Fall 12-18-2015

Evaluation of Posterior Pharyngeal Airway Volume and Cross-Sectional Area After Mandibular Repositioning in Centric Relation

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EVALUATION OF POSTERIOR PHARYNGEAL AIRWAY VOLUME AND CROSS-SECTIONAL AREA AFTER MANDIBULAR REPOSITIONING IN CENTRIC RELATION

By

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A THESIS

Presented to the Faculty of

The Graduate College in the University of Nebraska

In Partial Fulfillment of Requirements

For the Degree of Master of Science

Medical Sciences Interdepartmental Area
Oral Biology

Under the Supervision of Professor Sheela Premaraj

University of Nebraska Medical Center
Omaha, Nebraska

November, 2015

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AWKNOWLEDGEMENTS

I would like to start by thanking Dr. Mary Burns who first introduced me to this project and opened my eyes to the world of sleep apnea. Thank you for graciously inviting me into your private practice on multiple occasions to learn firsthand various diagnostic and treatment modalities for obstructive sleep apneic patients. Your experience and knowledge was invaluable for the completion of this project. Without your guidance and support none of this would have been possible.

Next I would like to thank Dr. Sheela Premaraj who always made herself available to give me key advice and guidance to help shape this project into what it is today. Thank you Dr. Sheela for your enthusiastic and contagious passion for research, and for the many hours you spent counseling and tutoring me. You have been a great research mentor and I have thoroughly enjoyed working with you these past couple years.

Also, thank you Dr. Sundaralingam Premaraj for spending hours reviewing and editing my thesis drafts, the final presentation, and in general for giving me helpful and thoughtful recommendations throughout the whole process. Your knowledge and experience has been instrumental in shaping nearly every aspect of this project.

A much deserved thank you to my other committee members, Dr. Peter Giannini and Dr. Aimin Peng. Thank you for taking the time to review my unorganized and typo-laden thesis drafts, and for making yourselves available to

offer helpful suggestions and insights at our committee meetings. Your support and professional guidance is greatly appreciated.

Lastly, but most importantly, thank you to my beautiful and loving wife, Katie, who has been by my side the past nine and a half years. Thank you for your unwavering love, encouragement, and patience with me, particularly when I am feeling stressed. To my wonderful children Braden, Jackson, and Leah, coming home to your loving arms and smiles each day has blessed my life more than you know. Your love is the source of my happiness and a constant reminder what matters most in life.

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ABSTRACT

Purpose: The purpose of this investigation was to determine the volumetric and cross-sectional changes that may occur within the posterior pharyngeal airway space after positioning the mandibular condyles in centric relation.

Materials and Methods: All subjects evaluated presented signs and symptoms of upper airway obstruction with significant CR-CO discrepancies. Stabilization maxillary splint therapy was employed to seat mandibular condyles in CR. Pre- and post-treatment CBCT scans were taken to compare airway changes. Thirty-one subjects (13 male and 18 female) with a mean age of 45.8 years at the time of the post-treatment scan were evaluated. DICOM files were interpreted using Anatomage Invivo5 viewing software version. Airway measurements included total volume, nasopharynx volume, oropharynx volume, minimum cross-sectional area, and cross-sectional area at PNS, CV2, and CV3. The location of the minimum cross-sectional area was recorded in reference to the superior, middle, and interior thirds of the bodies of CV2 and CV3, and also the occlusal plane. A paired two-sample for means T-test was performed to determine the significance of change in volume and cross-sectional area. F-test was performed to determine the variability for gender with all measurements.

Results: Pre-treatment total mean volume was 11.92 cm^3 and post-treatment total mean volume was 12.45 cm^3, a mean difference of 0.53 cm^3. Thirteen out of thirty-one subjects (42%) showed a decrease in total volume, whereas eighteen out of thirty-one (58%) exhibited an increase in total volume.

The mean increase in total volume was not statistically significant (p=0.22). Pre-treatment means for cross-sectional area measurements at PNS, CV2, and CV3 were 466.1, 202.3, and 226.3 mm^2, respectively. Post-treatment mean measurements at PNS, CV2 and CV3 were 474.9, 185.4 and 232.1 mm^2, respectively. The mean differences between these pre-and post- measurements for PNS, CV2, and CV3 are 8.77, -16.89, and 5.82 mm^2. These mean differences were not statistically significant (p=0.31, p=0.13, and p=0.34). Pre-treatment minimum cross-sectional area mean was 115.6 mm^2 and post-treatment mean was 105.5 mm^2. The mean difference was a -10.1 mm^2, though this difference was not statistically significant (p=0.23). Differences between pre- and post-treatment minimum cross-sectional area locations were found on fourteen of the thirty-one patients (45%). Twenty-six of the thirty-one subjects (84%) displayed a minimum cross-sectional area located at either the superior, middle, or inferior third of the CV2 body. In addition, the minimum cross-sectional area was found to be inferior to the occlusal plane in twenty-eight of the thirty-one subjects (90%).

Conclusion: Positioning the mandibular condyles in centric relation does influence posterior pharyngeal airway volume and cross-sectional area; however, the dimensional changes are not statistically significant. Post-treatment mean total volume, oropharynx volume, and nasopharynx volume increased. Mean cross-sectional area at PNS and CV3 increased, while mean cross-sectional area at CV2 and minimum cross-sectional area decreased. Further studies are

needed to assess the clinical efficacy of splint therapy to reduce severity and complications that arise from OSA.

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CHAPTER 1: INTRODUCTION

Sleep-disordered breathing (SDB) is a spectrum of conditions or diseases with abnormal respiratory patterns, resulting in decreased oxyhemoglobin saturation during sleep. Obstructive sleep apnea (OSA) is characterized by upper airway obstruction resulting in intermittent hypoxia during sleep in affected individuals. Complications can range from excessive daytime sleepiness and snoring to a variety of cardiovascular diseases including hypertension and heart failure (Coughlin S, *et al*., 2004).

Over the past two decades public health awareness of OSA and other sleep disorders have increased markedly. Epidemiological studies estimate that 18 million Americans are diagnosed with obstructive sleep apnea; and another 16 million remain undiagnosed. Once considered a disease that exclusively targeted middle-age adults, OSA is now evident in all age groups. Pediatric and adolescent victims are trending upward in prevalence. One study found a prevalence rate of 2-4% in the middle-aged adult population and 2-3% of children in North America (Young T, *et al*., 2008). Polysomnography has shown to be an effective and objective method to diagnose the prevalence and severity of sleep apnea. This test measures the apnea-hypopnea index (AHI) which quantifies the number of apneic or hypopneic episodes during sleep.

The management of OSA patients requires an interdisciplinary approach. Both surgical and non-surgical treatment options are available with the goal of improving airway patency and airflow. Continuous positive airway pressure (CPAP) works as a pneumatic stent and provides positive air pressure through a

nasal mask during sleep and has proven to be an effective method of treating severe OSA. The efficacy of CPAP therapy largely depends upon patient compliance, which has historically been very low. A proven alternative to CPAP treatment is oral appliance therapy that positions the mandible in a protruded position. These devices are designed not to cure OSA, but instead to maintain the airway open for adequate ventilation during sleep. Several studies have shown that oral appliance therapy effectively reduces common medical complications of OSA (Imran H, *et al*., 2013). Unfortunately significant advancement of the mandible often results in unwanted dentoalveolar effects, particularly when used over long periods of time. Several studies have documented these adverse effects to include proclination of mandibular incisors, retroclination of maxillary incisors, molar extrusion, and an anteroposterior change in molar relationship (Almeida FR, *et al*., 2006).

An alternative method of treatment for OSA is the use of splint therapy to fully seat the mandibular condyles in centric relation (CR) thereby positioning the mandible and nearby soft tissues and muscles of mastication in a physiologic and musculoskeletal stable position. This method is utilized in patients diagnosed with moderate obstructive sleep apnea who present with significant centric relation-centric occlusion (CO) discrepancies.

Centric relation is most commonly defined as the relationship of the mandible to the maxilla when the condyles are seated in their most superior-anterior position against the posterior slopes of the articular eminences. It is widely accepted among authors and clinicians that optimal functional occlusion

occurs when there is even and simultaneous contact of posterior teeth with condyles positioned in centric relation. This allows the joint and related structures to withstand maximum masticatory forces while placing the condyles in an orthopedic and musculoskeletal stable position (Okeson JP, 2015).

Several epidemiological studies have concluded that a large portion of the population presents with a small discrepancy between the centric occlusal position and the mandible in centric relation (Rider CE, 1978). However, the normal ranges for occlusal and condylar displacement in an asymptomatic population remains a controversial topic. In patients with significant CR-CO discrepancies, there is often a premature anterior/posterior contact with a resultant slide into CO upon maximum closure.

Splint therapy is most commonly utilized for treatment of temporomandibular joint disorder (TMD) and para-functional habits including nocturnal bruxism and clenching. Stabilization splint therapy is a common treatment that has proven effective in deprogramming masticatory muscles and stabilizing the temporomandibular joint in centric relation (Clark GT, 1984).

Identifying the relationship between centric relation and its influence on airway space has not previously been studied. Some clinicians have reported success treating mild OSA patients who present with significant CR-CO discrepancies with stabilization splint therapy. The purpose of this study is to determine the changes that may occur within the posterior pharyngeal airway space after positioning the mandibular condyles in centric relation.

CHAPTER 2: LITERATURE REVIEW

2.1 Sleep Disordered Breathing

Sleep disordered breathing (SDB) comprises a wide spectrum of sleep-related breathing abnormalities. These abnormalities include snoring, apneas, hypopneas, and respiratory effort-related arousals. SDB is often regarded as a spectrum of diseases which can range in severity. Contributory factors that determine the prevalence and severity include upper airway skeletal and soft tissue dimensions, body mass, age, and gender (Schwab, 1998).

SDB consists of three distinct clinical patterns (Young, 1993). Obstructive sleep apnea (OSA) occurs when airflow is impeded due to partial or full blockage of the upper airway passages, but respiratory effort is present. Central sleep apnea is caused by a disruption in the central neuromuscular mechanisms and occurs when both airflow and respiratory effort are absent. Mixed apnea occurs when characteristics of both obstructive and central sleep apnea are present. Obstructive sleep apnea accounts for more than 85% of sleep disordered breathing (Ho, 2011).

Upper airway resistance syndrome (UARS) is another sleep disorder characterized by airway resistance to breathing during sleep, but without any diagnosable apnea or hypopnea events. Clinical presentation of UARS can be similar to other sleep related disorders, in particular excessive daytime sleepiness and snoring.

2.2 Obstructive Sleep Apnea

Obstructive sleep apnea (OSA) is a highly prevalent condition characterized by repetitive upper airway obstruction resulting in intermittent hypoxia during sleep in affected individuals. These episodes are associated with recurrent oxyhemoglobin desaturation and arousals from sleep. OSA was once considered a disease that exclusively targeted middle-age adults; however, it is now evident that individuals of any age can be affected. One study estimated that 1 in 5 adults have mild obstructive sleep apnea, while 1 in 15 has moderate sleep apnea (Young, 1997). According to the U.S. Department of Health, 12 to 18 million adults are affected by sleep apnea while many more go undiagnosed. One prospective sleep study of 1023 infants found that obstructive and mixed apneas are rare in healthy infants (Kato, 2000). Predisposing factors of OSA include male gender, increased neck size, retrognathic mandible, increased body-mass index, increased age, and narrow airway dimensions (Abad, et al., 2009). Recent studies show that the current male-to-female ratio is approximately 2 to 3:1 (Davidson, 2005).

2.2.1 Diagnosis of OSA

Polysomnography is considered to be the gold standard for diagnosing sleep related breathing disorders. During this sleep test, approximately 20 sensors are attached to the patient, along with a pulse oximeter. Certain physiological parameters are recorded, including heart rate, respiratory effort, airflow, oxygen saturation, electrical current in the brain, resting potential of the

retina, and electrical currents associated with muscular action and cardiac cycle. Often a “split-night study” is utilized, where the patient is monitored for sleep related disorders during the first half of the night, and therapy is initiated and tested during the second half.

The apnea-hypopnea index (AHI) is commonly used to determine the severity of obstructive sleep apnea. The index represents the number of apnea and hypopnea events per hour of sleep. It is calculated by dividing the number of apnea or hypopnea events by the number of hours of sleep. The term “apnea” is defined as a cessation of airflow for at least 10 seconds or more. Partial obstruction can result in “hypopneas” and are defined as abnormal respiratory events that last for at least 10 seconds, have 30% reduction in airflow and cause 4% or more oxygen desaturation (Young, 1993). AHI values are used to determine the severity of OSA. Mild OSA is described as an AHI between 5 and 15, moderate OSA represents an AHI between 15 and 29, and severe OSA is identified with an AHI of 30 or greater (Ruehland WR, et al., 2009).

The respiratory disturbance index (RDI) is another formula used to interpret polysomnography findings. This index measures respiratory event related arousals (RERAs) and also the apnea/hypopnea episodes. RERAs indicate arousals from sleep but do not meet the definition of apnea or hypopnea episode. Often, these arousals from sleep are transitions from a deeper stage to more shallow stage of sleep (Richardson MA, 2007). Some studies have shown that RDI may be a more accurate indicator for OSA than the apnea-hypopnea index (Ho, ML, 2011).

A variety of subjective screening tests are also utilized to assess daytime sleepiness. The Epworth Sleepiness Scale (ESS) is widely used in the field of sleep medicine to measure the severity of excessive daytime sleepiness. During this self-evaluation test, the subjects rate themselves on a scale of 0 to 3 on how likely they are to fall asleep during different normal daytime activities. The greater the number, the higher the likelihood of the subject falling asleep. These scores are added to obtain a single number which indicates the severity of excessive daytime sleepiness. This assessment was first introduced by Dr. Murray Johns of Epworth Hospital in Melbourne, Australia (Johns, MW, 1991). Studies have validated the success of ESS to accurately detect obstructive sleep apnea, narcolepsy and idiopathic hypersomnia, and evaluate treatment outcomes for CPAP therapy (Hardinge FM, et al., 1995).

2.2.2 Complications of OSA

Several studies indicate a relationship between OSA and a variety of cardiovascular diseases, including hypertension, myocardial infarction, stroke heart failure, diabetes, and metabolic syndrome (Coughlin S, et al., 2004). One recent prospective study showed a strong association between hypertension and OSA, with a prevalence rate of 40% (Peppard P, et al., 2000). Patients with severe OSA, represented by a high AHI score, correlated with a higher systolic and diastolic blood pressure, even after adjustment for confounding factors such as age, gender and body mass index (BMI). Data from the Wisconsin Sleep Cohort Study provides longitudinal evidence for a causal relationship between OSA and hypertension (Peppard P, et al., 2000).

In addition to cardiovascular complications, patients with OSA can experience severe sleep deprivation which can lead to decreased physical activity, excessive daytime sleepiness, morning headaches and depression. Sleep deprivation may also impair carbohydrate metabolism and endocrine functions, contributing to weight gain and insulin resistance (Vgontzas A, et al., 2003).

2.2.3 Treatment of OSA

The management of OSA patients requires an interdisciplinary approach for both diagnosis and treatment. Comprehensive treatment may include correction of any craniofacial deformity that contributes to decreased airway dimensions. Both surgical and non-surgical methods are employed to improve ventilation by airway volume expansion and reduce collapsibility of soft tissues surrounding the airway, including the soft palate and tongue (Riley RW, et al., 1993). Non-invasive treatment protocols are recommended initially to improve the safety and comfort of the patient.

2.2.4 Non-Surgical Treatment of OSA

Non-surgical treatment typically begins with a variety of behavioral changes that encourage weight-loss, abstaining from alcohol, smoking or changes in sleeping position (Barrera JE, et al., 2007). Both obesity and OSA are associated with cardiopulmonary complications. Obese patients with cardiovascular risks are amplified in the presence of OSA. One study concluded that patients diagnosed with resistant hypertension show a higher prevalence

and severity of OSA due to the association of risk factors that are common to both conditions (Min HJ, et al., 2015). Weight loss has repeatedly shown to decrease the prevalence of OSA. One study of 690 patients showed a 10% weight gain led to a 32% worsening in RDI and a 10% weight loss led to a 26% improvement (Horner R, et al., 1989). Other studies have confirmed that weight loss can improve SDB (Mortimore I, et al., 1998).

Continuous positive airway pressure (CPAP) is currently the gold standard for non-surgical treatment of OSA. CPAP works as a pneumatic stent, providing a positive air pressure through a nasal mask and effectively preventing the collapse of the pharyngeal airway. Convincing data from numerous randomized controlled trials in OSA patients with hypertension or heart failure have demonstrated that treatment with CPAP not only reduces the risk of developing cardiovascular disorders but also disease severity (Mills et al, 2006; Kaneko Y, et al., 2003). However, the efficacy of CPAP largely depends upon patient compliance. Due to physical discomfort, drying of the nasal and oral mucosal membranes, dislodgement during sleep, noise, and social consequences patient compliance can be as low as 40% (Goodday RH, et al., 2006).

An effective alternative to CPAP treatment is oral appliance therapy. Two common oral appliance therapies include mandibular advancement devices (MADs) and the tongue retainer devices (TRD). MADs position the mandible in a protruded position, creating an anterior movement of the soft tissues and muscles surrounding the posterior pharyngeal airway, resulting in improved airway patency. Typically the mandible is advanced 50% to 70% of the maximum

protrusion. TRDs function by creating suction within the device to hold the tongue in a superoanterior position, preventing collapse into the airway during sleep in the supine position. These devices are not designed to cure OSA, but instead to maintain the airway open for adequate ventilation during sleep. Advantages of oral appliances include their small size, ease of adjustability, custom fabrication, and ease of use. These advantages have led to high levels of compliance. Yoshida found the compliance rate for mandibular advancement devices was nearly 90% after a 2.5 year period (Yoshida K, 2000). When placed in the mouth, the MAD will rest on the maxillary and mandibular dentitions. Some MAD's can be self-adjusted to increase or decrease mandibular advancement. This feature allows clinicians to perform a titration polysomnogram, where the mandible is advanced until apneas and hypopneas are eliminated or maximum tolerable advancement is reached. An example of a mandibular advancement device is shown in figure 2.1.

The American Academy of Sleep Medicine recommends oral appliance therapy for patients with mild to moderate OSA, and also for patients with severe OSA but are non-compliant with CPAP treatment (Kushida CA, et al., 2006). Numerous studies have confirmed the efficacy of oral appliance therapy to reduce severity and complications that arise from OSA. A meta-analysis of several randomized controlled trials found that oral appliance therapy is associated with significant blood pressure reduction in mild to moderate OSA patients (Imran H, et al., 2013). Another study of over 250 subjects found a 66% reduction in the mean AHI, with oxygen saturation, duration of apnea, sleep

efficiency and total arousals significantly improved (Yoshida K, 2000). In a study that compared the short-term clinical efficacy between mandibular advancement devices vs CPAP, the authors concluded that in adults with moderate to severe OSA, the use of an adjustable MAD was not inferior to CPAP in its impact on blood pressure, daytime sleepiness and general quality of life (White DP, et al., 2013).

Until recently, most randomized controlled trial studies were performed using 2D cephalometric radiographs. Cossellu performed a three-dimensional upper airway evaluation during oral appliance therapy. Nine out of ten subjects showed an overall improvement in the apnea-hypopnea index, with an increase in volume in both the posterior soft palate and posterior tongue regions (Cossellu G, et al., 2015). Another study with a larger sample size of 25 investigated the treatment effects of crossbow appliance (Great Lakes Orthodontics, Tonawanda, NY) on the upper airway dimensions and volume using cone beam computed tomography (CBCT). In addition to favorable class II correction, three-dimensional evaluation of the upper airway showed an increase in both dimension and volume. This study showed no changes in the nasopharyngeal region (Erbas B, et al., 2014).

There are potential risks with the use of mandibular advancers, especially when used long-term. Significant mandibular advancement, particular when using the dentition as anchorage, can result in adverse effects on the dentoalevolar structures. Almeida et al., found that after 5 years of oral appliance use, cephalometric measurements showed proclination of mandibular incisors,

maxillary incisor retroclination, molar extrusion, rotation of the mandible, and increase in the interincisal angle and lower facial height. Also there was an anteroposterior change in the molar relationship, indicating a more forward position of the mandibular arch (Almeida FR, et al., 2006). It is believed that these movements are a result of repositioning of the mandible forward, and the ensuing forces placed on the dentoalevolar structures. Almeida et al., findings were confirmed in several other studies. In an observation period of over 11 years, one study found a significant reduction in overbite, overjet, and mandibular crowding, along with incidences of anterior and posterior crossbite. These changes in occlusion were progressive in nature, indicating that the dental side effects continued to worsen with ongoing oral appliance use (Pliska BT, et al., 2014). While long-term use is associated with permanent occlusal changes, most studies agree that oral appliance therapy does not affect temporomandibular disorder prevalence (Martinez J, et al., 2010). One study concluded that patients with pre-existing signs and symptoms of TMD that are treated with MADs do not experience an exacerbation of those signs and symptoms. In fact, in many instances they decreased over time (Perez C, et al., 2011).

2.2.5 Surgical Treatment of OSA

Due to the low compliance rate of CPAP therapy with patients suffering from moderate to severe sleep apnea, surgical treatment is occasionally necessary. There are many surgical options depending on the specific location of airway obstruction. Surgical treatment is often classified as either phase I or phase II treatment. Phase I treatment may include any one or combination of the

following surgeries: septoplasty, adenoidectomy, tonsillectomy, turbinate reduction, uvulopalatopharyngoplasy (UPPP), genioglossus advancement, or hyoid suspension. Nasal septal and adenoid surgeries are performed to open the airway passage in the nasal cavity. Enlarged tonsils or adenoids may interfere with airway flow, especially in children. When an enlarged uvula is the site of obstruction, a UPPP procedure is performed to partially remove the uvula, making the soft palate shorter and firmer. Both genioglossus advancement and hyoid suspension are performed to advance the position of the tongue, increasing the airway passage (Abad VC, et al., 2009).

Phase II surgery is reserved for patients who were unsuccessfully treated in phase I. Orthognathic surgery is categorized as phase II surgery, and maxillomandibular advancement (MMA) surgery is the most common. The goal of MMA is to enlarge the airway passage by displacing the soft tissues, musculature, and hard tissues in an anterior and lateral direction. Certain patients with craniofacial abnormalities have a predisposition for a collapsed airway, and are recommended for immediate phase II surgery. Several studies have confirmed the efficacy of MMA to treat moderate to severe obstructive sleep apnea. In a retrospective study of 265 patients who underwent MMA surgery for treatment of OSA, Goodday found a significant reduction in post mean AHI score (Goodday RH, et al., 2015).

2.3 Centric Relation

The definition of centric relation (CR) has evolved over the past century and is often a topic of controversy. Up until the early 1980’s most clinicians

considered CR as the most retruded position of the mandibular condyle within the glenoid fossa. The concept of positioning the mandible in the most retruded position predominated until more sophisticated temporomandibular joint (TMJ) imaging became available. These images led to a change in the definition of CR from a posterior-superior to an anterior-superior position (Rinchuse DJ, et al., 2006). Dawson argued that positioning the condyle distally can cause anterior and medial displacement of the TMJ disc (Dawson PE, 1985). The posterior portion of the TMJ is composed of retrodiscal tissues and lamina which are highly vascularized and well supplied with sensory nerve fibers and posterior attachments to the articular disc. These structures are not anatomically structured to withstand masticatory forces. When condyles are displaced in a superior-posterior position these tissues can be compressed, eliciting pain and potential damage to the retrodiscal structures (Isberg A, et al., 1986). Currently, a widely accepted definition of CR can be described as the relationship of the mandible to the maxilla when the condyles are seated against the “thinnest avascular portion of the articular disc in their most superior-anterior position against the superoposterior slopes of the articular eminences and centered transversely, independent of tooth contact” (Howat AP, et al., 1991).

2.3.1 Musculoskeletal Stability

The TMJ is a bilateral synovial articulation between the mandible and temporal bone. Interposed between the condyle and articular eminence is the articular disc, which is composed of dense fibrous connective tissue to withstand heavy forces and stabilize the condyle during functional movements. However,

the articular disc does not determine the positional stability of the TMJ. Like other synovial joints, the stable position is determined by the directional forces of the muscles that are applied on the joint rather than the ligaments. Without influence from the occlusion, the TMJ is stabilized by the tonus of the masseter, medial and lateral pterygoid, and temporalis muscles. The temporalis muscle positions the condyle superiorly. The masseter and medial pterygoid muscles position the condyle superiorly and anteriorly. And the inferior lateral pterygoid muscle positions the condyle anteriorly against the posterior slopes of the articular eminence. The action of these directional forces are shown in figure 2.2. Therefore, the most stable position of the TMJ is when the condyles are in the superior-anterior position against the posterior slope of the articular eminence. Okeson described this as the most orthopedically and musculoskeletally stable position of the mandible (Okeson JP, 2015).

Other studies have shown how the action of a healthy musculature positions the condyles in an anterosuperior position (Crawford SD, 1999). One study evaluated condylar positions obtained from masticatory muscle contraction without influence from occluding teeth. An anterior deprogrammer was used to measure condyle position during contraction of masticatory muscles. They found that the contraction of masticatory muscles placed the condyles in the same position as centric relation, independent of occlusion (McKee JR, 2005).

In the musculoskeletally stable position, articular surfaces of the TMJ are positioned to withstand the greatest amount of force without causing significant damage to the temporal bone. Dry skull studies have shown that the anterior and

superior roof of the glenoid fossa is sufficiently thick to withstand the heavy forces produced by the muscles of mastication. Conversely, the superior and posterior roof of the mandibular fossa is composed of comparatively thin bone (Moffet BC, 1969).

2.3.2 Positioning and Reproducibility

Several studies have concluded that CR is the most accurate and reproducible reference point for recording the relationship of the mandible to the maxilla (Wood DP, et al., 1988). Several techniques exist on positioning a patient into centric relation. Dawson and Okeson recommend the bilateral manual manipulation, which has become a common clinical practice among prosthodontists and orthodontists. This technique involves manipulating the mandible when the patient is in a supine position with the chin lifted. The clinician places 4 fingers of each hand on the lower border of the mandible, with the thumbs resting on the symphysis of the chin. Firm but gentle force is placed to guide the mandible in a downward and backward direction, with the goal of positioning the condyles in their most superior-anterior position against the posterior slopes of the articular eminence. To ensure the condyles have not translated, it is recommended to disclude the anterior teeth approximately 10mm. The bilateral manipulation technique is shown in figure 2.3 (Okeson JP, 2015).

Tarantola performed a study to measure the reproducibility of centric relation using the bimanual manipulation technique. Dentists were randomly assigned to one of five patients and asked to position the patient in centric relation. The final position was recorded using the same wax recording

technique, and were analyzed using the Denar Centri-Check marking system. They found that the maximum variation of condylar positions were 0.1mm (Tarantola GJ, et al., 1997).

2.3.3 Centric Relation-Centric Occlusion Discrepancy

Centric occlusion (CO) and maximum intercuspation (MI) are often used synonymously, and represents the most closed position that the mandible assumes when teeth cusps are fully interposed with the cusps of the opposing arch. Centric occlusion defines the vertical dimension of occlusion in both the anteroposterior (AP) and vertical planes of space.

In an optimal functional occlusion, there is even and simultaneous contact of all posterior teeth, with light contact of anterior teeth, and condyles placed in centric relation. However, it is widely accepted that a large portion of the population shows a discrepancy between the centric occlusal position and the mandible in centric relation. An epidemiological study revealed nearly 86% of the 323 adult patients evaluated presented with a minor mandibular displacement from CR to CO. All of these patients demonstrated a shift in the vertical plane, nearly all exhibited an anterior component, and a third showed lateral movement. (Rieder CE, 1978). In a landmark study by Posselt in the early 1950's, he indicated that the average distance between the retruded CR position and CO was 1.25mm. This discrepancy remained constant after orthodontic treatment, and was smaller in children (Posselt U, 1952). However, the normal ranges for occlusal and condylar displacement in an asymptomatic population remains a controversial topic.

In Posselt's envelope of motion, a centric slide is described by the first CR tooth contact to maximum intercuspation. When CR and CO coincide, there is no premature contact and consequently no slide is observed upon maximum closure. The direction and magnitude of slide is based upon the presence and location of premature contacts, which may also trigger para-functional habits such as clenching and bruxism.

Several different clinical methods have been performed to evaluate condylar displacement, including radiographic imaging, centric relation mounting with mandibular position indicators, and chair side visualization. Arthrography and arthroscopy procedures can be utilized, but are often expensive and invasive with questionable value.

Movement of the condyles from CR to CO is most commonly in a posteroinferior direction, resulting in an anterior displacement of the mandiblular dentition. In addition, when condyles are displaced from CR to CO, overjet is often decreased and overbite is increased. Cordray found significant increased overjet, decreased overbite, midline differences, and Angle classification changes in patients with condyles fully seated when compared to CO (Cordray FE, 2006). These occlusal changes can significantly alter orthodontic diagnosis and treatment plans.

Several studies have evaluated condylar positions in CR vs CO and attempted to make correlations with certain population groups. A three-dimensional study was performed to compare the condylar position between CR and CO for 107 patients before orthodontic treatment. A mandibular position

indicator was used to ensure accurate CR mounting. Data from the MPI was used to examine the frequency, direction, and magnitude of CO-CR difference. This data was also correlated to the patients Angle classification, ANB angular measurement, age, or gender. The amount of CR-CO difference was identical for right and left sides, and found a mean displacement of 0.84 mm inferiorly, 0.61 mm posteriorly, and only 0.27 mm laterally. It found no correlation with the patient's age, ANB angle, gender, or Angle classification. Therefore, these variables cannot be used to predict the magnitude, frequency and direction of CO-CR changes at the condylar level (Utt TW, et al., 1995). A subsequent study confirmed no correlation between CO-CR shift and Angle's classification (Afzal A, et al., 1995).

In a prospective study of 596 asymptomatic patients, Cordray found that 94.1% had a premature contact on a posterior tooth with changes in condylar position from CR to CO in an inferior (98.1%) and distal or posterior (65.8%) direction when the teeth were brought into CO. Also, the mean magnitude of the vertical component between CR and CO was more than two times greater than the horizontal component (Cordray FE, 2006). These results support previous findings in terms of the direction and magnitude of condylar displacement from CR to CO.

2.3.4 Splint Therapy

Splint therapy can be defined as the "art and science of establishing neuromuscular harmony in the masticatory system by creating a mechanical disadvantage for parafunctional forces with removable appliances" (Dylina TJ,

2001). Occlusal splints simulate an ideal functional occlusion and are used to diagnose and treat various masticatory disorders, including bruxism and other parafunctional habits, fatigued masticatory muscles, myofascial pain, and temporomandibular joint disorder (TMD). Clinicians often “test” the response to splint therapy before considering definitive treatment while also ensuring a stable seated condylar position for proper occlusal diagnosis.

Various types of appliances can be fabricated to perform different functions depending on the needs of the patient. Most occlusal splints are fabricated with hard or soft acrylic and adjusted to fit on either the maxillary or mandibular dentition. Stabilization splints, also known as the Michigan splint or centric relation appliance, are commonly used for TMJ dysfunction and myofascial pain. It is constructed to achieve ideal functional occlusion. The maxillary anterior guided orthotic (MAGO) is a common occlusal splint that is horseshoe shaped and fits onto the maxillary dentition. When properly adjusted it simulates an ideal functional occlusion with even contact on all posterior teeth in CR and very little contact of anterior teeth. Adjustments are also made on lateral and protrusive excursive movements. The mandibular splint, or Tanner splint, is very similar to MAGO but instead is placed onto the mandibular dentition.

Several studies have confirmed the clinical effectiveness to reduce myofascial pain in patients with stabilization splints. Carraro performed a prospective study of 170 TMD patients treated with full coverage splints on either the maxillary or mandibular dental arches. They found that eighty-two percent of subjects responded favorably with significant reduction of TMJ pain and muscle

pain and also improved dysfunction (Carraro and Caffesse, 1978). A similar study was performed by Okeson in which pain responses of individual muscles and TMJ were scored before and after splint therapy. Eight-five percent of the 33 subjects showed a decrease in observable pain scores (Okeson, *et al*., 1982). In a recent systematic review of stabilization splint therapy for the treatment of temporomandibular myofascial pain, it was concluded that there is insufficient evidence either for or against the use of stabilization splint therapy over other active interventions and recommended well-conducted RCT's to clarify the clinical effectiveness. However, it did appear that stabilization splint therapy was effective at reducing pain severity at rest and on palpation when compared to no treatment (Al-Ani Z, *et al*., 2005).

Along with changes in the occlusion and muscle function, splints can also affect the temporomandibular joint. Repositioning splints act in the reverse of stabilization splints by moving condyles down the eminence and out of the glenoid fossa. This movement can be beneficial to patients suffering from internal disc derangement. Repositioning the condyles down the eminence relieves pressure on the retrodiscal tissue and facilitates soft tissue healing and resolution of effusion. Anterior repositioning splints are typically used for short periods of time and often concurrently with anti-inflammatory medication (Okeson JP, 2003).

Splint therapy has also proven to be an effective technique for deprogramming the neuromusculature in patients with significant CR-CO condylar discrepancies. The proprioception of masticatory muscles, tendons,

periodontal ligaments and the TMJ all influence the muscle programming of centric occlusion. When this occlusion does not coincide with centric relation, occlusal interferences can alter the arc of closure in an attempt to protect the interfering teeth from absorbing the entire masticatory force. Deconditioning these neuromuscular patterns to the ideal functional occlusion can be clinically challenging. Studies have shown splint therapy to be reliable in deprogramming neuromuscular habits through full-time wear of stabilization splints in CR, particularly when signs and symptoms of TMD are present (Clark GT, 1984).

2.4 Centric Relation and Airway

Numerous authors, clinicians and educators agree that a fully seated condylar position in centric relation is an essential component of a stable and functional occlusion. However, no studies have investigated what effect seated condyles in centric relation have on the posterior pharyngeal airway space.

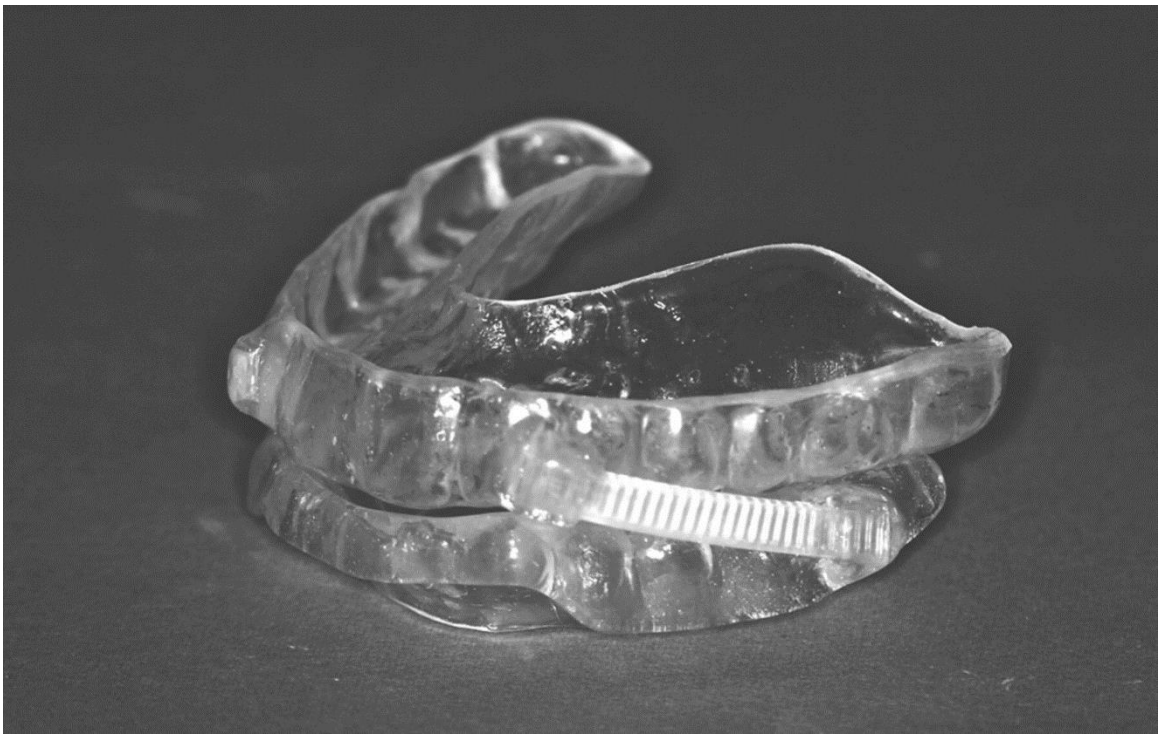

Figure 2.1 Mandibular advancement device (Naomi T, 2009).

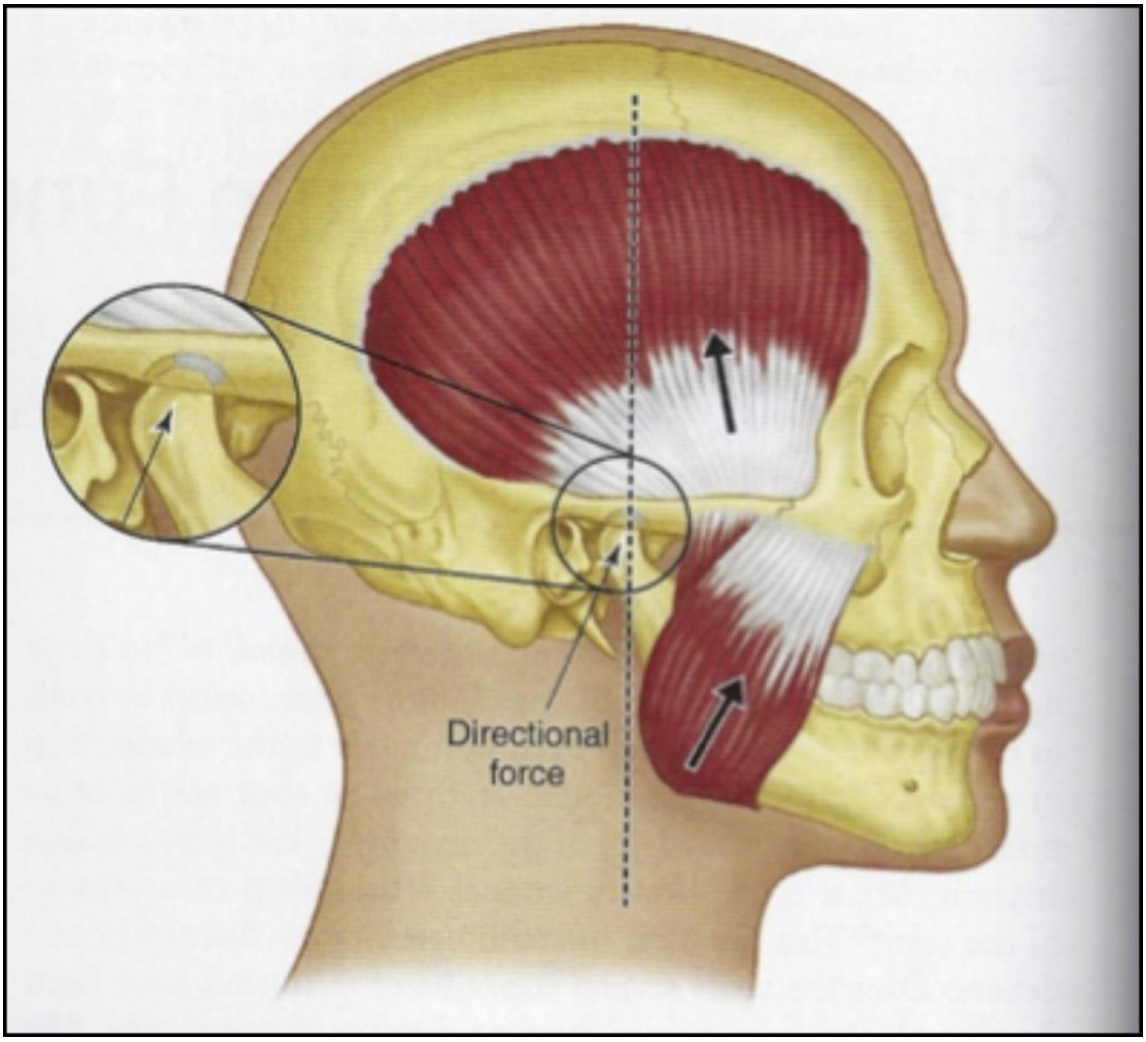

Figure 2.2 Directional forces of temporalis, masseter, and medial pterygoid muscles seat the condyles in a superior-anterior position in the fossae (Okeson JP, 2015).

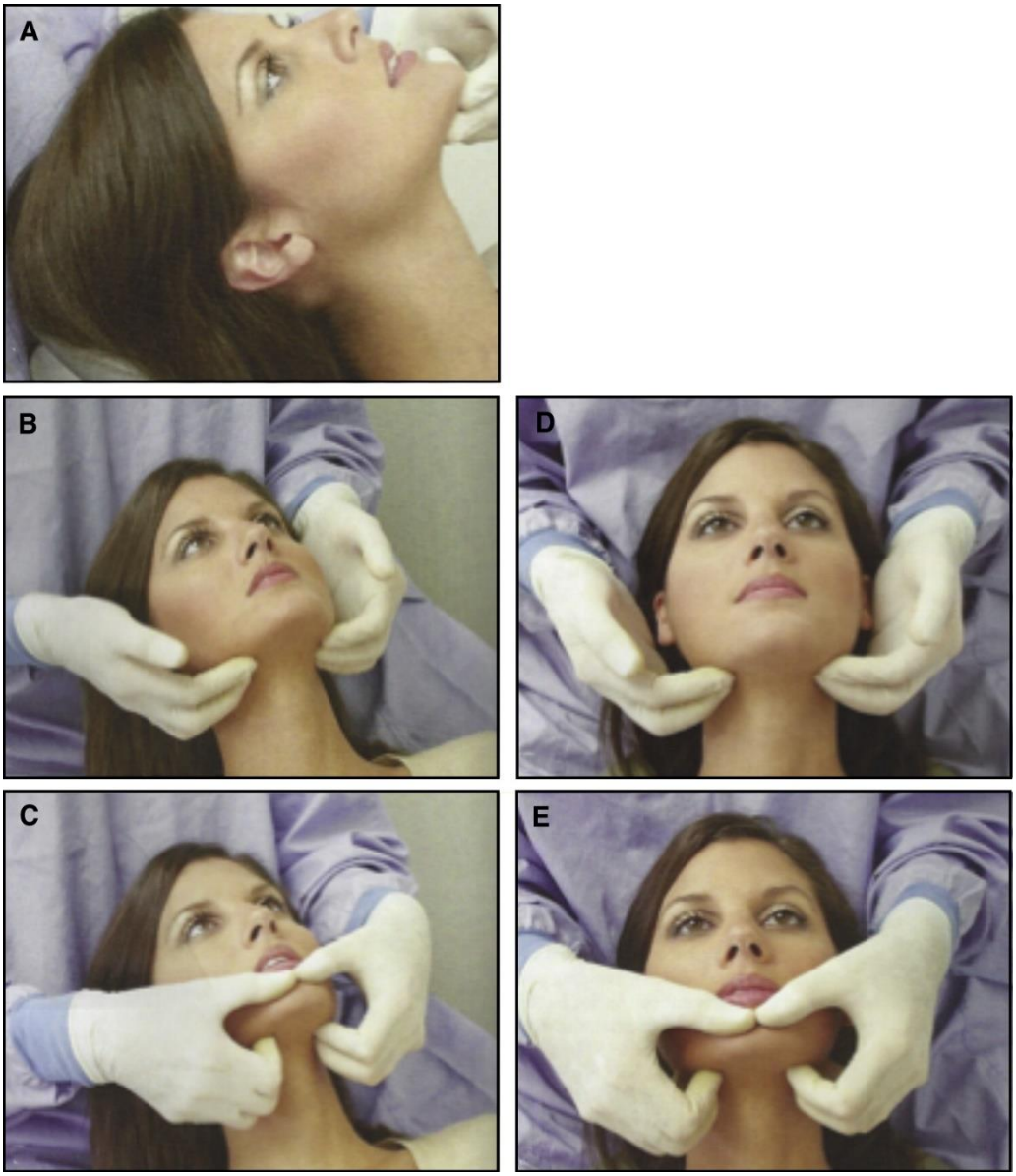

Figure 2.3 Representation of the bilateral manual manipulation technique to position the mandibular condyles in centric relation (Okeson JP, 2015).

CHAPTER 3: STUDY AIMS

3.1. Statement of the Problem

Currently the relationship between the volume of the posterior pharyngeal space and mandibular position is unknown. The effect that seating mandibular condyles in centric relation on the volumetric and cross-sectional area of the posterior pharyngeal airway is yet to be investigated.

3.2. Null Hypothesis

There is no difference in total posterior pharyngeal airway volume, nasopharynx volume and oropharynx volume before and after seating mandibular condyles in centric relation.

3.3. Specific aims of current study

- Compare total posterior pharyngeal volume before and after splint therapy.
- Compare nasopharynx & oropharynx volume before and after splint therapy
- Compare cross-sectional area at the level of the posterior nasal spine, cervical vertebrae 2, and cervical vertebrae 3 before and after splint therapy.
- Compare the cross-sectional area and location of the minimum cross-sectional area before and after splint therapy.

CHAPTER 4: MATERIALS & METHODS

4.1 Splint fabrication

All subjects were patients at a private orthodontic office (Dr. Mary Burns, New Hope, PA) and presented with signs and symptoms of upper airway obstruction with centric relation-centric occlusion discrepancies. Each subject was placed into centric relation using the bilateral manual manipulation technique. Wax registration material and facebow were used to record the inter jaw position, which was transferred to an articulator. Stone models were used to fabricate a maxillary anterior guided orthotic (MAGO) appliance (figure 4.24). The stabilization splint was then placed on the maxillary dentition and adjusted until the condyles were fully seated in centric relation. All subjects were asked to wear the appliance twenty-four hours a day.

4.2 Image acquisition

All radiographic scans analyzed in this study were taken with Kodak CBCT machine (Carestream Health, Toronto Canada) with a field view of 18.4 cm x 20.6 cm and a voxel size of 0.3 mm. All scans were completed at the private office of Dr. Mary Burns in New Hope, Pennsylvania.

Initial scans were taken on all subjects in maximum intercuspation in the upright position with Frankfurt horizontal parallel to the floor. Post treatment scans were taken in centric relation with the maxillary anterior guided orthotic placed on the maxillary arch. The average time between pre and post scans was

7 months and 8 days. A total of 31 subjects pre- and post-treatment CBCT scans were evaluated (13 male and 18 female). Although not all subjects underwent a comprehensive sleep study for diagnosis of obstructive sleep apnea, all presented with signs and symptoms of OSA. Many of the subjects received orthodontic treatment following MAGO therapy. Both the CBCT scans and orthodontic therapy were performed by Dr. Mary Burns. The mean subject age at the time of the post-MAGO scan was 45.8 years, and ranged from 19 to 64.4.

The study aims and protocols were reviewed and approval was obtained from the UNMC Institutional Review Board prior to commencement of the study (IRB approval # 681-14-EP). Informed consent was obtained from all subjects. All scans were acquired in DICOM file format and exported for interpretation. The interpretation of all CBCT images was performed on Anatomage Invivo5 viewing software version 2.1 (Anatomage, San Jose, California) licensed to the University of Nebraska Medical Center College of Dentistry.

4.3 Volumetric Airway Analysis

Airway volumetric analysis was performed using airway analysis tool in Anatomage Invivo5 viewing software. All scans were oriented in the sagittal view using the incisive canal and the 2nd cervical vertebrae (CV2). In preparation for upper airway analysis, several anatomic planes and points were determined to measure different regions of the airway. A plane between posterior nasal spine (PNS) and sella formed the superior limit, and a plane passing through the inferior border of the 3rd cervical vertebrae (CV3) formed the inferior limit. Total volume was defined as the sum of nasopharynx and oropharynx, and calculated

by measuring space between a horizontal plane at the inferior border of CV3 and vertical plane connecting sella turcica and PNS. Nasopharynx volume was defined as the area between a plane parallel with Frankfurt horizontal at PNS and a plane passing through PNS and sella. The oropharynx volume was defined by the area between a plane parallel with Frankfurt horizontal at PNS and a plane parallel with Frankfurt horizontal at the inferior border of CV3.

Clipping and sculpting tools were used to isolate total volume and oropharynx volume (figures 4.1-4.2, 4.7-4.8). Clipping was initially done in gray scale in order to better visualize the skeletal reference points. The sculpting tool was then used to remove unnecessary soft tissue and skeletal structures from both right and left sagittal views of the airway. The lateral walls of the airway were then sculpted in the frontal view (figures 4.3-4.5, 4.9-4.11). The volume measurement tool was used to calculate the volume in cubic centimeters (figures 4.6, 4.12). The nasopharynx volume was calculated by subtracting the total volume by oropharynx volume. All scans were measured with a lower threshold value of -1000 and upper value at -603 Hounsfield units (HU). These thresholds values were adapted from a previous study by Hart, et al, 2015. Pre- and post-treatment scans were recorded and compared for changes in airway volume for all three regions. A positive number represents an increase in volume. All volumetric analyses were performed by 1 examiner (JS).

4.4 Cross Sectional Area Analysis

Cross-sectional area measurements were taken at the inferior border of each volumetric region with the airway analysis tool in Anatomage Invivo5

viewing software. Each scan was oriented in the sagittal view using the incisive canal and CV2. Measurements were taken at horizontal plane parallel with Frankfurt horizontal at PNS, inferior border of CV2 and the inferior border of CV3. Using the area measurement tool, the airway border was traced and then calculated in millimeter squared (figures 4.13-4.21). Pre- and post-treatment scans were recorded and compared at all three airway levels.

4.5 Minimum Cross-Sectional Area Analysis

The minimum cross-sectional area is defined as the most constricted portion of the airway. The volume rendering tool was used to determine the minimum cross-sectional area along the total airway, bordered superiorly with a plane between PNS and sella, and inferiorly by a plane passing through the inferior border of CV3 and measured in millimeter squared (figures 4.22-4.23). The location of the minimum cross-sectional area was observed and recorded in relation to the superior, middle and inferior thirds of the bodies of CV2 and CV3 and the occlusal plane. Pre- and post-treatment minimum cross-sectional areas and locations were compared at all three regions.

4.6 Method Error

Intraobserver reliability tests were performed to investigate the potential error in identifying skeletal landmark and airway volumetric and cross-sectional area measurements. After one month of initial tracings, ten subjects were randomly selected (5 male and 5 female) and measured a second time by the same examiner (JS). The differences for all variables recorded in first and

second measurement periods were compared for all 10 subjects. Pearson correlation coefficient was calculated for each variable.

4.6 Statistical Analysis

Means for all volumetric and cross-sectional measurements were determined for pre-treatment and post-treatment scans. A paired two-sample T-test was performed using SPSS (version 16.0, IBM, Armonk, NY) to determine the significance of change in volume, cross-sectional area, and minimal cross-sectional area for all three airway regions. F-test was performed to determine the variability for gender and age with all measurements.

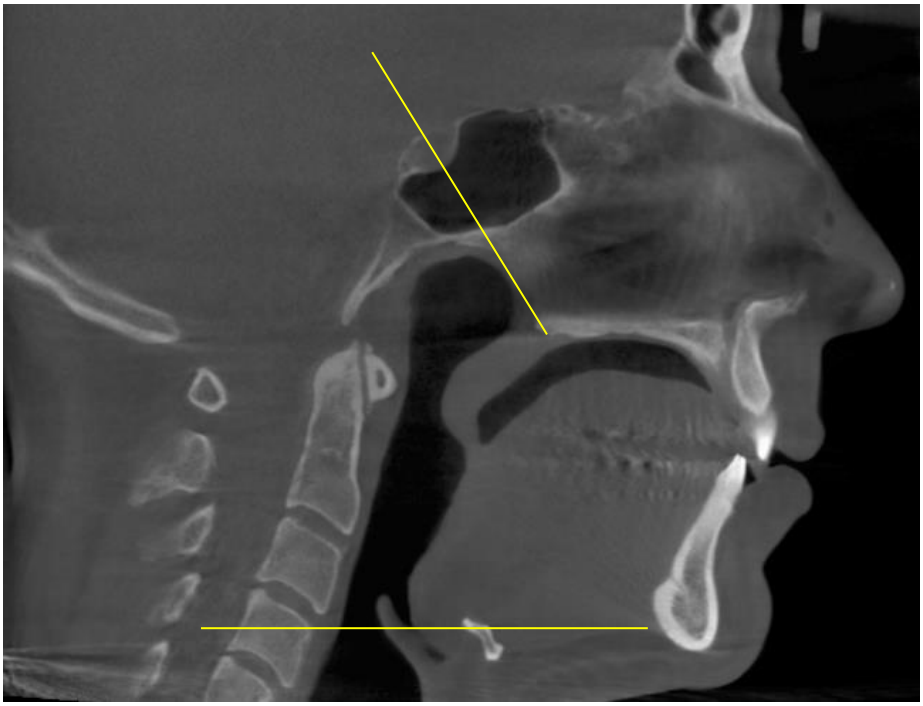

Figure 4.1. Polygon sculpture tool used to isolate total volume. Superior boundary of total volume defined by plane connecting posterior nasal spine (PNS) and sella (upper yellow line). Inferior boundary represented by horizontal line bisecting inferior border of CV3 (lower yellow line).

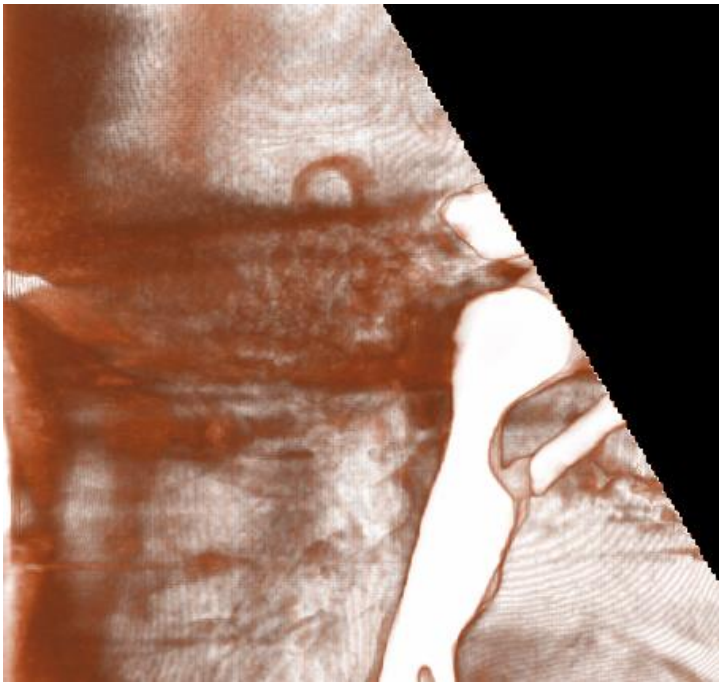

Figure 4.2. Total volume region of airway after initial clipping. Inverse color scale was used to better visualize the airway. Freehand sculpture tool was then used to draw the border of airway, removing unnecessary soft tissue and skeletal structures from both right and left sides.

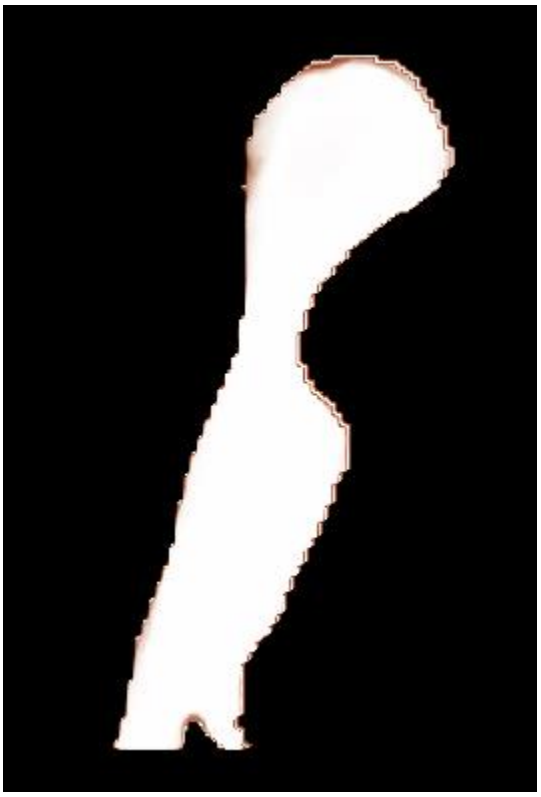

Figure 4.3. Sagittal view of total volume after freehand sculpture.

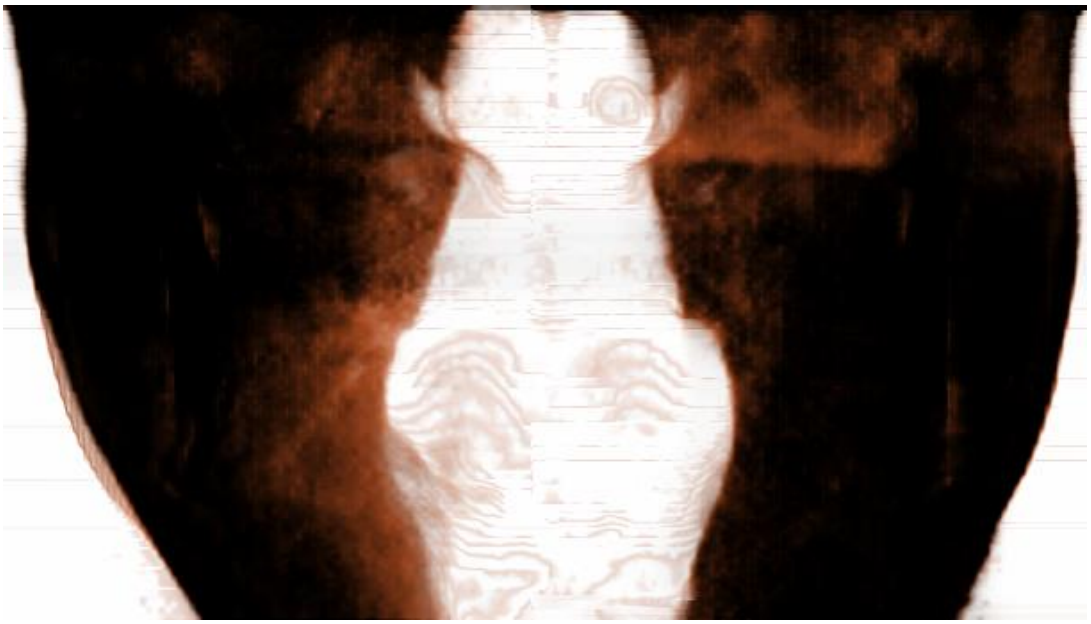

Figure 4.4. Frontal view of total volume. Freehand sculpture tool was used to outline the border of airway, removing unnecessary soft tissue and skeletal structures from the lateral boundaries.

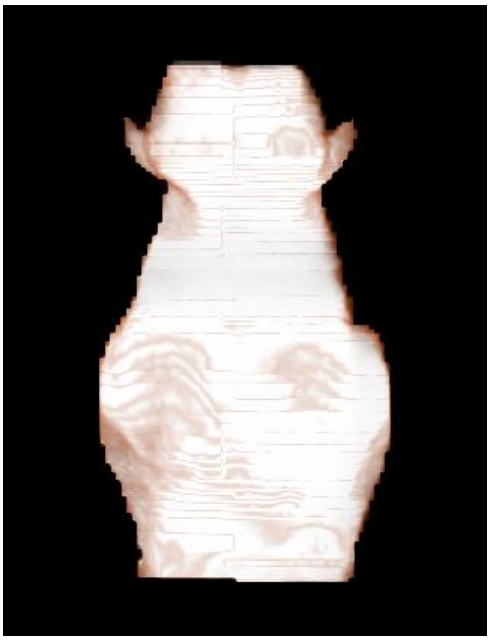

Figure 4.5. Isolated frontal view of total volume airway.

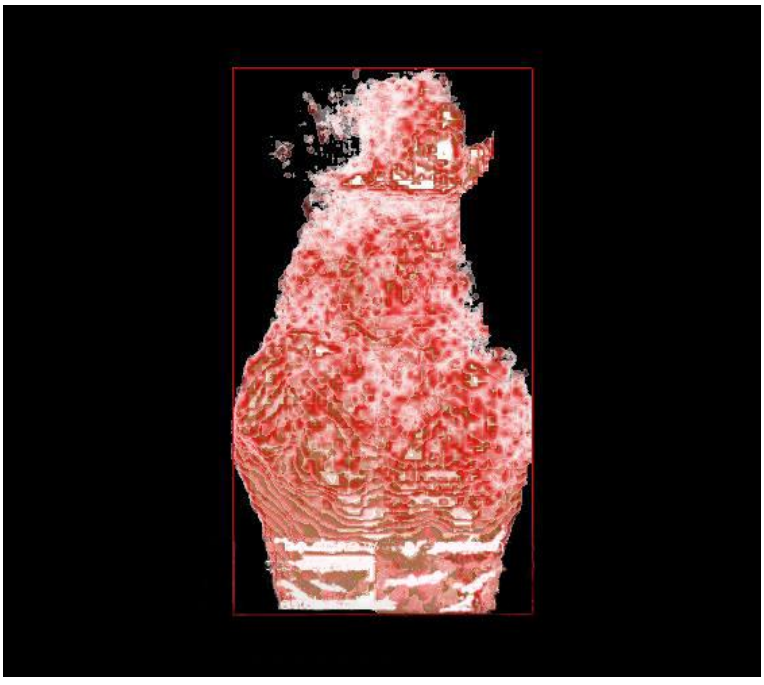

Figure 4.6. Volume rendering of isolated total volume airway with density of -603 HU. Airway volume was calculated in cubic centimeters.

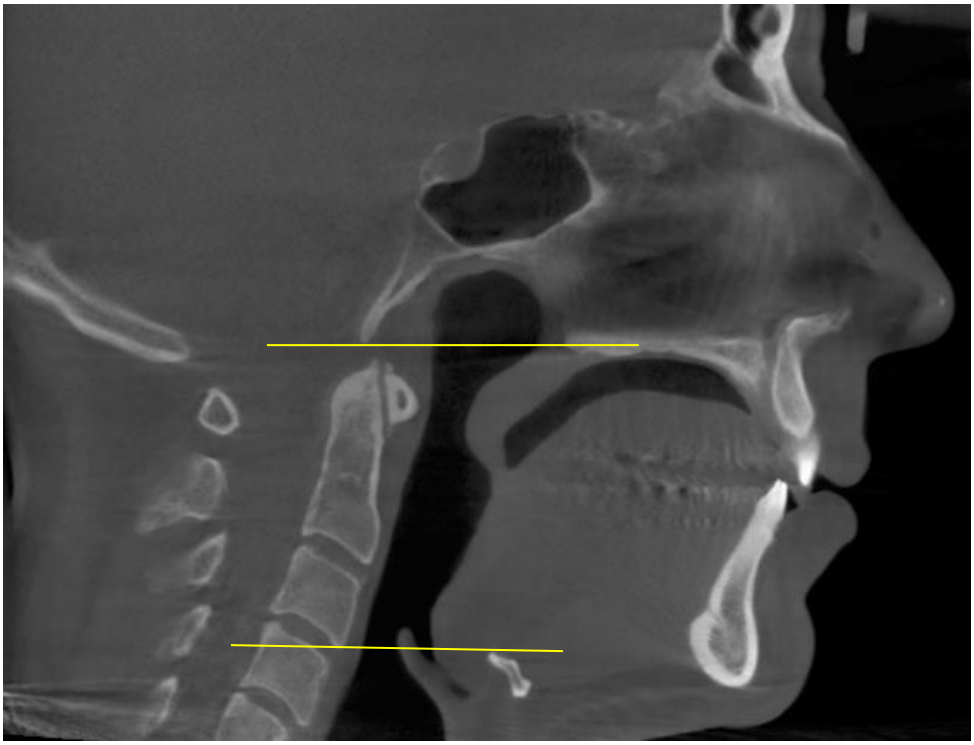

Figure 4.7. Polygon sculpture tool used to isolate oropharynx volume. Superior boundary of oropharynx defined by plane parallel with Frankfurt horizontal at PNS (upper yellow line). Inferior boundary defined by horizontal line parallel with Frankfurt horizontal bisecting inferior border of CV3 (lower yellow line).

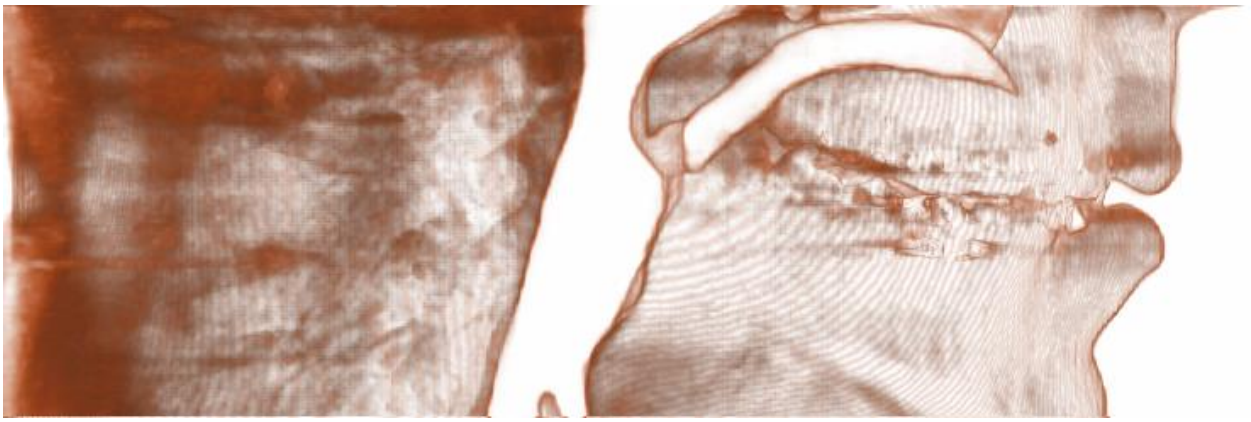

Figure 4.8. Oropharynx region of airway after initial clipping. Inverse color scale was used to better visualize the airway. Freehand sculpture tool was then used to draw the border of airway, removing unnecessary soft tissue and skeletal structures from both right and left sides.

Figure 4.9. Sagittal view of oropharynx after freehand sculpture.

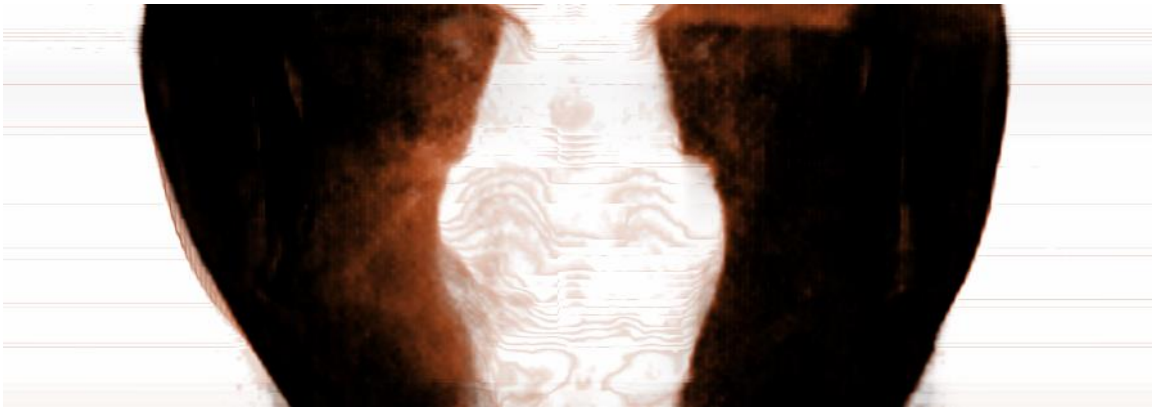

Figure 4.10. Frontal view of oropharynx. Freehand sculpture tool was used to outline the border of airway, removing unnecessary soft tissue and skeletal structures from the lateral boundaries.

Figure 4.11. Frontal view of oropharynx after freehand sculpture.

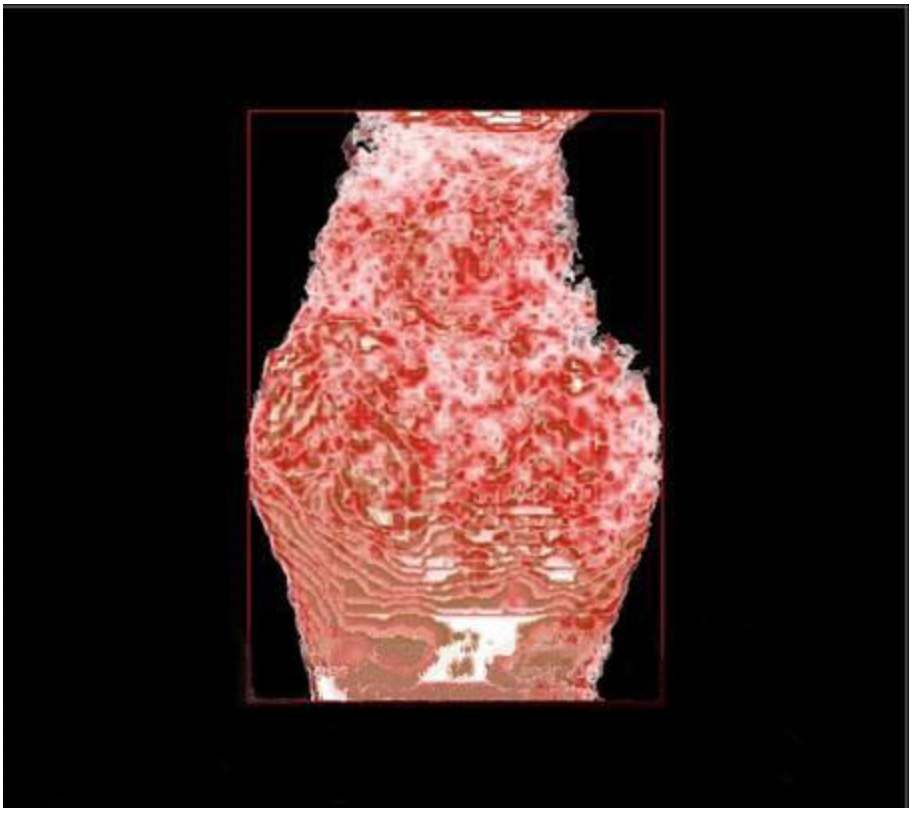

Figure 4.12. Volume rendering of the isolated oropharynx airway with density of -603 HU. Airway volume was calculated in cubic centimeters.

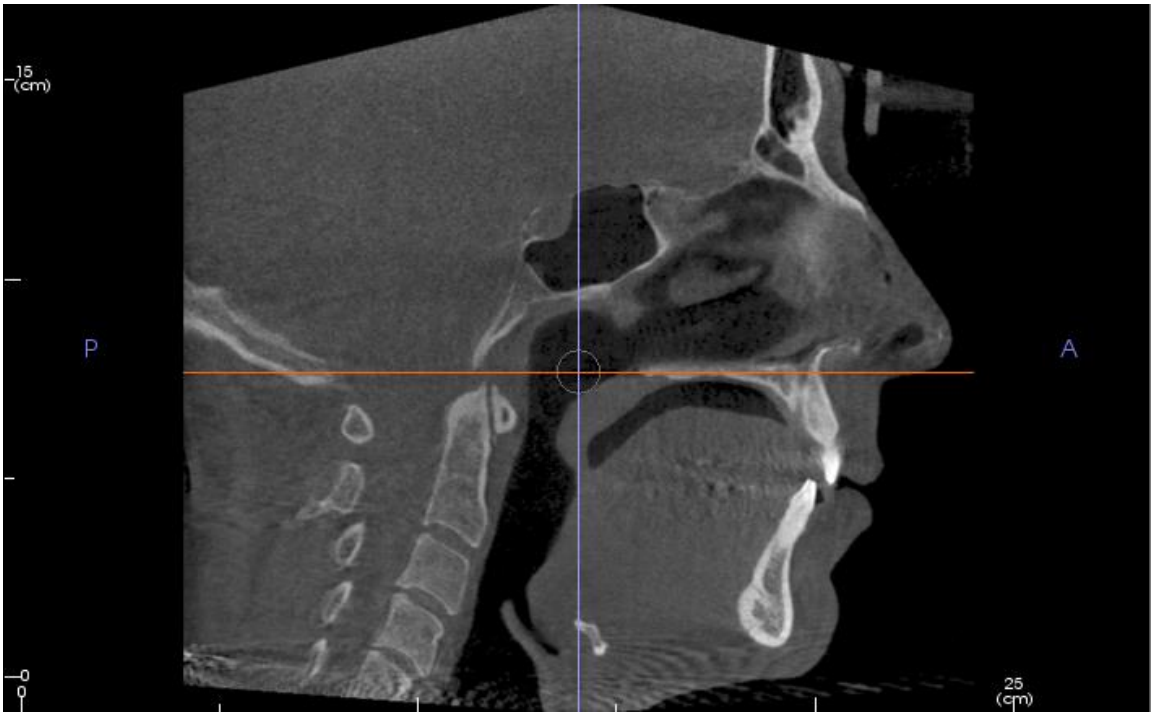

Figure 4.13. Images were oriented in the sagittal view using the incisive canal and CV2. Cross-sectional area measured at the level of PNS (orange horizontal line).

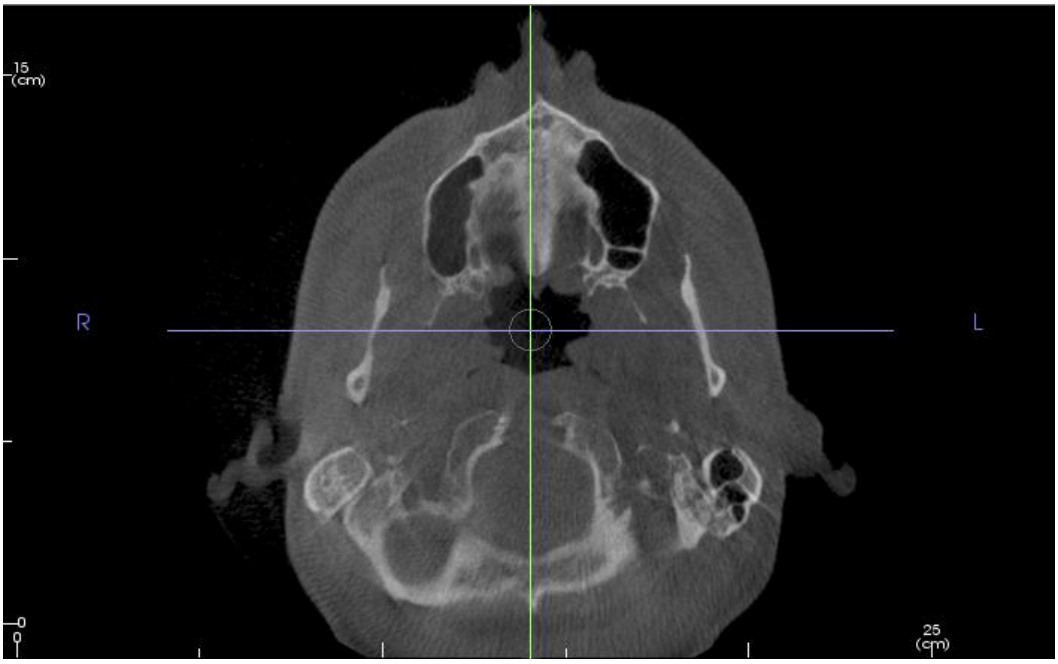

Figure 4.14. Transverse view of cross-sectional area at PNS.

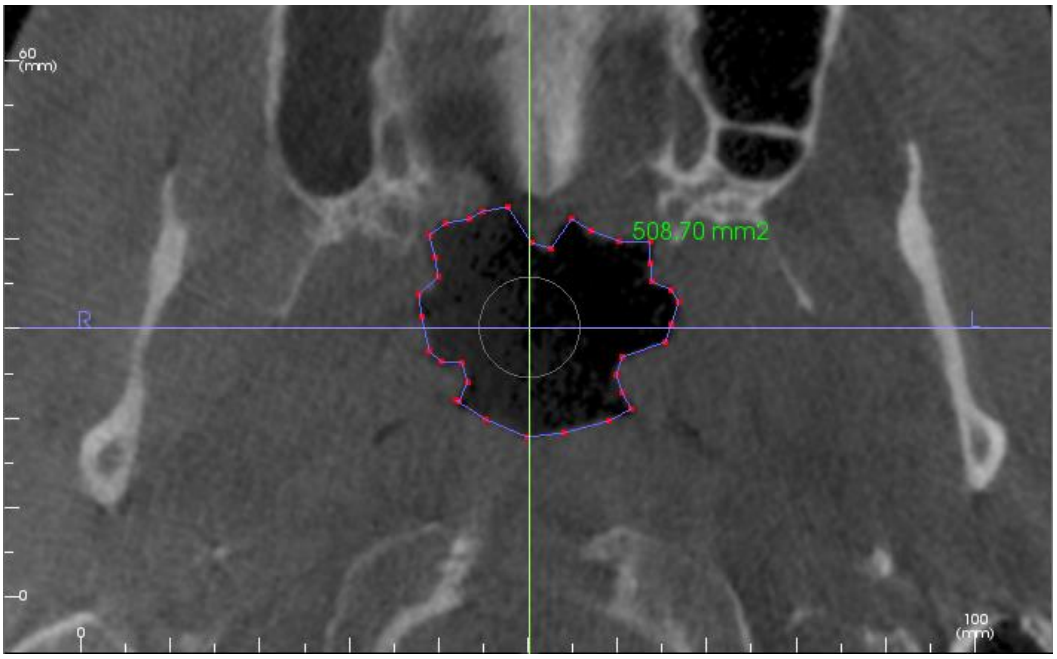

Figure 4.15. Area measurement tool used to trace airway border at PNS. Cross-sectional area was measured in millimeters squared.

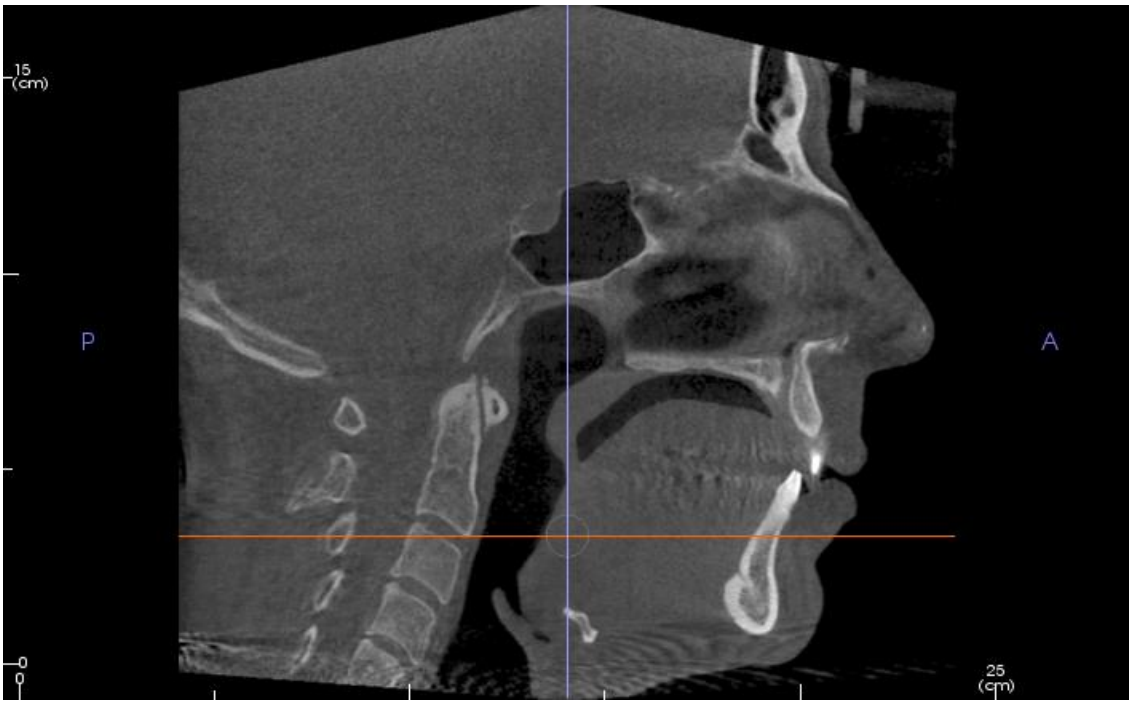

Figure 4.16. Images were oriented in the sagittal view using the incisive canal and CV2. Cross-sectional area measured at the level of CV2 (orange horizontal line).

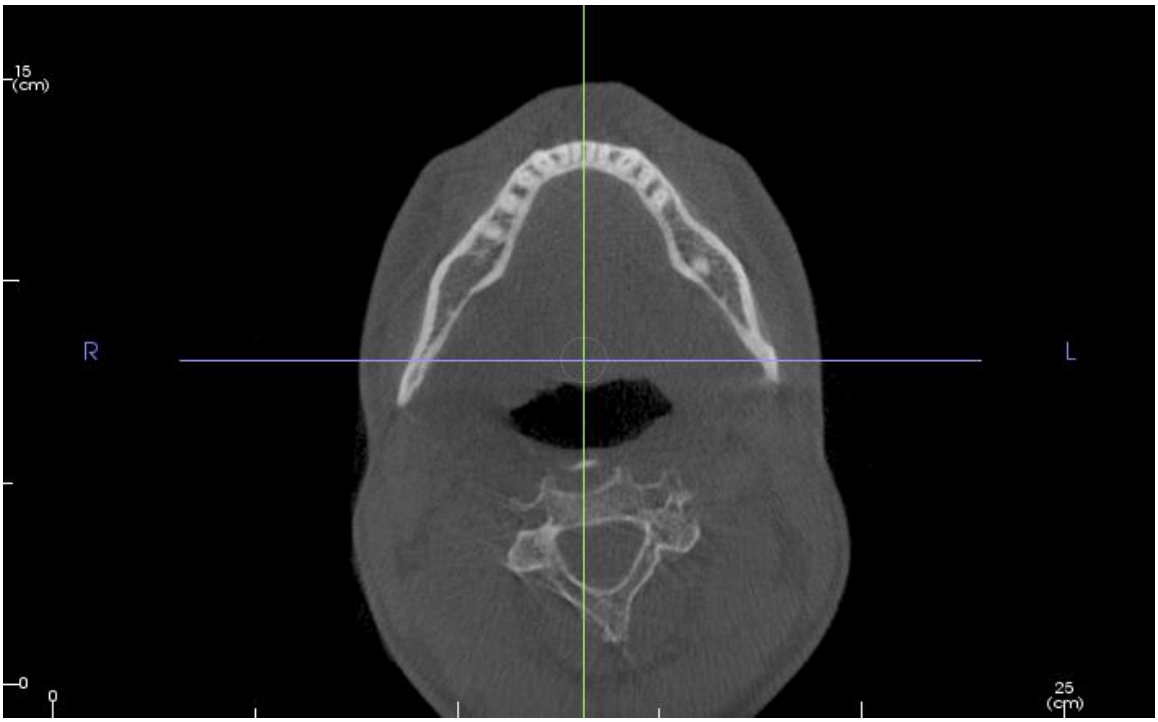

Figure 4.17. Transverse view of cross-sectional area at CV2.

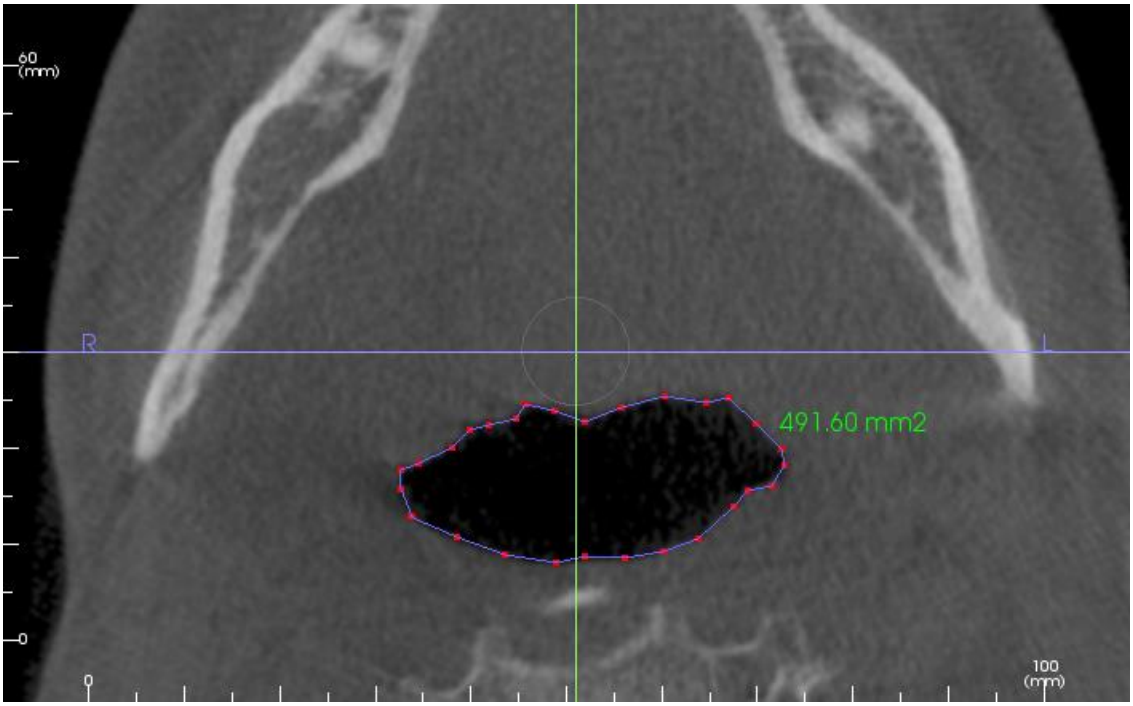

Figure 4.18. Area measurement tool used to trace airway border at CV2. Cross-sectional area was measured in millimeters squared.

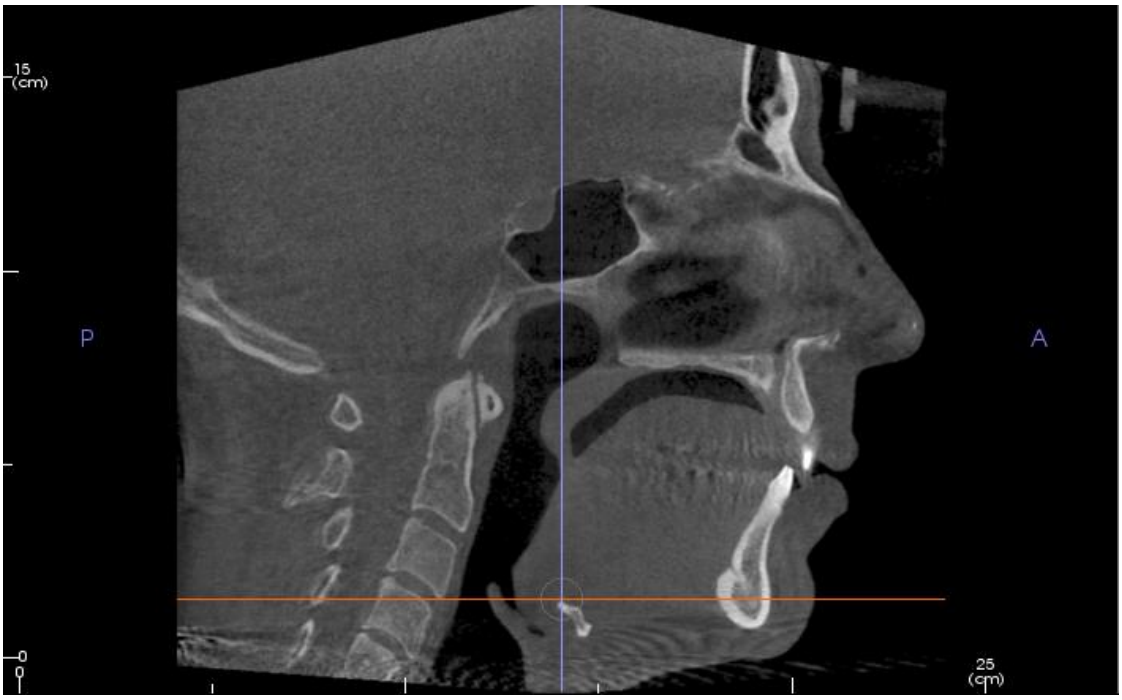

Figure 4.19. Images were oriented in the sagittal view using the incisive canal and CV2. Cross-sectional area measured at the level of CV3 (orange horizontal line).

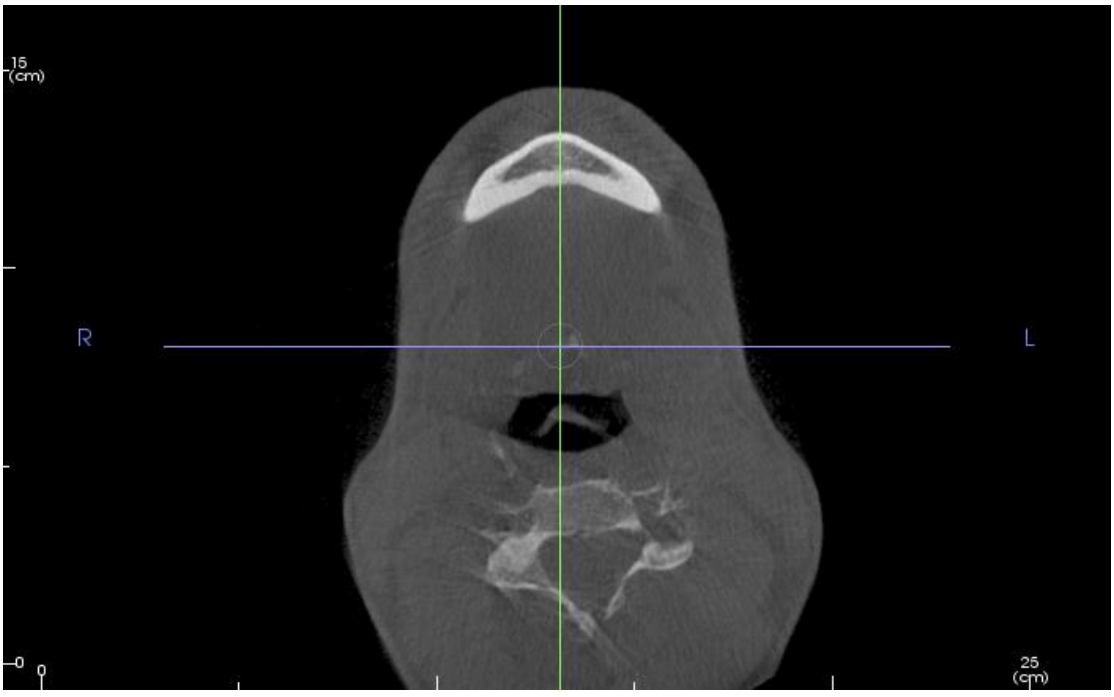

Figure 4.20. Transverse view of cross-sectional area at CV3.

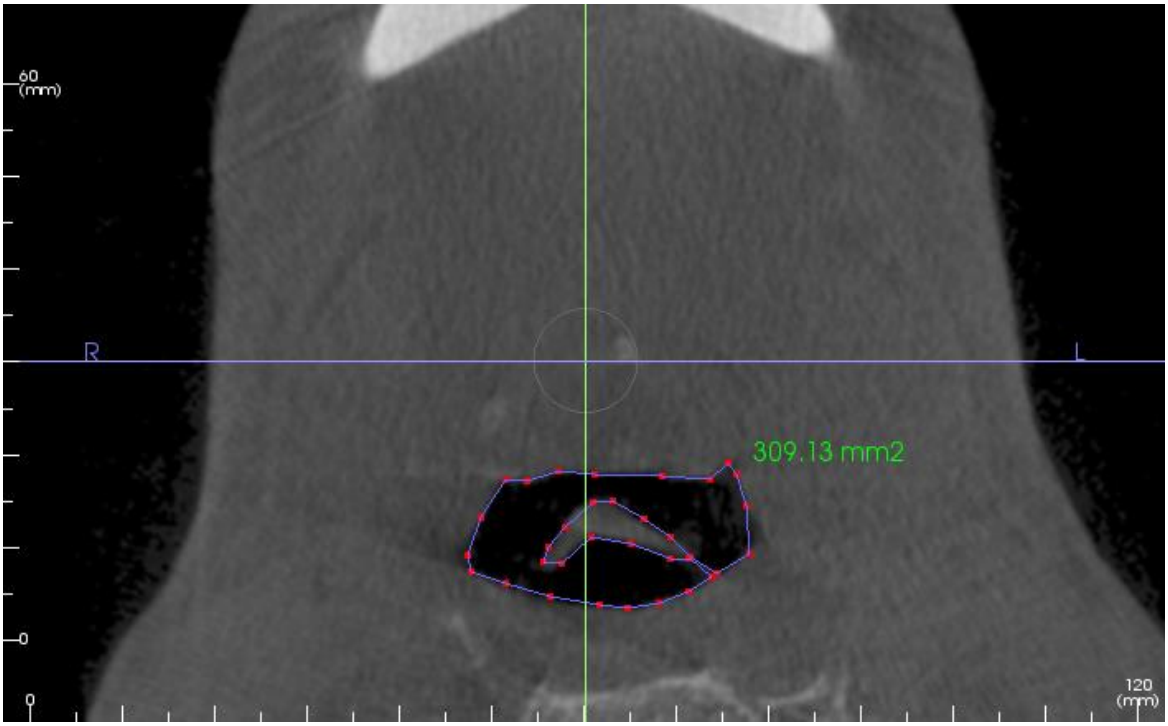

Figure 4.21. Area measurement tool used to trace airway border at CV3. Cross-sectional area was measured in millimeters squared.

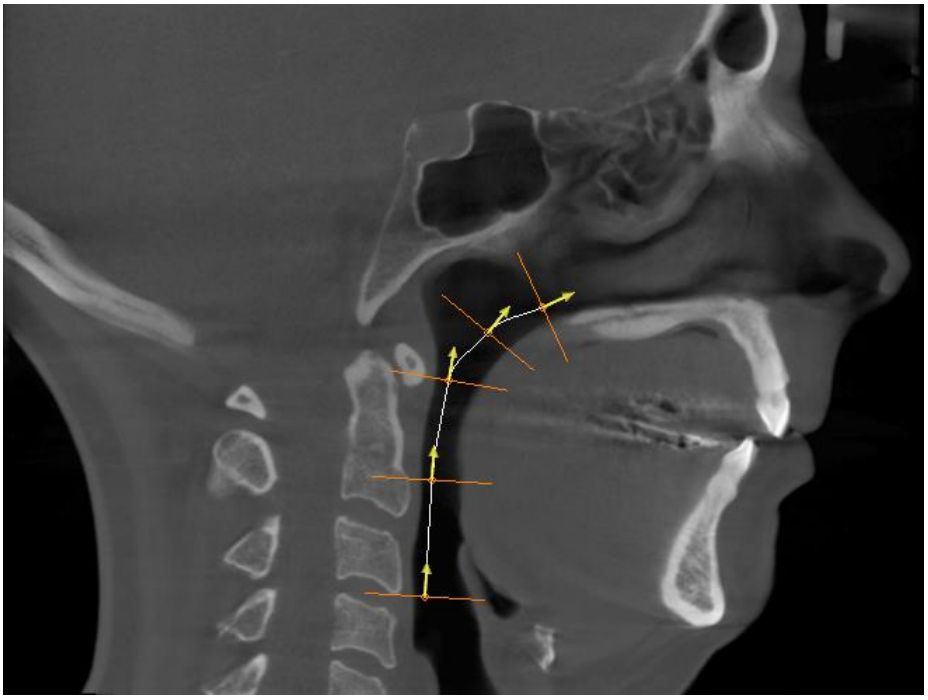

Figure 4.22. Images were oriented in the sagittal view using the incisive canal and CV2. Volume rendering tool used to determine the minimum cross-sectional area of total airway.

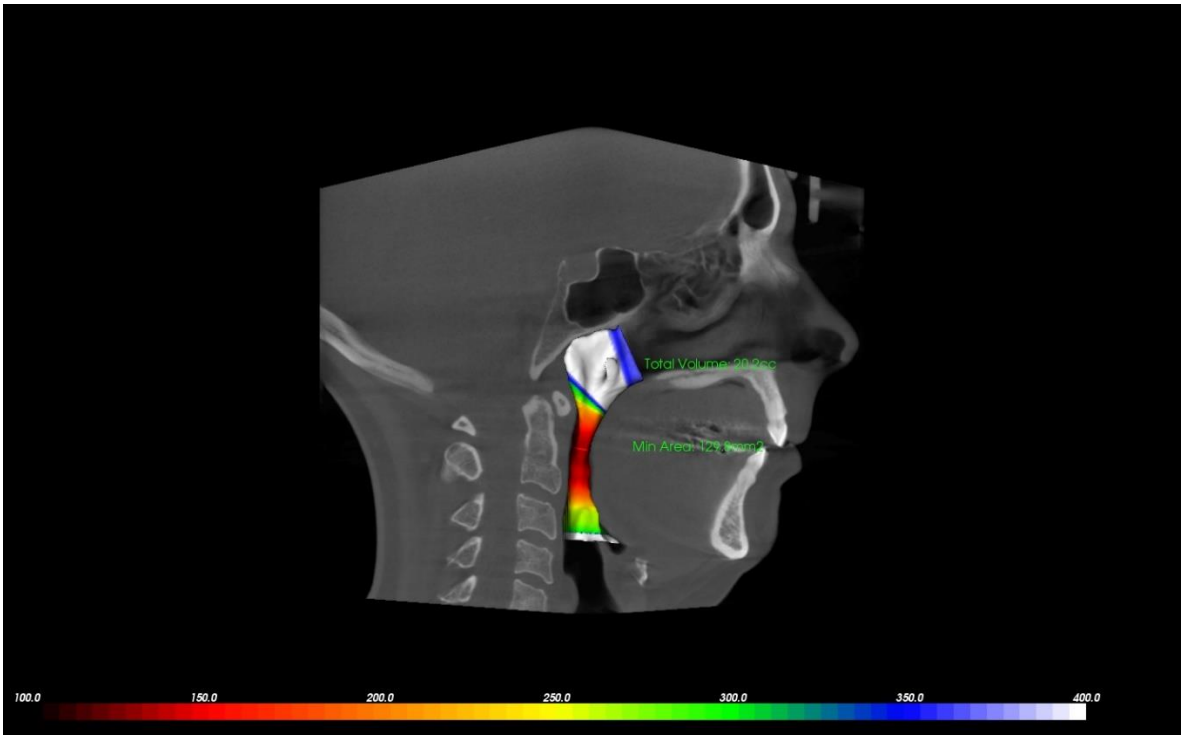

Figure 4.23. Minimum cross-sectional area identified and recorded in millimeter squared. The location of the minimum CSA was observed and recorded in relation to the superior, middle, and inferior thirds of the bodies of CV2 and CV3.

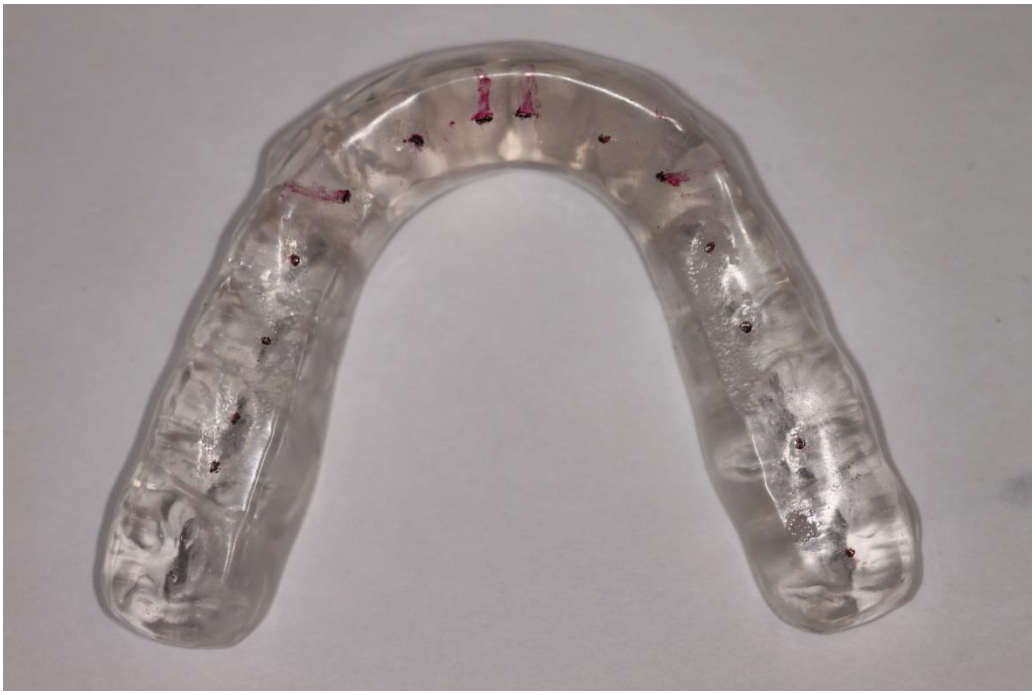

Figure 4.24. Maxillary anterior guided orthotic (MAGO). Courtesy of Dr. Mary Burns, New Hope PA.

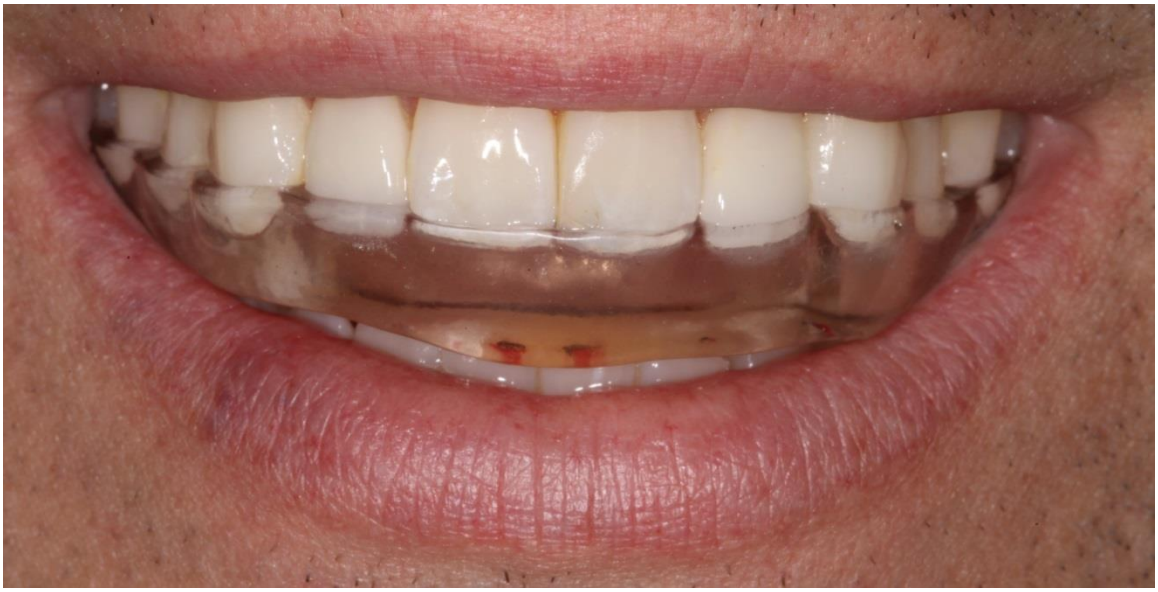

Figure 4.24. MAGO appliance. Courtesy of Dr. Mary Burns, New Hope, PA.

CHAPTER 5: RESULTS

5.1 Total Volume Measurements

The average pre- and post-treatment measurements for total volume, nasopharynx, and oropharynx on all subjects are shown in figure 5.1. The mean total volume comparison between pre- and post-treatment measurements are shown in figure 5.2. Error bars represent the upper and lower 95% confidence limits of each measurement. A summary of the paired two-sample T-test is shown in appendix B. P-value for all volumetric measurements was set at <0.05. Thirteen out of the 31 subjects (42%) showed a decrease in total volume, while 18 out of 31 (58%) exhibited an increase in total volume (p=0.53).

5.2 Regional Volume Measurements

The average pre- and post-treatment regional volume measurements at nasopharynx and oropharynx are shown in figures 5.3 and 5.4 respectively. All error bars represent the upper and lower 95% confidence limits of each measurement. A summary of the paired T-test for nasopharynx and oropharynx measurements are shown in appendix A.

5.3 Minimum Cross-Sectional Area Measurement

The mean minimum cross-sectional area measurements for all subjects pre- and post-treatment are shown in figure 5.5. Error bars represent the upper and lower 95% confidence limits of each measurement. P-value for all cross-

sectional measurements was set at <0.05. Similarly to total volume measurement, 13 out of the 31 subjects (42%) showed a decreased minimum cross-sectional area, while 18 out of 31 (58%) exhibited larger minimum cross-sectional areas.

5.4 Cross-Sectional Area Measurements

The average pre- and post-cross-sectional area measurements for all subjects at posterior nasal spine, second cervical vertebrae, and third cervical vertebrae are shown in figures 5.6, 5.7, and 5.8 respectively. All error bars represent the upper and lower 95% confidence limits of each measurement. The paired two-sample T-test results for cross sectional measurements at posterior nasal spine, second cervical vertebrae, and third cervical vertebrae are shown are shown in appendix A. Figure 5.9 shows the average pre- and post-treatment cross-sectional area measurements at PNS, CV2, CV3, and minimum cross-sectional area.

5.5. Volumetric and Cross-Sectional Mean Differences

The mean differences between pre- and post-treatment volumetric and cross-sectional area measurements are found in figures 5.10 and 5.11, respectively. The mean percent differences for all volumetric and cross-sectional area measurements are shown in figures 5.12 and 5.13, respectively. All standard error bars represent the upper and lower 95% confidence limits of each measurement.

5.6. Location of Minimum Cross-Sectional Area

The location of the minimum cross-sectional area was recorded in relation to the superior, middle and inferior thirds of the bodies of CV2 and CV3 and the occlusal plane. These findings are represented in figure 5.14.

5.7 Airway Changes All Subjects

Pre- and post-treatment mean volumetric and cross-sectional area measurements, and mean differences for each measurement are summarized in table 5.1 for all subjects. Standard deviation and p-values with associated significance for each measurement are shown.

5.8 Airway Changes Male vs Female

Table 5.2 summarizes airway changes for female subjects, and table 5.3 summarizes airway changes in male subjects with associated standard deviation, p-values, and mean differences. F-test was performed to determine the variability for gender with all measurements. No significant differences were found between male and female with all volumetric and cross-sectional area measurements.

5.9 Method Error

The repeatability of each value was tested by calculating the Pearson correlation coefficient on initial and final measurements one month later on 10 randomly chosen subjects. The average correlation coefficient was 0.986, ranging from 0.960 to 0.998, as shown in table 5.4.

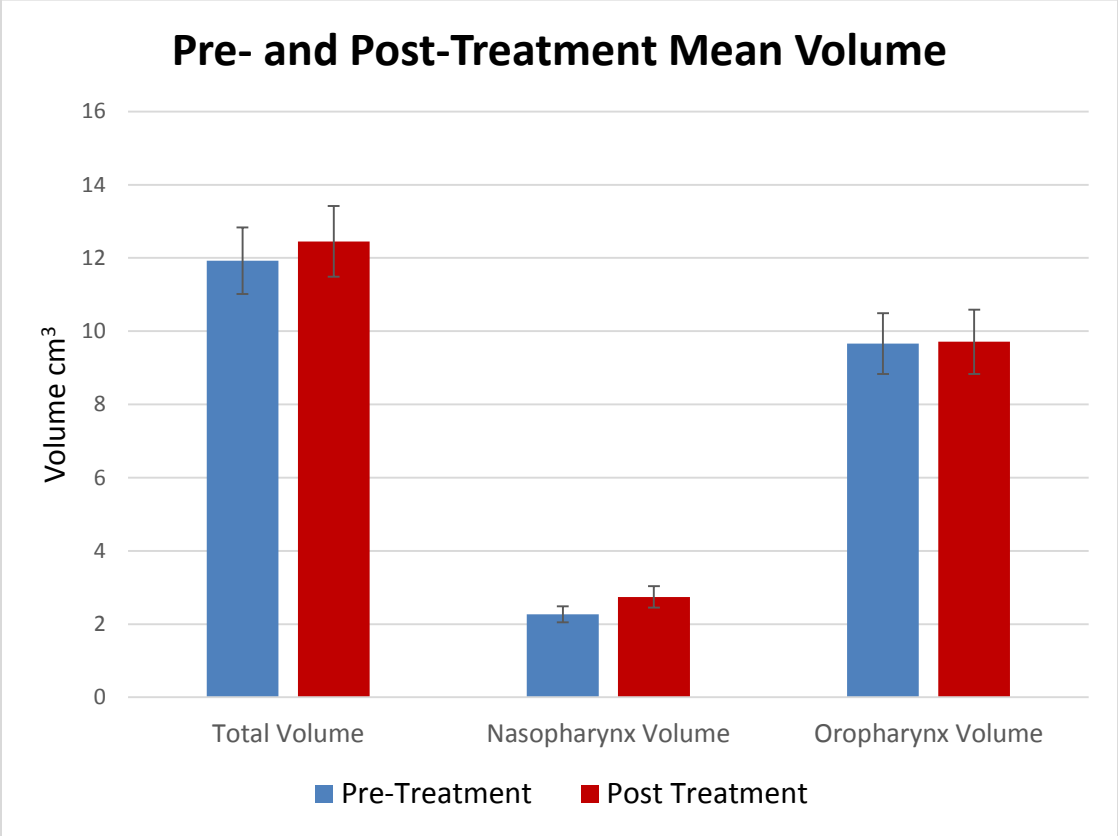

Figure 5.1. Pre- and post-treatment mean total volume, nasopharynx volume, and oropharynx volume.

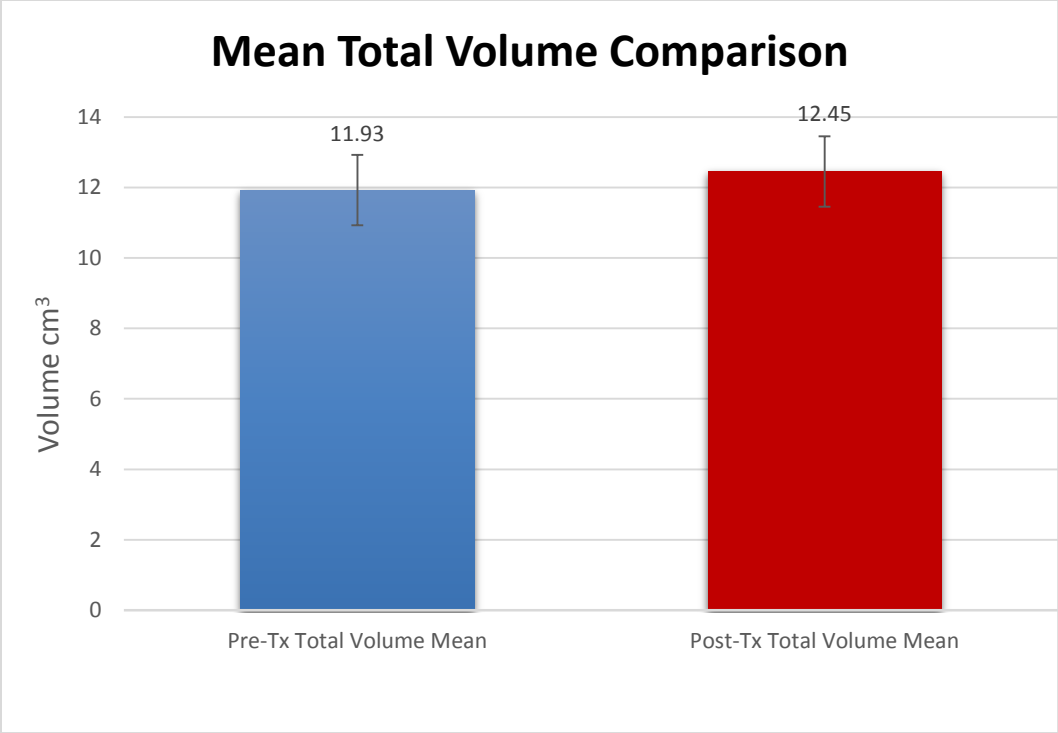

Figure 5.2. Pre- and post-treatment mean total volume (cm^3).

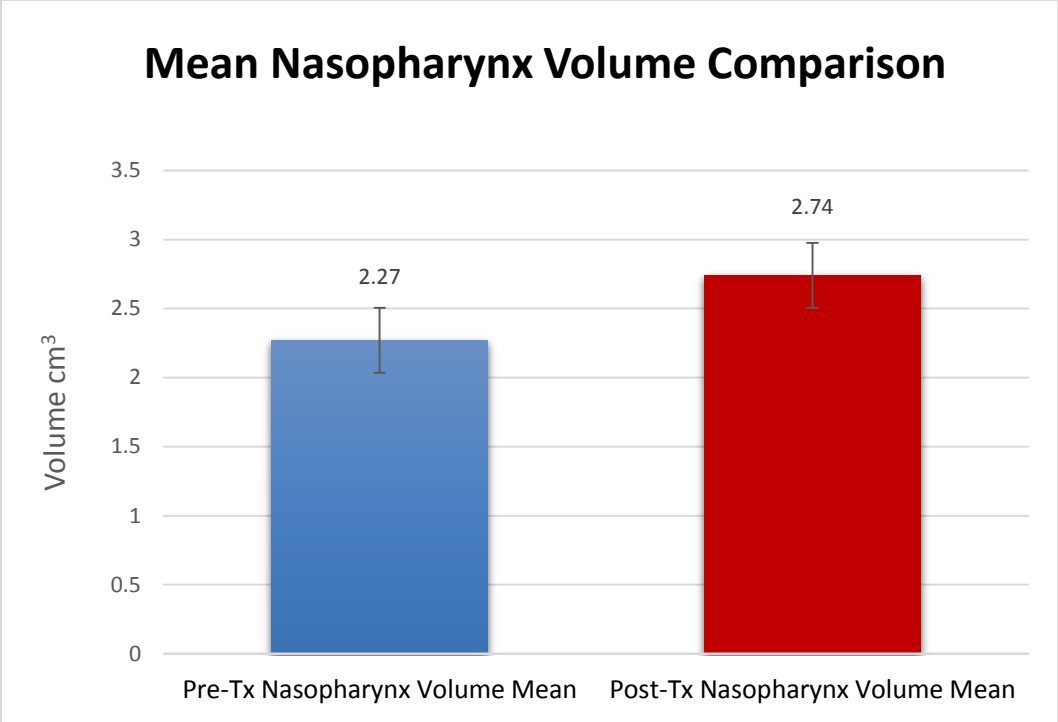

Figure 5.3. Pre- and post-treatment mean nasopharynx volume (cm^3).

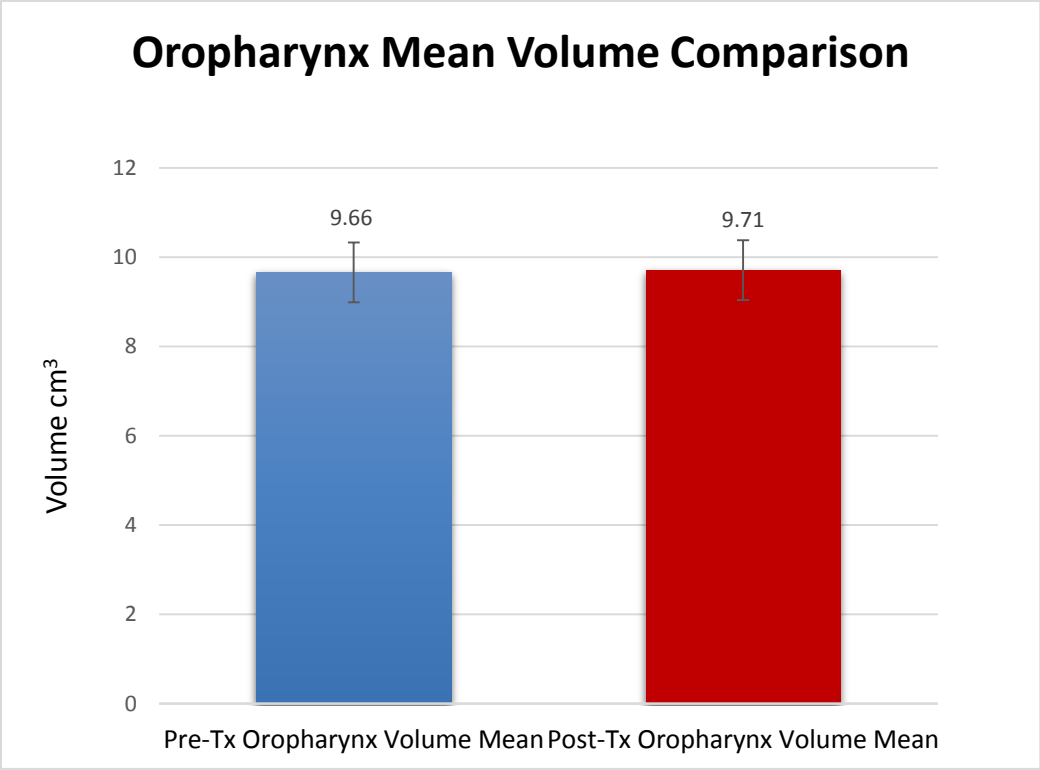

Figure 5.4. Pre- and post-treatment mean oropharynx volume (cm3).

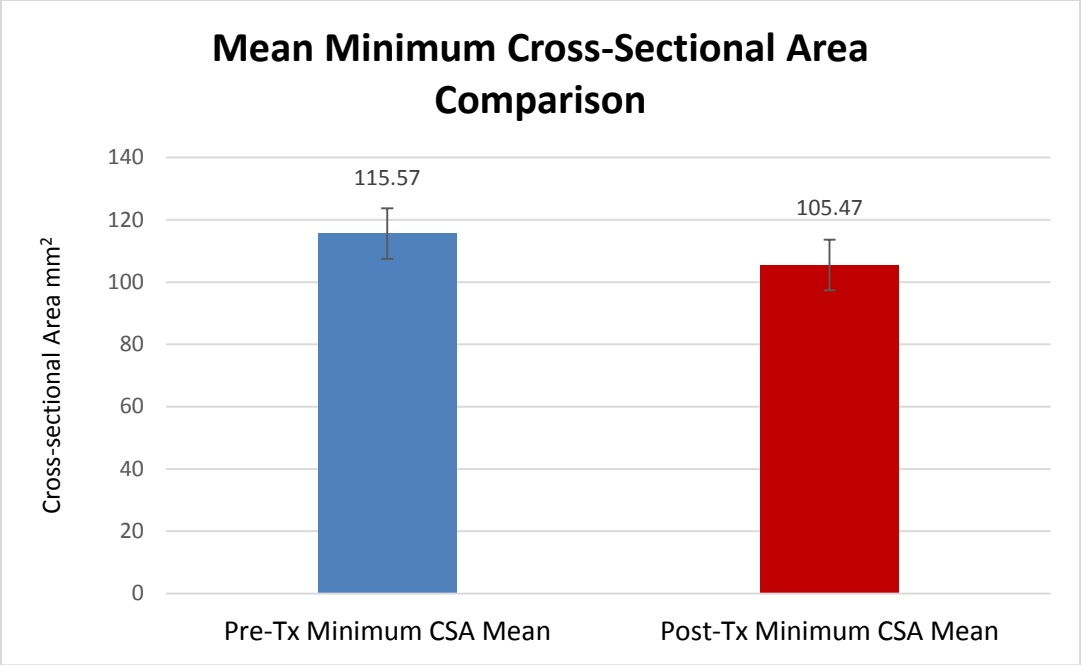

Figure 5.5. Pre- and post-treatment mean minimum cross-sectional area (mm2).

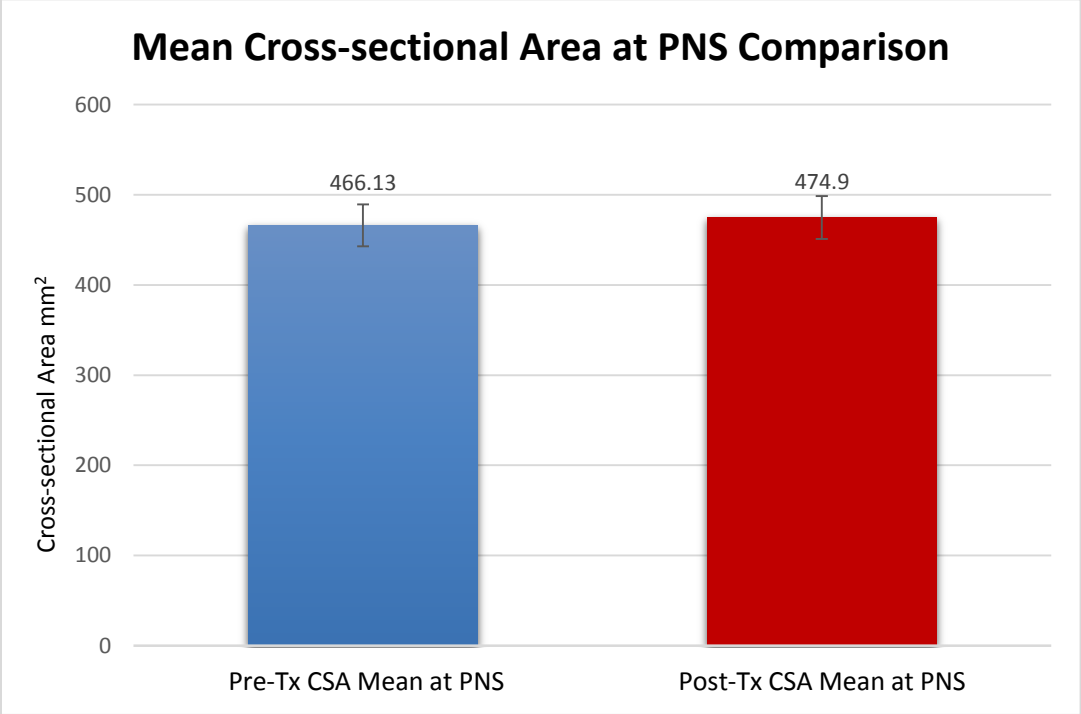

Figure 5.6. Pre- and post-treatment mean cross-sectional area at PNS (mm2).

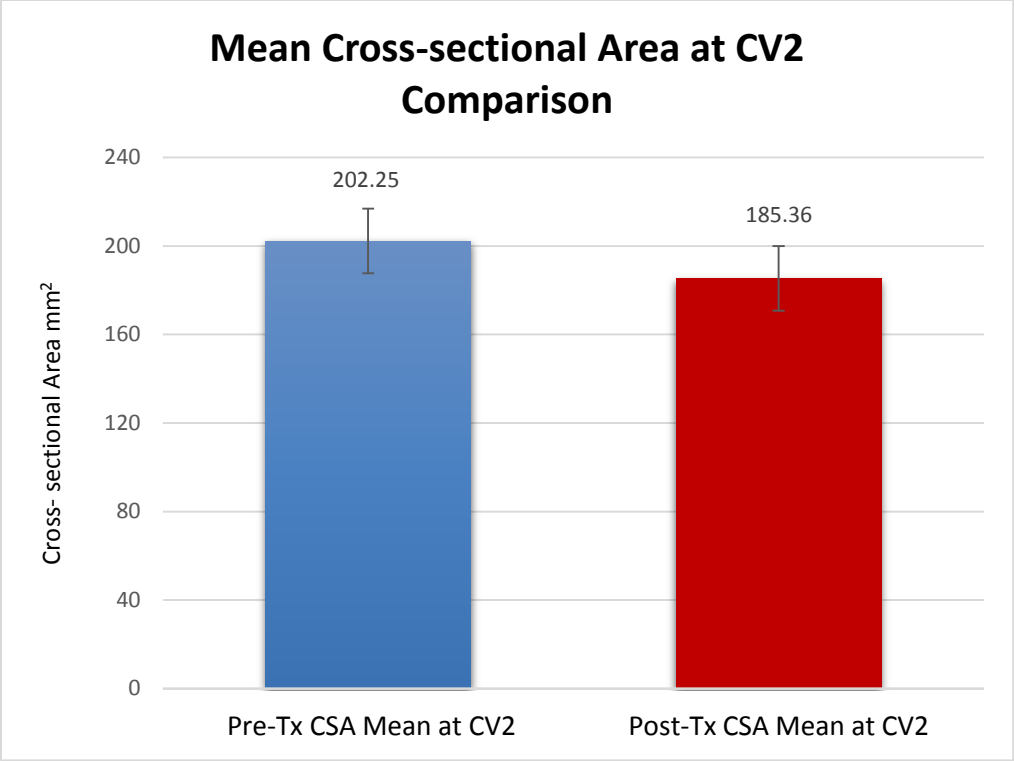

Figure 5.7. Pre- and post-treatment mean cross-sectional area at CV2 (mm2).

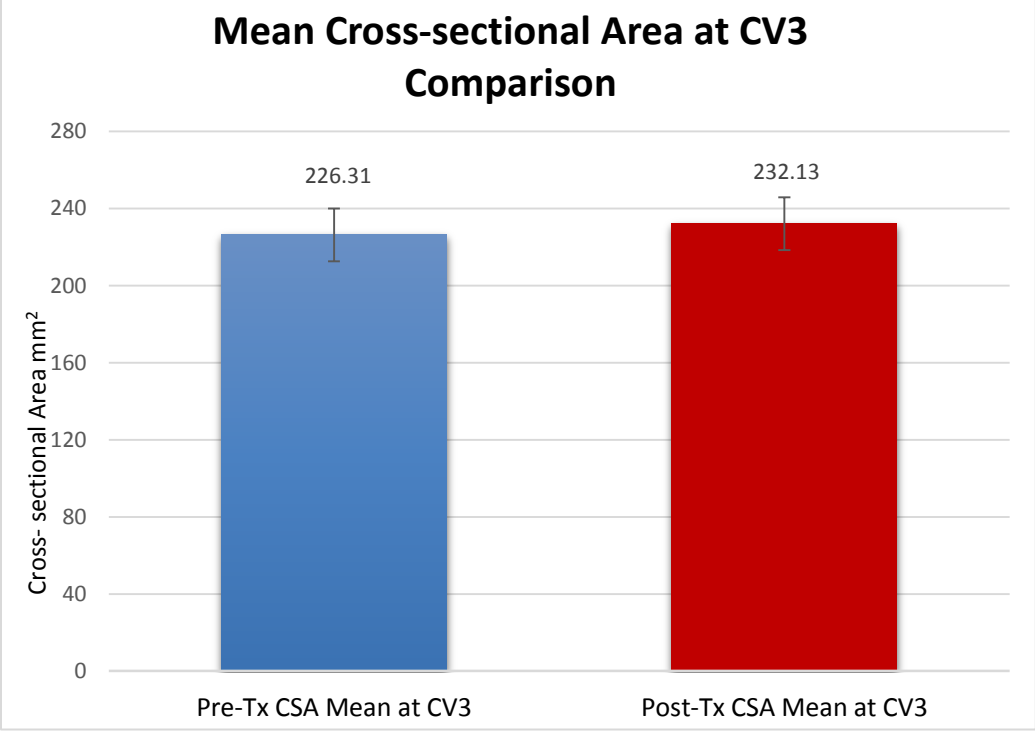

Figure 5.8. Pre- and post-treatment mean cross-sectional area at CV3 (mm2).

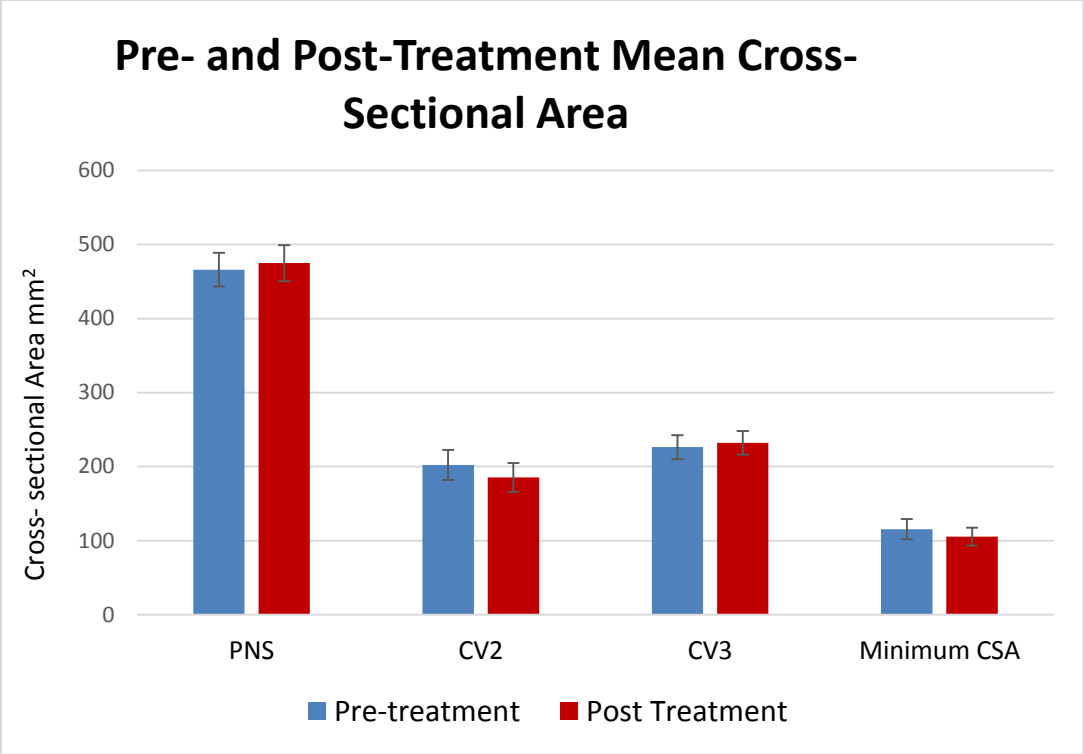

Figure 5.9. Pre- and post-treatment mean cross-sectional area at PNS, CV2, CV3, and minimum cross-sectional area.

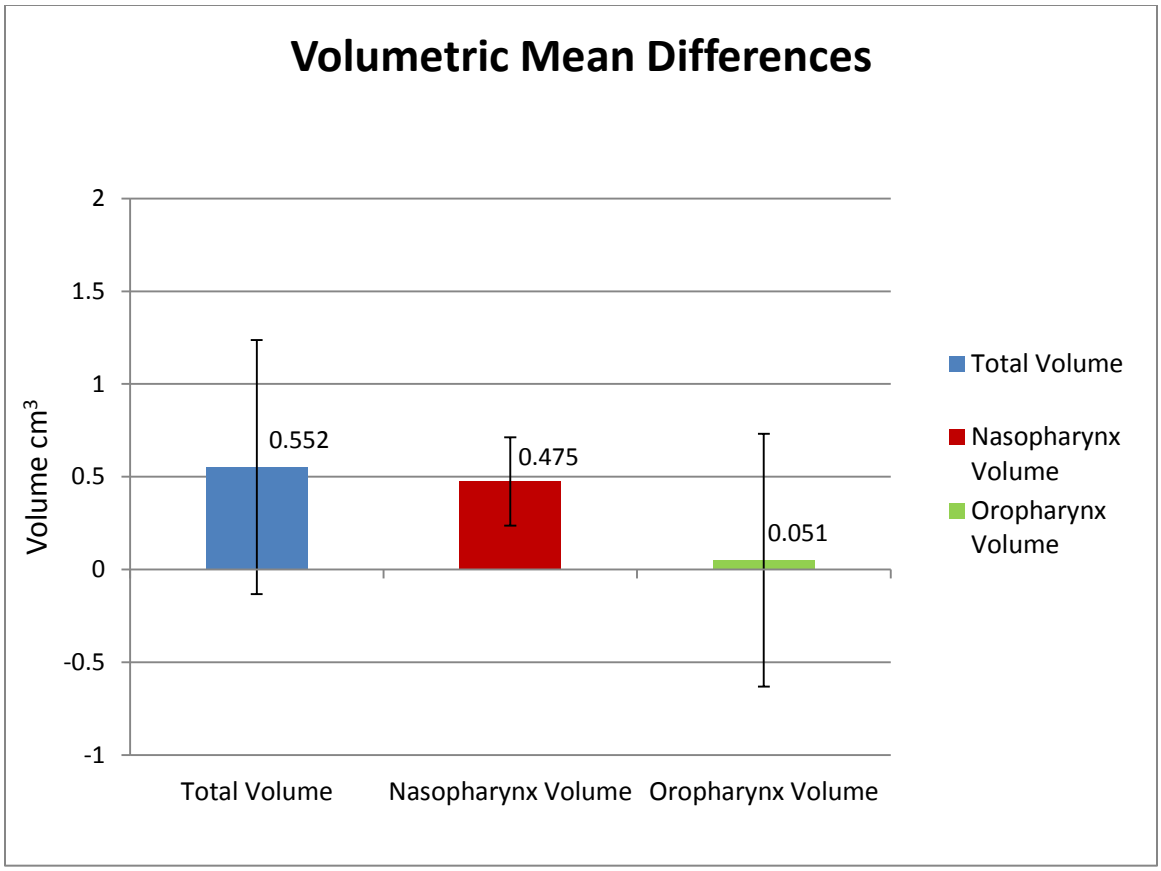

Figure 5.10. Pre- and post-treatment mean volumetric differences.

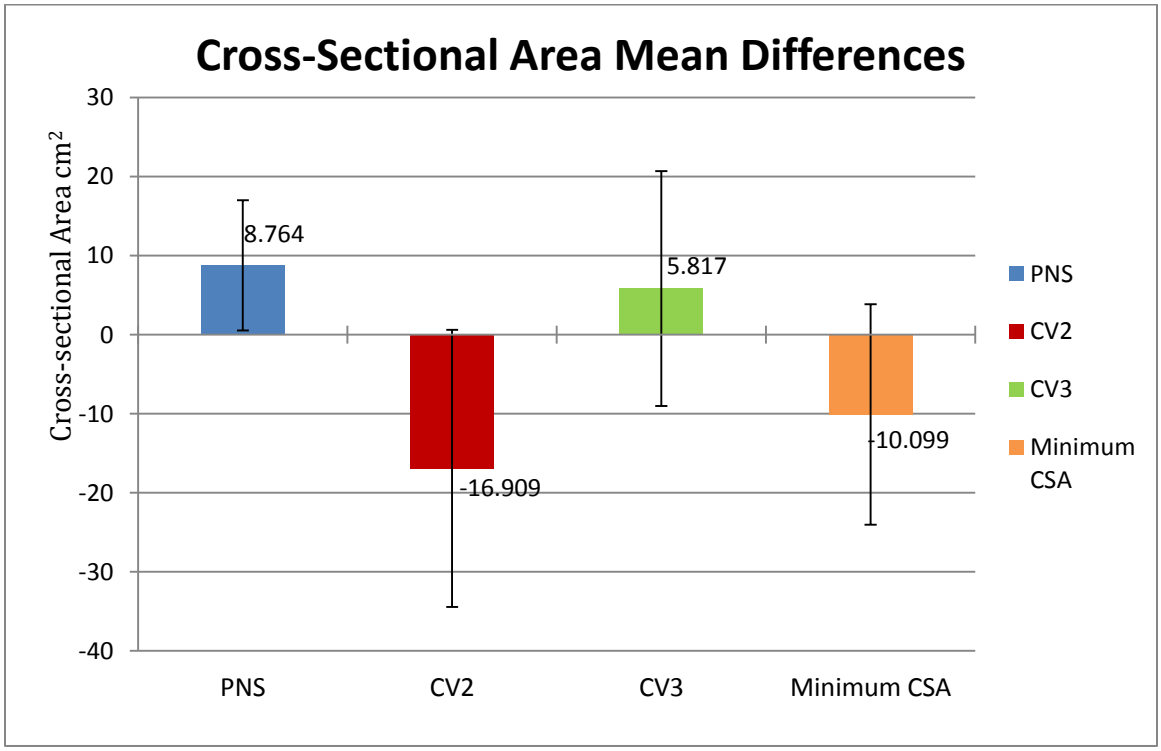

Figure 5.11. Pre- and post-treatment mean cross-sectional area mean differences

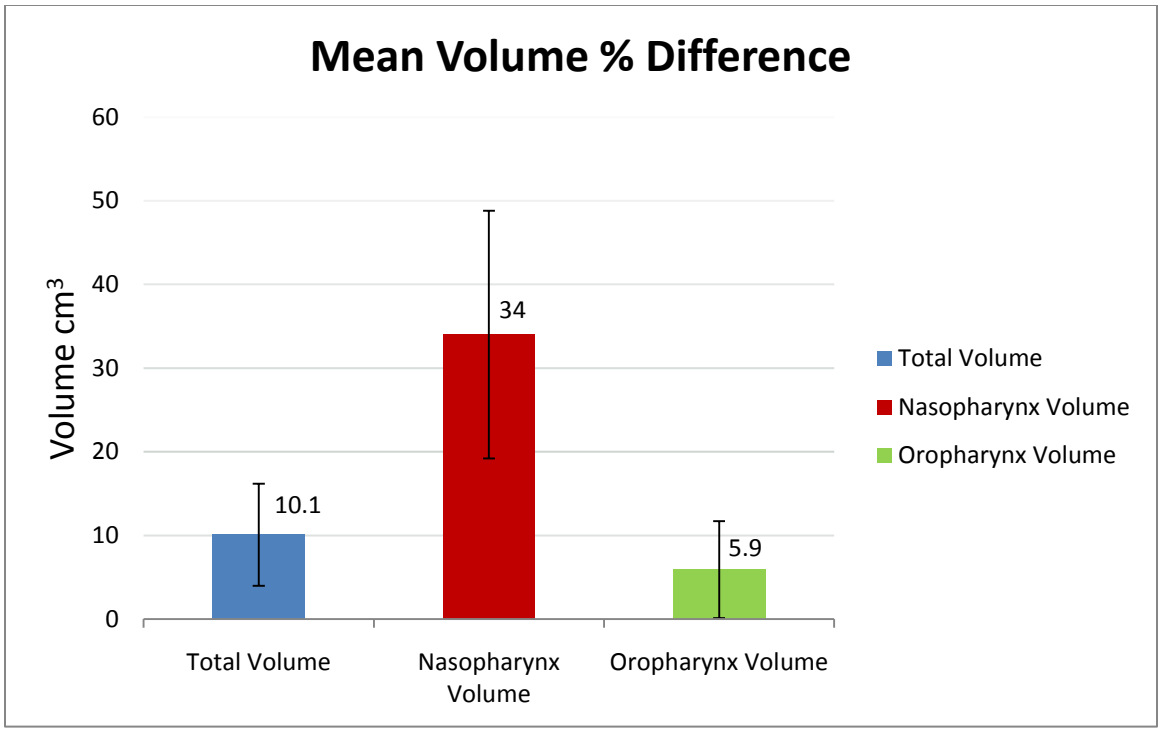

Figure 5.12 Pre- and post-treatment mean volume percent differences.

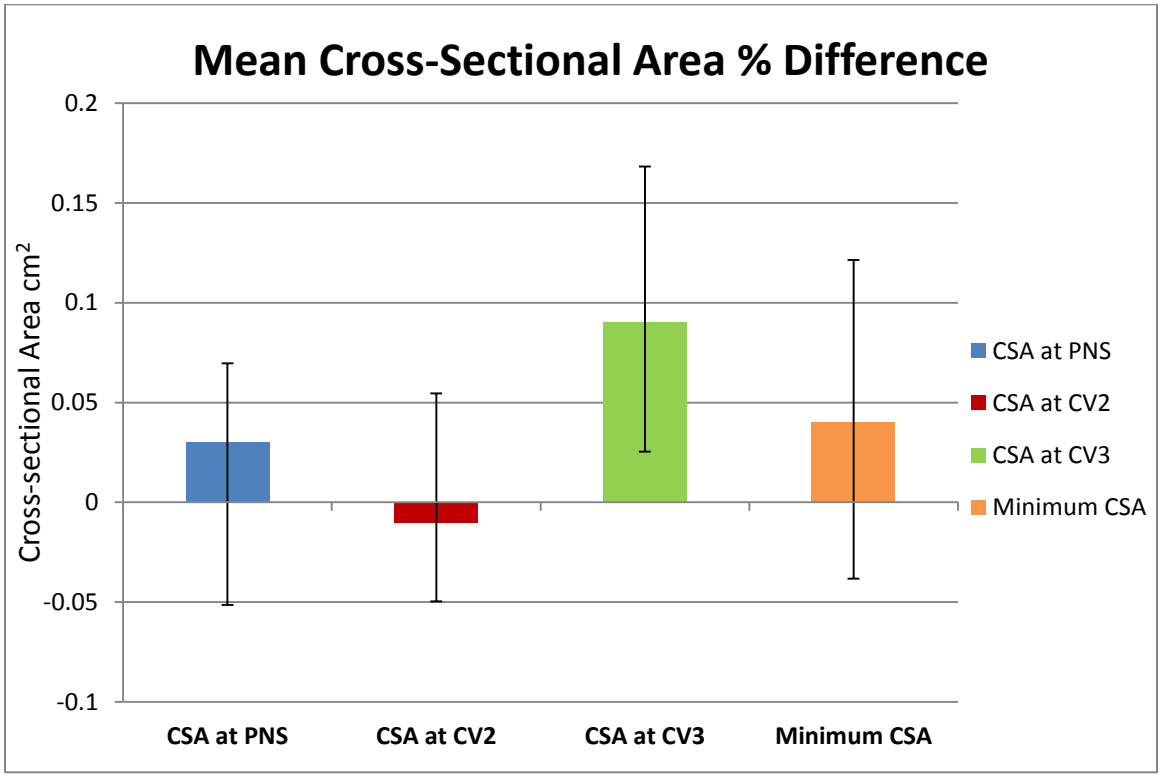

Figure 5.13. Pre- and post-treatment mean cross-sectional area percent differences.

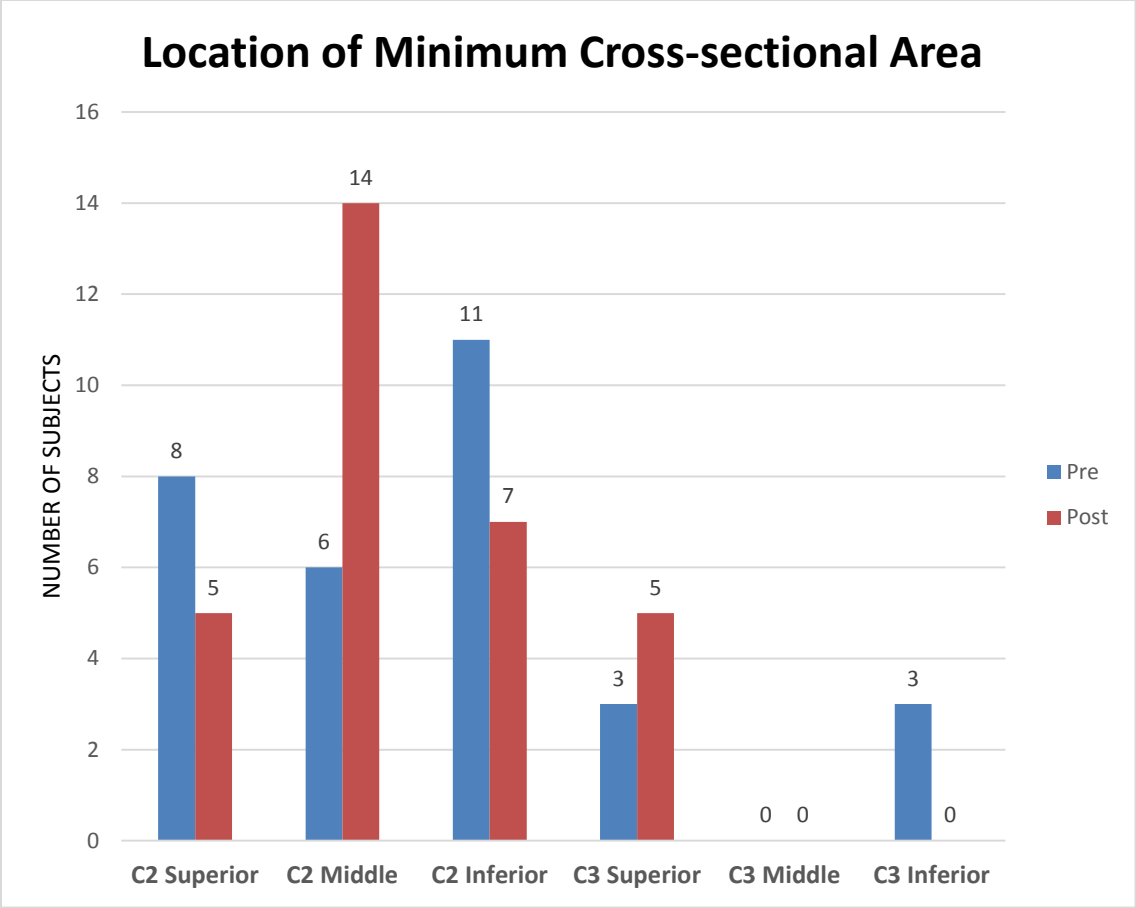

Figure 5.14. Location of minimum cross-sectional area pre- and post-treatment.

Table 5.1. Airway changes for all subjects (n=31).

All Subjects n=31	Pre-Treatment Mean	Post-Treatment Mean	Mean Difference	SD	P-Value	Sig
Pharyngeal Volume (cm^3)						
Total	11.92	12.45	0.53	3.81	0.44	NS
Nasopharyngeal	2.27	2.74	0.47	1.32	0.15	NS
Oropharyngeal	9.66	9.71	0.05	3.79	0.94	NS
Cross-sectional Area (mm^2)						
PNS	466.1	474.9	8.77	97.5	0.62	NS
CV2	202.3	185.4	-16.89	82.7	0.26	NS
CV3	226.3	232.1	5.82	77.5	0.68	NS
Min CSA	115.6	105.5	-10.1	45.8	0.23	NS

Table 5.2. Airway changes for female subjects (n=18).

Female n=18						
	Pre- Treatment Mean	**Post- Treatment Mean**	**Mean Difference**	**SD**	**P-Value**	**Sig**
Pharyngeal Volume (cm^3)						
Total	12.51	12.63	0.12	2.48	0.23	NS
Nasopharyngeal	2.36	2.74	0.38	1.14	0.17	NS
Oropharyngeal	10.14	9.89	-0.25	2.44	0.47	NS
Cross-sectional Area (mm^2)						
PNS	498.3	506	7.67	75.14	0.45	NS
CV2	184.9	162.6	-22.23	71.57	0.35	NS
CV3	248.7	243.2	-5.42	86.38	0.73	NS
Min CSA	109.9	101.8	-8.14	48.28	0.16	NS

Table 5.3. Airway changes for male subjects (n=13)

Male n=13	Pre- Treatment Mean	Post- Treatment Mean	Mean Difference	SD	P-Value	Sig
Pharyngeal Volume (cm^3)						
Total	11.12	12.22	1.1	5.19	0.56	NS
Nasopharyngeal	2.13	2.75	0.62	1.58	0.27	NS
Oropharyngeal	8.99	9.47	0.48	5.22	0.47	NS
Cross-sectional Area (mm^2)						
PNS	421.6	431.9	10.28	125.6	0.31	NS
CV2	226.4	216.8	-9.51	98.78	0.87	NS
CV3	195.4	216.7	21.38	63.41	0.34	NS
Min CSA	123.5	110.6	-12.82	44.03	0.28	NS

Table 5.4. Pearson correlation coefficient's for initial and final measurements on 10 randomly chosen subjects. Average correlation coefficient was 0.986, ranging from 0.960 to 0.998.

Total Volume	Nasopharynx Volume	Oropharynx Volume	Minmum CSA	CSA PNS	CSA C2	CSA C3
5.957	1.294	4.663	121.6	335.21	171.47	103.23
4.21	0.126	4.085	45.2	226.41	173.07	265.36
14.223	2.243	11.98	161.2	389.23	440.56	197.18
21.798	2.207	19.591	220.4	508.7	491.6	309.13
10.256	3.733	6.523	128.8	405.91	178.48	161.54
7.333	2.386	4.947	69.7	475.72	151.01	142.77
4.875	0.482	4.393	16.2	530.36	114.04	239.28
8.005	0.933	7.072	39.6	525.88	107.2	265.78
5.777	1.608	4.169	22.5	470.13	64.69	215.89
6.598	2.548	4.05	36.5	420.48	75.41	235.39

Total Volume	Nasopharynx Volume	Oropharynx Volume	Minmum CSA	CSA PNS	CSA C2	CSA C3
5.697	0.861	4.836	113.27	285.11	188.55	113.27
4.47	0.15	4.32	39.4	214.41	164.77	270.25
15.431	2.791	12.64	162.2	403.92	458.99	189.86
22.526	2.349	20.177	220.5	468.51	455.72	311.24
10.196	3.322	6.874	128.9	431.91	169.48	163.37
7.713	2.52	5.193	69.4	463.51	145.1	135.77
4.93	0.337	4.593	17	532.8	107.66	230.39
8.296	1.202	7.094	39.2	506.61	106.9	254.7
5.841	1.584	4.257	22.6	479.94	66.28	208.41
6.321	2.324	3.997	36.7	418.37	67.95	234.68

Pearson Coefficient:						
0.998202944	**0.998202944**	**0.998202944**	**0.998944505**	**0.998202944**	**0.994816315**	**0.99399**

CHAPTER 6: DISCUSSION

6.1. Method of Error

Pearson reliability coefficient was found to determine the repeatability made for all measured variables. After one month of initial tracings, ten subjects were randomly chosen to be re-measured (5 male and 5 female). The second measurements were performed by the same examiner (JS). The average correlation coefficient was 0.986, ranging from 0.960 to 0.998. This high correlation coefficient indicates a strong positive relationship between the two measurements, ensuring accurate reliability for all measured outcomes.

6.2. Total Volume Measurements

Total volume was defined as the sum of nasopharynx and oropharynx, and calculated by measuring space between a horizontal plane at the inferior border of CV3 and vertical plane connecting sella turcica. Pre-treatment total mean volume was 11.92 cm^3 and post-treatment total mean volume was 12.45 cm^3, a mean difference of 0.53 cm^3. Thirteen out of thirty-one subjects (42%) showed a decrease in total volume, whereas eighteen out of thirty-one (58%) exhibited an increase in total volume. Although the total mean volume was greater after treatment, this increase was not statistically significant ($p=0.22$). The methodology of the present study did not measure the biological significance of the increase in total mean volume. Further studies are needed to assess the

clinical efficacy of splint therapy to reduce severity and complications that arise from OSA.

6.3. Regional Volumetric Measurements

Nasopharynx volume was defined as the area between a plane parallel with Frankfurt horizontal at PNS and a plane passing through PNS and sella. Pre-treatment nasopharynx mean volume was 2.27 cm^3 and post-treatment mean volume was 2.74 cm^3, a mean difference of 0.47 cm^3. This mean increase was not statistically significant (p=0.13). Oropharynx volume was defined by the area between a plane parallel with Frankfurt horizontal at PNS and a plane parallel with Frankfurt horizontal at the inferior border of CV3. Pre-treatment oropharynx mean volume was 9.66 cm^3 and post-treatment mean was 9.71 cm^3, a mean difference of 0.05 cm^3. The mean increase was not statistically significant (p=0.47).

6.4. Cross-sectional Area Measurements

Cross-sectional area measurements were taken at a horizontal plane parallel with Frankfurt horizontal at PNS, inferior border of CV2 and the inferior border of CV3. Pre-treatment means for cross-sectional area measurements at PNS, CV2, and CV3 were 466.1, 202.3, and 226.3 mm^2, respectively. Post-treatment mean measurements at PNS, CV2 and CV3 were 474.9, 185.4 and 232.1 mm^2, respectively. The mean differences between these pre-and post-measurements for PNS, CV2, and CV3 are 8.77, -16.89, and 5.82 mm^2. These mean differences were not statistically significant (p=0.31, p=0.13, and p=0.34).

6.5. Minimum Cross-Sectional Area Measurements

The minimum cross-sectional area is defined as the most constricted portion of the airway. Pre-treatment minimum cross-sectional area mean was 115.6 mm^2 and post-treatment mean was 105.5 mm^2. The mean difference was a -10.1 mm^2, though this difference was not statistically significant (p=0.23).

6.6. Percent Differences

The percent difference of pre- and post-treatment measurements was calculated for volumetric, cross-sectional area, and minimum cross-sectional area dimensions. The greatest percent increase was found in the nasopharynx at 34%. Both total volume and oropharynx also revealed a positive percent increase. Total volume increased 10.1% and the oropharynx volume increased 5.9%. These data are consistent with the mean volumetric differences previously discussed.

The mean cross-sectional area percentage difference at PNS, CV3, and minimum cross-sectional area all increased very slightly. PNS increased 0.03%, CV3 increased 0.08% and the minimum CSA increased 0.04%.

6.7. Location of Cross-sectional Area

The location of the minimum cross-sectional area was recorded in reference to the superior, middle, and inferior thirds of the bodies of CV2 and CV3, and also the occlusal plane. Differences between pre- and post-treatment

minimum cross-sectional area locations were found on fourteen of the thirty-one patients (45%). One-half of these subjects showed minimum cross-sectional area relocation inferior to the pre-treatment recording, while the other half showed a more superior relocation.

Twenty-six of the thirty-one subjects (84%) displayed a minimum cross-sectional area located at either the superior, middle, or inferior third of the CV2 body. In addition, the minimum cross-sectional area was found to be inferior to the occlusal plane in twenty-eight of the thirty-one subjects (90%). This finding is consistent with Ogawa et al., who found the location of the minimum cross-sectional area in patients with OSA was below the occlusal plane in more than 70% of the subjects (Ogawa T, et al., 2007). This indicates that our image acquisition and radiographic interpretation methodology were accurate. Also, since 84% of the subjects displayed a minimum cross-sectional area at the level of CV2 body, the mean decrease in minimum cross-sectional area is consistent with our previous finding of a decrease in cross-sectional area at CV2.

6.8 Airway Changes Male vs Female

No significant differences were found between male and female with all volumetric and cross-sectional area measurements. This finding agrees with previous studies that found no correlation with gender after examining the frequency, direction and magnitude of condylar changes in CR vs CO (Utt TW, et al., 1995).

6.9 Centric Relation and Airway

Several studies have confirmed that a fully seated condylar position in centric relation is an essential component of a stable and functional occlusion, and is a desirable physiologic goal for orthodontic correction. Okeson describes it as the most orthopedically and musculoskeletally stable position of the mandible (Okeson JP, 2015). Additional studies have shown that a healthy masticatory musculature positions in the condyles in centric relation, independent of occlusion (Crawford SD, 1999). Presently, there is no published literature that documents the relationship between centric relation and its influence on the posterior pharyngeal airway.

Stabilization splint therapy has been shown to accurately seat the condyles in centric relation while deprogramming the neuromusculature in patients with significant CR-CO condylar discrepancies. This therapy has proven effective in diagnosing and treating myofascial pain, TMD, and various masticatory disorders. Several studies have documented the movement of the condyles from CR to CO, in both magnitude and direction. Cordray discovered that the most common direction of condylar movement was in a posterior and inferior direction, resulting in an anterior displacement of the mandible (Cordray FE, 2006). This movement resulted in decreased overjet and increased overbite. In addition, the mean difference in condylar position between CR and CO was almost double in the vertical plane (1.8 mm) compared to the horizontal (0.86 mm) and transverse plane (0.26 mm). This increase in vertical dimension may elucidate the overall increase in mean total airway volume in the present study.

6.10. Study Limitations

All subjects evaluated in this study presented with signs and symptoms of upper airway obstruction with significant CR-CO discrepancies. Not all subjects performed a sleep study test to confirm the presence and/or severity of OSA. In addition, the magnitude and direction of discrepancy was not available for each subject. Consequently, it was not possible to correlate the magnitude and direction of discrepancy with the final volumetric and cross-sectional area results.

All subjects were patients at a private orthodontic office, and may not accurately represent a sample of the general population. In addition, subjects presented with differing medical histories, ethnicities, and anatomical variations.

Although CBCT has been proven to be an effective tool in evaluating airway parameters, it is a static evaluation of a dynamic structure. All scans were taken in an upright position, which is not representative of the airway in the supine position during sleep. CBCT studies have shown that the airway's volumetric and cross-sectional area dimensions are significantly smaller in patients in supine position compared with an upright position (Camacho M, et al., 2014). In addition, positional and posture discrepancies between pre- and post-treatment scans may exist.

CHAPTER 7: CONCLUSION

Positioning the mandibular condyles in centric relation does influence posterior pharyngeal airway volume and cross-sectional area; however, the dimensional changes are not statistically significant. Post-treatment mean total volume, oropharynx volume, and nasopharynx volume increased. Mean cross-sectional area at PNS and CV3 increased, while mean cross-sectional area at CV2 and minimum cross-sectional area decreased. Twenty-six of the thirty-one subjects (84%) displayed a minimum cross-sectional area located at body of CV2. The minimum cross-sectional area was found to be inferior to the occlusal plane in twenty-eight of the thirty-one subjects (90%). Further studies are needed to assess the clinical efficacy of splint therapy to reduce severity and complications that arise from OSA.

LITERATURE CITED

Abad VC, Guilleminault C (2009). Treatment options for obstructive sleep apnea. *Curr Treat Options Neurol* **11**(5):358-367.

Afzal A, Shameem A (2005). Comparison of condylar positions in centric relation and centric occlusion in pre-treatment malocclusion cases. *J Coll Physicians Surg* **15**(10):620-3.

Al-Ani Z, Gray R, Davies S, Sloan P, Glenny, AM (2005). Stabilization splint therapy for the treatment of temporomandibular myofascial pain: A systematic review. *Journal of Dental Education* **69**(11):1242-1250.

Almeida FR, Lowe AA, Sung JO, Tsuiki S, Otsu-ka R (2006). Long-term sequelae of oral appliance therapy in obstructive sleep apnea patients: Part 1. Cephalometric analysis. *Am J Orthod Dentofac Orthop* **129**:195-204.

Barrera JE, Powell NB, Riley RW (2007). Facial skeletal surgery in the management of adult obstructive sleep apnea syndrome. *Clin Plast Surg* **34**(3):565-573.

Camcho M, Capasso R, Schendel S (2014). Airway changes in obstructive sleep apnea patients associated with a supine versus an upright position examined using cone beam computed tomography. J Laryngol Otol. **128**(9):824-30.

Clark GT (1984). A critical evaluation of orthopedic interocclusal appliance therapy: Design, theory, and overall effectiveness. *JADA* **108**:359-364.

Cordray FE (2006). Three-dimensional analysis of models articulated in the seated condylar position from a deprogrammed asymptomatic population: a prospective study part 1. *Am J Orthod Dentofacial Orthop* **29**(5):619-30.

Cossellu G, Biagi R, Sarcina M, Mortellaro C, Farronato G (2015). Three-dimensional evaluation of upper airway in patients with obstructive sleep apnea syndrome during oral appliance therapy. *J Craniofac Surg* **26**:745-748.

Coughlin S, Mawdsley L (2004). Obstructive sleep apnea is independently associated with an increased prevalence of metabolic syndrome. *Eur Heart J* **25**:735-741.

Crawford SD (1999). The relationship between condylar axis positions as determined by the occlusion and measured by the CPI instrument and signs and symptoms of the TM joint dysfunction. *Angle Orthod* **69**:103-115.

Davidson T (2005). The role of the dental profession in the diagnosis and treatment of sleep-disorders breathing. *Dent Today* **24**:1-3.

Dawson PE, Optimum TMJ (1985) Condylar position in clinical practice. *Int J Perio Rest Dent* **3**:11.

Dement W (1997). The perils of drowsy driving. *N Eng J Ned* **337**:783-784.

Dylina TJ (2001). A common sense approach to splint therapy. *J Prosth Dent* **86**:539-45

Erbas B, Kocadereli I (2014). Upper airway changes after Xbow appliance therapy evaluated with cone beam computed tomography. *Angle Orthodontist* **84**:693-700.

Goodday RH, Bourque SE, Edwards PB (2015). Objective and subjective outcomes following maxillomandibular advancement surgery for treatment of pateints with extremely severe obstructive sleep apnea. *J Oral Maxillofac Surg* **73**(15).

Goodday RH, Percious DS, Morrison AD, Robertson CG (2001). Obstructive sleep apnea syndrome: Diagnosis and management. *J Can Dent Assoc.* **67**(11):652-658.

Hardinge FM, Pitson DJ, Stradling JR (1995). Use of epworth sleepiness scale to demonstrate response to treatment with nasal continuous positive airways pressure in patients with obstructive sleep apnea. *Respir Med* **89** (9):617-20.

Hart PS, McIntyre BP, Kadioglu O, Currier GF, Sullivan SM, Li J, Shay C (2015). Postsurgical volumetric airway changes in 2-jaw orthognathic surgery patients. *Am J Orthod Dentofacial Orthop* **147**(5):536-546.

Ho ML, Brass SD (2011). Obstructive sleep apnea. *Neurol Int* **3**(3):15

Horner R, Mohiaddin R, Lowell D (1989). Sites and sizes of fat deposits around the pharynx in obese patients with obstructive sleep apnea and weight matched controls. *Eur Repir J* **2**:613-622.

Howat AP, Capp NJ, Barrett NVJ (1991). A color atlas of occlusion and malocclusion. *St Louis, CV Mosby* p97.

Imran HI, Rikard E (2013). Effect of oral appliances on blood pressure in obstructive sleep apnea: A systematic review and meta-analysis. *J. Clinical Sleep Medicine* **9**(2).

Isberg A, Isacsson G (1986) Tissue reactions associated with internal derangement of the temporomandibular joint. A radiographic, cryomophologic, and histologic study. *Acta Odontol Scand* **44**(3):160-164.

Johns MW (1991). A new method for measuring daytime sleepiness: the Epworth Sleepiness Scale. *Sleep* **14**:50-55.

Kaneko Y, Floras JS, Usui K (2003) Cardiovascular effects of continuous positive airway pressure in patients with heart failure and obstructive sleep apnea. *N Engl J Med* **348**:1233–41.

Kato I, Franco P, Groswasser J (2000). Frequency of obstructive and mixed sleep apneas in 1023 infants. *Sleep* **23**:487-492.

Kushida CA, Morgenthaler TI, Littner MR (2006). Practice parameters for the treatment of snoring and obstructive sleep apnea with oral appliances: an update for 2005. *Sleep* **29**:240-3.

Martinez-Gomis, J, Willaert E, Nogues L, Pascual M, Somoza M, Monasterio C (2010) Five years of sleep apnea treatment with a mandibular advancement device. *Angle Orthodontist* **80**:(1).

McKee JR (2005). Comparing condylar positions achieved through bimanual manipulation to condylar positions achieved through masticatory muscle contraction against an anterior deprogrammer: a pilot study. *J Prosthet Dent* **94**(4):389-93.

Mills PJ, Kennedy BP, Loredo JS, Dimsdale JE, Ziegler MG (2006). Effects of nasal continuous positive airway pressure and oxygen supplementation on norepinephrine kinetics and cardiovascular responses in obstructive sleep apnea. *J Appl Physiol* **100**:343–8.

Min HJ, Cho YJ (2015) Clinical features of obstructive sleep apnea that determine its high prevalence in resistant hypertension. *Yonsei Med J* **56**(5):1258-65.

Moffet BC (1969) Articular remodeling in the adult human temporomandibular joint, *Am J Anat* **115**:119-127.

Ogawa T, Enciso R, Shintaku WH, Clark GT. Evaluation of cross-section airway configuration of obstructive sleep apnea. *Oral Surgery, Oral Medicine, Oral Pathology, Oral Radiology, and Endodontology.* 2007;**103**(1):102-108.

Okeson JP (2015). Evolution of occlusion and temporomandibular disorders in orthodontics: Past, present, and future. *Am Jour of Ortho and Denofac* **147**(5) 216-223.

Peppard P, Young T, Palta M, Skatrud J (2000). Prospective study of the association between sleep disordered breathing and hypertension. *New Eng J Med* **342**:1378-1384.

Perez CV, Leeuw R, Okeson JP, Carlson CR, Li HF, Bush H, Falace D (2013). The incidence and prevalence of temporomandibular disorders and posterior open bite in patients receiving mandibular advancement device therapy for obstructive sleep apnea. *Sleep Breath* **17**:323-332.

Posselt, U (1952). Studies in the mobility of the human mandible. *Acta Odontologica Scandinavica* **10**:19.

Rieder, CE (1978). The prevalence and magnitude of mandibular displacement in a survey population. *Journal of Prosthetic Dentistry* **39**:324.

Riley RW, Powell NB, Guilleminault C (1993). Obstructive sleep apnea syndrome: A review of 306 consecutively treated surgical patients. *Otolaryngol Head Neck Surg* **108**:117-125.

Rinchuse DJ, Kandasamy S (2006). Centric relation: a historical and contemporary orthodontic perspective. *J Am Dent Assoc* **137**(4):494-501

Ruehland WR, Rochford PD, O'Donoghue FJ, Pierce RJ, Singh P, Thornton AT (2009). The new AASM criteria for scoring hypopneas: impact on the apnea hypopnea index. *Sleep* **32**(2):150-7.

Schwab RJ, Goldberg AN, Pack AJ (1998). Sleep apnea syndromes. *Fishman's Pulmonary Diseases and Disorders New York: McGraw-Hill* **3**:1617-1646.

Tarangola GJ, Becker IM, Gremillion H (1997). The reproducibility of centric relation: a clinical approach. *J Am Dent Assoc* **128**(9):1245-51.

Utt TW, Meyers CE Jr, Wierzba TF, Hondrum SO (1995). A three-dimensional comparison of condylar position changes between centric relation and centric occlusion using the mandibular position indicator. *Am J Orthod Dentofacial Orthop* **107**(3):298-308

Vgontzas A, Zoumakis M (2003). Impaired nighttime sleep in healthy old versus young adults is associated with elevated plasma interleukin-6 and cortisol levels:physiologic and therapeutic implications. *Int Clin Endocrinol Metab* **88**:2087-2095.

White DP, Shafazand S (2013). Mandibular advancement device vs CPAP in the treatment of obstructive sleep apnea: are they equally effective in short term health outcomes. *J Clin Sleep Med* **9**:971-2.

Wood DP, Elliot RW (1994). Reproducibility of the centric relation wax bite technic. *Angle Orthod* **64**:211-221.

Yoshida K (2000). Effects of a mandibular advancement device for the treatment of sleep apnea syndrome and snoring on respiratory function and sleep quality. *Cranio* **18**(2):98-105.

Young T, Evans L, Finn l, Palta M (1997). Estimation of the clinically diagnosed proportion of sleep apnea syndrome in middle-aged men and women. *Sleep* **20**(9):705-706.

Young T, Finn L, Peppard PE (2008). Sleep disordered breathing and mortality: eighteen-year follow-up of the Wisconsin sleep cohort. *Sleep* **31**(8):1071–8.

Young T, Palta M (1993). The occurrence of sleep-disordered breathing among middle-aged adults. *N Eng J Med* **328**:1230-1235.

Appendix A: Experimental Data

Appendix A: Experimental Data – Male

Subject	pre or post	Total Volume	Nasopharynx Volume	Oropharynx Volume	Minmum Area	CSA PNS	C2	C3	Location
GZ	Pre	13.419	5.046	8.373	122.4	449.51	146.98	184.14	c2 inferior
GZ	Post	12.509	4.445	8.064	58	462.6	96.17	206.75	c2 inferior
SD	Pre	16.951	1.904	15.047	239.9	386.29	245.68	342.31	c2 superior
SD	Post	25.491	1.427	24.064	284.6	506.53	451.49	427.99	c2 superior
ND	Pre	14.128	3.238	10.89	157.5	491.01	222.55	196.91	c2 middle
ND	Post	13.09	3.601	9.489	140.2	479.54	212.26	197.5	c2 middle
KG	Pre	5.197	0.217	4.98	74.2	308.93	108.67	139.23	c2 inferior
KG	Post	10.402	1.799	8.603	75.3	573.72	118.81	164.78	c2 inferior
CH	Pre	5.697	0.861	4.836	113.27	285.11	188.55	113.27	C3 inferior
CH	Post	4.47	0.15	4.32	39.4	214.41	164.77	270.25	C2 middle
RH	Pre	18.947	1.471	17.476	162.4	354.37	433.97	308.73	C2 superior
RH	Post	7.683	3.091	4.592	91.9	378.51	167.46	251.66	C2 inferior
EH	Pre	9.39	1.875	7.515	33.8	468.4	79.45	327.24	C2 middle
EH	Post	8.225	2.07	6.155	55.7	428.78	85.93	283.88	C2 middle
SA	Pre	4.123	0.987	3.136	46	366.44	125.8	77.83	C2 inferior
SA	Post	6.79	2.287	4.503	55.4	475.39	125.51	60.04	C2 middle
CJ	Pre	10.196	3.322	6.874	128.9	431.91	169.48	163.37	C2 inferior
CJ	Post	7.713	2.52	5.193	69.4	463.51	145.1	135.77	C2 middle
DK	Pre	8.043	1.225	6.818	135.3	482.45	228.63	115.91	C2 middle
DK	Post	10.84	2.78	8.06	153.1	455.43	242.23	125.21	C2 middle
RK	Pre	15.431	2.791	12.64	162.2	403.92	458.99	189.86	C2 superior
RK	Post	22.526	2.349	20.177	220.5	468.51	455.72	311.24	C2 superior
JL	Pre	10.952	3.202	7.75	67.1	732.71	242.44	176.01	C2 middle
JL	Post	17.141	8.054	9.087	42.4	456.49	236.43	178.69	C2 middle
CL	Pre	12.064	1.53	10.534	161.7	319.5	291.38	204.91	C2 inferior
CL	Post	11.929	1.183	10.746	152.3	250.8	316.97	203.85	C2 middle

Appendix A: Experimental Data – Female

Subject	pre or post	Total Volume	Nasopharynx Volume	Oropharnyx Volume	Minmum Area	CSA PNS	C2	C3	Location
JQ	pre	11.875	1.784	10.091	99.1	610.99	248.5	255.69	c2 middle
JQ	post	14.27	3.058	11.212	130	668.04	201.94	317.01	c2 middle
MB	pre	17.477	1.177	16.3	218.4	391.54	392.17	210.66	c2 superior
MB	post	17.984	4.219	13.765	236.5	435.12	226.63	256.3	c2 inferior
MG	pre	18.284	2.956	15.328	99.5	723.95	108.5	447.3	c2 inferior
MG	post	17.31	2.442	14.868	109.4	531.25	138.78	375.71	c2 superior
AG	pre	11.552	0.441	11.111	70.9	280.75	281.94	287.65	c2 superior
AG	post	11.259	0.234	11.025	83.9	251.01	294.09	327.88	c2 superior
MG	pre	12.015	3.553	8.462	67.3	572.09	88.5	154.8	c2 middle
MG	post	13.683	2.437	11.246	83.1	643.26	164.88	386.18	c2 inferior
CH	pre	9.394	3.486	5.908	78.5	294.8	90.2	174.2	c3 superior
CH	post	10.455	3.388	7.067	111.1	320.34	138.1	191.46	c2 middle
MH	pre	10.101	1.227	8.874	63	583.94	212.31	368.02	c2 middle
MH	post	11.314	2.152	9.162	67.5	570.84	134.51	301.22	c2 middle
MM	pre	5.841	1.584	4.257	22.5	479.94	66.28	208.41	c2 inferior
MM	post	6.321	2.324	3.997	36.7	418.37	67.95	234.68	c2 inferior
PH	pre	11.199	3.457	7.742	60	558.7	91.38	194.74	c2 middle
PH	post	14.371	3.944	10.427	110.8	647.89	133	154.71	c2 middle
JJ	pre	9.498	1.278	8.22	75.4	355.91	96.31	125.76	c3 superior
JJ	post	7.912	1.268	6.644	52.9	318.47	94.38	68.53	c3 superior
SJ	pre	11.374	3.368	8.006	60.5	497.62	75.64	178.11	c2 inferior
SJ	post	12.237	3.858	8.379	69.7	505.94	75.81	217.66	c2 inferior
DK	pre	28.649	4.088	24.561	368.5	741.48	375.36	351.73	c2 inferior
DK	post	26.279	6.619	19.66	280.1	862.97	328.43	291.4	c3 superior
JK	pre	11.335	2.984	8.351	85.5	498.61	208.41	232.49	c2 superior
JK	post	7.393	2.092	5.301	36.2	452.97	66.59	131.14	c2 middle
IK	pre	4.93	0.337	4.593	17	532.8	107.66	230.39	c2 superior
IK	post	8.296	1.202	7.094	39.2	506.61	106.9	254.7	c2 superior
DC	pre	15.063	3.185	11.878	147.1	428.54	252.19	342.31	c2 superior
DC	post	8.64	2.424	6.216	63.8	406.46	91.41	166.58	c2 middle
CL	pre	11.616	2.719	8.897	105.6	554.72	127.53	341.87	c2 inferior
CL	post	11.933	1.806	10.127	113.7	674.9	160.71	288.36	c3 superior
PC	pre	7.941	2.463	5.478	93.7	425.12	124.26	110.07	c3 superior
PC	post	10.058	3.338	6.72	91	470.64	114.93	141.38	c3 superior
MK	pre	17.039	2.542	14.497	245.6	438.1	380.1	261.64	c3 inferior
MK	post	17.536	2.484	15.052	115.9	422.56	388.19	273.38	c3 superior

Gender	Age	TV	NV	OV	MA	PNS	C2	C3
m	46.25	13.419	5.046	8.373	122.4	449.51	146.98	184.14
m	59.58	16.951	1.904	15.047	239.9	386.29	245.68	342.31
m	54.6	14.128	3.238	10.89	157.5	491.01	222.55	196.91
m	19	5.197	0.217	4.98	74.2	308.93	108.67	139.23
m	22.6	5.697	0.861	4.836	113.27	285.11	188.55	113.27
m	35.5	18.947	1.471	17.476	162.4	354.37	433.97	308.73
m	53	9.39	1.875	7.515	33.8	468.4	79.45	327.24
m	49.08	4.123	0.987	3.136	46	366.44	125.8	77.83
m	55.08	10.196	3.322	6.874	128.9	431.91	169.48	163.37
m	30.75	8.043	1.225	6.818	135.3	482.45	228.63	115.91
m	46.08	15.431	2.791	12.64	162.2	403.92	458.99	189.86
m	64.41	10.952	3.202	7.75	67.1	732.71	242.44	176.01
m	21.08	12.064	1.53	10.534	161.7	319.5	291.38	204.91
f	61.25	11.875	1.784	10.091	99.1	610.99	248.5	255.69
f	31.92	17.477	1.177	16.3	218.4	391.54	392.17	210.66
f	50.08	18.284	2.956	15.328	99.5	723.95	108.5	447.3
f	22.83	11.552	0.441	11.111	70.9	280.75	281.94	287.65
f	60.58	12.015	3.553	8.462	67.3	572.09	88.5	154.8
f	19.75	9.394	3.486	5.908	78.5	294.8	90.2	174.2
f	62.5	10.101	1.227	8.874	63	583.94	212.31	368.02
f	56.92	5.841	1.584	4.257	22.5	479.94	66.28	208.41
f	60.58	11.199	3.457	7.742	60	558.7	91.38	194.74
f	22.08	9.498	1.278	8.22	75.4	355.91	96.31	125.76
f	59.16	11.374	3.368	8.006	60.5	497.62	75.64	178.11
f	53.42	28.649	4.088	24.561	368.5	741.48	375.36	351.73
f	60.83	11.335	2.984	8.351	85.5	498.61	208.41	232.49
f	51.75	4.93	0.337	4.593	17	532.8	107.66	230.39
f	51.25	15.063	3.185	11.878	147.1	428.54	252.19	342.31
f	62.66	11.616	2.719	8.897	105.6	554.72	127.53	341.87
f	60.33	7.941	2.463	5.478	93.7	425.12	124.26	110.07
f	17.83	17.039	2.542	14.497	245.6	438.1	380.1	261.64
Mean	45.89451613	11.92648387	2.267677419	9.658806452	115.5732258	466.133871	202.2519355	226.3083871
Median	51.75	11.374	2.463	8.373	99.1	449.51	188.55	204.91
SD	16.15113182	5.06669378	1.20462947	4.629183005	75.04533223	126.7343414	113.7073192	91.04503578
SE	2.900828908	0.910005067	0.21635784	0.831425812	13.47853956	22.76215967	20.4224374	16.35217115

Appendix A: Experimental Data – Post Treatment

Gender	Age	TV	NV	OV	MA	PNS	C2	C3
m	46.25	12.509	4.445	8.064	58	462.6	96.17	206.75
m	59.58	25.491	1.427	24.064	284.6	506.53	451.49	427.99
m	54.6	13.09	3.601	9.489	140.2	479.54	212.26	197.5
m	19	10.402	1.799	8.603	75.3	573.72	118.81	164.78
m	22.6	4.47	0.15	4.32	39.4	214.41	164.77	270.25
m	35.5	7.683	3.091	4.592	91.9	378.51	167.46	251.66
m	53	8.225	2.07	6.155	55.7	428.78	85.93	283.88
m	49.08	6.79	2.287	4.503	55.4	475.39	125.51	60.04
m	55.08	7.713	2.52	5.193	69.4	463.51	145.1	135.77
m	30.75	10.84	2.78	8.06	153.1	455.43	242.23	125.21
m	46.08	22.526	2.349	20.177	220.5	468.51	455.72	311.24
m	64.41	17.141	8.054	9.087	42.4	456.49	236.43	178.69
m	21.08	11.929	1.183	10.746	152.3	250.8	316.97	203.85
f	61.25	14.27	3.058	11.212	130	668.04	201.94	317.01
f	31.92	17.984	4.219	13.765	236.5	435.12	226.63	256.3
f	50.08	17.31	2.442	14.868	109.4	531.25	138.78	375.71
f	22.83	11.259	0.234	11.025	83.9	251.01	294.09	327.88
f	60.58	13.683	2.437	11.246	83.1	643.26	164.88	386.18
f	19.75	10.455	3.388	7.067	111.1	320.34	138.1	191.46
f	62.5	11.314	2.152	9.162	67.5	570.84	134.51	301.22
f	56.92	6.321	2.324	3.997	36.7	418.37	67.95	234.68
f	60.58	14.371	3.944	10.427	110.8	647.89	133	154.71
f	22.08	7.912	1.268	6.644	52.9	318.47	94.38	68.53
f	59.16	12.237	3.858	8.379	69.7	505.94	75.81	217.66
f	53.42	26.279	6.619	19.66	280.1	862.97	328.43	291.4
f	60.83	7.393	2.092	5.301	36.2	452.97	66.59	131.14
f	51.75	8.296	1.202	7.094	39.2	506.61	106.9	254.7
f	51.25	8.64	2.424	6.216	63.8	406.46	91.41	166.58
f	62.66	11.933	1.806	10.127	113.7	674.9	160.71	288.36
f	60.33	10.058	3.338	6.72	91	470.64	114.93	141.38
f	17.83	17.536	2.484	15.052	115.9	422.56	388.19	273.38
Mean	45.89451613	12.45354839	2.743387097	9.71016129	105.4741935	474.8987097	185.3574194	232.1254839
Median	51.75	11.314	2.437	8.603	83.9	463.51	145.1	234.68
SD	16.15113182	5.378668837	1.616479295	4.88299768	68.26349912	135.772946	108.0592476	89.78158099
SE	2.900828908	0.966037441	0.290328252	0.877012273	12.26048638	24.38554098	19.4080138	16.12524797

Appendix A: Experimental Data – Mean Differences

Gender	Age	TV	NV	OV	MA	PNS	C2	C3
f	61.25	2.395	1.274	1.121	30.9	57.05	-46.56	61.32
f	31.92	0.507	3.042	-2.535	18.1	43.58	-165.54	45.64
f	50.08	-0.974	-0.514	-0.46	9.9	-192.7	30.28	-71.59
f	22.83	-0.293	-0.207	-0.086	13	-29.74	12.15	40.23
f	60.58	1.668	-1.116	2.784	15.8	71.17	76.38	231.38
f	19.75	1.061	-0.098	1.159	32.6	25.54	47.9	17.26
f	62.5	1.213	0.925	0.288	4.5	-13.1	-77.8	-66.8
f	56.92	0.48	0.74	-0.26	14.2	-61.57	1.67	26.27
f	60.58	3.172	0.487	2.685	50.8	89.19	41.62	-40.03
f	22.08	-1.586	-0.01	-1.576	-22.5	-37.44	-1.93	-57.23
f	59.16	0.863	0.49	0.373	9.2	8.32	0.17	39.55
f	53.42	-2.37	2.531	-4.901	-88.4	121.49	-46.93	-60.33
f	60.83	-3.942	-0.892	-3.05	-49.3	-45.64	-141.82	-101.35
f	51.75	3.366	0.865	2.501	22.2	-26.19	-0.76	24.31
f	51.25	-6.423	-0.761	-5.662	-83.3	-22.08	-160.78	-175.73
f	62.66	0.317	-0.913	1.23	8.1	120.18	33.18	-53.51
f	60.33	2.117	0.875	1.242	-2.7	45.52	-9.33	31.31
f	17.83	0.497	-0.058	0.555	-129.7	-15.54	8.09	11.74
m	46.25	-0.091	-0.601	-0.309	-64.4	13.09	-50.81	22.61
m	59.58	8.54	-0.477	9.017	44.7	120.24	205.81	85.68
m	54.6	-1.038	0.363	-1.401	-17.3	-11.47	-10.29	0.59
m	19	5.205	1.582	3.623	1.1	264.79	10.14	25.55
m	22.6	-1.277	-0.711	-0.516	-73.87	-70.7	-23.78	156.98
m	35.5	-11.264	1.62	-12.884	-70.5	24.14	-266.51	-57.07
m	53	-1.165	0.195	-1.36	21.9	-39.62	6.48	-43.36
m	49.08	2.667	1.3	1.367	9.4	108.95	-0.29	-17.79
m	55.08	-2.483	-0.802	-1.681	-59.5	31.6	-24.83	-27.6
m	30.75	2.797	1.555	1.242	17.8	-27.02	13.6	9.3
m	46.08	7.095	-0.442	7.537	58.3	64.59	-3.27	121.38
m	64.41	6.189	4.852	1.337	-24.7	-276.22	-6.01	2.68
m	21.08	-0.135	-0.347	0.212	-9.4	-68.7	25.59	-1.06
Mean	45.89451613	0.551870968	0.475709677	0.051354839	-10.09903226	8.76483871	-16.90903226	5.817096774
Median	51.75	0.497	0.195	0.288	8.1	8.32	-0.76	9.3
SD	16.15113182	3.811497289	1.322067225	3.791990063	45.84782542	97.55034433	82.74424707	77.57210535
SE	2.900828908	0.684565122	0.237450283	0.681061521	8.234512532	17.52055906	14.86130549	13.93236141

Appendix A: Experimental Data – Total Volume

TV Pre	TV Post	Difference
13.419	12.509	-0.91
16.951	25.491	8.54
14.128	13.09	-1.038
5.197	10.402	5.205
5.697	4.47	-1.227
18.947	7.683	-11.264
9.39	8.225	-1.165
4.123	6.79	2.667
10.196	7.713	-2.483
8.043	10.84	2.797
15.431	22.526	7.095
10.952	17.141	6.189
12.064	11.929	-0.135
11.875	14.27	2.395
17.477	17.984	0.507
18.284	17.31	-0.974
11.552	11.259	-0.293
12.015	13.683	1.668
9.394	10.455	1.061
10.101	11.314	1.213
5.841	6.321	0.48
11.199	14.371	3.172
9.498	7.912	-1.586
11.374	12.237	0.863
28.649	26.279	-2.37
11.335	7.393	-3.942
4.93	8.296	3.366
15.063	8.64	-6.423
11.616	11.933	0.317
7.941	10.058	2.117
17.039	17.536	0.497

Mean Difference	0.527064516
Standard Dev of Difference	3.81815692
Standard of Error Difference	0.685761227
T alpha half 95% CI	2.0422
P-value	0.448149

Appendix A: Experimental Data – Nasopharynx

NV Pre	NV Post	Difference
5.046	4.445	1.274
1.904	1.427	3.042
3.238	3.601	-0.514
0.217	1.799	-0.207
0.861	0.15	-1.116
1.471	3.091	-0.098
1.875	2.07	0.925
0.987	2.287	0.74
3.322	2.52	0.487
1.225	2.78	-0.01
2.791	2.349	0.49
3.202	8.054	2.531
1.53	1.183	-0.892
		0.865
1.784	3.058	-0.761
1.177	4.219	-0.913
2.956	2.442	0.875
0.441	0.234	-0.058
3.553	2.437	-0.601
3.486	3.388	-0.477
1.227	2.152	0.363
1.584	2.324	1.582
3.457	3.944	-0.711
1.278	1.268	1.62
3.368	3.858	0.195
4.088	6.619	1.3
2.984	2.092	-0.802
0.337	1.202	1.555
3.185	2.424	-0.442
2.719	1.806	4.852
2.463	3.338	-0.347
2.542	2.484	-0.058

Mean Difference	0.47571
Standard Dev of Difference	1.32207
Standard of Error Difference	0.23745
T alpha half 95% CI	2.0422
P-value	0.05424

Appendix A: Experimental Data – Oropharynx

OV Pre	OV Post	Difference
8.373	8.064	-0.309
15.047	24.064	9.017
10.89	9.489	-1.401
4.98	8.603	3.623
4.836	4.32	-0.516
17.476	4.592	-12.884
7.515	6.155	-1.36
3.136	4.503	1.367
6.874	5.193	-1.681
6.818	8.06	1.242
12.64	20.177	7.537
7.75	9.087	1.337
10.534	10.746	0.212
		0
10.091	11.212	1.121
16.3	13.765	-2.535
15.328	14.868	-0.46
11.111	11.025	-0.086
8.462	11.246	2.784
5.908	7.067	1.159
8.874	9.162	0.288
4.257	3.997	-0.26
7.742	10.427	2.685
8.22	6.644	-1.576
8.006	8.379	0.373
24.561	19.66	-4.901
8.351	5.301	-3.05
4.593	7.094	2.501
11.878	6.216	-5.662
8.897	10.127	1.23
5.478	6.72	1.242
14.497	15.052	0.555

Mean Difference	0.04975
Standard Dev of Difference	3.73034
Standard of Error Difference	0.66999
T alpha half 95% CI	2.04522
P-value	0.9289

Appendix A: Experimental Data – Minimum Sectional Area

MA Pre	MA Post	Difference
122.4	58	-64.4
239.9	284.6	44.7
157.5	140.2	-17.3
74.2	75.3	1.1
113.27	39.4	-73.87
162.4	91.9	-70.5
33.8	55.7	21.9
46	55.4	9.4
128.9	69.4	-59.5
135.3	153.1	17.8
162.2	220.5	58.3
67.1	42.4	-24.7
161.7	152.3	-9.4
		0
99.1	130	30.9
218.4	236.5	18.1
99.5	109.4	9.9
70.9	83.9	13
67.3	83.1	15.8
78.5	111.1	32.6
63	67.5	4.5
22.5	36.7	14.2
60	110.8	50.8
75.4	52.9	-22.5
60.5	69.7	9.2
368.5	280.1	-88.4
85.5	36.2	-49.3
17	39.2	22.2
147.1	63.8	-83.3
105.6	113.7	8.1
93.7	91	-2.7
245.6	115.9	-129.7

Mean Difference	-9.78344
Standard Dev of Difference	45.1376
Standard of Error Difference	8.10695
T alpha half 95% CI	2.0422
P-value	0.22958

Appendix A: Experimental Data – Cross-sectional area at PNS

CSA-PNS Pre	CSA-PNS Post	Difference
449.51	462.6	13.09
386.29	506.53	120.24
491.01	479.54	-11.47
308.93	573.72	264.79
285.11	214.41	-70.7
354.37	378.51	24.14
468.4	428.78	-39.62
366.44	475.39	108.95
431.91	463.51	31.6
482.45	455.43	-27.02
403.92	468.51	64.59
732.71	456.49	-276.22
319.5	250.8	-68.7
610.99	668.04	57.05
391.54	435.12	43.58
723.95	531.25	-192.7
280.75	251.01	-29.74
572.09	643.26	71.17
294.8	320.34	25.54
583.94	570.84	-13.1
479.94	418.37	-61.57
558.7	647.89	89.19
355.91	318.47	-37.44
497.62	505.94	8.32
741.48	862.97	121.49
498.61	452.97	-45.64
532.8	506.61	-26.19
428.54	406.46	-22.08
554.72	674.9	120.18
425.12	470.64	45.52
438.1	422.56	-15.54

Mean Difference	8.76484
Standard Dev of Difference	97.5503
Standard of Error Difference	17.5206
T alpha half 95% CI	2.0422
P-value	0.62054

Appendix A: Experimental Data – Cross-sectional area at CV2

CSA-CV2 Pre	CSA-CV2 Post	Difference
146.98	96.17	-50.81
245.68	451.49	205.81
222.55	212.26	-10.29
108.67	118.81	10.14
188.55	164.77	-23.78
433.97	167.46	-266.51
79.45	85.93	6.48
125.8	125.51	-0.29
169.48	145.1	-24.38
228.63	242.23	13.6
458.99	455.72	-3.27
242.44	236.43	-6.01
291.38	316.97	25.59
		0
248.5	201.94	-46.56
392.17	226.63	-165.54
108.5	138.78	30.28
281.94	294.09	12.15
88.5	164.88	76.38
90.2	138.1	47.9
212.31	134.51	-77.8
66.28	67.95	1.67
91.38	133	41.62
96.31	94.38	-1.93
75.64	75.81	0.17
375.36	328.43	-46.93
208.41	66.59	-141.82
107.66	106.9	-0.76
252.19	91.41	-160.78
127.53	160.71	33.18
124.26	114.93	-9.33
380.1	388.19	8.09

Mean Difference	-16.3666
Standard Dev of Difference	81.4521
Standard of Error Difference	14.6292
T alpha half 95% CI	2.0422
P-value	0.26461

Appendix A: Experimental Data – Cross-sectional area at CV3

CSA-CV3 Pre	CSA-CV3 Post	Difference
184.14	206.75	22.61
342.31	427.99	85.68
196.91	197.5	0.59
139.23	164.78	25.55
113.27	270.25	156.98
308.73	251.66	-57.07
327.24	283.88	-43.36
77.83	60.04	-17.79
163.37	135.77	-27.6
115.91	125.21	9.3
189.86	311.24	121.38
176.01	178.69	2.68
204.91	203.85	-1.06
		0
255.69	317.01	61.32
210.66	256.3	45.64
447.3	375.71	-71.59
287.65	327.88	40.23
154.8	386.18	231.38
174.2	191.46	17.26
368.02	301.22	-66.8
208.41	234.68	26.27
194.74	154.71	-40.03
125.76	68.53	-57.23
178.11	217.66	39.55
351.73	291.4	-60.33
232.49	131.14	-101.35
230.39	254.7	24.31
342.31	166.58	-175.73
341.87	288.36	-53.51
110.07	141.38	31.31
261.64	273.38	11.74

Mean Difference	5.63531
Standard Dev of Difference	76.3176
Standard of Error Difference	13.707
T alpha half 95% CI	2.0422
P-value	0.67927

Appendix B: t-Test Data

t-Test: Paired Two Sample for Means

	Post TV	*Pre TV*
Mean	12.4535	11.9265
Variance	28.9301	25.6714
Observations	31	31
Pearson Correlation	0.73431	
Hypothesized Mean Difference	0	
df	30	
t Stat	0.76858	
P(T<=t) one-tail	0.22407	
t Critical one-tail	1.69726	
P(T<=t) two-tail	0.44815	
t Critical two-tail	2.04227	

t-Test: Paired Two Sample for Means

	Post NV	*Pre NV*
Mean	2.74339	2.268
Variance	2.61301	1.451
Observations	31	31
Pearson Correlation	0.59475	
Hypothesized Mean Difference	0	
df	30	
t Stat	2.00341	
P(T<=t) one-tail	0.12712	
t Critical one-tail	1.69726	
P(T<=t) two-tail	0.15424	
t Critical two-tail	2.04227	

t-Test: Paired Two Sample for Means

	Post OV	*Pre OV*
Mean	9.71016	9.65881
Variance	23.8437	21.4293
Observations	31	31
Pearson Correlation	0.68336	
Hypothesized Mean Difference	0	
df	30	
t Stat	0.0754	
P(T<=t) one-tail	0.4702	
t Critical one-tail	1.69726	
P(T<=t) two-tail	0.94039	
t Critical two-tail	2.04227	

t-Test: Paired Two Sample for Means

	Post MA	*Pre MA*
Mean	105.4742	115.6
Variance	4659.905	5632
Observations	31	31
Pearson Correlation	0.799328	
Hypothesized Mean Difference	0	
df	30	
t Stat	-1.22643	
P(T<=t) one-tail	0.114789	
t Critical one-tail	1.697261	
P(T<=t) two-tail	0.229577	
t Critical two-tail	2.042272	

t-Test: Paired Two Sample for Means

	Post CSA-PNS	*Pre CSA-PNS*
Mean	474.8987097	466.133871
Variance	18434.29288	16061.59329
Observations	31	31
Pearson Correlation	0.725858044	
Hypothesized Mean Difference	0	
df	30	
t Stat	0.500260219	
P(T<=t) one-tail	0.310270984	
t Critical one-tail	1.697260887	
P(T<=t) two-tail	0.620541968	
t Critical two-tail	2.042272456	

t-Test: Paired Two Sample for Means

	Post CSA-CV2	*Pre CSA-CV2*
Mean	185.3574194	202.2519355
Variance	11676.80099	12929.35443
Observations	31	31
Pearson Correlation	0.722698463	
Hypothesized Mean Difference	0	
df	30	
t Stat	-1.136831571	
P(T<=t) one-tail	0.132304042	
t Critical one-tail	1.697260887	
P(T<=t) two-tail	0.264608085	
t Critical two-tail	2.042272456	

t-Test: Paired Two Sample for Means

	Post CSA-CV3	*Pre CSA-CV3*
Mean	232.1255	226.3084
Variance	8060.732	8289.199
Observations	31	31
Pearson Correlation	0.632022	
Hypothesized Mean Difference	0	
df	30	
t Stat	0.417524	
P(T<=t) one-tail	0.339634	
t Critical one-tail	1.697261	
P(T<=t) two-tail	0.679268	
t Critical two-tail	2.042272	