

Evaluation of Three-Dimensional Changes in Pharyngeal Airway Following Isolated Lefort One Osteotomy for the Correction of Vertical Maxillary Excess: A Prospective Study

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Received: 16 November 2017 / Accepted: 21 April 2018 / Published online: 8 May 2018
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Abstract

Background Orthognathic surgery involves movement of jaws in all three planes, and this being a part of airway complex, displacement of jaws can influence the dimension of airway at all levels. Lefort one osteotomy surgery with superior repositioning is a common procedure done for patients with vertical maxillary excess

Purpose The purpose of this study was to evaluate the three-dimensional volumetric changes in airway after lefort one impaction surgery using three-dimensional cone beam computed tomography (3D-CBCT) in patients with vertical maxillary excess (VME).

Methods A prospective analysis of 15 patients who underwent isolated lefort one impaction surgery was done with pre-operative (T0) and 3-months (T1) post-operative 3D-CBCT scans. Airway was divided into three segments, nasopharyngeal, velopharyngeal and oropharyngeal. Volumetric analysis of all these segments was done before and after surgery. Paired ‘t test’ was used to assess the mean difference in airway volume and area between T0 and T1. One-way ANOVA was used to check the mean percentage difference in airway volume and area among the three segments.

Results The mean percentage of nasopharyngeal volume difference was $-0.6299 \pm 0.9146\%$, velopharyngeal volume difference was $-0.5205 \pm 1.107\%$, oropharyngeal volume difference was $-1.492 \pm 2.745\%$. Though volume and area of pharyngeal airway were decreased after maxillary impaction surgery in all three segments of airway studied, they were not statistically significant.

Conclusion Among the three segments of airway studied, oropharyngeal airway volume has shown the highest post-surgical reduction though statistically insignificant. ESS scores were within normal limits. Hence, we are of the opinion that there is lack of evidence to conclude that the patients undergoing lefort one superior repositioning for the treatment of VME might develop significant narrowing of PAS that may predispose the patient to breathing disorders.

Keywords Pharyngeal airway volume · Lefort one superior repositioning · Maxillary impaction surgery

Introduction

Orthognathic surgery is advised to correct abnormally positioned jaws, other conditions such as obstructive sleep apnea, and also to achieve access to advanced tumors with intracranial extensions and other skull base surgeries.

Surgical alterations in the position of the bony facial skeleton will inevitably affect the soft tissues. However, an aspect of the orthognathic surgery that is never considered is the effect of the skeletal movements on the pharyngeal airway space (PAS). Changes in the airway dimension have been demonstrated after surgical repositioning of the mandible or maxilla and case reports of mandibular setback surgery inducing sleep-related breathing disorders, such as

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obstructive sleep apnea (OSA) associated with airway narrowing [1, 2], have been published before. Conversely, the oropharyngeal effects of maxilla–mandibular advancement surgery have been used to advantage in the treatment of refractive OSA [3].

Pharynx is part of the digestive system and also of the conducting zone of the respiratory system. The pharynx makes up the part of the throat situated immediately behind the nasal cavity, behind the mouth and above the esophagus and larynx, extending from the cranial base to the level of the sixth cervical vertebra and the lower border of the cricoid cartilage [18].

The human pharynx is conventionally divided into three sections: the nasopharynx, the oropharynx and the laryngopharynx. It is also important in vocalization [18].

Airway evaluation is possible using several techniques, including magnetic resonance imaging [4] (MRI), cine-magnetic resonance imaging [5], computed tomography (CT) [6], endoscopy [7] and optical coherence tomography [8]. However, the introduction of three-dimensional cone-beam computer tomography (3D-CBCT) has provided the chance to study the airway using a noninvasive, rapid and low radiation scan. In their study to measure the human airway with CBCT, Tso et al. [9] demonstrated that CBCT achieves highly correlative linear and cross-sectional area and volumetric measurements in addition to morphometric analysis of the airway. They found the narrowest region in an awake subject, sitting upright and breathing quietly, is located chiefly in the oropharynx [9]. Keeping the advantages of 3D-CBCT in mind, we have used this image modality in our study.

It is possible that orthognathic surgery, by altering facial skeletal anatomy, may induce a non-adaptive and unfavorable change in PAS promoting or exacerbating a sleep-related breathing disorder. There has been no study conducted so far, to our best knowledge, three-dimensionally assessing the PAS following isolated Lefort one maxillary impaction surgery in patients with vertical maxillary excess (VME).

Materials and Methods

This was a prospective cohort study. Fifteen patients were recruited from the department of Oral and Maxillofacial Surgery (of which 8 were females and 7 were males) with the age range of 17–30 years (mean age 22.125 years). The patients provided written informed consent, using a Committee on Human Research-approved consent form. Patient's identity was protected, and enrollment was open from 2013 to 2014.

Healthy patients of age 17–30 years having vertical maxillary excess underwent isolated Lefort one osteotomy

with superior repositioning (without any mandibular surgery) (Figs. 1, 2) operated by the same surgeon with same surgical technique and have a lateral cephalogram and craniofacial 3D-CBCT images available at two examination points. These two points were just before surgery (T0); 3 months after surgery (T1) were included in our study.

Medically compromised patients, deemed unfit for surgery by the anesthetist, patients with craniofacial anomalies, patients who already had undergone orthognathic surgery, previously diagnosed sleep apnea, or patients who had chronic upper airway disease or were excessively obese were excluded from the study.

Ethical approval was obtained from the Institutional Human Ethical Committee.

Imaging

The 3D-CBCT scans were all taken by the same technician at AARTHI scans (Vadapalani, Chennai) using KODAK 9500 CBCT system. The 184 × 206 mm field of view was



Fig. 1 Pre-OP profile



Fig. 2 Post-OP profile

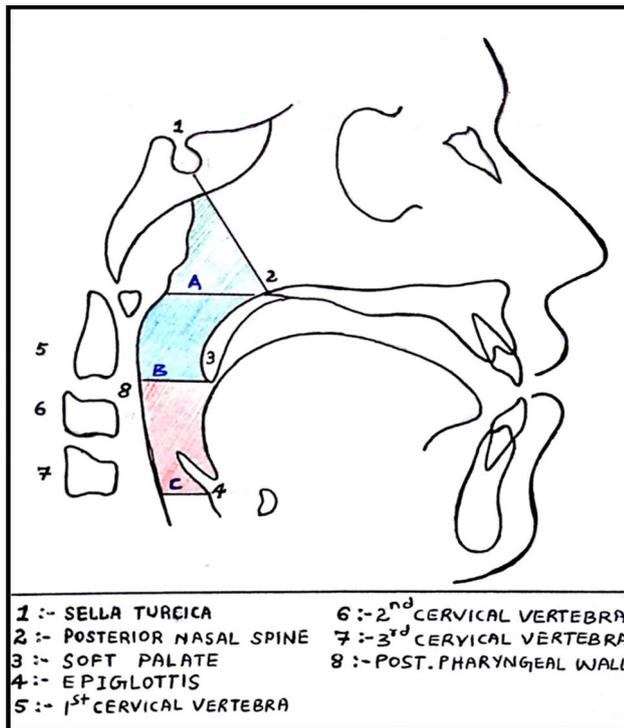


Fig. 3 Landmarks

used to capture the entire length of the airway using the parameters of 10 mA, 90 kVp and 140 kHz. The equivalent radiation dosage for each scan was 146,664 mGy/cm². Voxel size was 300 μm × 300 μm × 300 μm.

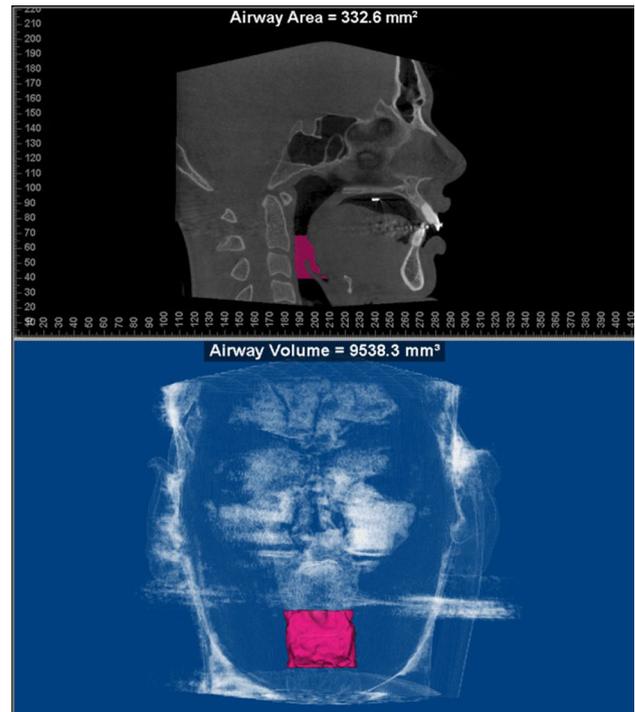
The patients undergoing the scans were instructed to stand very still, breathe slowly through their nose, bite down completely, place their tongue on the roof of the mouth and not to swallow. Craniofacial 3D-CBCT scans were completed on this machine in 14.2 s. The images were stored in DICOM format.

3D-Analysis

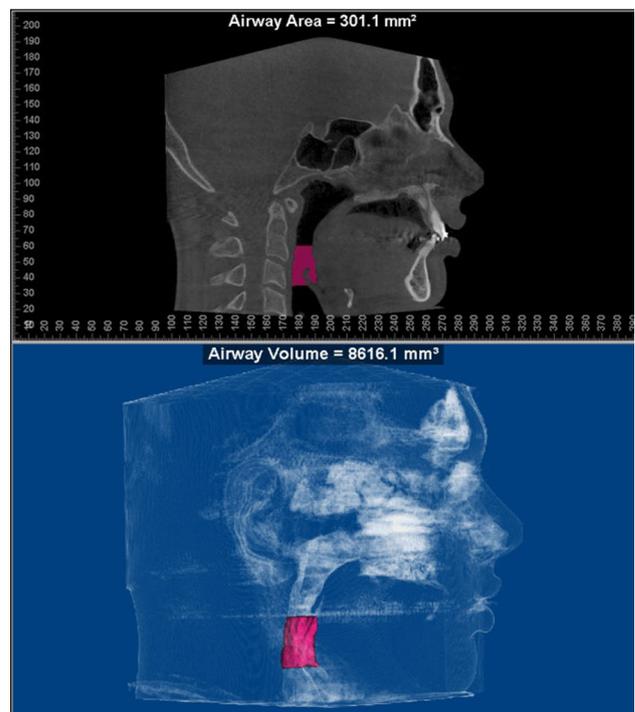
For volumetric analysis of PAS following only maxillary displacement, the pharynx was segmented into nasopharynx (A), velopharynx (B) and oropharynx (C), and their volume and area were designated as VOL A and Ar A, VOL B and Ar B, VOL C and Ar C, respectively.

The landmarks and planes were defined (inspired from Hong et al. [10]) as the sella point (S), the Frankfort horizontal (FH) plane, posterior nasal spine (PNS), posterior pharyngeal wall (PPW), tongue base (TB), tip of soft palate (SP) and the third cervical vertebra (C3) (Fig. 3).

Plane N—plane (parallel to FH) passing from PNS to the PPW.



(a)



(b)

Fig. 4 a Preoperative area and volume. b Postoperative area and volume

Table 1 Paired-sample statistics

Volume mm ³	Mean	SD	<i>t</i>	<i>df</i>	<i>p</i>	
VOL A	Pre-OP	5156.4600	2126.20000	1.893	14	0.079
	Post-OP	5117.7333	2091.25413			
VOL B	Pre-OP	9490.0800	2714.34770	1.624	14	0.127
	Post-OP	9435.8800	2689.13889			
VOL C	Pre-OP	6883.6733	3409.14926	1.464	14	0.165
	Post-OP	6795.7600	3380.99815			

Table 2 One-way ANOVA

Volume	Mean	SD	<i>F</i>	<i>df</i>	<i>p</i>
<i>Per volume difference</i>					
A	– 0.6299%	0.91468	1.328	44	0.276
B	– 0.5205%	1.10710			
C	– 1.4924%	2.74537			

Plane V—plane (parallel to FH) passing from SP to the PPW.

Plane O—plane (parallel to FH) passing from the TB to the most anteroinferior point on the C3.

The nasopharynx (A)—was defined as the airway space above plane (N) and anteriorly limited by a plane passing from the S point to the PNS.

The velopharynx (B)—was defined as the airway space between the plane (V) and the plane (N).

The oropharynx (C)—was defined as the airway space between plane (O) and plane (V).

The CBCT volumetric datasets were imported in DICOM file format into Dolphin Imaging software version 11.0 (Dolphin Imaging and Management Solutions, Chatsworth, CA, USA licensed to M/S Essential dental products, New Delhi, India). Once imported, segmentation was manually adjusted for each volume, limited to the software capabilities.

Once the region of interest was defined, the airway analysis tool calculated volume (VOL) and area (Ar) of each space (A, B, C) for the presurgical (T0) (Fig. 4a) and longest follow-up records (T1) (Fig. 4b).

All the patients were asked to fill Epworth Sleepiness Scale (1990) (ESS) questionnaire at the end of 3 months postoperatively. Score of more than 10 indicated a possible sleep disorder.

Statistical analysis

In the present study, paired ‘t test’ was used to assess the mean difference in airway volume and area between pre-operative (T0) and postoperative intervals (T1) (Tables 1 and 4). One-way ANOVA was used to check the mean

Table 3 Tukey HSD post hoc test

Group 1	Group 2	<i>p</i>
VOL A	VOL B	0.985
	VOL C	0.392
VOL B	VOL C	0.307

Table 4 Paired-samples statistics

Area mm ²	Mean	SD	<i>t</i>	<i>df</i>	<i>p</i>	
Ar A	Pre-OP	226.5600	52.78943	1.884	14	0.080
	Post-OP	222.0333	51.22167			
Ar B	Pre-OP	294.4533	59.79541	1.964	14	0.070
	Post-OP	285.4400	54.83541			
Ar C	Pre-OP	297.6867	69.37517	1.940	14	0.073
	Post-OP	289.8933	71.96490			

Table 5 One-way ANOVA

	Mean	SD	<i>F</i>	<i>df</i>	<i>p</i>
<i>Per area difference</i>					
AR A	– 1.8463%	3.43761	0.175	44	0.840
AR B	– 2.7107%	4.71281			
AR C	– 2.7577%	5.79362			

percentage difference in pre- and postoperative airway volume and area among the three segments (A, B, C) (Tables 2 and 5) (Figs. 5, 6).

Pairwise comparison was done using Tukey post hoc test between A and B, B and C and between A and C (Tables 3 and 6).

Results

The mean percentage nasopharyngeal volume difference was $-0.6299 \pm 0.9146\%$, area difference was $-1.8463 \pm 3.437\%$, velopharyngeal volume difference was $-0.5205 \pm 1.107\%$, area difference was $-2.710 \pm 4.712\%$, oropharyngeal volume difference was $-1.492 \pm 2.745\%$, area difference was $-2.757 \pm 5.79\%$. Though after Lefort one osteotomy with superior repositioning the airway volume and area decreased at all levels (A, B, C) studied, there was no statistically significant difference studied at 5% significance level ($p = 0.276$).

Post hoc test showed no statistically significant difference between all the three segments of airway.

All the patients at T1 had ESS score of less than 8 indicating they did not perceive any disordered breathing during sleep.

Fig. 5 Volume difference

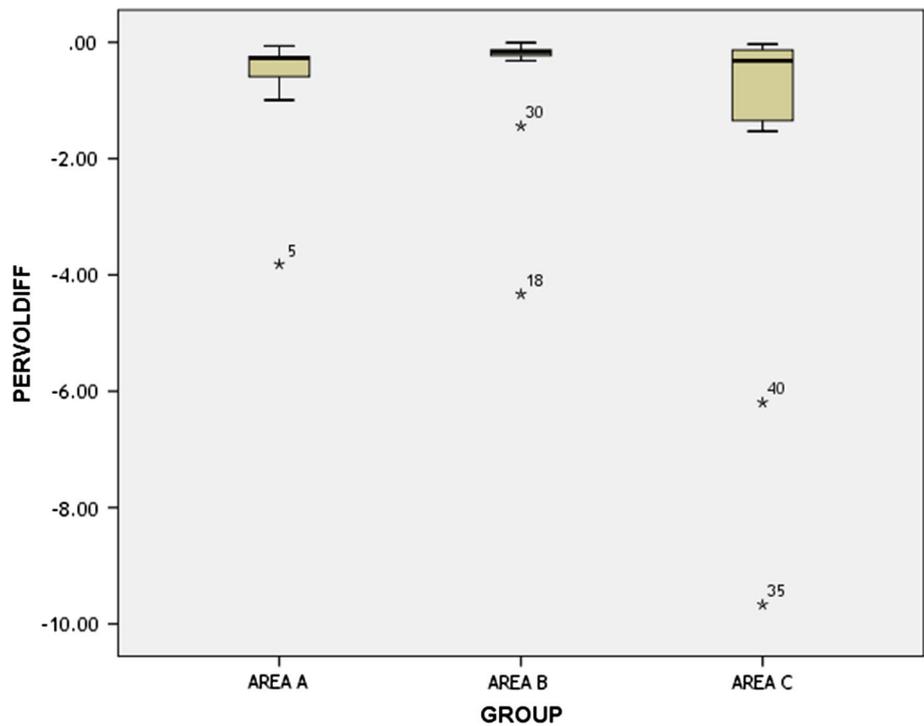


Fig. 6 Area difference

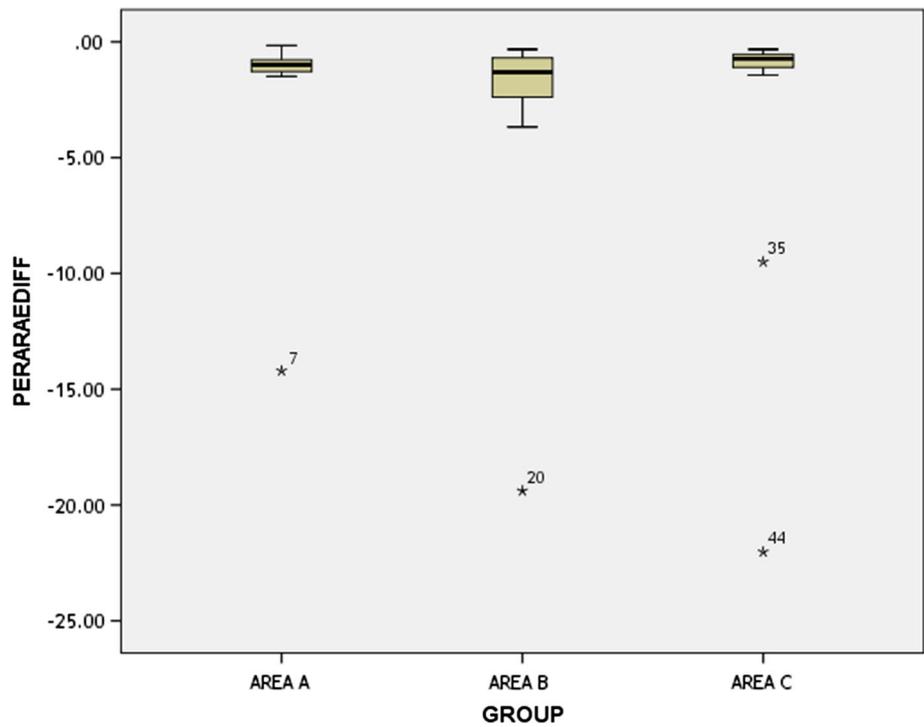


Table 6 Tukey HSD post hoc test

Group 1	Group 2	<i>p</i>
Ar A	Ar B	0.872
	Ar C	0.859
Ar B	Ar C	1.000

Discussion

The positional changes resulting from the movements of the jaws have been shown to be responsible for airway narrowing and to be associated with sleep-related breathing disorders, such as OSA [2]. Conversely, it has been

reported that there is no decrease in the upper airway with bimaxillary (mandible setback + maxillary advancement) correction of Class III malocclusion [11] and that pharyngeal airway volumes are increased as a result of the surgery [12]. In the present study, the average interval between the surgery and the second 3D-CBCT scan was 3 months. This interval was chosen in order to avoid the postsurgical tissue swelling as well as inflammation of the tongue, uvula, and pharynx that may occur immediately after surgery, thereby leading to biased results.

Most of the previous studies dealing with the influence of orthognathic surgery on PAS have been conducted on lateral cephalometric films [11] which do not give an accurate indication of the complexity of these structures or of their true size. We chose to conduct our study using 3D-CBCT because of its advantages over the CT scans, the most important being their lower radiation dose, reduced artifact and lower costs [19, 20]. With CBCT, it was possible to perform the scanning with the patients sitting upright, which is a benefit, since the supine position used in CT imaging causes significant morphologic changes of the airway because gravity affects the soft tissues surrounding the PAS. However, CBCT does have some inherent deficiency, in particular its static evaluation of the pharyngeal airway space. Airway imaging studies have shown that the airway dimensions change at different levels with breathing [4, 6], especially in the lateral dimension. It is essential that the patient does not swallow, cough, speak, or do any motor response other than breathe quietly during the scanning process. After all of the data were concentrated, DOLPHIN 3D software was incorporated in order to process the CBCT images and to calculate the volume of the pharyngeal airway. The pharyngeal airway was defined according to the specific borders described previously, which were formed after evaluation and modification of the borders defined in other similar studies. In the present study, the pharyngeal airway was divided into nasopharynx, velopharynx and oropharynx.

The mean nasopharyngeal volume and area reduced after surgery by 0.62 and 1.84%.

The mean velopharyngeal volume and area reduced after surgery by 0.52 and 2.7%.

The mean oropharyngeal volume and area reduced after surgery by 1.49 and 2.75%.

Most of the studies conducted to evaluate airway after orthognathic surgery measured airway as a whole, but we preferred to segment the airway into three anatomical spaces to find out which one was more affected due to surgery, as it is perceived that patients with sleep apnea often have narrow oropharyngeal airway [2]. It is evident in this study that the airway volume and area have decreased at all three levels following Lefort one impaction surgery,

though it is statistically insignificant. Oropharyngeal airway was more influenced by the surgery compared to the other two in our study. It could be because muscles attached to the palate, tongue and pharynx are closely related. The two muscles that could have influenced PAS in our study were palatoglossus and palatopharyngeus. Following Lefort one impaction, the pulling effect of these muscles originating from the palate would have raised the tongue and the pharynx causing reduction in the diameter of the airway.

The ESS is a self-administered questionnaire with eight questions to assess daytime sleepiness. Patients were asked to rate, on a 4-point scale (0–3), their usual chances of dozing off or falling asleep while engaged in eight different activities. ESS by itself is not a diagnostic tool, but it is an aid and it reflects the sleep-disordered breathing. It is believed to be less subjective compared to other questionnaires and also high has test–retest reliability. ESS score > 10 represents excessive daytime sleepiness. All the patients in our study were asked to take up ESS at T1, and all had scored less than 8 signifying no underlying disordered breathing during sleep after undergoing maxillary impaction surgery for VME.

In a CT-based study, Degerliyurt et al. [13] found that after bimaxillary surgery, only midsagittal anteroposterior dimensions were significantly decreased at the level of the soft palate and the base of the tongue. Hong et al. [10] conducted a study that consisted of preoperative and postoperative CBCT scans of 21 skeletal Class III patients who were assigned to either mandibular setback surgery or bimaxillary surgery. They reported that the PAS 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. The advancement of the velum and velopharyngeal muscles caused by the Le Fort I osteotomy might be a reason for partly reducing the constriction effect of mandibular setback surgery.

Tselnik and Pogrel [14] found a strong correlation between the amount of mandibular setback and the decrease in PAS area. Furthermore, Jakobsone et al. [15] suggested that clinically significant maxillary advancement of ≥ 2 mm causes a significant increase in the airway dimensions at the nasopharyngeal level. Brunetto et al. [16] found stronger correlations between the jaws and the volume segment that was closer to them. In the same way, when comparing patients subjected to isolated mandibular setback to maxillary setback associated with mandibular setback, Lee et al. [17] found greater decrease in the nasopharynx and oropharynx volumes of the latter group. This probably occurs because the maxilla and soft palate have their correlated muscles and ligaments attached to the

upper portion of the pharynx, and the mandible and tongue have their structures attached to the lower portion. Mandibular displacement actually had an influence in the upper airway segment volume. One likely explanation for this fact is the intimate relationship between the base of the tongue and the inferior portion of the soft palate. Therefore, when the first goes backward, it probably pushes the soft palate with it, decreasing the upper airway volume.

The narrowing of the pharyngeal airway may lead to increased velocity of air flow and subsequently to a further reduction in intra-luminal pressure, with further pharyngeal narrowing. Eventually, complete pharyngeal obstruction occurs. Guilleminault et al. [1] and Riley et al. [2] reported two cases of OSA that were previously treated with mandibular setback as a surgical correction of mandibular hyperplasia with Class III malocclusion. But the subsequent studies done in this subject have not reported any cases of OSA following orthognathic surgery, though there has been some airway narrowing being reported in many studies specially following mandibular setback. But to our knowledge there is hardly any study done that has evaluated airway following maxillary surgeries alone. Hence, we have made an attempt in this study to accomplish this.

Conclusion

It is evident in this study that the airway volume and area have decreased at all three levels following Lefort one impaction surgery. Among the three segments of airway studied, oropharyngeal airway volume has shown the highest postsurgical reduction though statistically insignificant. ESS scores were within normal limits. Hence, we are of the opinion that there is lack of evidence to conclude that the patients undergoing Lefort one superior repositioning for the treatment of VME might develop significant narrowing of PAS that may predispose the patient to breathing disorders.

It warrants further research having larger sample size with assessment of breathing patterns using sleep studies and with comparison groups undergoing other maxillary and/or associated mandibular orthognathic surgery procedures.

MRI scans can be a better alternative as an imaging modality, if easily available. It can also assess the dimensional and positional changes of the associated muscles of maxilla–mandible–tongue–palate–airway complex.

Acknowledgements We thank M/s Essential Dental Products, New Delhi, for helping us with the Dolphin software.

Compliance with Ethical Standards

Conflict of interest The authors declare that they have no conflict of interest.

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