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Original Article

Alterations in upper airway dimensions following bimaxillary and mandibular setback surgery in skeletal Class III patients: A cone-beam computed tomography study

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Upper airway

Abstract *Background/Purpose:* Orthognathic surgery can result in a decreased upper airway volume, potentially increasing the risk of developing sleep disorders. This study aimed to evaluate upper airway changes following bimaxillary orthognathic surgery and mandibular setback surgery alone. Additionally, to investigate any correlation between factors such as mandibular plane angle and mandibular length on airway changes in skeletal Class III patients, utilizing cone beam computed tomography (CBCT) data.
Materials and methods: A total of 78 patients with maxillomandibular discrepancy ≤ -2 were divided to Group 1 (mandibular setback, n = 17) and Group 2 (maxillary advancement with mandibular setback, n = 61). CBCT scans were obtained 2–3 weeks preoperatively and 6 months postoperatively to measure airway volumes, minimal axial area, linear dimensions, and angles using Dolphin Imaging software. Statistical analyses, including the Wilcoxon signed-rank test and paired t-test, assessed pre- and postoperative effects, while Spearman's correlation evaluated the associations between variables and postoperative changes.
Results: The results revealed a significant reduction in oropharynx volume (OPV), hypopharynx volume (HPV), total pharyngeal volume (TPV), and minimum cross-sectional area (CSA^{min}) following mandibular setback surgery, while bimaxillary surgery of mandibular setback with maxillary advancement resulted in significant decreases in nasopharynx volume (NPV), TPV, and CSA^{min}. Both surgical approaches caused narrowing of the anteroposterior length (APL) and significant constriction in the lateral transverse width (LTW) of the pharyngeal airway

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space, with Spearman's correlation indicating no significant relationships between these variables and postoperative changes.
Conclusion: Both types of orthognathic surgeries caused significant decreases in total airway volume, CSA^{min} and lateral airway dimension.

Introduction

Orthognathic surgery (OGS) is clinically indicated for patients with dental and skeletal discrepancies that cannot be corrected adequately with orthodontic treatment alone to achieve harmonious occlusion and balanced jaw proportions.[1] OGS involving either one-jaw (mandibular setback) or two-jaw (mandibular setback with maxillary advancement), is widely recognized as an effective treatment for patients with skeletal Class III deformities, offering significant improvements in facial aesthetics, and masticatory function.[2] In recent years, the prevalence of mandibular setback has declined to 10 %, In contrast, two-jaw surgery is utilized in approximately 40 % of cases, while maxillary advancement alone is employed in the remaining patients because bimaxillary surgery provides long-term stability and less airway narrowing as compared to mandibular setback alone.[3,4]

Previous studies demonstrated that pharyngeal airway volume (PAV) reduction is a common outcome following mandibular setback surgery or bilateral sagittal split ramal osteotomy (BSSRO) in Class III patients.[5,6] Studies also suggest that two-jaw surgery of mandibular setback combined with maxillary advancement via Le Fort I osteotomy mitigates the reduction in oropharyngeal airway volume.[6–9] However, reports indicate that the decrease in PAV is more significant in patients undergoing isolated mandibular setback surgery compared to those undergoing mandibular setback combined with maxillary advancement.[10] Reasons behind the fact are that OGS affects the positions of surrounding bony and soft tissues, including the tongue, soft palate, and hyoid bone, leading to a consequent narrowing of the pharyngeal airway space (PAS). This concern changes the trend of OGS to forward movement of the facial skeleton.[11] Changes to the facial skeleton resembling these characteristics have the potential to cause airway disorders. Some studies have suggested that the narrowing of the pharyngeal airway space may play a role in the development of obstructive sleep apnea (OSA).[12,13] This evidence is insufficient to support the development of sleep disorders following OGS in patients with skeletal Class III deformities.[14] Given this concern, postoperative airway changes should be carefully considered by oral surgeons during the surgical planning process.

Historically, lateral cephalometric radiographs have been utilized to assess dentoskeletal and soft tissue changes using standardized anatomical landmarks. However, as cephalograms are limited to two-dimensional (2D) imaging, accurate representation of PAS, a three-dimensional (3D) structure comprising various anatomical components is impossible.[15] In the past decade, cone beam computed tomography (CBCT) has been acknowledged as a precise and dependable method for the 3D assessment of the upper airway. Because it provides high-resolution images and precise 3D reconstructions with minimized; radiation exposure, and reduced positioning errors.[16] Even though CBCT is a beneficial tool for acquiring comprehensive three-dimensional diagnostic data while upholding standards for patients in ethical terms.[17] The upper airway is commonly divided into distinct segments like nasopharynx, oropharynx, and hypopharynx, due to its clinical significance and anatomical locations as implemented in this study. However, a consensus on the terminology for different airway segments is lacking, and the definition of these pharyngeal segments, including their borders and anatomical landmarks, remains inconsistent.[18]

Previous studies have reported specific airway changes associated with particular surgical patterns. However, data exploring the relationship between airway changes and the amount of skeletal movement remain limited.[19] Enough research is present to establish that mandibular setback surgery often results in the reduction of PAS. However, evidence regarding the impact of bimaxillary OGS and PAS decrease remains limited and insufficient.

Based on the above literature review, certain aspects appear to require further detailed analysis. Therefore, the primary objective of this research was to assess whether airway dimensions decrease following bimaxillary OGS and to compare these changes with those who have undergone mandibular setback surgery alone. The secondary objective was to examine how factors such as the extent of mandibular setback, the mandibular plane angle, and mandibular length (both pre- and postoperatively) affect changes in the PAS in patients with skeletal Class III malocclusion, using a 3D modeling program.

Materials and methods

Data collection

This retrospective cohort study according to the Declaration of Helsinki and approved by the Human Research Ethics Committee of China Medical University Hospital under protocol NO. CMUH113-REC1-061.

The study included patients aged 18–40 years who were diagnosed with skeletal Class III malocclusion and exhibited a maxillomandibular discrepancy lesser than −2 mm (ANB angle ≤ -2). Specifically, patients with anteroposterior maxillary hypoplasia combined with anteroposterior mandibular excess were selected. Exclusion criteria encompassed those with congenital craniofacial abnormalities, such as cleft lip and/or palate, significant facial asymmetry, a history of adenoidectomy or tonsillectomy, obstructive sleep apnea syndrome (OSAS), traumatic head or neck injuries, systemic conditions affecting bone growth, and maxillary or mandibular fractures.[20]

The participants were categorized into two groups based on the type of surgical procedure performed. Group 1 comprised 17 patients who underwent combined BSSRO alone, while Group 2 included 61 patients who underwent BSSRO with Le Fort I osteotomy. All surgeries took place between January 2018 and December 2023. Rigid fixation with titanium miniplates was applied to all patients, and maxillomandibular fixation was maintained for approximately two weeks post-surgery. Additionally, all patients received both pre-surgical and post-surgical orthodontic treatment.

Cone-beam computed tomography (CBCT)

CBCT scans were acquired within 2—3 weeks before surgery (T1) and at 6 months postoperatively (T2) by using the ProMax 3D Max Proface system (Planmeca, Helsinki, Finland). All imaging procedures were conducted by a single radiologist to ensure consistency. The scans were performed using a voxel size of 0.400 mm, a field of view of 17 × 23 cm, a tube voltage of 96 KVp, and a tube current between 5.6 and 12.5 mA as per the standardized protocol, patients were seated during scanning and instructed to maintain a natural head position, with the tongue and lips relaxed, breathing softly, and refraining from swallowing.[21—23] The CBCT image files were converted to DICOM (Digital Imaging and Communication in Medicine) format using Romexis software and subsequently imported into Dolphin Imaging software (version 11.95, Dolphin Imaging & Management Solutions, Chatsworth, CA, USA). Image orientation was performed for all patients in the axial, coronal, and sagittal planes, following the user guide of the software.

Airway volumes

Airway volume is segmented and measured across three regions: the nasopharynx, oropharynx, and hypopharynx. The total airway volume is defined as the sum of these three segments as shown in Fig. 1. The nasopharynx is defined as the region enclosed between two planes: one parallel and the other perpendicular to the Frankfort horizontal (FH) at the level of the PNS as shown in Fig. 1. The oropharynx was defined as the region between the PNS-plane (an axial plane aligned parallel to the FH) and the ES-plane (an axial plane parallel to the FH that passes through the uppermost point of the epiglottis) as shown in Fig. 1. The Hypopharynx consists of the area between ES-plane and EI-plane (A plane oriented parallel to the FH that intersects the base of the epiglottis) as shown in Fig. 1. Airway volumes were measured using the sinus/airway tool in the Dolphin software. Airway sensitivity value was adjusted to a range of 200—350 grayscale units for all patients. Maximum constriction of the pharynx was the minimum cross-sectional area (CSA^{min}) between the PNS plane and the EI plane. CSA^{min} was detected and measured automatically by the Dolphin Imaging Software. Linear measurements of anteroposterior length (APL) and transverse width (LTW) were obtained at the level of epiglottis on the axial slice as shown in Fig. 2(B and C). Mandibular plane angle and mandible length were measured in sagittal slices using the measure tool in the software. The airway changes were quantified using both absolute measurements (expressed in mm^3 or mm^2) and linear dimensions (measured in mm).

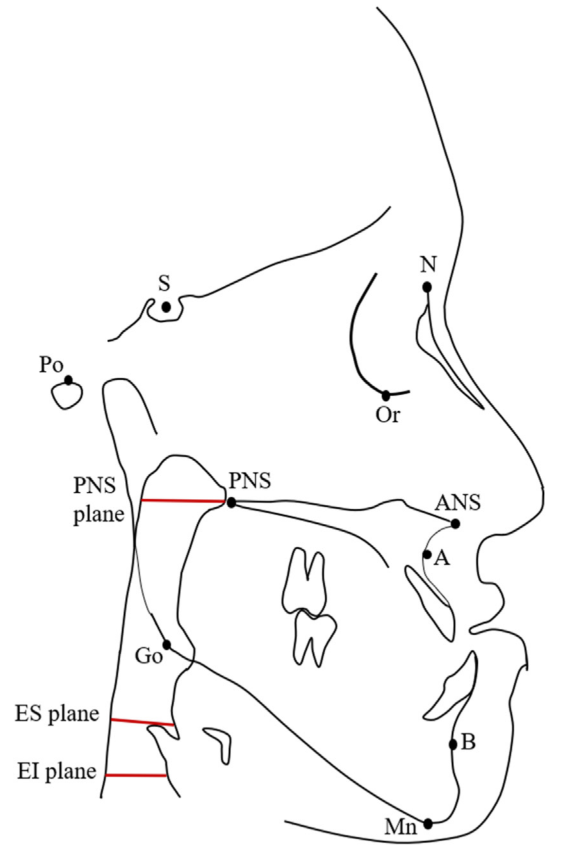

Figure 1 Anatomical landmarks: S: sella. N: nasion. Or: orbitale. Po: porion. ANS: anterior nasal spine. A: deepest point in concavity of maxillary alveolar process. PNS: posterior nasal spine. B: deepest point in concavity of mandibular alveolar process. Mn: menton. Go: gonion. ES: epiglottis superior. EI: epiglottis inferior.

Jaw movements were assessed using the superimposition tool in Dolphin software, with preoperative CBCT images serving as the baseline volume and postoperative CBCT images as the second volume. The side-by-side superimposition tool was used to approximate the T1 and T2 CBCT images, based on four reference points: the right superior frontal foramen, the right and left frontozygomatic sutures, and the left mental foramen as shown in Fig. 3 (A). The cranial base was subsequently superimposed using the voxel-based auto-superimposition tool, with the region of interest marked by a red box in the sagittal reconstructions as shown in Fig. 3 (B). This method allowed Dolphin software to merge the voxels within the specified area and automatically superimpose both 3D images. In the verify/result view, the forward and backward movements of points A and B were assessed using the measure tool on sagittal slices as shown in Fig. 3 (C).

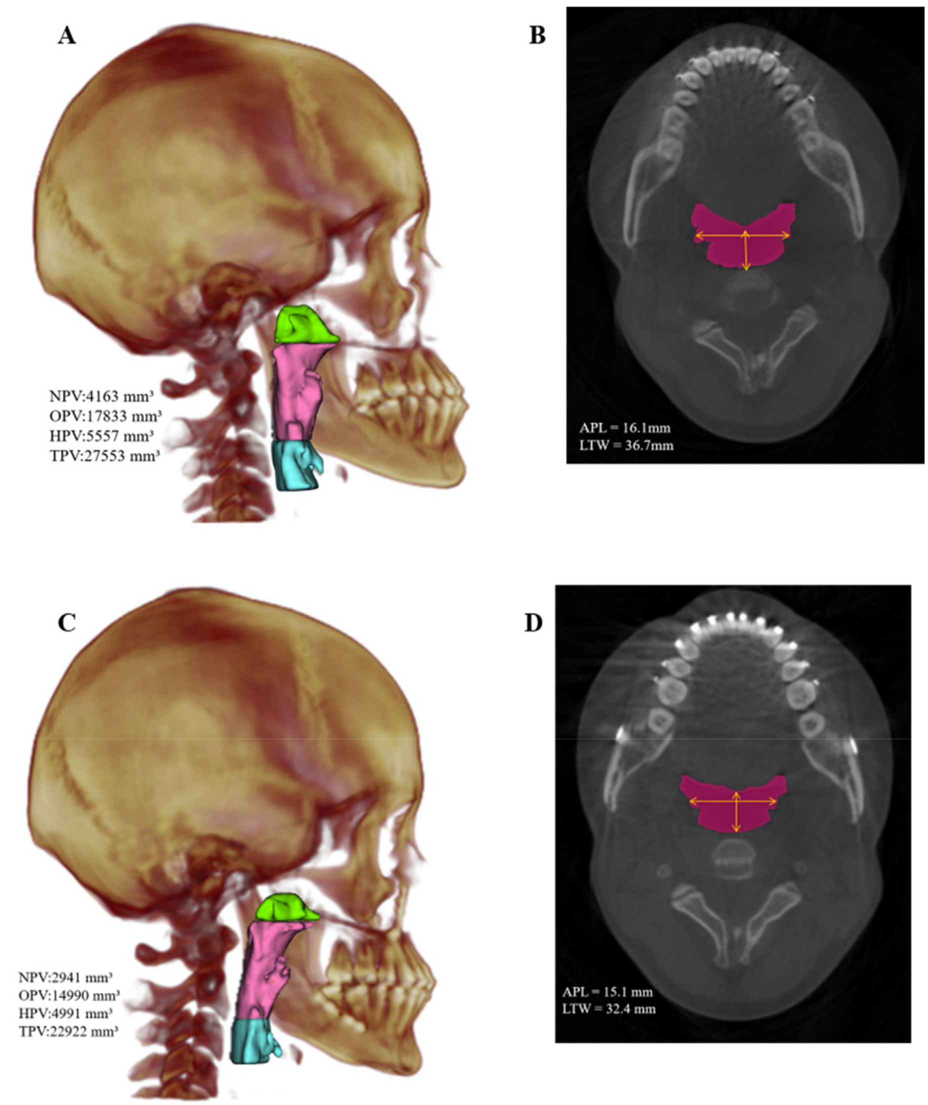

Figure 2 Sagittal and axial view of pharyngeal airway (A) Airway volume before surgery. (B) Airway dimensions before surgery. (C) Airway volumes after surgery. (D) Airway dimensions after surgery. Airway volumes and maxillary dimensions including nasopharynx volume (NPV), oropharynx volume (OPV), hypopharynx volume (HPV), anteroposterior length (APL), and lateral transverse width (LTW).

Statistical analysis

Preoperative and postoperative measurements were statistically analyzed using SPSS software (version 22 for Windows; SPSS, Chicago, IL, USA). The normality of the data was assessed using the Kolmogorov—Smirnov and Shapiro—Wilk tests. To evaluate the differences between pre- and post-surgical measurements, both the Wilcoxon signed-rank test and paired t-test were employed, depending on the distribution of the data. The correlation analysis between the change in variables (ΔT2—T1) and the change in postoperative airway (ΔT2—T1) was performed using Spearman's rank correlation analysis, with a significance level set at 0.01. Airway segments served as the dependent variables, while the independent variables included A-point, B-point, mandibular plane angle (MNPA), and mandibular length.

Results

The study included a total of 78 patients, comprising 41 men and 37 women. The participants were divided into two groups: Group 1 consisted of 17 patients who underwent a mandibular setback of 7.02 $\pm$ 3.21 mm, while Group 2 included 61 patients who underwent a mandibular setback of 7.83 $\pm$ 3.66 mm combined with a maxillary advancement of 2.31 $\pm$ 1.62 mm. Detailed demographic information for the study participants is summarized in Table 1.

The results showed the reductions in variables observed following bimaxillary surgery are less pronounced compared to those associated with mandibular setback surgery. Our findings demonstrated a significant postoperative reduction in total pharyngeal volume in both groups. Conversely, the total pharyngeal area decreased in both groups, the reduction was statistically significant only

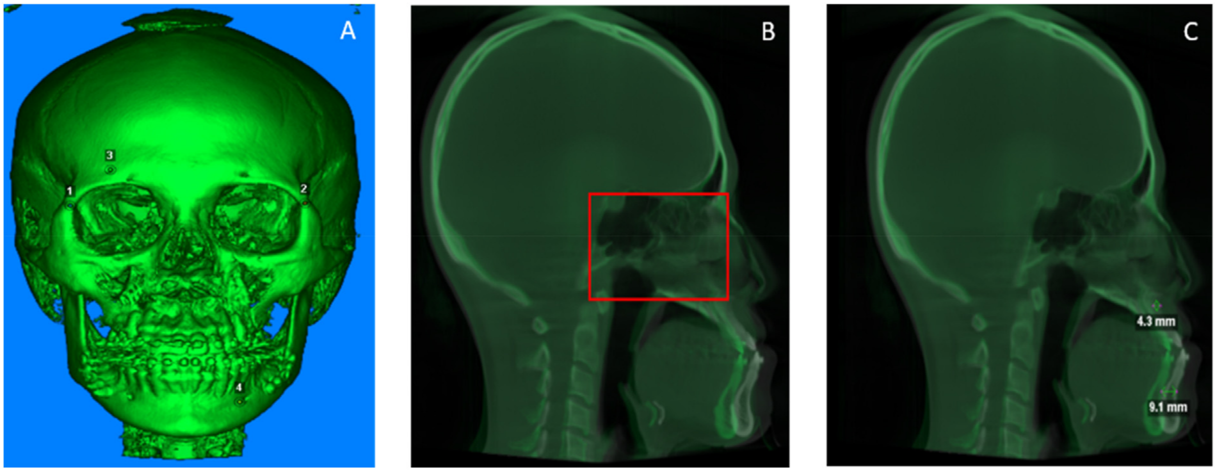

Figure 3 Superimposition (A) Reference points frontal foramen, frontozygomatic sutures and mental foramen. (B) Defined area. (C) Linear movement of A and B points.

Table 1 Demographic characteristics of Patients.

Variable	Group 1 (n = 17)	Group 2 (n = 61)
Age (mean ± SD)	29.29 ± 8.67	23.37 ± 3.88
Gender (n, %)		
Males	10 (58.82)	31 (50.82)
Females	7 (41.18)	30 (49.18)
SNA	80.89 ± 3.85	82.65 ± 3.24
SNB	86.69 ± 2.78	89.73 ± 3.41
ANB	−5.80 ± 2.53	−7.09 ± 2.381
T1	29 ± 20.17	60.71 ± 95.32
T2	213.94 ± 107.56	220.71 ± 125.60
A point	–	2.31 ± 1.62
B point	7.02 ± 3.21	7.83 ± 3.66

Data are presented as the mean ± standard deviation (range). Abbreviations: Group 1: mandibular setback surgery. Group 2: bimaxillary surgery. SNA angle is formed by S sella, N nasion, and A point. SNB angle is formed by S sella, N nasion, and B point. ANB = SNA-SNB. T1: days before surgery. T2: days after surgery. A point: maxillary advancement. B point: mandibular setback movement.

in Group 1. The results indicated that the volumes of other segments, such as the nasopharynx, decreased in both groups, with statistical significance observed only in Group 2. Similarly, the volumes of the oropharynx and hypopharynx also decreased in both groups, but these reductions were statistically significant only in Group 1 as shown in Table 2.

The results showed the CSA^{min} and mandibular length decreased significantly in both groups. Similarly, other variables, such as anteroposterior length and transverse width, showed reductions in both dimensions; however, this decrease was statistically significant only in the transverse dimension. Other measurements of the mandibular plane angle also exhibited a decreasing trend in both groups; however, this decrease was not statistically significant in Group 1 but significant in Group 2 as shown in Table 2.

Our results did not demonstrate any significant correlations between variables and volumetric changes for the different segments in either Group 1 or Group 2. However, in Group 2, the degree of posterior displacement of the B-point showed a significantly weak correlation with a reduction in OPV and HPV, as shown in Table 3.

Discussion

In Asia, the prevalence of skeletal Class III malocclusion has been reported to range from 12.58 % to 26.67 %.[24] Previous studies have highlighted that upper airway reduction may contribute to the development of OSA.[12,13] Sufficient research has demonstrated a reduction in airway volume following isolated mandibular setback surgery. However, previous studies remain insufficient to conclusively demonstrate a decrease in the airway space after bimaxillary surgery (mandibular setback combined with maxillary advancement), and to identify the specific factors contributing to this reduction. These factors have highlighted the need for further investigation and motivated the present study. This study is important in adding valuable information in this field.

On isolated mandibular setback OGS most of the studies have concluded that it leads to a reduction in airway volume.[5,6] A systematic review comprising nine studies on mandibular setback surgery identified significant reductions in the volumes of all three pharyngeal airway segments and the total pharyngeal airway volume post-following the procedure.[25] Similarly, the present study demonstrated statistically significant decreases in oropharyngeal and hypopharyngeal volumes, although the decrease in nasopharyngeal volume was not statistically significant. Additionally, a significant reduction in the CSA^{min} was observed, consistent with another study.[26] Kawamata et al. and Lee et al. reported decreases in both frontal and lateral dimensions after mandibular setback surgery,[2,6] while another study noted a reduction in the APL accompanied by an increase in LTW.[27] In contrast, the present study observed decreases in both the APL and LTW. These reductions can be attributed to the posterior repositioning of the mandible, which displaces anatomical structures such as the hyoid bone posteriorly and inferiorly, backward

Table 2 Comparison between airway parameters before and after BSSRO ± LeFort I.

Variable	Group 1			Group 2		
	T1Mean ± SD	T2Mean ± SD	(*P*-value)	T1Mean ± SD	T2Mean ± SD	(*P*-value)
NPV	8591.00±2630.61	8287.59±2687.30	(0.209)	8591.21±2389.56	7362.89±2376.77	(0.000*)
OPV	26718.65±69912.52	22524.94±7705.19	(0.020*)	27289.32±8822.11	26317.53±8920.79	(0.339)[a]
HPV	8390.88±2523.09	6632.41±2188.97	(0.012*)	7536.84±3061.91	7305.58±3151.39	(0.402)
TPV	43700.52 ± 9696.22	35195.23±13463.27	(0.011*)	43417.37±11842.82	40986±12009.28	(0.019*)[a]
CSA^{min}	414.00±107.18	314.94±109.30	(0.003*)	402.24±118.67	371.98±136.34	(0.035*)
Mand. length	69.39±4.19	66.74±5.23	(0.000*)	71.97 ± 5.49	68.47±5.20	(0.000*)
MNPA	27.43±4.75	27.19±4.45	(0.797)	26.27±5.93	24.65±5.28	(0.002*)
APL	15.04±3.44	13.10±3.51	(0.082)	16.73±5.19	15.55±4.92	(0.121)[a]
LTW	24.94±4.13	22.15±5.07	(0.002*)	24.27±4.70	23.01±4.66	(0.003*)
TAA	1370.71±227.59	1281.06±218.06	(0.045*)	1378.18±273.47	1348.03±289.89	(0.224)

*$P < 0.05$.
[a] Wilcoxon sign rank test. SD standard deviation. Group 1: mandibular setback surgery. Group 2: bimaxillary surgery. T1: before surgery. T2: 6 months after surgery. NPV: nasopharynx volume. OPV: oropharynx volume. HPV: hypopharynx volume. TPV; total pharyngeal volume. CSA^{min}.: minimum axial area. Mand. length: mandibular length. MNPA: mandibular plane angle. APL: anteroposterior length. LTW: lateral transverse width. TAA: total airway area.

Table 3 Correlation(r) between variable changes (ΔT2−T1) and postoperative airway changes (ΔT2−T1).

Variables	Group 1						Group 2					
	MNPA		Mand. length		B-point		MNPA		Mand. length		B-point	
	r	*P*	r	*P*	r	*P*	r	*P*	r	*P*	r	*P*
NPV	0.47	0.06	−0.04	0.87	−0.25	0.34	−0.12	0.33	−0.07	0.54	0.24	0.05
OPV	−0.21	0.42	0.08	0.74	0.22	0.41	0.23	0.07	0.06	0.63	0.32*	0.01
HPV	−0.35	0.17	−0.23	0.39	0.39	0.12	0.05	0.67	−0.03	0.76	0.34*	0.00
TPV	0.20	0.44	0.09	0.71	0.26	0.32	−0.07	0.57	0.07	0.58	−0.06	0.61

r: Spearman's correlation coefficient. *Significance levels: *$P < 0.01$. Group 1: mandibular setback surgery. Group 2: bimaxillary surgery. NPV: nasopharynx volume. OPV: oropharynx volume. HPV: hypopharynx volume. TPV: total pharyngeal volume. MNPA: mandibular plane angle. Mand. length: mandibular length. B-point: mandibular setback movement.

movement of the tongue,[28] and backward movement of the soft palate.[9] The backward positioning of all these structures into the pharyngeal airway cavity caused constriction of the airway.

On bimaxillary surgery, previous studies have reported varying outcomes for nasopharyngeal volume. Kim et al. observed a decrease in nasopharyngeal volume, whereas another study reported an increase following bimaxillary surgery. However, some studies also suggest a potential decrease in this region.[9,29] In the present study, nasopharynx volume statistically deceases in patients who have undergone bimaxillary surgery. This decrease is attributed to the posterior maxillary pitch-up and clockwise rotation of the anterior maxilla, movements made to allow large mandibular setback during Le Fort I osteotomy in mandibular prognathism patients. The posterior and upward displacement of the posterior nasal spine (PNS) contributes to nasopharyngeal constriction. In bimaxillary cases, the extent of mandibular setback plays a critical role. Previous studies show that bimaxillary surgery involving a large mandibular setback of more than 8 mm significantly decreases the volume of the oropharynx and hypopharynx.[6,13] If the magnitude of mandibular setback is equal to or only slightly greater than that of maxillary advancement, it may result in either an increase or no significant change in airway volume in these regions.[30,31] In the present study (mandibular setback of 7.83 mm) reductions were observed in oropharyngeal, hypopharyngeal, and total airway volumes postoperatively, though only the decrease in total airway volume reached statistical significance. These differences from previous research may be attributed to variations in airway segmentation and the magnitude of mandibular setback across studies. A previous study utilizing CBCT reported no significant changes in the CSA^{min} following bimaxillary surgery.[32] In contrast, another study observed a significant decrease in CSA^{min} after bimaxillary surgery.[33] Aligning with these findings, our study also demonstrated a significant decrease in CSA^{min} six months postoperatively. Ceylan et al. reported a reduction in the APL and an increase in the LTW of the airway following bimaxillary surgery, with the mandibular setback contributing larger than maxillary advancement.[17] Conversely, a study observed decreases in both APL and LTW after bimaxillary surgery.[6] Similarly, the findings of the present study indicated reductions in both APL and LTW, though the decrease was statistically significant only for the LTW. These reductions are attributed to the posterior movement of the mandible during bilateral sagittal split osteotomy, along with the posterior displacement of surrounding soft tissues into the posterior airway space, as previously discussed. Our results indicate a significant yet weak correlation between the posterior movement of the B-point and changes in oropharyngeal and hypopharyngeal volumes as shown in Table 3.

An et al. conducted a six-year follow-up study on patients who underwent maxillary advancement (1.90 ± 1.31 mm) and mandibular setback (8.14 ± 4.62 mm) and concluded that 6 months is a stable stage for assessing changes PAS changes in skeletal Class III patients.[34] In the present study, postoperative changes were also assessed after 6 months. A review using the PICO framework (Population, Intervention, Comparison, Outcome), identified that reduced CSA^{min} as the most relevant anatomical feature of the upper airway associated with the pathogenesis of OSA. In the present study, the CSA^{min} showed a significant decrease in both groups.[35] Previous studies have reported the development of OSA in two patients following mandibular setback surgery,[36] as well as in 33 % of patients who underwent bimaxillary surgery with a larger mandibular setback.[13] The present cohort study also demonstrated a decreasing trend in parameters between preoperative and postoperative values, suggesting a potential risk for the development of OSA.

Mandibular setback can be performed with maxillary advancement rather than as an isolated mandibular setback procedure. However, extensive maxillary advancement may not be suitable for all patients, as an excessively protrusive maxilla may compromise aesthetic outcomes. When planning larger mandibular setback, clockwise rotational movement, such as maxillary posterior impaction, can be advantageous, as it allows more mandibular setback without necessitating maxillary advancement. However, maxillary impaction may contribute to nasopharyngeal narrowing. Since most of the patients undergoing orthognathic surgery are young and prioritize aesthetic concerns, but post-surgical airway changes should be discussed with patients preoperatively. Minimized mandibular setback with posterior impaction of the maxilla and lifestyle modifications, such as weight management, could be a reliable option for severe skeletal Class III patients.

This study has several limitations. First, the sample size for the mandibular setback group was limited; however, this study included a sufficient number of patients who underwent bimaxillary OGS. Second, the demographic data did not include other potential contributing factors to obstructive sleep apnea, such as body mass index, smoking, and alcohol consumption, in addition to upper airway anatomy. All participants in this study were between 18 and 30 years of age, whereas OSA is more commonly prevalent in middle age groups. A long-term study is needed to assess the post-surgical effects of OGS, such as a reduction in airway volume, on patients' sleep quality while considering additional contributing factors such as weight, gender, and age.

Within the limitations of this study, the following conclusions could be drawn: 1. Both mandibular setback surgery and bimaxillary surgery were found to reduce total airway volume, CSA^{min}, and the lateral dimensions of the airway. 2. Mandibular setback surgery had a greater impact on airway segments compared to bimaxillary surgery. 3. No significant correlation was observed between changes in MNPA or mandibular length and post-operative reductions in airway volumes.

Declaration of competing interest

The authors have no conflicts of interest relevant to this article.

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