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INVESTIGATION OF THE DIMENSIONAL CHANGES OF MAXILLARY SINUSES AND PHARYNGEAL AIRWAY IN CLASS III PATIENTS UNDERGOING BIMAXILLARY ORTHOGNATHIC SURGERY

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II. CONTENTS

III. ABBREVIATIONS

>: Greater than

≥: Equal to or greater than

<: Smaller than

3D: 3 Dimensional

ANS: Anterior Nasal Spine

BSSRO: Bilateral Sagittal Split Ramus Osteotomy

CBCT: Cone Beam Computed Tomography

COGS: Cephalometrics for Orthognathic Surgery

DICOM: Digital Imaging and Communications in Medicine

Et al: And others

FH: Frankfort Horizontal

Fig.: Figure

FOV: Field Of View

G´: Glabella

Gn: Gnathion

Go: Gonion

HAS: Hyperinsomnia Sleep Apnea

HP: Horizontal Plane

HU: Hounsfield Units

IVRO: Intraoral Vertical Ramus Osteotomy

KV: Kilovolt

L.M.S.1: Left Maxillary Sinus Before Surgery

L.M.S.2: Left Maxillary Sinus After Surgery

L.P.A.1: Lower Pharyngeal Airway Before Surgery

L.P.A.2: Lower Pharyngeal Airway After Surgery

L.P.A.D: Lower Pharyngeal Airway Difference

M.C.S.A.1: Minimal Cross-Sectional Area Before Surgery

M.C.S.A.2: Minimal Cross-Sectional Area After Surgery

MRI: Magnetic Resonance Imaging

MS-CT: Multi-Slice Computed Tomography

n: Number

N: Nasion point

OSA : Obstructive Sleep Apnea

p: probability

PAS : Pharyngeal Airway Space

Pg: Pogonion point

PNS: Posterior Nasal Spine

PONV: Post Operative Nausea Vomiting

r: Correlation Coefficient

RIF: Rigid Internal Fixation

R.M.S.1: Right Maxillary Sinus Before Surgery

R.M.S.2: Right Maxillary Sinus After Surgery

Ru: Radius union

SD: Standard Deviation

Sig.: Significance

Sn: Subnasale

SpO_2: Arterial Oxygen Saturation

SRBD: Sleep-Related Breathing Disorders

T: Time

TMD: Temporomandibular Disorders

TMJ: Temporomandibular Joint

T.M.S.1: Total Maxillary Sinus Before Surgery

T.M.S.2: Total Maxillary Sinus After Surgery

T.M.S.D: Total Maxillary Sinus Difference

T.P.A.1: Total Pharyngeal Airway Before Surgery

T.P.A.2: Total Pharyngeal Airway After Surgery

T.P.A.D: Total Pharyngeal Airway Difference

U.P.A.1: Upper Pharyngeal Airway Before Surgery

U.P.A.2: Upper Pharyngeal Airway After Surgery

U.P.A.D: Upper Pharyngeal Airway Difference

X: Mean

IV. GRAPH, FIGURE AND TABLE LIST

1. SUMMARY

The aim of this study was to evaluate the pharyngeal airway and maxillary sinus volume changes after bimaxillary surgical treatment of Class III skeletal deformities. Seventeen Class III skeletal patients (11 females, 6 males) who required bimaxillary orthognathic surgery as a part of their orthodontic treatment were selected. Volumetric measurements were performed using Cone Beam Computed Tomograpy (CBCT) scans, preoperatively and 3.9±0.87 months postoperatively. All the CBCTs were assessed and analyzed using MIMICS 14.0 software launched by Materialise (Materialise Europe, World Headquarters, Leuven, Belgium), in order to reconstruct three-dimensional images and calculate the volume of the pharyngeal airway and the maxillary sinuses. The preoperative and postoperative volumes of pharyngeal airway and maxillary sinuses, and the relation between the amounts of surgical movements of the jaws and the above volumes were statistically evaluated. The results of the present study showed a significant decrease only for lower and total pharyngeal airway volumes in males, a significant decrease in the volume of maxillary sinus, and no correlation between the skeletal movements and the volumetric changes of the pharyngeal airway and the maxillary sinus.

Key words: Pharyngeal airway, maxillary sinus, Cone Beam Computed Tomography, Class III bimaxillary orthognathic surgery

2. ÖZET

Sınıf III Hastaların Çift Çene Ortognatik Cerrahi Sonrası Maksiller Sinüslerinde ve Farengeal Hava Yollarında Oluşan Boyutsal Değişikliklerin İncelenmesi

Bu çalışmanın amacı, iskeletsel Sınıf III vakaların çift çene ortognatik cerrahi sonrası farengeal hava yolu ve maksiller sinüs hacim değişikliklerini değerlendirmektir. Çalışma için iskeletsel Sınıf III malokluzyona sahip ortodontik tedavi ile birlikte bimaksiller ortognatik cerrahi gerektiren 17 hasta (11 kadın, 6 erkek) seçilmiştir. Volumetrik ölçümler operasyon öncesinde ve operasyondan 3.9±0.87 ay sonra alınan Cone Beam bilgisayarlı tomografi (CBBT) görüntüleri üzerinde yapılmıştır. Tüm CBBT görüntüleri yeniden üç boyutlu görüntü oluşturmak, farengeal hava yolu ve maksiller sinüs hacmini ölçmek amacıyla Materialise firması (Materialise Avrupa, Genel Merkez, Leuven, Belçika) tarafından hazırlanan MIMICS 14.0 yazılımı kullanılarak analiz edilmiş ve değerlendirilmiştir. Farengeal hava yolu ve maksiller sinüslerin preoperatif ve postoperatif dönemdeki hacimleri ve bu hacimsel değişiklikler ile cerrahi operasyon sırasında yapılan çene hareketlerinin miktarları arasındaki ilişki istatistiksel olarak değerlendirilmiştir. Bu çalışma erkeklerde sadece alt ve toplam farengeal hava yolu hacminde önemli miktarda azalma olduğunu, maksiller sinüste önemli miktarda azalma olduğunu ve iskeletsel hareketler ile farengeal hava yolu ve maksiller sinüs hacmindeki değişiklikler arasında bir korelasyon bulunmadığını göstermiştir.

Anahtar Kelimeler: farengeal hava yolu, maksiller sinüs, Konik ışınlı bilgisayarlı tomografi, Sınıf III bimaksiller ortognatik cerrahi

3. INTRODUCTION AND AIMS

In patients with severe skeletal and dental dysplasias where orthodontics alone cannot lead to a desirable result, combined orthodontic-orthognathic surgical treatment offers a solution to the problem.

Class III deformity can be the result of mandibular anteroposterior true prognathism, maxillary deficiency, or both of these conditions occurring simultaneously (Degerliyurt et al 2008, Samman, Tong, Cheung, Tideman 1997).

In the past, the surgical treatment of Class III anteroposterior excess was achieved by various types of mandibular setback surgeries alone (Degerliyurt et al 2008). Later studies indicated that isolated mandibular anteroposterior excess occurs approximately in only 20% to 25% of Class III cases. Some maxillary skeletal anteroposterior deficiency is also involved in 75% of cases with Class III deformities (Degerliyurt et al 2008, Reyneke 2003). Moreover, in some Class III skeletal cases, vertical maxillary excess or deficiency can exist as well. For the cases where both mandible and maxilla are responsible for the skeletal deformity, bimaxillary surgery is indicated. In these cases, in addition to mandibular setback, the maxilla is repositioned in the anteroposterior or in the vertical direction, or in both directions, depending on the etiology of the skeletal deformity.

Both mandibular setback surgery and bimaxillary surgery can improve occlusion, masticatory function, and esthetics by significantly changing the position of the maxilla and mandible (Degerliyurt et al 2008).

Surgical changes in the position of the facial skeleton will inevitably alter the soft tissue-hard tissue relationships. A very important aspect of the surgical correction of a skeletally Class III relationship, is that it causes changes in the position of the hyoid bone and the tongue. However, shortly after mandibular setback the hyoid bone goes downward for physiologic adaptation to the soft tissue (Kawakami et al 2005, Muto, Yamazaki, Takeda, Sato 2008).

Moreover, the morphology of the soft palate changes significantly. The reasons may be that the tongue base shifts posteriorly when the mandible is set back. This change in the tongue base causes the palatoglossus muscle to become less upright increasing the length of the soft palate. The posterior shift of the tongue base is associated with an increase in the contact length between the soft palate and the tongue. This change appears to push the soft palate posteriorly and decrease the Pharyngeal Airway Space (PAS) (Muto et al 2008).

Due to these changes in hard and soft tissues, it has been suggested that mandibular setback surgery produces a shift in oropharyngeal characteristics to a morphology commonly associated with sleep disordered breathing, typified by Obstructive Sleep Apnea (OSA) (Hochban, Schürmann, Brandenburg, Conradt 1996, Riley, Powell, Guilleminault, Ware 1987).

OSA is a potentially life threatening disorder caused by narrowing and obstruction of the upper airway during sleep. Reduced pharyngeal airway space is due to structural narrowing of the pharynx and/ or the base of the tongue against the posterior pharyngeal wall (Fairburn et al 2007). OSA has been associated with loud snoring and apnea. It is regarded as one of the risk factors of hypertension, ischemic myocardial disease and cerebral vascular disease. It is also thought to be one of the causes of traffic accidents (Turnbull and Battagel 2000, Kitagawara et al 2008).

There have been some reports of cases of sleep-disordered breathing caused by mandibular surgery, as a result of changes in the position of the hyoid bone and the tongue (Riley et al 1987, Kitagawara et al 2008).

Turnbull et al in a study based on cephalometric radiographs of 32 orthognathic surgery cases found that there was a significant decrease in the retrolingual airway dimension after mandibular setback surgery (Turnbull and Battagel 2000).

Kitagawara et al (2008), studied the effects of mandibular setback surgery in 17 subjects and concluded that, postoperatively, inferior displacement of the hyoid bone and decreased arterial oxygen saturation (SpO_2) was found.

In bimaxillary surgery where maxilla is advanced in addition to mandibular setback, this effect may be less pronounced, as shown by the conflicting results between the authors.

Chen, Terada, Hua, Saito (2007), found no significant upper airway changes two years after bimaxillary surgery, while Degerliyurt et al (2008), concluded that bimaxillary surgery rather than mandibular setback alone, is preferable to correct a Class III deformity in order to prevent narrowing of the PAS.

Conversely, Degerliyurt et al (2009), stated that in the skeletal Class III patients receiving double jaw surgery, the anteroposterior dimension of the pharyngeal airway was the most narrowed part.

Marşan et al (2009) based on a study of 53 lateral cephalometric radiographs of female Class III patients treated by bimaxillary surgery, stated that that bimaxillary surgery causes an increase in upper retropalatal airway space and a posterior and inferior movement of hyoid bone one week postoperatively.

It is also postulated that the inflammatory process after the surgery increases the thickness of the velum and narrows the upper airway (Chen et al 2007).

It becomes apparent that due to the contradicting outcomes, there are no distinct results about this issue.

It has also been noted that maxillary impaction surgery may influence the maxillary sinus. It is reported that the superior positioning of the maxilla by removal of bone in the vertical direction may result in a decrease in the maxillary sinus area (Halawa 2005). The clinical implications of such a decrease in sinus area are unknown. Until now there has been no report of the volumetric changes in the maxillary sinuses after bimaxillary surgery of Class III cases.

The majority of research in the past has measured airway and maxillary sinuses in two dimensions mainly, whereas they are three-dimensional structures.

Three-dimensional craniofacial imaging techniques are becoming increasingly popular and have opened new possibilities for patient diagnosis, treatment planning and follow–up (Swennen and Schutyser 2006). After the development of spiral Multi-Slice Computed Tomography (MS-CT), high quality, accurate and reliable quantitative 3-dimensional (3D) data could be provided. Furthermore, a new generation of dentofacial imaging system, namely Cone Beam Computed Tomography (CBCT), was relatively recently introduced, contributing in the diagnosis and treatment planning of maxillofacial deformities.

Even though CBCTs are nowadays widely used in the diagnosis and treatment planning of maxillofacial deformities, there are limited publications available in the literature, concerning this three-dimensional imaging technique.

The purpose of the current study was to evaluate-using 3D CBCTs- the pharyngeal airway and maxillary sinus volume changes, following bimaxillary surgical treatment of Class III skeletal deformities. In addition, we also aimed to determine if a correlation existed between the amounts of the surgical movements of the jaws and the amounts of changes in the volumes of the pharyngeal airway and maxillary sinus.

4. LITERATURE REVIEW

4.1 History of Orthognathic Surgery

Surgery for mandibular prognathism began early in the twentieth century with occasional treatment that consisted of a body osteotomy, removing a molar or premolar tooth and an accompanying block of bone (Proffit, Fields, Sarver 2007). Edward Angle, commenting on a patient who had treatment of this type of surgery over 100 years ago, described how the result could have been improved if orthodontic appliances and occlusal splints have been used (Proffit et al 2007). Although there was gradual progress in techniques for setting back a prominent mandible throughout the first half of this century, the introduction of the sagittal split ramus osteotomy in 1957 marked the beginning of the modern era in orthognathic surgery (Proffit et al 2007, Trauner and Obwegeser 1957). This technique used an intraoral approach, which avoided the necessity of a potential disfiguring skin incision (Proffit et al 2007). The sagittal split design also offered a biologically sound method for lengthening or shortening the lower jaw with the same bone cuts, thus allowing treatment of mandibular deficiency or excess (Proffit et al 2007).

During the 1960s, American surgeons began to use and modify techniques for maxillary surgery that have been developed in Europe, and a decade of rapid progress in maxillary surgery culminated in the development of the Le Fort I downfracture technique that allowed repositioning of the maxilla in all three planes of space (Proffit et al 2007, Bell 1975, Epker and Wolford 1975). By the 1980s, it was possible to reposition either or both jaws, move the chin in all three planes of space, and reposition dentoalveolar segments surgically as desired. In the 1990s, rigid internal fixation (RIF) greatly improved patient comfort by making immobilization of the jaws unnecessary, and a better understanding of typical patterns of postsurgical changes made surgical outcomes more stable and predictable (Proffit et al 2007).

4.2 Class III Skeletal Relationship

4.2.1 Etiology

The etiology of skeletal orthodontic problems can arise from a number of causes: Inherited patterns, defects in embryologic development, trauma and functional influences can contribute (Proffit et al 2007). Specific genetic syndromes or congenital defects involving the jaws are rare (Proffit et al 2007).

There is a definite familial and racial tendency to mandibular prognathism. Excessive mandibular growth could arise because of mandibular posture, since constant distraction of the mandibular condyle from the fossa may stimulate growth. Functional mandibular shifts affect only tooth position, however, constant posturing because of respiratory needs, tongue size or pharyngeal dimensions may affect the size of the jaw. It is almost entirely unknown why maxillary deficiency occurs, but a simple environmental cause appears unlikely, and the majority of Class III problems are related to inherited jaw proportions (Proffit et al 2007).

4.2.2 Treatment

There are three main treatment options for skeletal Class III malocclusion: growth modification, dentoalveolar compensation (orthodontic camouflage), and orthognathic surgery. Growth modification should start before the pubertal growth spurt. After this spurt, only the last two options are possible (Rabie, Wong, Min 2008).

Surgical correction of Class III malocclusion can be achieved by mandibular setback, maxillary advancement, or combination of both procedures (Rabie et al 2008). In cases where bimaxillary surgery is needed, mandibular setback can be combined with maxillary advancement or impaction or a combination of the last two. In cases with deficit in maxillary height, maxilla is inferiorly placed, increasing the vertical dimension.

4.2.3 Orthognathic surgery

4.2.3.1 Mandibular setback surgery

A bilateral sagittal split ramus osteotomy (BSSRO) or an intraoral vertical ramus osteotomy (IVRO) can be performed.

Technically, the IVRO is a much simpler, faster, and less morbid procedure, compared to BSSRO (Nanda 2005). However, the sagittal split osteotomy is now used for almost all mandibular surgery because of the following advantages (Proffit, et al 2007):

- The mandible can be moved forward or back as desired, and the tooth-bearing segment can be rotated down anteriorly if additional anterior face height is desired.
- It is quite compatible with the use of RIF.
- Excellent bone-to-bone contact after the osteotomy minimizes healing problems.

Nanda (Nanda 2005) describes the most common cephalometric indications for orthognathic surgery, based on the cephalometrics for orthognathic surgery (COGS) analysis, introduced by Burstone (Burstone, James, Legan, Murphy, Norton 1978).

The base line for the measurements is the constructed Horizontal Plane (HP), which is a plane constructed by drawing a line 7° to the SN plane. The measurements are made from projections parallel or perpendicular to the constructed HP.

Cephalometric measurements that will assist in the diagnosis of mandibular hyperplasia include:

- Increased mandibular projection (N-B)
- Chin projection (N-Pg)
- Normal maxillary projection (N-A and G'-Sn)

Some of the clinical characteristics include:

- Retroclined mandibular incisors
- Minimal mandibular arch length deficiency
- Minimal curve of Spee

4.2.3.2 Maxillary orthognathic surgery

The Le Fort I osteotomy with down-fracture of the maxilla dominates contemporary maxillary surgery. It allows the maxilla to be moved up and/or forward with excellent stability.

Impaction

The most common indication for maxillary surgery is vertical maxillary excess. Some of the cephalometric indications for maxillary impaction surgery according to the COGS analysis (Nanda 2005), include:

- Increased upper and lower facial height (N-ANS and ANS-Gn)
- Increased mandibular plane angle (MP-HP)
- Increased posterior facial height (S-PNS)
- Increased gonial angle (Ar-Go-Gn)
- Increased facial height ratio (N-ANS/ANS-Gn)
- Divergent occlusal planes

A typical clinical presentation includes:

- Increased tooth-to-lip relation
- Increased gingival display
- Increased interlabial gap
- Relative mandibular deficiency
- Anterior open bite (not always present due to dentoalveolar compensations and teeth overeruption)

Advancement

Some of the COGS analysis indicators for maxillary anteroposterior deficiency and normal mandibular position include:

- Nasion –A point (N-A) mm
- Nasion –B point (N-B) mm
- Nasion –Pogonion (N-Pg) mm

Clinical indicators for performing maxillary advancement include:

- Decreased pharyngeal airway
- Excessive submental adipose tissue
- Decreased malar convexity
- Increased nasolabial grooves upon smiling

Inferior Repositioning (Down graft)

Vertical maxillary deficiency is less common than vertical maxillary excess. Some of the indicators within the COGS analysis for inferior maxillary repositioning include:

- Decreased lower facial height (ANS-Gn)
- Decreased mandibular plane angle (MP-HP)
- Decreased gonial angle (Ar-Go-Gn)
- Increased facial height ratio (N-ANS/ANS-Gn)
- Deep overbite

A typical clinical presentation includes:

- Decreased tooth –to- lip relation
- Decreased gingival display
- No interlabial gap
- A relative mandibular prognathism and /or prominent chin button

4.2.4 Changes caused by surgical correction of Class III malocclusion

According to Reyneke (2003) the changes induced by surgical correction of Class III malocclusion are the following:

4.2.4.1 Mandibular setback

Frontal changes

- Decrease in mandibular prominence
- Upper lip vermilion becomes more prominent
- Decrease in lower third face height

Profile changes

- Decreased mandibular anteroposterior prominence
- Reduced lower lip vermilion exposure
- Reduced chin-throat length
- Increased chin-throat angle

4.2.4.2 Maxillary impaction

Frontal changes

- Reduced maxillary incisor exposure
- Reduced upper lip vermilion exposure
- Reduced interlabial distance
- Reduced upper lip length (controllable)
- Reduced lower -third face height
- Reduced gingival exposure when smiling
- Increased alar base width (controllable)

Profile changes

- Elevated nasal tip (controllable)
- Reduced lower -third face height
- Reduced interlabial distance
- Increased mandibular anteroposterior prominence (autorotation)
- Increased paranasal fullness

4.2.4.3 Maxillary advancement

Frontal changes

- Elevated nasal tip
- Increased upper lip fullness
- Increased upper lip vermilion exposure
- Increased paranasal fullness

Profile changes

- Increased paranasal area fullness
- Elevated nasal tip (controllable)
- Increased upper lip fullness
- Decreased prominence of chin and nose (relative)

4.2.4.4 Maxillary down graft

Frontal changes

- Increased lower-third face height
- Increased upper lip length
- Increased upper lip vermilion exposure
- Increased maxillary tooth exposure

Profile changes

- Increased upper lip prominence
- More obtuse nasolabiale angle
- Less prominent mandible anteroposteriorly (autorotation)

4.2.5 Side effects - Complications

Orthognathic surgery may have certain complications.

During surgery, unanticipated fractures, that make fixation and stabilization difficult, may occur (Kim and Park 2007). This is most common in the mandibular ramus with the bilateral sagittal split osteotomy and in the pterygoid plates with the Le Fort I osteotomy (Kim and Park 2007). When an impacted third molar is present, the frequency of bony fragmentation could increase (Kim and Park 2007, Mehra, Castro, Freitas, Wolford 2001). Inappropriate bone fragmentation could result in sequestrum formation, delayed union, non-union, or fibrotic union at the side of bone fragmentation. (Kim and Park 2007, Guernsey and DeChamplain 1971).

Hemorrhage can rarely occur in the intraoperative period, although bleeding from larger vessels may be difficult to control in some cases, because of difficulty with access (Kim and Park 2007, Proffit, White, Sarver 2003).

Tooth injury may occur in cases undergoing Le Fort I osteotomy and genioplasty combined with anterior segmental osteotomy (Kim and Park 2007).

Soft tissue injury can occur during various stages of surgery, for example if traction of the lip or mucosa is prolonged in order to secure the operative field and facilitate access (Kim and Park 2007).

The inferior alveolar nerve is in close proximity to osteotomy cuts which poses risk for transaction (Kim and Park 2007, Proffit et al 2003). After sagittal split ramus osteotomy inferior alveolar nerve numbness is reported (Kim and Park 2007). Nerve distraction and secession can occur during lateral dissection of the ascending ramus of the mandible, the nerve can be cut during bony dissection using a bur or other instruments, the nerve can tear during the separation and movement of the distal and proximal bone fragments, and compression injury can occur during stabilization of the distal fragments (Kim and Park 2007).

Respiratory difficulty is an emergency. In that case insufficient air movement will be apparent, therefore the surgeon must assess current airway obstruction (Kim and Park 2007, Miloro, Ghali, Larsen, Waite 2004).

Neck pain is a temporary condition that disappears with time, however, some need medical diagnosis and treatment to relief the symptoms (Kim and Park 2007).

Postoperatively, anterior open bite may also occur due to a failure of the screws and\or plates at the time of fixation, or technical difficulties at the time of splitting the segments with resulting edema in the joints which resolves with time. Anterior open bite is more commonly seen in patients following an intraoral vertical ramus osteotomy when maxillomandibular fixation is released (Kim and Park 2007).

Another common concern is that rigid fixation may torque the condyles relative to the glenoid fossa (Kersey, Nebbe, Major 2003). Alteration of TMJ morphology may adversely affect function leading to temporomandibular disorders (TMD) (Kersey et al 2003). Moreover, orthognathic surgery can induce some tenseness or clicking on TMJs, and cause increased mandibular hypomobility due to atrophy and scarring on connective tissues (Dujoncquoy, Ferri, Raoul, Kleinheinz 2010).

Post-operative bleeding, nausea and vomiting (PONV), serosanginous nasal and post-nasal drainage-especially following maxillary osteotomy- are also common occurrences (Phillips, Blakey, Jaskolka 2008).

Additionally, reduction in the pharyngeal airway dimensions has been reported (Muto et al 2008), and this reduction is believed to be a factor leading to O.S.A syndrome (Turnbul and Battagel 2000).

Finally, reduction in the area of the maxillary sinuses after superior positioning of the maxilla has been reported by Halawa (2005). However, the clinical implications of such a change are still unknown.

4.2.6 Retention and stability

Stability after surgical repositioning of the jaws depends on the direction of movement, the type of fixation and the surgical technique. In the treatment of Class III patients, the maxilla remains just where it was placed in about 80% of the patients, and there is almost no tendency for major relapse (>4mm). With rigid fixation, the combination of maxillary advancement and mandibular setback is acceptably stable. In contrast, isolated mandibular setback is often unstable. So is downward movement of the maxilla that creates downward-backward rotation of the mandible (Proffit et al 2007).

Some changes are expected during the first post-surgical year, and the probability that relapse will occur with various directions of movement now have been well documented. Although most patients are quite stable long-term and present small average changes, 5-year follow- up data show that some patients have a significant amount of change in the position of skeletal landmarks beyond the first postsurgical year (Proffit et al 2007).

It is remarkable that although surgical correction of Class III problems is less stable than Class II correction in the short-term postsurgically, it appears to be more stable long-term (Proffit et al 2007).

4.3 Anatomy and Development

4.3.1 Anatomy and development of the pharyngeal airway

The pharyngeal airway is a complex structure. In conjuction with its surrounding structures, it is responsible for the physiologic processes of swallowing, vocalization and respiration (Schwab and Goldberg 1998). The airway is located posterior to the nasal cavity, oral cavity and larynx. It extends from the posterior part of the nasal turbinates until the esophagus inferiorly. The superior wall is formed by the body of the sphenoid bone and the basilar part of the occipital bone (Schwab and Goldberg, 1998). The nasal turbinates, soft palate, tongue, and glottis form the anterior border

(Burgess 2008). The posterior is formed by the pharyngeal constrictor muscles. The lateral walls contain adipose tissue, lymphoid tissue, and numerous muscles (Schwab and Goldberg 1998).

The airway is subdivided into three anatomical regions: the nasopharynx, the oropharynx and hypopharynx (Burgess 2008) (Fig. 1). The nasopharynx is the area between the nasal turbinates and the hard palate. The oropharynx consists of two areas: retropalatal (from the hard palate to the tip of the soft palate) and retroglossal (from the tip of the soft palate to the epiglottis). The hypopharynx extends from the epiglottis to the esophagus (Schwab and Goldberg 1998).

The form and function of the pharynx has been of interest to orthodontic researchers for many years. Pharyngeal space size is determined primarily by relative growth and size of the soft tissues surrounding the dentofacial skeleton.

Tourne (1991) reviewed the growth of the pharynx and concluded that the adult bony nasopharyngeal depth was established early in life. Taylor, Hans, Strohl, Nelson, Broadbent (1996), showed increase up to 12 years of age, while Linder-Aronson and Leighton (1983) showed increase up to 16 years of age. The longitudinal data of a study conducted by Johnston and Richardson (1999), indicated that while the bony periphery of the nasopharynx remains stable during adulthood, soft tissue changes induce a decrease in the sagittal depth of the nasopharynx, which does not undergo any significant change after 20 years of age. From adulthood to older age (20–50 years of age), the nasopharyngeal skeleton may change (Johnston and Richardson 1999).

In a study conducted by Grauer, Cevidanes, Styner, Ackerman, Proffit (2009) in a group of 62 non growing patients, based on Cone Beam Computed Tomography, it was stated that the average volume of the pharyngeal airway was 20.3±7.3 cm^3, with mean volumes of 8.8±2.9 cm^3 for the superior component and 11.5 ±4.9 cm^3 for the inferior component. They also found a statistically significant relationship ($p=0.01$) between sex and upper airway volume (Grauer et al 2009).

It has been suggested that a significant relationship exists between airway space and facial morphology (Jung, Cha, Chung 2007). Moreover, airway space may be affected by conditions such as functional anterior shifting (Ucar, Kurt, Ekizer, Ramoglu 2009), head posture (Zhong, Tang, Gao, Zeng 2010), sagittal skeletal relation (Hiyama et al 2002), and maxillary protraction (Oktay and Ulukaya 2008).

In the study of Ucar and Uysal (2011), it has been found that nasopharyngeal airway space, as measured in lateral cephalograms, was 5.0±1.4 mm^2 in low angle patients, in normal angle it was 4.3±1.1 mm^2 and in high angle patients 4.0±1.0 mm^2.

4.3.2 Anatomy and development of the maxillary sinus

The maxillary sinuses occupy a central position in the facial skeleton and are formed as a result of pneumatization of the maxilla. The base of the maxillary sinus is directed medially and is formed by the lateral wall of the nasal cavity. Its apex is directed superolateraly projecting into the zygomatic process. The anterior wall corresponds to the facial surface of the maxilla and the posterior wall to the infratemporal surface of the maxilla. Its roof is the orbital surface of the maxilla, and its floor is formed by the palatine and alveolar maxillary processes (Fig.2). The limits of the maxillary floor are usually marked anteriorly by the first bicuspid and posteriorly by a small recess posterior to the roots of the third molar. Recesses within the sinus can occur and when present are described as zygomatic, palatine, anterior, and alveolar (Graney 1986).

The maxillary sinus is the first of the paranasal sinuses to develop, and its growth ends with the eruption of the third molars at approximately 20 years of age. The adult sinus is variable in its extension (Kilic, Kamburoglu, Yuksel, Ozen 2010).

The maxillary sinus is reported as being the largest of the paranasal sinuses (Kawarai et al 1999, Sanchez Fernandez, Anta Escuredo, Sanchez Del Rey, Montoya 2000, Emirzeoglu, Sahin, Bilgic, Celebi, Uzun 2007), with its volume is fluctuating between 8.6 cm^3 and 24.9 cm^3 (Emirzeoglu et al 2007).

Investigations on the size of human maxillary sinuses revealed that volumetric values can differ depending on age, gender, state of dentition and even bilateral comparison in the same patient (Jun et al 2005, Ikeda, Ikeda, Komatsuzaki 1998).

Oktay (1992), investigated the maxillary sinus areas of the human beings on orthopantomograhs and found that malocclusions had no effect on the size of the maxillary sinuses but gender was a significant factor only in Class II malocclusions.

Ariji, Kuroki, Moriguchi, Ariji, Kanda (1994) made a study based on 115 CT scans in order to evaluate the age changes in the volume of the human maxillary sinus. He stated that there was no significant sex difference, there was a close correlation between right and left sides, and the maxillary sinus volume increased up to the age of 20 years, showing a decrease in the following years (Ariji et al 1994).

The same results were achieved also later, in 1996, when Ariji, Ariji, Yoshiura, Kanda (1996), utilized CT scans of 107 subjects to analyze the sinus volume, and they found an increase up to the age of 20, followed by a decrease in the next years.

In another study by Spaeth, Krügelstein, Schlöndorff (1997), it was stated that most of the sinuses of females are significantly larger than those of males of the same age until 5 or 6 years of age. However this tend reverses afterwards.

Shah, Dhingra, Carter, Rebeiz (2003), in their radiographic study found that maxillary sinus development in the lateral dimension was most significant during the ages of 1 to 8 years, and the development in the vertical dimension during the ages of 3 months to 5 years.

Barghouth et al (2002), analyzed the Magnetic Resonance Imaging (MRI) scans of 153 patients and concluded that maxillary sinuses measured at birth were 7.3±2.7 mm long, 4.0±0.9 mm high, and 2.7±0.8 mm wide, and the Sinus Volume Index (SVI) was 0.08 cm^3. They also observed that there is a rapid increase in anteroposterior growth during the first years of life. Craniocaudal and transverse diameters show gradual expansion until the end of adolescence. The dimensions of maxillary sinuses at 16 years of age were 38.8±3.3 mm long, 36.3±6.2 mm high, and 27.5 ±4.2 mm wide, and the SVI was 18.3 cm^3. Furthermore, they stated that they observed no statistically significant differences between left and right volume indexes and between males and females.

Jun et al (2005), in their study conducted using CT scans, suggested that the development of the maxillary sinus continued until the third decade in males and until the second decade in females. The mean maxillary sinus volume in early adults was 24,043 mm^3 (males) and 15,859.5 mm^3 (females). There was a significant difference in the sinus volume ($p<0.05$) according to gender, and there was also a significant difference in the sinus volume according to age before it reached maximum. After its maximum growth period, however, no statistically significant difference was observed in the volume change of maxillary sinus.

Emirzeoglu et al (2007), in their sterological study estimated the volumes of the paranasal sinuses and found that the bilateral mean volumes of the maxillary sinuses were 35.9±1.3 cm^3.

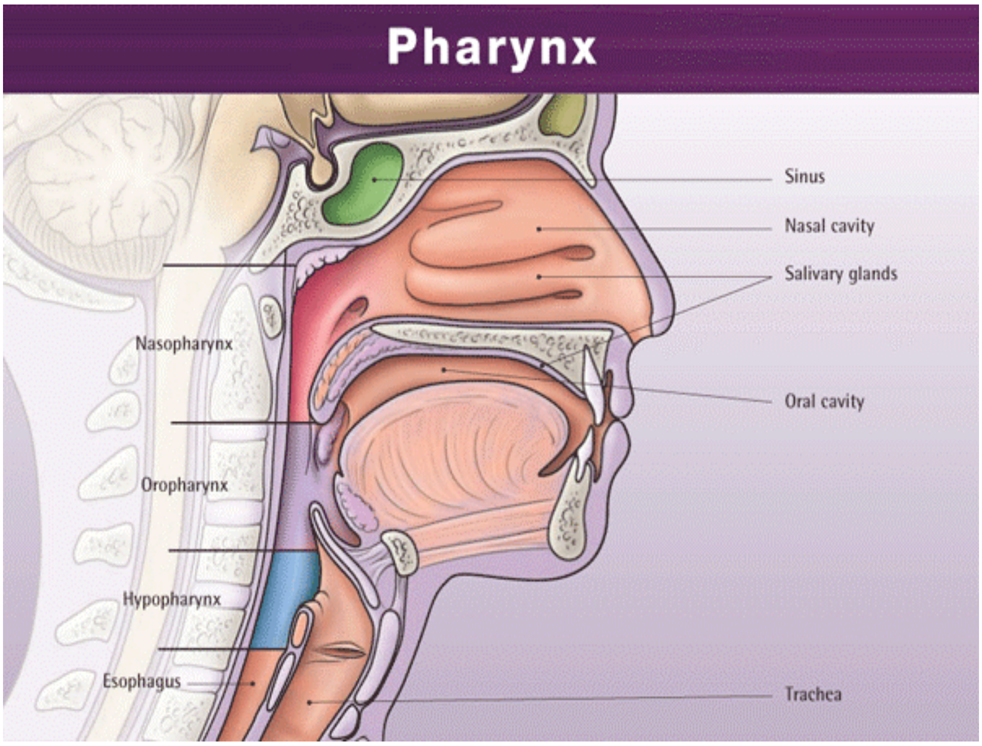


Figure 1: Anatomy of pharyngeal airway (www.painneck.com)

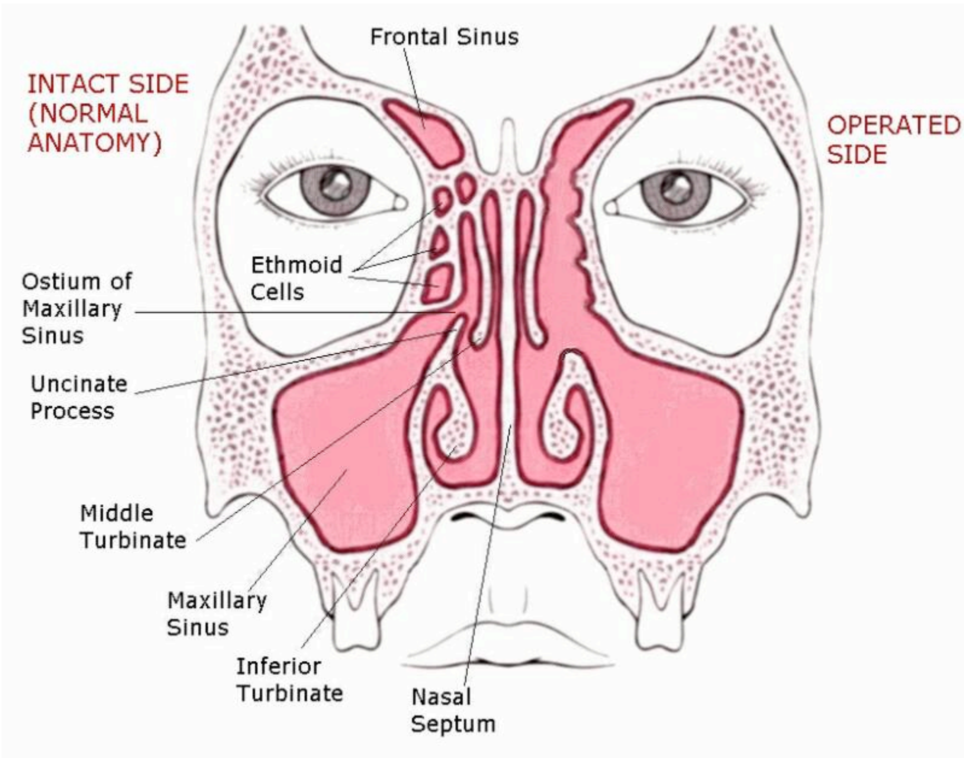


Figure 2: Anatomy of Maxillary Sinuses (www.ghorayeb.com)

4.3.3. Function of maxillary sinuses

There are various theories about the function of the maxillary sinuses. Blanton and Biggs claim that sinuses serve the following functions (Blanton and Biggs 1969):

- Impart resonance to the voice
- Humidify and warm the inspired air
- Regulate intranasal pressure
- Increase the area of the olfactory membrane
- Absorb shock applied to the head for protection of the sensory organs
- Secrete mucus for keeping the nasal channels moist
- Provide thermal insulation for the nervous centers
- Contribute to facial growth and architecture
- Lighten the bones of the skull for maintenance of proper balance of head and for flotation purposes.

4.4 Pharyngeal Airway and Class III Orthognathic Surgery

The soft palate, the tongue, the hyoid bone and the associated muscles are attached directly or indirectly to the maxilla and the mandible (Lye 2008). This means that movement of the jaws will not only affect the position of the above structures, but it will also cause changes in the tension of the attached soft tissue and muscle. This will result in an alteration in the volume of the nasal and oral cavities and PAS dimensions depending on the direction and magnitude of the skeletal movements (Lye 2008).

The orthognathic surgical procedures commonly used to correct Class III skeletal deformity are the mandibular setback combined or not with maxillary advancement and/or impaction as mentioned previously.

The effects of Class III orthognathic surgery in pharyngeal airway dimensions have been the subject of many studies (Chen, Terada, Hanada, Saito 2005, Muto et al 2008, Kitagawara et al 2008, Foltán et al 2009, Jakobsone, Neimane, Krumina 2010, Jakobsone, Stenvik, Espeland 2011, Hong, Park, Kim, Hong, Oh 2011).

4.4.1 Mandibular setback surgery

The isolated mandibular setback has been the subject of several studies (Takagi, Gamble, Proffit, Christiansen, 1967, Wickwire, White, Proffit 1972, Wenzel, Williams, Ritzau 1989, Athanasiou, Toutountzakis , Mavreas , Ritzau , Wenzel, 1991, Hochban et al 1996, Tselnik and Pogrel 2000, Kawamata, Fujishita, Ariji, Ariji 2000, Saitoh 2004, Kawakami et al 2005, Eggenperger, Smolka, Iizuka 2005, Lye 2008, Marşan, Cura, Emekli 2008 , Kitahara, Hoshino, Maruyama, In, Takahashi 2010, Park, Kim, Kim, Kim, Chang 2010). Surgical correction of mandibular prognathism was reported in an early study, by Takagi et al (1967), to alter the position of the hyoid bone by downward repositioning, carrying downwards the root of the tongue.

Later, Wickwire et al (1972), demonstrated a posteroinferior repositioning of the hyoid bone immediately postoperatively, which was followed by a tendency to return to its original position. This was also supported by Athanasiou et al (1991) and Enacar, Aksoy, Sençift, Haydar, Aras (1994). Posteroinferior displacement of the hyoid bone postoperatively, which moved the tongue in the similar vector, was also reported by Liukkonen, Vähätalo, Peltomäki, Tiekso, Happonen (2002) and Lye (2008).

Apart from the change in the position of the hyoid bone, many studies have also reported reduction in the dimensions of the pharyngeal airway after mandibular setback surgery (Riley et al 1987, Wenzel et al 1989, Greco, Frohberg, Van Sickels 1990, Katakura, Umino, Kubota 1993, Hochban et al 1996, Turnbull and Battagel 2000, Lye 2008)

There are conflicting views on the duration and degree of the postoperative changes in the hyoid bone position and PAS decrease (Lye 2008).

More specifically, Wenzel et al (1989), found a 2 mm decrease of nasopharyngeal airway following mandibular setback surgery

Kawakami et al (2005), showed that the hyoid bone returned to its original position after 1 year, narrowing simultaneously the retrolingual dimension. They also stated that mandibular setback causes airway narrowing late after surgery, while in the early postoperative period the airway dimension does not show any change.

Hochban et al (1996), conducted a polysomnographic evaluation for sleep-related breathing disorders, in patients that underwent mandibular setback surgery. They also performed cephalometric analysis 1 week, 3 months and 1 year postoperatively and concluded that PAS decreased considerably in all the patients.

Kawamata et al (2000), found that the lateral and frontal widths of the pharyngeal airway narrow after manibular setback surgery.

Saitoh (2004) evaluated the long term changes in pharyngeal airway morphology in 10 female patients. The subjects were assessed before treatment (T1), 3-6 months after BSSRO (T2), and 2 or more years after BSSRO (T3). From T1 to T2, the pharyngeal airway constricted significantly, while from T2 to T3, the lower facial morphology showed no significant changes. They also concluded that although the lower facial morphology and the pharyngeal airway morphology showed marked changes after BSSRO, the pharyngeal airway morphology exhibited gradual physiologic readaptation (Saitoh 2004).

Eggensperger et al (2005), in a study with follow up of 12 years concluded that the decrease in the lower PAS was stable but the upper and middle pharyngeal airway continued to decrease over the 12 years.

In a study conducted in Turkish Class III patients, Güven and Saraçoğlu (2005) reported that narrowing of the hypopharyngeal airway space due to posterior and inferior movement of the tongue can be permanent after mandibular setback surgery.

Chen et al (2005), studied the lateral cephalometric radiographs of 23 female adults who underwent mandibular setback surgery by BSSRO. The subjects were evaluated within 6 months before operation and 1 to 1.5 years after surgery. They produced a method for predicting airway changes after BSSRO and they concluded that a mandibular setback surgery could possibly predispose to the development of sleep apnea syndrome.

Marşan et al (2008) found that the lower facial morphology significantly changed and the pharyngeal airway narrowed 1.5 ± 0.4 years after mandibular setback surgery.

Degerliyurt et al (2009), in a study based on CT scans, concluded that the anteroposterior and cross-sectional area of the pharyngeal airway at the level of the soft palate and base of tongue were significantly reduced for men or women who received mandibular setback surgery.

Significant decreases in the lower PAS were observed after orthognathic surgery in Class III patients, according to Kitahara et al (2010).

Contrarily, Park et al (2010), reported that even though the structures around the mandible inevitably moved posteriorly after mandibular setback surgery, however, the airway was not reduced significantly by mandibular setback surgery, according to volumetric analysis.

4.4.2 Bimaxillary surgery

Bimaxillary surgery is considered to decrease the reduction effect of mandibular setback surgery (Degerliyurt et al 2008). A study performed by Chen et al (2007), showed that bimaxillary surgery, caused an increase at the nasopharyngeal level and decreases at the oropharyngeal and hypopharyngeal levels only in the short term, with no changes seen in the long term.

This is due to the following issues:

First, maxillary advancement results in adaptive changes of the soft palate in order to maintain velopharyngeal seal and palatal function (Lye 2008). Moreover, the posterior and superior movement of the tongue from the mandibular setback comes into contact and displaces the soft palate backwards and upwards (Lye 2008).

Combining the two factors, the soft palate becomes longer and thinner and the palatal angle increases (Lye 2008).

Samman, Tang, Xia (2002), investigated changes in the upper airway after surgical correction of Class III skeletal dentofacial deformity by measuring the cephalometric radiographs of 70 Class III subjects before surgery and 6 months after surgery. They also carried out a comparison of the results with those of a normal group of 74 subjects without deformity or surgery. They divided their sample in subgroups according to the type of surgery that was performed (mandibular setback or bimaxillary surgery) and they concluded that after mandibular setback, the tongue base was more posterior and the hypopharyngeal depth was reduced. The bimaxillary surgery group also demonstrated a more posterior tongue base but without reduction of the hypopharyngeal depth.

Chen et al (2005), in their study based on lateral cephalometric radiographs, concluded that -when possible- bimaxillary surgery rather than only mandibular setback surgery is preferable to correct a Class III deformity to prevent narrowing of PAS.

Similarly, a study by Degerliyurt et al (2008), suggested that bimaxillary surgery can prevent narrowing of the upper airway in the correction of Class III deformities in comparison with mandibular setback surgery used as the sole treatment.

Similar results were found by Marşan et al (2009), who found that bimaxillary surgery caused an increase in the upper retropalatal airway space, together with posterior and inferior movement of hyoid bone one week postoperatively.

Foltán et al (2009), investigated the impact of Le Fort I advancement and BSSRO setback on ventilation during sleep. Their results indicated that bimaxillary surgery for Class III malocclusion increased upper airway resistance.

In another study conducted by Jakobsone et al (2010), based on CT scans, bimaxillary surgery for correction of Class III malocclusion did not cause decrease of the posterior airway space.

More recently, Jakobsone et al (2010), concluded that a clinically significant advancement (≥2mm) of the maxilla increased significantly the airway dimension at the nasopharyngeal level, after simultaneous maxillary advancement and/or impaction and mandibular setback in skeletal Class III malocclusion.

Pereira-Filho et al (2011), conducted a study in Class III skeletal patients who underwent either bimaxillary surgery, mandibular setback, or maxillary advancement. They concluded that the patients who received mandibular setback, showed no changes in the PAS, while those who underwent maxillary advancement showed a significant increase of the PAS. The patients who were subjected to bimaxillary surgery presented changes in the PAS in the immediate postoperative period, however, the long term measurements at the oropharyngeal level returned to the preoperative values.

In another recent study, Hong et al (2011), evaluated the pharyngeal airway changes in skeletal Class III patients undergoing either mandibular setback alone, or bimaxillary orthognathic surgery. They found that the pharyngeal airway showed significant narrowing after both mandibular setback surgery and bimaxillary surgery, and that the amount of narrowing of the pharyngeal airway was smaller in patients undergoing bimaxillary surgery than in the patients undergoing mandibular setback surgery.

4.4.3 Class III surgery and OSA

OSA is a disorder characterized by repetitive upper airway collapse during sleep. It affects 5% of the general population with a male to female ratio 3:1 (Cheng and Darendeliler 2010). The hallmark of sleep apnea is snoring, accompanied by periodic airway obstruction and cessation of breathing, resulting in arousal and sleep fragmentation, which produces excessive daytime sleepiness. This is usually progressive, with the patient falling asleep in ever more active situations, and related to an increase in automobile accidents (Findley, Levinson, Bonnie 1992) The condition is potentially life threatening and the consequent reduction in blood oxygen saturation can give rise to hypertension, and cardiac and pulmonary complications (Turnbull and Battagel 2000).

Several anatomical and physiological factors have been suggested as causes of sleep apnea, but the disorder is likely to be due to inter-related factors, which in the presence of sleep and decreased muscle tone, lead to airway occlusion. A lot of studies have suggested differences in craniofacial structure in sleep apnea subjects, such as mandibular deficiency, bimaxillary retrusion, reduced cranial base length, increased lower face height, elongated soft palate, larger base of tongue, retropositioned tongue, short chin- neck line, decreased PAS, inferior position of the hyoid bone, and often Class II dental relationship (Turnbull and Battagel 2000, Mehra, Downie, Pita, Wolford 2001).

Many studies on changes in craniofacial and pharyngeal morphology after mandibular setback surgery have been carried out (Riley et al 1987, Enacar et al 1994, Eggensperger, Smolka, Iizuka 2005, Güven and Saraçoğlu 2005), and it has been suggested that patients treated with mandibular setback surgery might suffer from sleep apnea (Kitagawara et al 2008).

Kuo, West, Bloomquist, McNeil (1979), studied three patients who presented with Hypersomnia Sleep Apnea (HSA) and had surgical advancement of their underdeveloped mandibles. They found that surgery corrected the symptoms of HAS rapidly.

Hochban et al (1996), performed polysomnographic evaluation for sleep-related breathing disorders (SRBD) according to the Marburg graded diagnostic protocol, before and after surgery in 16 patients who underwent surgical mandibular setback using BSSRO. Cephalometric analysis was performed preoperatively, and 1 week, 3 months, and 1 year postoperatively, with particular attention to pharyngeal changes. PAS decreased considerably in all patients. Despite the pharyngeal narrowing, in this study there was no evidence of postoperative SRBD in any of these patients.

Kitagawara et al (2008) measured the arterial oxygen saturation (SpO_2) during sleep by pulse oximetry, of 17 patients whom skeletal Class III malocclusions were corrected by BSSRO. Morphological changes were also studied using cephalograms. They found decreased (SpO_2) during sleep just after surgery, but it had improved 1 month postoperatively. Although there was no significant change at the oropharyngeal airway, significant protrusive head position and inferior displacement of the hyoid bone were seen after the surgery.

4.5 Maxillary Sinus and Orthognathic Le Fort I Surgery

There are not many studies dealing with maxillary sinuses and how they change with orthodontic and orthognathic procedures.

Garrett et al (2008), using CBCT scans of 17 patients who required Rapid Maxillary Expansion (RME) with Hyrax appliances as part of their comprehensive orthodontic treatment, found that RME produces a statistically significant increase in nasal width and a decrease in maxillary sinus width ($p < 0.0001$).

Motro (2011) in his doctorate thesis, investigated by spiral CT scans the volumetric changes in the maxillary sinuses of 21 patients, who underwent RME with cap split Hyrax appliance, after a period of 3 months retention (T1) and after 1 year follow up (T2). He concluded that there was a significant increase in the total sinus volume in T1 and T2.

Until the current moment, the only study concerning changes of the maxillary sinus after orthognathic surgery is the doctorate thesis of Halawa (2005).

Halawa (2005) studied as a part of a doctorate thesis, the cephalometric radiographs of 36 patients before (T1) and after (T2) Le Fort I maxillary impaction surgery. Of those, 12 had also cephalometric radiographs taken from 7 months to 2 years postsurgically (T3). His aim was to investigate the changes in the maxillary sinus size after this type of surgery. He showed that the maxillary sinus area has been significantly decreased after maxillary Le Fort I impaction surgery. However, there was a significant increase in the maxillary sinus area in the postsurgical period.

In maxillary surgery cases the condition of the maxillary sinus is a very important concern. The incidence of sinus disease after maxillary orthognathic surgery is no greater than in the general population (Young and Epker 1972, Nustad, Fonseca, Zeitler 1986). Routinely removing only diseased sinus membranes at the time of maxillary surgery is advised. Moreover, removal of wire sutures or small bone plates used to immobilize the maxilla may be helpful to relief sinus symptoms following surgery (Halawa 2005). However, if sinus disease occurs, it must be treated appropriately.

4.6 Airway Imaging Techniques

Most morphometric investigations of the upper airway in orthodontics have used lateral cephalometric radiographs, with specific skeletal and soft tissue landmarks to characterize the airway (Aboudara et al 2009). The nasopharyngeal region was selected because the lymphatic tissue outline is easy to identify. However, it is believed that a 2-dimensional view of the airway space does not give an accurate indication of the complexity of this structure or its true size.

Digital orthodontic technology opened new possibilities for patient diagnosis, treatment planning, follow-up, and outcome analysis (Swennen and Schutyser 2006). From a single computed tomography (CT) data set, virtual lateral and frontal cephalograms are computed and linked with both hard and soft tissue 3-dimensional (3-D) surface representations This innovative 3-D virtual approach allows the setup of a precise and reproducible 3-D cephalometric reference system and accurate and reliable definition of 3-D cephalometric hard and soft tissue landmarks. Voxel based 3-D cephalometry was developed and validated by using spiral multi-slice CT (MS-CT) data (Swennen and Schutyser 2006).

Recently, a new generation of dentofacial imaging systems based on Cone Beam CT (CBCT) scanning, was introduced, and it has already made major contributions to dentofacial imaging, volumetric analysis and surgery planning.

CBCT is a tomographic scanning technology that can scan and acquire a specified volume of the patient head and generate a 3D data set at much lower radiation doses than their medical CT counterparts. In effect, CBCT represents the latest generation in medical imaging scanning machines ascending from conventional x-ray to panoramic and cephalometric x-ray to medical spiral CT. It provides numerous advantages over the other imaging modalities in favor for its accuracy, speed and safety. Above all, it is an economical and cost effective system that can replace to a huge extent the existing modalities to be the standard of health care.

With the introduction of CBCT, the three-dimensional diagnosis of the patient has become more accessible in dentistry. CBCT became a well accepted oral and maxillofacial diagnostic imaging technique in a short time, mainly due to lower radiation exposure and shorter scan acquisition times, necessary to obtain an acceptable image compared with conventional CT scans (El and Palomo 2010).

4.6.1. How MS-CT 3-D cephalometry works

The patient's head is scanned according to a strict standardized scanning protocol, while the patient is in horizontal position (Swennen and Schutyser 2006). The CT scanner utilizes a narrowly collimated, fan shaped x-ray beam that is projected through a limited thickness slice through the human body. Then, these projections will be detected through a linear array of detectors and the patient has to be advanced through the gantry while the x-ray tube and the detectors are rotating around the patient. Based on the specific system configuration, both of the x-ray tube and the detectors' array may be rotating around the patient, alternatively, the detectors' array can be static while only the x-ray tube is rotating. The CT images are stored by using digital imaging and communications in medicine (DICOM) as a medical-image file format into a personal computer (Swennen and Schutyser 2006). DICOM is the accepted file format for a medical image, and a DICOM viewer allows viewing, measuring, segmentation, and analysis of a CBCT scan (El and Palomo 2010). Then the DICOM files are converted into mxm files. The bone and soft- tissue surfaces are segmented by applying a threshold on the acquired image volume of radiographic densities expressed in Hounsfield units (HU). To begin the analysis, the segmented hard -and soft -tissue surface representations of the skull are rendered in a virtual scene. After semiautomated virtual standardized positioning of the skull, high- quality virtual lateral and frontal cephalograms are computed as orthogonal projections from the single CT data set and linked to the 3D hard- and soft-tissue surface representations.

4.6.2 Advantages and disadvantages of MS-CT 3D cephalometry

MS-CT 3D cephalometry is a powerful craniofacial measurement tool with several advantages (Swennen and Schutyser 2006). :

- Truly volumetric 3D depiction of hard and soft tissues of the skull
- Real size (1:1 scale) and real time 3D cephalometric analysis
- No superimposition of anatomic structures
- High accuracy and reliability
- The setup of a biological meaningful 3D cephalometric reference system for cross- sectional and longitudinal analysis of craniofacial changes.

However, data acquisition still has some drawbacks:

- Horizontal positioning of the patient during record taking falsifies the position of the soft-tissue facial mask
- Lack of a detailed occlusion due to artifacts
- Limited access for the routine craniofacial patient because of higher cost
- Higher radiation exposure than other craniofacial x-ray acquisition system

4.6.3 How CBCT 3D cephalometry works

CBCT scanners have a two-dimensional detector that allows imaging of a large part of the skull with only a 360° rotational sequence (Swennen and Schutyser 2006). Some machines allow the operator to adjust the field of view (FOV) protocol to small, medium, and large. In this way, the scan can be customized, so the patient's anatomic structures are not exposed outside the selected field of view. Thus, the patient is exposed to less radiation.

With dedicated Cone Beam reconstruction algorithms a detailed CT data volume is obtained. Similar to MS-CT, CBCT images are stored by using DICOM as a medical image-file format (Swennen and Schutyser 2006).

For clearer analysis and visualization, segmenting and structuring the airway is necessary. This means to remove and delineate all the other surrounding structures either manually or automatically (El and Palomo 2010).

The fundamental variation between CBCT and spiral CT is that CBCT utilizes a cone shaped beam and an area detector and that it acquires a full volume of images in a single rotation with no need for patient movement. While, spiral CT utilizes a narrowly collimated, fan-shaped x-ray beam and a linear array of detectors and the patient has to be advanced continuously while the x-ray beam rotates around the patient.

Moreover, because the focus of these CT devices is on bone imaging, the radiation dose could significantly be reduced. Specifically, the effective dose for a CBCT acquisition is 0.05mS, while for a spiral CT full skull acquisition is 0.93mS (Swennen and Schutyser 2006).

4.6.4 Advantages and disadvantages of CBCT 3D cephalometry

CBCT 3D cephalometry has some interesting advantages (Swennen and Schutyser 2006):

- Reduced radiation exposure
- Natural shape of the soft -tissue facial mask because of the vertical scanning procedure
- Reduced artifacts at the level of the occlusion
- Increased access for the routine dentofacial patient because of in-office imaging

- Reduced costs

The current limitations of CBCT 3D cephalometry are:

- The scanning volume
- The positional dependency of the image value of a structure in the field of view of the scanner

5. SUBJECTS AND METHODS

5.1 Patient selection

The sample of this study consists of 17 patients who were under treatment at the Department of Orthodontics, Faculty of Dentistry, Marmara University, for the combined orthodontic and surgical correction of their skeletal Class III malocclusion. Initially the sample consisted of 23 patients, however, during the period that the present study was conducted, two patients did not return for the post operative CT, while 4 patients postponed their surgery date.

The patients were selected according to following selection criteria:

- Completed growth and development as assessed by visualization of Radius union (Ru) stage on hand-wrist radiographs, existing in patients' files.
- Class III skeletal relationship planned to be treated by bimaxillary orthognathic surgery: mandibular setback combined with maxillary advancement, with or without maxillary impaction.
- No systemic disease
- No syndrome

Informed consent forms were signed by all patients or their parents and this project was approved by the Ethical Committee of the Institute of Health Sciences of Marmara University.

5.2 Demographic Data

All subjects were Caucasian and from the same geographic area (Turkey). Our sample consisted of 6 male and 11 female patients with mean age 22.59 years (Table 1). The mean age for females was 22.54 ±5.90 years and the mean age for males was 22.67±4.54 years. The youngest patient was 17 years of age and the oldest was 34 years of age.

Table 1: Gender and age distribution of the sample

Sex	n	%	Age (mean)	Age (S.D.)	Minimum	Maximum

Male	6	35.30	22.67	4.54	18	30
Female	11	64.70	22.54	5.90	17	34
Total	17	100.00	22.59	5.30	17	34

5.3 Data gathering

All the patients were referred to NET Radiology and Diagnostic Center, Nisantasi, Istanbul and the pre-operative CBCT evaluation was performed within a period of 1 week before surgery (T1). All the postsurgical CBCT scans were obtained between a period of 10-22 weeks after the surgery (T2). The average interval period between the surgery and the second scan was 3.90±0.87 months. All the scans were acquired with the patient sitting upright with the Frankfort Horizontal plane parallel to the floor, at maximum intercuspation. The patient's head position was adjusted with the help of two lazer beams, one parallel to the floor, coinciding with the Frankfort Horizontal plane, and one vertical beam passing through the patient's facial midline. The patients were asked not to swallow and not to move their heads or tongues during exposure.

5.4 Machines and software used in the study

The technical properties of the Cone Beam machine which is used are the following:

- Brand Name: Iluma Imtec imaging a 3M company
- X-ray tube is working with Cone –Beam technology
- Focal Spot: 0.3 mm x 0.3 mm
- X-ray tube is working with 120 KV
- X-ray tube current: 1-4 mA
- Detector size :19.5 x 24.5 cm
- Scanning with 360 degrees rotation

- Radiation: 58 microsieverts maximum
- Scanning time 40 seconds maximum and 7.8 seconds minimum (180 degrees rotation angle option)
- FOV –Field of View or Imaging area: 14.2 cm x 21.1 cm
- Voxel Size: 0.0936 mm
- Grey Scala: 14 bit

The data obtained from CT images were transferred to a network computer workstation, where volumetric changes of the pharyngeal airway and maxillary sinuses were measured using MIMICS 14.0 software launched by Materialise (Materialise Europe, World Headquarters, Leuven, Belgium).

Materialise Interactive Medical Image Control System (MIMICS) is an interactive tool for the visualization and segmentation of CT images as well as MRI images and 3D rendering of objects. Therefore, in the medical field MIMICS can be used for diagnostic, operation planning or rehearsal purposes. The software divides the screen into four views (Fig.3):

- The original axial view
- The coronal view (made up by the resliced data)
- The sagittal view (made up by the resliced data)
- The 3-D view

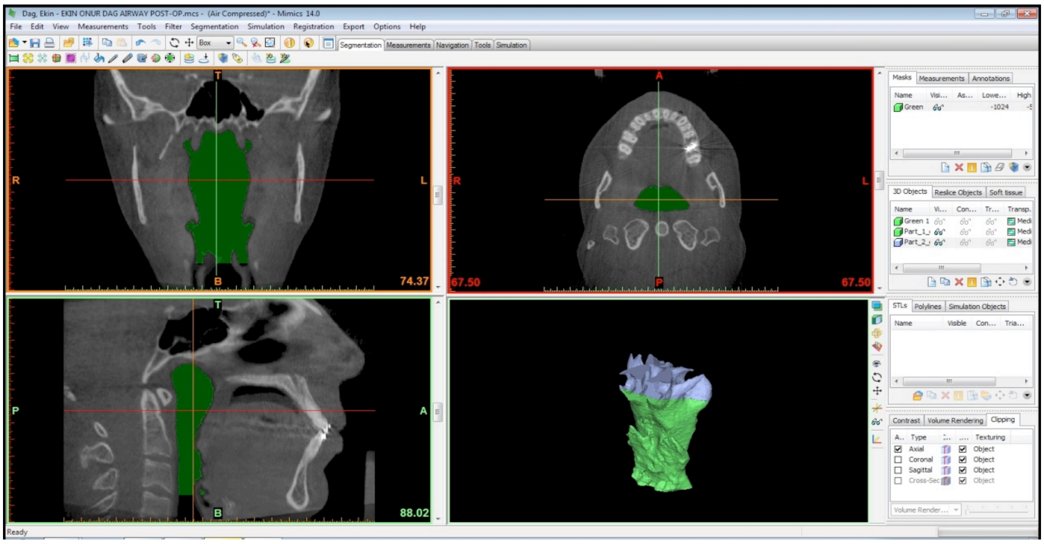


Figure 3: Full screen

5.5 Assessment of the Pharyngeal Airway

All patients' CBCTs were processed and analyzed by the same operator (Eleni Panou). The method that was applied is the following: initially, on the sagittal view, while going through the sliced images, the slice where all the borders of the pharyngeal airway were clearly defined was selected (Fig.4). "Thresholding" was applied with a minimum limit of -1024 HU and a maximum of -526 HU (Fig.5). The pharyngeal airway was cropped, using the "cropping" tool provided by the software, according to the following borders: The anterior border was defined by a vertical plane passing through PNS. The superior was the roof of the pharynx. The posterior border was the posterior pharyngeal wall. The inferior border was a horizontal plane passing from the most anterior and inferior point of the third vertebra (Fig.6). Then, the connection with the outer air was cropped slice by slice using the segmentation tools (Fig.7, 8). Finally, "region growing"- the tool that makes it possible to split the segmentation created by thresholding into several objects and to remove floating pixels- was applied.

As a result, the structures that have failed to connect with outer airway were separated, and the three-dimensional image of pharyngeal airway was constructed and calculated. The three-dimensional image of pharyngeal airway was divided into upper and lower parts by a plane drawn from PNS to the most anterior and inferior point of the first vertebrae (Fig. 9, 10, 11). The volumes of upper, lower and total pharyngeal airway were calculated using the "Calculate 3D" tool provided by the software, thus creating a new "3D mask" (Fig.12).

In addition the smallest cross-sectional airway area was measured in each CT using the axial image and the "Export 2D mask area" tool of the software.

5.6 Assessment of the Maxillary Sinus

For the assessment of maxillary sinuses volumes the coronal image was selected. The same thresholding limits were applied as in the pharyngeal airway assessment and the sinuses were cropped in the slice where their widest size was apparent (Fig13). Cropping was also done in axial and sagittal views. Using the "segmentation" tool, any connection with the outer air was eliminated, three-dimensional images of the left and right sinus were constructed and their volumes were calculated, using the same software tools described above (Fig 14, 15, 16, 17, 18).

It must be noted that in cases where polyps were observed inside the cavities of the maxillary sinuses, these polyps were included in the mask of the isolated sinus, since they were occupying space that should be normally occupied by air.

Consequently, the volumetric values of the pharyngeal airway and maxillary sinuses of every patient, before surgery (T1) and on average 3.9±0.87 months after surgery (T2), as well as the minimal cross-sectional area of their pharyngeal airway were obtained.

More specifically, the parameters measured in the present study are the following:

- U.P.A.1 (Upper Pharyngeal Airway Before Surgery)
- L.P.A.1 (Lower Pharyngeal Airway Before Surgery)

- T.P.A.1 (Total Pharyngeal Airway Before Surgery)
- M.C.S.A.1 (Minimal Cross-Sectional Area Before Surgery)
- R.M.S.1 (Right Maxillary Sinus Before Surgery)
- L.M.S.1 (Left Maxillary Sinus Before Surgery)
- T.M.S.1 (Total Maxillary Sinus Before Surgery)
- U.P.A.2 (Upper Pharyngeal Airway After Surgery)
- L.P.A.2 (Lower Pharyngeal Airway After Surgery)
- T.P.A.2 (Total Pharyngeal Airway After Surgery)
- M.C.S.A.2 (Minimal Cross-Sectional Area After Surgery)
- R.M.S.2 (Right Maxillary Sinus After Surgery)
- L.M.S.2 (Left Maxillary Sinus After Surgery)
- T.M.S.2 (Total Maxillary Sinus After Surgery)
- U.P.A.D: Upper Pharyngeal Airway Difference
- L.P.A.D: Lower Pharyngeal Airway Difference
- T.P.A.D: Total Pharyngeal Airway Difference
- T.M.S.D: Total Maxillary Sinus Difference

5.7 Assessment of the Surgical Jaw Movements

For some of the cases, complete data about the amounts of surgical jaw movements were not available in the patients' files. For that reason, the observer superimposed the CBCT images before and after surgery in order to assess the amount of the surgical movements. The procedure was the following: Initially, in the pre-operative CBCT, thresholding was applied with a minimum limit of 226 HU and a maximum of 3071 HU representing the Hounsfield Units for bone. "Region growing" feature was selected and a new mask comprised only from the bony parts was formed. The 3D image of the mask was created by using the "Calculate 3D from mask" tool. After creating the 3D object in the software, the data was exported as an STL file. The same procedure was followed for the post-operative CBCT. After the completion of this procedure, the image representing the contour of the two STLs was selected and the two bony masks were superimposed. The software gives to the operator the opportunity to move and rotate the masks in order to achieve superimposition in the most precise way. The two masks were superimposed by the observer on the contour of the sphenoid bone (Fig.19).

In order to assess mandibular setback, a line from point B in the pre-operative contour (B1) was drawn parallel to the true horizontal plane. A perpendicular line to that, was drawn from the B point of the postsurgical contour (B2) and the intersection point of the two lines was named B´. The distance between B1-B´ was measured using the “Distance” tool of the “Measurements” option, and the movement of the mandible in the sagittal plane (mandibular setback amount) was defined. Any other movement of the mandible in the vertical or coronal planes was out of our interest.

In order to assess maxillary advancement, in cases that there was no impaction, the pre-operative A point (A1) and the post-operative A point (A2) were at the same horizontal level, so the distance between them was measured and the amount of advancement was found. In cases that there was maxillary advancement together with impaction or down graft, a horizontal line (A1-line) was drawn parallel to the true horizontal plane from the pre-operative A point (A1). A perpendicular line was drawn from the post-operative A point (A2) to the A1-line and the intersective point was named as A´. The distance between A1-A´ represented the maxillary advancement amount.

For the assessment of maxillary impaction amount, a horizontal line was drawn parallel to the true horizontal plane from the pre-operative A point (A1). Another horizontal line parallel to the true horizontal plane was drawn from the postoperative A point (A2). The vertical distance between the two lines represented the amount of maxillary impaction.

5.8. Amounts of the Surgical Movements of the Jaws

Table 2 shows the data regarding the amount of surgical movements of the jaws to which the patients were subjected. 17 patients underwent mandibular setback and maxillary advancement (the whole sample). 8 patients underwent mandibular setback, maxillary advancement and impaction and 4 patients underwent mandibular setback, maxillary advancement and maxillary down graft. The average amount of mandibular setback was 3.35±1.84 mm, the average amount of maxillary advancement was 5.00±2.50 mm, the average amount of maxillary impaction was 3.00±1.07 mm and the average amount of maxillary down graft was 4.5±2.38 mm.

Table 2: Amounts of surgical movements of the jaws

	n	%	Mean(mm)	S.D.(mm)
MAX ADVANCEMENT	17	100.00	5.00	2.50
MAX IMPACTION	8	47.06	3.00	1.07
MAND SETBACK	17	100.00	3.35	1.84
DOWN GRAFT	4	23.53	4.50	2.38

5.9 Statistical Method

Data analysis was performed using SPSS 16.0. Means and standard deviations for all parameters were calculated. The initial values of all the parameters related to pharyngeal and sinus dimensions, were evaluated for gender differences using Mann-Whitney U-Test. There was no statistically significant difference between the two genders except for the parameters of L.P.A and T.P.A. For these parameters, preoperative and postoperative comparisons were made separately in males and females using Wilcoxon test. For the rest of the parameters all the comparisons were made in the whole sample, using Paired Samples T-test. The amounts of mandibular setback in female and male patients were compared with Mann-Whitney U-Test as well. The patients who underwent mandibular setback and maxillary advancement with impaction were evaluated again as a separate group. Wilcoxon test was used to test for significant differences in pharyngeal airway and maxillary sinus volume in this group. The 4 patients who underwent mandibular setback, maxillary advancement and maxillary down graft were not considered as a separate group, due to the very small sample size. Pearson’s correlation was used to determine if a relationship existed between the amount of the surgical movements and the volumetric changes observed between the time points. For reliability testing, ten patients were randomly selected and all the parameters were remeasured. Cronchbach's Alpha Intraclass Correlation Coefficient was used in order to determine reliability of the measurements.

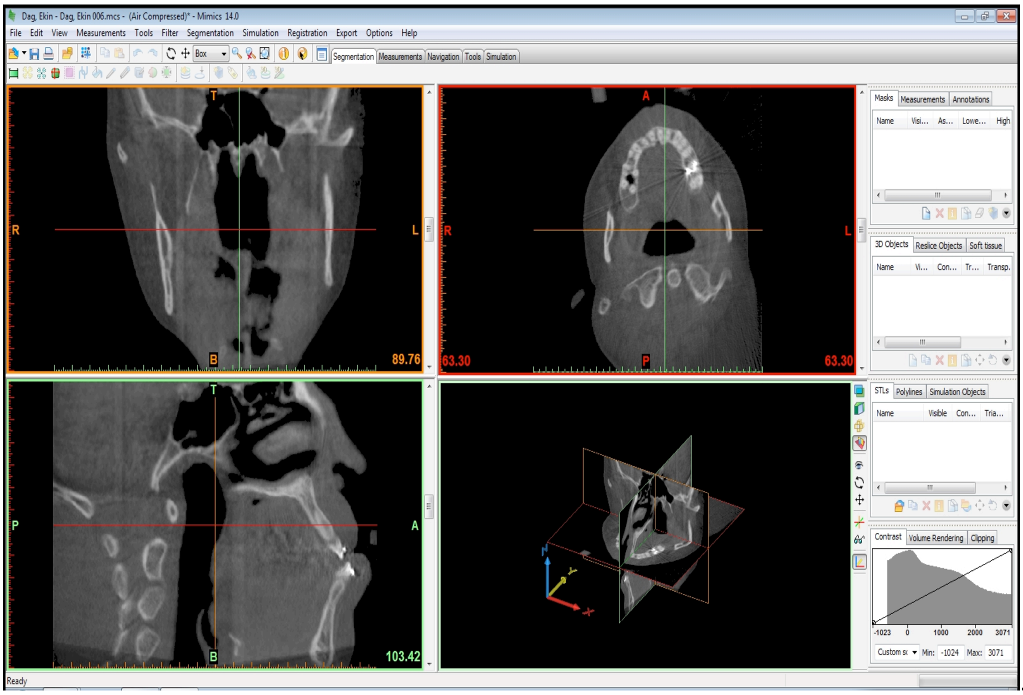


Figure 4: Image before thresholding

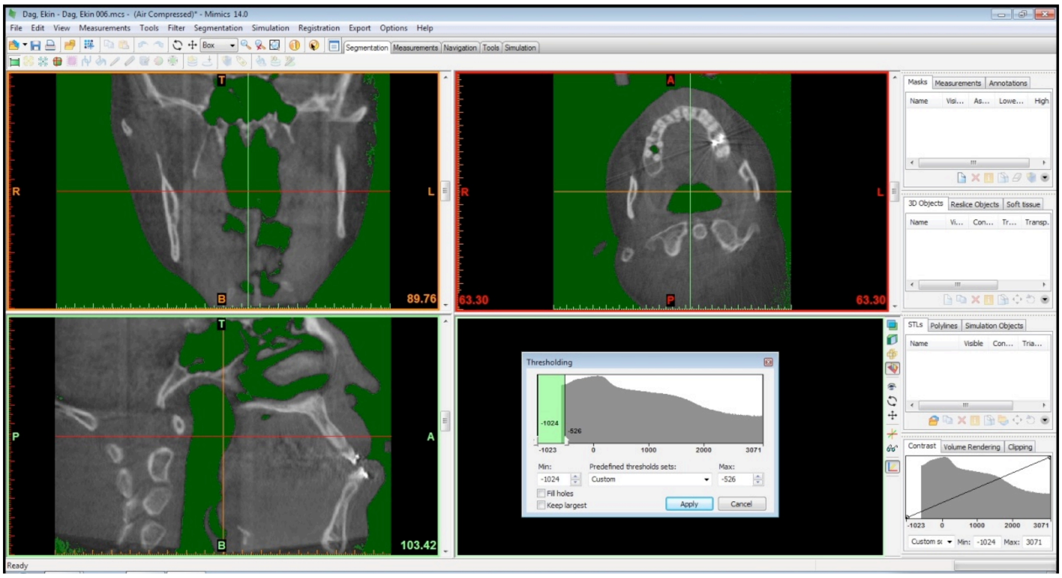


Figure 5: Image after thresholding values were selected

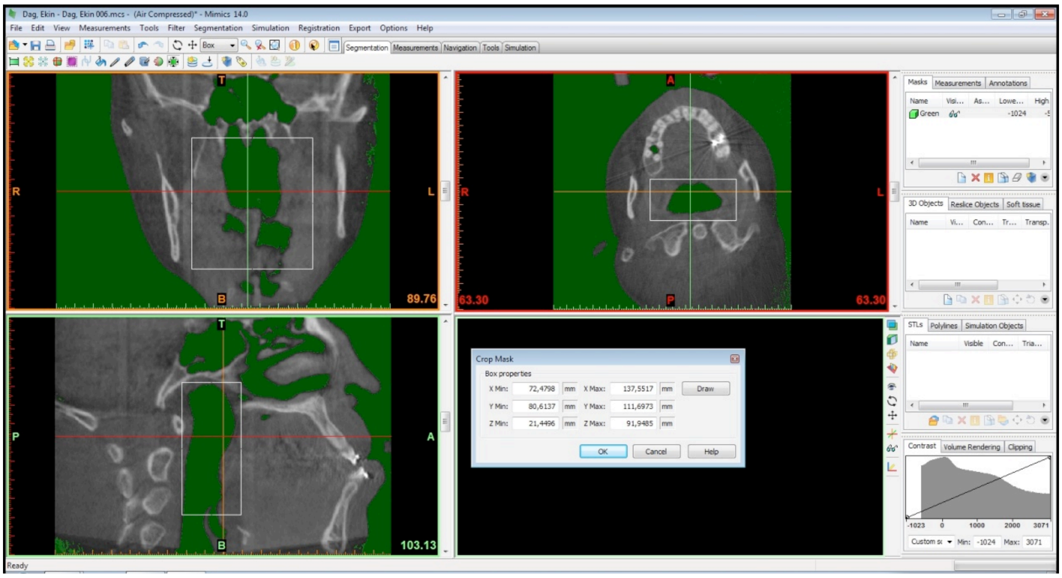


Figure 6: The pharyngeal airway cropped. The defined borders are clearly seen in the sagittal view.

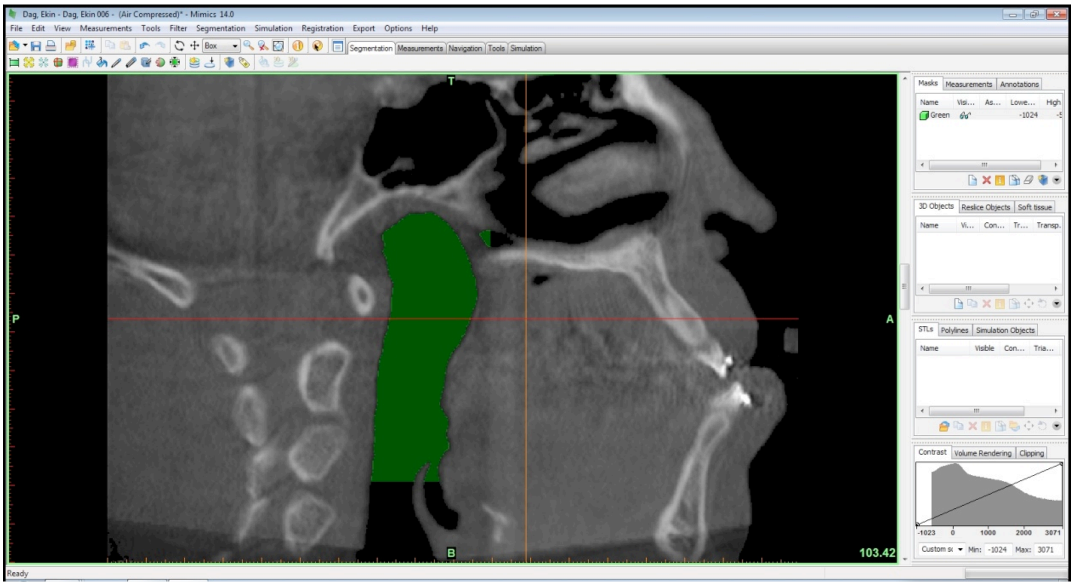


Figure 7: Sagittal view. The connections with the external air are visible.

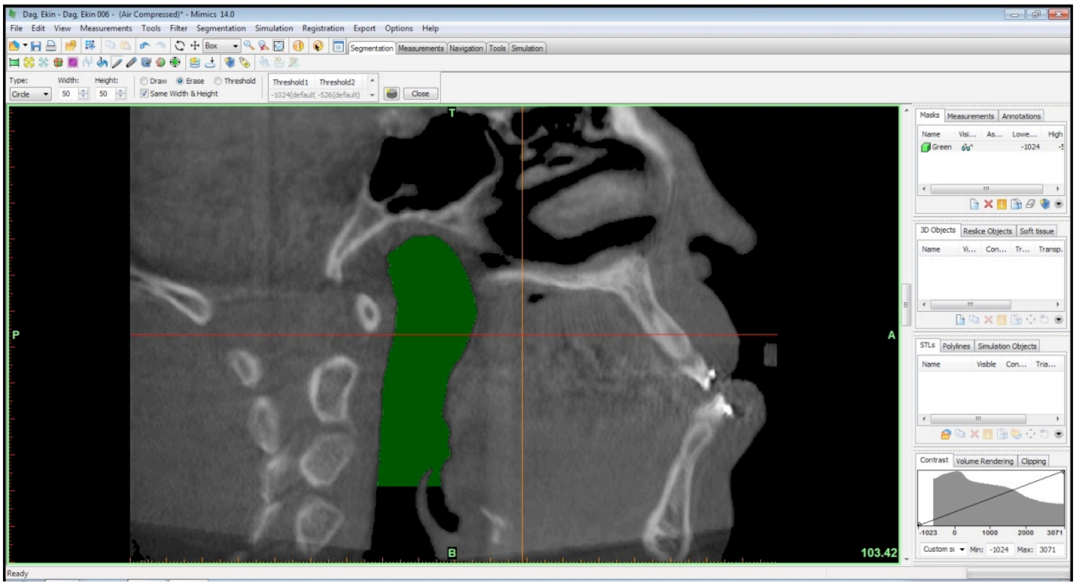


Figure 8: Sagittal view. The connections of the pharyngeal airway with the external air are removed.

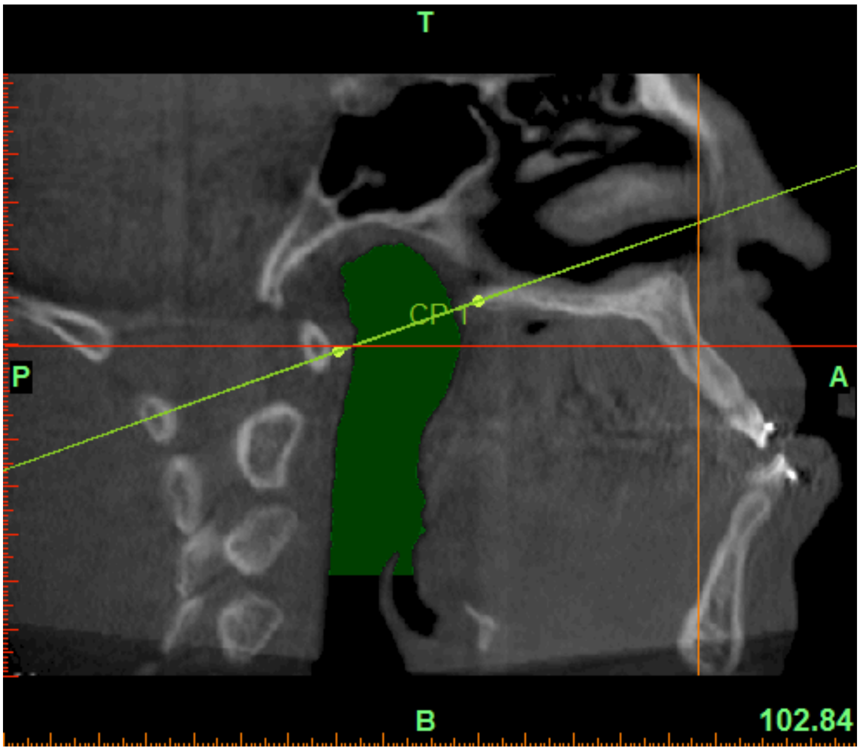


Figure 9: Sagittal view. The plane that divides the pharyngeal airway into upper and lower compartments is visible.

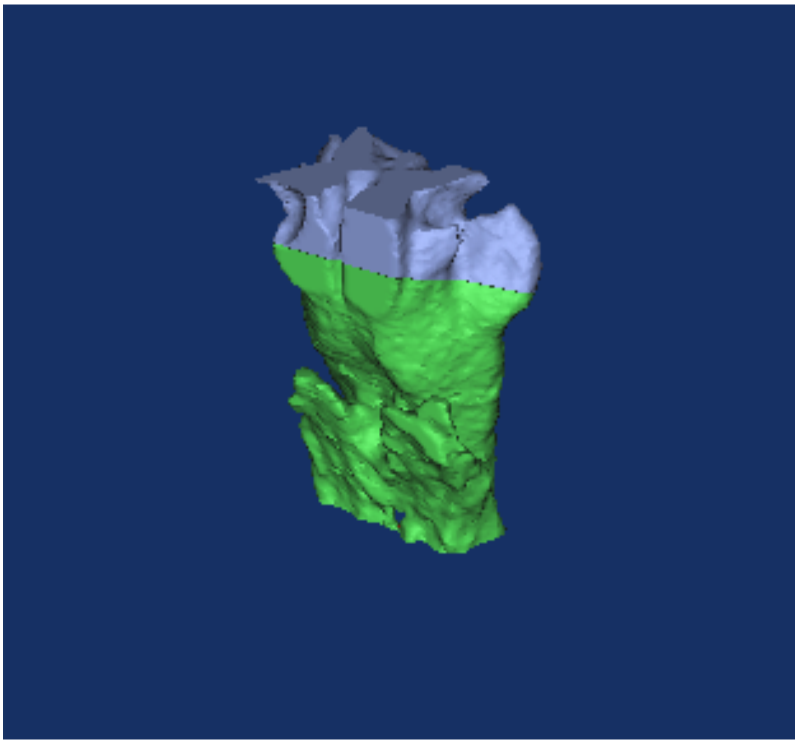


Figure 10: 3D model of the pharyngeal airway. The blue segment represents the upper part of the airway and the green segment represents the lower part.

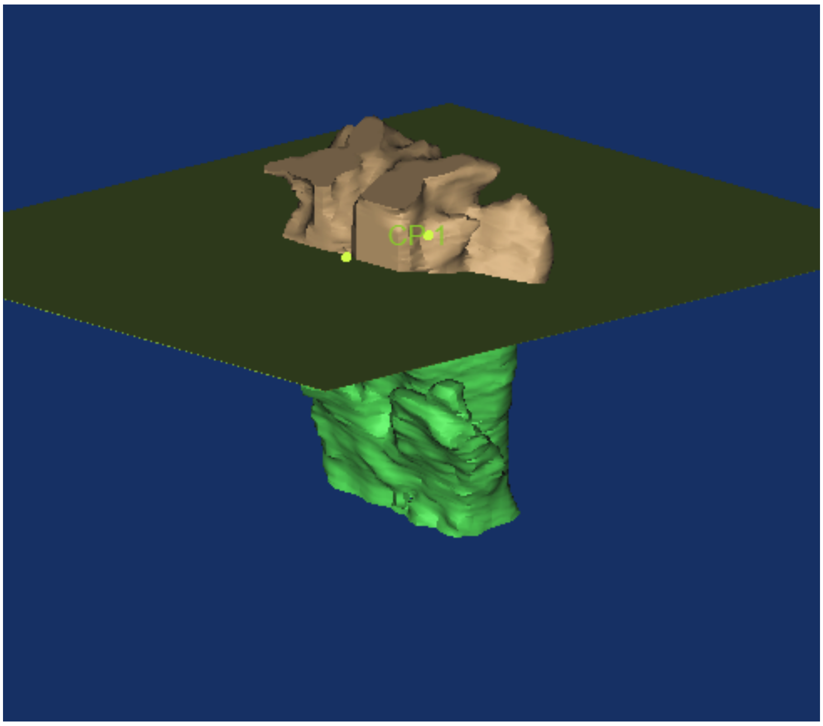


Figure 11: The plane separating the upper and lower pharyngeal airway is apparent.

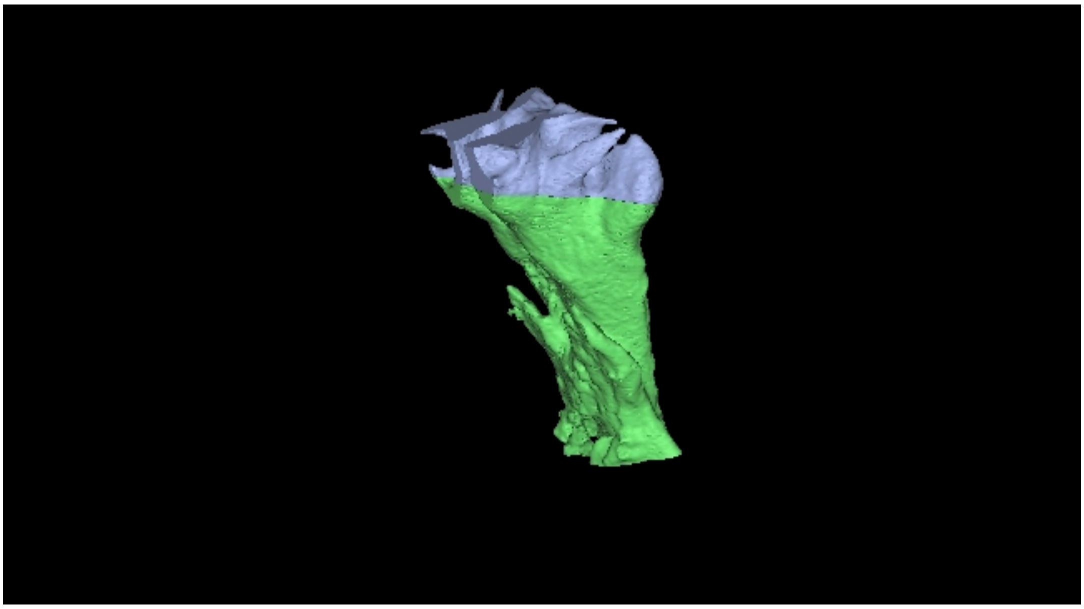


Figure 12: 3D model of the pharyngeal airway (lateral view)

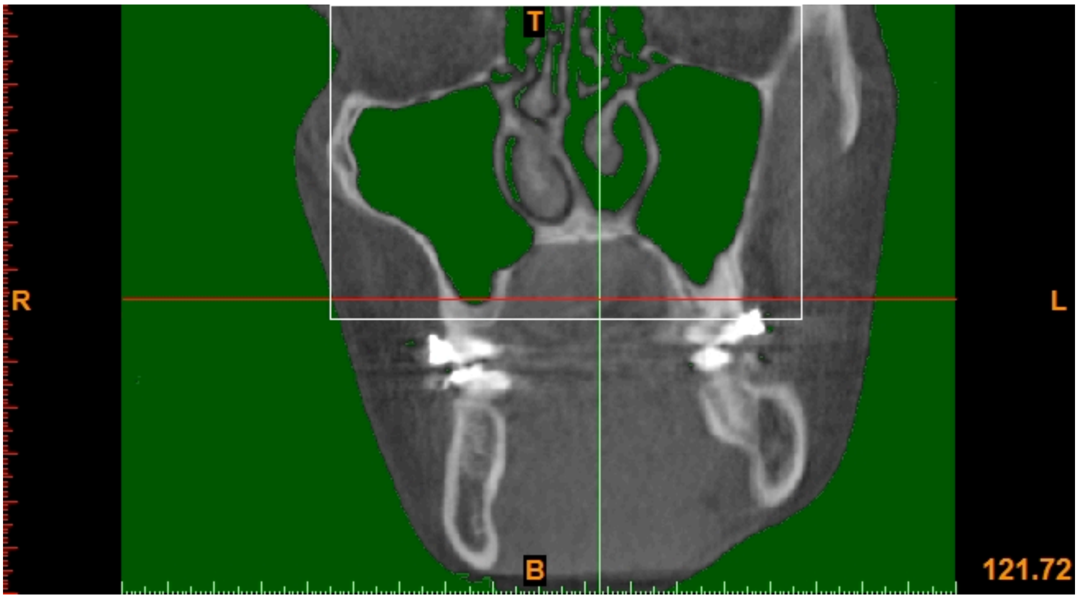


Figure 13: Maxillary sinuses cropped

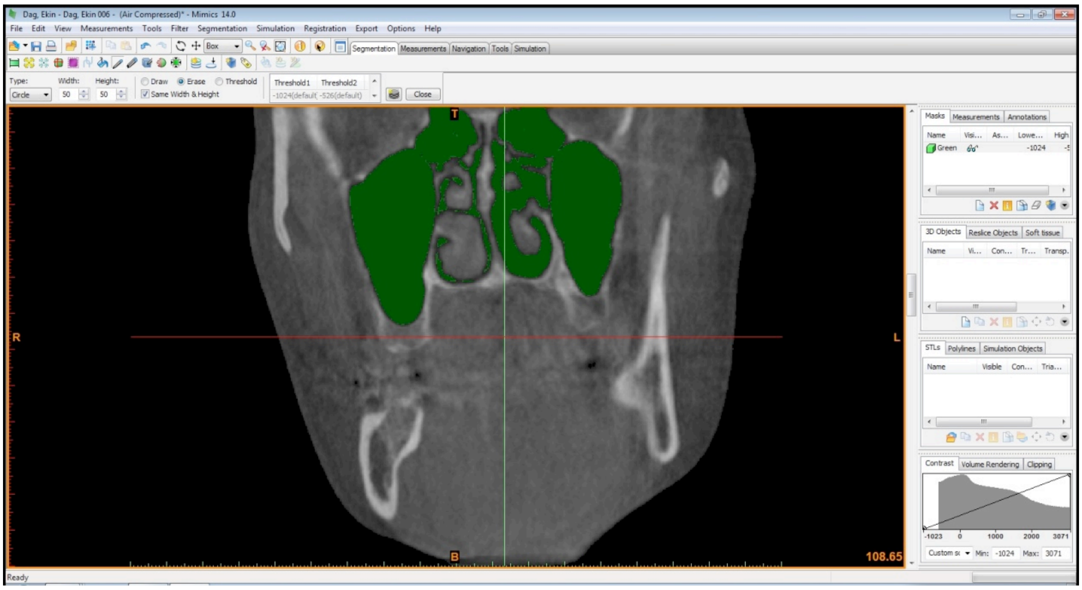


Figure 14: Maxillary sinuses’ coronal view. The connections with the outer air are visible.

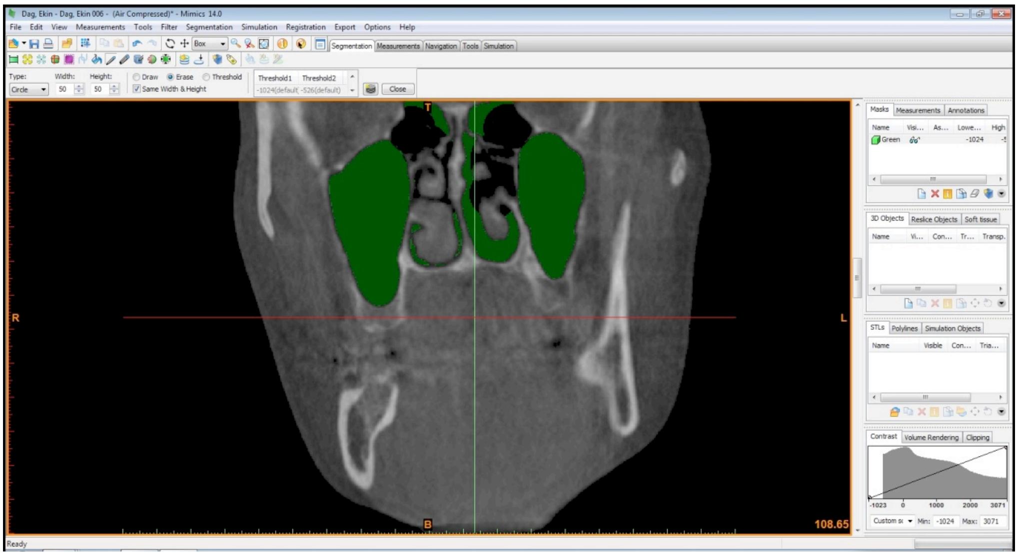


Figure 15: Maxillary sinuses’ coronal view. The connections with the outer airway are removed.

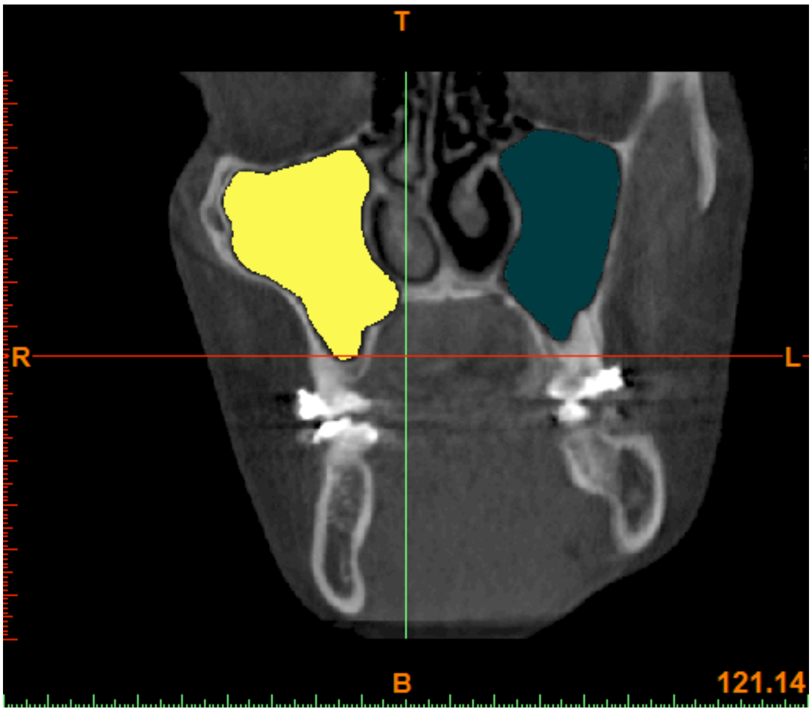


Figure 16: Maxillary sinuses' coronal view. The isolated maxillary sinuses are clearly visible.

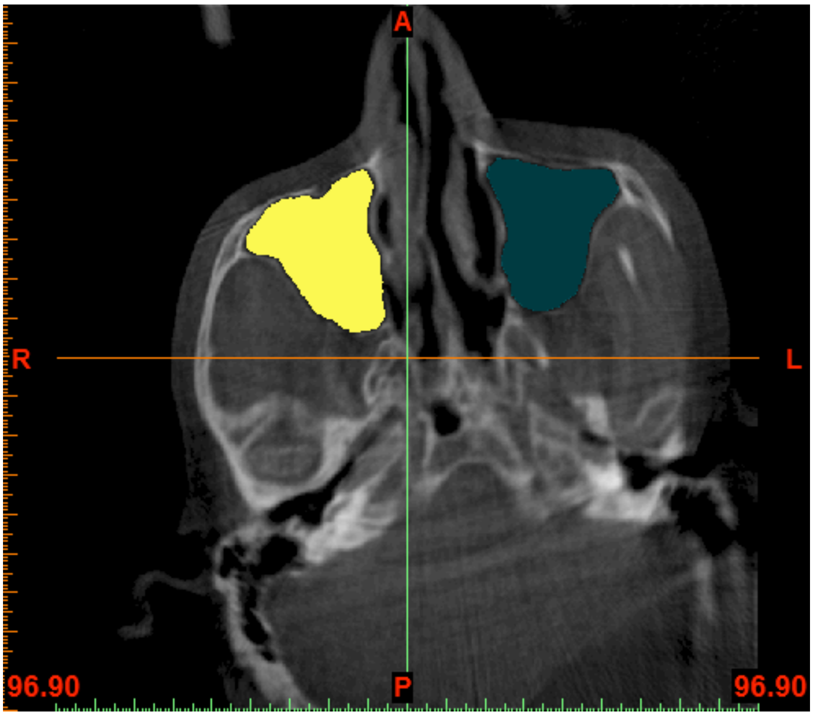


Figure 17: Maxillary sinuses' axial view. The isolated maxillary sinuses are clearly visible.

Figure 18: 3D image of the maxillary sinuses

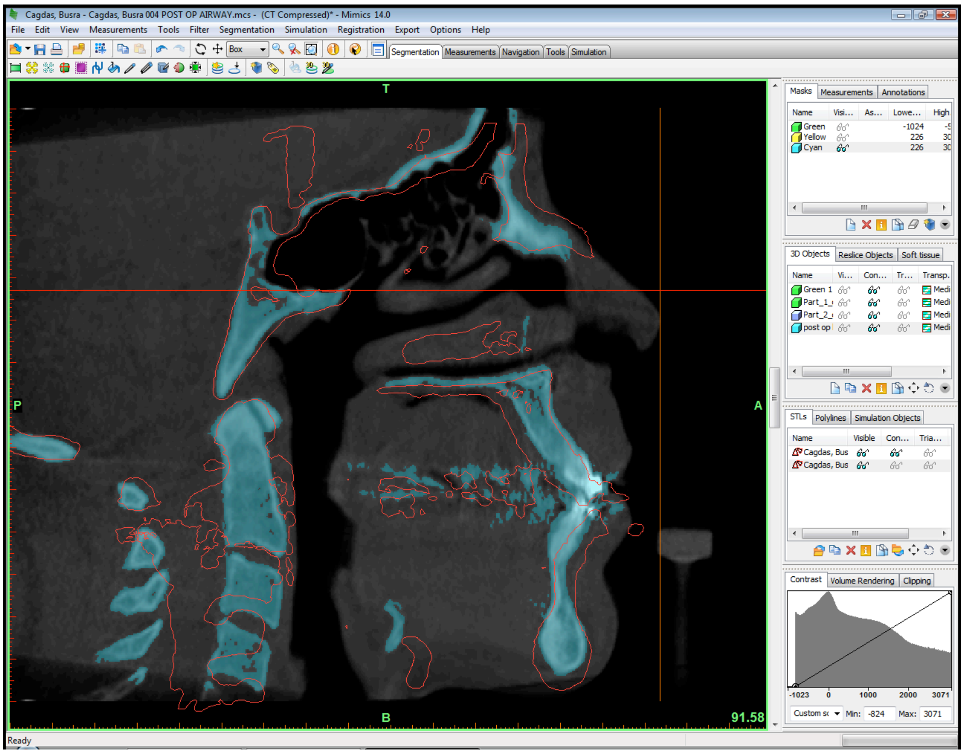


Figure 19: Superimposition of the preoperative (red) and the postoperative (blue) masks

6. RESULTS

6.1 Evaluation of the Reliability of the Method

The data presented on Table 3 demonstrate a high agreement between the duplicate measurements conducted by the same examiner (E.P). The Intraclass Correlation Coefficient of all the measurements for 10 randomly selected cases, shows a high rate of consonance between measurements.

The highest Intraclass Correlation Coefficient were observed in the R.M.S.1, R.M.S.2 and M.C.S.A.2 measurements (0.999 for the three of them), while the lowest was observed in the U.P.A.2 measurement (0.950).

Table 3: Intraclass Correlation Coefficient for measurements' reliability.

Variables	Intraclass Correlation	95% CI
U.P.A.1	0.975	0.898-0.994
U.P.A.2	0.950	0.798-0.988
L.P.A.1	0.984	0.939-0.996
L.P.A.2	0.990	0.960-0.998
T.P.A.1	0.986	0.948-0.997
T.P.A.2	0.994	0.976-0.998
R.M.S.1	0.999	0.998-1.000
R.M.S.2	0.999	0.994-1.000
L.M.S.1	0.997	0.986-0.999
L.M.S.2	0.988	0.955-0.997
T.M.S.1	0.998	0.994-1.000
T.M.S.2	0.996	0.986-0.999
M.C.S.A.1	0.956	0.834-0.989
M.C.S.A.2	0.999	0.997-1.000

6.2 Volumetric Measurements

6.2.1 Volumetric changes of the pharyngeal airway after surgery

Tables 4 and 5 show all the data derived from CBCT examination concerning the pharyngeal airway and maxillary sinuses respectively.

Table 4: All the data derived from CBCT examination concerning pharyngeal airway

n	Sex	Pharyngweal Airway volume before surgery (mm^3)			Pharyngweal Airway volume after surgery (mm^3)			Smallest Cross Sectional Area (mm^2)	
		Upper	Lower	Total	Upper	Lower	Total	Before	After
1	f	9432.41	11834.65	21267.06	9661.29	14366.79	24028.08	148.01	172.41
2	f	9494.44	13842.35	23336.79	11429.31	26083.07	37512.38	155.66	329.80
3	f	7903.26	9905.10	17808.36	7016.15	11083.00	18099.15	112.27	130.62
4	f	5011.29	6801.02	11812.31	5659.32	11289.32	16948.64	158.00	147.23
5	f	3270.65	4668.92	7939.57	5417.83	5543.14	10960.97	44.40	37.89
6	m	8543.02	13048.21	21591.23	9356.47	12013.37	21369.84	151.40	131.48
7	m	10777.30	24915.66	35692.96	14455.32	20435.01	34890.33	171.68	273.68
8	f	9877.20	15356.72	25233.92	8860.35	9902.57	18762.92	137.50	129.77
9	m	12205.88	13491.45	25697.33	14426.91	10887.08	25313.99	129.09	126.66
10	m	13979.77	37615.39	51595.16	11255.75	30980.36	42236.11	266.59	288.11
11	f	2378.94	13487.91	15866.85	2239.17	8657.56	10896.73	173.68	103.04
12	f	4870.16	9924.98	14795.14	5675.81	7849.28	13525.09	95.70	46.58
13	f	12035.03	26042.34	38077.37	9256.62	24567.26	33823.88	283.97	221.95
14	f	5354.30	17195.55	22549.85	5732.85	23038.42	28771.27	153.74	198.32
15	m	6059.25	16018.56	22077.81	6526.37	10249.10	16775.47	110.38	95.11
16	f	5676.43	6873.32	12549.75	8705.81	10713.35	19419.16	90.21	180.43
17	m	13201.94	26395.13	39597.07	13670.80	21741.87	35412.67	261.19	196.80

Table 5: All the data derived from CBCT examination concerning maxillary sinuses

n	Sex	Maxillary Sinus volume before surgery (mm^3)			Maxillary Sinus volume after surgery (mm^3)		
		Right	Left	Total	Right	Left	Total
1	f	19977.28	21445.24	41422.52	19375.25	19064.33	38439.58
2	f	20126.67	18997.27	39123.94	20124.68	17454.94	37579.62
3	f	15583.57	17641.32	33224.89	10771.13	12318.83	23089.96
4	f	11101.50	13617.13	24718.63	8730.80	12160.66	20891.46
5	f	9925.60	12831.86	22757.46	8734.26	10939.10	19673.36
6	m	17121.03	21386.88	38507.91	17243.77	22805.59	40049.36
7	m	17625.53	16792.23	34417.76	18002.05	15703.24	33705.29
8	f	10183.05	12178.53	22361.58	9118.51	11336.75	20455.26
9	m	17558.37	16197.18	33755.55	11903.26	13952.11	25855.37
10	m	28997.46	29012.58	58010.04	23604.40	25138.67	48743.07
11	f	11489.11	11077.70	22566.81	10882.00	9380.94	20262.94
12	f	14051.63	13823.26	27874.89	13927.86	13656.25	27584.11
13	f	19056.14	18231.45	37287.59	17426.93	16000.29	33427.22
14	f	11170.77	12814.64	23985.41	8580.09	11987.89	20567.98
15	m	20782.02	22802.29	43584.31	17752.65	19356.03	37108.68
16	f	11051.33	9419.72	20471.05	10384.28	6845.10	17229.38
17	m	5135.36	4835.24	9970.60	5637.93	5122.78	10760.71

Table 6 and Graph 1 demonstrate that the upper pharyngeal airway volume before and after the surgery were 8239.49±3539.92 mm^3 and 8785.07±3477.15 mm^3 respectively. The 545.58±4027.07 mm^3 average increase in the volume of the upper pharyngeal airway was not statistically significant ($p=0.584$).

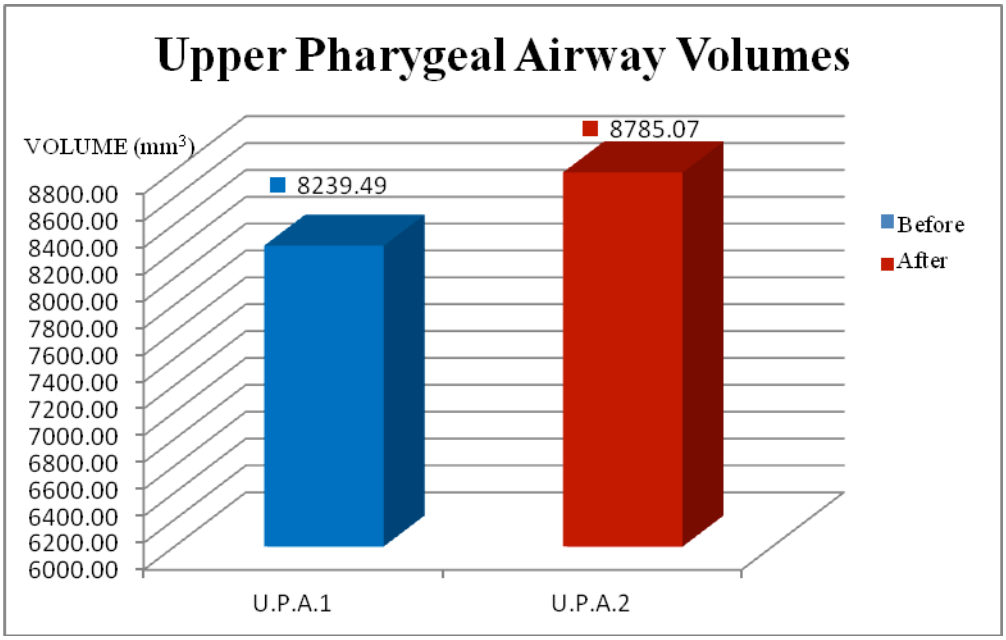
Furthermore, the minimal cross-sectional area of the pharyngeal airway before and after surgery was 155.50±64.13 mm^2 and 165.28±80.63 mm^2, respectively. There was an average increase of 9.79±64.65 mm^2, but it was not statistically significant (p=0.541) (Graph 2).

Table 6: Volumetric changes of the pharyngeal airway after the surgery

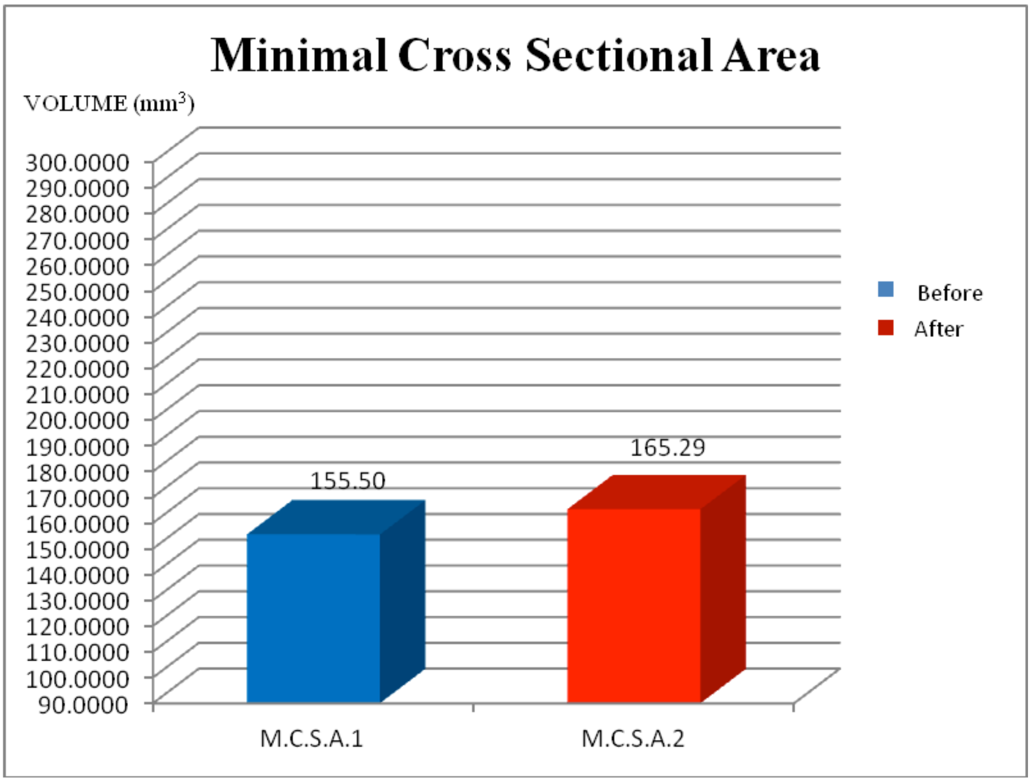
	T0		T1		Change		p
	X (n=17)	SD	X (n=17)	SD	X (n=17)	SD	
U.P.A(mm^3)	8239.49	3539.92	8785.07	3477.15	545.58	4027.07	0.584
M.C.A(mm^2)	155.50	64.13	165.28	80.63	9.79	64.65	0.541

n: number of individuals p: probability SD: Standard Deviation

T0: Before surgery T1: After surgery X: mean



Graph 1: Upper pharygeal airway volumes before and after surgery



Graph 2: Minimal cross sectional area

Tables 7, 8 and Graph 3 present the changes in the lower and total pharyngeal airway in males and females, respectively.

We can see from Table 7 that there is a significant decrease of 4196.27±2061.11 mm^3 in the lower pharyngeal airway in males ($p=0.028$) since the preoperative value was 21914.07±9590.85 mm^3 and it became 17717.80±8178.66 mm^3 postoperatively. The total pharyngeal airway was 32708.59±11822.24 mm^3 preoperatively and it reduced to 29333.07±9711.77 mm^3 after the surgery. This 3375.53±3624.67 mm^3 decrease was statistically significant ($p=0.028$).

In females (Table 8) there was observed an increase in lower pharyngeal airway volume of 1560.08±5101.18 mm^3 which was not significant ($p=0.424$). The preoperative value was 12357.53±5961.79 mm^3 and the postoperative was 13917.61 ±7216.37 mm^3. The total pharyngeal airway volume was 19203.36±8266.93 mm^3

and it increased to 21158.93±8930.06 mm^3 after the surgery. The 1955.57 ±6117.80 mm^3 average increase that was observed was not statistically significant (p=0.328).

Table 7: Lower and total pharyngeal airway changes in males

	MALES						
	T0		T1		Change		p
	X (n=6)	SD	X (n=6)	SD	X (n=6)	SD	
L.P.A(mm^3)	21914.07	9590.85	17717.80	8178.66	4196.27	2061.11	0.028
T.P.A(mm^3)	32708.59	11822.24	29333.07	9711.77	3375.53	3624.67	0.028

n: number of individuals p: probability SD: Standard Deviation

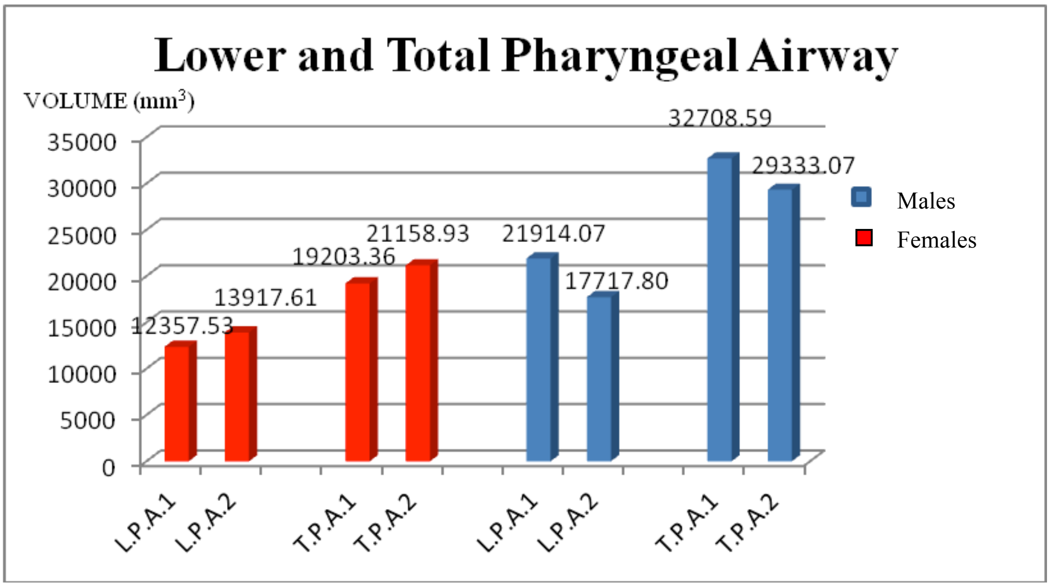
T0: Before surgery T1: After surgery X: mean

Table 8: Lower and total pharyngeal airway changes in females

	FEMALES						
	T0		T1		Change		p
	X(n=11)	SD	X(n=11)	SD	X (n=11)	SD	
L.P.A(mm^3)	12357.53	5961.79	13917.61	7216.37	1560.08	5101.18	0.424
T.P.A(mm^3)	19203.36	8266.93	21158.93	8930.06	1955.57	6117.80	0.328

n: number of individuals p: probability SD: Standard Deviation

T0: Before surgery T1: After surgery X: mean



Graph 3: Lower and total pharyngeal airway volumes before and after surgery

6.2.2 Volumetric changes of the maxillary sinuses after surgery

The data presented in Table 9 and Graph 4 show that the right maxillary sinus volume before the surgery was 15349.20±5689.99 $mm^3$and after surgery it reduced to 13658.81±5155.57 mm^3. The mean change of 1690.39±1999.46 mm^3 in the volume of the right maxillary sinus was statistically significant (p=0.003).

The left maxillary sinus volume before the surgery was 16064.97±5749.48 mm^3 and postoperatively decreased to 14307.26±5311.25 mm^3. There was observed a statistically significant (p=0.000) average decrease of 1757.7±1594.31 mm^3.

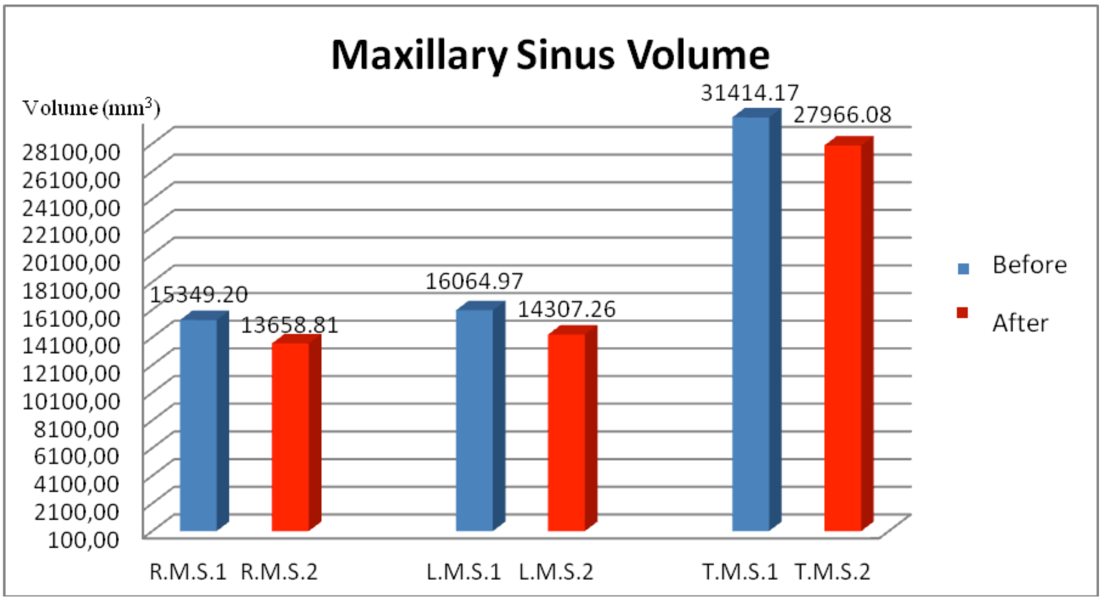
The volume of the total maxillary sinuses before and after surgery was 31414.17 ±11305.27 mm^3 and 27966.08±10170.83 mm^3 respectively. Table 9 shows that there was a statistically significant decrease by 3448.09±3315.56 mm^3 (p=0.001).

Table 9: Volumetric changes of maxillary sinuses

	T0		T1		Change		p
	X (n=17)	SD	X (n=17)	SD	X (n=17)	SD	
R.M.S(mm^3)	15349.2	5689.99	13658.81	5155.57	1690.39	1999.46	0.003
L.M.S(mm^3)	16064.97	5749.48	14307.26	5311.25	1757.7	1594.31	0.000
T.M.S(mm^3)	31414.17	11305.27	27966.08	10170.83	3448.09	3315.56	0.001

n: number of individuals p: probability SD: Standard Deviation

T0: Before surgery T1: After surgery X: mean



Graph 4: Maxillary sinus volume before and after surgery

6.2.3. Volumetric changes of the pharyngeal airway and maxillary sinuses in patients undergoing maxillary impaction

Tables 10 and 11 and Graphs 5, 6 and 7, represent data derived from the group of patients that underwent mandibular setback, maxillary advancement and impaction.

Table 10 shows that the upper pharyngeal airway volume before and after the surgery was 7403.06±4174.90 mm^3 and 7031.93±2898.43 mm^3 respectively. There was an average decrease of 371.13±1702.92 mm^3 but it was not statistically significant (p=0.557).

The preoperative lower pharyngeal airway volume was 16334.35±10655.09 mm^3 and the postoperative volume was 15760.73±9284.60 mm^3. There was observed a mean decrease of 573.63±4033.97 mm^3 in the volume of the lower pharyngeal airway, which was not statistically significant (p=0.700).

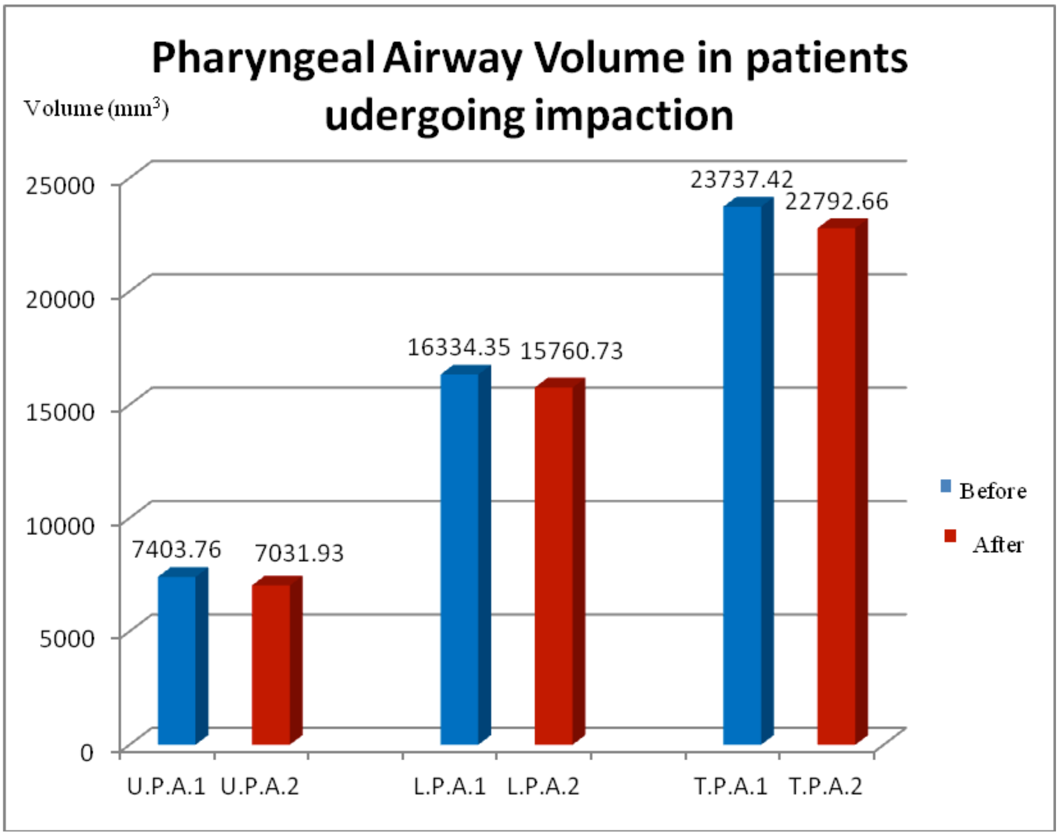
Additionally, the total pharyngeal airway before surgery was 23737.42 ±14221.90 mm^3 and it decreased to 22792.66 ±11504.19 mm^3. Table 10 shows that the decrease of 944.76±5076.57 mm^3 was not statistically significant (p=0.615).

Moreover, the minimal cross-sectional area of the pharyngeal airway before and after surgery was 159.79±81.83 mm^2, and 149.86±86.96 mm^2 respectively. Again, the mean decrease of 9.93±44.54 mm^2 that was observed was not statistically significant (p=0.548) (Table 10).

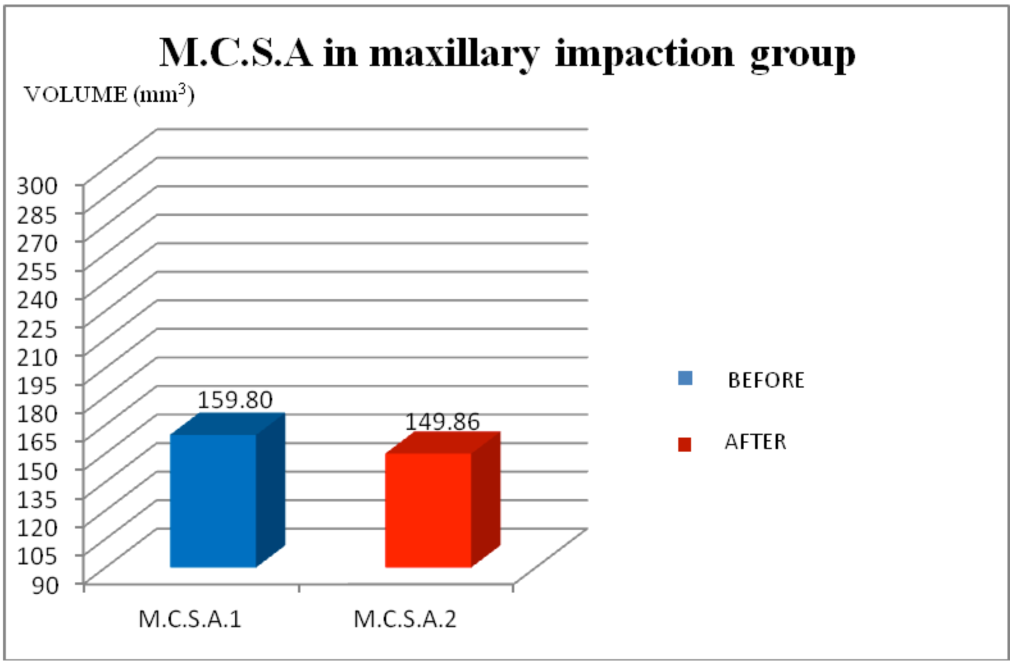
Table 10: Volumetric changes of the pharyngeal airway in patients undergoing maxillary impaction

	T0		T1		Difference		p
	X (n=8)	SD	X (n=8)	SD	X (n=8)	SD	
U.P.A.(mm^3)	7403.06	4174.90	7031.93	2898.43	371.13	1702.92	0.557
L.P.A.(mm^3)	16334.35	10655.09	15760.73	9284.60	573.63	4033.97	0.700
T.P.A.(mm^3)	23737.42	14221.90	22792.66	11504.19	944.76	5076.57	0.615
M.C.S.A. (mm^2)	159.79	81.83	149.86	86.96	9.93	44.54	0.548

n: number of individuals	p: probability	SD: Standard Deviation
T0: Before surgery	T1: After surgery	X: mean



Graph 5: Pharyngeal airway volume in patients undergoing maxillary impaction



Graph 6: M.C.S.A in maxillary impaction group

The data presented in Table 11 and Graph 7, show that before and after surgery the volume of the right maxillary sinus was 16281.44 ±6301.89 mm^3 and 14162.74± 5476.26 mm^3, respectively. The decrease of 2118.7 ±1995.17 mm^3 that was observed was statistically significant (p=0.020).

There was also observed a significant decrease of 2298.97±1642.03 mm^3, (p=0.005) in the volume of the left maxillary sinus which preoperatively was 17109.76±5927.53 mm^3 and postoperatively reduced to 14810.79±5156.93 mm^3.

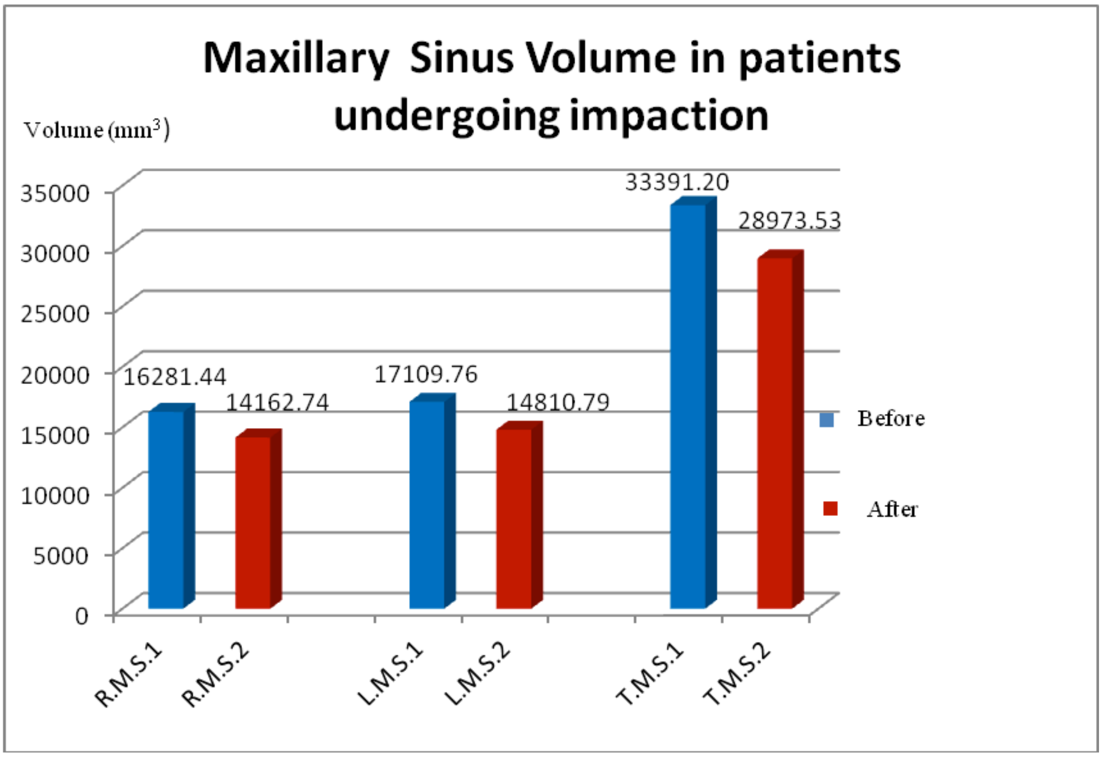
The total volume of the maxillary sinuses decreased from 33391.2±12159.3 mm^3 to 28973.53±10487.02 mm^3 and this decrease of 4417.67±3440.31 mm^3 was statistically significant (p=0.008).

Table 11: Volumetric changes of maxillary sinuses in patients undergoing maxillary impaction.

	T0		T1		Difference		p
	X (n=8)	SD	X (n=8)	SD	X (n=8)	SD	
R.M.S. (mm^3)	16281.44	6301.89	14162.74	5476.26	2118.70	1995.17	0.020
L.M.S. (mm^3)	17109.76	5927.53	14810.79	5156.93	2298.97	1642.03	0.005
T.M.S. (mm^3)	33391.20	12159.30	28973.53	10487.02	4417.67	3440.31	0.008

n: number of individuals p: probability SD: Standard Deviation

T0: Before surgery T1: After surgery X: mean



Graph 7: Maxillary sinus volume in patients undergoing maxillary impaction

Table 12 shows that there was no significant correlation between the volumetric change of the total pharyngeal airway and the maxillary impaction, maxillary advancement and mandibular setback amounts (r=0.232 p=0.580, r= 0.234 p=0.348, and r=0.288, p=0.262 respectively). No significant correlation was found between the volumetric change of the upper pharyngeal airway and the amount of maxillary impaction and maxillary advancement (r=0.166 p=0.695, and r=0.106 p=0.686 respectively), either. The lower pharyngeal airway change showed no correlation with maxillary impaction, maxillary advancement and mandibular setback amounts (r=0.222 p=0.597, r=0.244 p=0.345, and r=0.307 p=0.231 respectively), and the total volumetric change of the maxillary sinuses showed also no correlation with the amounts of maxillary impaction and maxillary advancement (r=0.253 p=0.545 and r=0.217 p=0.403 respectively).

Table 12: Relationship between the amounts of surgical movements of the jaws and changes in pharyngeal airway and maxillary sinus volumes.

	maxillary impaction n=8		maxillary advancement n=17		mandibular setback n=17	
	r	p	r	p	r	p
T.P.A.D. (mm^3)	0.232	0.580	0.234	0.348	0.288	0.262
U.P.A.D. (mm^3)	0.166	0.695	0.106	0.686	-	-
L.P.A.D. (mm^3)	0.222	0.597	0.244	0.345	0.307	0.231
T.M.S.D. (mm^3)	0.253	0.545	0.217	0.403	-	-

r: Correlation Coefficient

n: number of individuals

p: probability

Table 13 shows the comparison of the mean amount of mandibular setback received by female and male patients. There was no significant difference between the two groups.

Table 13: Comparison of the mean amount of mandibular setback in female and male patients.

	FEMALES		MALES		p
	X (n=11)	SD	X (n=6)	SD	
SETBACK (mm)	2,68	0,64	4,58	2,69	0.301

X: mean

n: number of individuals

SD: Standard Deviation

p: probability

7. DISCUSSION

7.1. Discussion of Aim, Subjects and Methods

Surgical alterations in the position of the bony facial skeleton will inevitably affect the soft-hard tissue relationships. It has been noted from early years that movement of the jaws will result in positional changes of the structures directly attached to the bone, and changes in the tension of the attached soft tissue and muscles (Takagi et al 1967, Wickwire et al 1972, Gu et al 2000, Lye 2008).

The positional changes mentioned above have been shown to be responsibe for airway narrowing (Katakura et al 1993, Enacar et al 1994, Kawakami et al 2005).

Airway narrowing induced after surgical correction of Class III malloclusion with mandibular setback surgery, has been associated with sleep related breathing disorders, such as OSA (Riley et al 1987, Turnbull and Battagel 2000, Kitagawara et al 2008, Hasebe et al 2011).

Conversely, it has been also reported that there is no decrease of the upper airway if bimaxillary correction of Class III malocclusion is performed (Chen et al 2007, Marşan et al 2009, Jakobsone et al 2010) and that pharyngeal airway volumes increased as a result of the surgery (Pereira et al 2011). On the other hand, Turnbull and Battagel (2000) found that Class III setback surgery caused a decrease in retropalatal airway width, even when combined with a maxillary advancement procedure. Similarly, Hong et al (2011), reported that airway showed significant narrowing after both mandibular setback alone and bimaxillary surgery.

As long as maxillary sinus is concerned, although its physiological dimensions have been studied in the past, the consequences of the maxillary surgical movements in the volume of this anatomic structure have been studied, to our knowledge, only by Halawa (2005) until the current moment. Halawa showed that the area of the maxillary sinuses, as measured in lateral cephalometric radiographs, decreased by 1.69 ± 1.07 cm^2 after Le Fort I impaction surgery. After a postsurgical period of 15 months there was a statistically significant increase of 0.52 ± 0.53 cm^2.

It becomes obvious, that the literature does not offer a firm conclusion about the impact of the surgical correction of Class III skeletal cases on the volumes of the pharyngeal airway and maxillary sinuses.

The aim of the present study was to examine the changes in the volume of pharyngeal airway and maxillary sinuses after mandibular setback surgery combined with maxillary advancement with or without maxillary impaction. We also aimed to evaluate the change in the smallest cross sectional area of the pharyngeal airway.

Our sample comprised of 17 patients of Turkish descent 35.30% male and 64.70% female, according to the selection criteria of the study. The age range of the patients included in our study was 22.59±5.30 years of age. All subjects were patients enrolled for orthodontic treatment in the Orthodontic Department of the Dental Faculty of Marmara University, Istanbul. All patients presented with Class III skeletal and dental relationship. Patients with craniofacial syndromes were excluded, since they could present anatomic variations which could affect our results. As all these patients were under treatment for orthognathic surgery, they were all skeletally mature. Initially the sample consisted of 23 subjects from whom the initial CBCT scan was obtained and analyzed. However, 2 of them did not come back within a period of 6 months after surgery, so a second CBCT was not obtained. In addition 4 patients had their surgery postponed, so they would have their postoperative scan after the present study would be finished.

The average interval between the surgery and the second CBCT scan was 3.90±0.87 months. This interval was chosen in order to avoid the postsurgical tissue swelling as well as inflammation of the tongue, uvula and hypopharynx that may occur immediately after surgery, and lead to biased results. Additionally, in order to be able to assess the immediate changes induced by surgery, before any significant relapse or remodeling may occur, no scan was taken after a period of 6 months after surgery. Gu et al (2000), have stated that the maximum forward relapse of the pogonion (Pg) occurred mostly within 6 months after the surgery. Many authors suggest similar interval periods for CT scan evaluation. Cevidanes et al (2007), suggested CBCT evaluations 1week before and 1 week after the surgery, while Jakobsone et al (2010) obtained the CBCTs within 2 weeks before the surgery and 6 months after. In the study of Degerliyurt et al (2009), the first CT was performed in the week before surgery-like in Cevidanes protocol-and the second at least 3 months postoperatively. In the study of Kawamata et al (2000) the first CT was obtained within 1 year and 1 month before the surgery, while the second one 3 months after the surgery. However, in Kawamatas' study there was a second follow up CT examination 6 months postoperatively for one group of the initial sample and 1 year postoperatively for a second group of the initial sample. Similarly, Eggensperger et al (2005), evaluated the long-term changes in hyoid bone position and pharyngeal airway size, by studying serial cephalograms of 12 patients who underwent mandibular setback surgery, pre-operatively (T0), and at 1 week (T1), 6 months (T2) and 14 months post-operatively (T3) and finally after an average of 12 years (T4). A possible limitation in our study may be the fact that there is no evaluation in the long term, in order to assess the stability of the postoperative results. However, it should also be kept in mind that current regulations of the local ethical committee do not encourage repeated scanning of patients for research purposes.

Most of the previous studies dealing with the influence of orthognathic surgery on pharyngeal airway and maxillary sinus volume, have been conducted on lateral cephalometric films (Chen et al 2005, Kawakami 2005, Chen et al 2007, Kitahara 2010). The use of lateral cephalograms for morphologic investigations of the pharyngeal airway and maxillary sinuses, does not give an accurate indication of the complexity of these structures or their true size.

A literature review shows that there has been conducted a number of studies for the 3-dimensional evaluation of the upper airway after surgical correction of Class III malocclusion.

Computed Tomographies have many advantages compared to radiographs, as they allow clear visualization of sections of the human body without structure overlap, and they are invaluable tools for volumetric assessments. Bohlman et al (1983), assessed the cross sectional area of the airway using computed tomography. Kawamata et al (2000), utilized CT examinations in order to observe changes in the pharyngeal airway and the hyoid bone position after mandibular setback osteotomy. Iwasaki, Hayasaki, Takemoto, Kanomi, Yamasaki (2009), studied the characteristic shape of oropharyngeal airway in children with Class III malocclusion, using Cone – Beam Computed Tomography. Jakobsone et al (2011), evaluated the area and volumetric changes in the upper airway after bimaxillary correction of Class III malocclusion by means of Computed Tomography.

We chose to conduct our study using Cone Beam Computed Tomographies due to their advantages over the MS-CT scans, the most important being their lower radiation dose, reduced artifacts and lower costs. With CBCT, it was possible to perform the scanning with the patients sitting upright, which is an advantage over MS-CT imaging, which requires the patients to be in a supine position. Supine position causes significant morphologic changes of the airway, since gravity affects the soft tissues surrounding the oropharyngeal cavity.

After all the data were concentrated, MIMICS 14.0 software was incorporated in order to process the CBCT images and calculate the volume of pharyngeal airway and maxillary sinuses. The pharyngeal airway was defined according to the following borders: The anterior border was defined by a vertical plane passing through PNS. The superior was the roof of the pharynx. The posterior border was the posterior pharyngeal wall. The inferior border was a horizontal plane passing from the most anterior and inferior point of the third vertebra. The three-dimensional image of pharyngeal airway which was constructed, was divided into upper and lower parts by a plane drawn from PNS to the most anterior and inferior point of the first vertebrae. The volumes of upper, lower and total pharyngeal airway, as well as the minimal cross-sectional airway area were finally calculated. The above anatomical borders were formed after evaluation and modification of the borders defined in other similar studies. Burgess (2008), in a study evaluating the pharyngeal airway volume after maxillomandibular advancement using CBCTs, suggested that the anterior border could be comprised of the posterior soft palate and base of the tongue, the superior/anterior border was defined by a line created from PNS to Sella (S), the superior border was a line along the inferior border of the body of the sphenoid bone, and the inferior border was a line created from the tip of the epiglottis perpendicular to the posterior pharyngeal wall (Burgess 2008). The pharyngeal airway was divided into superior and inferior aspects by a line from the maxillary incisal edge perpendicular to the inferior aspect of the posterior pharyngeal wall. In the present study, the incisal edge was not selected as a reference point since the metal brackets placed on the teeth could cause artifacts on the CBCT images. Moreover, minor tooth movements may occur between preoperative and postoperative scanning acquisition, which makes incisal edges not reliable reference points. Park et al (2010) using computed tomography scans, assessed the volume of the pharynx as the sum of the nasopharynx and the oropharynx. The nasopharynx was defined as the airway space between a plane parallel to Frankfort Horizontal (FH) plane, passing through posterior nasal spine (PNS) and a plane passing through the right and left pterygomaxillary fissure (PT) points, and the PNS. The oropharynx was defined as the airway space between a plane parallel to FH passing through PNS and a plane parallel to FH passing through the third cervical vertebra (C3). Iwasaki et al (2009), in his study, based on cone- beam tomography, measured the upper airway volume between the hard palate and the base of the epiglottis. El and Palomo (2010), using CBCT scans, divided upper airway into oropharynx (OP) and nasal passage (NP). OP volume was defined as the volume of the pharynx between the palatal plane (ANS-PNS) extending to the posterior wall of the pharynx and the plane parallel to the palatal plane that passes from the most anteroinferior point of the second cervical vertebrae. The inferior limit of the NP airway was defined as the superior limit of the OP airway, and the superior limit was defined as the last slice before the nasal septum fused with the posterior wall of the pharynx. In addition, Grauer et al (2009), in their CBCT based assessment of pharyngeal airway volume and shape, subdivided the pharyngeal airway into superior and inferior compartments by a plane perpendicular to the sagittal plane that included the posterior nasal spine and the lower medial border of the first cervical vertebra. In the present study the pharyngeal airway was divided into upper and lower parts according to the method described by Grauer et al (2009).

The same procedure that was followed for the assessment of the pharyngeal airway volume was followed for the assessment of maxillary sinuses volume. After all the connections of the outer air with the anatomical borders of the maxillary sinuses were eliminated, three-dimensional images of the left and right sinus were constructed and their volumes were calculated. In cases where polyps were observed inside the cavities of the maxillary sinuses, the polyps were calculated and included in the sinus volume as well.

The accuracy, upon which the anatomical borders of the pharyngeal airway and maxillary sinuses were selected, is of utmost importance since we planned to measure volume differences between the same areas of the patients' anatomical structures. We have to admit that we faced difficulties during identifying the maxillary sinus borders in areas where there were connections between nasal cavity and maxillary sinus cavity. In those instances we depicted the most suitable outline that was harmonious with the more clearly defined borders. Correlation analysis demonstrated a high rate of consonance between the measurements, providing a good reproducibility for our method.

Assessment of the amounts of the jaw movements induced by surgery, were necessary in order to perform correlation analysis between them and the amount of volumetric changes. Since, complete data of the surgical movement amounts were not available in the patients files, the author had to superimpose the preoperative and postoperative scans. The scans were superimposed, as described above, on the sphenoid bone since it remains unaffected after the surgery. During the superimposition procedure it became apparent that the superimposition was not as accurate as desired, since it was possible to superimpose the sphenoid bone pre- and post-surgically, however, there were differences between the positions of the vertebrae. A more accurate superimposition could have been done by superimposing lateral cephalometric radiographs, but since CBCTs were already available we did not intend to expose the patients in additional radiation.

Studies show that anatomically the size of the pharyngeal airway and maxillary sinus may differ between males and females (Spaeth et al 1997, Samman et al 2002, Jun et al 2005, Grauer et al 2009). For this reason, in the present study, the initial values of the variables were compared between males and females. We found that there was statistically significant difference only for the parameters of lower and total pharyngeal airway. For those two variables we performed separate statistics dividing the sample according to the gender.

It is preferable if homogeneity exists among the subjects of the sample. In the present study, due to its duration limitations, it was not possible to obtain a large sample where patients could be divided into subgroups according to the type of the surgery. However, it was possible to isolate 8 patients who received mandibular setback combined with maxillary advancement and maxillary impaction surgery and repeat all the statistical evaluations for this subgroup. We did not divide further this subgroup into males and females due to its small size.

7.2. Discussion of Results

As it has already been mentioned above, according to many authors, the surgical correction of Class III malocclusion induces narrowing of the pharyngeal airway (Greco et al 1990, Enacar et al 1994, Hochban et al 1996). Furthermore, this narrowing has been considered as a predisposal factor for the development of O.S.A. in this type of patients (Turnbull and Battagel 2000, Kitagawara et al 2008). However, it has been mentioned that when simultaneous mandibular setback and maxillary advancement/impaction is performed, the patients present an increase in the PAS, a compensation for the changes brought about by mandibular setback (Frohberg and Greco 1990, Pereira-Filho et al 2011).

According to the results of the present study, in males there is a significant decrease of 4196.27±2061.11 mm^3 in the lower pharyngeal airway (p=0.028) and a significant decrease in total pharyngeal airway of 3375.53±3624.67 mm^3 (p=0.028) (Table 7).

In females there was observed an increase in lower pharyngeal airway volume of 1560.08±5101.18 mm^3 which was not significant (p=0.424). The total pharyngeal airway volume increased by 1955.57 ±6117.80 mm^3, and this increase was not statistically significant (p=0.328) (Table 8).

In an effort to find an explanation for this difference in L.P.A and T.P.A volume changes between males and females, the mean setback amounts of males and females were compared to see if the males had a significantly greater amount of setback than females. However, there was no significant difference between the setback amounts of males and females (Table 13).

Degerliyurt et al (2009), in a CT based study, found that after bimaxillary surgery, only midsagittal anteroposterior dimensions were significantly decreased at the level of the soft palate and the base of tongue for males and females. In our study, however, we observed a significant decrease only in the male group for the lower and total pharyngeal airway volumes.

Chen et al (2005), compared the short-term and long –term effects of bimaxillary surgery with those of mandibular setback surgery concerning pharyngeal airway. They studied lateral cephalometric radiographs from 66 Japanese women divided in 2 groups, who had been diagnosed with Class III skeletal deformities and had undergone surgical-orthodontic treatment. Those in group A underwent BSSRO, those in group B underwent Le Fort I procedures with BSSRO. Lateral cephalograms were assessed within 6 months before surgery (T1), 3-6 months after (T2) and at least 2 years after surgery (T3). They concluded that in the group that underwent only mandibular setback, there were significant decreases in the nasopharyngeal, oropharyngeal and hypopharyngeal airway space from T1 to T2, while in the bimaxillary surgery group, they found a significant increase in the nasopharyngeal airway space. However, the oropharyngeal and hypopharyngeal airway spaces showed again significant decreases. If we consider that nasopharyngeal airway in this study corresponds to the upper pharyngeal airway measured in the present study, we can say the results of the two studies are not in accordance. However, the decrease in the oropharyngeal airway space -if we consider that the oropharyngeal airway corresponds to the lower airway measured in the present study- is in agreement with the decrease measured in the male subgroup in the present investigation.

Marsan et al (2008), evaluated oropharyngeal airway changes following Le Fort I maxillary advancement and impaction with mandibular setback in Class III deformity. Their sample was comprised of lateral cephalograms of 53 female patients before surgery, one week post-operatively and 1.3±0.2 years after bimaxillary surgery. They concluded that bimaxillary surgery caused an increase in the upper retropalatal airway space and a posterior and inferior movement of hyoid bone at one week postoperatively. There was an insignificant increase in the lower retropalatal airway space. In the long-term follow up, they found moderate relapse in these changes. The results of this study are not in accordance with the results of our study.

Jakobsone et al (2011), evaluated the upper airway changes after maxillary advancenment and/or impaction in combination with mandibular setback in skeletal Class III malocclusion. They analyzed lateral cephalograms which were taken before surgery, 2 months and 3 years postoperatively and the material was divided into subgroups according to whether the maxillary impaction and advancement were clinically significant (>2 mm) or not. They found that advancement of the maxilla with or without impaction resulted in a significant long-term increase ($p<0.001$) in airway dimension at the nasopharyngeal level (13%–21% increase). If we consider that the nasopharyngeal level corresponds to the upper pharyngeal airway of the present study, the results of the two studies are not in accordance. At the oropharyngeal and retrolingual levels, a decrease took place but was significant ($p <0.05$) only at the oropharyngeal level when the maxilla was not impacted. When the maxilla was not advanced, there was no significant change, except at the hypopharyngeal level (12% decrease) ($p<0.01$).

The importance of the minimal cross-sectional airway area was emphasized by Lenza, Lenza, Dalstra, Melsen, Cattaneo (2010), who performed a 3D evaluation of the upper airway using CBCT scans of 34 patients. They found a weak correlation between the minimal sagittal, minimal transversal and minimal area with the total volume of the upper airway. This means that, according to the authors, the total volume of the upper airway fails to provide the relevant information about the more constricted cross-sectional area, which is the main factor in increasing the resistance to airflow. It is also worth noticing that they calculated the cross-sectional areas on inclined planes corresponding to the sagittal measurements and not only along horizontal plane.

In the present study, the minimal cross-sectional area of the pharyngeal airway before and after surgery was 155.50±64.13 mm^2 and 165.28±80.63 mm^2 respectively. There was an average increase observed of 9.79±64.65 mm^2, but it was not statistically significant ($p=0.541$). This finding may be explained by the physiologic adaptation that occurs in the postsurgical period, mentioned by various authors (Athanasiou et al 1991, Enacar et al 1994).

Degerliyurt et al (2008), evaluated the morphologic changes of the upper airway space in 47 Class III patients who underwent mandibular setback or bimaxillary surgery, based on Computed Tomography and measuring anteroposterior, lateral and cross-sectional area dimensions at the levels of soft palate and base of tongue. They concluded that the anteroposterior dimensions of pharyngeal airway decreased in both groups, however, the reduction was significantly less in the bimaxillary surgery group. More specifically the reduction ratio of the anteroposterior dimension was 20% for the mandibular setback group and 16% for the bimaxillary surgery group. The cross-sectional area of the airway decreased significantly in the mandibular setback group, while in the bimaxillary surgery group this value was decreased but the reduction was not statistically significant. In the present study the change in the minimal cross –sectional area showed as well no statistical significance.

Jakobsone et al (2010), based on CT scans and lateral cephalograms of 10 Class III patients taken 1 week before and 6 months after bimaxillary surgery, evaluated the area and volume changes in the upper airway. They concluded that bimaxillary surgery for correction of Class III malocclusion did not cause decrease of the posterior airway space. This finding is not in accordance with our findings, since we found a significant decrease for the lower and total pharyngeal airway in the males subgroup.

Recently, Hong et al (2011), conducted a study that consisted of preoperative and postoperative Cone-Beam CT scans of 21 skeletal Class III patients who were assigned to either mandibular setback surgery or bimaxillary surgery. They measured the anteroposterior dimension, lateral width, cross-sectional area, and volume of each subjects' pharyngeal airway in both scans. They reported that the pharyngeal airway showed significant narrowing after mandibular setback and bimaxillary surgery. However, the amount of narrowing was smaller in patients undergoing bimaxillary surgery than in patients undergoing mandibular setback surgery. They also found that the amount of change in the anteroposterior dimension and cross-sectional area on the posterior nasal spine plane and the length of the pharyngeal airway presented significant differences between the 2 groups.

The study of Degerliyurt et al (2008) is based on CT scans, while the study of Hong et al (2011) and the present study, are based on Cone Beam CT scans. The studies of Degerliyurt et al (2008), and Hong et al (2011) include a larger group divided into two subgroups depending on the type of surgery. In our study, however, all the patients of the group underwent bimaxillary surgery. The results of the study of Hong et al (2011) are in agreement with the results of the male subgroup of the present study. Hong et al (2011), as well as Degerligurt (2008), concluded that there is a significant decrease in the dimensions of the pharyngeal airway after the surgical correction of Class III skeletal relationships. Both studies included two subgroups, one receiving single –jaw and the other receiving double –jaw surgery. They also both stated that this decrease on airway dimensions was significantly smaller in the bimaxillary group.

As long as maxillary sinuses are concerned, there are very few studies concerning its size in general and to our knowledge, no CBCT study has been conducted concerning its volume changes after maxillary osteotomies.

Halawa (2005), studied as a part of his doctorate thesis the maxillary sinus size before and after Le Fort I impaction surgery. The study was based on lateral cephalometric radiographs of 36 patients, obtained before and after the surgery. Additionally, for 12 patients lateral cephalometric films were also taken on average 15 months after surgery. The maxillary sinus areas were traced on the lateral cephalograms and then they were transferred to a computer, where AutoCAD R14 software was used to digitally measure the size of the maxillary sinus. They concluded that maxillary sinus area decreased significantly by 1.69cm^2±1.07 cm^2 after surgery. However, during the average postsurgical period of 15 months there was an increase in maxillary sinus area by 0.52 cm^2±0.53cm^2. The use of lateral cephalometric radiographs in Halawa's study consists a limitation for that investigation, since three dimensional structures are assessed by a two dimensional method. Additionally, in a lateral cephalometric radiograph the left and right sinuses are superimposed, making the evaluation of the sinuses dimensions more inaccurate.

According to our CBCT based study, there was a significant decrease in the total volume of the maxillary sinus by 3448.09 mm^3±3315.56 mm^3 observed in the whole sample. In the group of subjects that underwent maxillary impaction, there was a decrease of 4417.67 mm^3±3440.31 mm^3. It would be recommended, however, to further investigate if in our sample this reduction in the maxillary sinus volume was permanent or if there was an increase in the long term as reported by Halawa (2005). Another interesting topic for research could be the clinical implications of this reduction in maxillary sinus size, if there is any.

Finally, the results of the present study indicated that there was no correlation between the amount of surgical movements and the volumetric changes observed. Conversely, Tselnik et al (2000), in his study of the lateral cephalograms of 14 subjects preoperatively, immediately postoperatively, and at long-term follow-up, found a strong correlation between the amount of mandibular setback and the decrease in PAS area. Furthermore, Jakobsone et al (2011), suggested that clinically significant maxillary advancement ≥2mm, causes significant increase in the airway dimensions at the nasopharyngeal level. In our study, although the mean values of the amount of mandibular setback are higher in the male group, Mann- Whitney U test showed no statistically significant difference between the amounts of setback in the two groups (p=0.301) (Table 13). This statistical result, though, may have occurred due to limited male sample size.

Overall, the results of the present study show that there is no significant change in the volume of pharyngeal airway after bimaxillary surgery for correction of Class III skeletal relationship, except for the lower and total pharyngeal airway volumes in males. However, there was a significant decrease observed in the total volume of the maxillary sinuses. There was also no correlation between the amount of the surgical movements and the change in the volume of the pharyngeal airway or the volume of the maxillary sinuses. It is evident that a prospective study conducted on a larger and more uniform sample would provide more definitive answers to the questions addressed in this study.

8. CONCLUSIONS

- The pharyngeal airway area presented no significant change after bimaxillary surgery for correction of Class III skeletal relationship, except for the lower and total pharyngeal airway volumes in males, where a significant decrease was observed.
- No significant change was observed in the minimal cross-sectional area of the pharyngeal airway.
- There was a significant decrease in the volume of the maxillary sinuses after the surgery by 3448.09±3315.56 mm^3.
- No correlation was found between the amount of the skeletal movements and the change in the volume of pharyngeal airway or maxillary sinuses.

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Biography

I was born in Athens, Greece in March 1983. I studied at the Dental School of the National and Kapodestrian University of Athens from September 2000 until June 2006. I also studied as an Erasmus student for the winter semester of 2005-2006, at the Faculty of Dentistry, University of Gothenburg, Sweden. After my graduation, I worked as a volunteer in the Orthodontic Department of the 401 Military Hospital in Athens, Greece for two years. Since September of 2008, I have been enrolled in the MSc program at the Department of Orthodontics, Faculty of Dentistry, Marmara University, Turkey.

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T.C.

MARMARA ÜNİVERSİTESİ

Sağlık Bilimleri Enstitüsü Klinik Araştırmalar

Ön Değerlendirme Komisyonu

PROJENİN ADI: İnvestigation Of The Dimensional Changes Of Maxillary Sinuses And Pharyngeal Airway İn Class III Patients Undergoing Bimaxillary Orthognathic Surgery
PROJE YÜRÜTÜCÜSÜ: Prof. Dr. Ahu ACAR
PROJEDEKİ ARAŞTIRICILAR: Eleni PANOU
ONAY TARİHİ VE ONAY SAYISI: 27.07.2010 – 02

Sayın Prof. Dr. Ahu ACAR

25 protokol nolu "İnvestigation Of The Dimensional Changes Of Maxillary Sinuses And Pharyngeal Airway İn Class III Patients Undergoing Bimaxillary Orthognathic Surgery" isimli projeniz Enstitümüzün ön değerlendirme komisyonunda incelenmiş ve araştırmanın Komisyonumuzun ön değerlendirme kriterlerine uygunluğuna karar verilmiştir.

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