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EFFECT OF SUPINE AND UPRIGHT POSITIONS ON AIRWAY DIMENSIONS IN PATIENTS WITH OBSTRUCTIVE SLEEP APNEA

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ABSTRACT

Effect of supine and upright positions on airway dimensions in patients with obstructive sleep apnea

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AIM: The aim of the study was to assess the effect of supine vs upright imaging positions on airway dimensions in patients with obstructive sleep apnea (OSA).

MATERIALS AND METHODS: This retrospective study included three-dimensional (3D) data of 30 subjects diagnosed with OSA. Patients' ages ranged from 26 to 60 years (35.7 ± 2.3 years). Subjects were scanned with a low-dose multiplanar CT scanner in a supine position using X-vision EX, (Toshiba Medical Systems, Otawara-Shi, Japan) at a voxel size of 0.4 mm and a second scan in an upright position using iCAT CBCT scanner (Imaging Sciences International, Hartfield, PA) at the same voxel size. Airway volume was measured at the level of the nasal cavity, nasopharynx, oropharynx, and hypopharynx using Dolphin imaging software (version 11.5; Patterson Dental Supply, Chatsworth, CA). The differences in the measurements in both positions were compared using Student's t-test and $p \leq 0.05$ was considered statistically significant.

RESULTS: Significant statistical differences were reported between the measurements at the two positions. The nasopharynx and oropharynx area were significantly less when measured at the supine position. The airway volume measured at the nasal cavity and hypopharynx did not show significant differences between both positions.

CONCLUSION: The patient's position during the imaging session significantly affects the airway measurements. Airway volume measurement recorded when patient scanned in supine position shows less values than those recorded with upright scanning position.

DEDICATION

I wholeheartedly dedicate this thesis to my Mother, Fatma Ali, for always being there for me, encouraging and supporting me for as long as I can remember and continues to do so. For consistently reminding me that there is a solution for every problem and always pushing me to be the best version of myself- Thank You.

DECLARATION

I hereby declare that the dissertation entitled "EFFECT OF SUPINE AND UPRIGHT POSITIONS ON AIRWAY DIMENSIONS IN PATIENTS WITH OBSTRUCTIVE SLEEP APNEA" submitted by me for the partial fulfillment of the Master of Science in Orthodontics at the Hamdan Bin Mohamed College of Dental Medicine (HBMCDM), Mohammed Bin Rashid University of Medicine and Health Sciences (MBRU) is my original work under the direct supervision of Professor Ahmed Ghoneima, and that the thesis has not previously formed the basis for the award to me of any degree, diploma, fellowship or any other title in this university or any other institution.

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1. INTRODUCTION

Sleep disordered breathing (SDB) can be classified into various types one of which is obstructive sleep apnea. Obstructive sleep apnea (OSA) is a respiratory disorder characterized by repetitive episodes of breathing cessation (apnea) or airflow reduction (hypopnea) frequently during sleep, causing a disruption of air flow affecting the quality of life and representing a risk factor for other diseases (Lawati, 2009). OSA affects approximately 9% to 38% of the general population and is higher in men, increasing with age (Senaratna et al, 2016). In some elderly groups the prevalence of OSA is 90% in men and 78% in women (Senaratna et al, 2016). OSA prevalence in the United Arab Emirates is 20.9% (22.9% males and 19.5% females) (Vats et al, 2016).

The airway remains open in normal situations. The shape and diameter of airway passage determine the volume of air passing through to the lung. OSA ranges from mild, moderate, to severe when the airway narrows or closes completely (Peppard et al, 2013). When the airway collapse, the airway becomes partially blocked. This makes it harder for the air to pass through and may cause snoring when the air squeezes through this narrow area (Peppard et al, 2013).

Airway obstructions most likely occur at the retropalatine and/or retrolingual areas particularly when an individual is lying in a supine position (Tang et al, 2012). The soft tissue thickness of the airway passage, the size of the tongue and/or soft palate have been associated with OSA (Tang et al, 2012).

The effect of sleeping position whether it is supine or laterally positioned and its effect on the upper airway collapsibility and obstruction using CBCT has not been widely investigated. The three-dimensional imaging of CT and CBCT has been used in the current research to find out if there is a significant difference in airway parameters while patients lying in supine position compared to those standing in upright position. The aim of the current study is to assess the effect of supine and upright positions on airway dimensions in patients with obstructive sleep apnea using CBCT.

2. LITERATURE REVIEW

2.1. Anatomy of the Upper Airway

In OSA the upper airway is of prime importance. The upper airway is also called the upper respiratory tract (Scanlon et al, 2003). It includes all of the following: Nose, nasal cavity, sinuses and pharynx (Shier et al, 2010). The pharynx is located anterior to the cervical vertebrae and posterior to the nasal and oral cavities and larynx (Scanlon et al, 2003) (Shier et al, 2010) . In order to simplify the structure of the pharynx, it is subdivided into three anatomic parts: Nasopharynx, oropharynx and laryngopharynx (hypopharynx) (Kheirandish et al, 2012). While the nasopharynx is situated superior to the soft palate, it communicates anteriorly with the nasal cavity (Tatlipinar et al, 2012). On the superoposterior roof of the nasopharynx is a collection of nodular lymphoid tissue known as the pharyngeal tonsil (adenoid) (Tatlipinar et al, 2012). Hypertrophy of the adenoids can cause an increase in upper airway resistance leading to intermittent obstruction of the airway, chronic alveolar hypoventilation, right ventricular failure and cor pulmonale (Tatlipinar et al, 2012).

The oropharynx is located between the soft palate and the upper border of the epiglottis. In its anterior aspect, it communicates with the oral cavity (Angle, 1907). The anterior border comprises the posterior one-third of the tongue and soft palate. The posterior border of the oropharynx constitutes the superior, middle, and inferior constrictor muscles (Angle, 1907). The lateral border of the oropharynx is formed by muscles, parapharyngeal fat pads and lymphoid tissues (mainly the palatine tonsils) (Angle, 1907). In the midsagittal view, the oropharynx can be further subdivided into retropalatal component and retroglossal component (Angle, 1907).

The retropalatal component is bounded by the hard palate and the inferior margin of the soft palate (Liebgott, 2011). At the end of the soft palate is a projection known as the ‘uvula’(Liebgott, 2011). Two arches support the soft palate on either side. These are the palatoglossal and palatopharyngeal arches. The palatine tonsils are contained within these two arches (Liebgott, 2011). The retroglossal component is bounded by the inferior margin of the soft palate and the tip of the epiglottis. Anterior to the retroglossal component is the dorsum of the posterior third of the tongue (Angle, 1907; (Liebgott, 2011).

The laryngopharynx is positioned posterior to the larynx. It extends from the superior surface of the hyoid bone to the inferior of the lower border of the cricoid cartilage. From there on, it continues as the oesophagus (Angle, 1907; Liebgott, 2011).

2.2. Airway Disorders and Craniofacial Morphology

There are various craniofacial disorders that are associated with airway obstruction. One of them is known as craniofacial clefts. These include cleft lip, cleft palate or both cleft lip and palate (Cielo et al, 2015). Pierre Robins sequence, craniosynostosis and achondroplasia are associated with airway obstruction (Cielo et al, 2015). Patients with Down's syndrome are also subject to OSA due to midface and mandibular hypoplasia that result in a narrowed hypopharynx and relative macroglossia (Cielo et al, 2015).

Airway impairments due to genetic or environmental factors can have a profound effect on the occlusion and craniofacial morphology. Whenever the airway is impaired, the respiratory system responds with postural compensations by oral structures in order to maintain an optimal level of airway resistance and airway size (Warren et al,1991). Orthodontists are interested in postural compensations that may occur because of the possible effects they have on dentofacial growth and development (Tatlipinar et al, 2012). They are also keen to discover if the compromise in the nasal airway that eventually leads to mouth breathing has an effect on dentofacial growth or not (Aravind et al, 2012). It has been noted that Class II division I malocclusion appears with mouth breathing due to nasal obstruction (Angle, 1907). It has also been observed that nasopharyngeal obstruction increased in patients with Class III malocclusion (McCoy, 1949).

When left untreated, OSA can affect the cardiovascular system, cause neurocognitive impairment, daytime sleepiness, and increase the risk of motor vehicle accidents (Carberry at al, 2018). Severe OSA increases chances of getting arrythmias, atrial fibrillation and stroke (Ralls et al, 2019). Untreated OSA may also lead to ocular and retinal vascular changes (Ralls et al, 2019).

Craniofacial morphology and occlusal patterns are influenced by a myriad of factors (Principato, 1991). The relation between upper airway obstruction and craniofacial development has long been investigated (Principato, 1991). It was found that a relationship exists between adenoid tissue and some skeletal and dental patterns (Principato, 1991). Because nasal obstruction may lead to mouth breathing, some changes may occur such as clockwise rotation of the mandible, resulting in elongation of lower anterior facial height, open bite development and retrognathism of the mandible (Principato, 1991). It was also observed that the gonial angle was very obtuse and the mandibular plane was steep (Principato, 1991). Additional findings include shallow nasopharyngeal space, constricted and elevated palate, a tendency toward crossbite development and crowding in both arches (Principato, 1991).

With regards to the maxilla, oral respiration entails lower tongue posture albeit decreasing lateral expansive forces exerted by the tongue (Principato, 1991). It was observed that in the sagittal plane, the maxilla was shorter and the maxillary incisors were more proclined (Gungor et al, 2009). Whereas in the transversal plane, patient presented with narrow, V-shaped maxillary arches and high palatal vaults which may lead to a collapsed maxillary arch and it may also develop a posterior crossbite (Gungor et al, 2009). The presence of crossbite was significant in children with severe airway obstruction, especially in those with hypertrophied adenoids and tonsils (Gungor et al, 2009). The severity of the posterior crossbite is correlated to the degree of upper airway obstruction in the form of hypertrophied adenoids or tonsils and allergic rhinitis (Gungor et al, 2009).

A term known as “Adenoid Facies”, was coined by C.V. Tomes in 1872. This was used to describe a patient who has their mouth open and a long face associated with a constricted nose, shortened upper lip, tapered palate, high palatal vault and crowding (Sheeba et al, 2018). These patients develop these features due to upper airway obstruction that leads to mouth breathing (Agarwal, 2016). This in turn results in open mouth, lowered position of the tongue, clockwise mandibular rotation and head posture changes (Agarwal, 2016). In addition to the before mentioned features, Adenoid Facies show increased overjet, crossbite, open bite and retroclination of upper and lower incisors (Agarwal, 2016). Cephalometrically, it was found that there was an increase in incisor mandibular plane angle (IMPA), interlabial gap and facial convexity in patients with adenoid hypertrophy (Basheer at al, 2014).

Even though there is significant evidence that mouth breathing can be a result of poor nasal breathing, its impact on dentofacial growth is unclear (Warren, 1990).

2.3. Types of Sleep Disorders

According to the American Academy of Sleep Medicine Task Force, sleep disorders can be classified into six categories. These include insomnia, sleep-related breathing disorders (such as obstructive sleep apnea, central sleep apnea and sleep-related hypoventilation disorders), central disorders of hypersomnolence, circadian rhythm sleep-wake disorders, parasomnias and sleep-related movement disorders (Darien, 2014). Central sleep apnea results from a temporary failure in the pontomedullary pacemaker that generates breathing rhythm (Javaheri, 2010). This is reflected in the loss of ventilatory effort that can last more than or equal to 10 seconds (Javaheri, 2010). Sleep-related hypoventilation disorders are characterized by a reduction in breathing frequency, an increase in partial pressure of carbon dioxide more than

45 mmHg and a normal pH level with an elevated HCO_3^- level (Boing et al, 2015). On the other hand, extreme daytime sleepiness despite normal quality of nighttime sleep comprises central disorders of hypersomnolence (Khan et al, 2015). Circadian rhythm sleep-wake disorders occur when the sleep-wake cycle is not well-aligned with the environment and interferes with daily activities (Pavlova, 2017). Parasomnias are a type of sleep disorder where there is a dissociation between wakefulness and NREM or REM sleep leading to one state superimposing on another (Kotagal, 2009). Simple, stereotyped movements that disturb sleep are part of sleep-related movement disorder (Thorpy, 2012). These disorders are further classified into periodic limb movement disorder and restless leg syndrome (Thorpy, 2012).

In addition, obstructive sleep apnea (OSA) is a sleep-related disorder in which the person experiences episodes of breathing cessation (apnea) or airflow reduction (hypopnea) frequently during sleep (Lawati, 2009). This occurs as a result of an obstruction in the upper airway during sleep due to insufficient motor tone of the tongue, with or without airway dilator muscles (Park et al, 2011). In the United States, the prevalence of OSA is found to be around 3% to 7% in men and 2% to 5% in women (Punjabi, 2008).

2.4. Severity of OSA

In order to quantify the severity of OSA, the apnea-hypopnea index (AHI) is used. This index equals the number of apneas plus hypopneas per hour of documented sleep (Task Force, 1999). AHI can be categorized according to the American Academy of Sleep Medicine into mild sleep apnea (5 to 15 events per hour), moderate sleep apnea (more than 15 to 30 events per hour) and severe sleep apnea (more than 30 events per hour) (American Academy of Sleep Medicine Task Force, 1999).

2.5. Risk Factors for OSA

There are many documented risk factors for OSA. Obesity is one of the risk factors that may lead to OSA. The mechanisms by which obesity predisposes to OSA include: Upper airway narrowing due to fat deposition, upper airway functional changes, changes in the balance between ventilatory drive and load and reduced lung volumes (Lawati, 2009). Another risk factor is gender. Males have almost twice the risk of OSA as females (Lawati, 2009). Ethnicity of the person can also play a role as a risk factor for OSA (Lawati, 2009). African Americans and Asians are at a higher risk for OSA at a given BMI (Lawati, 2009). It has been demonstrated that genetics may also play a part as risk factors for OSA as OSA has been observed within families (Lawati, 2009). A person who has a family member with OSA are at increased risk of having apnea themselves (Campana et al, 2010). Since obesity has a strong predisposition for OSA, some have postulated that maybe the genetic basis to OSA is secondary to genes that control adipose levels (Campana et al, 2010). A causal genetic factor for OSA has been investigated but to date none of the genes directly cause OSA (Campana et al, 2010).

In addition, nasal obstruction increases the risk of OSA (Lawati, 2009). Another risk factor is smoking. Smoking appears to possibly cause smoke-related airway inflammation and interferes with sleep stability (Lawati, 2009). Other risk factors may encompass hypothyroidism, acromegaly, benzodiazepines and exogenous testosterone (Lawati, 2009). The prevalence of hypothyroidism is greater in patients diagnosed with OSA than that in suspected OSA patients (Zhang et al, 2016). In acromegaly patients who have OSA, they show an increase in vertical dolichofacial growth and a narrowed posterior airway space (Hochban et al, 1999). As sedative hypnotics, benzodiazepines are a risk for OSA patients as these drugs may transform a partial obstruction into a complete obstruction (Guilleminault, 1990). Even though the mechanism by which testosterone administration affects OSA is unclear, it has been demonstrated that testosterone was associated with increased upper airway collapse during sleep which improves after cessation of testosterone administration (Cistulli, 1994). Moreover, menopause also poses a significant risk factor for OSA in women, and it has been shown that hormone replacement therapy reduces the risk (Bixler, 2001).

2.6. Diagnostic Tools for Assessing the Airway

Nasal resistance can be measured using either acoustic rhinometry (AR) or rhinomanometry (RM). Acoustic rhinometry measures nasal cross-sectional area at various distances from the nasal inlet with the aid of acoustic reflections (Masdeu et al, 2011). Rhinomanometry assesses the nasal airway by registering transnasal pressure and airflow simultaneously during the occlusion of one nostril (Masdeu et al, 2011). Even though AR and RM were not related to each other in the sitting position, they were correlated when in the supine position (Masdeu et al, 2011).

Polysomnography (PSG) is the gold standard used to evaluate OSA (Marcus et al, 1992). PSG is essential in reaching diagnoses for sleep disorders (Keenan, 2005). This method of assessment investigates physiological changes, impact on sleep and consequences during waking function, performance and behaviour (Keenan, 2005). The PSG includes a record of sleep state parameters such as 4-lead electroencephalogram, bilateral electro-oculogram and submental and bilateral leg electromyogram (Weaver et al, 2004). It also includes oronasal airflow, oximetry, electrocardiogram and infrared video (Weaver et al, 2004). When comparing PSG to portable monitors such as thermistors and pressure sensors that sense changes in airflow, it was found that PSG has high sensitivity and low specificity (Woodson et al, 2013). It was also found that both PSG and portable devices are useful for high risk OSA patients and was less sensitive for low-risk patients (Woodson et al, 2013).

2.7. Treatment Modalities for OSA

There are different treatment modalities for treating OSA. They can be classified as non-invasive (including CPAP, weight loss, positional therapy, nEPAP, oral pressure therapy, oral appliances) and invasive (including tongue suspension, uvulopharyngopalatoplasty, maxillomandibular advancement, radiofrequency ablation, tracheostomy, nasal surgery, glossectomy and hypoglossal nerve stimulation).

Continuous positive airway pressure (CPAP) is one way to treat OSA. CPAP operates by pneumatically stabilizing the upper airway by splinting the upper airway and so hindering its collapse during sleep (Calik, 2016). The efficacy of CPAP has been proven and it has also been shown to reduce health morbidities and/or motor vehicle accidents (Calik, 2016). Even though CPAP is efficacious, it is not well tolerated by patients thus has low compliance (Calik, 2016). Side effects that occur due to the use of CPAP include dry mouth, nose blockage, increased number of awakenings, mask pressure and mask leaks (Ulander et al, 2014).

Another treatment for OSA is weight loss through dieting and lifestyle change. Weight loss reflected a decrease in the severity of OSA (Calik, 2016). Moreover, positional therapy can be used to treat OSA. This therapy entails that the patient wears a device that alerts the patient whenever they are in a supine position (Calik, 2016). This significantly reduces AHI, but as for CPAP, compliance is an issue (Calik, 2016).

Furthermore, there is another device used to treat OSA called nasal expiratory positive airway pressure (nEPAP). This is a single-use device that works by attaching to the nostrils with an adhesive to establish an airtight seal (Calik, 2016). It contains a mechanical valve that produces high resistance while expiring but not while inspiring (Calik, 2016). The risk of upper airway collapse occurs at the end of the expiratory phase of respiration due to a lack of positive pressure (Calik, 2016). nEPAP acts by elevating airway pressure at the end of the expiratory phase of the respiratory cycle thus preventing airway collapse (Calik, 2016). Compliance with nEPAP is still an issue but it fares better when compared to CPAP (Calik, 2016).

Oral pressure therapy is another treatment modality used to treat OSA. It is a device that induces suction anteriorly and superiorly (negative pressure) to displace both the tongue and the soft palate in such a way that breathing ensues via the nasopharynx (Calik, 2016).

Oral appliances can be used to treat OSA as a non-invasive approach. These appliances can work by advancing the mandible, stabilizing the tongue, and lifting the soft palate to increase the volume of the upper airway in order to decrease the severity of OSA (Calik, 2016). Function of oral appliances is to protrude the mandible (Scherr et al, 2014). They are fabricated from biocompatible materials using digital or physical impressions and models of a patient's oral structures (Scherr et al, 2014). The oral appliances allow for mandibular advancement in increments of 1 mm or less with a protrusive adjustment range of at least 5 mm (Scherr et al, 2014). These appliances demonstrated that apnea-hypopnea index was significantly reduced more than 50% of pretreatment values (Scherr et al, 2014). It has also been observed that oral appliances reduce blood pressure by reducing systolic and diastolic blood pressure and mean arterial blood pressure (Scherr et al, 2014). It was also established that the use of oral appliances in combination with nasal CPAP reduced velopharyngeal resistance to a greater extent than nasal CPAP alone (Scherr et al, 2014). Research demonstrates the effectiveness of oral appliances in reducing snoring and obstructive breathing events and improving daytime sleepiness (Sutherland et al, 2014).

Using oral appliances causes vertical jaw displacement that was found not to have a detrimental effect on the apnea-hypopnea index but this increased vertical mouth opening may lead to an adverse effect on upper airway patency (Sutherland et al, 2014). Therefore, bite opening should be minimized as much as possible (Sutherland et al, 2014).

Oral appliances present some side effects one of which is temporomandibular joint pain and tenderness in the muscles of mastication (Sheats et al, 2017). Intraoral side effects culminate as soft tissue, tongue and gingival irritation together with excessive salivation and possibly dry mouth (Sheats et al, 2017). Occlusal changes include altered occlusal contacts, decreased overjet and overbite and interproximal gaps (Sheats et al, 2017). In addition, also considered as a side effect of oral appliances is the risk of appliance breakage, allergies developed as a reaction to appliance material, gagging and anxiety that may arise as a result of using oral appliances (Sheats et al, 2017).

There are a number of surgeries that can be used in the treatment of OSA. One example is uvulopalatopharyngoplasty (UPPP). UPPP includes excision of tonsil and posterior soft palate/uvula as well as closure of tonsillar pillars (Caples, 2010). Even though a reduction in the apnea-hypopnea index was observed as a result of this surgery, there was post-operative bleeding and difficulty in swallowing (Caples, 2010). There is a modified UPPP where additional mucosa and submucosal tissue is removed around the tonsillar fossa superiorly and laterally and from the posterior soft palate (Caples, 2010). This surgery also showed a reduction in the apnea-hypopnea index (Caples, 2010). Laser assisted uvulopalatoplasty is another surgery that encompasses a series of laser incisions and vaporization that shorten the uvula and tighten the soft palatal tissue (Caples, 2010). Another surgery technique is upper airway radiofrequency treatment which involves applying precisely temperature-controlled energy to target tissue while sparing nearby tissue using a probe tip (Caples, 2010). For patients with mild to moderate OSA, soft palatal implants is a surgical method that can be used (Caples, 2010). Rods are inserted into the soft palate under local anesthesia (Caples, 2010). A multilevel skeletal surgery known as maxillomandibular advancement works to enlarge the veloorohypopharyngeal airway but avoiding direct manipulation of pharyngeal tissues (Caples, 2010). This is accomplished by a LeFort I and bilateral sagittal split rami osteotomies to advance anterior pharyngeal tissues (including tongue bas, soft palate and suprahyoid muscles) (Caples, 2010)

Hypoglossal nerve stimulation is another treatment modality for OSA. The hypoglossal nerve is a motor nerve innervates the protrusor and retractor muscles of the tongue (Calik, 2016). OSA patients can experience upper airway obstruction due to the inactivity of the genioglossus muscle during sleep (Calik, 2016). Therefore, the hypoglossal nerve is stimulated between the end of expiration and the start of the next respiratory cycle (Calik, 2016). This activates and protrudes the genioglossus muscle thus preventing upper airway collapse (Calik, 2016).

Even though there are various treatment options for OSA, CPAP remains as the gold standard treatment for OSA since it significantly decreases the severity of OSA (Calik, 2016). It must be noted that a combination of two or more of the above-mentioned treatments can be used to treat OSA (Calik, 2016).

2.8. Effect of Sleep Position on the Airway

Sleeping position of the person while in the supine or lateral position and its effect on the upper airway is continually being investigated. It has been observed that more than 50% of OSA is position dependent (Richard et al, 2006). Lateral positioning has been shown to markedly improve passive airway collapsibility and the ability of the airway to dilate (Joosten et al, 2015). In one of the studies, it was found that collapsibility of the upper airway is profoundly affected by the position of the body in such a way that pharyngeal critical pressure (Pcrit) decreased from supine to lateral position (Penzel et al, 2001). Pcrit represents the extrapolated air pressure at zero flow (Sforza et al, 1999). There is an evidence that suggests that the Pcrit in OSA patients is greater hence the increased upper airway collapsibility (Sforza et al, 1999). In addition, Kim et al, found that the change in position of the patient from supine to lateral position expanded the upper airway, in particular the retroglossal space (Kim, 2019). Moreover, marked improvement was seen in patients with epiglottic collapse when the changed from supine to lateral position (Marques et al, 2017). In one study conducted by Camacho et al, it was found that total airway volume and cross-sectional area measurements decreased when obstructive sleep apnea patients were in a supine position compared to an upright position (Camacho, 2014).

Some studies have shown that obstructive respiratory events during sleep were found to be less with lateral position than supine position (Menon, 2013). The improvement demonstrated in the lateral position may be due to changes in the structure of the airway in the lateral position and heightened activity of pharyngeal dilator muscles (Menon, 2013). It was also found that for anesthetized patients with OSA, changing body position from supine to lateral increased both retropalatal and retroglossal airways and decreased closing pressure (Menon, 2013). Some authors showed that apneic events that occur in the supine position were more severe than those occurring in the lateral position (Menon, 2013). Furthermore, oropharyngeal stenosis in the supine position was found to be more severe due to the backward prolapse of the tongue and the soft palate (Menon, 2013). This prolapse could be due to the effect of gravity on the tongue as it falls back on the pharyngeal wall (Menon, 2013).

With regards to pediatric patients, in the prone position, the lung capacity may become reduced due to pressure on the thorax leading to narrowing of the upper airway (Menon, 2013). Children undergoing general anesthesia who are in the prone position displayed a decrease in the maximal distension of the most collapsible part of the pharynx and the neck rotation involved leads to an increase in pharyngeal closing pressure compared with supine position (Menon, 2013).

2.9. Effect of Malocclusion on the Airway

Some studies suggest that there is a correlation between upper airway dimensions and various skeletal patterns (Shokri et al, 2018). Whereas the mean airway area of skeletal Class III pattern was found to be larger than those in skeletal Class II pattern, the minimum axial area of skeletal Class III pattern was greater than those in skeletal Class I and II patterns (Shokri et al, 2018). In addition, the oropharyngeal airway volumes of skeletal Class II pattern was found to be less than that for skeletal Class I and III patterns (El et al, 2011). It was perceived that was due to the position of the mandible with respect to the cranial base and its effect on the oropharyngeal airway volume (El et al, 2011). Moreover, it was shown that there was a significant difference in the nasopharyngeal volume between skeletal Class I and II in such a way that skeletal Class II patients reflected a smaller volume (El et al, 2011).

2.10. Assessment of the Upper Airway

Assessing the airway a very crucial tool. This is achieved by a number of different methods. Physical examination involves evaluating the morphology of the face, the oral cavity and the oropharynx (Togeiro et al, 2010). On the other hand, nasal examination includes using a speculum to carry out an anterior rhinoscopy while the patient is seated with their head positioned slightly back (Togeiro et al, 2010). This is performed in order to detect septal deviation, hypertrophy of the turbinates, nasal polyps and the internal nasal pathway (Togeiro et al, 2010).

Other ways to assess the upper airway is by using lateral cephalometry, conventional tomography (CT) or magnetic resonance imaging (MRI). Even though lateral cephalograms are 2D images of a 3D structure- the pharynx- lateral cephalometry is commonly used because of its relative simplicity, reduced cost and minimal radiation (Togeiro et al, 2010). Cephalometric variables that can be quantified are soft tissue, hyoid bone position, upper airway size and craniofacial variables (Sforza et al, 2000). The soft tissue variables include the length of the soft palate extending from the posterior nasal spine of the maxilla to the inferior border of the uvula, the soft palate width, the tongue length extending from the inferior part of the epiglottis to the tip of the tongue and the tongue width (Sforza et al, 2000). Hyoid bone position can be measured from the hyoid bone to the mandibular plane, to the posterior pharyngeal wall and to the posterior nasal spine (Sforza et al, 2000). Upper airway variables may include measuring the distance between the posterior pharyngeal wall to the posterior soft palate (superior posterior airway space) and to the dorsum of the tongue (inferior posterior airway space) (Sforza et al, 2000). Craniofacial variables may include the length of the anterior cranial base (nasion to sella), angulation of the cranial base, sagittal dimension of the bony pharynx, position of the maxilla (SNA), position of the mandible (SNB), difference in prognathism (ANB), lower facial height, total face height, angulation of mandibular plane with the cranial base, maxillary length (between anterior and posterior nasal spines) and mandibular length extending from the medial condylar of the mandible to gnathion (the most anterior-inferior point on the symphysis of the mandible) (Sforza et al, 2000).

The advantages of using cephalometry include its wide availability, it has no weight limitations, it is useful in evaluating patients with bony facial abnormalities (such as retrognathia) and it is useful in evaluating dental appliances (Schwab et al, 1998). On the other hand, the disadvantages are that the patient must be in sitting or standing position and not supine (therefore, cannot be performed when the patient is sleeping), it is a two-dimensional evaluation of a three-dimensional structure, it provides limited information about anteroposterior structures and no information on lateral soft tissue structures (Schwab et al, 1998).

The airway can also be assessed by computerized tomography (CT). Cine CT or ultra-fast CT have been used to produce many images with a lower exposure to radiation as compared to standard CT (Togeiro et al, 2010). In addition, Cone-Beam Computed Tomography (CBCT) can also be used to assess the airway. CBCT provides 3D image volumes of all structures in the maxillofacial complex (Zinsley et al, 2010). By utilizing certain software and acquisition protocols based on individual needs, these digital scans can be converted into multiple planar view images (axial, coronal and sagittal) (Zinsley et al, 2010). The advantages of CBCT comprise improved efficiency, reduced acquisition time and by using specific software, improvement of image processing and analysis of the 3D images in the maxillofacial region is possible (Zinsley et al, 2010). As compared to lateral cephalometry, CBCT provides a complete analysis of the airway with regards to linear measurements, area and volume (Lenza et al, 2010). CBCT can quantify the trasverse dimensions of the airway (Aboudara et al, 2009). Lateral cephalometry can only measure the pharynx's height and depth but not width (Zinsley et al, 2010). Moreover, CBCT can measure the airway dimensions in both upright and supine positions but the lateral cephalometry can only measure the airway in the upright position (Aboudara et al, 2009).

As CBCT is capable of measuring the cross-sectional area of the airway, it can also determine the most constricted area which relies on the relationship between craniofacial skeleton and surrounding soft tissue structures (Zinsley et al, 2010). This most constricted area is significantly constricted in OSA patients as compared to non-OSA patients (Zinsley et al, 2010). In treating OSA patients, it is paramount that the most constricted area is improved (Zinsley et al, 2010).

Another modality of assessing the airway is magnetic resonance imaging (MRI) which can detect lateral narrowing in patients with OSA (Togeiro et al, 2010).

Another questionnaire is the Berlin questionnaire. This questionnaire reveals middle-aged and older people who are at high risk for OSA by including questions about snoring (category 1), daytime somnolence (category 2), body mass index and hypertension (category 3) (Thurtell, 2011). Subjects who score positive on 2 or more categories were at high risk for OSA (Thurtell, 2011).

2.11. Reliability of CBCT Imaging to Assess Upper Airway

In one study, the intra-examiner and inter-examiner reliability was assessed in volumetric and cross-sectional area assessments of the upper airway using CBCT. The examiner reliabilities were assessed using intraclass correlation coefficient (ICC). They found that of all the parameters that were measured, both intra-examiner and inter-examiner reliability were excellent for oropharyngeal airway volume (Zimmerman et al, 2019). The researchers further concluded that the more experience and education the examiner had the higher the reliability observed (Zimmerman et al, 2019).

Another study pointed out that examiners who were not experienced in the anatomy of the region pose a limiting factor that may put reliability at risk (Souza et al, 2013). Yet another study demonstrated that examiners with various backgrounds (undergraduate student, orthodontist and dental radiologist) have reliable anteroposterior linear measurements, cross-sectional areas at the levels of the tongue, soft palate and palatal plane and sagittal area and volume (Mattos et al, 2014). But the measurements of linear width, cross-sectional area at the level of the vallecula, and minimum axial area were unreliable (Mattos et al, 2014).

Ryan et al also investigated the reliability of CBCT. They measured CBCT scans at two time points (Obelenis et al, 2019). They also measured the same CBCT scan twice. They found that ICC for measuring the same scan twice was high (Obelenis et al, 2019). However, the ICC for measurements obtained from the CBCT scans at two time points demonstrated that the only variable with high reproducibility was the cranial base (Obelenis et al, 2019).

On the other hand, a study investigated the reliability of CBCT imaging by comparing CBCT measurements of the total and internal airway volume and the most constricted airway area to those measurements on a model (Ghoneima et al, 2013). It was discovered that intra-examiner reliability with ICC was high for all measurements (Ghoneima et al, 2013). Aboudara et al, found a significant positive correlation between nasopharyngeal airway size in adolescents between a headfilm and its size from a CBCT scan (Aboudara et al, 2009).

Moreover, three commercially available DICOM viewers (Dolphin3D OnDemand3D and InVivoDental) were compared to OrthoSegment program. They found that all programs were highly reliable in measuring airway volume and showed high correlation of the results (El et al, 2010). This may be due to systematic errors (El et al, 2010). Another study conducted by Schendel et al demonstrated that CBCT imaging can be utilized to determine the precise location of the anatomical area of airway obstruction (Schendel et al, 2010). Reconstructing the airway from CBCT scans and segmentation techniques has proved to be reliable (Schendel et al, 2010). It has also been concluded by Tso et al, that CBCT can assess the airway by using highly correlative linear, cross-sectional and volumetric measurements (Tso et al, 2009).

3. AIM

The aim of the current study was to assess the effect of supine and upright positions on airway dimensions in patients with obstructive sleep apnea.

4. MATERIALS AND METHODS

This retrospective study included 30 subjects who were at high risk of developing OSA as indicated by Epworth Sleepiness Scale (ESS). To identify patients at risk of OSA, the Epworth Sleepiness Scale (ESS) was used. This is a self-administered questionnaire that provides a measurement of a person's daytime sleepiness (Johns,1991). The questionnaire asks questions based on eight situations: Sitting and reading, watching TV, sitting in a public place, as a car passenger, lying down to rest, sitting and talking to someone, sitting quietly after lunch without alcohol and in a car for a few minutes in traffic (Johns,1991). Subjects were asked to rate on a scale of 0-3 (0= would never doze, 3=high chance of dozing) how likely they would doze off or fall asleep in the before mentioned eight situations (Johns, 1991).

3D data of male subjects with age range of 26 to 60 years (mean, 35.7 ± 2.3 years) were retrieved from the archives. Each subject scanned twice with a low-dose multiplanar CT scanner in a supine position (T1) using Xvision EX, (Toshiba Medical Systems, Otawara-Shi, Japan), at a voxel size of 0.4 mm and a full field of view (FOV) and a second scan that was obtained on the same day using iCAT CBCT scanner (Imaging Sciences International, Hartfield, PA) at 8.9 seconds, with the same voxel size and FOV while patients were scanned in upright position (T2).

Subjects who had limited jaw movement, a history of temporo-mandibular disorders (TMD), previous orthodontic treatment, orthognathic surgery, craniofacial anomalies, a history of significant medical disease, airway pathology, subjects on medications that depress respiration, or subjects who are mouth breathers were excluded from the study. All subjects were positioned while taking the scans by adjusting the longitudinal light beam passing through the center of the glabella and the philtrum, and the transverse light beam passing through the lateral eye canthi.

All parameters were measured twice by the same examiner (MA) with two weeks interval period between both times. Intra-examiner reliability was assessed with the intraclass correlation coefficient (ICC) to be equal to or greater than 0.90. Otherwise, the process would have been repeated two weeks later.

The selected parameters of airway volume of nasal cavity, nasopharynx, oropharynx, hypopharynx, total airway volume and minimum axial area were measured using Dolphin imaging software (version 11.95.08.67 Patterson Dental Supply, Chatsworth, Calif). Airway space was segmented at the same threshold level of 50% using the sensitivity built-in module available in Dolphin software.

Before any measurement was obtained, the scans were digitally oriented using Dolphin software according to three planes of space. The mid-sagittal plane was oriented on the skeletal facial midline, the axial plane was oriented on the Frankfurt Horizontal plane (right orbitale to right porion) and the coronal plane was oriented to pass through the trifurcation area of the right maxillary first molar (Fig. 1).

The landmarks were identified on the scans and the parameters were calculated using the Dolphin Software. The definitions of the parameters are presented in Table 1 and Figures 2-12.

Table 1: Definitions of parameters

Nasal Cavity	ANS to tip of nasal bone to N to S to PNS to ANS
Nasopharynx	S to PNS to tip of odontoid process to S
Oropharynx	PNS to tip of odontoid process to posterior-superior CV4 to base of epiglottis to PNS
Hypopharynx	Base of epiglottis to base of symphysis to posterior-inferior CV4 to posterior-superior CV4 to base of epiglottis
Total Airway	S to PNS to base of epiglottis to base of symphysis to posterior-inferior CV4 to posterior-superior CV4 to tip of odontoid process to S
Soft Palate	Soft palate that starts and ends at PNS through uvula tip
Prevertebral Soft Tissue Thickness	Distance parallel to Frankfurt Horizontal Plane from the following points to the posterior wall of the airway: • Inferior-anterior CV4 • Superior-anterior CV4 • Inferior-antherior CV3 • Superior-anterior CV3 • Inferior-anterior CV2 • Anterior CV1

ANB	The intersection of N-A line with N-B line
N perpendicular to Pog	Horizontal distance parallel to Frankfurt Horizontal Plane from Pog to a perpendicular line dropped from N point.
Overjet	Horizontal distance parallel to Frankfurt Horizontal Plane from tip of lower incisor to tip of upper incisor.
Anterior Facial Height	Distance from N to Menton
Cervical Vertebrae Angulation	Angle between posterior-inferior CV4 to line tangent to CV2 to True Horizontal

CV= cervical vertebra. PNS= posterior nasal spine. ANS= anterior nasal spine. S= sella. N= nasion. Pog=pogonion.

Statistical Analyses

One-way ANOVA was performed to check whether an acceptable power was obtained with the used sample size. Power calculation showed that the power of the study was 90%.

Descriptive statistics included the mean, standard deviation (SD), maximum, and minimum of each parameter and for the changes from supine to an upright position. Differences between the selected parameters in both positions were tested by using paired t tests. The results were based on the averages readings of both positions. Within-group comparisons of quantitative variables between T1 and T2 were made by using the Wilcoxon signed rank test. A probability value less than 0.05 was considered statistically significant. All statistical calculations were done by using the computer programs Excel 2020 (Microsoft, Redmond, Wash) and the Statistical Package for the Social Science (version 25; SPSS, Chicago, Ill) for Windows.

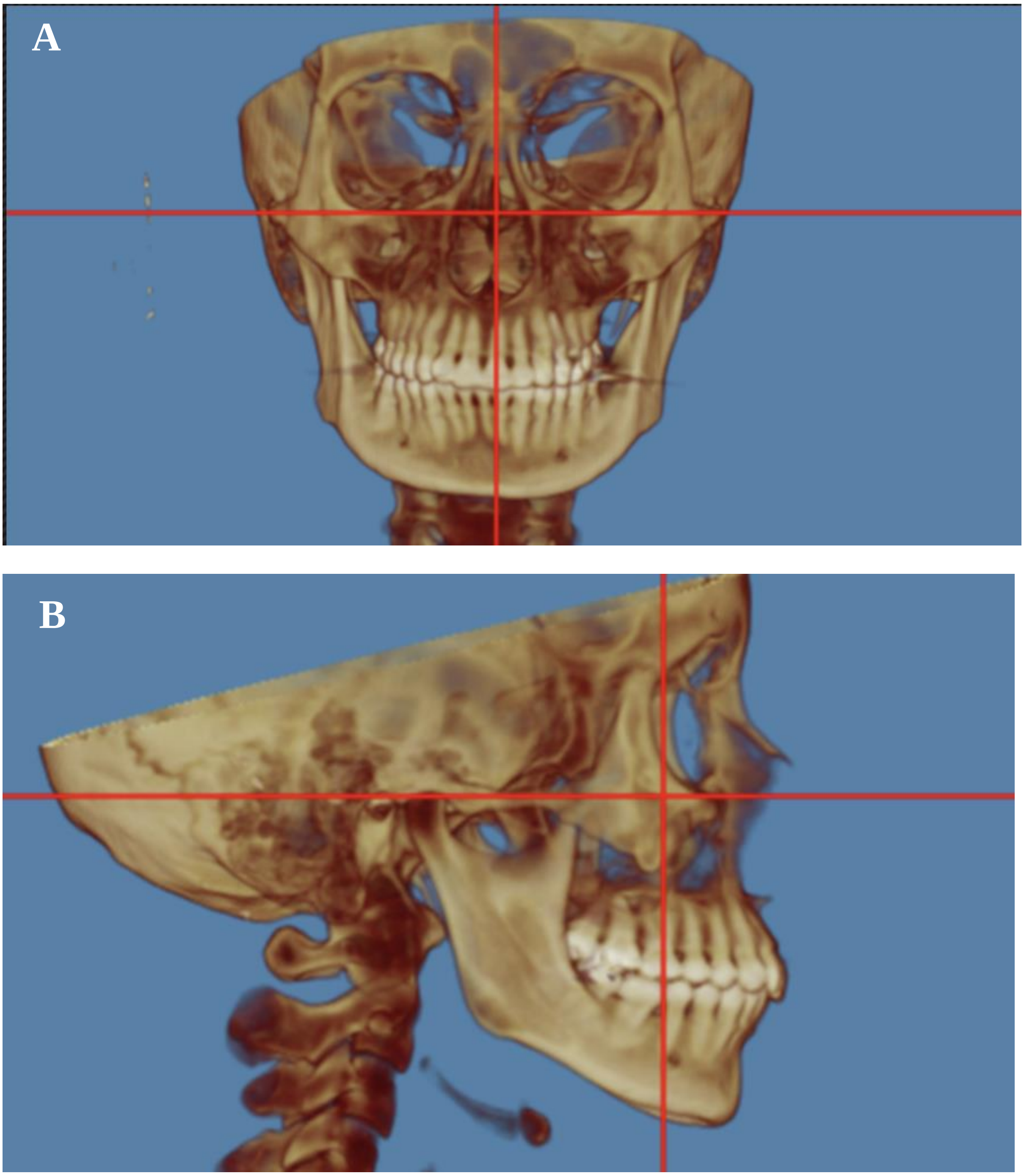

Figure 1 A: The mid-sagittal plane was oriented on the skeletal facial midline, the axial plane was oriented on the Frankfurt Horizontal plane (right orbitale to right porion). B: The coronal plane was oriented to pass through the trifurcation area of the right maxillary first molar

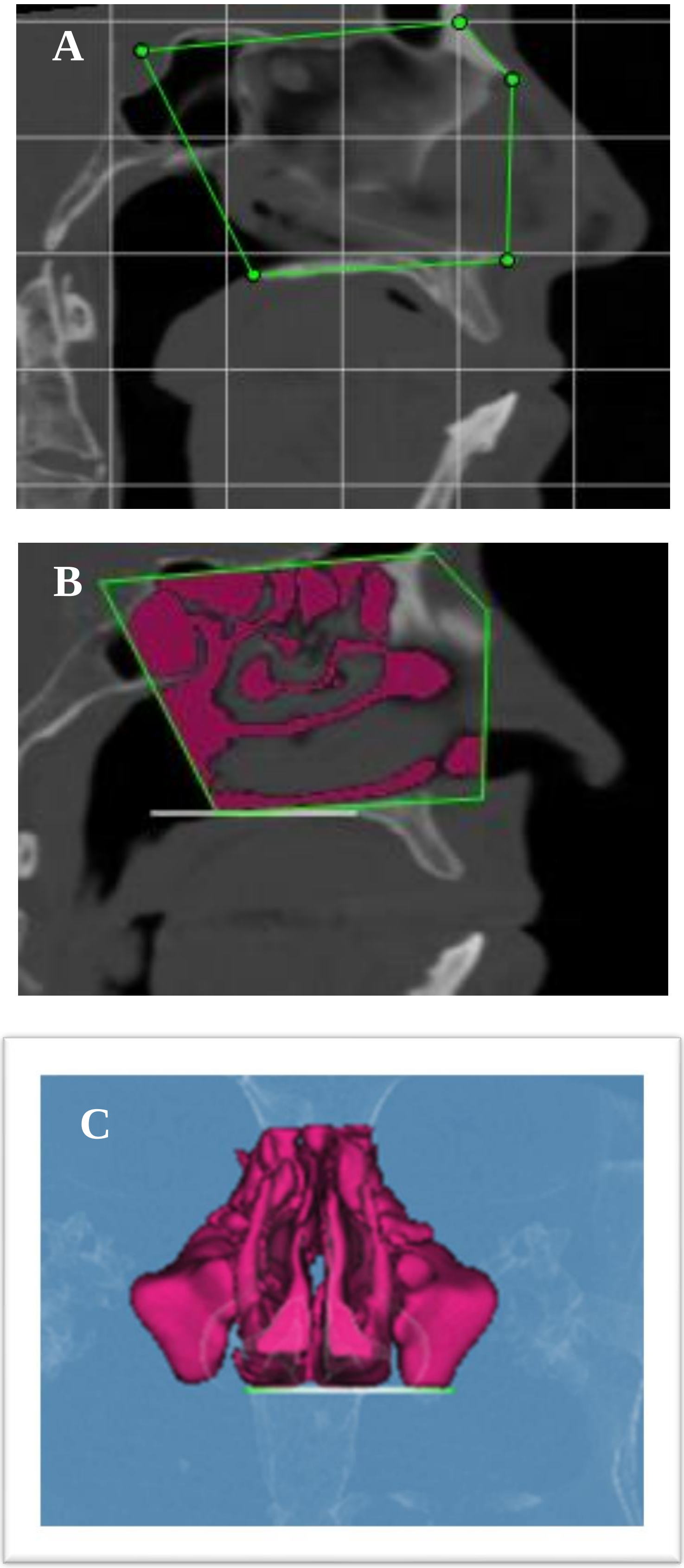

Figure 2: A) Nasal cavity boundaries, B) Nasal cavity area, C) Nasal cavity volume

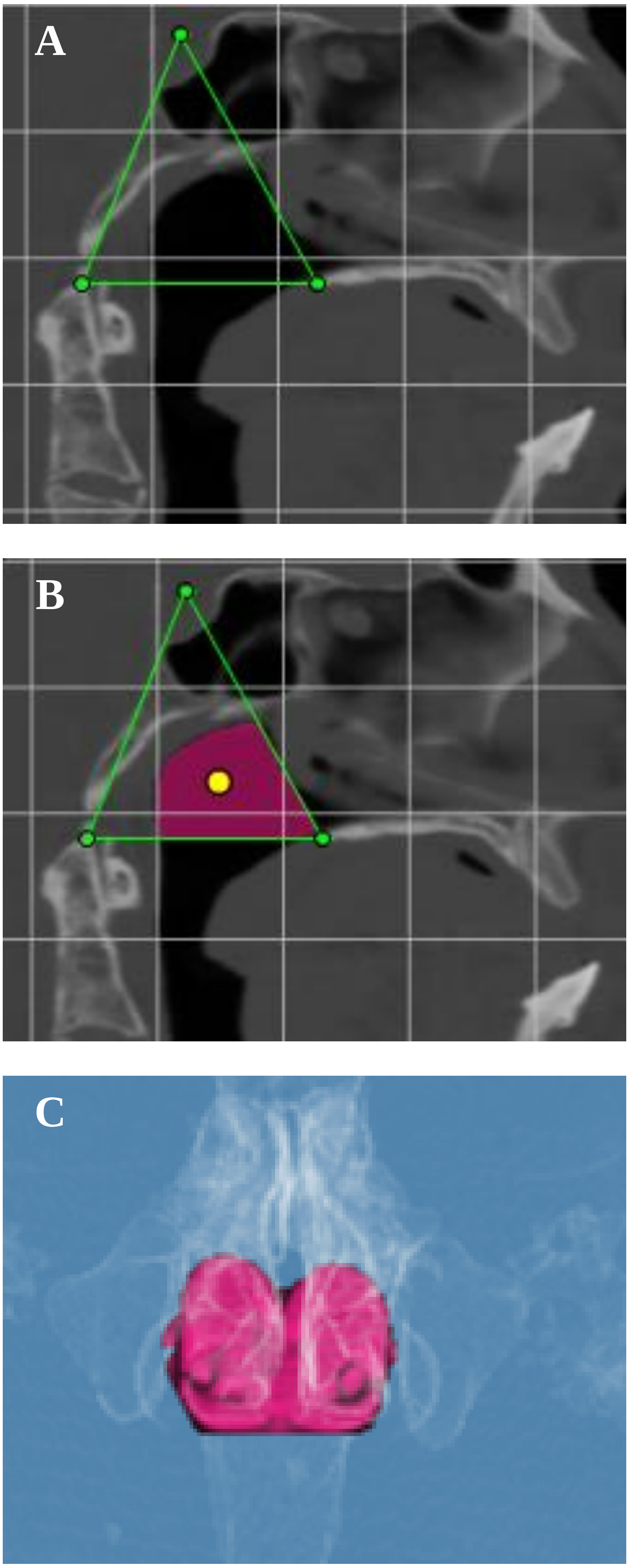

Figure 3: A) Nasopharynx boundaries, B) Nasopharynx area, C) Nasopharynx volume

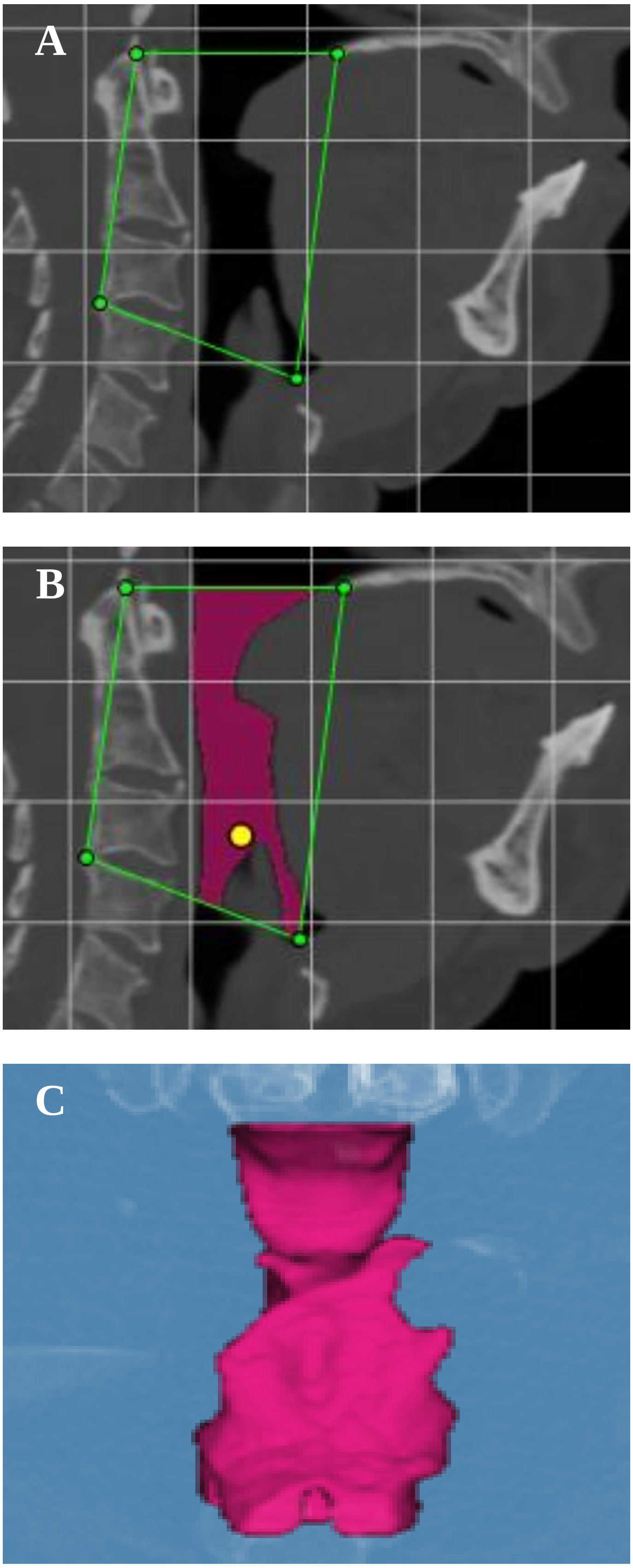

Figure 4: A) Oropharynx boundaries, B) Oropharynx area, C) Oropharynx volume

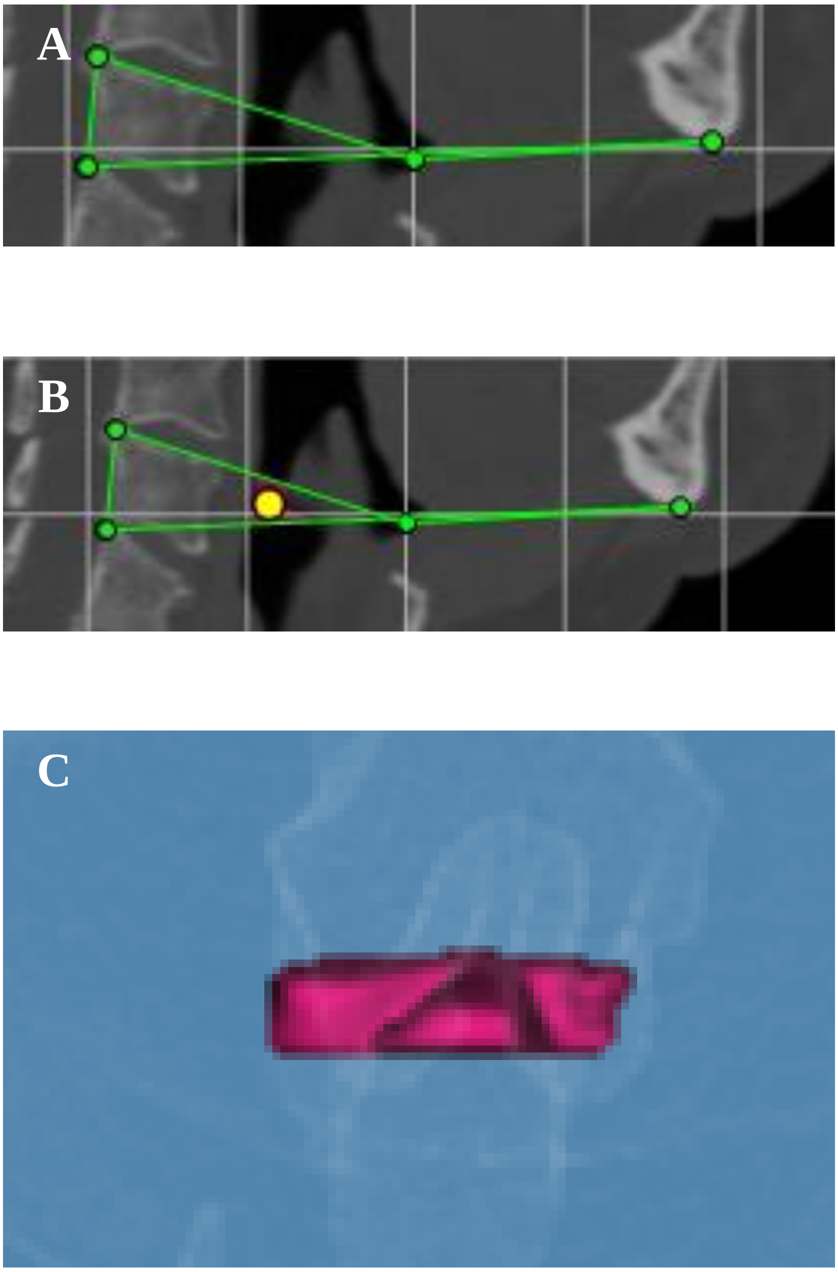

Figure 5: A) Hypopharynx boundaries, B) Hypopharynx area, C) Hypopharynx volume

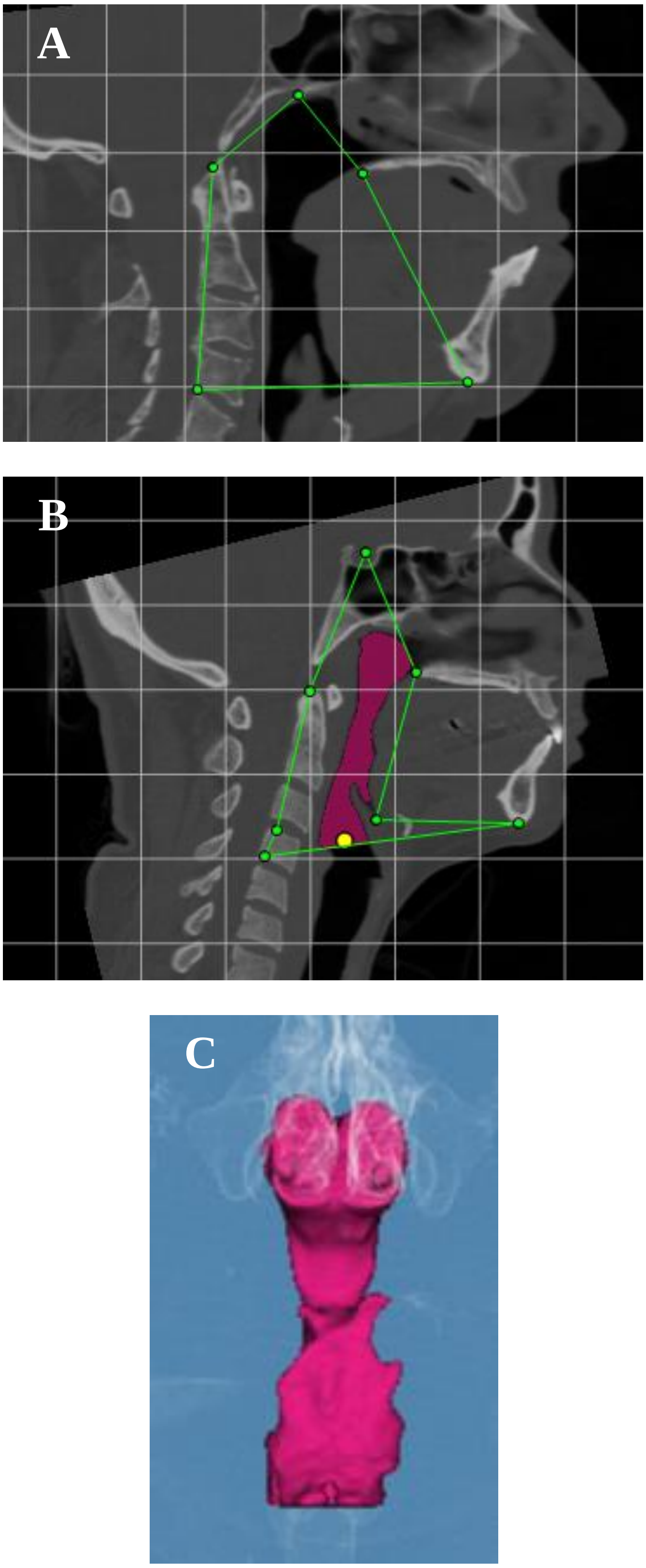

Figure 6: A) Total airway boundaries, B) Total airway area, C) Total airway volume

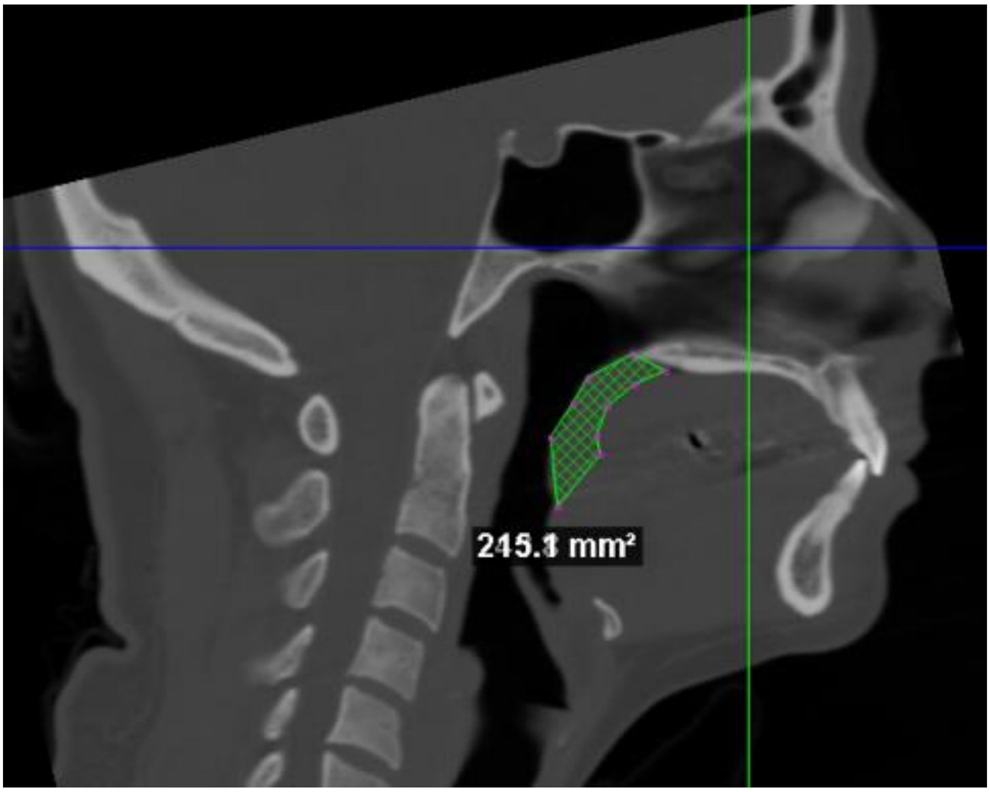

Figure 7: Soft palate area

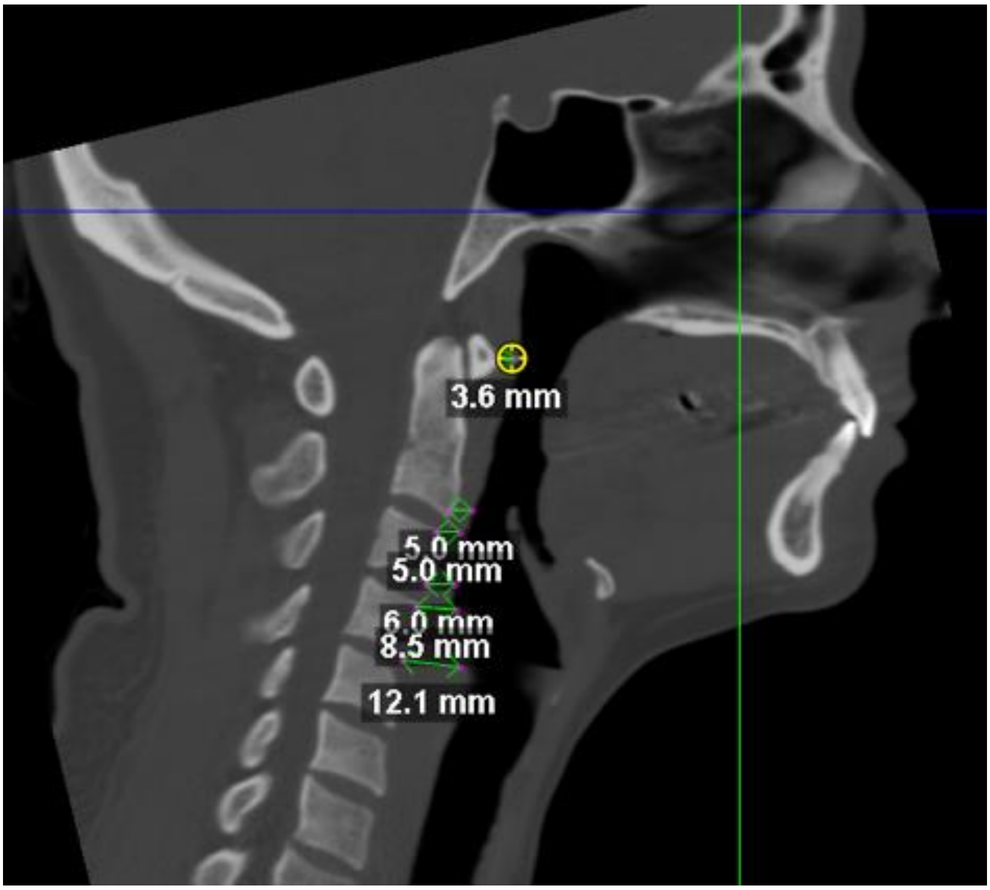

Figure 8: Prevertebral soft tissue thickness

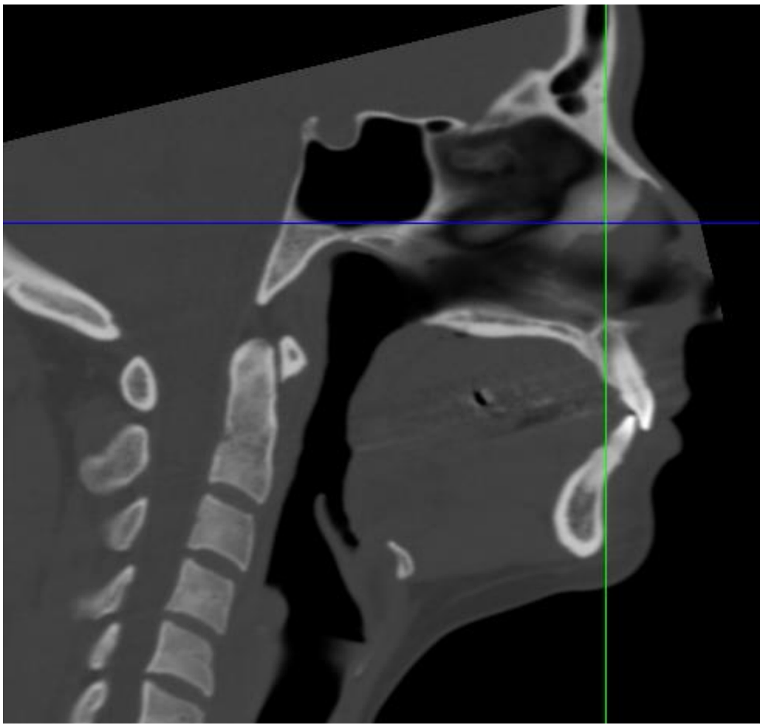

Figure 9: N perpendicular to Pogonion point

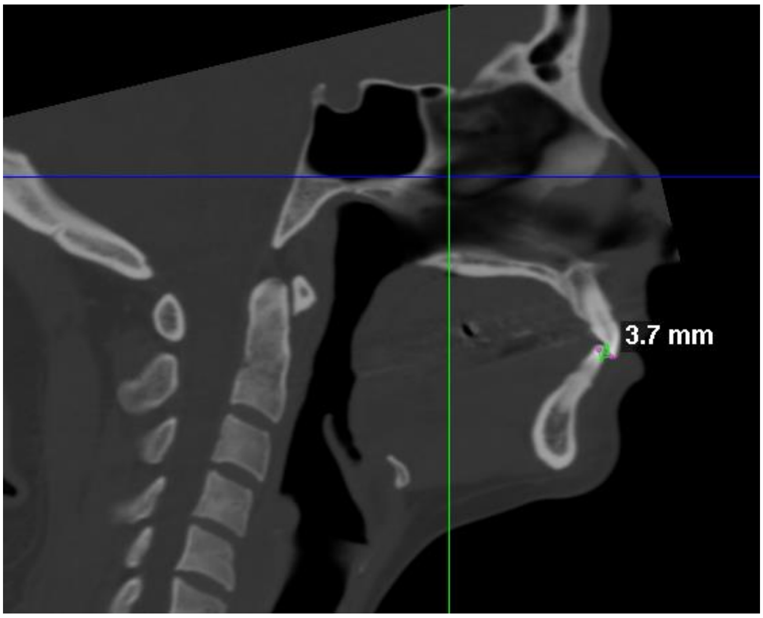

Figure 10: Overjet

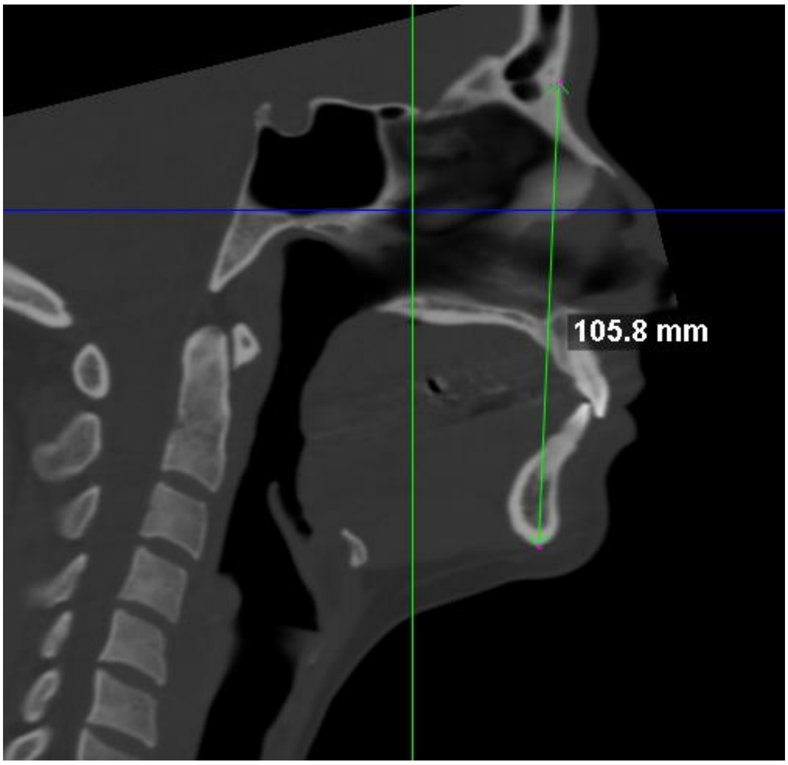

Figure 11: Anterior facial height

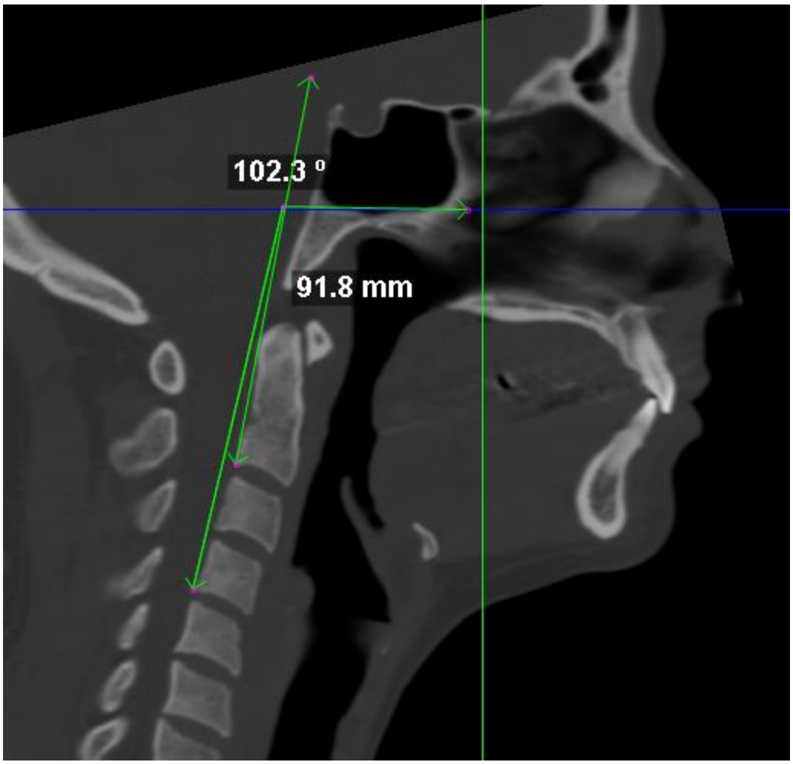

Figure 12: Cervical vertebrae angulation

5. RESULTS

All the airway parameters measured in the current study showed higher values at T2 compared to T1 except for nasal cavity volume where T1 was higher than T2 (Table 2). Statistically significant differences were recorded in the nasopharynx volume ($p=0.04$), oropharynx volume ($p=0.02$), and minimum axial area ($p=0.05$) indicating that these parameters recorded in the upright position were significantly higher as compared to the supine position. Although the soft tissue thickness and soft palate measurements in the upright position recorded higher values than those in the supine position, the differences were not statistically significant except for the soft tissue thickness measured anterior to CV3 which showed statistically significant increase in the upright position ($p=0.01$) (Table 3). All cephalometric parameters that were investigated in this study did not show statistical significance differences between the supine and upright positions (Table 4).

Table 2: Comparison of airway parameters in supine and upright positions

	T1				T2				Change				t	P-value
	Mean	SD	Max	Min	Mean	SD	Max	Min	Mean	SD	Max	Min		
Nasal cavity volume	13354.6	7089.2	32051	3604	11905.9	7246.9	39017.0	895.0	-1352.0	10628.2	28656	-31116	-0.12	0.45
Nasopharynx Volume	5855.9	1659.5	8973	2901	6008.3	1610.5	9019	2840	152.4	554.3	2092	-1534	-1.09	0.04*
Nasopharynx area	280.5	75.2	477	165	292	72.5	477	161	11.5	41	109	-63	-1.12	0.14
Oropharynx Volume	6923.3	2418.6	11512	486	8514.5	3214.1	17889	3178	1591.2	3685.9	8542	-6687	-2.05	0.02*
Oropharynx Area	493.9	181.8	884	185	652.6	1250.2	7239	167	158.7	1287.3	6885	-617	0.01	0.50
Hypopharynx Volume	1561.0	763.4	3355	426	1565.2	932.5	3708	341	4.2	1075.7	1848	-2490	2.23	0.98
Hypopharynx Area	89.6	58.4	280	15	95.4	47.4	219	15	5.7	59.2	150	-130	0.25	0.60
Total Airway Volume	14540.2	4024	21090	1610	15408.6	4716.4	28627	1170	868.4	3985.6	9570	-7962	-0.71	0.24
Total Airway Area	816.5	165.6	1283	437	856.3	202.4	1374	479	39.8	239.1	532	-401	-0.34	0.37
Minimum Axial Area	63.7	32.3	131	18	74.4	44.8	176	24	10.7	28.7	73	-59	-1.71	0.05*

*statistically significant p-value

Table 3: Comparison of soft tissue thickness of airway in supine and upright positions

	T1				T2				Change				t	P-value
	Mean	SD	Max	Min	Mean	SD	Max	Min	Mean	SD	Max	Min		
soft tissue thickness from anterior inferior CV4	19	4.5	32	9	19.6	4.2	32.7	12.9	0.6	6.4	15.2	-14.7	0.29	0.61
soft tissue thickness from anterior superior CV4	15.4	3.6	21.5	7.5	16.3	5	26.3	8.4	1.0	5.7	16.3	-8.6	-0.36	0.36
soft tissue thickness from anterior inferior CV3	11.5	3.2	17.7	6.5	14.6	4.8	24.7	7.1	3.1	5.9	18	-4.9	-2.60	0.01*
soft tissue thickness from anterior superior CV3	14.9	4.6	23.1	7.4	15.5	3.8	24.5	9.8	0.6	5.6	10.4	-10.1	0.14	0.55
soft tissue thickness from anterior inferior CV2	13.2	5.0	25.6	0	13.6	4.6	24	0	0.4	6.7	12.7	-17.6	0.67	0.75
soft tissue thickness from anterior CV1	15.9	4.9	23.8	2.8	16.6	5.0	28.8	8.5	0.7	6.3	11.9	-10.9	0.14	0.56
soft palate area	284.7	71.2	417.9	144.1	307.1	102.5	603.3	185.4	22.3	113.6	275.7	-184.8	-0.56	0.29

*statistically significant p-value

Table 4: Comparison of cephalomateric parameters in supine and upright positions.

	T1				T2				Change				t	P value
	Mean	SD	Max	Min	Mean	SD	Max	Min	Mean	SD	Max	Min		
ANB	4.2	2.1	9.4	0.1	4.2	2.1	9.2	0.3	-0.02	0.3	0.8	-0.6	0.63	0.73
N perpendicular to Pog	5.5	7.6	25.2	-8.7	4.5	8.2	26.8	-10.4	-0.9	3.9	1.6	-21.5	-0.75	0.23
Overjet	3.8	1.4	7.5	1.1	3.8	1.4	7.3	1.1	-0.1	0.3	0.4	-1.1	-1.19	0.12
Anterior Facial Height	115.4	6.9	130.2	102.8	115.5	6.9	130.9	101.8	0.1	0.8	3.4	-1.1	0.43	0.66
Cervical Vertbrae Angulation	93	9.0	108.8	76.3	89.7	6.8	104.3	78.1	-3.4	9.5	14.6	-24.5	-1.59	0.06

6. DISCUSSION

OSA is a common respiratory disorder characterized by repetitive episodes of airway collapse during sleep, generating an interruption in breathing, affecting the quality of life and representing a risk factor for other diseases (Lawati et al, 2009). Airway changes associated with supine vs upright position on the different airway areas and the most constricted area have not been extensively investigated using three-dimensional imaging. The aim of the current study was to assess the effect of supine and upright imaging positions on airway dimensions in patients with obstructive sleep apnea using CBCT.

Even though lateral cephalometric radiographs have been routinely used to assess the airway dimension, CBCT has revealed more reliable information about the upper airway space. Since CBCT is three-dimensional, it allows clinicians to accurately assess the airway space and surrounding structures in such a way that provides crucial information about the three-dimensional measurements of the nasopharynx, the oropharynx and the hypopharynx. These measurements include airway volume, the most constricted area and pharyngeal dimensions in OSA patients. Ghoneima and Kula, (2013) evaluated the accuracy and reliability of airway volume digital measurements of CBCT compared with the manual measurements of an airway model. They found that the three-dimensional CBCT scan is a simple, reliable, and effective method to accurately measure the airway volume.

In the current study, the Epworth Sleepiness Scale (ESS) was used to identify patient's at risk of OSA. ESS is a self-administered questionnaire that measures a subject's general level of daytime sleepiness (Johns, 1991). ESS is commonly used to measure subjective sleepiness by using 0-3 scale in which (0) indicates 'would never doze' and (1, 2 and 3) indicate that there is a slight, moderate, and high chance of dozing throughout the day or during critical activities. Even though it is brief and simple to fill out, subjects can over- or underscore (Banerjee, 2007). Another disadvantage lies in the fact that it is subjective but can be considered reliable measuring tool for assessing the daytime sleepiness in adult subjects (Banerjee, 2007).

Currently, no studies have investigated the effects of the supine and upright positions on the different airway areas of nasal cavity, nasopharynx, oropharynx, hypopharynx, and the most constricted airway area using 3D imaging. Therefore, using CBCT to investigate that is of paramount importance to aid in understanding the effect of position on upper airway measurements.

Lateral positioning has been shown to markedly improve passive airway collapsibility and the ability of the airway to dilate (Joosten et al, 2015). This confirms the finding of the current study where airway measurements were reduced in the supine position as compared to the upright imaging position with statistical significance found in the airway volume of nasopharynx, oropharynx and the most constricted area of the airway. The decrease of the airway volume could be explained by the fact that the soft palate and the epiglottis might take a lower position and drop off impinging on the airway space while patients are lying on their back. According to a study conducted by Penzel et al, they concluded that pharyngeal critical pressure decreased form supine to lateral position (Penzel et al, 2001).

Another study by Kim et al, found that the change in the position of the patient from supine to lateral position expanded the upper airway, especially the retroglossal space (Kim, 2019). This also confirms the fact that the position of the patient during imaging acquisition does influence airway measurements. The improvement demonstrated in the lateral position may be due to changes in the structure of the airway in the lateral position and increased activity of pharyngeal dilator muscles (Menon, 2013). It has also been reported by Camacho, et al in 2014 that the total airway volume and cross-sectional area measurements decreased when patients were in supine position as compared to upright position (Camacho, 2014).

In a study conducted by Ghoneima, et al in 2017 to evaluate the effect of the mandibular advancement appliances on the airway in patients with OSA they reported statistically significant decreases in the soft tissue thickness of the airway at the nasopharynx and oropharynx areas. This was associated with increase in the airway volume at the same areas. In the current study, we found significant increase in the airway volume at the nasopharynx and oropharynx areas. The prevertebral soft tissue thickness and soft palate measurements showed increase in the upright position when compared with the supine position but no statistical significance differences were found except for the soft tissue thickness measured anterior to CV3. The contradictory findings in the soft tissue thickness could be due to the effect of the mandibular advancement appliances that was used in the former study which possibly causes stretching of the soft tissue thickness.

Ferguson et al in 2006 reported that the severity of OSA might be affected by several factors related to the position of individuals during sleep. In agreement with previous studies, this study has found that the position of the patients does in fact influence airway measurements at the nasopharynx, oropharynx, and the most constricted area of the airway (Ferguson et al, 2006).

The cephalometric parameters that were investigated in this study such as ANB, N perpendicular to Pogonion, overjet and cervical vertebrae angulation, with the exception of anterior facial height, showed that the measurements in the supine position were greater than in the upright position but with no statistical significance differences. This could be related to the backward movement of the mandible when the patients were scanned in the supine position therefore affecting certain parameters. In our study, no significant differences were found in the cervical vertebrae angulations. This eliminates any variables related to the scanning orientation that might impact the airway space and also indicates that patient's head was well oriented during the scanning time.

Potential limitation associated with this study is the sample size as some of the CBCT scans were excluded since they were not clear and/or some anatomical landmarks were not easy to find. Confounding factors, such the Body Mass Index (BMI) and female gender, that were not included in the study could have had a potential influence on the study outcomes if they have been included.

7. CONCLUSION

The findings of the present study demonstrated that there were significant differences in the airway volume at the nasopharynx, oropharynx, and the most constricted airway area when OSA patients were scanned in an upright position as compared to supine position. These are important findings as we can extrapolate that OSA patients can avoid lying in supine position when sleeping to ensure that the airway volume is not impacted during sleep and less potential risk for airway collapsibility. Clinicians should also pay attention to the position of the patient during imaging acquisition since it significantly affects the dimensions of the airway volumetric measurements while imaging being analyzed. Further studies are required to confirm the results evident in this study.

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