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Evaluation of Upper Airway Changes Following Surgical Removal of the Adenoids Using 3-D Cone Beam CT

Christopher C. Schultz
University of Nebraska Medical Center

EVALUATION OF UPPER AIRWAY CHANGES FOLLOWING SURGICAL REMOVAL OF THE ADENOIDS USING 3-D CONE BEAM CT

By

Christopher C. Schultz, D.D.S

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Advisory Committee:

Sundaralingam Premaraj, BDS, MS, PhD, FRCD(C)

Sheela Premaraj, BDS, PhD

Peter J. Giannini, DDS, MS

Stanton D. Harn, PhD

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Christopher Schultz, M.S.

University of Nebraska, 2015

Advisor: Sundaralingam Premaraj, BDS, MS, PhD

Purpose: The purpose of this study was to evaluate the changes in volume, cross-sectional area and depth of the upper airway following the surgical removal of the adenoids.

Materials and Methods: 16 patients were diagnosed with hypertrophic adenoids and referred for surgical removal. Pre-surgical and post-surgical CBCT scans were taken on each patient. Volume measurements of the total airway, oropharynx and nasopharynx were recorded. In addition, cross-sectional areas and airway depths at the posterior nasal spine (PNS) and cervical vertebrae 2 were recorded. 15 patients diagnosed with no or mild adenoid hypertrophy were treated as the control group. The controls received no surgery and only a pre-surgical scan. Pre-surgical, post-surgical and control group measurements were compared for statistically significant differences.

Results: Following surgery, a significant increase in total and nasopharyngeal airway volumes, cross-sectional area at PNS and airway depth at PNS was measured between the pre- and post-surgical groups. When compared with controls, the pre-surgical group demonstrated significantly smaller measurements for total and nasopharyngeal airway volume, cross-sectional area at PNS and airway depth at PNS. The post-surgical group did not exhibit any significant differences with the control group in any measurements.

Conclusions: Surgical removal of adenoids results in significant changes in the total and nasopharyngeal airway volume. Significant changes also occur in cross-sectional area and airway depth at PNS.

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CHAPTER 1: INTRODUCTION

The adenoids are a soft tissue mass located in the posterior pharynx, posterior to the nasal cavity (Figure 1.1). Adenoids, along with the lingual tonsil, tubal tonsils, and palatine tonsils, form the set of lymphatic tissue known as Waldeyer's tonsillar ring (Brambilla *et al*, 2014). The adenoids follow the lymphoid tissue curve where they are present at birth and grow throughout childhood, reaching their peak size in early adolescence. After reaching peak size, the adenoids typically experience an involution and are absent in many adults (Malina *et al*, 2004). While the exact role of the adenoids in the body still isn't completely known, they isolate harmful bacteria and viruses that are inhaled. The adenoids can become a source of recurrent or chronic respiratory infections, resulting in their hypertrophy (Demirhan *et al*, 2010)

Hypertrophic adenoids are a common occurrence in adolescents, with an estimated frequency of 19-58% among children 6 months through 15 years of age (Major *et al*, 2014). While the adenoids can naturally be larger in some children, the hypertrophy can also be linked to bacterial or viral infections and allergies (Evcimik *et al*, 2015). The diagnosis of hypertrophic adenoids can be made based on patient symptoms or clinically through physical examination to visualize the adenoids. The most common exam used to visualize the adenoids is nasal endoscopy. Other imaging options can include two and three-dimensional radiographs and magnetic resonance imaging (MRI) scans (Baldassari *et al*, 2014 and Brambilla *et al*, 2014).

When a patient is diagnosed with hypertrophic adenoids, there are a number of treatment modalities that can be used. If the hypertrophy is mild, the patient can be managed by observation to determine if the adenoids will decrease in size as the patient ages. If the hypertrophy is mild to moderate and an infection is suspected, a pharmacological approach can be used through the use of either corticosteroids or antibiotics. However, if the adenoidal hypertrophy is more severe, the best treatment choice often includes surgical removal of the adenoids (Demirhan *et al*, 2009).

If left untreated adenoidal hypertrophy can present with a variety of different symptoms. Due to close proximity of the adenoids with the Eustachian tubes, ear infections may be a common occurrence with enlarged adenoids. Because of the location of the adenoids, the airway is commonly affected when the adenoids are enlarged. This can present as dyspnea, mouth breathing, snoring, restlessness, and periods of paused breathing throughout the night (Brambilla *et al*, 2014). The periods of paused breathing throughout the night has led many patients to be diagnosed with obstructive sleep apnea (Shen *et al*, 2015).

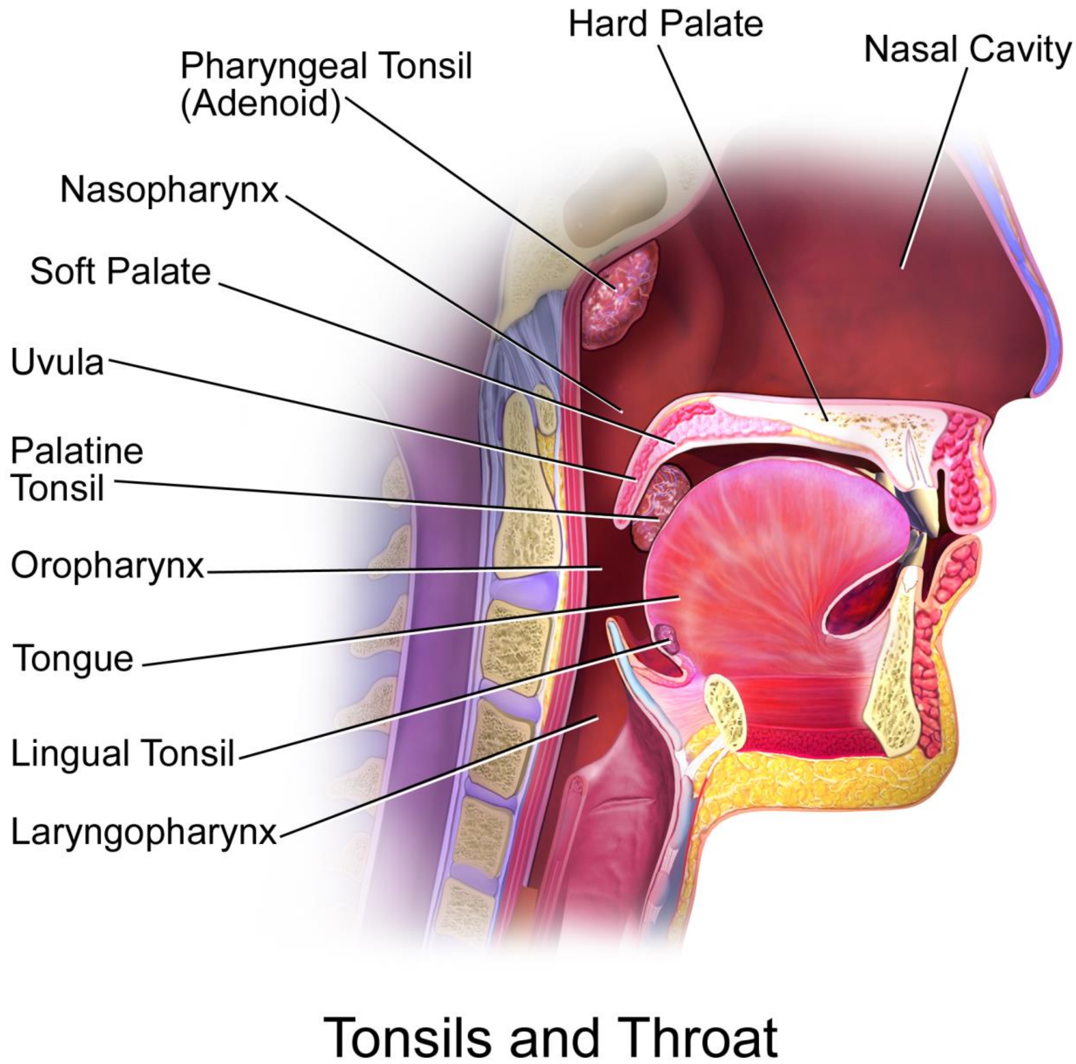
Obstructive sleep apnea (OSA) is characterized as a condition in which the upper airway collapses during sleep, either partially or completely, impeding air flow into the lungs (Volsky *et al*, 2014). Symptoms include snoring, gasping for air, open mouth breathing, restless sleep, and sleeping in abnormal positions. Untreated OSA has been linked with daytime sleepiness, short and long term cognitive effects, behavioral disturbances, hypertension, metabolic disturbances, and increased cardiovascular and cerebrovascular disease (Shen *et al*, 2015). The prevalence of obstructive sleep apnea in children has been on the rise. Currently, OSA is thought to affect 2-3% of the general pediatric population. This number, however, is increased in obese adolescents, where prevalence percentages are estimated between 13-59% (Reiter *et al*, 2014). These percentages obviously point to a strong association between OSA and obesity. Obstructive sleep apnea can be the result of a number of conditions. These include hypertrophy of the adenoids, mandibular retrognathia, macroglossia leading to obstruction of the airway, and obesity leading to a narrowing of the airway.

The first step in treating OSA is obtaining a proper diagnosis. OSA can often be diagnosed based on the signs and symptoms that are present. Polysomnograph (PSG) sleep studies are the gold standard for diagnosis of OSA (Volsky *et al*, 2014). PSG's study a full night of sleep, observing a patient's breathing patterns, number of arousals and sleeping patterns. The underlying causes that lead to narrowing of the airway should be identified for effective treatment. Increasing the airway volume is the goal in eliminating OSA. Radiographs have become common diagnostic tools for viewing the airway. Traditionally, a lateral cephalogram has been taken to view the upper airway. While this has proven to be a useful tool, it has a number of drawbacks and limitations. The first of these limitations is use of a 2-dimensional image to represent a 3-dimensional object. The lateral cephalogram gives a good representation of the airway space in the sagittal plane; however the frontal and coronal views can't be visualized. Another drawback with the lateral cephalogram is its limitations in displaying soft tissues. This imaging modality is primarily used for visualizing hard tissues such as tooth and bone as opposed to soft tissues (Oh *et al,* 2013).

Recently, clinicians have begun replacing the traditional 2-dimensional lateral cephalogram with 3-dimensional imaging modalities. The most commonly used 3-D radiographic technique in dentistry is the cone beam CT. The obvious advantage of this method is the 3-dimensional image produced. With the availability of a 3-D image, the clinician can obtain an accurate view of the airway, allowing for precise volumetric measurements of the airway to be made. The most significant drawback with CBCT is the increase in radiation exposure. While the newer CBCT machines have seen improvements in the amount of radiation exposure to patients, many clinicians believe that the taking a CBCT image on every patient is unnecessary. Some clinicians believe that the traditional pantomograph and lateral cephalogram provide the necessary information for treatment planning without exposing patients to large amounts of radiation.

The primary treatment for OSA with hypertrophic adenoids is surgical removal of the adenoids. Controversies regarding this treatment of choice for the cure of OSA exist (Shen *et al,* 2015). Because of the cost and risks involved with surgery, it is important to evaluate the effectiveness of this procedure in increasing the airway volume and thereby eliminating OSA.

Figure 1.1: Location of Adenoids



https://upload.wikimedia.org/wikipedia/commons/8/89/Blausen_0861_Tonsils%26Throat_Anatomy2.png

CHAPTER 2: AIMS OF THE STUDY

2.1 Statement of the Problem

Currently, research in adenoid removal has used 2-dimensional radiographs to measure the airway. There are no studies that have used 3-dimensional CBCT to measure the airway and there is little data on volumetric changes that occur after the removal of the adenoids.

2.2 Null Hypothesis

There is no difference in the total airway, nasopharyngeal airway and oropharyngeal airway volumes following the surgical removal of the adenoids. In addition, there is no difference in the cross-sectional areas or airway depths at the level of PNS and CV2 after removing the adenoids.

2.3 Specific Aims of the Study

The specific aims of the study are as follows:

- Compare the changes of pre- and post-surgical patients for the total, nasopharyngeal, and oropharyngeal airway volumes
- Compare the changes of pre- and post-surgical patients for the cross-sectional areas at the level of PNS and CV2.
- Compare the changes of pre- and post-surgical patients for the airway depth at the level of PNS and CV2.
- Compare pre- and post-surgical measurements with the volume, area and depth measurements of patients not requiring adenoid surgery.

CHAPTER 3: LITERATURE REVIEW

3.1 Clinical Significance

Hypertrophic adenoids are a primary cause of obstructive sleep apnea in children. The gold standard for treating these patients is surgical removal of the adenoids. In many cases, a surgeon will also remove the palatine tonsils at the same time. This procedure is known as an adenotonsillectomy. Adenoidectomies are believed to increase the airway space for the patient, making breathing easier and decreasing the likelihood of the patient experiencing apnea events throughout the night.

Many studies have been conducted to examine the different observed effects following adenoidectomy. Reddy et al. studied the adenoidal nasopharyngeal ratio (ANR), airway area, and airway percentage as the measured variables using cephalometric radiographs before and after surgical adenoid removal to examine the changes seen in the airway. The ANR represents the nasopharyngeal space taken up by soft tissues. The airway area was described as a sagittal cross-sectional area bounded by the hard and soft tissues of the nasopharynx. The airway percentage was represented as a ratio of the airway area compared to the adenoidal area. The study found a decrease in ANR, with an increase in the airway area of 184 mm^2, and an increase in the airway percentage of 42% (Reddy *et al.*, 2012).

When the adenoids begin to impinge on the nasal airway, the patient often struggles to breathe normally, and may begin breathing through the mouth (Jefferson, 2010). This change in breathing pattern can lead to changes in both the skeletal and dental patterns. These changes result in a facial pattern referred to as "Adenoid Facies." Common features with this include long, narrow faces, pinched nostrils, open bite, high narrow palate and a dull appearance in the eyes (Jefferson, 2010). Muscular and functional changes have also been examined after having an adenotonsillectomy. A month after the surgery, patients showed significant improvements in the posture and mobility of facial structures, including the tongue and lips (Bueno *et al*, 2015).

Obstructive sleep apnea in children has also been linked to decreased growth and in some cases has been described as “failure to thrive.” Failure to thrive refers to patients whose current rate of weight or height gain has fallen behind the normal rates of growth for children of similar age. In a literature review, 6 of 8 published studies found that patients exhibiting sleep disturbances associated with adenoid hypertrophy demonstrated decreases in height or weight percentiles (Bonuck *et al*, 2006).

Enlarged adenoids and obstructive sleep apnea have also been linked to obesity in children (Soultan *et al*, 1999). The combination of hypertrophic adenoids and increased adipose tissue can lead to a narrowing of the airway space. The overlying question is whether the hypertrophic adenoids could be the cause of the obesity. A study hypothesized that hypertrophic adenoids led to the development of OSA symptoms, which can include increased daytime sleepiness and decreased activity. This decreased activity, could then result in an increase in weight gain. They looked at children in four different weight categories (underweight, normal weight, obese and morbidly obese) and how the height and weight of each patient was affected after surgery. Following surgery, a majority of patients in all 4 categories exhibited increases in height, weight and body mass index (BMI). BMI score increases were demonstrated by 65% of the patients in the obese and morbidly obese categories. The study concluded that removal of adenoids and tonsils will not necessarily result in weight loss in obese patients (Soultan *et al*, 1999)

Surveys and patient questionnaires have been commonly used to measure observed changes after adenoidectomy. Quality of life questionnaires were used to compare 2 groups of patients diagnosed with obstructive sleep apnea and hypertrophic adenoids. One group underwent an adenotonsillectomy, while the other group declined surgery and was only observed. The study found that patients who underwent surgery had significant improvements in quality of life scores. There was also a small subset of patients in the observation group that showed significant improvements in quality of life scores as well, meaning in some cases, simple observation can be a viable treatment option (Volsky *et al*, 2014). Another similar study using neuropsychological testing found that patients undergoing surgery didn't show any improvements in attention or executive functioning, but did show improvements in behavior, quality of life, and polysomnographic findings. The greatest improvements were noted in patients who underwent surgery and were classified as being obese (Marcus *et al*, 2013).

3.2 CBCT Imaging

One of the many uses that have been prescribed for CBCT imaging is airway analysis. By providing a three-dimensional view, the airway can be measured in all three planes of space, allowing for linear, area, and volumetric measurements to be made (Chiang *et al*, 2012). Many studies have used CBCT as a measurement tool for airway analysis.

3.2.1 CBCT Imaging Accuracy

The key to using CBCT as an effective tool for airway measurement is the reliability of CBCT to accurately model the dimensions of the airway. In a dry skull study using an airway with known volume and areas made from acrylic, it was found that CBCT measurements were both accurate and reliable compared to physical measurements made on the constructed airway (Ghoneima *et al*, 2013).

3.2.2 CBCT vs. Two-dimensional Lateral Cephalograms

Before the advent of three-dimensional imaging, traditional two-dimensional imaging was used as a diagnostic tool for the airway. The most commonly used two-dimensional radiograph was the lateral cephalogram. Previous studies have found that it is difficult to accurately determine the airway volume from a lateral cephalogram because there is great variability in the three-dimensional airway (Aboudara *et al.,* 2009). Other studies have shown that linear measurements using CBCT and lateral cephalograms are both reliable and there is a positive correlation with respective area measurements (Vizzotto *et al.,* 2012).

While the traditional two-dimensional radiograph can't be used to measure the airway volume, studies have been performed to look for correlations between linear measurements made on the two-dimensional radiographs and the airway volume. One study examined the use of the adenoidal nasopharyngeal ratio (ANR) from a lateral cephalogram to estimate the airway volume. The ANR is a ratio comparing the linear measurements of the adenoids and nasopharynx. It was found that the ANR can be used as an initial screening method to estimate nasopharyngeal volumes (Feng *et al.,* 2015). Another study found weak correlations between linear measurements made on lateral cephalograms and the nasopharyngeal airway volume measured using CBCT (Sears *et al.,* 2011).

3.2.3 CBCT and Radiation Exposure

One of the biggest drawbacks with the use of CBCT is the increased radiation exposure compared with the traditional radiographs used in orthodontics, the lateral cephalograph and the pantomograph. The effective radiation dose of CBCT can be several to hundreds of factors higher than traditional radiography depending on the machine and the field of view used for exposure (Li, 2013).

3.3 Airway Studies Using CBCT

CBCT has been used in a number of different studies as a tool to assess airway volume (Aboudara *et al*, 2009, Chiang *et al*, 2012 and Hart *et al*, 2015). With the increased use of CBCT in dental and orthodontic offices, more studies have become feasible.

3.3.1 Airway changes associated with age and sex

A study was conducted to evaluate airway length, volume and area of maximum constriction on 387 patients ages 8 to 18 presenting to a university-based orthodontic clinic. The study examined airway differences based on patient's age and sex. The study found that males had longer and larger airways when compared to females, and males demonstrated greater increases with age. In both sexes, the volume increased continuously from age 8 to 18, while the length of the airway plateaued in females at age 15 (Chiang *et al*, 2012).

3.3.2 Airway changes associated with orthognathic surgery

Studies have examined the changes in the airway using CBCT following different orthognathic surgeries (Hart *et al*, 2015 and Park *et al*, 2010). One such study looked at the airway changes following a two-jaw surgery. The study looked at the total airway changes, as well as the changes in the nasopharyngeal airway and oropharyngeal airway. It was found that the airway was increased in a two-jaw surgery patient who exhibited a Class II skeletal relationship, while the overall airway decreased slightly in patients exhibiting a Class III skeletal relationship (Hart *et al*, 2015).

3.3.3 Airway and Skeletal Pattern

The shape and size of the airway can be heavily influenced based on the skeletal pattern of the patient. Patients are classified into three categories based on the antero-posterior relationship of the maxillary and mandibular skeletal bases. A class I relationship is described as the normal A-P relationship between the skeletal bases. A class II relationship is described as the maxillary base being positioned further anterior than normal. This can be due to the maxilla being too far forward or the mandible being too far back. A class III relationship is described as the maxillary base being positioned further posterior than normal, and can be created due to the maxilla being too far back or the mandible being too far forward (Proffit *et al*, 2007). A class II pattern with a retruded mandible is often the greatest concern to clinicians, as the retruded mandible can impinge on the airway space. Mandibular deficiency in a class II skeletal patient was found to result in smaller airway volume, area, and pharyngeal airway space compared to class I skeletal patients (Alves *et al*, 2012).

3.4 Adenoidal Hypertrophy

3.4.1 Assessment and Diagnosis

Various methods have been employed to evaluate the size of the adenoids and the amount of airway space that adenoids are blocking. Nasal endoscopy is the standard test used by clinicians to visualize the adenoids and assess if any airway blockage is present. Additional diagnostic aids that have been used include rhinomanometry, acoustic rhinometry, lateral cephalometry, computed tomography and MRI (Major *et al*, 2014). Nasal endoscopy is typically well tolerated by patients and benefits from the added value of direct visualization. Lateral cephalometry allows for assessment of the adenoid-nasopharynx ratio (ANR) which correlates well with adenoid size. However, this method can be affected by patient positioning and subjects the patient to a small amount of radiation (Baldassari *et al,* 2014 and Feres *et al,* 2012).

Cone beam CT's have allowed clinicians to visualize the adenoids and airway space in three-dimensions. As with lateral cephalometry, the patient is exposed to small amounts of radiation to capture the CBCT image. CBCT images have demonstrated strong sensitivity, specificity, accuracy and reliability for the diagnosis of adenoidal hypertrophy when compared with nasal endoscopy, and thus can be considered a useful diagnostic tool for clinicians concerned with the adenoids (Major *et al*, 2014).

Patient positioning is an important factor to consider when diagnosing adenoidal hypertrophy. Symptoms are typically worse when the patient is lying down. Using nasal endoscopy, open airway space was increased 53% in seated patients compared with patients in a supine position (Oliveira *et al*, 2012).

3.4.2 Possible Etiologies and Risk Factors

The etiology of hypertrophic adenoids is often unknown and can be difficult to ascertain. Due to their role in the immune response, hypertrophic adenoids are commonly associated with chronic and recurrent respiratory infections. These infections can be bacterial or viral in nature. The most common viral infections of the adenoids include the human adenovirus, enterovirus, rhinovirus, bocavirus, metapneumovirus and respiratory syncytial virus (Brambilla *et al*, 2014).

Exposure to certain irritants, respiratory diseases, and allergies can also be significant risk factors for the development of adenoid hypertrophy. Numerous studies have linked hypertrophy with exposure to cigarette smoke. Patients with allergies have also been shown to have an increased incidence of adenoid hypertrophy, specifically those with sensitivity to household dust mites. In addition to allergies, patients with adenoid hypertrophy were more commonly diagnosed with asthma, allergic rhinitis and atopic dermatitis than those in whom no adenoid hypertrophy was detected (Evcimik *et al*, 2015).

Typically, the adenoids follow the lymphoid tissue growth curve. Adenoid tissue will restrict the upper airway space in a majority of patients until the age of 8. In patients who do no demonstrate snoring, the adenoid tissue will diminish. In patients with snoring, however, the adenoids will persist, and continue to restrict the upper airway (Papaioannou *et al*, 2013).

3.4.3 Alternative Treatments

While surgery remains the gold standard treatment for hypertrophic adenoids, other treatments are available. Due to the risk of infection and inflammation, a pharmacological approach is common. Fluticasone propionate nasal drops have been shown to decrease adenoid size when compared to a control of saline drops. The reduction allowed for 76% of patients once thought to need surgery, to be treated with steroids alone (Demirhan *et al*, 2010).

The treatment of choice is often dependent on the degree of adenoid hypertrophy of the adenoids. In patients with mild to moderate hypertrophy, drug therapy, along with negative-pressure sputum aspiration, was effective in reducing the apnea hypopnea index (AHI) score. When the hypertrophy was more severe, patients treated with surgery saw greater reductions in AHI score than patients treated with drug therapy (Shen *et al*, 2015).

3.5 Obstructive Sleep Apnea Studies

While the most common treatment for pediatric patients with obstructive sleep apnea is removal of the adenoids and palatine tonsils, many other treatments have been studied. These treatments include the use of rapid palatal expanders, mandibular anterior repositioning devices, and maxillofacial surgery to reposition the jaws in a more anterior position.

3.5.1 Rapid Palatal Expansion

Rapid palatal expanders are appliances used by orthodontists to treat a narrow maxilla by splitting the intermaxillary and mid-palatine suture to increase the transverse dimension of the maxilla. It has been postulated that widening of the maxilla will result in an increase in nasopharyngeal airway space, thus helping address some of the symptoms associated with OSA. Rapid palatal expansion has been shown to increase total nasal volume and nasal valve area (De Felippe *et al*, 2008). The changes can be associated with reduced nasal resistance and an increase in nasal airflow. However, rapid palatal expansion should not be performed with the sole intent of improving nasal breathing (Baratieri *et al*, 2011).

Sleep study results have demonstrated that patients with malocclusions treated with rapid palatal expansion experience decreases in their apnea hypopnea index (AHI) score and decreased clinical symptoms. These changes were stable after a 24 month period. However, results were from a small sample size with no control (Villa *et al*, 2011).

3.5.2 Oral Appliances

Oral appliances used to treat obstructive sleep apnea reposition retrusive mandibles into a forward position. Patients receiving this treatment are typical have Class II skeletal patterns with retruded mandibles. The repositioning of the mandible is thought to increase the airway space and help treat apnea symptoms. One common functional appliance used for treatment of a retrusive mandible is the Herbst appliance. A cone beam CT study found that a Herbst appliance increased the total airway volume, oropharyngeal volume and laryngopharyngeal volumes. The appliance also resulted in increases in oropharyngeal and laryngopharyngeal airway depths and the oropharyngeal airway width (Iwasaki *et al*, 2014).

Positive results have also been demonstrated when rapid palatal expansion was paired with the Herbst appliance. Following this combination treatment, patients exhibited decreases in respiratory effort-related arousals and indicated improvement in respiration during sleep. Sleep study results also found that mouth breathing and snoring, which were present before treatment, ceased after treatment (Schutz *et al*, 2011).

3.5.3 Maxillofacial Surgery

Another option for treating obstructive sleep apnea in patients with unfavorable skeletal relationships is orthognathic surgery. The surgery involves anterior repositioning of one or both jaws and is usually reserved for adults. Cone beam CT results have shown that an increase in airway volume and area can be expected with surgical anterior repositioning of both the maxilla and mandible. In addition to dimensional increases, patients also experienced significant improvements in apnea-hypopnea index scores (Schendel *et al*, 2014).

CHAPTER 4: MATERIALS AND METHODS

4.1 IRB Approval

An application for research was submitted and approved by the UNMC Institutional Review Board (IRB). The IRB protocol number for the study was 711-14-EP.

4.2 Patient Pool

A total of sixteen patients were identified from a private orthodontic office to participate in the retrospective study. The test group consisted of 12 females and 4 males. The average age of the test group was 11.24 years old with a range of 2.58 years to 18.5 years. Patient demographics are displayed in Table 4.1. Inclusion criteria in the study were presence of adenoidal hypertrophy, previous history of adenoid removal and availability of pre- and post-surgical CBCT scans. Exclusion criteria included any patients with previous diagnosis of any craniofacial disease or syndrome.

The control group consisted of 15 patients (7 females and 8 males). The average age of the control group was 12.86 years with a range of 8.17 years to 17.83 years. Patient demographics are displayed in Table 4.1. Inclusion criteria in the control group included no history of adenoid tissue removal, no history of reported sleep problems and presence of a CBCT scan taken during the orthodontic records appointment. Exclusion criteria included any patients with a previous diagnosis of any craniofacial disease or syndrome. All patients' ages and sex were recorded.

4.3 Adenoidal Hypertrophy Diagnosis and Removal

Patients included in the test group were diagnosed with hypertrophic adenoids using a cone beam CT scan taken at the records appointment at the private orthodontic office. The diagnosis of adenoid hypertrophy and the decision for the need of surgery was made by a single practitioner through subjective evaluation of the CBCT scan and clinical examination. After consultation with the orthodontist, all sixteen test patients agreed to have his or her adenoids removed. All adenoidectomies were performed by the same ENT surgeon with the same surgical procedure. After having the adenoids removed, patients were allowed to heal. A second cone beam CT image was then taken to examine the changes that occurred as a result of the adenoid removal surgery. The average time between scans was 33.75 weeks with a range of 9 to 74 weeks.

Patients in the control group received a cone beam CT at the same private practice office at their records appointment with the same practitioner. Based on the results of their initial CBCT image, the control group patients were diagnosed with no hypertrophy or mild hypertrophic adenoids, thus not requiring surgery or any other additional treatment for adenoid hypertrophy. Because no surgery was performed, the control group did not receive a second CBCT as minimal changes to the airway would be expected and exposing the patient to a second round of radiation was not clinically necessary.

4.4 Cone Beam CT Imaging

All cone beam CT images included in the study were taken using the same Kodak 9500 machine (Carestream, Rochester, New York). The patients were placed in a standing position in their natural head position with their Frankfurt Horizontal plane parallel to the floor. All patients were positioned by the same practitioner and the image was taken under the recommended settings listed in the Kodak 9500 manual. The field of view for the produced image was 18.4 cm x 20.6 cm and a voxel size of 0.3 was used. Files produced by the CBCT scan were imported into Invivo5 Anatomage software version 2.1 (San Jose, California) licensed to the University of Nebraska Medical Center. All CBCT analyses were performed by a single examiner, CS.

4.5 Adenoidal Hypertrophy Grading

An extensive literature review was performed to find an accepted grading scale for adenoidal hypertrophy. After completing the review, no accepted grading system was discovered. As a result, a grading system was developed for this study using the Brodsky Grading System for palatine tonsil hypertrophy as a guideline (Kumar *et al*, 2014). To grade the adenoids, the midsagittal image was used to determine the impedance of the adenoids onto the airway. The grade was given based on a visual assessment by the examiner. When no adenoidal hypertrophy was visibly present in the CBCT image a grade of “none” was given. When 0-33% of the airway was compromised by the adenoids, a grade of “mild” was given. When 33-66% of the airway was compromised by the adenoids, a grade of “moderate” was assigned. Finally, when 66% or greater of the airway was compromised by the adenoids, a grade of “severe” was given. The grading system is summarized in Table 4.2 and an example of each grade is displayed in Figure 4.1. Adenoidal hypertrophy grading was performed by a single examiner, CS.

4.6 Airway Volumetric Analysis

Volumetric analyses were performed using In Vivo Anatomage software. In the study, total upper airway volume, oropharynx volume and nasopharynx volume were calculated. The total upper airway was defined with the following borders: anterior-superior border consisting of a plane passing through the posterior nasal spine (PNS) and sella turcica, the inferior border consisting of a plane parallel to the floor passing through the most anterior-inferior point of the 3rd cervical vertebrae (CV3), the posterior border consisting of the soft tissue of the posterior pharyngeal wall, and the anterior border consisting of the soft tissue of the anterior pharyngeal wall (Figure 4.3). The nasopharynx was defined as the portion of the airway with the anterior-superior border of a plane passing through PNS and sella turcica and an inferior border of a plane parallel to the floor passing through PNS (Figure 4.4). The oropharynx was defined as the portion of the airway with the superior border of a plane parallel to the floor passing through the

PNS and with the inferior border of a plane parallel to the floor passing through the most anterior-inferior point of CV3(Figure 4.5). Total airway, oropharynx and nasopharynx definitions were made based on studies by Kim et al and Hart et al (Kim *et al*, 2010 and Hart *et al*, 2015).

To perform the volumetric analysis, the image was first oriented in the midsagittal position, using CV2 and the incisive canal to orient the image. The airway was trimmed using the trimming tool in Anatomage according to the previously described borders. After trimming in the sagittal position, the image was oriented in the frontal position, where the rest of the airway was trimmed according to the borders of the soft tissue of the lateral pharyngeal walls (Figure 4.5 – 4.11). After trimming of the selected airway was completed, the volume measurement tool was selected and a volume measurement was generated. The lower Hounsfield Unit (H.U.) parameter was placed at -1000, and the upper Hounsfield Unit (H.U.) parameter was placed at -596.7. Volumetric measurements were recorded for all patients.

4.7 Airway Cross-Sectional Area Analysis

Cross-sectional area analyses were performed using Anatomage software. Area measurements were taken in two locations: a plane passing through PNS and a plane passing through the most anterior-inferior point of cervical vertebrae 2 (CV2). The sagittal view was first used to place a plane parallel to the floor through either PNS or CV2. This plane represented a coronal slice through the skull at the level of PNS or CV2. The coronal view was then used to trace the airway space. The image was traced in the inverse color view to easily distinguish between the soft tissues and airway easier. The airway surface area was traced using the area measurement tool in Anatomage (Figures 4.12 – 4.15).

4.8 Airway Depth Analysis

Airway depth analyses were performed using Anatomage software. Airway depth measurements were taken in the sagittal view display. As done in the surface area measurement, the image was traced in the inverse color view to make distinguishing between the soft tissue and airway easier. The airway depth was defined as the distance from the soft tissue of the posterior pharyngeal wall to the soft tissue of the anterior pharyngeal wall. Measurements were made such that the depth being measured was parallel to the floor. The two points selected to be measured in this study were the depth of the airway at PNS and at the most anterior-inferior point of CV2 (Figures 4.16-4.18).

4.9 Reliability

All CBCT scans used in the study were analyzed by a single examiner, CS. One month after all scans had been analyzed, 10 scans were re-analyzed by the same examiner to measure reliability of the analysis. Scans were randomly selected to be re-analyzed. In each scan, all volumes, surface areas, and airway depths were again calculated. Pearson correlation statistical tests were performed to determine the repeatability of each measure.

4.10 Statistical Analysis

Statistical t-tests were performed in the study at a 95% confidence interval. The statistics tested for differences in the airway measurements between pre- and post-surgical patients, and also differences between the control patients and the test patients at the pre-surgical and post-surgical time points. F test statistics were performed to test for any co-variate relationships based on the age, gender, and adenoid hypertrophy grade of the patients.

Table 4.1: Patient Demographics

	Male	Female	Mean Age
Pre-surgical group	4	12	10.68
Post-surgical group	4	12	11.31
Control Group	8	7	12.86

Table 4.2: Adenoid Hypertrophy Grading

	Adenoid Grade			
	None	Mild	Moderate	Severe
Percentage of airway blocked	0%	0-33%	33-66%	66-100%

(a)

(b)

(c)

(d)

Figure 4.1a-d: Examples of adenoid hypertrophy grades: (a) none; (b) mild; (c) moderate; and (d) severe

Figure 4.2: Sagittal view of airway prior to trimming

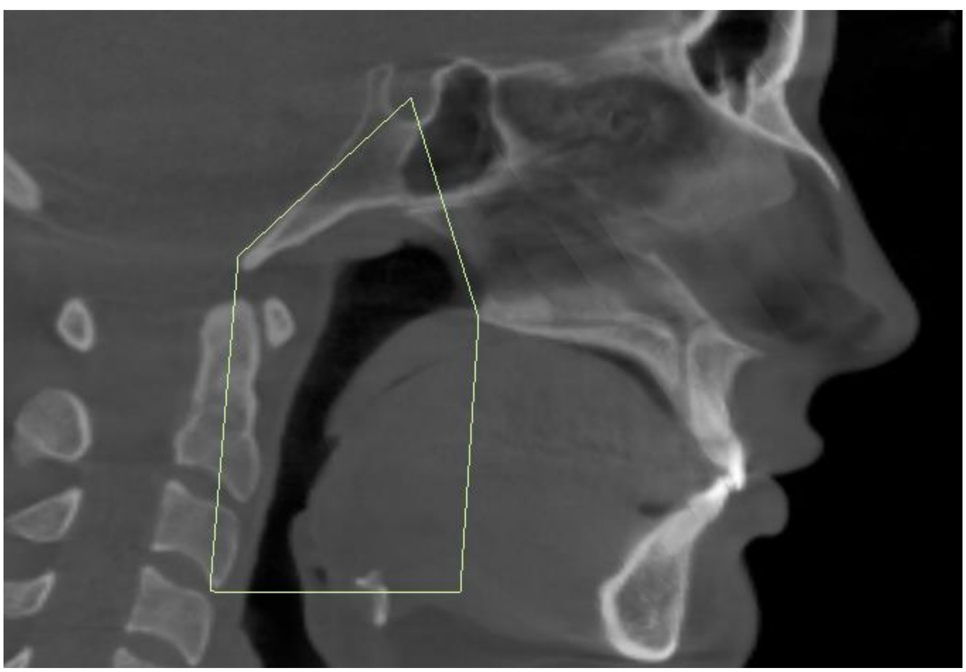


Figure 4.3: Total airway boundaries with inferior border at CV3 and anterior-superior border of plane connecting PNS and sella turcica

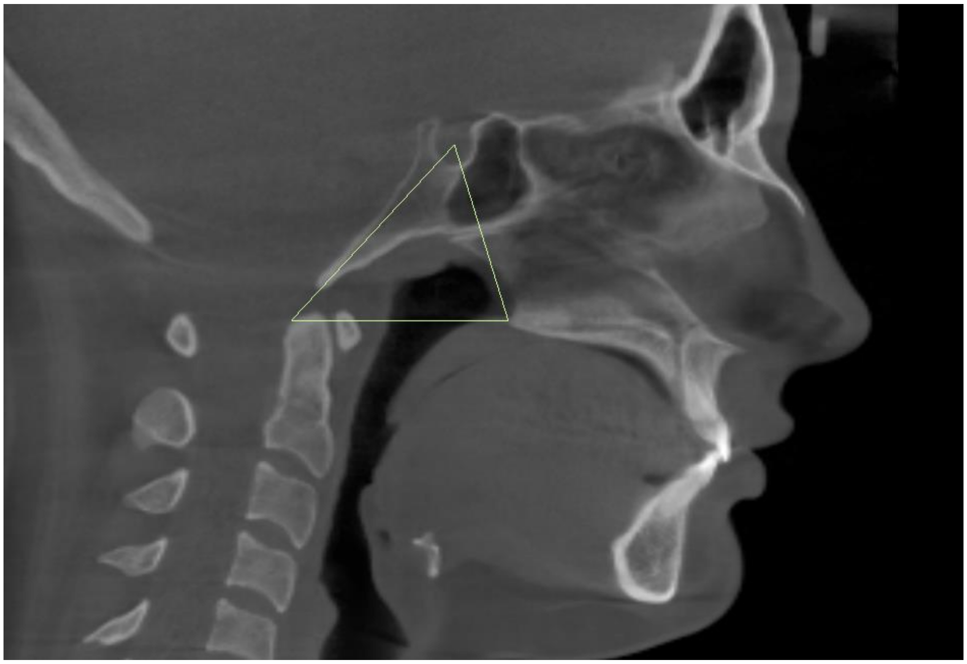


Figure 4.4: Sagittal view with nasopharyngeal boundaries with inferior border at PNS and anterior-superior border at plane connecting PNS and sella turcica

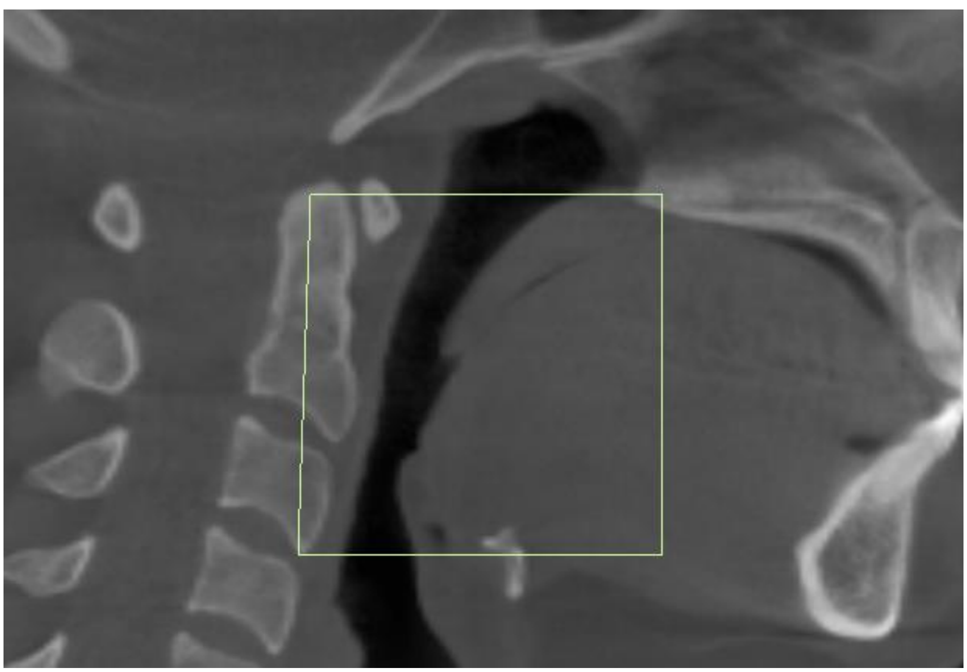


Figure 4.5: Sagittal view oropharyngeal boundaries with inferior border at CV3 and superior border at PNS

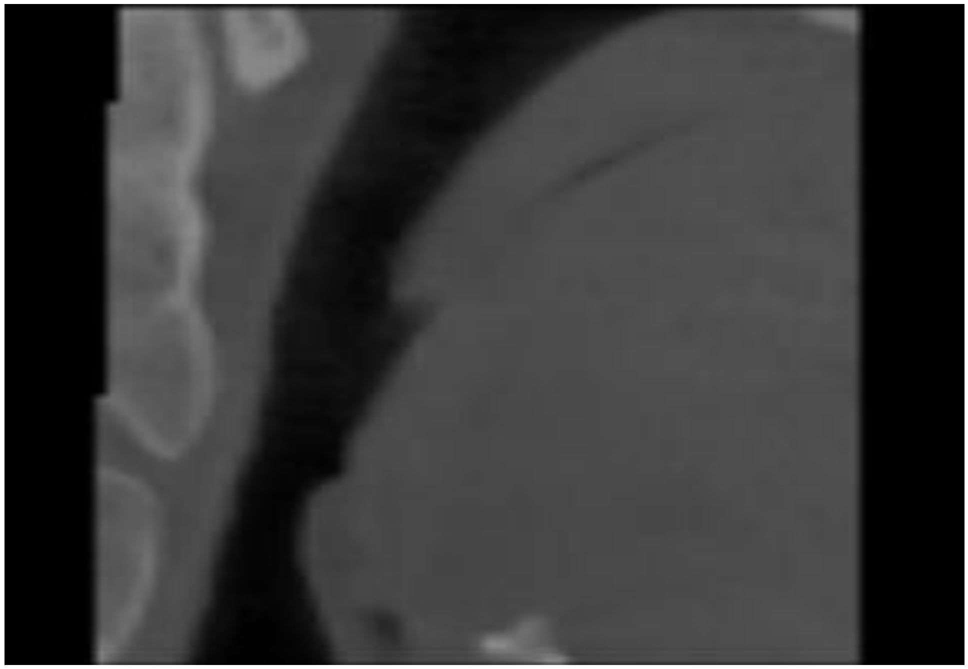


Figure 4.6: Oropharyngeal airway with superior and inferior boundaries trimmed

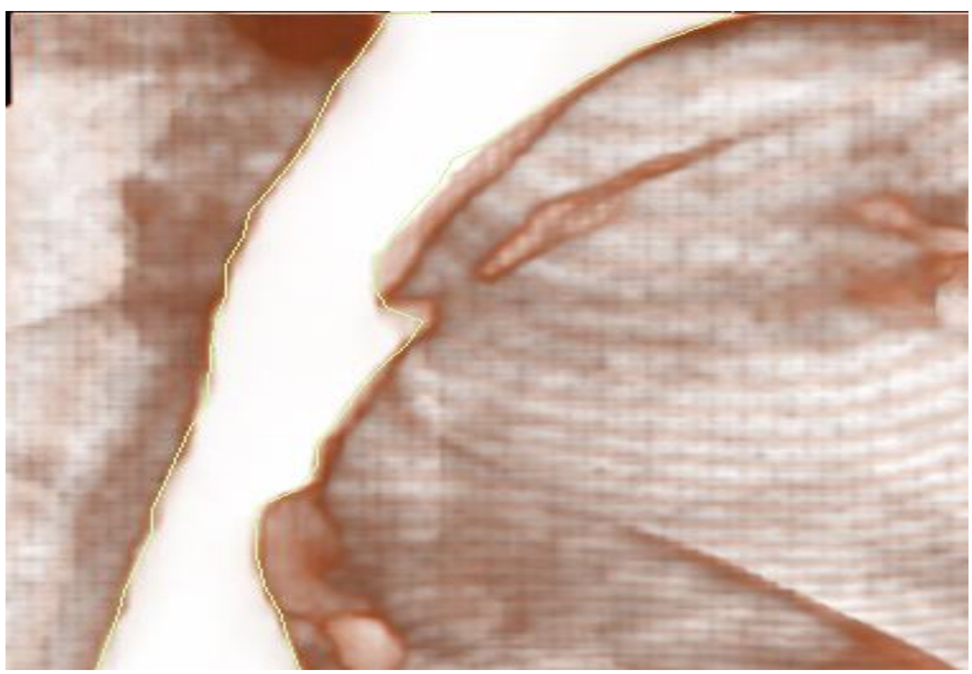


Figure 4.7: Oropharyngeal airway with boundaries traced before trimming

Figure 4.8: Oropharyngeal airway in sagittal view after trimming

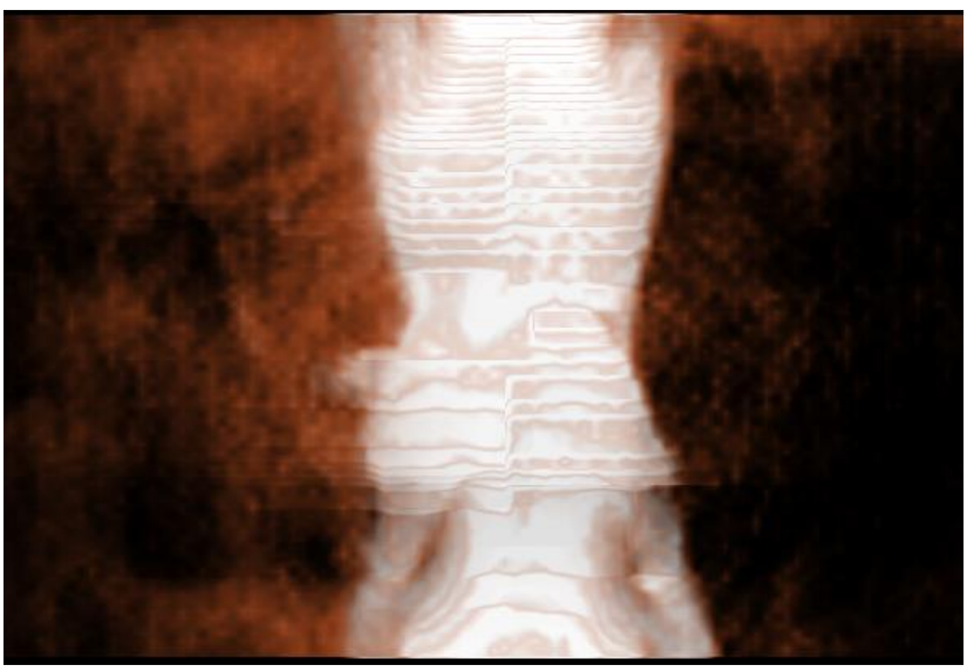


Figure 4.9: Oropharyngeal airway in frontal view prior to trimming

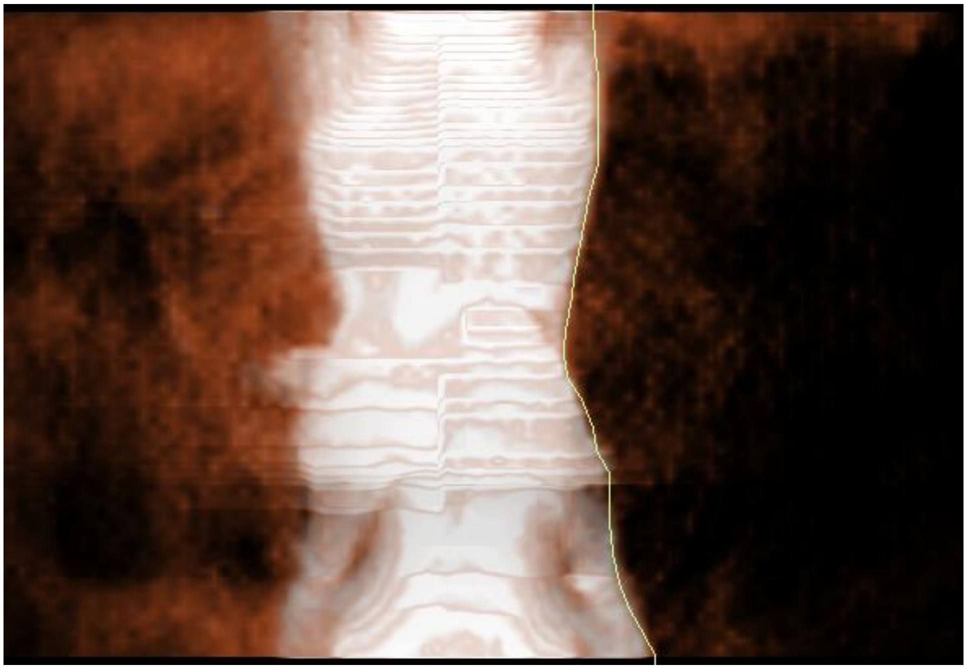


Figure 4.10: Oropharyngeal airway with lateral border traced before trimming

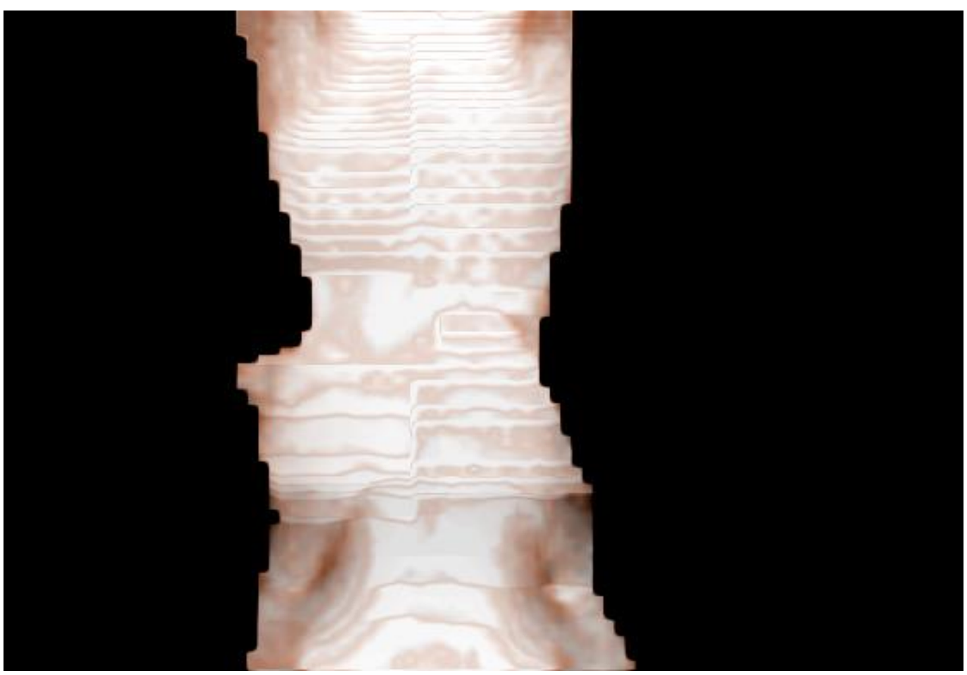


Figure 4.11: Oropharyngeal airway with all boundaries trimmed

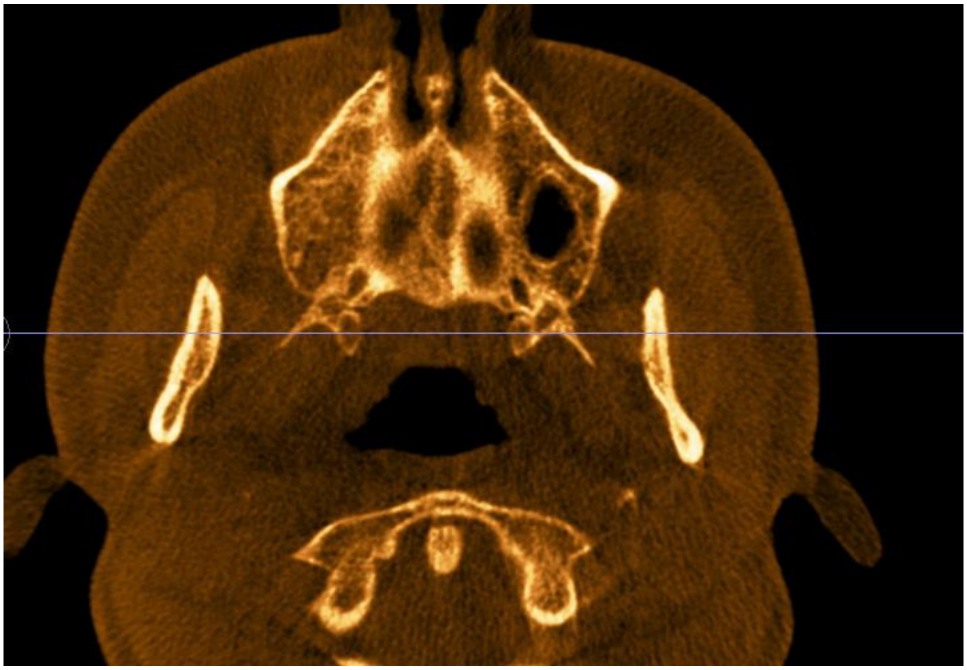


Figure 4.12: Skull placed in the coronal view at the level of PNS before cross-sectional area tracing

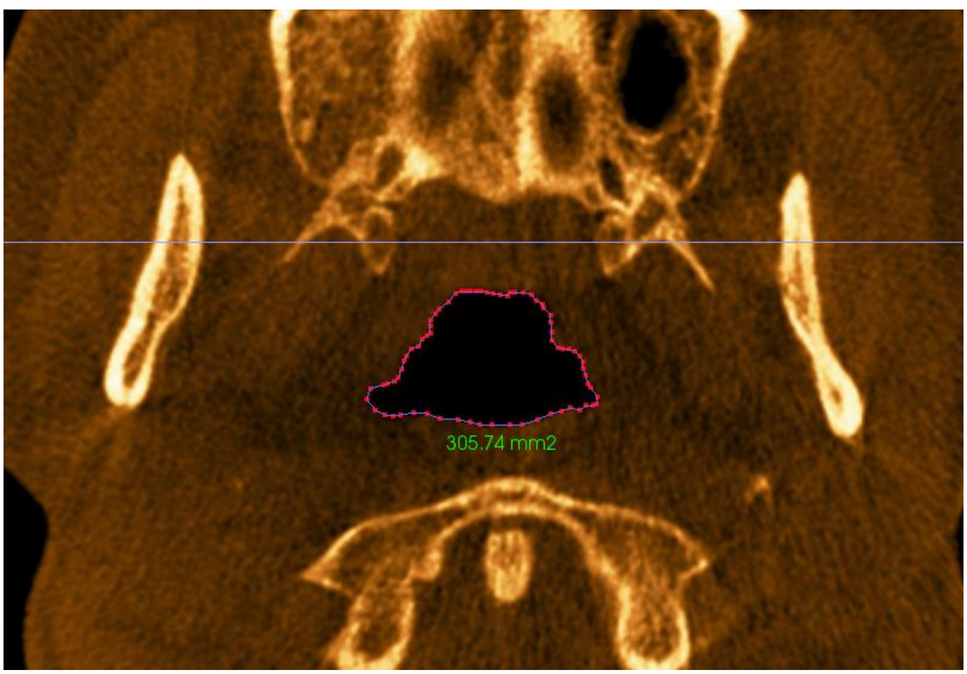


Figure 4.13: Cross-sectional area traced at PNS

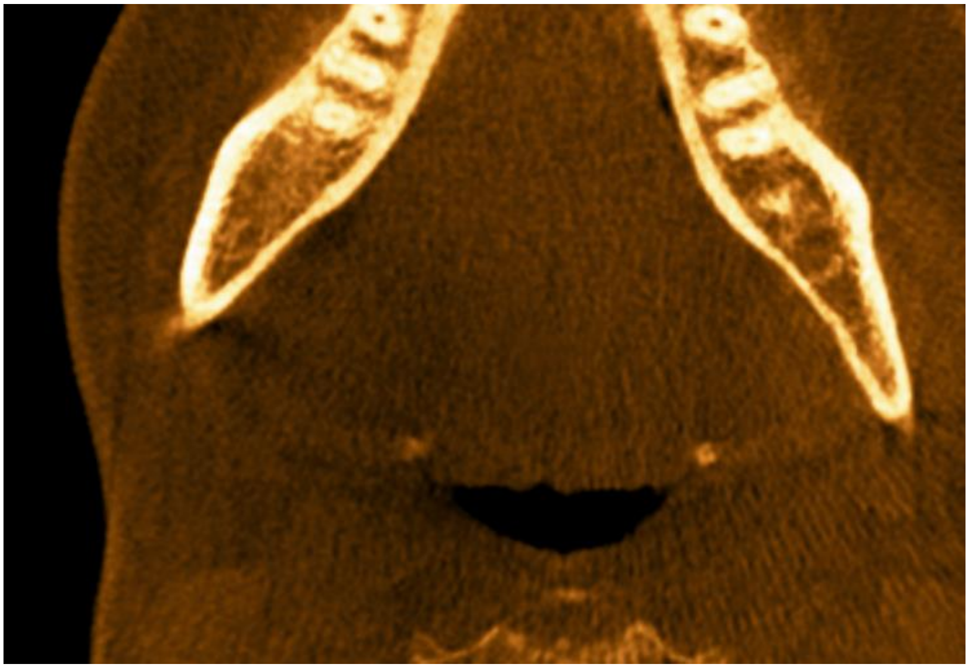


Figure 4.14: Skull placed in the coronal view at the level of CV2 before cross-sectional area tracing

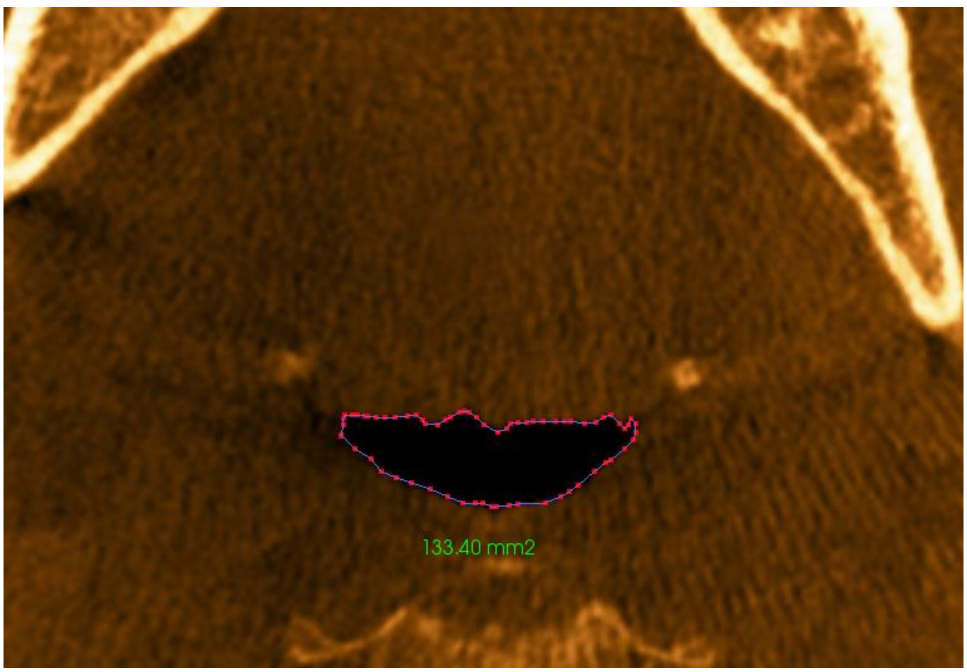


Figure 4.15: Cross-sectional area traced at CV2

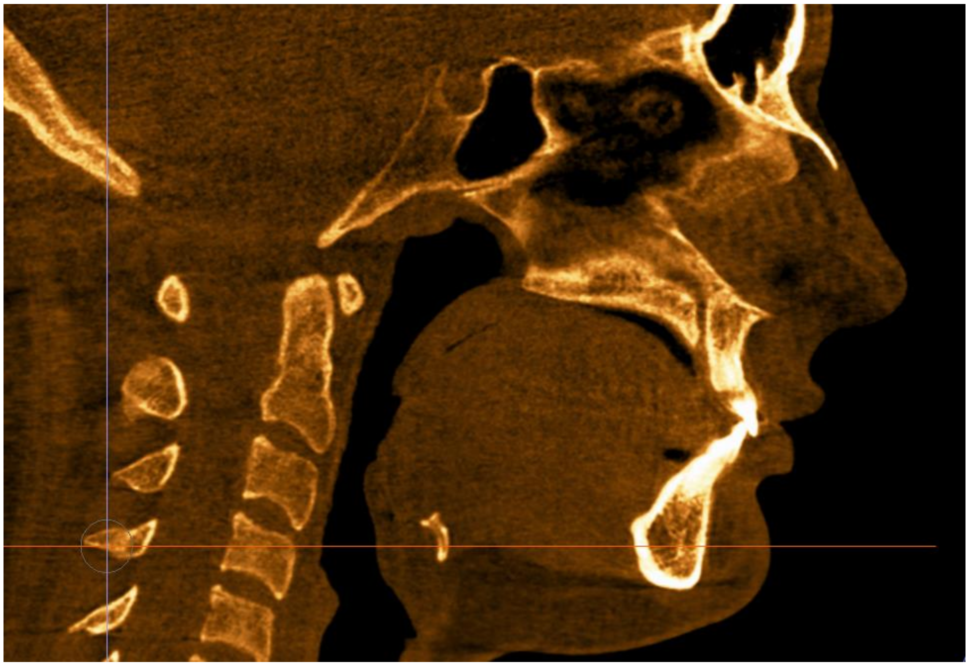


Figure 4.16: Scan placed in inverse color view prior to measuring depth at PNS and CV2

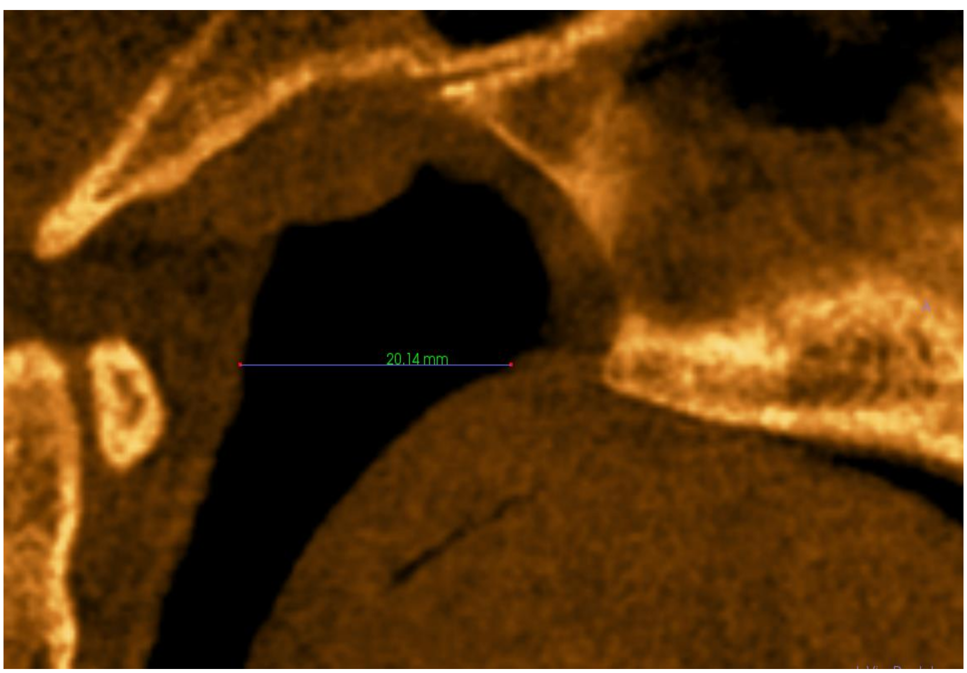


Figure 4.17: Airway depth measurement at PNS

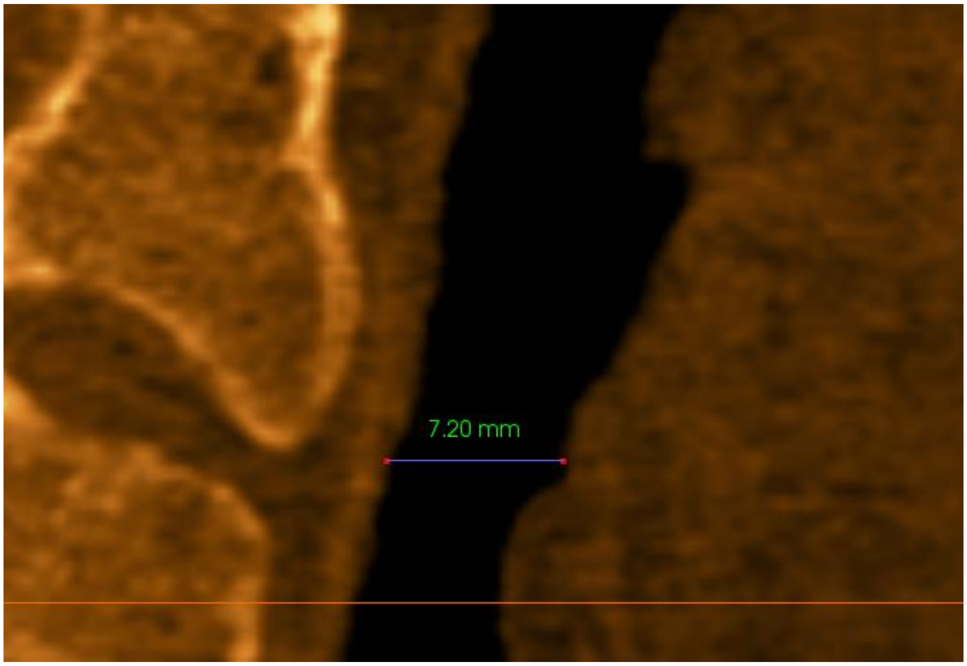


Figure 4.18: Airway depth measurement at CV2

CHAPTER 5: RESULTS

5.1 Pre-surgical Measurements

Sixteen patients were included in the surgical group. Mean pre-surgical measurements for adenoid hypertrophy grade, airway volumes, airway cross-sectional area and airway depth can be found in Figures 5.1-5.3. Error bars represent the standard error of each measurement group. Standard error was defined as the standard deviation divided by the square root of n, with n representing the number of subjects. Means and standard deviations for each parameter evaluated can be found in Table 5.1. All raw data collected from each patient can be found in Appendix A.

5.2 Post-surgical Measurements

Mean post-surgical measurements for adenoid hypertrophy grade, airway volume, airway cross-sectional area and airway depth can be found in Figures 5.4-5.6. Error bars represent the standard error of the mean of each measurement group. Means and standard deviations for each measurement can be found in Table 5.1. All raw data collected from each patient can be found in Appendix A.

5.3 Control Group Measurements

Fifteen patients were included in the control group. Mean control measurements for adenoid hypertrophy grade, airway volume, airway cross-sectional area and airway depth can be found in figures 5.7-5.9. Error bars represent the standard error of the means of each measurement group. Means and standard deviations for each measurement can be found in Table 5.1. All raw data collected on each patient can be found in Appendix A.

5.4 Changes after Surgery

Mean changes comparing pre-surgical and post-surgical measurements can be found in figures 5.10-5.12. Error bars represent the standard error of each measurement group. Standard t-test statistics were used to test for differences in the measurements following surgery.

Statistically significant volume increases were found for the total airway volume and the nasopharynx airway volume ($P < 0.05$), while changes in the oropharynx airway volume were not statistically significant. Cross-sectional area changes measured at the posterior nasal spine (PNS) were statistically significant ($P < .05$), while cross-sectional area changes at the level of cervical spine 2 (CV2) were not. Finally, airway depth at PNS was statistically significant ($P < .05$), while there was no significant change in airway depth at CV2. Table 5.2 displays the mean changes of each measurement along with the standard deviations. Figures 5.13-5.19 display the pre-surgical and post-surgical measurements for each individual patient. Statistical analyses for each individual variable are found in Appendix B.

5.5 Comparison of Controls with Pre- and Post-Surgical Groups

Comparisons of adenoid hypertrophy grade, airway volumes, airway cross-sectional areas and airway depths among controls, pre-surgical, and post-surgical measurements can be found in Figures 5.20 – 5.26. T-test statistics were used to test for differences between the subject groups. Statistical significance was represented by p-values < 0.05. Pre-surgical patients demonstrated statistically significant differences compared to the controls in the adenoid hypertrophy grade, total airway volume, nasopharyngeal airway volume, cross-sectional area at PNS, and airway depth at PNS. Post-surgical patients demonstrated statistically significant differences compared to the controls only in adenoid hypertrophy grade.

5.6 Gender and Age Effects

F-test statistics were performed to test for effects due to gender and age of the patient. No measurement variables demonstrated statistically significant correlations with age or gender of patients ($p < 0.05$).

5.7 Adenoid Hypertrophy Grade Effects

T-test statistics were used to determine if the adenoid hypertrophy grade before surgery had any effect on the post-surgical measurements. Adenoid hypertrophy grade had a statistically significant effect on the change in total airway volume, oropharynx volume, cross-sectional area at PNS, and airway depth at PNS ($p < 0.05$). Table 5.3 displays the number of patients in the different adenoid hypertrophy categories for the pre-surgical, post-surgical and control groups.

5.7 Reliability

Measurements were repeated in ten CBCT scans by the same examiner, CS. All previously measured variables were calculated again and compared with the original values. Pearson correlation statistics were calculated for each measurement. Correlation coefficients ranged from 0.979 – 0.998. Statistical tests for the reliability testing can be found in appendix B.

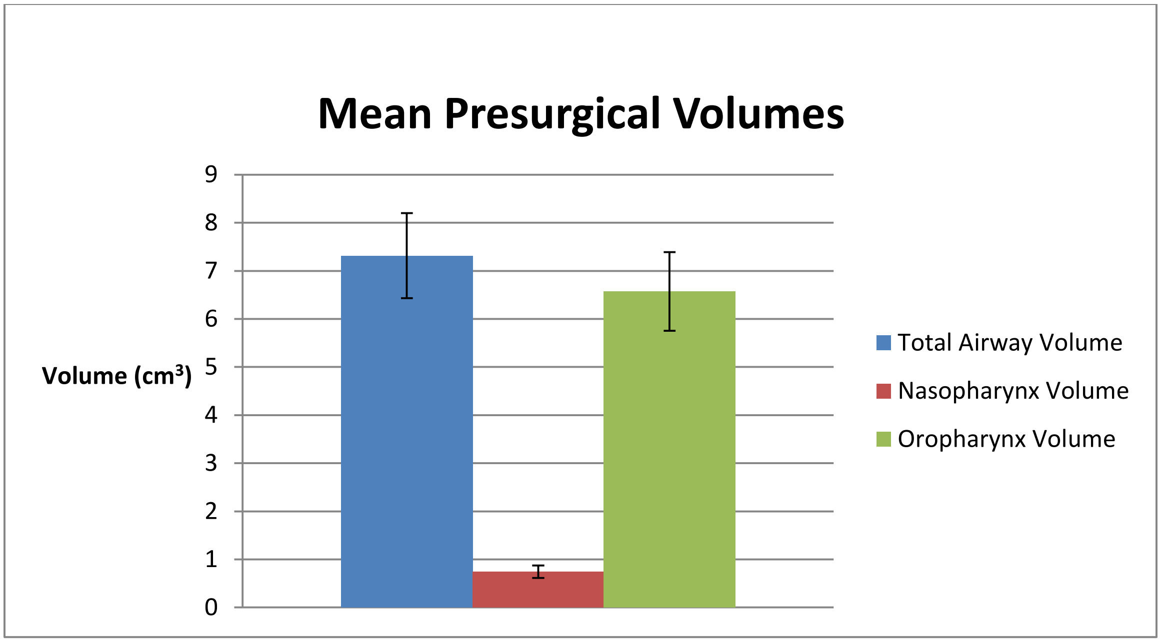


Figure 5.1: Mean volumes (cm^3) on patients prior to adenoid removal surgery

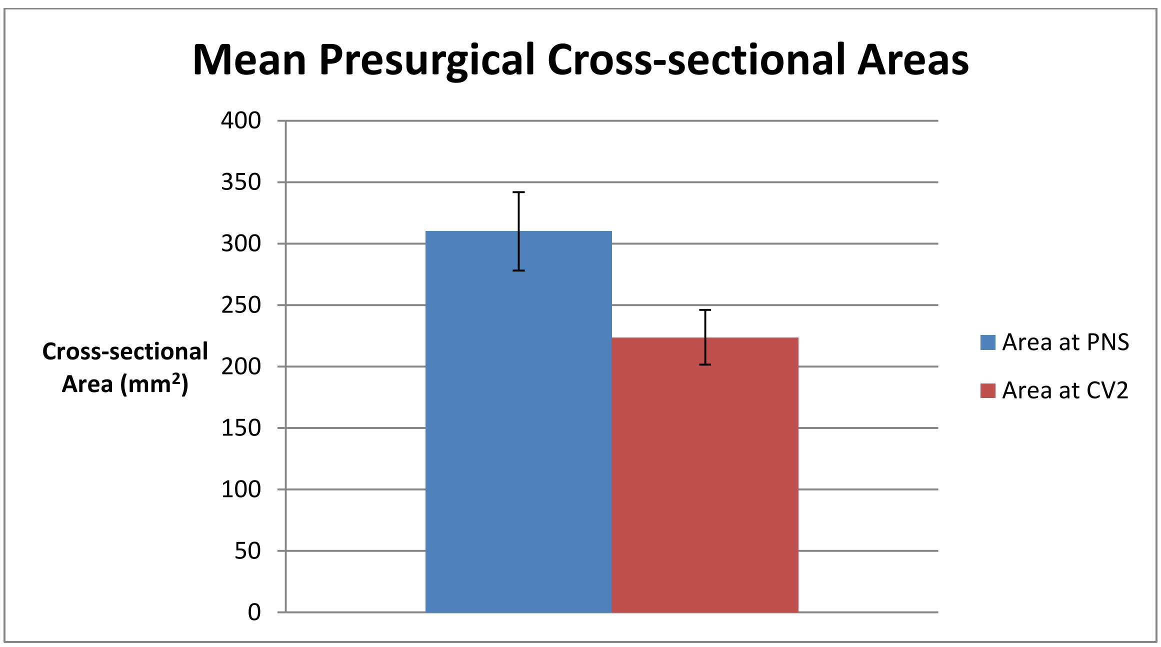


Figure 5.2: Mean cross-sectional areas (mm^2) on patients prior to adenoid removal surgery

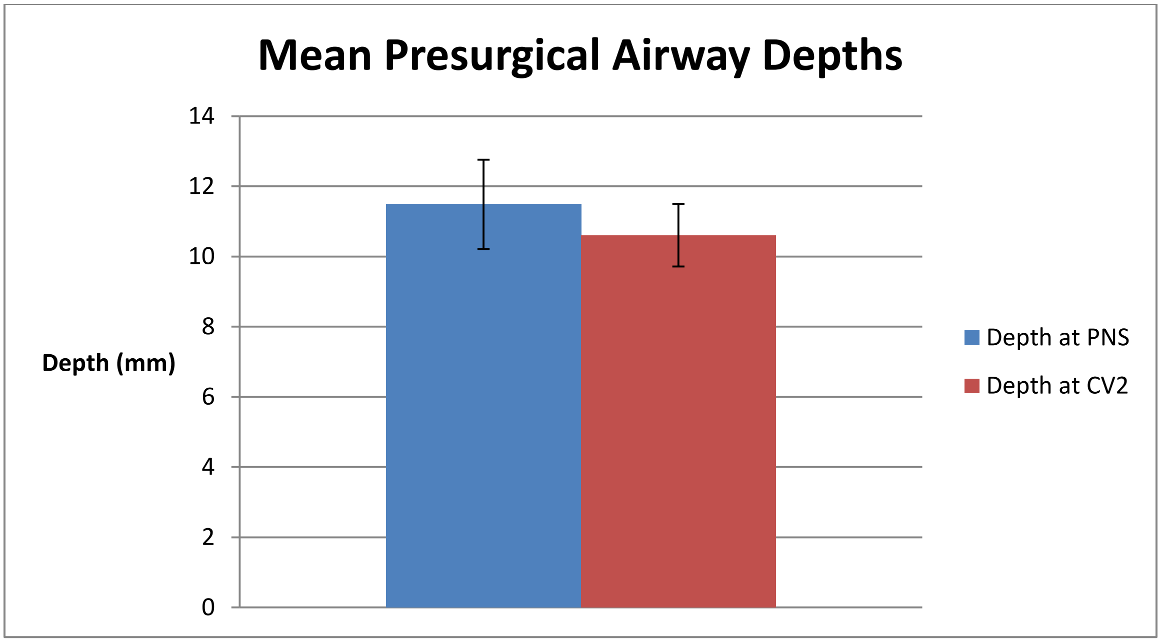


Figure 5.3: Mean airway depths (mm) on patients prior to adenoid removal surgery

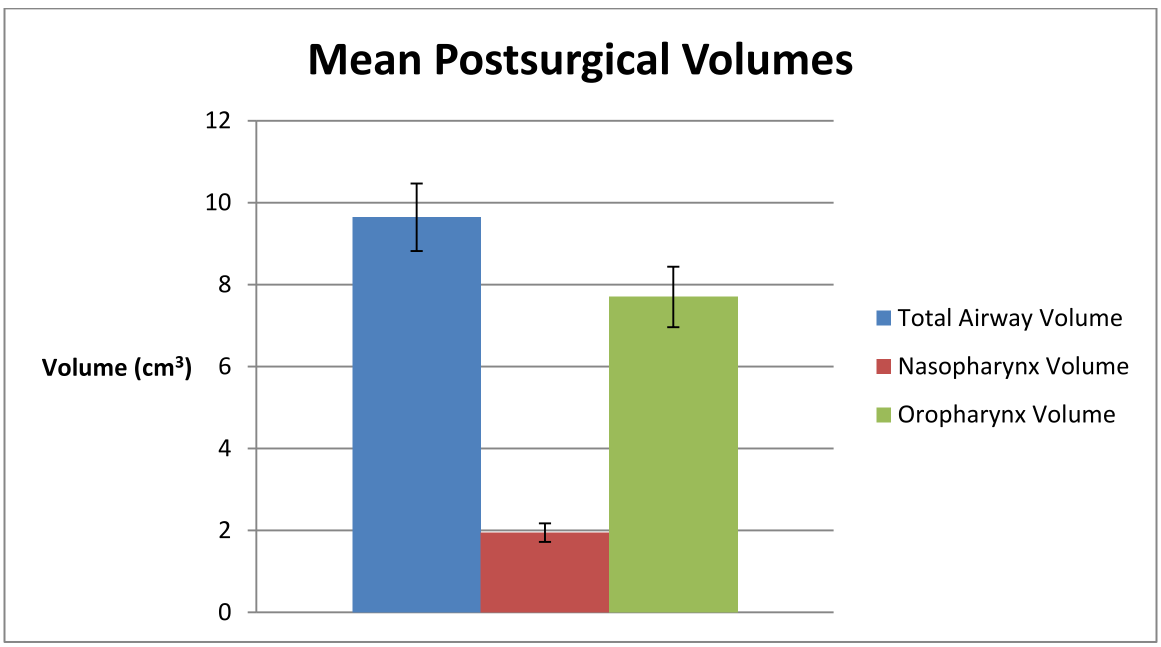


Figure 5.4: Mean volumes (cm^3) on patients following adenoid removal surgery

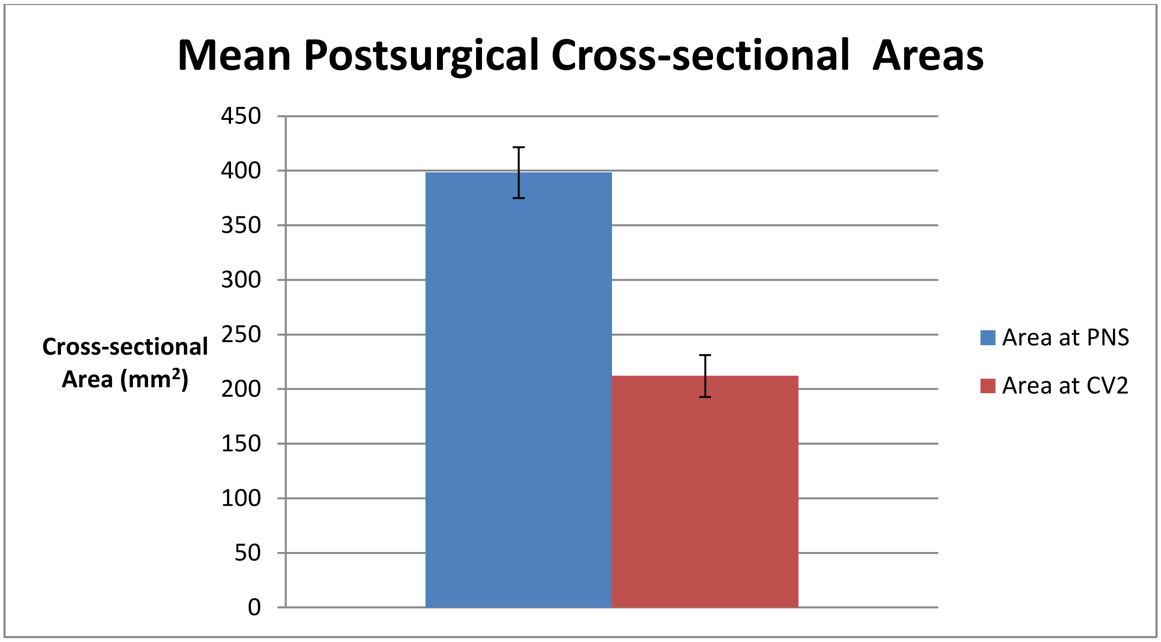


Figure 5.5: Mean cross-sectional areas (mm^2) on patients following adenoid removal surgery

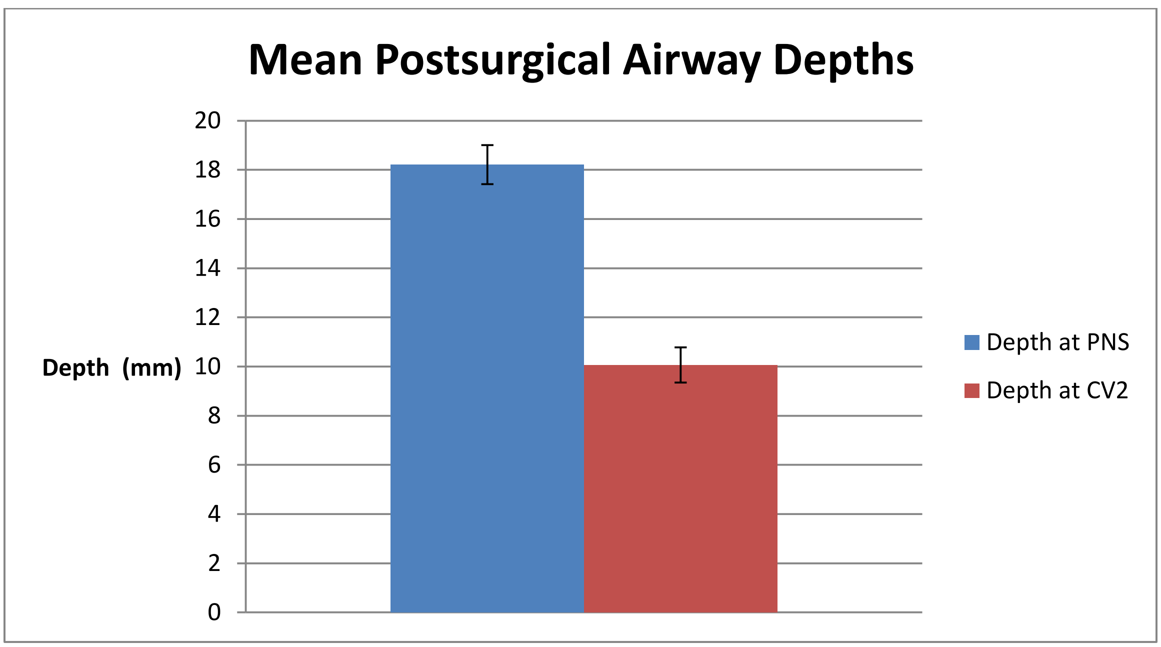


Figure 5.6: Mean airway depths (mm) on patients following adenoid removal surgery

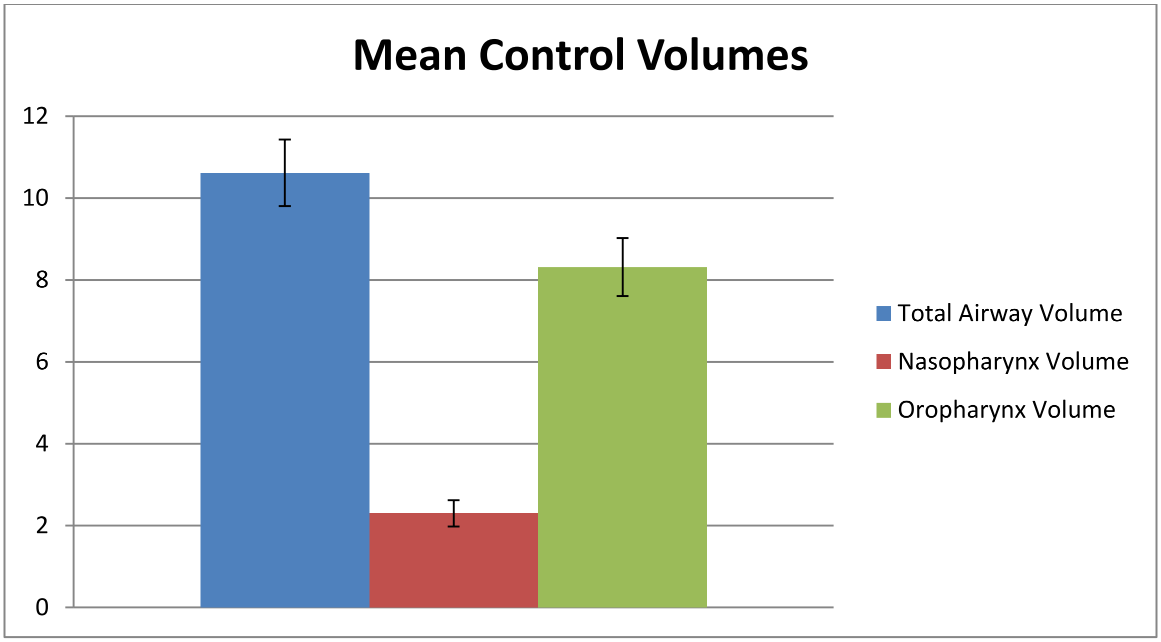


Figure 5.7: Mean volumes (cm^3) from the control group

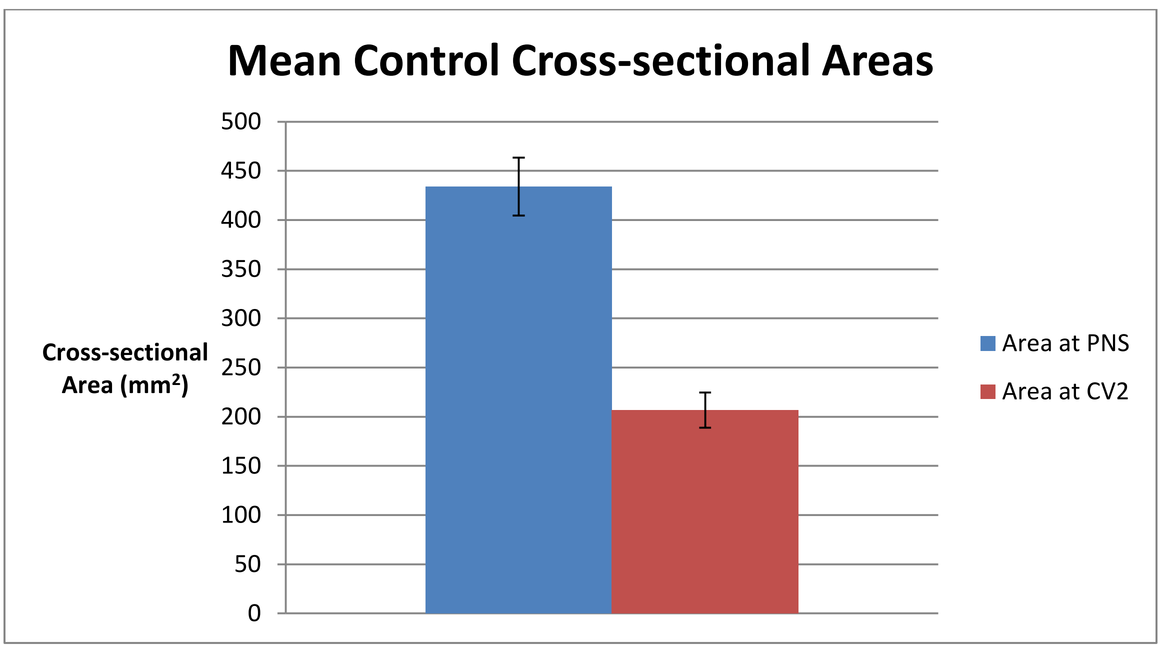


Figure 5.8: Mean cross-sectional areas (mm^2) from the control group

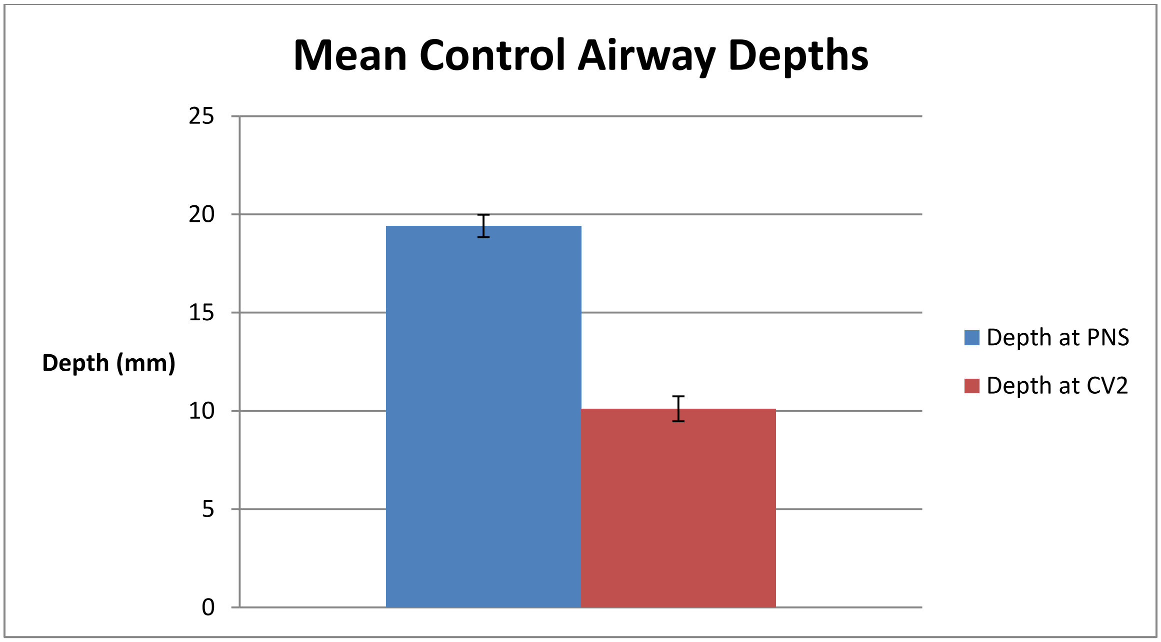


Figure 5.9: Mean airway depth (mm) from the control group

Table 5.1: Means and standard deviations for airway volume, cross-sectional area, depth and adenoid hypertrophy grade for pre-surgical, post-surgical and control groups.

	Pre-Surgical		Post-Surgical		Control	
	Average	Std Deviation	Average	Std Deviation	Average	Std Deviation
Total Airway Volume (cm^3)	7.32	3.53	9.64	3.29	10.61	3.15
Nasopharygeal Airway Volume (cm^3)	0.74	0.51	1.95	0.90	2.30	1.25
Oropharyngeal Airway Volume (cm^3)	6.57	3.26	7.70	2.95	8.31	2.75
Surface Area at PNS (mm^2)	309.99	127.77	398.22	92.76	434.00	114.40
Surface Area at CV2 (mm^2)	223.79	89.10	212.01	76.24	206.72	69.57
Airway Depth at PNS (mm)	11.49	5.08	18.21	3.16	19.42	2.23
Airway Depth at CV2 (mm)	10.61	3.58	10.07	2.86	10.11	2.47
Adenoid Hypertrophy Grade	2.13	0.78	0	0	0.93	0.44

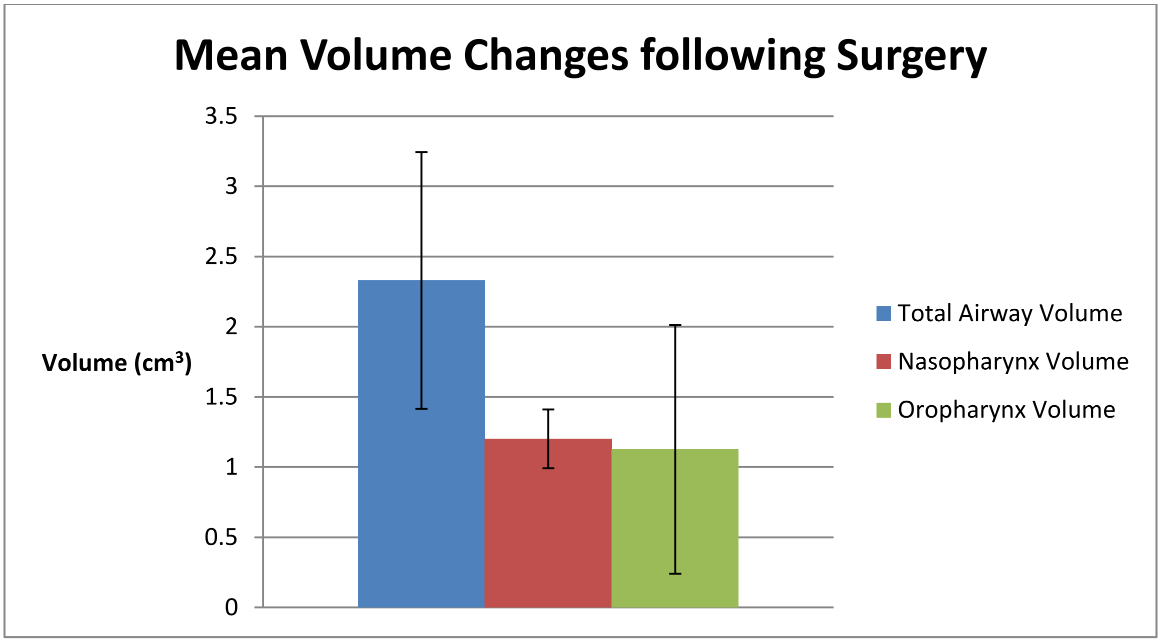


Figure 5.10: Mean volume changes following adenoid removal surgery

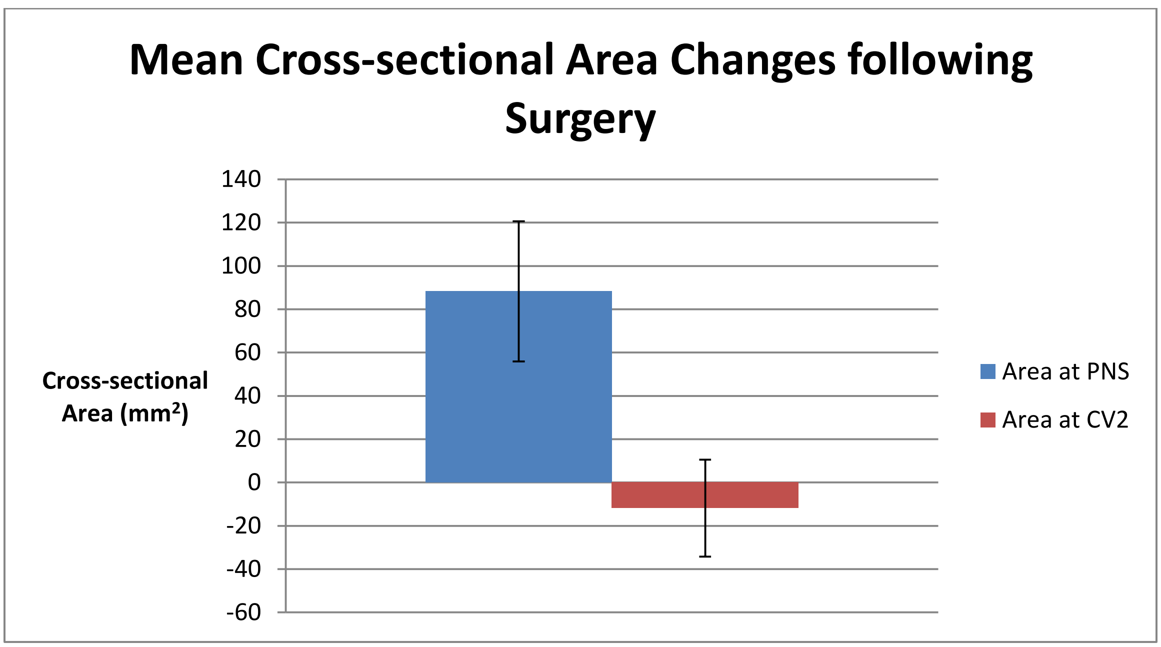


Figure 5.11: Mean cross-sectional area changes following adenoid removal surgery

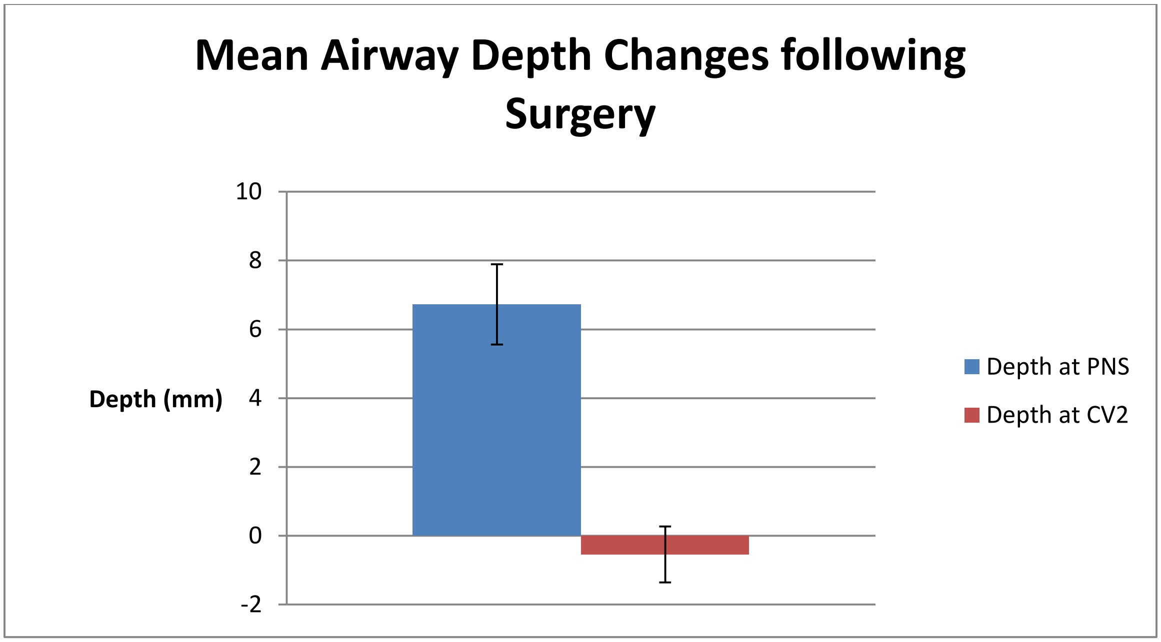


Figure 5.12: Mean airway depth changes following adenoid removal surgery

Table 5.2: Mean and standard deviations for pre-surgical and post-surgical patient measurements and amount of change between pre- and post-surgical measurements.

	Pre-Surgical		Post-Surgical		Change	
	Average	Std Deviation	Average	Std Deviation	Average	Std Deviation
Total Airway Volume (cm^3)	7.32	3.53	9.64	3.29	2.33*	3.66
Nasopharygeal Airway Volume (cm^3)	0.74	0.51	1.95	0.90	1.20*	0.84
Oropharyngeal Airway Volume (cm^3)	6.57	3.26	7.70	2.95	1.13	3.54
Surface Area at PNS (mm^2)	309.99	127.77	398.22	92.76	88.23*	129.57
Surface Area at CV2 (mm^2)	223.79	89.10	212.01	76.24	-11.78	89.57
Airway Depth at PNS (mm)	11.49	5.08	18.21	3.16	6.72*	4.66
Airway Depth at CV2 (mm)	10.61	3.58	10.07	2.86	-0.54	3.25
Adenoid Hypertrophy Grade	2.13	0.78	0	0	2.13*	0.78

* Statistically significant difference ($p < 0.05$)

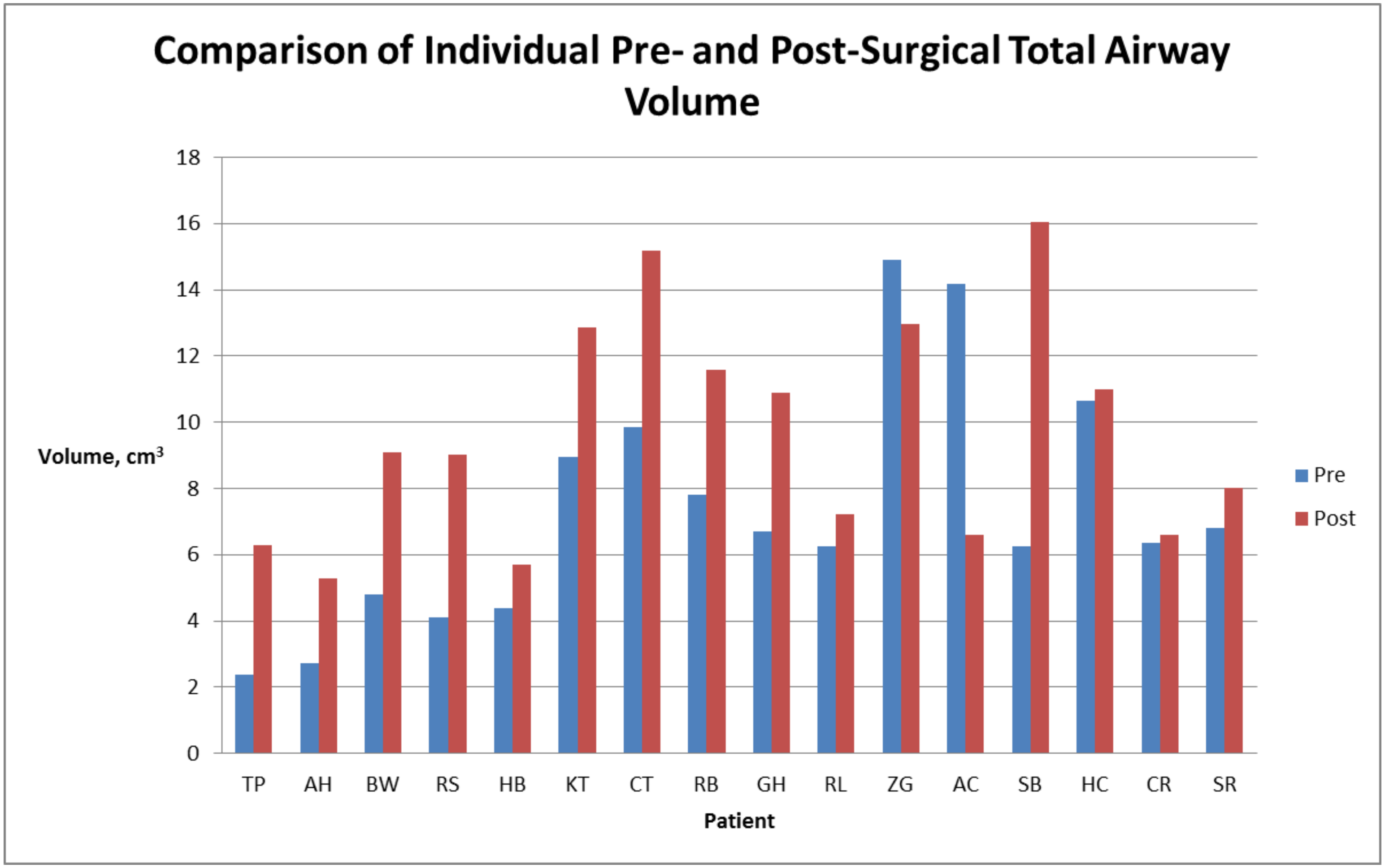


Figure 5.13: Individual comparisons of pre- and post-surgical total airway volume.

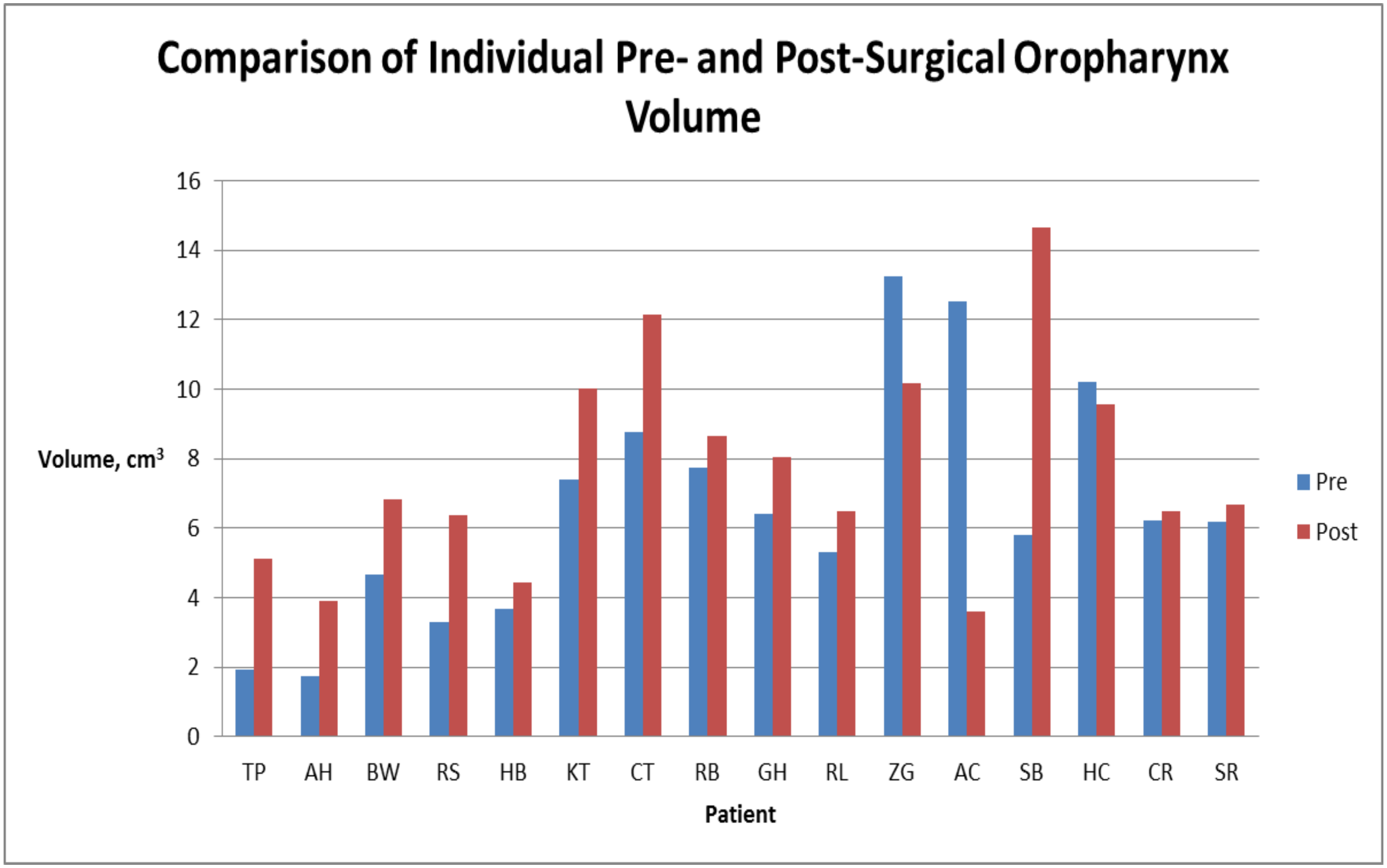


Figure 5.14: Individual comparisons of pre- and post-surgical oropharynx airway volume.

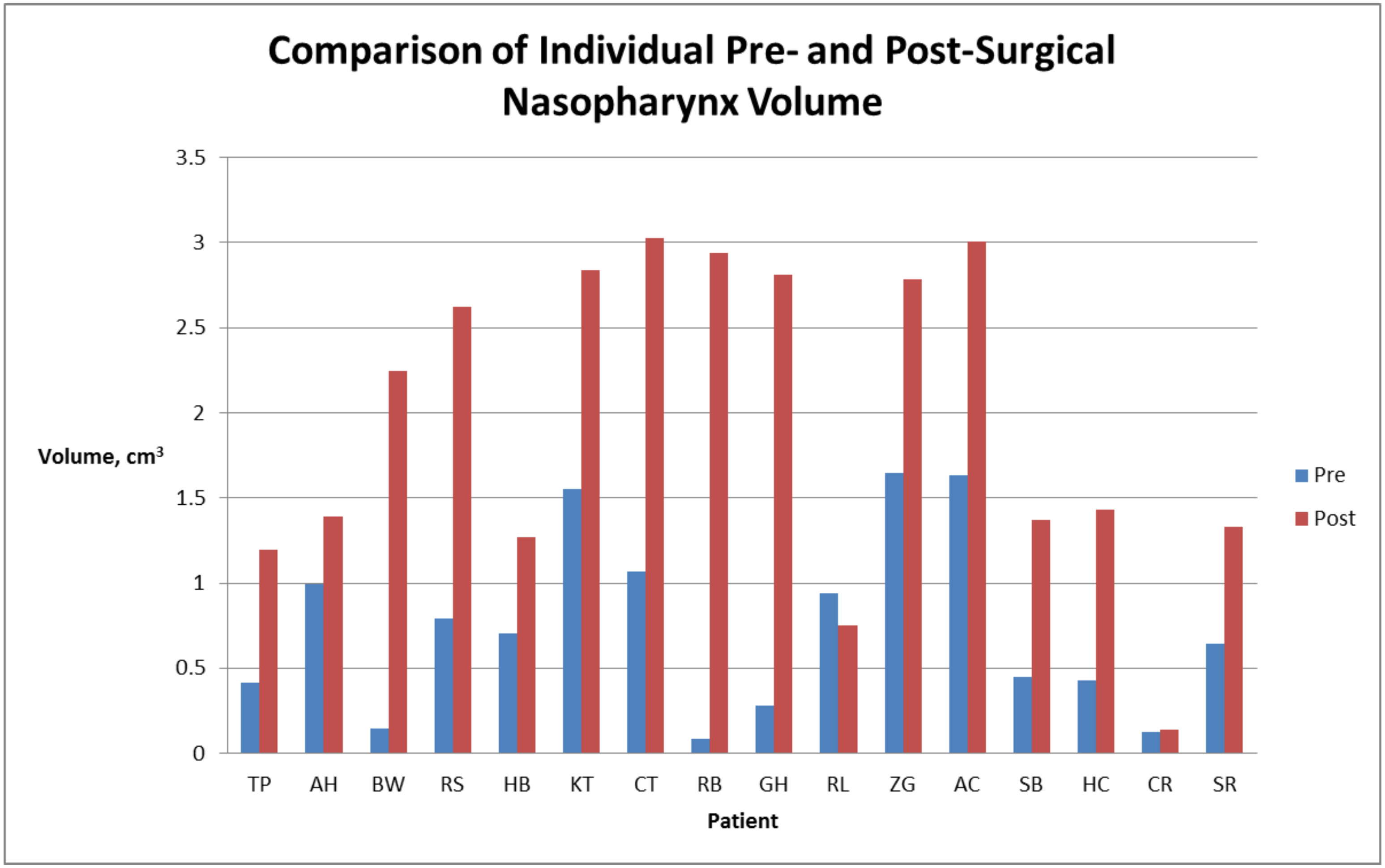


Figure 5.15: Individual comparisons of pre- and post-surgical nasopharynx airway volume.

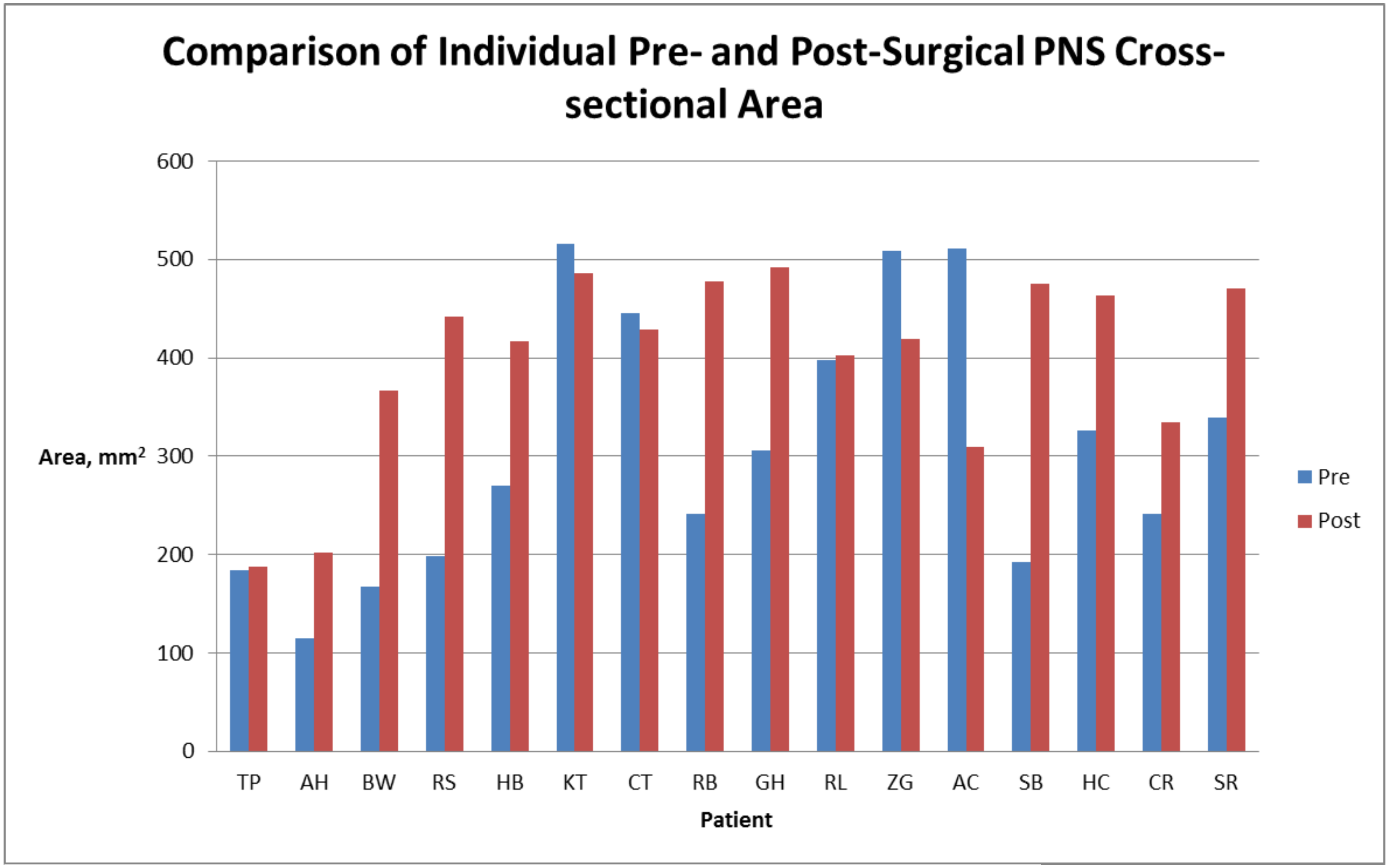


Figure 5.16: Individual comparisons of pre- and post-surgical cross-sectional areas at PNS

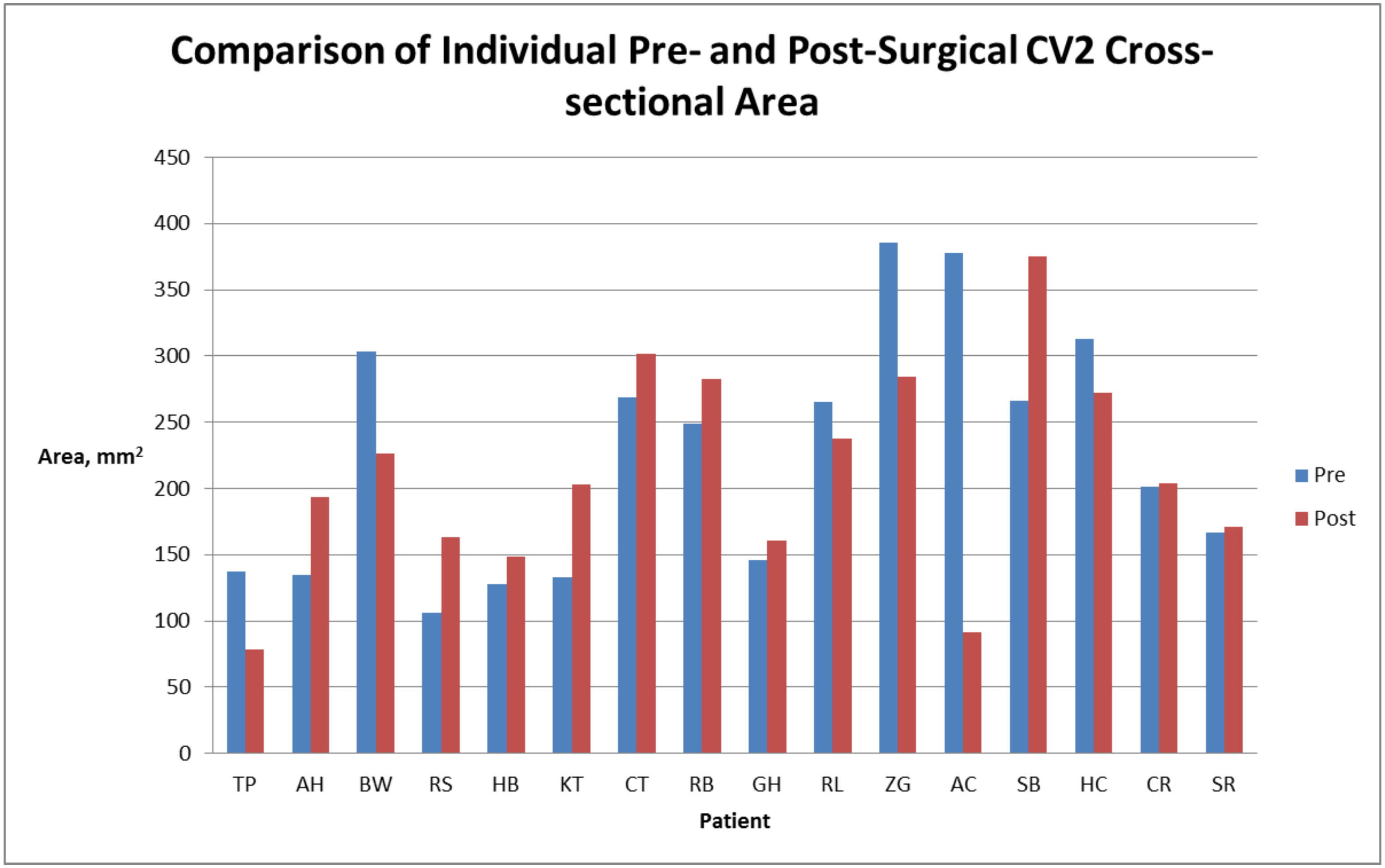


Figure 5.17: Individual comparisons of pre- and post-surgical cross-sectional area at CV2.

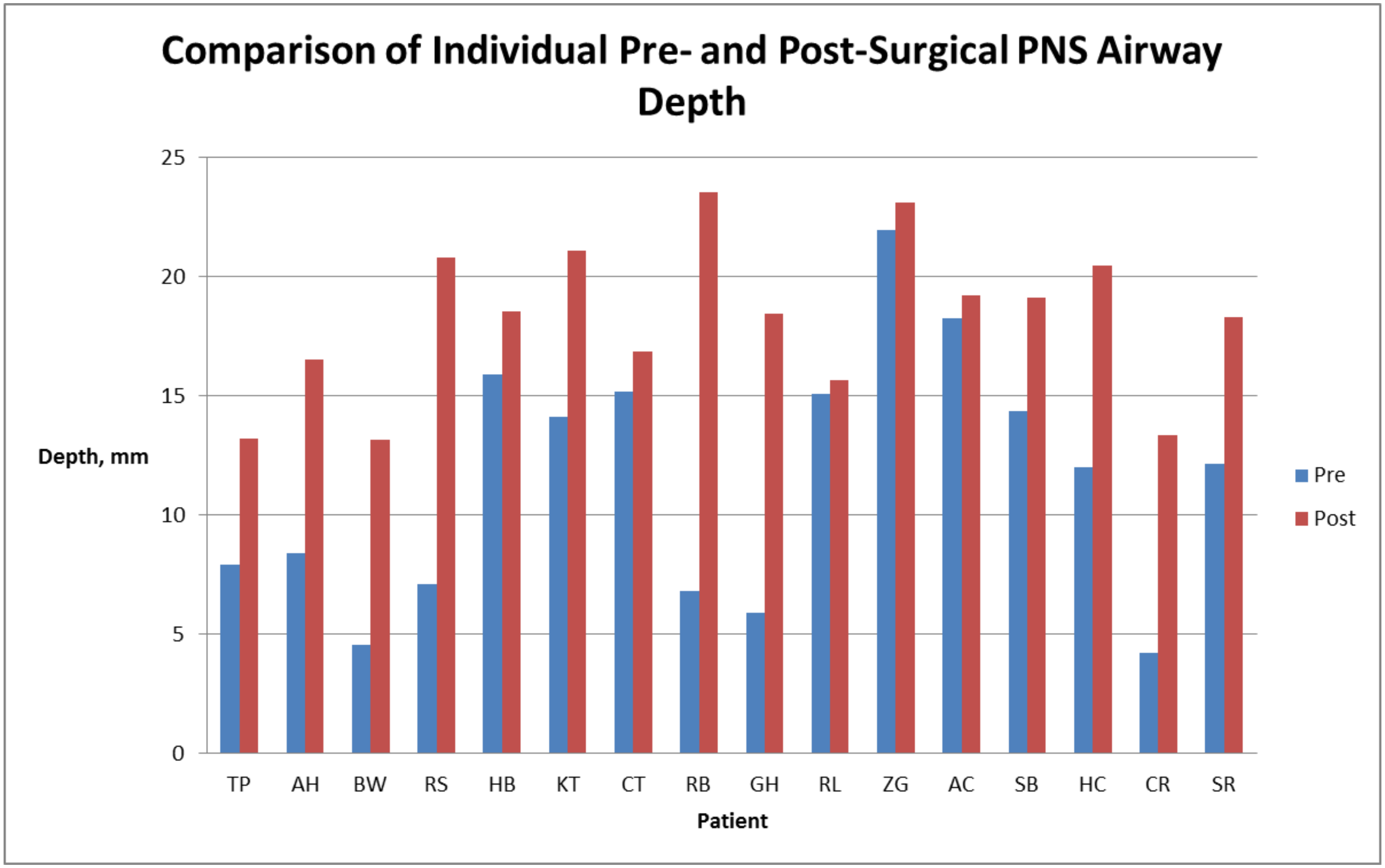


Figure 5.18: Individual comparisons of pre- and post-surgical airway depth at PNS.

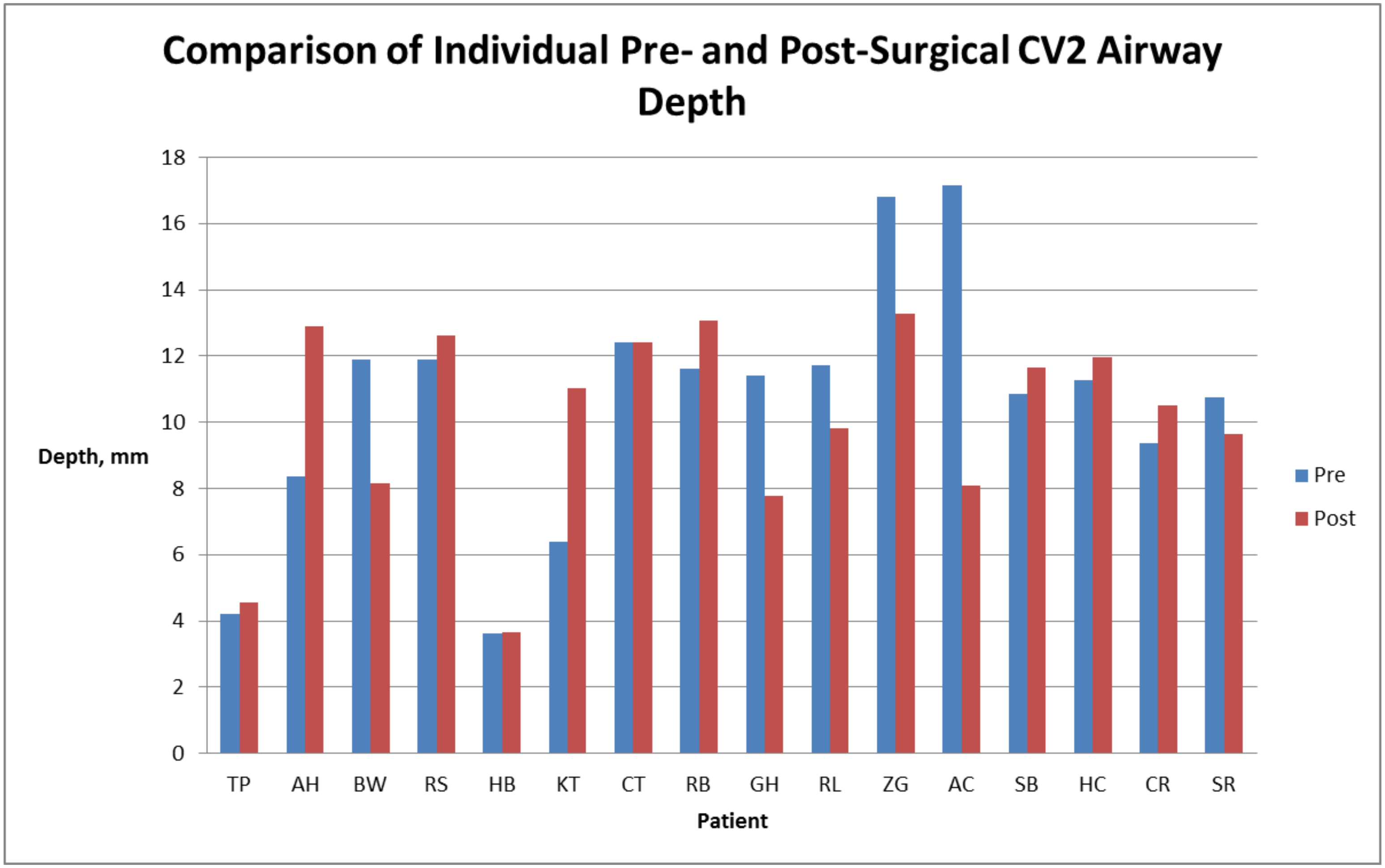


Figure 5.19: Individual comparisons of pre- and post-surgical airway depth at CV2.

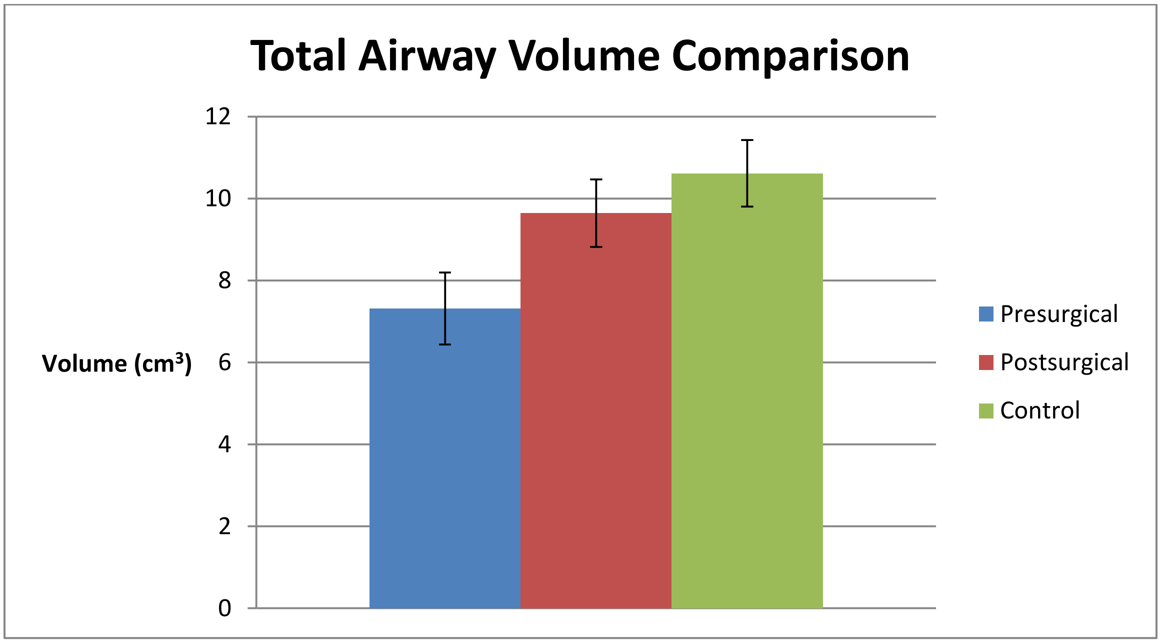


Figure 5.20: Comparison of total airway volume among pre-surgical, post-surgical and control groups.

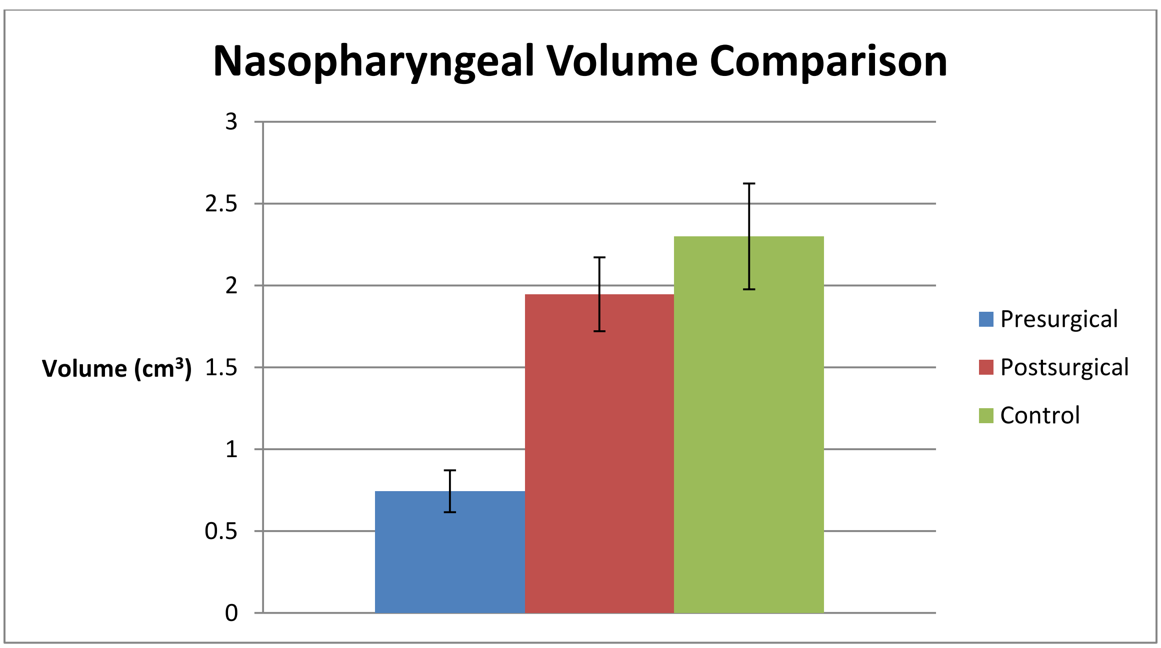


Figure 5.21: Comparison of nasopharyngeal volume among pre-surgical, post-surgical and control groups.

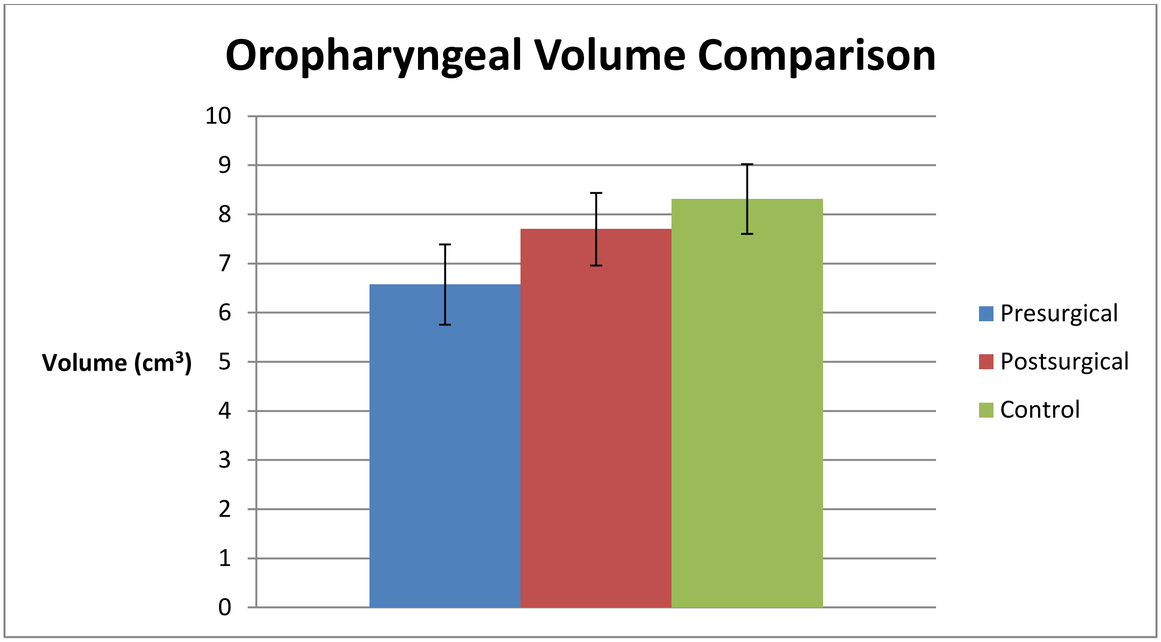


Figure 5.22: Comparison of oropharyngeal volume among pre-surgical, post-surgical and control groups.

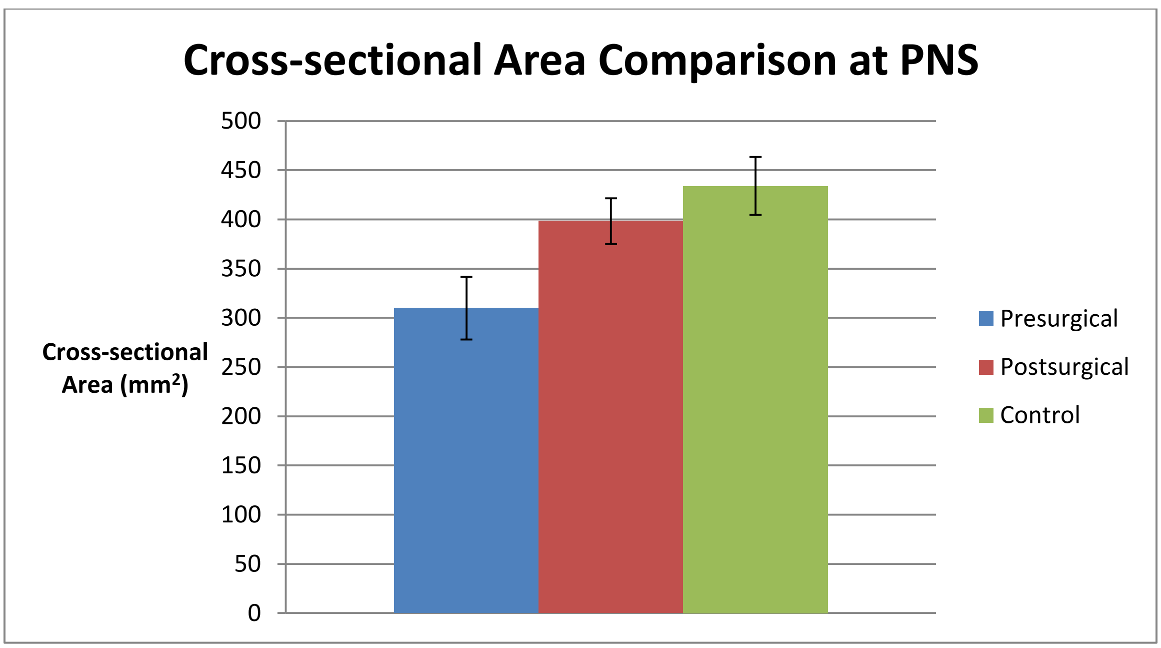


Figure 5.23: Comparison of cross-sectional area at PNS among pre-surgical, post-surgical and control groups.

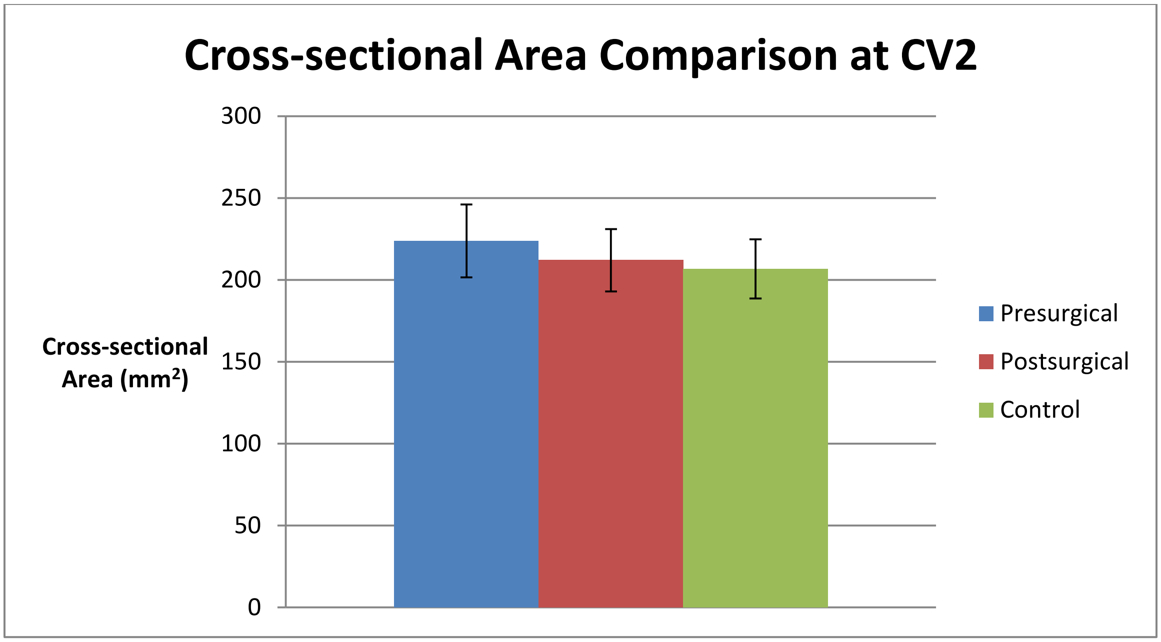


Figure 5.24: Comparison of cross-sectional area at CV2 among pre-surgical, post-surgical and control groups.

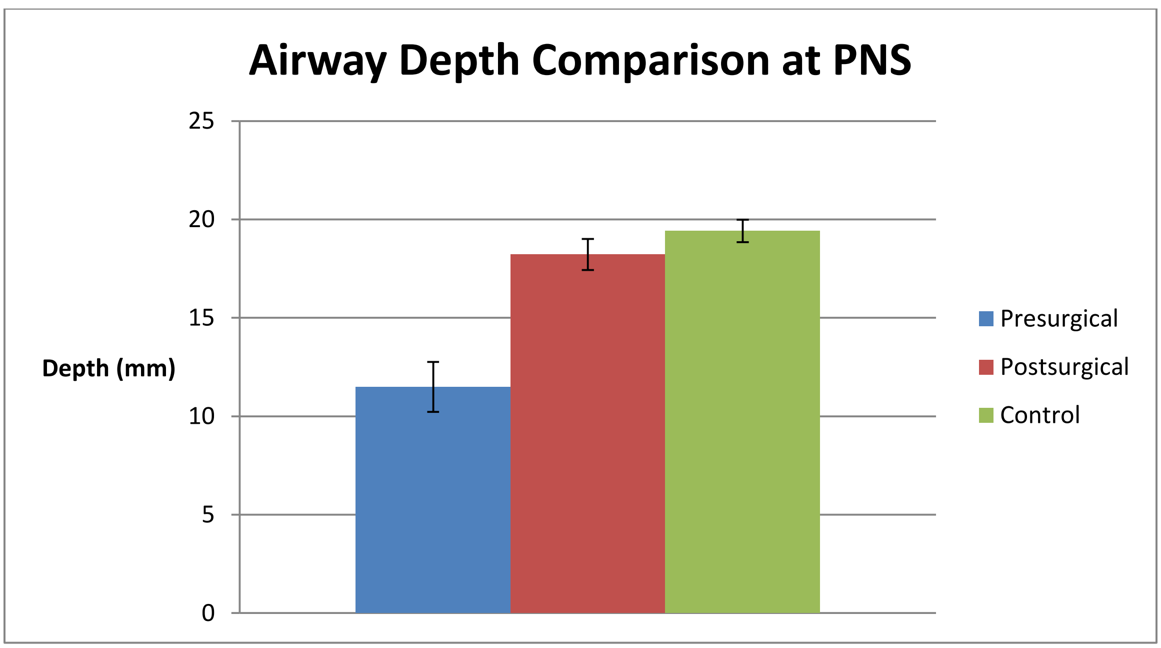


Figure 5.25: Comparison of airway depth at PNS among pre-surgical, post-surgical and control groups.

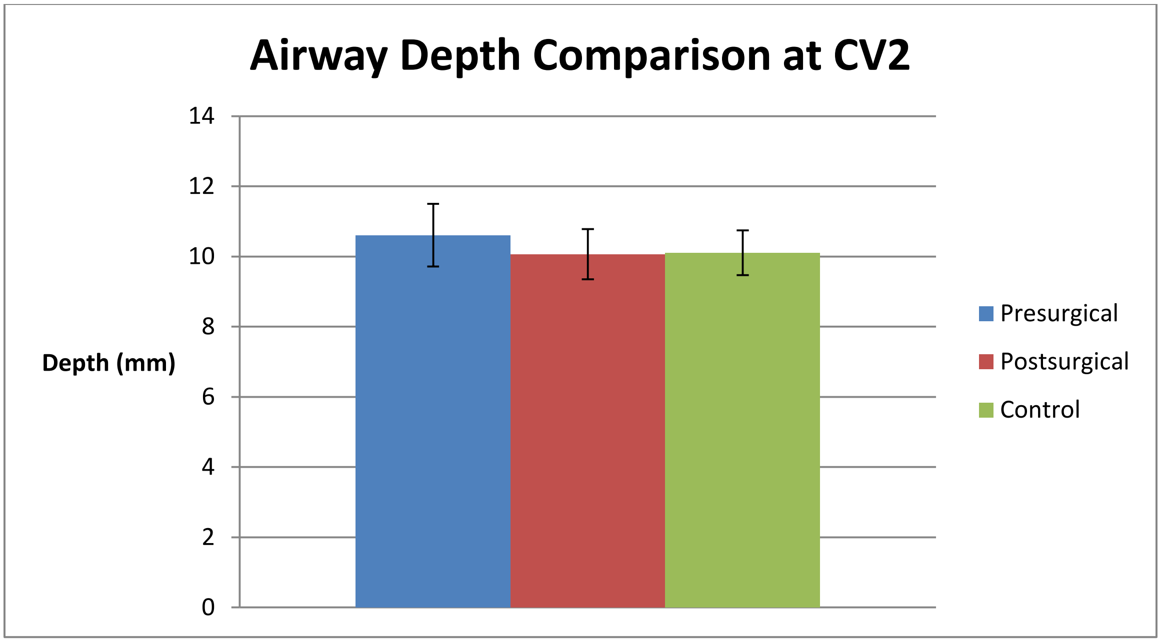


Figure 5.26: Comparison of airway depth at CV2 among pre-surgical, post-surgical and control groups.

Table 5.3: Number of patients in each adenoid hypertrophy grade for pre-surgical, post-surgical and control groups.

	Adenoid Hypertrophy Grade			
	None	Mild	Moderate	Severe
Pre-surgical	0	4	6	6
Post-surgical	16	0	0	0
Controls	2	12	1	0

CHAPTER 6: DISCUSSION

Many studies have been conducted examining the changes in patients following the surgical removal of hypertrophic adenoids. The studies have used measuring tools such as surveys, polysomnograph sleep studies and two-dimensional radiographs to evaluate the changes between pre- and post-surgical groups. Volsky et al reported that patients exhibited improved scores on quality of life (QOL) surveys following adenotonsillectomy (Volsky *et al,* 2014). Shen et al demonstrated that patients exhibited improvements in AHI score and lowest oxygen saturation percentage ($LSaO_2$) following surgery (Shen *et al,* 2015). In this study, CBCT images were used to measure the changes in the airway volume, cross-sectional areas and airway depths in patients following surgical removal of the adenoids.

6.1 Airway Volumes

6.1.1 Total Airway Volume

In this study, the total airway volume was defined as the airway volume between a plane connecting the posterior nasal spine (PNS) and sella turcica and a horizontal plane passing through the most anterior and inferior point of cervical vertebrae 3 (CV3). The mean total airway volume of a patient diagnosed with hypertrophic adenoids before having the adenoids surgically removed was 7.32 $cm^3 \pm 3.53$. After having the adenoids surgically removed, the patients mean total airway increased to 9.64 $cm^3 \pm 3.29$, resulting in an overall increase of 2.33 $cm^3 \pm 3.66$. Increase in total airway volume following adenoidectomy was observed in fourteen of the sixteen patients that received the surgical treatment. The overall increase was statistically significant ($p < 0.05$). The results of the study show that the removal of the adenoids does have an overall effect of increasing the total airway volume.

A separate control group that was not diagnosed with hypertrophic adenoids had an average total airway volume of 10.61 $cm^3 \pm 3.15$. T-test statistics demonstrated the total airway volumes of the control patients were significantly different from those of the pre-surgical patients ($p < 0.05$) but were not significantly different from patients after the adenoids were removed.

Figure 6.1 demonstrates the effect surgery can have on a patient. Panel A is the CBCT image of the patient pre-surgically, while Panel B is the post-operative scan. The patient was given the grade of severe adenoid hypertrophy and before surgery had a total airway volume of 4.81 cm^3. After the surgery, the total airway volume measured 9.09 cm^3, resulting in an overall increase of 4.28 cm^3.

6.1.2 Nasopharyngeal Airway Volume

The nasopharyngeal airway was defined as the airway space between a horizontal plane passing through PNS and a plane connecting PNS with sella turcica. The average nasopharyngeal airway volume for patients diagnosed with hypertrophic adenoids before surgical intervention was 0.74 $cm^3 \pm 0.51$, while the average post-surgical airway measured at 1.95 $cm^3 \pm 0.90$. This overall increase of 1.20 cm^3 was statistically significant ($p < 0.05$). Fifteen of the sixteen patients who received the surgical treatment experienced some degree of increase in nasopharyngeal airway volume following surgery.

The control group average nasopharyngeal airway volume was 2.30 $cm^3 \pm 1.25$. When compared to the control group, the pre-surgical group volume was statistically different than that of the control group. After the surgery, however, the post-surgical airway volume was found to not be statistically different from the control group ($p > 0.05$).

Figure 6.2 displays an example of a patient's scans in the study before and after having undergone surgery. The patient was given the grade of severe adenoid hypertrophy and before surgery had a nasopharynx airway volume of 0.143 cm^3 (Panel A). After the surgery, the nasopharynx volume measured 2.242 cm^3, resulting in an overall increase of 2.099 cm^3 (Panel B).

6.1.3 Oropharyngeal Volume

The oropharyngeal airway was defined as the airway space between a horizontal plane passing through PNS and a horizontal plane passing through cervical vertebrae 3 (CV3). Prior to adenoidectomy, test group patients had an average volume of 6.57 $cm^3 \pm 3.26$, while after surgery the average volume was measured at 7.70 $cm^3 \pm 2.95$. Thirteen of the sixteen patients in the treatment group did experience some degree of increase in the oropharyngeal airway volume, with the average increase being 1.13 $cm^3 \pm 3.54$. This change, however, was not statistically significant. The results of this study show that there is no significant difference in the oropharyngeal airway volume after removal of the adenoids.

The average oropharyngeal airway volume for the control group was measured at 8.31 $cm^3 \pm 2.75$. This was not significantly different from either the pre- or post-surgical oropharyngeal volumes. Based on this, it can be inferred that neither adenoid hypertrophy nor adenoidectomy has a significant effect on the oropharyngeal volume.

6.2 Airway Cross-sectional Areas

6.2.1 Cross-sectional Area at PNS

Cross-sectional area in the coronal plane was measured at the level of PNS. Twelve of the sixteen patients who underwent an adenoidectomy procedure experienced increases in the cross-sectional area at PNS. Prior to adenoidectomy, the average area was 309.98 $mm^2 \pm 127.77$. After surgery, the average cross-sectional area was 398.22 $mm^2 \pm 92.76$, resulting in an overall average increase of 88.23 $mm^2 \pm 129.57$. The change in cross-sectional area at PNS following surgery was statistically significant ($p < 0.05$). Reddy et al. also found that the cross-sectional area increases in the region of the nasopharynx following surgical removal of the adenoids. The study examined at the cross-sectional area in the sagittal plane, while in this study the cross-sectional area was measured in the coronal plane (Reddy *et al* 2012). This result is also in agreement with Mihaescu et al, who found an increase in cross-sectional area in the retropalatal pharynx near PNS (Mihaescu *et al*, 2008). The Mihaescu study, however, was a single case study, a sample size which is not large enough to result in statistically significant outcomes.

The average cross-sectional area at PNS of the control group measured 434.00 mm^2 ± 114.40. When compared with the control group measurements, the cross-sectional area at PNS was significantly decreased in pre-surgical patient scans. There was no difference between the control group and post-surgical group cross-sectional areas measurements at PNS.

Figure 6.3 demonstrates the cross-sectional area at PNS of a patient before and after adenoidectomy. The initial cross-sectional area was 167.02 mm^2, while the final cross-sectional area was 366.45 mm^2, resulting in an overall change of 199.43 mm^2.

6.2.2 Cross-sectional Area at CV2

Cross-sectional area in the coronal plane was measured at the level of CV2. Before adenoidectomy, the average area was 223.79 mm^2 ± 89.10. After surgery, the average cross-sectional area was 212.01 mm^2 ± 76.24, resulting in an overall change -11.78 mm^2 ± 89.57. The change in cross-sectional area at CV2 following surgery was not statistically significant ($p > 0.05$).

The average cross-sectional area at CV2 of the control group measured 206.72 mm^2 ± 69.57. When compared with the control group measurements, the cross-sectional area at CV2 was not significantly different in pre-surgical or post-surgical patient scans.

6.3 Airway Depths

6.3.1 Airway Depth at PNS

Airway depths were measured in the sagittal plane at the level of PNS. The average pre-surgical airway depth at PNS was 11.49 mm ± 5.08. The average airway depth following adenoid removal was 18.21 mm ± 3.16. The overall change in airway depth at PNS was 6.72 mm ± 4.66. Some degree of airway depth increase was seen in all sixteen patients in the treatment group and the amount of change between pre- and post-surgical airway depths at PNS was statistically significant ($p < 0.05$).

The average airway depth at PNS of the control group measured 19.42 mm ± 2.23. When compared with the control group measurements, the airway depth at PNS was significantly different in patients prior to surgery. Following surgery, there was no statistically significant difference between the control and treatment groups.

Figure 6.2 demonstrates the airway depth at PNS of a patient before and after adenoidectomy. The pre-surgical depth was 4.55 mm, while the post-surgical depth was 13.14 mm, resulting in an overall change of 8.59 mm.

6.3.2 Airway Depth at CV2

Airway depth was measured in the sagittal plane at the level of CV2. Before adenoidectomy, the average airway depth was 10.61 mm ± 3.58. After surgery, the average depth was 10.07 mm ± 2.86, resulting in an overall change -0.54 mm ± 3.25. The change in airway depth at CV2 following surgery was not statistically significant ($p > 0.05$).

The average airway depth at CV2 of the control group measured 10.11 mm ± 2.47. When compared with the control group measurements, the average depth at CV2 was not significantly different in pre-surgical or post-surgical patient scans.

6.4 Influence of Adenoid Hypertrophy

The degree of adenoid hypertrophy prior to surgery had a significant effect on the amount of change associated with the total airway volume, cross-sectional area at PNS, and airway depth at PNS. These results are in agreement with Shen et al. who observed greater surgical results in patients with increased hypertrophy grade. The Shen study used surveys and apnea hypopnea index (AHI) to measure the changes before and after surgery (Shen *et al*, 2015). Interestingly, in this study the results did not show a relationship between the amount of pre-surgical adenoid hypertrophy and the change in nasopharyngeal airway volume as one would expect. One possible explanation for this is the large ranges used in the grading scale for adenoid hypertrophy. It could be possible that a relationship could be present if a grading scale with more precise ranges for grades was used.

6.5 Study Limitations

A number of limitations could have affected the findings of the present study. The first such limitation was the number of patients available to be included in the study. The treatment group consisted of 16 patients who underwent adenoidectomy, while the control group consisted of 15 patients who were diagnosed with no to mild adenoid hypertrophy not requiring surgery. Because the study was retrospective in nature, it was not possible to increase the number of participants as all patients from a private orthodontic office who had had their adenoids removed were included in the study.

Another limitation was matching the control and treatment groups, most notably the ages of the participants. Control patients were typically patients who presented to the office in search of an orthodontist, and thus were typically in early to mid-adolescence with an age range of 8.50 – 17.83 years with a majority of patients in his or her middle to late teenage years. Conversely, the treatment group consisted of patients in many different stages of development with an age range of 2.58 – 16.67 years, with most patients under the age of 13.

Final limitations of the study were associated with the CBCT images and the inherent weaknesses that can be associated with the images. Cone beam CT imaging is a very useful tool to view areas of the head and neck in three dimensions, including the airway. The airway is, however, a dynamic structure that constantly changes depending on the positioning of structures including the mandible, tongue and neck. The cone beam takes a snapshot image of the airway, thus presenting the airway as a static structure. In this study, measures were taken to minimize the impact of positioning of structures on the airway. The same imaging parameters were used for pre- and post-surgical scans and the same operator took all scans. By having the same operator take all the scans, the patient received the same instructions for each scan and also was placed in their natural head position each time. Even with these control measures, the patient could have changed positions during the scan, resulting in possible changes in the airway.

6.6 Outliers

Possible outliers were noted in both the treatment group and control group. One patient was of a much younger age (2.58 years) than the rest of the patients in the treatment group. In addition, 2 patients experienced large decreases in the total airway volume and oropharyngeal airway volume after surgery. After examining the scans of these patients, it appeared that there could have been an inconsistency with the patients' positioning for the CBCT, leading to changes in the total and oropharyngeal airway volumes. Finally, one control patient was given an adenoid hypertrophy grade of moderate, while all other patients in the control group had either no hypertrophy or mild hypertrophy.

Statistical analyses were performed again with each possible outlier removed individually, and then with combinations of the outliers omitted. Based on the comparison of the initial statistics and recalculated statistics, the outlier due to a patient's younger age and the control outlier due to moderate adenoid hypertrophy had little effect on the results, as initial results and the recalculated results were in near agreement.

The outliers due to improper patient positioning appeared to have a significant effect on the statistics. By removing the two patients with the improper positioning, the p-values comparing pre- and post-surgical, as well as p-values comparing pre-surgical and controls, were reduced for the total airway volume and oropharyngeal airway volume. In fact, if the two outliers were omitted, the oropharyngeal volume becomes statistically significant when comparing the pre- and post-surgical patients, as well as the pre-surgical and control patients.

Figure 6.4 displays a comparison of the scans of one of the patients with inconsistent positioning. The pre-surgical total airway volume was 14.166 cm^3, while the post-surgical total airway volume was 6.611 cm^3, a decrease of 7.555 cm^3. This decrease in total airway volume can be attributed to a decrease in the oropharyngeal airway volume, which went from a pre-surgical measurement of 12.535 cm^3, to a post-surgical measurement of 3.609 cm^3, a decrease of 8.926 cm^3. The nasopharyngeal airway volume behaved as expected, having an overall increase of 1.371 cm^3.

Differences in the CBCT scans in Figure 6.4 are likely due to the positioning of the soft tissues, including the tongue. In the post-surgical scan, the tongue appears to be positioned in a more posterior position, pushing the soft tissues of the anterior pharynx posteriorly as well. This led to a narrowing of the airway in the oropharyngeal area.

While CBCT has been shown to be an accurate tool for representing the airway in 3-dimensions, the outliers demonstrate that even CBCT has its limitations. By representing the airway as a static object, the clinician is relying on the patient to correctly follow all directions and not move during the scan. In addition, by using pre- and post-surgical scans, the study relied on the patients' ability to repeat the same imaging position for each scan in order to obtain measurements that were as accurate as possible.

Because there are limitations associated with CBCT, it may be best to use CBCT scans in conjunction with additional tests that could account for the dynamic movements of the airway. These tests could include rhinomanometric tests that examine airflow and nasal resistance. Having these dynamic measurements, along with the CBCT scans would allow the clinicians to measure the volumetric and area changes, while also processing data that would assess how the respiratory process has changed as a result of the surgery.

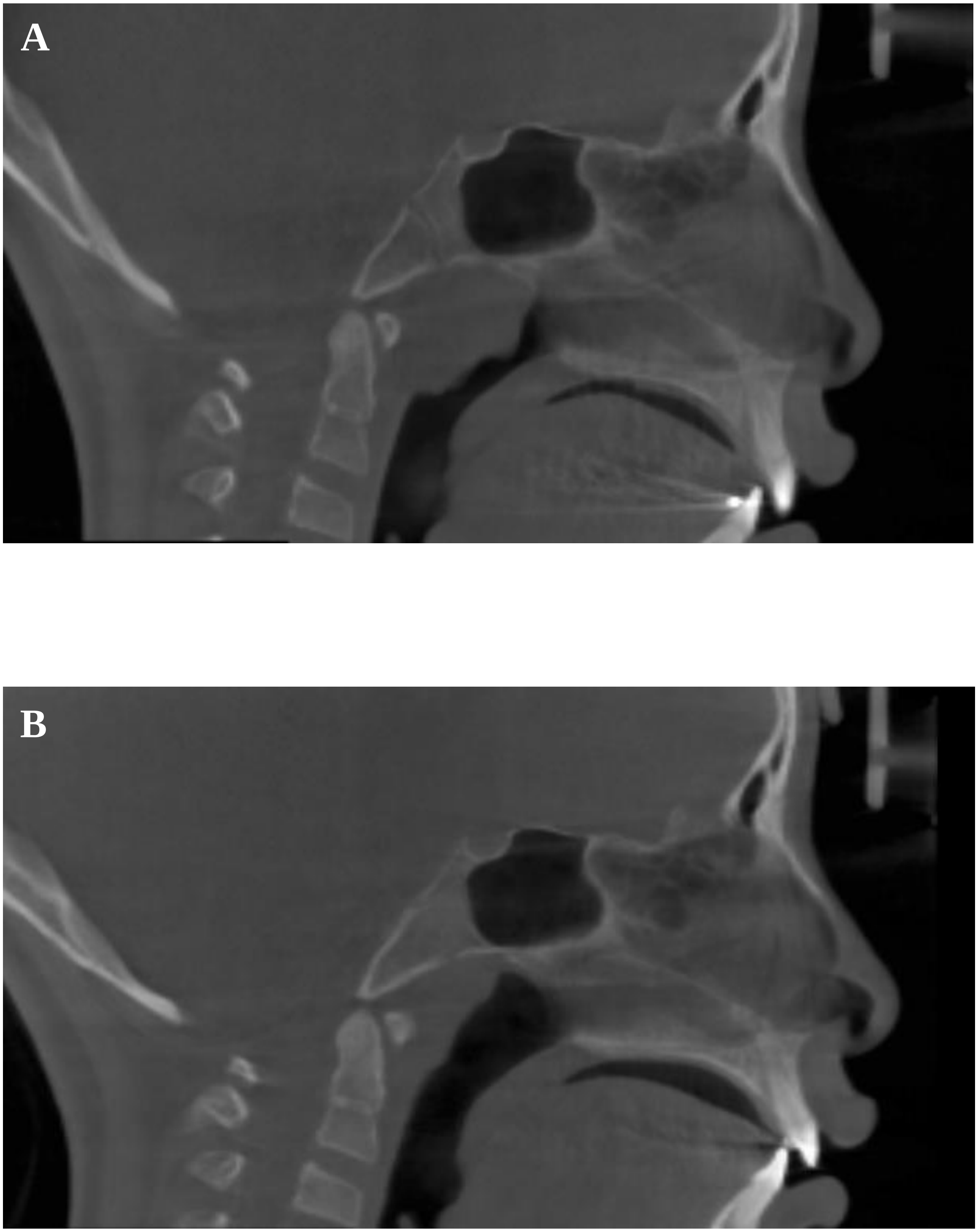
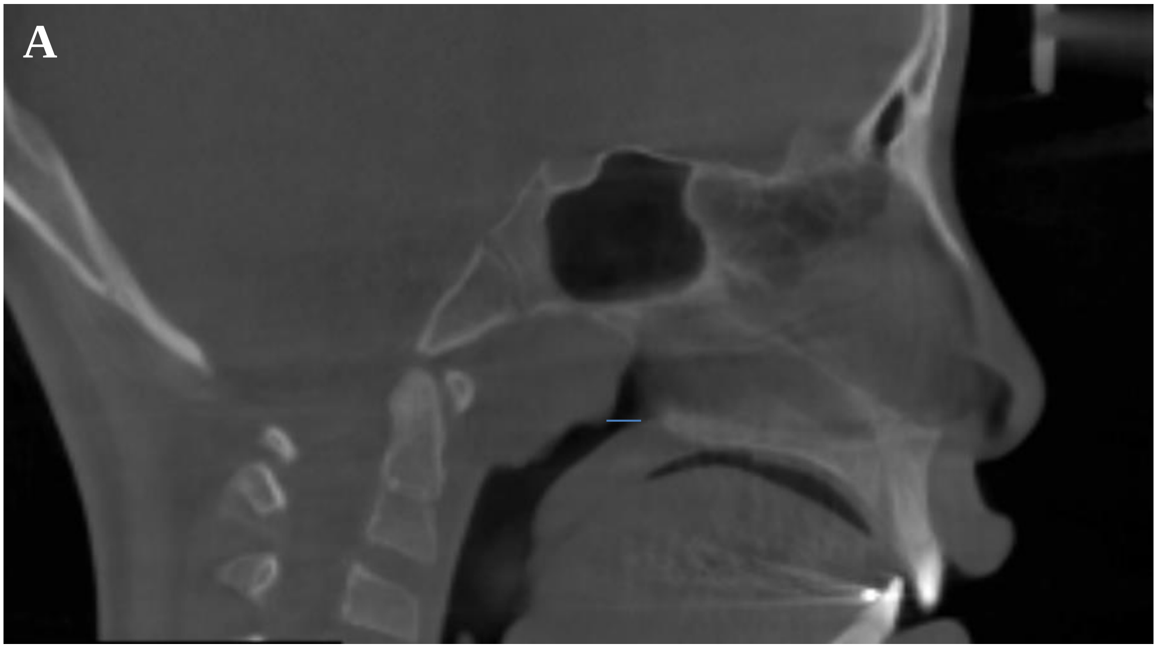


Figure 6.1A-B: Pre-surgical (A) and post-surgical (B) CBCT scans demonstrating increased total airway volume



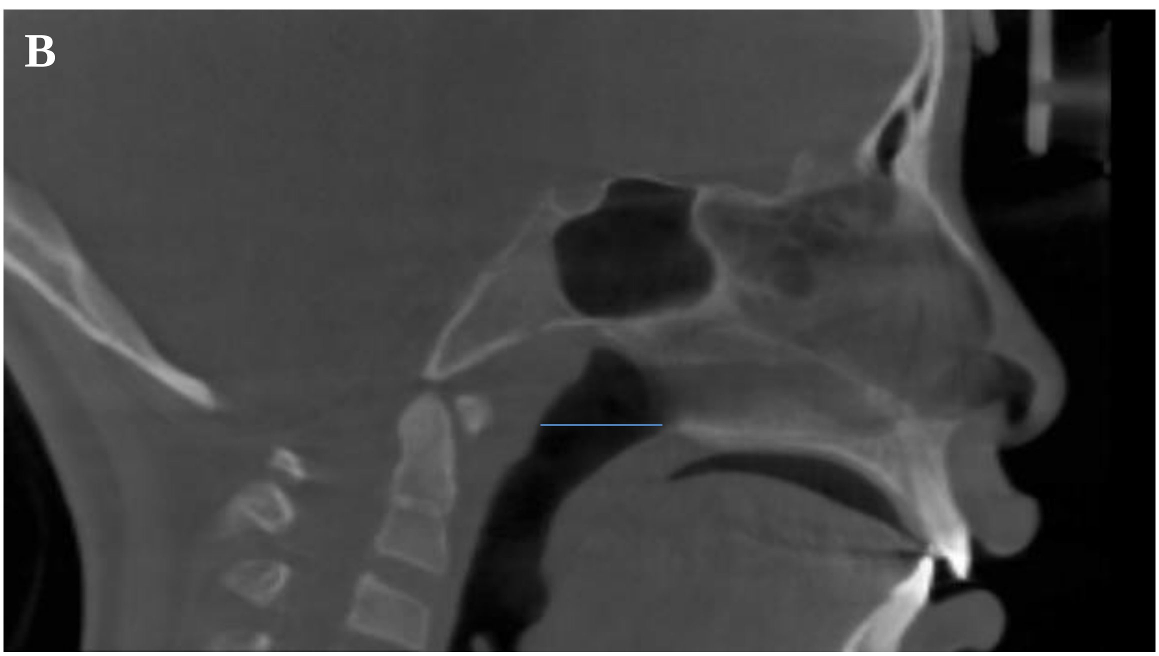


Figure 6.2A-B: Pre-surgical (A) and post-surgical (B) CBCT scan demonstrating increased nasopharyngeal airway volume. The nasopharyngeal space is found superior to the blue line at PNS and airway depths are represented by the blue lines.

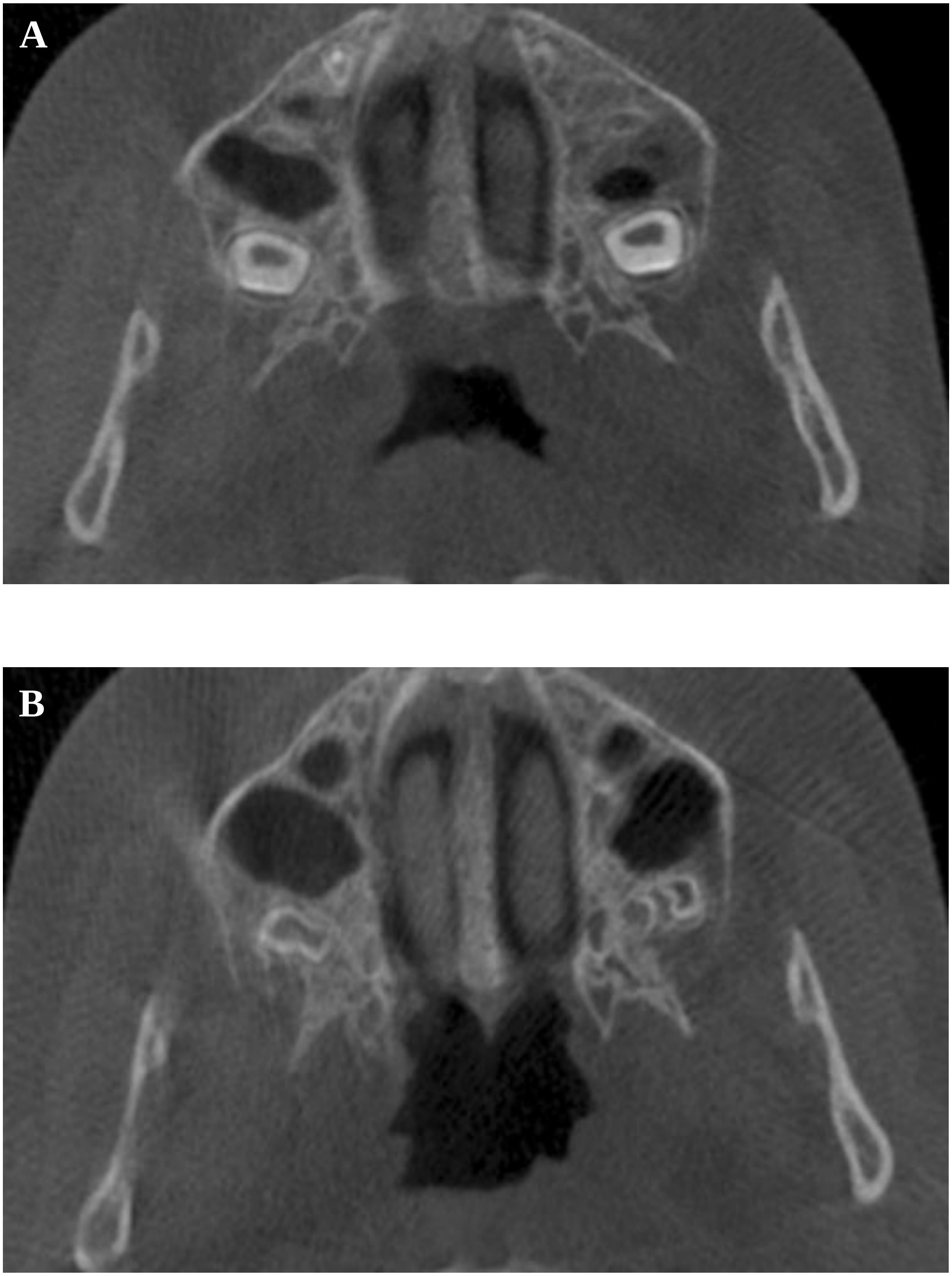


Figure 6.3A-B: Pre-surgical (A) and post-surgical (B) CBCT scans demonstrating cross-sectional area at the level of PNS

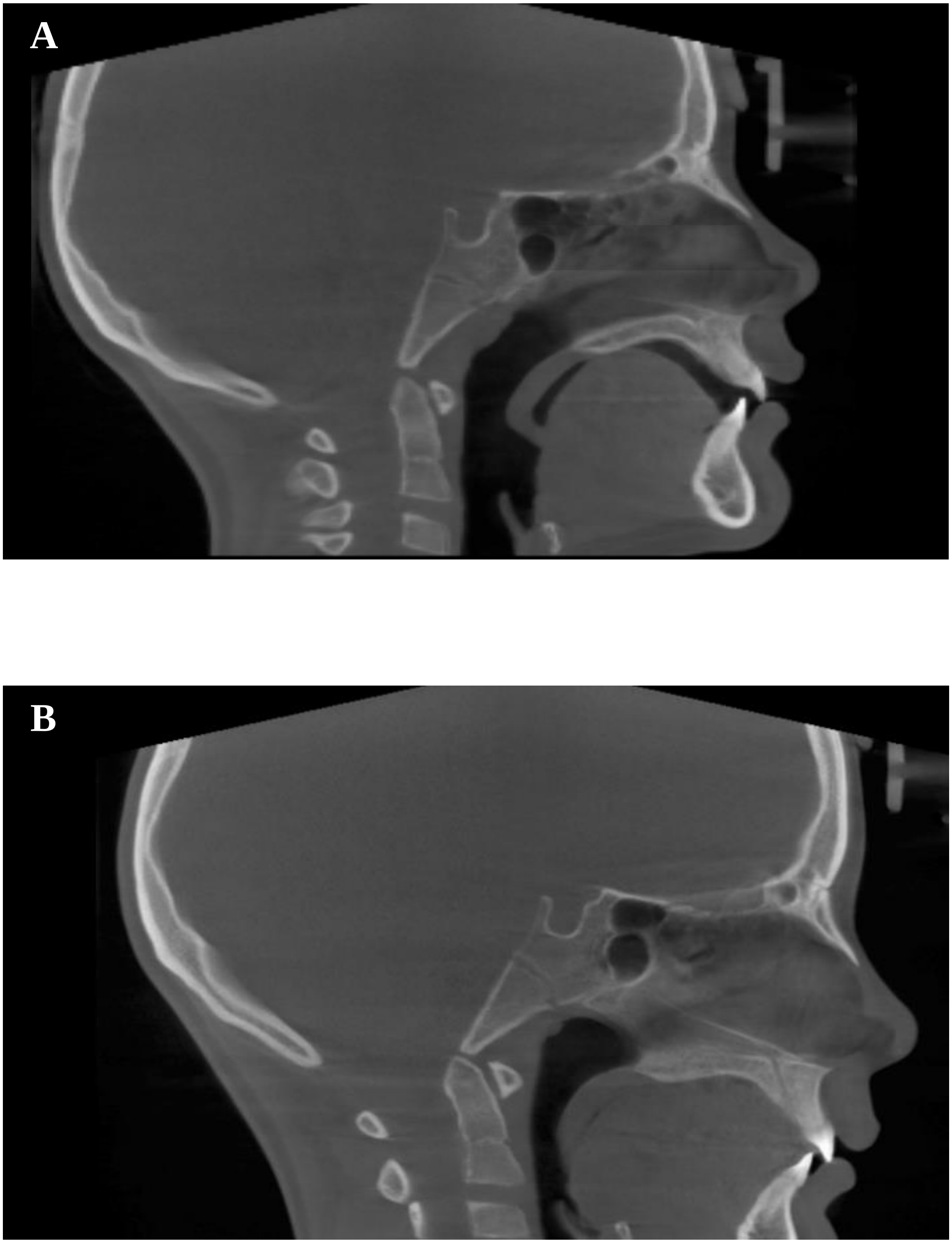


Figure 6.4a-b: Pre-surgical (A) and post-surgical (B) CBCT scans revealing decreased airway space due to positioning of soft tissues

Figure 6.5a-b: Pre-surgical (A) and post-surgical (B) scans demonstrating cross-sectional area at the level of CV2

CHAPTER 7: CONCLUSIONS

Surgical removal of the adenoids is often performed to increase the airway dimension. Results of this study found a significant increase in the total airway and nasopharyngeal airway volumes following surgery. An increase in the cross-sectional area at the level of PNS and the airway depth at PNS were also noted in the study. The airway volume of the oropharynx, cross-sectional area at CV2 and airway depth at CV2 did not reveal significant changes following adenoidectomy.

The amount of change that occurs in the total airway volume, cross-sectional area at PNS, and airway depth at PNS was found to increase with an increasing grade of adenoid hypertrophy. The study did not, however, find a correlation between the amount of adenoid hypertrophy and the change in nasopharyngeal airway volume. No correlations were found for any variables with regards to patient age and sex.

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APPENDIX A: Experimental Data

Table A.1: Data from pre-surgical Patients

Patient	Age	Sex	AH Grade	Total Airway Volume	Nasopharynx Volume	Oropharynx Volume	Area at PNS	Area at C2	Width at PNS	Width @ C2
1	5.42	M	3	2.364	0.417	1.947	184.35	137.06	7.92	4.22
2	2.58	M	2	2.735	0.993	1.742	114.91	134.49	8.4	8.36
3	9.42	F	3	4.81	0.143	4.667	167.02	303.41	4.55	11.9
4	10.17	F	3	4.1	0.791	3.309	198.78	106.14	7.09	11.89
5	16.67	F	2	4.386	0.701	3.685	270.37	127.47	15.89	3.63
6	11.83	F	1	8.948	1.554	7.394	515.74	133.33	14.12	6.38
7	16.50	M	1	9.838	1.069	8.769	445.24	268.33	15.16	12.42
8	11.67	F	3	7.82	0.087	7.733	241.06	248.55	6.82	11.62
9	14.25	F	3	6.685	0.282	6.403	305.21	146.09	5.87	11.41
10	12.08	F	2	6.247	0.941	5.306	397.94	265.08	15.09	11.71
11	7.08	F	1	14.886	1.645	13.241	509	385.53	21.96	16.82
12	8.08	F	1	14.166	1.631	12.535	511.42	378.13	18.24	17.14
13	11.08	F	3	6.249	0.449	5.8	192.45	266.54	14.37	10.84
14	10.50	F	2	10.644	0.427	10.217	326.46	312.85	12.02	11.26
15	12.83	F	2	6.359	0.127	6.232	241	201.29	4.2	9.38
16	10.75	M	2	6.82	0.646	6.174	338.82	166.33	12.13	10.74
Average	10.68		2.13	7.32	0.74	6.57	309.99	223.79	11.49	10.61
St D	3.591		0.78	3.53	0.51	3.26	127.77	89.10	5.08	3.58

Table A.2: Data from post-surgical Patients

Patient	Age	Sex	AH Grade	Total Airway Volume	Nasopharynx Volume	Oropharynx Volume	Area at PNS	Area at C2	Width at PNS	Width @ C2
1	6.75	M	0	6.302	1.195	5.107	187.82	78.33	13.22	4.57
2	2.75	M	0	5.28	1.388	3.892	201.5	193.48	16.53	12.89
3	10.08	F	0	9.09	2.242	6.848	366.45	225.96	13.14	8.15
4	10.75	F	0	9.011	2.622	6.389	441.42	163.06	20.81	12.62
5	17.50	F	0	5.7	1.269	4.431	416.75	148.1	18.54	3.64
6	12.25	F	0	12.861	2.839	10.022	485.66	202.84	21.06	11.01
7	16.75	M	0	15.172	3.027	12.145	428.73	301.73	16.87	12.41
8	12.17	F	0	11.587	2.938	8.649	477.07	282.22	23.55	13.06
9	15.25	F	0	10.871	2.812	8.059	491.88	161.01	18.45	7.78
10	12.58	F	0	7.232	0.752	6.48	402.38	237.54	15.67	9.81
11	7.92	F	0	12.965	2.782	10.183	419.32	284.67	23.12	13.28
12	8.83	F	0	6.611	3.002	3.609	309.15	91.3	19.22	8.08
13	11.67	F	0	16.038	1.369	14.669	475.63	375.09	19.12	11.64
14	11.17	F	0	10.986	1.433	9.553	463.57	271.94	20.47	11.96
15	13.42	F	0	6.607	0.137	6.47	334.1	204.01	13.35	10.51
16	11.17	M	0	8.005	1.329	6.676	470.05	170.9	18.3	9.64
Average	11.31		0	9.64	1.95	7.70	398.22	212.01	18.21	10.07
St D	3.58		0	3.29	0.90	2.95	92.76	76.24	3.16	2.86

Table A.3: Data from control patients

Patient	Age	Sex	AH Grade	Total Airway Volume	Nasopharynx Volume	Oropharynx Volume	Area at PNS	Area at C2	Width at PNS	Width @ C2
1	14.75	M	1	14.966	4.447	10.519	425.73	242.13	19.73	10.66
2	8.50	M	1	7.35	1.826	5.524	268.33	111.86	18.07	10.38
3	8.67	F	1	9.677	2.953	6.724	487.72	178.98	20.47	10.82
4	12.00	F	1	10.13	1.225	8.905	469.94	213.44	17.66	10.12
5	17.83	F	1	9.137	3.08	6.057	312.93	130.56	20.24	7.49
6	13.58	M	1	10.421	2.936	7.485	489.14	189.48	21.95	8.58
7	15.00	M	0	14.357	1.006	13.351	438.38	309.35	16.97	10.26
8	13.42	M	1	8.508	0.71	7.798	294.02	203.43	15.18	14.16
9	13.42	M	1	8.488	0.889	7.599	411.26	202.7	16.03	11.69
10	9.42	F	1	10.997	0.966	10.031	397.05	258.65	19.7	12.07
11	8.17	M	1	6.212	2.09	4.122	270.56	119.72	18.63	6.49
12	14.67	M	1	7.346	1.264	6.082	550.96	191.39	20.7	7.73
13	13.00	F	1	15.225	2.918	12.307	544.58	381.06	22.35	15.33
14	12.58	F	2	9.437	3.742	5.695	445.86	145.64	20.39	6.68
15	17.83	F	0	16.959	4.443	12.516	703.56	222.41	23.17	9.21
Average	12.86		0.93	10.61	2.30	8.31	434.00	206.72	19.42	10.11
St D	2.98		0.44	3.15	1.25	2.75	114.40	69.57	2.23	2.47

APPENDIX B: Statistical Tests

Table B.1: T-test comparing pre- and post-surgical total airway volume

t-Test: Paired Two Sample for Means

	Variable 1	*Variable 2*
Mean	7.3160625	9.644875
Variance	13.27584273	11.55364025
Observations	16	16
Pearson Correlation	0.426453096	
Hypothesized Mean Difference	0	
Df	15	
t Stat	-2.466253438	
P(T<=t) one-tail	0.013095472	
t Critical one-tail	1.753050356	
P(T<=t) two-tail	0.026190943	
t Critical two-tail	2.131449546	

Table B.2: T-test comparing pre- and post-surgical nasopharyngeal airway volume

t-Test: Paired Two Sample for Means

	Variable 1	*Variable 2*
Mean	0.7439375	1.946
Variance	0.277079529	0.871150133
Observations	16	16
Pearson Correlation	0.403904277	
Hypothesized Mean Difference	0	
Df	15	
t Stat	-5.547093075	
P(T<=t) one-tail	2.79524E-05	
t Critical one-tail	1.753050356	
P(T<=t) two-tail	5.59047E-05	
t Critical two-tail	2.131449546	

Table B.3: T-test comparing pre- and post-surgical oropharyngeal airway volume

t-Test: Paired Two Sample for Means

	Variable 1	*Variable 2*
Mean	6.572125	7.698875
Variance	11.33341078	9.299112383
Observations	16	16
Pearson Correlation	0.352932644	
Hypothesized Mean Difference	0	
Df	15	
t Stat	-1.231857035	
P(T<=t) one-tail	0.118482579	
t Critical one-tail	1.753050356	
P(T<=t) two-tail	0.236965159	
t Critical two-tail	2.131449546	

Table B.4: T-test comparing pre- and post-surgical cross-sectional area at PNS

t-Test: Paired Two Sample for Means

	Variable 1	*Variable 2*
Mean	309.985625	398.2175
Variance	17414.07949	9178.787887
Observations	16	16
Pearson Correlation	0.343513866	
Hypothesized Mean Difference	0	
df	15	
t Stat	-2.637394241	
P(T<=t) one-tail	0.009327592	
t Critical one-tail	1.753050356	
P(T<=t) two-tail	0.018655184	
t Critical two-tail	2.131449546	

Table B.5: T-test comparing pre- and post-surgical cross-sectional area at CV2

t-Test: Paired Two Sample for Means

	Variable 1	*Variable 2*
Mean	223.78875	212.01125
Variance	8468.322532	6199.732785
Observations	16	16
Pearson Correlation	0.421652446	
Hypothesized Mean Difference	0	
Df	15	
t Stat	0.509255545	
P(T<=t) one-tail	0.308991178	
t Critical one-tail	1.753050356	
P(T<=t) two-tail	0.617982357	
t Critical two-tail	2.131449546	

Table B.6: T-test comparing pre- and post-surgical airway depth at PNS

t-Test: Paired Two Sample for Means

	Variable 1	*Variable 2*
Mean	11.489375	18.21375
Variance	27.54853958	10.66203833
Observations	16	16
Pearson Correlation	0.43909763	
Hypothesized Mean Difference	0	
Df	15	
t Stat	-5.589140381	
P(T<=t) one-tail	2.58442E-05	
t Critical one-tail	1.753050356	
P(T<=t) two-tail	5.16883E-05	
t Critical two-tail	2.131449546	

Table B.7: T-test comparing pre- and post-surgical airway depth at CV2

t-Test: Paired Two Sample for Means

	Variable 1	*Variable 2*
Mean	10.6075	10.065625
Variance	13.67778	8.73510625
Observations	16	16
Pearson Correlation	0.509650759	
Hypothesized Mean Difference	0	
Df	15	
t Stat	0.645610953	
P(T<=t) one-tail	0.264142297	
t Critical one-tail	1.753050356	
P(T<=t) two-tail	0.528284594	
t Critical two-tail	2.131449546	

Table B.8: T-test comparing pre-surgical and control group total airway volume

t-Test: Two-Sample Assuming Equal Variances

	Variable 1	*Variable 2*
Mean	7.3160625	10.614
Variance	13.27584273	10.64282543
Observations	16	15
Pooled Variance	12.00473093	
Hypothesized Mean Difference	0	
Df	29	
t Stat	-2.64844513	
P(T<=t) one-tail	0.006472727	
t Critical one-tail	1.699127027	
P(T<=t) two-tail	0.012945455	
t Critical two-tail	2.045229642	

Table B.9: T-test comparing post-surgical and control group total airway volume

t-Test: Two-Sample Assuming Equal Variances

	Variable 1	*Variable 2*
Mean	9.644875	10.614
Variance	11.55364025	10.64282543
Observations	16	15
Pooled Variance	11.11393654	
Hypothesized Mean Difference	0	
df	29	
t Stat	-0.808854888	
P(T<=t) one-tail	0.212592559	
t Critical one-tail	1.699127027	
P(T<=t) two-tail	0.425185119	
t Critical two-tail	2.045229642	

Table B.10: T-test comparing pre-surgical and control group nasopharyngeal airway volume

t-Test: Two-Sample Assuming Equal Variances

	Variable 1	*Variable 2*
Mean	0.7439375	2.299666667
Variance	0.277079529	1.683811381
Observations	16	15
Pooled Variance	0.956191458	
Hypothesized Mean Difference	0	
df	29	
t Stat	-4.42676368	
P(T<=t) one-tail	6.21449E-05	
t Critical one-tail	1.699127027	
P(T<=t) two-tail	0.00012429	
t Critical two-tail	2.045229642	

Table B.11: T-test comparing post-surgical and control group nasopharyngeal airway volume

t-Test: Two-Sample Assuming Equal Variances

	Variable 1	*Variable 2*
Mean	1.946	2.299666667
Variance	0.871150133	1.683811381
Observations	16	15
Pooled Variance	1.263469356	
Hypothesized Mean Difference	0	
df	29	
t Stat	-0.875460481	
P(T<=t) one-tail	0.194258545	
t Critical one-tail	1.699127027	
P(T<=t) two-tail	0.38851709	
t Critical two-tail	2.045229642	

Table B.12: T-test comparing pre-surgical and control group oropharyngeal airway volume

t-Test: Two-Sample Assuming Equal Variances

	Variable 1	*Variable 2*
Mean	6.572125	8.314333333
Variance	11.33341078	8.101173952
Observations	16	15
Pooled Variance	9.773020589	
Hypothesized Mean Difference	0	
df	29	
t Stat	-1.550638111	
P(T<=t) one-tail	0.06591712	
t Critical one-tail	1.699127027	
P(T<=t) two-tail	0.13183424	
t Critical two-tail	2.045229642	

Table B.13: T-test comparing post-surgical and control group oropharyngeal airway volume

t-Test: Two-Sample Assuming Equal Variances

	Variable 1	*Variable 2*
Mean	7.698875	8.314333333
Variance	9.299112383	8.101173952
Observations	16	15
Pooled Variance	8.720797279	
Hypothesized Mean Difference	0	
df	29	
t Stat	-0.57988962	
P(T<=t) one-tail	0.283233777	
t Critical one-tail	1.699127027	
P(T<=t) two-tail	0.566467555	
t Critical two-tail	2.045229642	

Table B.14: T-test comparing pre-surgical and control group cross-sectional area at PNS

t-Test: Two-Sample Assuming Equal Variances

	Variable 1	*Variable 2*
Mean	309.985625	434.0013333
Variance	17414.07949	14022.16343
Observations	16	15
Pooled Variance	15776.60277	
Hypothesized Mean Difference	0	
df	29	
t Stat	-2.747228142	
P(T<=t) one-tail	0.00511159	
t Critical one-tail	1.699127027	
P(T<=t) two-tail	0.010223179	
t Critical two-tail	2.045229642	

Table B.15: T-test comparing post-surgical and control group cross-sectional area at PNS

t-Test: Two-Sample Assuming Equal Variances

	Variable 1	*Variable 2*
Mean	398.2175	434.0013333
Variance	9178.787887	14022.16343
Observations	16	15
Pooled Variance	11516.96918	
Hypothesized Mean Difference	0	
df	29	
t Stat	-0.927774718	
P(T<=t) one-tail	0.180591207	
t Critical one-tail	1.699127027	
P(T<=t) two-tail	0.361182414	
t Critical two-tail	2.045229642	

Table B.16: T-test comparing pre-surgical and control group cross-sectional area at CV2

t-Test: Two-Sample Assuming Equal Variances

	Variable 1	*Variable 2*
Mean	223.78875	206.72
Variance	8468.322532	5185.466443
Observations	16	15
Pooled Variance	6883.495454	
Hypothesized Mean Difference	0	
df	29	
t Stat	0.57242946	
P(T<=t) one-tail	0.285721306	
t Critical one-tail	1.699127027	
P(T<=t) two-tail	0.571442612	
t Critical two-tail	2.045229642	

Table B.17: T-test comparing post-surgical and control group cross-sectional area at CV2

t-Test: Two-Sample Assuming Equal Variances

	Variable 1	*Variable 2*
Mean	212.01125	206.72
Variance	6199.732785	5185.466443
Observations	16	15
Pooled Variance	5710.086965	
Hypothesized Mean Difference	0	
df	29	
t Stat	0.19483263	
P(T<=t) one-tail	0.423441263	
t Critical one-tail	1.699127027	
P(T<=t) two-tail	0.846882527	
t Critical two-tail	2.045229642	

Table B.18: T-test comparing pre-surgical and control group airway depth at PNS

t-Test: Two-Sample Assuming Equal Variances

	Variable 1	*Variable 2*
Mean	11.489375	19.416
Variance	27.54853958	5.328082857
Observations	16	15
Pooled Variance	16.82142254	
Hypothesized Mean Difference	0	
df	29	
t Stat	-5.37751619	
P(T<=t) one-tail	4.44305E-06	
t Critical one-tail	1.699127027	
P(T<=t) two-tail	8.8861E-06	
t Critical two-tail	2.045229642	

Table B.19: T-test comparing post-surgical and control group airway depth at PNS

t-Test: Two-Sample Assuming Equal Variances

	Variable 1	*Variable 2*
Mean	18.21375	19.416
Variance	10.66203833	5.328082857
Observations	16	15
Pooled Variance	8.087025345	
Hypothesized Mean Difference	0	
df	29	
t Stat	-1.176319124	
P(T<=t) one-tail	0.124516741	
t Critical one-tail	1.699127027	
P(T<=t) two-tail	0.249033482	
t Critical two-tail	2.045229642	

Table B.20: T-test comparing pre-surgical and control group airway depth at CV2

t-Test: Two-Sample Assuming Equal Variances

	Variable 1	*Variable 2*
Mean	10.6075	10.11133333
Variance	13.67778	6.531426667
Observations	16	15
Pooled Variance	10.22781632	
Hypothesized Mean Difference	0	
df	29	
t Stat	0.431678976	
P(T<=t) one-tail	0.334583621	
t Critical one-tail	1.699127027	
P(T<=t) two-tail	0.669167243	
t Critical two-tail	2.045229642	

Table B.21: T-test comparing post-surgical and control group airway depth at CV2

t-Test: Two-Sample Assuming Equal Variances

	Variable 1	*Variable 2*
Mean	10.065625	10.11133333
Variance	8.73510625	6.531426667
Observations	16	15
Pooled Variance	7.671260934	
Hypothesized Mean Difference	0	
df	29	
t Stat	-0.045918404	
P(T<=t) one-tail	0.481845018	
t Critical one-tail	1.699127027	
P(T<=t) two-tail	0.963690037	
t Critical two-tail	2.045229642	

Table B.22: Pearson correlation for total airway volume

Total Airway Volume

Pearson Correlation Coefficients, N = 10
Prob > |r| under H0: Rho=0

	TAV1	**TAV2**
TAV1	1.00000	0.99817 <.0001
TAV2	0.99817 <.0001	1.00000

Table B.23: Pearson correlation for nasopharyngeal airway volume

Nasopharyngeal Airway Volume

Pearson Correlation Coefficients, N = 10 Prob > |r| under H0: Rho=0		
	NPV1	**NPV2**
NPV1	1.00000	0.98761 <.0001
NPV2	0.98761 <.0001	1.00000

Table B.24: Pearson correlation for oropharyngeal airway volume

Oropharyngeal Airway Volume

Pearson Correlation Coefficients, N = 10 Prob > |r| under H0: Rho=0		
	OPV1	**OPV2**
OPV1	1.00000	0.99657 <.0001
OPV2	0.99657 <.0001	1.00000

Table B.25: Pearson correlation for cross-sectional area at PNS

Cross-sectional Area at PNS

Pearson Correlation Coefficients, N = 10 Prob > |r| under H0: Rho=0		
	AP1	**AP2**
AP1	1.00000	0.98446 <.0001
AP2	0.98446 <.0001	1.00000

Table B.26: Pearson correlation for cross-sectional area at CV2

Cross-sectional area at CV2

Pearson Correlation Coefficients, N = 10 Prob > |r| under H0: Rho=0		
	AC1	**AC2**
AC1	1.00000	0.99841 <.0001
AC2	0.99841 <.0001	1.00000

Table B.27: Pearson correlation for airway depth at PNS

Airway Depth at PNS

Pearson Correlation Coefficients, N = 10 Prob > |r| under H0: Rho=0		
	WP1	**WP2**
WP1	1.00000	0.97964 <.0001
WP2	0.97964 <.0001	1.00000

Table B.28: Pearson correlation for airway depth at CV2

Airway Depth at CV2

Pearson Correlation Coefficients, N = 10 Prob > |r| under H0: Rho=0		
	WC1	**WC2**
WC1	1.00000	0.99743 <.0001
WC2	0.99743 <.0001	1.00000