopharynx, oropharynx and hypopharynx. From Anatomy and Physiology of Upper Airway Obstruction. Samuel Kuna and John E Remmers 840±858

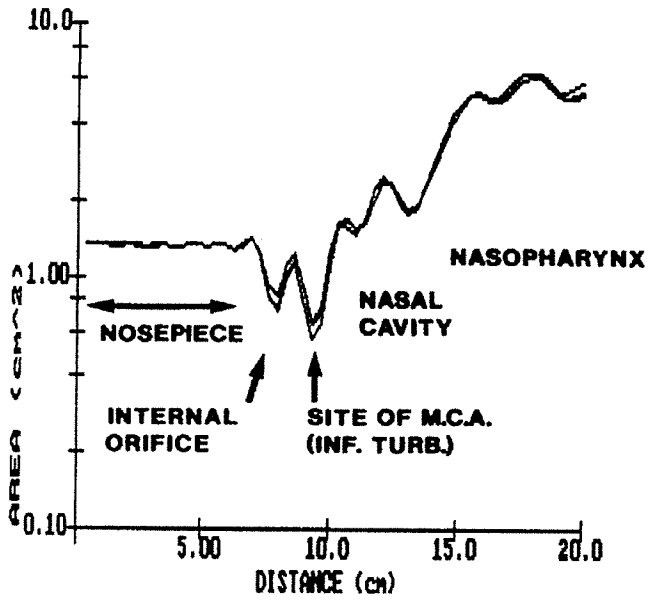


Figure 2. A plot of cross-sectional area against distance from the nostril

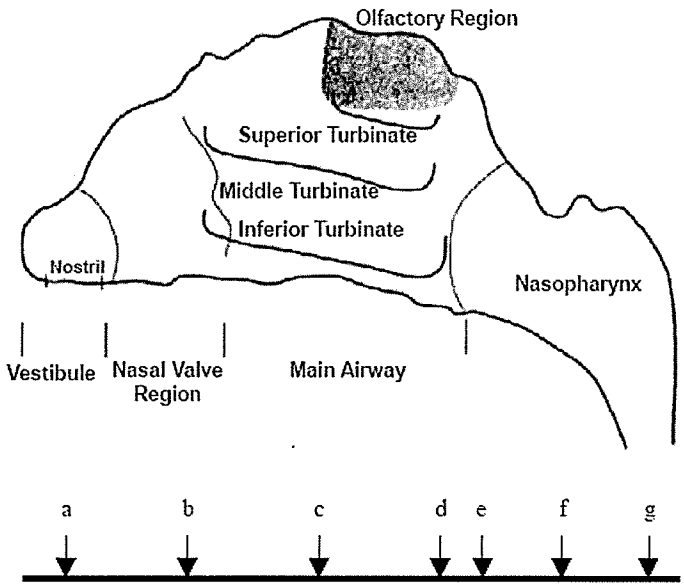


Figure 3. In this graph, the x-axis represents the distance into the nasal cavity, and the y-axis represents the 2-dimensional area relative to distance.

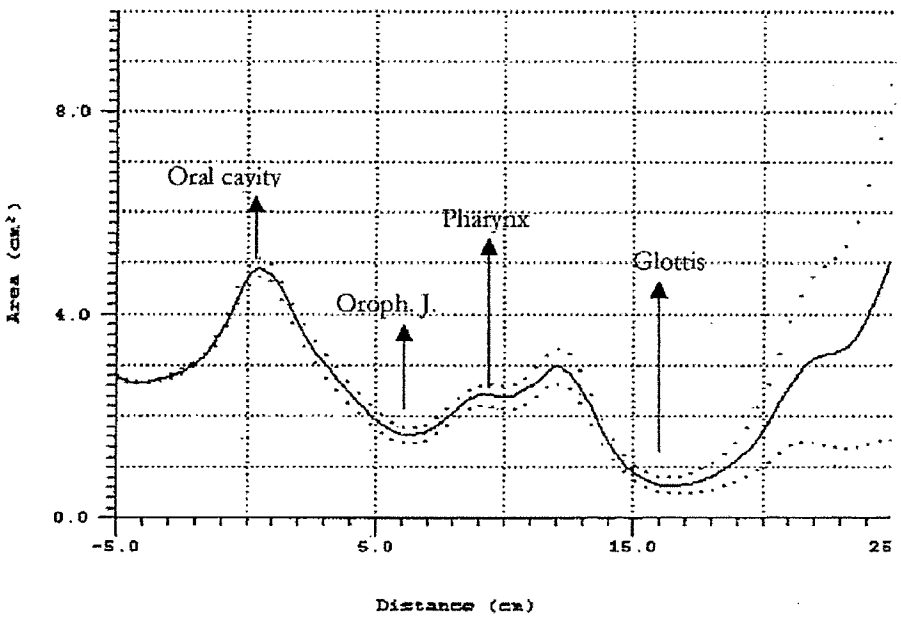


Figure 4. Graph illustrating cross sectional area and distant from the oral cavity into the pharynx generated by acoustic pharyngometry

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STATEMENT OF THESIS

The aim of this study is to investigate the differences between cone beam CT and acoustic reflection in calculating airway volume. If there are differences between the two methods, quantification of the two methods will be performed. It is hypothesized that there is no difference between the two methods of upper airway measurements.

Manuscript

WHEN STATIC MEETS DYNAMIC: COMPARING CBCT AND ACOUSTIC REFLECTION FOR UPPER AIRWAY ANALYSIS

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Abstract

Objective: The aim of this study is to investigate the differences between cone beam CT and acoustic reflection in calculating airway volume. **Methods:** Subjects from the Orthodontic department at Case Western Reserve University were screened according to the selection criteria. A total of 59 subjects (mean age 15 ± 3.8 years) had their upper airway (5 different areas) measured from existing CBCT images, acoustic rhinometry, and acoustic pharyngometry. Volume and minimal cross section area were extracted and compared using SPSS to analyze the means. **Results:** All measurements showed great reproducibility with high intra-class reliability (>0.77). Data were mostly non-parametric. Means of total nasal volume were significantly difference between the two methods (p value = 0.035*), the anterior nasal volume and the minimal cross-sectional area (MCA) had no significant differences (p=0.532 and 0.066 respectively). The pharyngeal volume between the machines had significant differences (p=0.01*) with high correlation (0.755) and the MCA of the pharynx showed no differences (p=0.109). **Conclusions:** Cone Beam Computed Tomography is an accurate method for the measuring of anterior nasal volume, nasal minimal cross sectional area, pharyngeal volume, and pharyngeal minimal cross sectional area. Further research is needed to confirm if it is also accurate when measuring the total nasal volume, since AR is not accurate in that region.

Introduction

The measurements of the upper airway can be significantly important for the diagnosis of breathing disorders. A partial or complete collapse of the upper airway (UA) during sleep is the hallmark of sleep apnea. Sleep-disordered breathing (SDB) was defined as weekly occurrences of a) loud snoring, b) gasping/choking or snorting, c) awakening with gasping or choking, or d) momentary periods of stopped or abnormal breathing.[1] More than 20% of the adolescents snore at least a few nights per month, 6% snore every night or nearly every night, and apnea-like symptoms affect from 2.5% to 6.1% of adolescents.[1] Even though sleep studies are still the official method to diagnose SDB conditions, using imaging techniques, the clinician is able to assess potential risk factors on their patients, for a more complete pre-treatment diagnosis. Airway analysis usually consists of nasal passage and oropharynx volumes and assessment of areas of maximum constriction. Acoustic reflection (AR), first described over 25 years ago, has been used in many industries and is probably one of the most accepted tools for studying the airway.[2-4] This non-invasive technique uses sound waves that go through the airway and back, collecting data and calculating volumes and areas of maximum constriction. Its accuracy and reliability have been examined with special focus on the anterior nasal passage, and the most constricted area in both nasal and oropharynx. Acoustic reflection encounters some limitations when the airway becomes narrower, and the sound waves have difficulty getting back to the sensor.[2-4] The acoustic pharyngometry technique has been validated against computed tomography scans and experimental models.[5] Hoffstein and Fredberg reported that using acoustic reflective method can accurately measure the upper airway and is highly reproducible.[6]

Cone beam computer tomography (CBCT) was created by Robles RA in 1982 for angiography purpose.[7] CBCT captures different images while rotating around the patient's head, and creates a

3D volume, in a similar way as computed tomography, but in a volumetric way which allows a single rotation, resulting in much lower radiation doses. Further changes in the capturing methods used by CBCT has recently allowed for less radiation to the patient than traditional two-dimensional radiographs.[8]

Aboudara et al reported one of the first studies that tried to measure the volume of the nasopharynx in CBCT, and concluded that airway measurement with CBCT can be accurately achieved by segmentation of the image.[9] In medical imaging, segmentation is defined as the construction of 3D virtual surface models to match the volumetric data.[10] Upper airway segmentation can be either manual or semiautomatic. In the manual approach, the segmentation is performed slice by slice by the user. This method is time-consuming and almost impractical for clinical application. On the contrary, semiautomatic segmentation of the airway is significantly faster than manual segmentation.[11] Tso et al suggested that CBCT measurement of the upper airway is a feasible and reliable technique to quantify airway volume and minimal cross section of living human subjects.[12] El and Palomo tested manual to different methods of semiautomatic segmentation, and found that different software give different values, but show great correlation, suggesting systematic error.[11] Weissheimer et al confirmed those conclusion, and reported that upper airway measurement using Mimics, Dolphin3D, ITK-Snap, and OsiriX were similar and more accurate than InVivo Dental and Ondemand 3D.[13]

The question of how useful and complete is the CBCT airway assessment is still controversial since it is based on a static capture, while the airway is a dynamic structure.

The aim of this study is to compare CBCT upper airway analysis to the dynamic acoustic reflection method.

Materials and Method

Institutional Review Board approval was obtained prior to the start of this study. Subjects were recruited from the Craniofacial Imaging Center at Case Western Reserve University in Cleveland, Ohio. Inclusion criteria consisted of subjects seeking orthodontic treatment whose records included CBCT images and acoustic reflection. Subjects with existing intra oral appliances, congestion, or asthmatic conditions were excluded. A sample size calculation was performed by using a pilot study with 10 subjects, suggesting 39 subjects for a confidence level of 95%. A sample of 59 subjects were recruited and used in this project.

Acoustic reflection consists of two separate analysis with separate sensors, acoustic rhinometry (ACRh) and acoustic pharyngometry (ACPh). ACRh is used to measure nasal cavity and requires a nasal mask, while ACPh is for pharyngeal areas and uses a mouth piece (Figure 1). For all subjects, the CBCT, acoustic rhinometry (ACRh), and acoustic pharyngometry (ACPh) were taken on the same day, by a single operator, with the patient sitting on the same chair, with the same head orientation. Calibration and orientation of the acoustic techniques were performed prior to each measurement. Patients were instructed to breathe normally during the measurement, and four separate measurements were taken for each ACRh and ACPh (Figure 2). The graphs generated by ACRh and ACPh show different areas of constriction on the X-axis and y-axis showing the distance that sound has traveled. The areas under the graphs represent the volume at a certain distance. For ACRh, we calculated the area under the graph to the first most constricted area, which is often identified as the nasal valve. ACRh reported the area in this region and is recorded as the anterior most constricted area.

All CBCT images were imported into Dolphin 3D Imaging program version 11.0 (Dolphin Imaging and Management Solutions, Chatsworth, CA), where they were oriented according to

Wu's technique (Figure 3).[14] Data collected from the CBCT image included total nasal volume (CBRh), anterior nasal valve volume (CBNasal), nasal minimal cross sectional area (CBNx), pharyngeal volume (CBPh), and pharyngeal minimal cross sectional area (CBPx) (Figure 4): For all nasal data, after orientation of the skull, a vertical plane is constructed perpendicular to the horizontal border. The vertical plane is then used to rotate the axial slice 90 degrees, making it parallel to the horizontal line. After the skull is properly oriented, borders of the nasal passage are drawn on all three slices: axial, coronal and sagittal. The naso-pharyngeal volume (NP) was defined as being the pharyngeal volume located between the palatal plane and a parallel plane passing through the last axial slice before the nasal septum fused with the posterior pharyngeal wall. The minimum cross sectional area for that volume was also calculated. The nasal valve was identified using the cross sectional slices right before the passage was slit into several narrow pathways (Figure 5).

All pharyngeal data was collected from a pre-determined pharyngeal area. The superior border starts by moving downwards parallel to the palatal plane (ANS to PNS) until it reaches the end of the uvula in the axial plane. The glottis marks the most inferior point in this cavity, which is has a prominent notch after the epiglottis. The volume in this cavity is generated with its minimal cross sectional area (figure 5).

All CBCT, ACRh and ACPh data were imported into a Microsoft Excel spreadsheet (Microsoft Corporation, Redmond, WA, USA.) and Statistical analysis was performed using SPSS Version 22 (IBM Corporation, Armonk, NY, USA). Normal distribution of the data was tested using Shapiro Wilk's test. The only variables showing normal distribution were CBRh, CBNasal, and ACNasal. Paired t tests were used for variables showing normal distribution, and Wilcoxon sign rank test was used for data not normally distributed.

Results

The sample included 59 subjects, with 34 females, and a mean age of 15.4±3.8 years (Table 1). The operator's reliability was calculated using intraclass correlation on 20 randomly selected subjects, whose data was re-measured 2 weeks apart. All measurements with both CBCT and Acoustics Reflection methods were highly reliable (Table 2).

Nasal cavity

The mean total nasal passage volume was 10462 mm^3±2726 for CBCT, and 9194.7 mm^3 ± 4224.7 for acoustic rhinometry. There was significant difference between the two methods (p=0.035*). The CBCT measured slightly higher volume than the acoustic rhinometry method. The two measurements showed low correlation (r=0.274) (Table 3).

Anterior nasal valve volume measured by CBCT had a mean 2,787.02 mm^3±845.59 and acoustic rhinometry had 2544.2 mm^3±1045.3. There was no significant difference between the two different methods (p=0.532) (Table 3).

The means the minimal area cross section of the nasal valve between CBCT and acoustic rhinometry had no statistical significant difference (p= 0.066) with respective means of 125.7 mm^2±44.6 and 128.6 mm^3±47.3. The two methods were highly correlated (r=0.974).

Pharyngeal cavity

Pharyngeal volume measured by CBCT had a mean of 12,062mm^3±4,471.36 while acoustic pharyngometry showed 11,303.63 mm^3±6,325.034. There was significant difference between the two methods (p=0.01). CBCT tender to show higher values than the acoustic pharyngometry method. The two methods were highly correlated (r=0.755) (Table 3).

The mean the minimal area cross section of the pharyngeal space between CBCT (78.23 $mm^2 \pm 44.96$) and acoustic pharyngometry (75.11 $mm^3 \pm 49.04$) showed no statistical significant difference ($p=0.109$). The two methods were also highly correlated ($r=0.944$) (Table 3).

Discussion

This study compared a CBCT and Acoustic Reflection (AR) methods, for the measurement of nasal and pharyngeal volumes and cross sections.

Previous studies have validated the acoustic reflection method for the measurement of anterior nasal volume and minimal cross sectional areas in the anterior part of the nasal cavity.[15-17] Our study showed no significant differences for those measurements when using either CBCT or AR, which validates the CBCT method. Hilberg et al compared MRI measurements of the anterior nasal volume to AR measurements, and found MRI to be accurate, with differences of less than 15%.[18] Our study found CBCT and AR differences for those same measurements to be less than 7.8%. Terheyden et al found that when comparing CT scan in the nasal minimal cross sectional area with AR, the differences between the two measurements were around 4.5%.[19] The present study found CBCT and AR differences for that same measurements to be less than 3.2%. Corey et al compared MRI measurements to AR, and found both methods to be highly correlated when measuring the minimal cross sectional area of the nasal cavity (0.95).[20] The present study shows an even higher correlation between CBCT and AR ($r=0.974$).

A difference between CBCT and AR methods was found when measuring the total nasal volume, but those same articles point out that AR is not accurate in the posterior nasal cavity and the epipharynx.[18, 19] It is reported that the accuracy of AR decreases as the distance from the nares increases, with the best accuracy in the first 5 cm, which is the present study's anterior nasal area.[21] It is possible for the CBCT measurements to be accurate in the posterior nasal region, but

further studies may be needed to confirm such finding. The difference, even though statistically significant, was 1,268mm^3, which is less than half the standard deviation (2,726 for the CBCT, and 4,424 for the AR method).

Acoustic pharyngometry was found to provide accurate measurements for airway volume and cross sectional area.[22] In our findings, the CBCT values of the pharyngeal volume were slightly higher than the acoustic measurements. Even though significant, this difference may be considered not clinically significant, since it is of only 758mm^3, for measurements showing means of over 11,000mm^3 ±4,000. Since there was a high correlation between both methods, a possible explanation may be that the slight overestimation results from the operator adjusting the automatic segmentation sensitivity when calculating the volume. In 1993, Marshall et al found that when compared to MRI scans, the acoustic reflection showed differences of less than 10% for pharyngeal volume calculation, and deemed the MRI accurate.[22] The CBCT volume measurement showed less than 6.3% difference against the acoustic reflection, which would suggest equivalent accuracy. Alves et al suggested overestimation of CBCT was found but had no clinical significance and was highly reliable.[23] This would agree with our findings.

Kamal reported that the acoustic reflection technique has been used to assess pharyngeal cross-sectional area due to its accuracy.[24] The pharyngeal minimal cross sectional area measured by CBCT and AR was found to be same, with a mere 3mm^2 difference, validating the CBCT method. D'Urzo et al suggested that the minimal cross sectional area measured by both acoustic reflection and CT scan are accurate with differences of less than 4.3%, showing a high correlation of 0.92.[25] Our results showed that CBCT and AR had a difference of less than 4%, for that same pharyngeal minimal cross sectional area, with an even higher correlation of 0.94.

Accurate upper airway measurements can play a pivotal role in identifying patients with breathing or sleep disorders. The airway in an apneic person shows thinner lateral wall dimension and significantly smaller retropalatal area.[26] Two dimensional images from lateral cephalograms are not an adequate tool for analyzing those important regions, thus it is essential to use 3D imaging techniques. The most common 3D imaging techniques used are CBCT, CT, and MRI. With recent low dose CBCT options, such imaging technique may become more common. It may be in the patient's best interest that when a CBCT volume is taken, for the airway to be properly studied, since we now know that such measurements are accurate.

Conclusion

Cone Beam Computed Tomography is an accurate method for the measuring of anterior nasal volume, nasal minimal cross sectional area, pharyngeal volume, and pharyngeal minimal cross sectional area. It is possible that it is also accurate for the measuring of total nasal volume, but further research is needed to confirm such finding.

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Figures



Figure 1. Left: Rhinometry: mask and orientation, Right: Pharyngometry: mouth piece

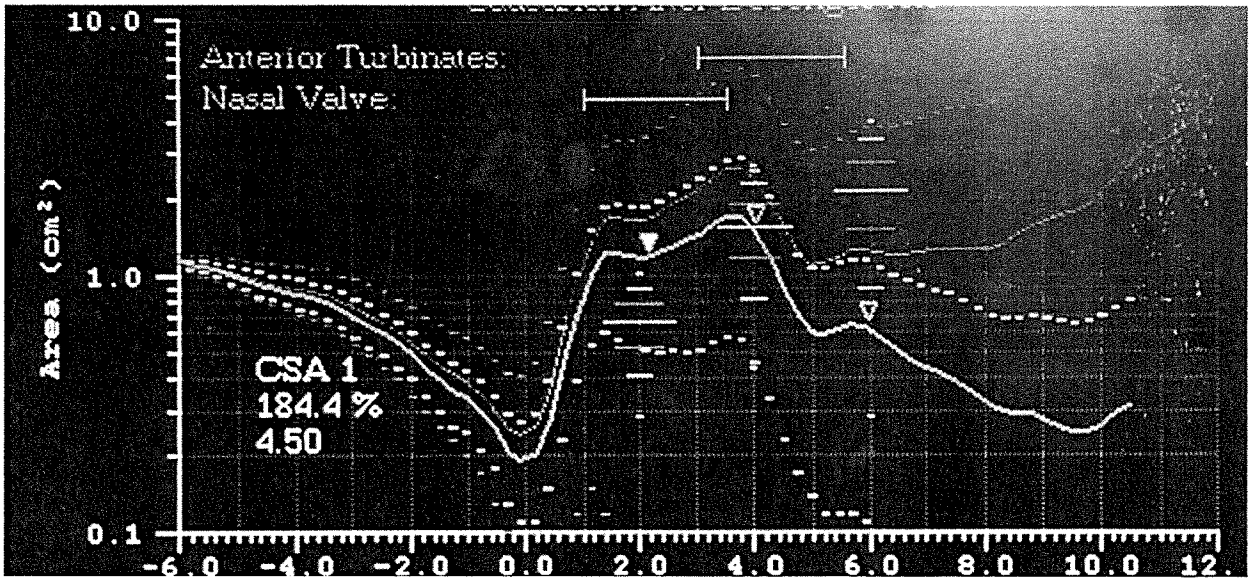
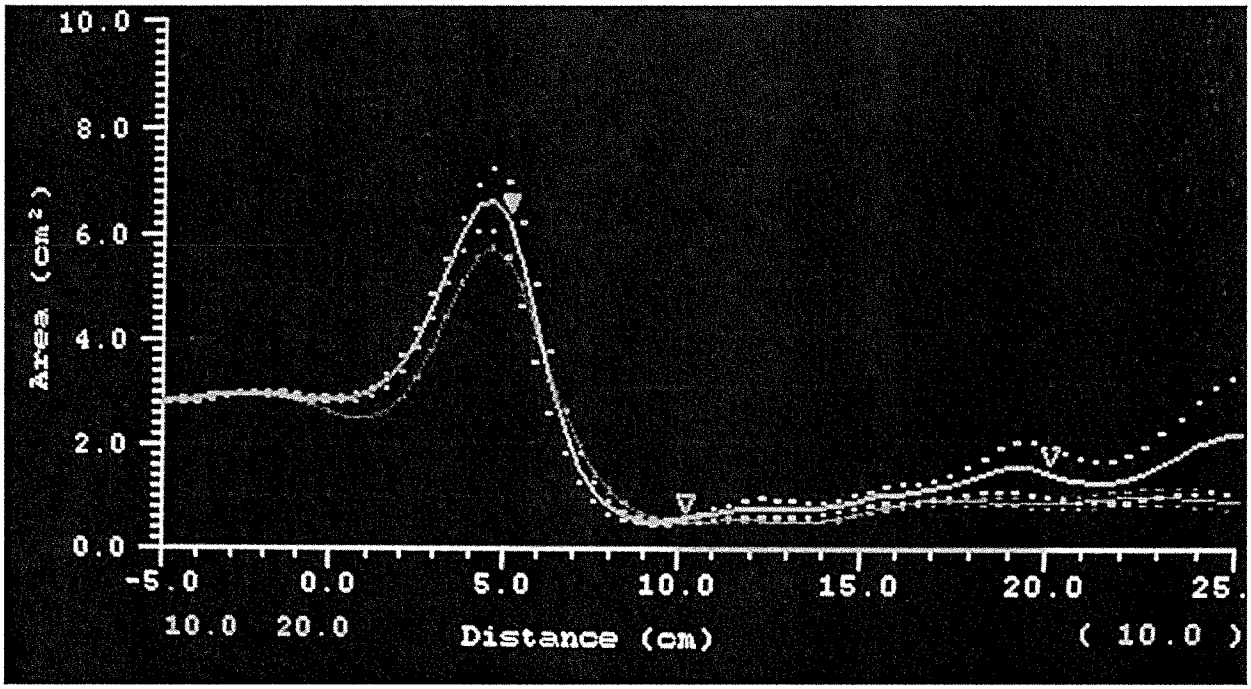


Figure 2. Top: Graph illustrating cross sectional area and distant from the nostrils into nasal cavity by acoustic rhinometry. Bottom: Graph illustrating cross sectional area and distant from the oral cavity into the pharynx generated by acoustic pharyngometry



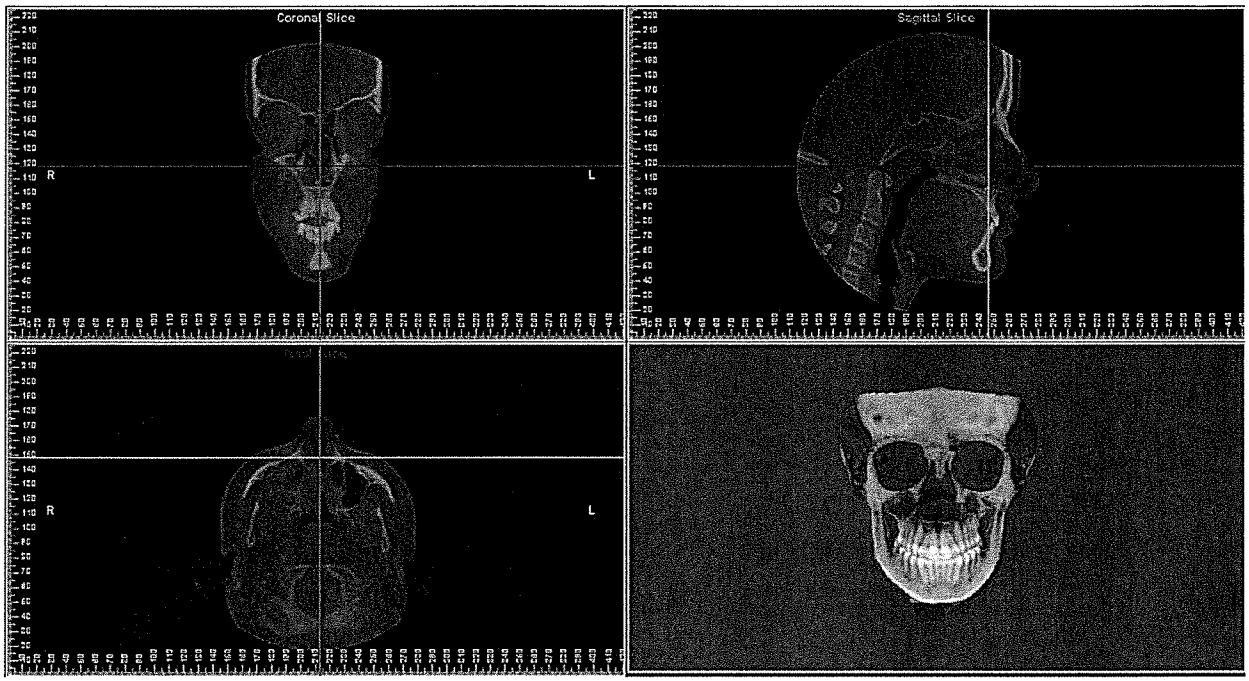


Figure 3. CBCT orientation: Orient the subject in the coronal view so that the axial plane is aligned with the optic foramen, in the axial view so that the coronal plane is aligned with the left and right foramen ovale. Orientation of the sagittal plane with foramen cecum in the coronal view and the axial plane with McRae's line in the sagittal view.

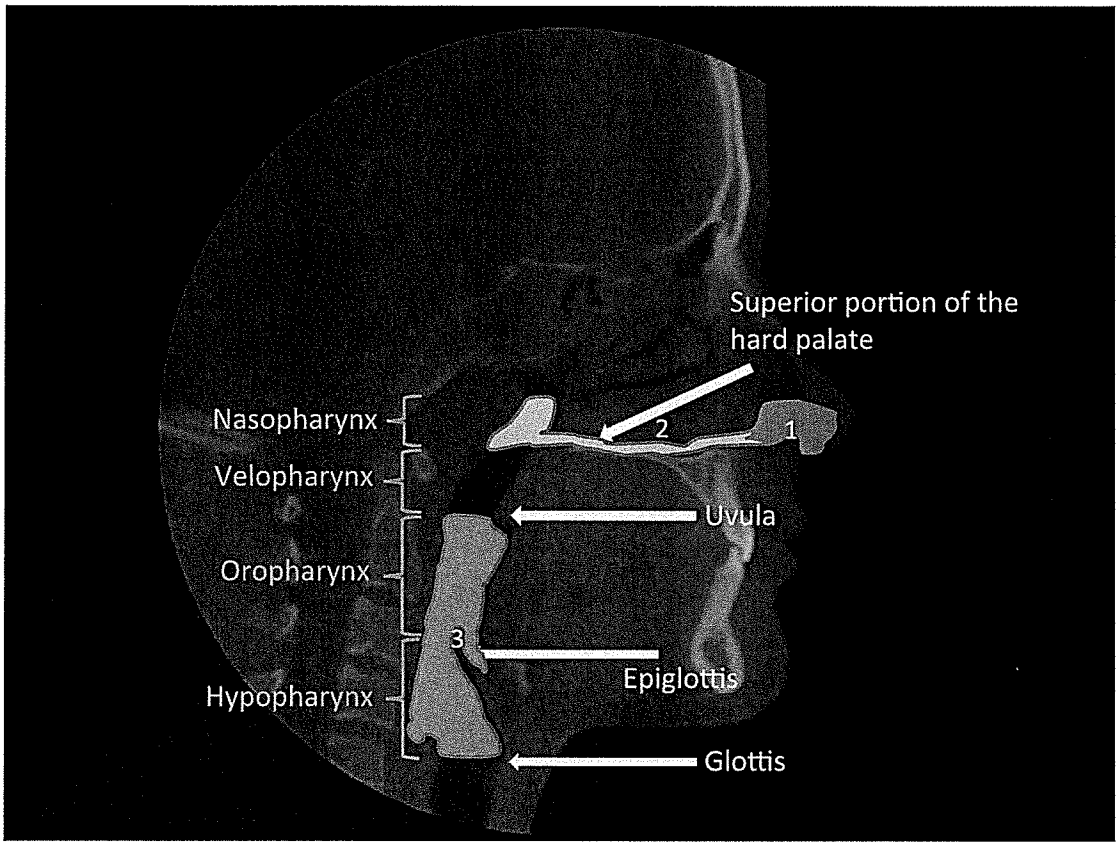


Figure 4. Radiographic anatomy of upper airway. 1. Anterior nasal valve volume (CBNasal), 2. Total nasal volume (CBRh), and 3. Pharyngeal volume (CBPh).

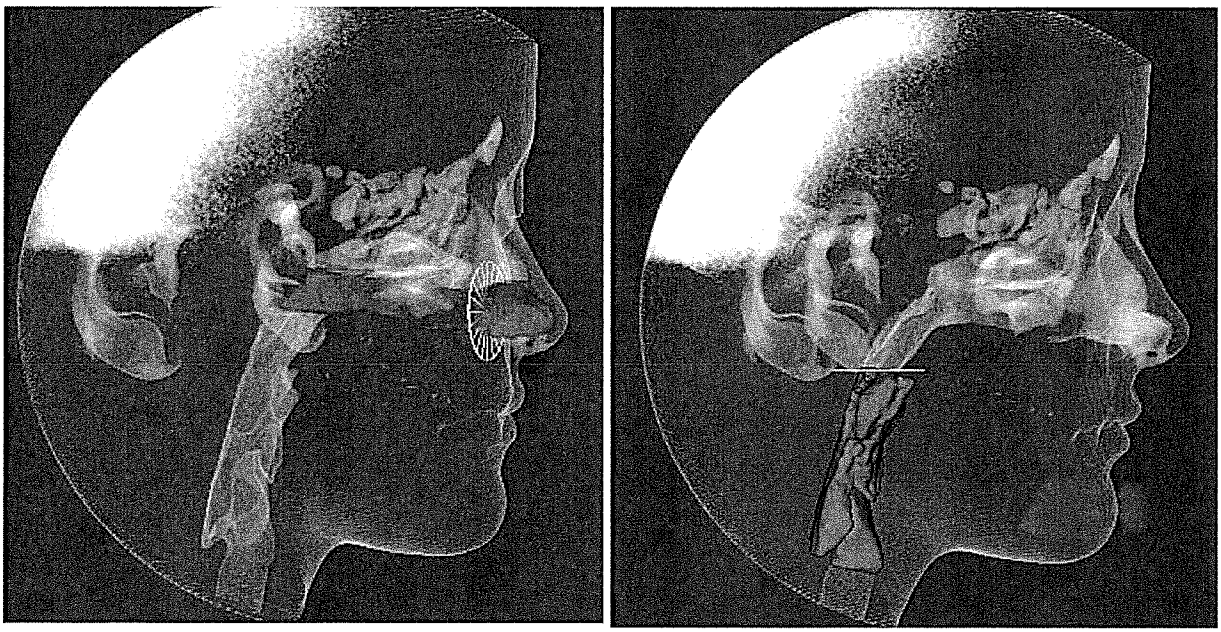


Figure 5. Left: CBCT Total nasal volume (CBRh) and minimal cross sectional area (CBRx), Right: CBCT pharyngeal volume (CBPh) and minimal cross sectional area (CBPx).

TABLES

	Gender	Age	Race	
Male	25	15.12 ± 2.57	Caucasian	20
			Asian	2
			Hispanic	2
			African-American	1
Female	34	15.61 ± 4.5	Caucasian	30
			Asian	1
			Hispanic	0
			African-American	3
Total	59	Mean 15.41 ± 3.8	Mode Caucasian	

Table 1. Demographic data

Variables		Cochran's alpha
Volume	CBCT-total nasal cavity (CBRh)	0.833
	Acoustic rhinometry- total nasal cavity (ACRh)	0.807
	CBCT-anterior nasal cavity (CBNasal)	0.859
	Acoustic rhinometry- anterior nasal cavity (ACNasal)	0.777
	CBCT-Pharyngeal cavity (CBPh)	0.984
	Acoustic pharygometry-Pharyngeal cavity (ACPh)	0.964
Minimal cross sectional area	CBCT-nasal valve (CBNx)	0.871
	Acoustic rhinometry- nasal valve (ACNx)	0.917
	CBCT-Pharyngeal cavity (CBPx)	0.809
	Acoustic pharygometry-Pharyngeal cavity (ACPx)	0.981

Table 2. Reliability performed on 20 randomly selected subjects re-measured 2 weeks apart.

Methods	Mean Volume (mm3)	S.D.	Min-Max	P value	Correlation
CBRh	10,462	2,726	5,440-17,820	0.035	0.274
ACRh	9,194	4,424	3,510-18,648		
CBNasal	2,787	845.6	1,300-4,750	0.532	0.786
ACNasal	2,544	1,045	794-4,903		
CBNx	125	44	44-213	0.066	0.974
ACNx	128	47	45-228		
CBPh	12,062	4,471	5,985-29,650	0.01	0.755
ACPh	11,304	6,325	3,999-35,050		
CBPx	78.2	44.9	34-245	0.109	0.944
ACPx	75.1	49.0	28-251		

Table 3. Results for all variables measured, with means, standard deviations, and ranges. Methods were compared using t-test for parametric values and Wilcoxon Sign Test for non-parametric values. The last column shows a Pearson's correlation comparing both methods.

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RAW DATA

ID	CBPh 1	CBPh 2	CBPh	ACPh1	ACPh2	ACPh3	ACPh4	ACPh	Diff
1	7.46		**7.46**	5.75	5.35	5.47	6.73	**5.83**	1.64
2	12.87		**12.87**	13.06	14.25	12.85	14.70	**13.72**	-0.85
3	24.20		**24.2**	33.82	33.53	29.69	22.69	**29.93**	-5.73
4	11.10		**11.1**	13.20	14.43	16.60	12.40	**14.16**	-3.06
5	6.34		**6.34**	9.93	7.04	7.53	12.40	**9.23**	-2.89
6	8.75		**8.75**	16.80	13.30	13.90	13.80	**14.45**	-5.70
7	10.09		**10.09**	6.13	0.00	7.24	6.12	**4.87**	5.22
8	16.39		**16.39**	13.84	29.07	31.44	28.05	**25.60**	-9.21
9	9.70		**9.7**	25.30	25.30	25.30	23.90	**24.95**	-15.25
10	9.77		**9.77**	8.72	9.00	8.87	9.25	**8.96**	0.81
11	20.20		**20.2**	20.90	20.06	20.07	23.00	**21.01**	-0.81
12	12.38		**12.38**	11	12.43	11.52	12.27	**11.81**	0.58
13	16.6		**16.6**	6.93	15.1	9.15	15.47	**11.66**	4.94
14	19.13		**19.13**	29	30	31	20	**27.50**	-8.37
15	13.9		**13.9**	11.93	10.96	10.63	11.1	**11.16**	2.75
16	14.3		**14.3**	9.6	9.56	9.65	9.33	**9.54**	4.77
17	13.4		**13.4**	7.52	7.78	7.67	7.12	**7.52**	5.88
18	9.8	9.9	**9.85**	8.06	7.4	8.58	7.6	**7.91**	1.94
19	9.34	8.9	**9.12**	7.06	7.88	10.66	7.86	**8.37**	0.76
20	13.9	13.1	**13.5**	6.09	4.98	5.53	5.36	**5.49**	8.01
21	7.87	8.8	**8.335**	8.59	7.85	7.78	8.39	**8.15**	0.18
22	30.5	28.8	**29.65**	33.3	34.5	39.3	33.1	**35.05**	-5.40

23	12.8	12.6	**12.7**	12.73	6.82	12.9	6.99	**9.86**	2.84
24	11.65	10.51	**11.08**	12.14	7.13	6.83	10.62	**9.18**	1.90
25	10.03	9.5	**9.765**	7.34	7.12	6.68	6.77	**6.98**	2.79
26	10.62	9.07	**9.845**	9.39	7.91	8.46	6.2	**7.99**	1.86
27	8.21	7.24	**7.725**	9.07	7.66	7.87	7.49	**8.02**	-0.30
28	9.61	11.8	**10.705**	8.29	8.62	6.98	5.88	**7.44**	3.26
29	8.16	7.64	**7.9**	7.34	6.8	6.47	7.82	**7.11**	0.79
30	10.6	12.27	**11.435**	6.33	6.93	6.88	5.62	**6.44**	5.00
31	7.28	7.77	**7.525**	7.48	5.23	8.42	5.78	**6.73**	0.80
32	11.16	10.44	**10.8**	8.03	8.45	8.21	8.17	**8.22**	2.59
33	14.41	11.41	**12.91**	14.43	11.67	10.29	10.21	**11.65**	1.26
34	17.03	18.51	**17.77**	13.94	9.88	11.53	10.68	**11.51**	6.26
35	5.75	6.22	**5.985**	5.78	6.08	6.36	6.6	**6.21**	-0.22
36	11.74	12.14	**11.94**	8.76	7.78	10.15	8.93	**8.91**	3.04
37	17.6	15.5	**16.55**	10.57	10.58	12.05	11.07	**11.07**	5.48
38	11.44	9.82	**10.63**	9.25	13.36	9.2	7.23	**9.76**	0.87
39	15.43	14.31	**14.87**	14.55	14.62	14.72	14.68	**14.64**	0.23
40	10.78	10.51	**10.645**	11.71	10.39	10.11	10.16	**10.59**	0.05
41	12.81	11.24	**12.025**	11.7	10.91	12.14	10.48	**11.31**	0.72
42	6.85	5.66	**6.255**	5.17	5.21	4.5	4.54	**4.86**	1.40
43	6.7	5.56	**6.13**	3.53	3.7	4.76	3.97	**3.99**	2.14
44	7.79	8.01	**7.9**	6.34	6.03	9.43	6.31	**7.03**	0.87
45	16.38	19.86	**18.12**	10.08	10.32	10.23	10.69	**10.33**	7.79

46	8.6	10.7	**9.65**	10.29	12.96	16.75	5.91	**11.48**	-1.83
47	10.8	10.19	**10.495**	8.52	8.45	9.04	8.7	**8.68**	1.82
48	10.92	11.47	**11.195**	8.97	9.9	8.56	9.65	**9.27**	1.93
49	10.6	12.2	**11.4**	9.28	8.59	9.75	10.63	**9.56**	1.84
50	7.95	7.56	**7.755**	6.69	6.92	6.89	5.77	**6.57**	1.19
51	15.04	13.93	**14.485**	6.94	7.18	10.09	8.23	**8.11**	6.38
52	14.33	15.2	**14.765**	10.18	9.45	10.74	10.47	**10.21**	4.56
53	7.4	8.54	**7.97**	8.28	8.15	7.39	7.97	**7.95**	0.02
54	9.35	10.26	**9.805**	7.39	6.89	8.17	7.18	**7.41**	2.40
55	15.59	14.5	**15.045**	12.16	15.35	16.31	8.75	**13.14**	1.90
56	18.3	17.24	**17.77**	21.1	25.04	18.7	15	**19.96**	-2.19
57	9.62	9.18	**9.4**	8.81	8.81	9.09	8.22	**8.73**	0.67
58	14.44	15.17	**14.805**	14.03	12.21	10.78	19.42	**14.11**	0.69
59	7.87	8.8	**8.335**	8.59	7.85	7.78	8.39	**8.15**	0.18

ID	CBPx1	CBPx2	CBPx	ACPx1	ACPx2	ACPx3	ACPx4	ACPx

1	1.6		**1.6**	1.74				**1.74**
2	0.48	0.42	0.45	0.43	0.47	0.45	0.46	0.4525
3	0.85		**0.85**	0.76				**0.76**
4	0.89		**0.89**	0.51				**0.51**
5	2.45		**2.45**	2.46				**2.46**
6	0.78	0.43	0.605	0.67	0.61	0.43	0.67	0.595
7	0.579		**0.579**	0.52				**0.52**
8	0.81		**0.81**	0.7				**0.7**
9	0.6		**0.6**	0.75				**0.75**
10	0.58		**0.58**	0.65				**0.65**
11	1.85		**1.85**	2.4				**2.4**
12	0.64		**0.64**	0.79				**0.79**
13	0.71		**0.71**	0.66				**0.66**
14	0.74		**0.74**	0.55				**0.55**
15	0.5	0.45	**0.475**	0.51				**0.51**
16	0.73	0.68	**0.705**	0.5	0.64	0.51	0.51	**0.54**
17	0.39	0.32	**0.355**	0.5	0.54	0.61	0.5	**0.5375**
18	0.62	0.67	**0.645**	0.68	0.63	0.78	0.7	**0.6975**
19	0.67	0.8	0.735	0.41	0.67	1	1.3	0.845
20	2.59	1.93	**2.26**	2.5	2.3	2.17	3.06	**2.5075**
21	0.84	0.34	**0.59**	0.69	0.48	0.59	0.52	**0.57**
22	0.98	0.7	**0.84**	0.5	0.98	0.78	0.49	**0.6875**
23	0.58	0.53	**0.555**	0.58	0.52	0.61	0.61	**0.58**

24	0.59	0.71	**0.65**	0.94	0.62	0.79	0.61	**0.74**
25	0.69	0.5	**0.595**	0.5	0.5	0.54	0.5	**0.51**
26	0.25	1.2	**0.725**	0.39	0.61	0.62	0.5	**0.53**
27	0.48	0.64	**0.56**	0.49	0.56	0.45	0.59	**0.5225**
28	0.45	0.65	**0.55**	0.44	0.45	0.39	0.42	**0.425**
29	0.51	0.49	0.5	0.46	0.47	0.49	0.48	0.475
30	0.49	0.67	**0.58**	0.5	0.67	0.61	0.45	**0.5575**
31	0.83	0.75	**0.79**	0.62	0.58	0.55	0.56	**0.5775**
32	1.03	0.59	**0.81**	0.96	0.47	0.65	0.59	**0.6675**
33	1.05	0.68	**0.865**	0.82	0.84	1.11	0.93	**0.925**
34	0.57	0.66	**0.615**	0.5	0.48	0.48	0.45	**0.4775**
35	0.46	0.4	0.43	0.43	0.36	0.45	0.45	0.4225
36	0.78	0.43	**0.605**	0.67	0.61	0.43	0.67	**0.595**
37	0.39	0.72	**0.555**	0.56	0.62	0.61	0.62	**0.6025**
38	0.56	1.04	**0.8**	0.47	0.61	0.91	0.66	**0.6625**
39	1.2	1.09	**1.145**	1.15	1.22	1.05	1.07	**1.1225**
40	0.66	0.83	**0.745**	0.47	0.44	0.5	0.71	**0.53**
41	0.55	0.51	**0.53**	0.5	0.51	0.53	0.56	**0.525**
42	0.46	0.4	**0.43**	0.43	0.36	0.45	0.45	**0.4225**
43	0.35	0.32	**0.335**	0.36	0.29	0.23	0.25	**0.2825**
44	0.44	0.48	**0.46**	0.49	0.55	0.52	0.48	**0.51**
45	0.97	1.23	**1.1**	0.6	0.59	0.62	0.58	**0.5975**
46	0.67	0.8	**0.735**	0.41	0.67	1	1.3	**0.845**

47	0.48	0.4	**0.44**	0.42	0.42	0.42	0.42	**0.42**
48	0.41	0.51	0.46	0.42	0.51	0.51	0.43	0.4675
49	0.59	0.66	**0.625**	0.59	0.61	0.64	0.62	**0.615**
50	0.58	0.72	**0.65**	0.54	0.5	0.61	0.43	**0.52**
51	0.51	0.49	**0.5**	0.46	0.47	0.49	0.48	**0.475**
52	0.63	0.51	**0.57**	0.51	0.58	0.48	0.5	**0.5175**
53	0.55	0.62	**0.585**	0.69	0.52	0.52	0.64	**0.5925**
54	0.41	0.51	**0.46**	0.42	0.51	0.51	0.43	**0.4675**
55	0.47	0.52	**0.495**	0.42	0.55	0.49	0.44	**0.475**
56	0.54	1.1	**0.82**	1.01	1.19	0.59	0.57	**0.84**
57	2.01	1.88	**1.945**	1.53	1.06	1.99	1.43	**1.5025**
58	0.48	0.42	**0.45**	0.43	0.47	0.45	0.46	**0.4525**
59	0.47	0.51	**0.49**	1	0.51	0.49	0.46	**0.615**

ID	**CBRh1**	**CBRh2**	**CBRh**	**ACRh1**	**ACRh2**	**ACRh3**	**ACRh4**	**ACRh**	**Diff**

1	6.64	5.53	**6.085**	16.09	8.56	2.89	14.01	**10.39**	-4.30
2	7.07	6.08	**6.575**	4.47	3.57	7.45	5.66	**5.29**	1.29
3	9.04	11.20	**10.12**	11.40	9.55	11.74	18.42	**12.78**	-2.66
4	10.10		**10.1**	17.18	19.17	8.94	15.35	**15.16**	-5.06
5	11.74	17.50	**14.62**	12.61	13.95	16.96	14.36	**14.47**	0.15
6	7.20	6.06	**6.63**	8.93	6.99	4.92	6.02	**6.72**	-0.09
7	4.47	6.47	**5.47**	14.55	14.88	9.51	17.29	**14.06**	-8.59
8	8.11	7.50	**7.805**	5.87	14.80	8.20	13.67	**10.64**	-2.83
9	7.91	11.17	**9.54**	13.16	10.62	7.01		**10.26**	-0.72
10	12.11	16.24	**14.175**	13.36	11.55	17.54	1.96	**11.10**	3.07
11	5.67	5.21	**5.44**	12.58	14.52	11.52	16.02	**13.66**	-8.22
12	9.52	10.7	**10.11**	6.5	26.6	10.09	13.5	**14.17**	-4.06
13	14.56	10.2	**12.38**	13.22	6.29	7.92	7.06	**8.62**	3.76
14	13.2	11.74	**12.47**	3.14	16.43	16.16	2.27	**9.50**	2.97
15	13.16	12.4	**12.78**	14.64	6.69	13.08	14.64	**12.26**	0.52
16	9.69	11.49	**10.59**	11.25	13.11	11.79	9.17	**11.33**	-0.74

17	6.62	7.1	**6.86**	8.99	12.32	13.1	17.31	**12.93**	-6.07
18	7.4	6.9	**7.15**	3.89	5.28	13.65	17.91	**10.18**	-3.03
19	12.57	10.95	**11.76**	14.22	16.27	11.85	13.33	**13.92**	-2.16
20	13.92	11.97	**12.945**	13.24	15.35	21.33	13.9	**15.96**	-3.01
21	12.34	11.29	**11.815**	13.38	19.2	12.65	15.19	**15.11**	-3.29
22	7.07	6.08	6.575	4.47	3.57	7.45	5.66	5.29	1.29
23	16.79	14.17	**15.48**	16.37	18.15	20.17	12.14	**16.71**	-1.23
24	13.56	14.71	**14.135**	17.45	17.83	18.56	20.75	**18.65**	-4.51
25	13.87	14.8	**14.335**	6.17	10.49	9.18	8.57	**8.60**	5.73
26	7.84	9.3	**8.57**	10.05	14.76	3.54	12.28	**10.16**	-1.59
27	10.07	8.88	**9.475**	3.51	5.81	2.89	4.62	**4.21**	5.27
2	9.36	11.42	**10.39**	5.81	8.47	5.17	6.2	**6.41**	3.98

8									
29	13.05	10.23	**11.64**	6.91	5.82	8.19	2.35	**5.82**	5.82
30	11.71	12.52	**12.115**	6.68	3.75	2.45	6.95	**4.96**	7.16
31	12.29	13.59	**12.94**	5.65	5.69	4.11	5.18	**5.16**	7.78
32	9.04	11.20	10.12	11.40	9.55	11.74	18.42	12.78	-2.66
33	11.03	10.4	**10.715**	3.72	6.07	5.06	3.75	**4.65**	6.07
34	12.45	13.61	**13.03**	4.24	7.16	4.97	5.69	**5.52**	7.52
35	14.73	12.64	**13.685**	4.34	7.76	4.5	1.9	**4.63**	9.06
36	9.22	10.68	**9.95**	4.04	3.53	1.34	5.83	**3.69**	6.27
37	6.92	6.33	**6.625**	4.61	6.13	3.62	4.26	**4.66**	1.97
38	13.16	12.4	12.78	14.64	6.69	13.08	14.64	12.26	0.52
39	11.13	11.98	**11.555**	5.77	3.1	5.98	4.73	**4.90**	6.66

40	9.72	10.94	**10.33**	6.84	6.94			**6.89**	3.44
41	7.47	8.15	**7.81**	4.82	2.78	2.66	11.93	**5.55**	2.26
42	8.506	10.76	**9.633**	2.95	2.77	6.21	8.89	**5.21**	4.43
43	7.628	6.78	**7.204**	14.8	11.19	2.45	3.18	**7.91**	-0.70
44	7.841	8.494	**8.1675**	4.09	4.58	4.46		**4.38**	3.79
45	9.504	10.229	**9.8665**	3.64	2.37	4.52		**3.51**	6.36
46	10.76		**10.76**	4.56	4.5	5.47	5.44	**4.99**	5.77
47	9.083	9.83	**9.4565**	9.11	9.3	7.02	9.95	**8.85**	0.61
48	10.97		**10.97**	12.54	12.42			**12.48**	-1.51
49	8.45		**8.45**	9.42	16.2	10.01		**11.88**	-3.43
50	13.04		**13.04**	5.95	3.23	8.76		**5.98**	7.06
5	13.16	12.4	12.78	14.64	6.69	13.08	14.64	12.26	0.52

1									
52	7.07	6.08	6.575	4.47	3.57	7.45	5.66	5.29	1.29
53	16.79	14.17	15.48	16.37	18.15	20.17	12.14	16.71	-1.23
54	7.07	6.08	6.575	4.47	3.57	7.45	5.66	5.29	1.29
55	12.29	13.59	12.94	5.65	5.69	4.11	5.18	5.16	7.78
56	7.91	11.17	9.54	13.16	10.62	7.01		10.26	-0.72
57	9.04	11.20	10.12	11.40	9.55	11.74	18.42	12.78	-2.66
58	7.628	6.78	7.204	14.8	11.19	2.45	3.18	7.91	-0.70
59	7.518		**7.518**	5.95	9.07			**7.51**	0.01

ID	CBNx1	CBNx2	CBNx	ACNx1	ACNx2	ACNx3	ACNx4	ACNx
1	0.52	0.6	**0.56**	0.56	0.62	0.65	0.51	**0.585**
2	0.67	0.87	**0.77**	0.8	1.29	0.99	0.67	**0.9375**
3	0.91		**0.91**	1.91	1.68	1.68		**1.756667**
4	1.93	1.69	**1.81**	3.17	2.75	1.61	3.33	**2.715**
5	1.37	1.48	**1.425**	1.45	1.82	1.49	1.48	**1.56**
6	0.81	1.11	**0.96**	1.31	1.62	0.95	1.19	**1.2675**
7	1.42	1.63	**1.525**	2.48	1.59	2.5	2.43	**2.25**
8	1.26	1.34	**1.3**	1.2	1.5	2.1	2.2	**1.75**
9	1.88	1.52	**1.7**	2.01	1.72			**1.865**
10	1.96	2.31	**2.135**	2.68	1.95	2.04		**2.223333**
11	2.06	2.08	**2.07**	2.55	2.61	2.17	2.24	**2.3925**
12	1.7	1.9	**1.8**	2.01	1.22	3.3	1.34	**1.9675**
13	1.49	1.41	**1.45**	2.1	1.36	1.39	1.3	**1.5375**
14	0.79	0.95	**0.87**	0.42	0.62	0.63	2.3	**0.9925**
15	1.67	1.77	**1.72**	3.1	2.88	3.2		**3.06**
1	1.5	2.2	**1.85**	2.06	2.26	1.99		**2.10333**

6								**3**
17	1.4	1.88	**1.64**	1.71	1.28	1.94	2.25	**1.795**
18	1.01	1.43	**1.22**	0.84	2.47	1.88	0.66	**1.4625**
19	1.92	2.22	**2.07**	2.05	1.9	2	2.5	**2.1125**
20	1.81	1.67	**1.74**	2.2	2.02	3.25	2.2	**2.4175**
21	1.88	1.94	**1.91**	2.12	2.64	1.89	2.29	**2.235**
22	0.95		**0.95**	1.05	1.19	0.98	0.7	**0.98**
23	2.2	1.59	**1.895**	2.7	3	1.86	2.99	**2.6375**
24	2.04	2.1	**2.07**	2.35	2.64	2.6	2.83	**2.605**
25	1.06	1.45	**1.255**	1.09	1.35	1.37	1.46	**1.3175**
26	1.14	1.26	**1.2**	1.7	0.65	1.95	2.35	**1.6625**
27	0.76	0.64	**0.7**	0.68	0.47	0.81	1	**0.74**

28	1.03	1.15	**1.09**	1	0.97	1.17	1.4	**1.135**
29	0.91	1.35	**1.13**	0.8	1.3	1.35		**1.15**
30	0.93	1.03	**0.98**	1.07	1.37	0.79		**1.076667**
31	0.9	1.04	**0.97**	1	1.07	0.7	0.94	**0.9275**
32	0.52	0.6	0.56	0.56	0.62	0.65	0.51	0.585
33	0.88	0.76	**0.82**	0.71	1.1	0.9	0.66	**0.8425**
34	0.81	0.91	**0.86**	0.68	0.8	0.87	1.28	**0.9075**
35	0.89	1.02	**0.955**	0.83	1.35	0.89		**1.023333**
36	0.84	0.66	**0.75**	0.47	0.98			**0.725**
37	1.06	0.94	**1**	0.97	0.77	0.88	1.26	**0.97**
38	1.92	2.22	2.07	2.05	1.9	2	2.5	2.1125
3	0.94	1.02	**0.98**	1.2	1.15	0.98		**1.11**

9								
40	1.35	1.12	**1.235**	1.75	0.62	1.72	1.53	**1.405**
41	1.57	1.25	**1.41**	0.98	2.13			**1.555**
42	0.66	0.79	**0.725**	0.48	0.89	1.15	0.49	**0.7525**
43	0.49	0.39	**0.44**	0.41	0.36	0.54	0.51	**0.455**
44	0.74	0.8	**0.77**	0.72	0.9	0.59	0.85	**0.765**
45	0.81	0.89	**0.85**	0.82	0.97			**0.895**
46	1.03		**1.03**	1.01	1.21	1.16	0.97	**1.0875**
47	1.41	1.56	**1.485**	2.04	2.11	1.48	1.96	**1.8975**
48	1.76		**1.76**	1.61	1.95	1.83		**1.796667**
49	1.83		**1.83**	1.8		1.91		**1.855**
50	0.95		**0.95**	1.25				**1.25**

51	1.92	2.22	2.08	2.05	1.9	2	2.5	2.12
52	0.90		**0.90**	0.87	0.9	0.95	0.85	**0.8925**
53	1.1		**1.1**	0.8	1.85	0.5	1.3	**1.1125**
54	1.29		**1.29**	1.6	1.45	1	1.2	**1.3125**
55	3.2		**3.2**	3.4	2.4	3.6		**3.133333**
56	1.4	1.88	1.64	1.71	1.28	1.94	2.25	1.795
57	0.76	0.64	0.7	0.68	0.47	0.81	1	0.74
58	1.96	2.31	2.13	2.68	1.95	2.04		2.22
59	1.16		**1.16**		1.18			**1.18**

ID	CBNasal 1	CBNasal 2	CBNasal	ACRHNasal
8	2.7		**2.7**	**3.16575**

9	2.2	2.7	**2.45**	**2.504375**
10	2.9	2.5	**2.7**	**2.779**
11	3.1	4.452	**3.776**	**4.807425**
12	3.3	3.02	**3.16**	**3.100675**
13	2.49	2.2	**2.345**	**2.05615**
14	2.96	3.46	**3.21**	**3.70725**
15	2.99	3.2	**3.095**	**3.208**
16	3.4	3.8	**3.6**	**3.6835**
17	3.876	3.31	**3.593**	**3.848**
18	3.47	3.99	**3.73**	**3.8805**
19	3.08	3.3	**3.19**	**3.15275**
20	2.7	2.5	**2.6**	**2.595**

21	1.6	1.3	**1.45**	**1.2755**
22	3.7	3.9	**3.8**	**4.842**
23	3.8	3.33	**3.565**	**3.5135**
24	2.9	2.69	**2.795**	**2.82375**
25	2.54	2.74	**2.64**	**2.60225**
26	3.45	3.71	**3.58**	**3.560875**
27	4.061	3.802	**3.9315**	**3.949**
28	3.54	3.15	**3.345**	**3.4985**
29	3.876	3.31	3.593	3.848
30	4.31	4.5	**4.405**	**4.539**
31	3.99	4.19	**4.09**	**4.09625**
3	2.6	2.36	**2.48**	**2.2635**

2				
33	2.81	3.1	**2.955**	**2.84**
34	1.8	1.79	**1.795**	**1.392625**
35	1.56	2.14	**1.85**	**2.0955**
36	2.65	2.2	**2.425**	**1.98933333 3**
37	2.02	1.61	**1.815**	**1.91386666 7**
38	1.94	1.7	**1.82**	**1.4569**
39			2.62	2.612
40	2.7	2.2	**2.45**	**1.362**
41	2.031	2.368	**2.1995**	**1.5135**
42	2.4	2.08	**2.24**	**1.42866666 7**
43	4.9	4.6	**4.75**	**1.379**

44	2.39	2.17	**2.28**	**1.687**
45	3.88	3.3	3.6	3.8
46	3.95	3.3	**3.625**	**1.98**
47	2.8	2.52	**2.66**	**2.5795**
48	2.45	3.11	**2.78**	**2.78**
49	1.62	1.92	**1.77**	**1.184**
50	1.6	1.02	**1.31**	**0.79375**
51	1.18	1.42	**1.3**	**1.22875**
52	1.8	1.6	**1.7**	**1.671**
53	1.84	2.01	**1.925**	**1.9935**
54	2.86	3.065	**2.9625**	**3.321**
5	3.02		**3.02**	**3.08**

5				
56	3.47		**3.47**	**3.64**
57	2.44		**2.44**	**2.596**
58	2.26		2.26	1.98
59	1.45		**1.45**	**1.4465**
60	1.9		**1.90**	**1.84875**
61	2.12		**2.12**	**2.134**
62	4.88		**4.88**	**4.903333333**
63	3.86	3.31	3.53	3.68
64	4.31	4.5	4.405	4.539
65	3.2	3.02	3.12	3.100675
66	2.6		2.6	2.59

6 7	2.02		**2.02**	**2.1145**