Pharyngeal Airway Morphology in Skeletal Class III With Mandibular Asymmetry is Improved After Bimaxillary Orthognathic Surgery

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Purpose: The relationship between pharyngeal airway morphology and jawbone movements in skeletal Class III patients with mandibular asymmetry after orthognathic surgery remains unclear. This study was to measure the changes in pharyngeal airway morphology in skeletal Class III patients with mandibular asymmetry after bimaxillary surgery and evaluate associations between changes in pharyngeal airway morphology and skeletal movements.

Methods: In this retrospective cohort study, skeletal Class III patients who underwent bimaxillary surgery were enrolled. The predictor variable was facial symmetry status divided into 2 groups, asymmetric (Group A) and symmetric (Group B). The primary outcome variables were changes in airway parameters, including cross-sectional linear distances, cross-sectional area (CSA), minimum CSA (Min-CSA), and volume; and airway asymmetry index between the preoperative and 6-month postoperative imaging studies. Correlation analysis was performed between upper airway and skeletal changes.

Results: Twenty-five patients were included in this study, with 15 patients in Group A (mean age: 23.00 years; BMI: 22.83) and 10 patients in Group B (mean age: 22.30 years; BMI: 22.48). Group A showed a higher asymmetry index than Group B at T0; however, no significant differences compared to Group B at T1. The airway volume was significantly decreased in the oropharynx in Group A at T1, whereas it showed no significant differences in Group B ($P < .05$). Lateral movement of B point and Menton showed positive correlations with changes in Min-CSA in the oropharynx and negative correlations with changes in airway asymmetry index ($P < .05$).

Conclusions: Pharyngeal airway exhibited an asymmetrical and constricted morphology in Group A before surgery. The airway morphology in Group A showed a tendency to adopt a symmetrical and less constricted shape after surgery. The airway space was reduced in the oropharynx in Group A after surgery.

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Surgical correction of mandibular asymmetry correlated with the improvement of pharyngeal airway morphology.

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The pharyngeal airway has been considered important by orthodontists and maxillofacial surgeons during diagnosis and treatment planning for orthognathic surgery. For determining the configuration and dimensions of the pharyngeal airway, several anatomical structures, such as the craniofacial skeleton and the surrounding pharynx, have been investigated.[1] The relationship between skeletal patterns and craniofacial morphology, and the volume of the pharyngeal airway has been assessed by previous studies.[2,3] In patients with skeletal Class III malocclusion, these relationships have been focused on changes in airway dimensions after treatment with maxillary expansion,[4] mandibular setbacks, or bimaxillary surgery.[5]

In skeletal Class III malocclusion, mandibular asymmetry frequently presented with an incidence of 25 to 34%.[6] As mandibular deviation becomes severe, the pharyngeal airway exhibited a tendency toward constriction and a more elliptical shape.[7] Due to the risk of causing pharyngeal airway obstruction, the characteristics of the upper airway must be considered in such patients during treatment planning.[8] However, evidence on changes in upper airway morphology in Class III patients with mandibular asymmetry, after orthognathic surgery was limited.

Bimaxillary orthognathic surgery is a common treatment modality to correct skeletal Class III malocclusion.[5] Due to changes in the anatomical location of the skeletal and soft tissues, including the muscles around the jaw and tongue base, pharyngeal airway also changes in both morphology and volume.[9,10] Airway volume could be controlled optimally through the horizontal movement of the mandible and vertical movement of the maxilla.[11] However, the relationship between the lateral movement of the mandible to correct mandibular asymmetry and its effects on the changes in the pharyngeal airway remained unclear.

Computed tomography is a useful tool that enables greater accuracy and reliability in facial anatomy analysis, especially in patients with skeletal asymmetry.[12] In addition, 3D reconstruction of airway structures provided an improved comprehension of airway investigations and reduced the limitations encountered in traditional methods.[13,14] Therefore, the relationship between reshaping of the pharyngeal airway and skeletal movements as a result of bimaxillary orthognathic surgery in skeletal class III malocclusion with mandibular asymmetry can be measured precisely using computed tomography.[14]

The purpose of this study was to investigate the changes in the pharyngeal airway dimension and morphology in skeletal Class III patients with mandibular asymmetry after bimaxillary surgery and to evaluate the correlation between changes in pharyngeal airway and skeletal movements following orthognathic surgery. The hypothesis was that there was no significant difference in the pharyngeal airway morphology in skeletal Class III patients with and without mandibular asymmetry after surgery. The specific aims of the study were as follows: *1)* To compare the pharyngeal airway dimension and morphology by using airway parameters and airway asymmetry indices between skeletal Class III patients with and without mandibular asymmetry before and after bimaxillary orthognathic surgery; and *2)* To evaluate the correlation between the changes in upper airway measurements and the movement of various skeletal landmarks.

Patients and Methods

STUDY DESIGN AND SAMPLE

To address the research purpose, we designed and implemented a retrospective cohort study. The study design and reports followed the STROBE guidelines (Strengthening the Reporting of Observational Studies in Epidemiology). The study population was composed of all patients presenting for evaluation and bimaxillary orthognathic surgery at the Department of Oral and Maxillofacial Surgery, Samsung Medical Center, from 12 Jan 2017 to 15 Dec 2019. To be included in the study sample, patients had to present with skeletal Class III malocclusion (ANB $< 0.3°$, Wits appraisal < -4.80; Norm of ANB $2.26 \pm 1.79°$, Wits appraisal norms -2.49 ± 2.48), and be treated with bimaxillary orthognathic surgery with maxillary posterior impaction and mandibular setback. Patients were excluded as study subjects if they had congenital diseases, trauma, or pharyngeal or nasal pathology. This study was approved by the Institutional Review Board (IRB) (Approval No. SMC MD IRB 2020-02-138-001). Due to the retrospective nature of this study, the Committee waived the requirement for informed consent.

STUDY VARIABLES

The symmetry status of the jawbone was defined as the primary predictor variable for this study. The airway parameters and airway asymmetry index were defined as the primary outcome variables. The airway parameters included the maximum anteroposterior width (AP), maximum lateral width (LW), cross-sectional areas (CSA), minimum CSA (Min-CSA), and volume (V) (Table 1).[15] The skeletal changes after surgery were measured as secondary outcome variables (Table 1). Demographic characteristics of the sample population, including age, characteristics of anteroposterior and vertical skeletal patterns, BMI, and the asymmetry index of mandibular measurements in both groups are compared as other variables.

DATA COLLECTION METHODS

Computed tomography (CT) images (GE LightSpeed VCT XT; General Electronics Medical Systems, Milwaukee, WI, USA) with the following parameter such as tube voltage of 120 kVp, tube current of 80 mAs, and a slice thickness of 0.625 mm, were obtained before surgery (T0) and 6 months postsurgery (T1). Patients were scanned in the supine position with centric occlusion and relaxed facial musculature.

Table 1. DEFINITION OF UPPER AIRWAY AND SKELETAL VARIABLES USED IN THIS STUDY

	Variables	Definition
Airway parameter	C1AP, C2AP, C3AP	The maximum anteroposterior width at C1, C2, C3 levels
	C1LW, C2LW, C3LW	The maximum lateral width at C1, C2, C3 levels
	C1C, C2C, C3C	The corresponding cross-sectional areas at C1, C2, C3 levels
	MinC1C, MinC2C, MinC3C	The minimum cross-sectional area at C1, C2, C3 levels
	V1, V2, V3, V	The nasopharyngeal, oropharyngeal, hypopharyngeal, total airway volume
Airway asymmetry index	C1APA, C2APA, C3APA	The difference of maximum anteroposterior width between deviated side/right side and nondeviated side/left side at C1, C2, C3 levels
	C1LWA, C2LWA, C3LWA	The difference of maximum lateral width between deviated side/right side and nondeviated side/left side at C1, C2, C3 levels
	C1CA, C2CA, C3CA	The difference of cross-sectional areas in the deviated side/right side and the nondeviated side/left side at C1, C2, C3 levels
Skeletal landmarks	A point	The most posterior and deepest point on the anterior contour of the maxillary alveolar process in the midsagittal plane
	Posterior nasal spine (PNS)	Point located at the tip of the posterior nasal spine
	Jugular (Jug)	Midpoint at the concavity of zygomaticoalveolar crest in frontal view
	B point	Point located at the largest concavity of the anterior portion of the mental symphysis
	Menton (Me)	Most inferior point of symphysis of mandible
	Gonion (Go)	The most inferior point at jaw angle between mandibular plane and ramus
	Ramal point at the level of gonion (RmG)	Most lateral point of ramus contour at the level of gonion. The point on mandibular angle at the junction of ramus and body
	Ramal point at the level of the sigmoid notch (RmS)	Most lateral point of ramus contour at the level of the sigmoid notch
Skeletal measurements	Mandibular body length	The distance between gonion and menton
	Mandibular ramus length	The distance between ramal point at the level of the sigmoid notch and ramal point at the level of gonion
	Mandibular body length asymmetry	The mandibular body length on the deviated side or right side minus the nondeviated side/left side
	Mandibular ramus length asymmetry	The mandibular ramus length on the deviated side or right side minus the nondeviated side/left side

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The images were imported as Dicom (Digital Imaging and Communications in Medicine) format using InVivo5 software (Anatomage, San Jose, CA, USA) and reoriented according to the midsagittal plane (MSP, created from Sella, Nasion, and Basion points) and Frankfort horizontal plane (FH plane, created from the orbitale of both sides and the right portion). The coordinate system consisted of 3 axes (x, y, and z) with their origin (0,0,0) registered at Nasion (N). Assuming that the subject was in an anatomical position, positive values were to the left, posterior, and superior to the N point of the subject. In contrast, negative values were to the right, anterior, and inferior to the N point. The 3-dimensional coordinates (x, y, z) of any landmark represented its 3D position relative to N (0,0,0) (Fig 1).

Three-dimensional skull images acquired at T0 and T1 were superimposed using a point-to-point and volumetric registration method with specifically normalized mutual data based on the anterior cranial base as proposed by Bazina et al.[16] for nongrowing patients. The method of superimposition utilized the voxel grayscale and was fully automated by the Automatic Registration tool of the software to avoid errors related to the operator. Upon volumetric registration, the T0 and T1 images shared the same coordinate system, which compensated for discrepancies and minimized the risk of measurement errors (Fig 1).[16]

Airway Parameter Measurements

Landmarks were defined using the lateral view (cross-section at the MSP). The pharyngeal airway was studied at 3 levels: the planes parallel to the FH plane and passing through the lowermost protruding part of the cervical vertebrae 1, 2, and 3 (C1, C2, and C3) (Fig 2, Table 1). The maximum anteroposterior width (AP), maximum lateral width (LW), and corresponding cross-sectional area (CSA)[15] at the cross-section where the C1, C2, and C3 planes passed through the airway space were measured for T0 and T1 in the axial view (Fig 3, Table 1). The total airway volume (V), the nasopharyngeal airway volume (V1), the oropharyngeal airway volume (V2), and the hypopharyngeal airway volume (V3), along with their minimum cross-sectional areas (Min-CSA) at each level for T0 and T1 were measured (Fig 4, Table 1). The threshold value was set ranged from −1024 to −600 Hounsfield units for the evaluation of the airway volume, allowing that the pharyngeal airway could be distinguished with adjacent soft tissue.

Airway Asymmetry Index

The airway space was divided into 2 parts: deviated and nondeviated, or right and left using the MSP at C1, C2, and C3 levels. The maximum anteroposterior width (AP), maximum lateral width (LW), and the

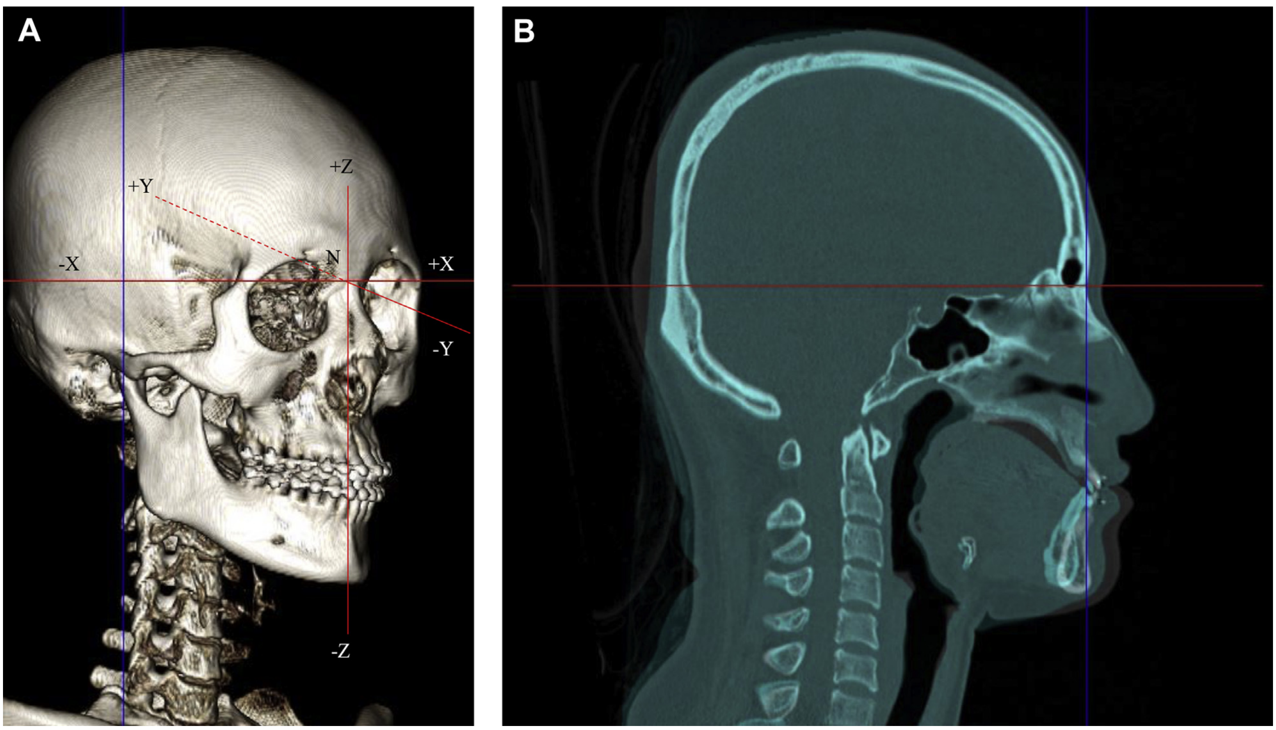

FIGURE 1. *A*, Horizontal, sagittal, and coronal reconstruction after head reorientation. *B*, Superimposition of three-dimensional images acquired before (*white*) and after surgery (*blue*) using a point-to-point and volumetric registration method with specifically normalized mutual data based on the anterior cranial base.

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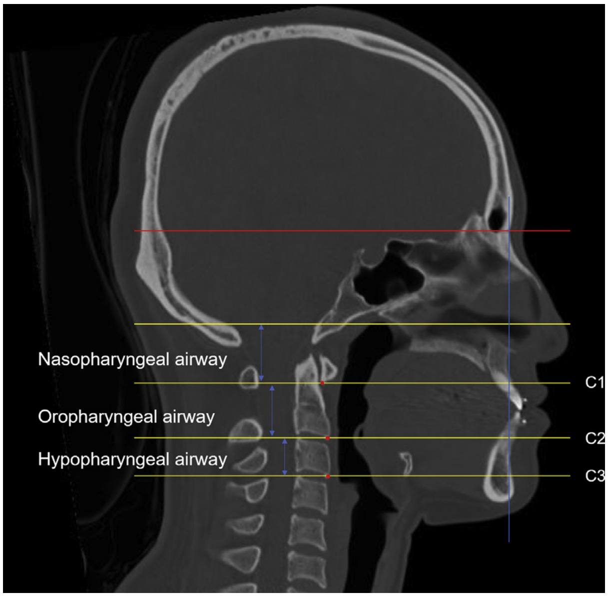

FIGURE 2. Landmarks and reference planes in the pharyngeal airway: C1, C2, and C3, the planes parallel to the FH plane and passing through the lowermost protruding part of the cervical vertebrae 1, 2, and 3; Nasopharyngeal airway, the airway space above the C1 plane; Oropharyngeal airway, the airway space between C1 and C2 planes; Hypopharyngeal airway, the airway space between C2 and C3 planes; Total airway, the airway space was combined by the nasopharyngeal, oropharyngeal, and hypopharyngeal airway.

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corresponding cross-sectional areas (CSA) were measured for each part (Fig 5). The asymmetry indices of airway assessment parameters were calculated using the difference between the deviated and nondeviated parts in Group A, and between right and left sides in Group B for each airway parameter (Fig 5, Table 1).

Skeletal Movement

Displacements of the maxilla and mandible were analyzed along the x, y, and z axes by calculating the movement of each landmark between T0 and T1. Definitions of skeletal landmarks and measurements used in this study are described in Table 1. Movements of posterior nasal spine (PNS) and A point were measured to determine the amount of maxillary posterior impaction, anterior impaction, and horizontal movement. Anteroposterior and horizontal movements of B point were used to determine the amount of mandibular setback and asymmetry correction.

DATA ANALYSES

To assess the intraobserver variability and reproducibility, the measurements were assessed twice at an interval of 2 weeks by a single inspector. The resulting correlation coefficient (ICC) indicated high reliability (ICC > 0.90). Cronbach's Alpha, used to evaluate the reliability of the measurements, was equal to 0.88, indicating appropriate superimposition and measurement agreement. Descriptive analyses were performed to calculate the mean and standard error of variables in both groups at T0 and T1. Normality of data was confirmed using the Shapiro–Wilk test. To assess changes in airway measurements and skeletal movements before and after surgery within each group, a paired t test was used based on the normal distribution of variables. An independent t test was used to compare the changes in airway measurement and skeletal movements between Group A and B at T0 and T1, respectively. Pearson's correlation analysis was performed to evaluate correlations between the changes in airway parameters and skeletal landmarks. SPSS 24.0 Statistical Software (SPSS, Inc., Chicago, IL) was used for all statistical analyses. For the multiple comparison correction of the primary outcome variables, the significance level was set at P value adjusted with false discovery rate (FDR) < 0.05. For the multiplicity correction of the secondary outcome variables, P value was corrected with Bonferroni's method, and the significance level was set at $P < .0055$.

Results

Twenty-five patients (16 males and 9 females, mean age of 23.2 ± 4.34 years) were included in this retrospective study. Patients were divided into 2 groups according to mandibular symmetry status based on the distance from Menton (Me) to the MSP: Asymmetry group (Group A) with a distance greater than 4 mm, and symmetry group (Group B) with a distance between 0 and 2 mm.[17] Subjects with a deviation from 2 to 4 mm were excluded as atypical asymmetry. The demographic characteristics of the sample population were 15 patients in Group A (mean age: 23.00 ± 3.68 years; 5 females and 10 males; BMI: 22.83 ± 2.66) and 10 patients in Group B (mean age: 22.30 ± 3.23 years; 4 females and 6 males; BMI: 22.48 ± 4.77). In total, 15 patients in Group A and 10 patients in Group B were required to reject the null hypothesis that there was significant difference in the upper airway space between skeletal Class III patients with and without mandibular asymmetry, after bimaxillary orthognathic surgery with at least 80% power, and a significance level of 0.05 using a 2-sided paired t test.

Comparison of demographic characteristics of sample population between groups including gender, age, and BMI showed no significant difference ($P < .05$, Table 2). Changes of skeletal parameters between groups at T0 and T1 showed no significant

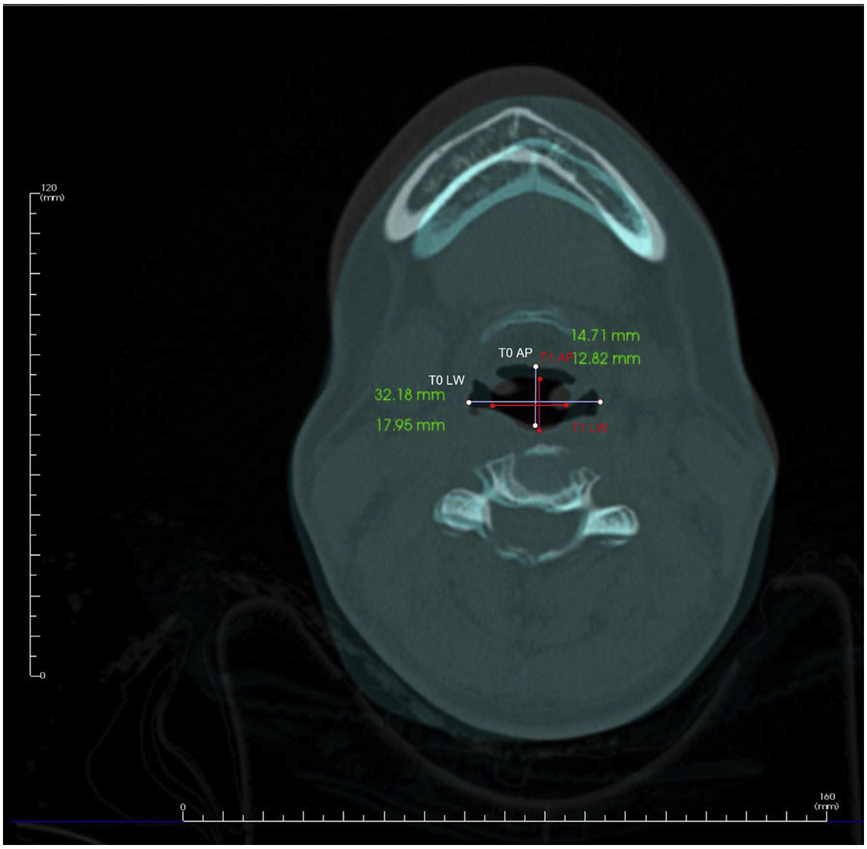

FIGURE 3. Linear and area measurements of the pharyngeal airway at presurgery and postsurgery. Airway parameter measurements at T0 and T1, including maximum anteroposterior width (AP), maximum lateral width (LW), and the area of the cross-section (CSA) on the horizontal view at C1, C2, and C3 levels measured at T0 (*white*) and T1 (*blue*).

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difference in cephalometric measurements for anteroposterior and vertical skeletal patterns. However, significant difference in the mandibular asymmetry indices between groups were found at T0 ($P < .05$, Table 3). In Group A, the mandibular asymmetry indices were greater than those in Group B at T0 for body length asymmetry, ramus length asymmetry, and Me deviation by -4.88 ± 3.25 mm, -1.81 ± 2.31 mm, and -6.52 ± 2.62 mm, respectively ($P < .05$, Table 3). At T1, the mandibular asymmetry indices in Group A decreased significantly and showed no significant differences between groups ($P < .05$, Table 3).

AIRWAY PARAMETER MEASUREMENTS

The changes in airway parameters in Group A and Group B before and after surgery are shown in Table 4. The airway parameters such as maximum anteroposterior width at C1, C2, and C3 level (C1AP, C2AP, C3AP), maximum lateral width at C1 level (C1LW), cross-sectional area at C1, C2, and C3 level (C1C, C2C, C3C), minimum cross-sectional area at C1 level (MinC1C), airway volume at oropharynx (V2), and total airway volume (V) were significantly reduced in Group A after surgery (FDR-adjusted $P < .05$, Table 4). However, no significant differences were observed in Group B after surgery (FDR-adjusted $P < .05$, Table 4). No significant differences were observed between groups at T0 and T1 (FDR-adjusted $P < .05$, Table 4). The positive correlation between Me deviation and MinC2C before surgery were found (Pearson's correlation coefficient 0.644, $P = .010$).

AIRWAY ASYMMETRY INDEX

The airway asymmetry index in both groups at T0 and T1 are presented in Table 5. The airway asymmetry index of the cross-sectional areas at C3 level (C3CA) was significantly greater in Group A than in Group B at T0 (62.58 ± 44.41 mm^2 in Group A; 27.89 ± 19.91 mm^2 in Group B) (FDR-adjusted $P < .05$, Table 5). No significant differences were observed in airway asymmetry indices within Group B and between groups at T1. In Group A, C2LWA, C1CA, C2CA, and C3CA were significantly decreased after surgery (FDR-adjusted $P < .05$, Table 5). In Group

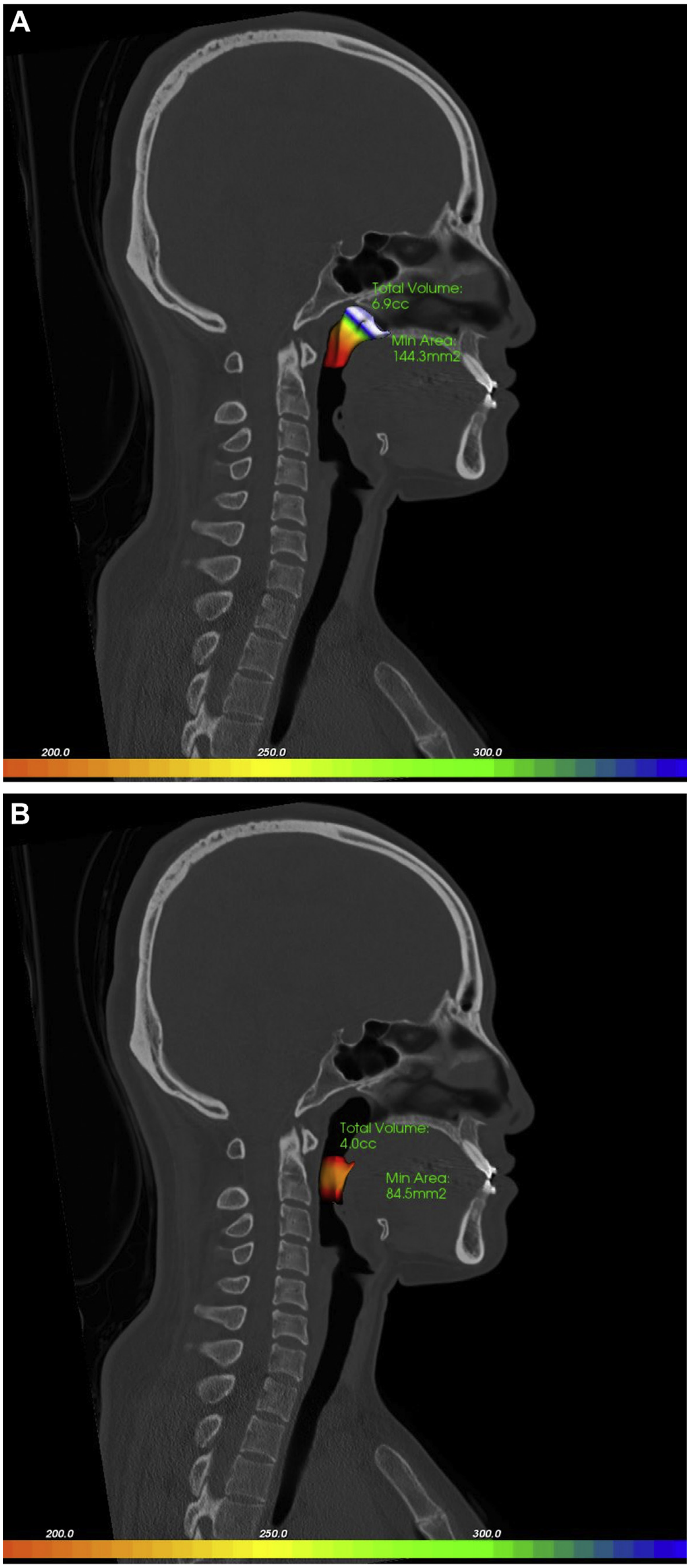

FIGURE 4. Volumetric and minimum cross-sectional area measurements of the pharyngeal airway at the nasopharynx (*A*), oropharynx (*B*), **(Fig 4 continued on next page.)**

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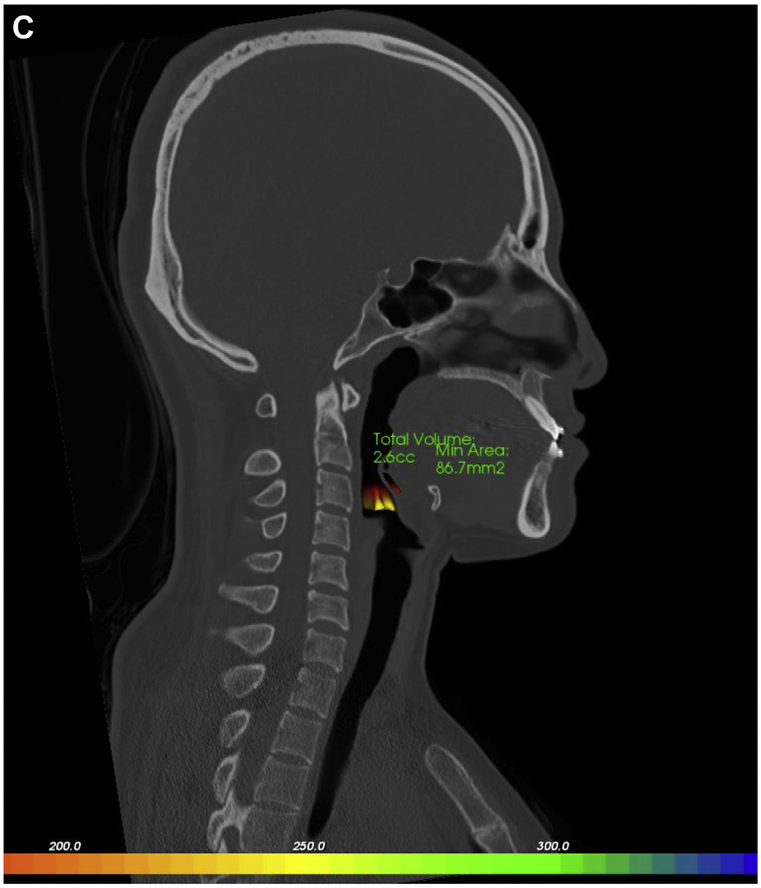

FIGURE 4 (cont'd). and hypopharynx (*C*).

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A, the CSA was larger on the deviated side than on the nondeviated side at C2 and C3 levels (176.98 ± 85.30 mm^2 and 133.16 ± 42.90 mm^2, respectively, at C2 level; 175.94 ± 90.46 and 134.66 ± 47.51 mm^2, respectively, at C3 level; FDR-adjusted $P < .05$, Supplementary Table 1).

SKELETAL DISPLACEMENT AND CORRELATION WITH AIRWAY CHANGES AFTER SURGERY

The changes in the jawbones after surgery in both groups are shown in Table 6. Correlation analysis of upper airway changes and skeletal movements after surgery in Group A are presented in Table 7. Vertical movement of PNS was positively correlated with changes in V1, V2, and V ($P < .05$, Table 7). Lateral movement of B point was negatively correlated with C2LWA, C1CA, and C2CA; and was positively correlated with MinC2C ($P < .05$, Table 7). The linear regression analysis between mandibular asymmetry correction and upper airway changes is shown in Table 8.

Discussion

This study investigated the changes in pharyngeal airway morphology and dimensions in skeletal Class III patients with mandibular asymmetry after bimaxillary surgery. Further, we evaluated the relationship between upper airway changes and jawbone displacements following surgery. The pharyngeal airway morphology was expected to be improved after surgery, and the pharyngeal airway changes were expected to be correlated with skeletal movements. The specific aims of this study were to measure the airway parameters and airway asymmetry index in both groups before and after surgery to compare the differences in these changes between asymmetry and symmetry groups and to analyze the relationship between the pharyngeal airway changes and the skeletal movements. This study showed that there were no significant differences in airway parameters and airway asymmetry index between Group A and B after surgery, and the airway space was reduced in Group A. Surgical correction of mandibular asymmetry

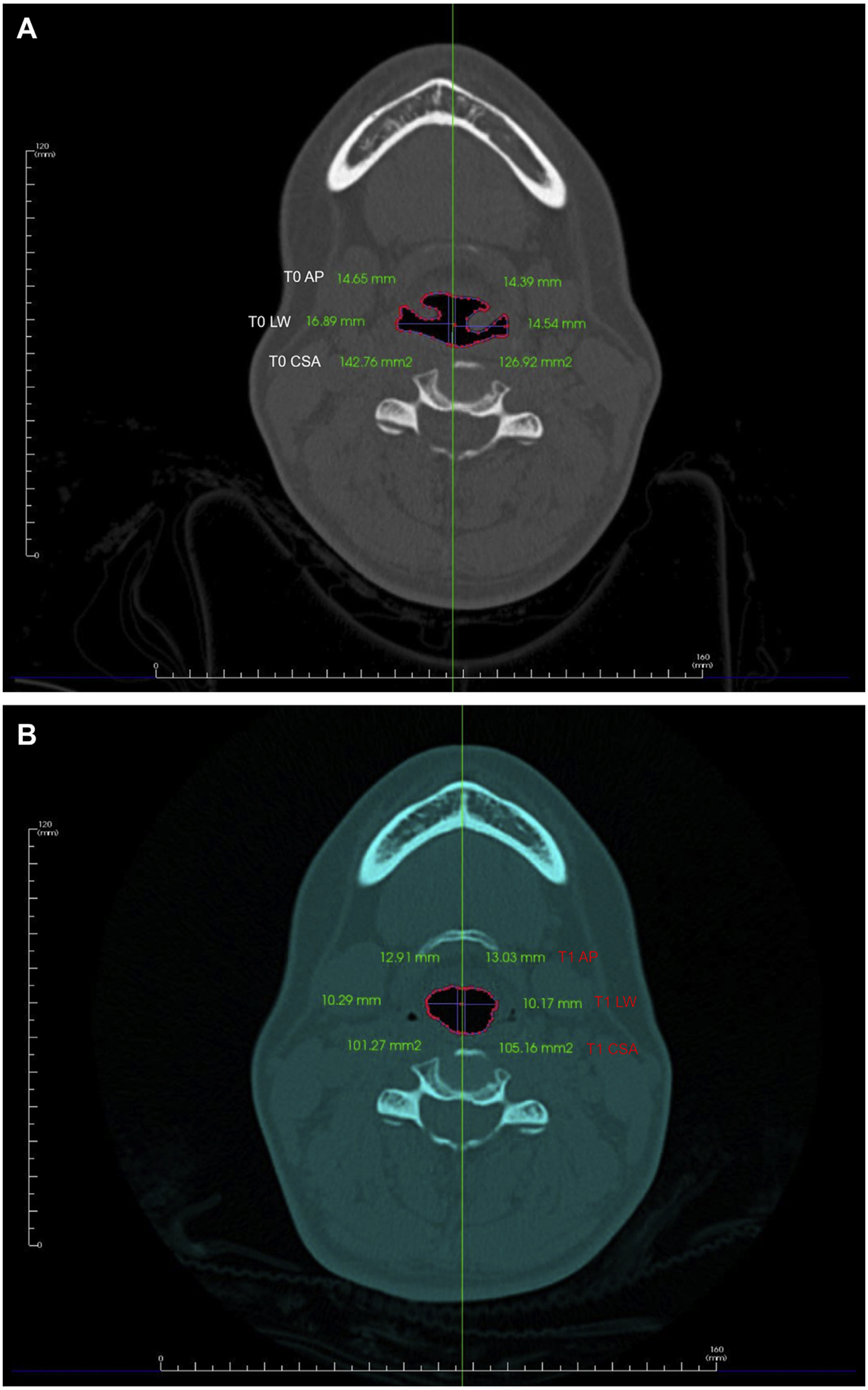

FIGURE 5. Airway asymmetry indices of maximum anteroposterior width (AP), maximum lateral width (LW), and the area of the cross-section (CSA) on the horizontal view at C1, C2, and C3 levels measured at T0 (*A*) and T1 (*B*).

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correlated with the improvement of pharyngeal airway morphology to become more symmetrical and less constricted.

Various factors influencing airway dimensions and shape have been reported, such as age,[18] different characteristics of anteroposterior and

Table 2. DEMOGRAPHIC CHARACTERISTICS OF THE PATIENTS IN GROUP A AND GROUP B

Variables	Group A	Group B	*P* Value
Gender			.734
Female	5	4	
Male	10	6	
Age	23.00 ± 3.68	22.30 ± 3.23	.630
BMI	22.83 ± 2.66	22.48 ± 4.77	.817

Data are shown as mean ± standard deviation.

Intergroup comparison was tested by the independence *t* test.

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vertical skeletal patterns,[2] and BMI.[2,3,19] Subjects enrolled in this study between 18 and 37-year-olds presented with no significant between-group differences in anteroposterior and vertical skeletal patterns, or BMI, which could avoid potential confounding effects of these factors on airway volume and shape (Tables 2 and 3).

Before surgery, a positive correlation between Me deviation and airway constriction at the oropharyngeal level was noted ($P = .010$). These findings suggest that a more constricted airway morphology will present in cases where mandibular deviation becomes more severe, similar to the findings of Wen et al.[7] This issue may markedly increase inspiratory resistance and decrease airflow, which in turn is exacerbated by the large negative pressures distal to the obstruction, with further increase in resistance to the extent that the pharyngeal airway in the critical region collapses under negative pressure.[20]

In this study, Group A presented a significantly more asymmetrical airway morphology compared to Group B before surgery, especially at hypopharyngeal levels, characterized by greater asymmetry indices of the airway in this region (Table 5). Differences in airway parameters were observed between the deviated and nondeviated sides of airway space, especially in C2C and C3C, which were significantly larger on the deviated side than on the nondeviated side (Supplementary Table 1). These findings are consistent with the results of Zheng et al.,[21] who reported that the Class III mandibular-deviated group presented with significant asymmetry, characterized by larger mean cross-sectional area and volume on the deviated side than on the nondeviated side in the glossopharyngeal segment and hypopharyngeal portion. These results suggest that mandibular asymmetry may contribute to pharyngeal airway collapsibility and pharyngeal compliance, which increases morbidity of obstructive sleep apnea (OSA).[22] The condition of airway space in subjects with mandibular asymmetry should be considered in diagnosis and treatment planning, especially for surgery cases.

Bimaxillary orthognathic surgery is often used to correct severe skeletal discrepancies in skeletal Class III patients with mandibular deviation.[5,23] However, changes in the upper airway after surgery remain a controversial issue.[23] Uesugi et al.[24] reported that the pharyngeal airway volume did not change after a mandibular setback (3.2 ± 3.2 mm) and maxillary advancement (2.1 ± 0.9 mm). Lee et al.[25] reported that the oropharyngeal and the upper hypopharyngeal volume were significantly reduced after surgery with 5.36 ± 3.2 mm mandibular setback at B point, and 1.95 ± 1.96 mm forward and 3.9 ± 1.7 mm upward movement at A point. Park et al.[26] reported that only oropharyngeal volume was reduced after bimaxillary surgeries with mandibular setback (7.2 ± 3.4 mm) and maxillary advancement (4.2 ± 1.7 mm). In contrast, Yang et al.[27] reported that the total pharyngeal, oropharyngeal, and hypopharyngeal volumes were significantly reduced after bimaxillary surgery with large mandibular setback movements (11.08 mm, range: 9.61-14.26 mm at B point).

In this study, airway space was significantly reduced, especially at the oropharynx in Group A after bimaxillary surgery with asymmetric mandibular setback (−5.07 ± 3.64 mm and −10.15 ± 1.79 mm in deviated and nondeviated sides, respectively; 5.60 ± 2.38 mm backward and 5.12 ± 2.36 mm horizontal movement at B point), and maxillary posterior impaction (4.19 ± 1.52 mm) (Tables 4 and 6). Whereas, the airway space was not significantly decreased in Group B after bimaxillary surgery with a mandibular setback at B point (8.26 ± 2.66 mm) and maxillary posterior impaction at PNS (3.84 ± 1.69 mm) (Tables 4 and 6). Comparison of the amount of mandibular setback and maxillary posterior impaction between Groups A and B with regards to changes in airway dimensions postsurgery suggest that lateral movement to correct mandibular deviation may increase the risk of airway space reduction.

After surgery, no significant differences were noted in airway asymmetry indices between groups (Table 5). In Group A, C2LWA, C1CA, C2CA, and C3CA were decreased, whereas C2C and C3C in deviated and nondeviated sides tended to be similar (Table 5 and S1). Thus, the airway space in Group A showed the tendency to adopt a symmetrical shape after surgery. Although the airway space was reduced postsurgery, the constriction shape and asymmetrical

Table 3. CHANGES OF SKELETAL PARAMETERS OF CEPHALOMETRIC MEASUREMENTS AND MANDIBULAR ASYMMETRY INDEX BETWEEN GROUPS AT T0 AND T1

		Group a			Group B			Sig. (2-tailed)†	
		T0	T1	P*	T0	T1	P*	T0	T1
Cephalometric measurement	ANB	−2.52 ± 2.26	3.07 ± 0.64	0.000§	−2.17 ± 1.95	2.93 ± 0.72	0.000§	0.698	0.624
	Wits	−5.76 ± 0.89	1.81 ± 0.51	0.000§	−5.59 ± 0.35	1.72 ± 0.37	0.000§	0.520	0.639
	FMA	24.43 ± 1.72	25.60 ± 2.36	0.060	24.33 ± 0.44	24.75 ± 1.64	0.444	0.821	0.332
	MP to SN	32.44 ± 1.70	33.60 ± 1.90	0.059	32.53 ± 1.15	33.00 ± 2.00	0.470	0.888	0.460
Mandibular asymmetry index	Ramus length asymmetry	−1.81 ± 2.31	−0.36 ± 2.54	0.009§	0.27 ± 1.48	−0.39 ± 0.98	0.839	0.011‡	0.388
	Body length asymmetry	−4.88 ± 3.25	0.20 ± 0.74	0.000§	0.79 ± 0.81	0.68 ± 0.98	0.521	0.000§	0.172
	Me deviation	−6.52 ± 2.63	−0.42 ± 0.55	0.000§	0.66 ± 1.34	0.02 ± 0.77	0.112	0.000§	0.111

Data are shown as mean ± standard deviation (linear: mm, angle:°).

Abbreviations: T0, before surgery; T1, 6 months after surgery.

* Postoperative changes (T1 to T0) were compared by paired t test.

† Intergroup comparison was tested by the independence t test.

‡ Statistically significant at $P < .05$.

§ Statistically significant at $P < .01$.

morphology of the airway were improved. These improvements may reduce additional geometric changes along the path from the nares or lips to the thoracic inlet which could mitigate negative effects on airflow.[20]

The effects of skeletal movement on airway space as a result of surgery have been examined previously. However, these studies focused predominantly on the anteroposterior and vertical movements of the maxilla and mandible.[5] Lateral movement of the mandible and its effects on airway space after surgery are not fully understood, and to the best of our knowledge, this is the first study to demonstrate the positive effect of orthognathic surgery on the pharyngeal airway in subjects with mandibular deviation. In this study, vertical movement of PNS was positive correlated with changes in V1, V2, and V (Table 7), suggesting that maxillary posterior impaction could compensate for the pharyngeal airway narrowing caused by an isolated mandibular setback surgery, in agreement with previous reports.[5,23] Lateral movements of B point was negatively correlated with changes in C2LWA, C1CA, and C2CA; and positively correlated with changes in MinC2C (Table 7). This relationship with the asymmetry index indicated that the correction of the mandibular asymmetry affected the reshaping of airway morphology to be more symmetrical and less constricted.

Pharyngeal airway changes in skeletal Class III malocclusion with and without mandibular deviation obtained in this study provide a direction for orthodontists and surgeons during treatment planning. Orthognathic surgery with the mandibular setback to correct skeletal deformities may significantly reduce the airway space and is a risk factor for the development of OSA.[27] Therefore, surgeons should be aware of this potential surgical consequence. Although upper airway space was reduced after surgery, skeletal and occlusal problems may be improved with the enhancement of airway morphology as a result of orthognathic surgery. Thus, adaptation of the respiratory system to the neuromuscular system, which is important for the patency of the airway during sleep, may demonstrate favorable responses.[28] There are limitations in this study related to its small sample size, retrospective nature, and limited observation period. Another limitation is the nonassessment of the functional evaluation of the airway, such as polysomnography, to analyze the dynamics of the respiratory process and the physiologic adaptation of the airway. Therefore, further studies with the increased sample size for the objective examination of respiratory resistance while sleeping and subjective test like surveys would be necessary to evaluate the relationship of airway morphology and function.

In conclusion, the pharyngeal airway presented with an asymmetrical morphology and constricted shape in

Table 4. CHANGES IN AIRWAY PARAMETERS IN GROUP A AND GROUP B AT T0 AND T1

	Group A			Group B			Sig. (2-Tailed)†	
	T0	T1	P*	T0	T1	P*	T0	T1
C1AP	12.97 ± 3.26	10.06 ± 2.55	0.000§	14.69 ± 4.32	13.06 ± 4.30	0.163	0.269	0.069
C2AP	14.83 ± 4.34	11.86 ± 3.03	0.001§	15.17 ± 4.32	13.08 ± 4.24	0.082	0.850	0.409
C3AP	15.66 ± 3.70	13.72 ± 3.97	0.041‡	13.26 ± 3.98	11.49 ± 3.58	0.144	0.137	0.165
C1LW	26.09 ± 5.39	21.35 ± 4.32	0.003§	26.64 ± 6.05	22.36 ± 6.10	0.145	0.815	0.632
C2LW	26.07 ± 8.51	23.52 ± 4.96	0.171	24.73 ± 7.02	26.62 ± 4.26	0.313	0.683	0.120
C3LW	30.63 ± 7.46	28.59 ± 6.86	0.370	34.09 ± 4.31	32.35 ± 5.03	0.424	0.199	0.152
C1C	269.73 ± 115.02	178.65 ± 67.49	0.001§	310.83 ± 161.03	221.75 ± 76.67	0.037	0.463	0.152
C2C	310.14 ± 124.45	207.38 ± 79.11	0.000§	326.82 ± 156.00	245.12 ± 67.11	0.052	0.769	0.228
C3C	310.60 ± 128.61	239.75 ± 105.78	0.006§	298.46 ± 140.20	243.65 ± 79.20	0.212	0.825	0.922
MinC1C	208.26 ± 118.55	152.31 ± 47.37	0.045‡	265.58 ± 149.25	181.85 ± 68.87	0.034	0.296	0.215
MinC2C	138.77 ± 78.07	110.39 ± 56.96	0.282	237.78 ± 140.17	143.29 ± 37.88	0.048	0.033	0.123
MinC3C	169.63 ± 96.87	140.53 ± 98.30	0.452	200.15 ± 80.33	172.15 ± 59.42	0.294	0.418	0.373
V1	8.81 ± 2.74	7.96 ± 1.89	0.142	8.20 ± 3.83	6.87 ± 2.61	0.143	0.644	0.237
V2	6.46 ± 3.13	4.57 ± 1.84	0.005‡	6.77 ± 3.80	4.83 ± 1.70	0.032	0.826	0.728
V3	4.42 ± 1.56	3.38 ± 1.45	0.048	4.53 ± 2.77	3.45 ± 1.89	0.153	0.900	0.917
V	19.69 ± 6.80	15.91 ± 4.23	0.016‡	19.50 ± 10.08	15.15 ± 5.49	0.080	0.955	0.698

Data are shown as mean ± standard deviation (linear: mm, area: mm^2, volume: mm^3).
Abbreviations: T0, before surgery; T1, 6 months after surgery.
* Postoperative change (T1 to T0) were compared by paired *t* test.
† Intergroup comparison was tested by the independence *t* test.
‡ Statistically significant at FDR-adjusted $P < .05$.
§ Statistically significant at FDR-adjusted $P < .01$.

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subjects with mandibular deviation before surgery. The airway morphology showed a tendency to adopt a symmetrical shape after surgery. The airway space exhibited a significant reduction in the oropharynx in the asymmetry group. The correction of the mandibular asymmetry with orthognathic surgery positively

Table 5. CHANGES IN AIRWAY ASYMMETRY INDEXES OF AIRWAY SPACE IN GROUP A AND GROUP B AT T0 AND T1

	Group A			Group B			Sig. (2-Tailed)†	
	T0	T1	P*	T0	T1	P*	T0	T1
C1APA	0.57 ± 0.46	0.52 ± 0.47	0.736	0.61 ± 0.54	0.70 ± 0.49	0.620	0.850	0.388
C2APA	0.88 ± 0.71	1.13 ± 0.71	0.179	1.05 ± 1.53	0.93 ± 1.01	0.827	0.701	0.562
C3APA	1.79 ± 1.43	1.65 ± 1.64	0.796	1.12 ± 1.23	0.80 ± 0.86	0.465	0.238	0.105
C1LWA	2.68 ± 1.75	2.05 ± 1.30	0.227	2.08 ± 1.08	1.27 ± 2.21	0.192	0.341	0.333
C2LWA	4.06 ± 2.45	2.31 ± 1.68	0.000§	2.19 ± 1.63	3.19 ± 2.42	0.355	0.046	0.292
C3LWA	4.06 ± 3.22	4.49 ± 3.47	0.704	2.51 ± 1.29	2.80 ± 2.08	0.714	0.110	0.141
C1CA	29.38 ± 14.87	16.46 ± 14.11	0.028‡	26.52 ± 26.35	26.09 ± 14.38	0.946	0.731	0.111
C2CA	56.69 ± 36.84	28.41 ± 25.30	0.001§	34.49 ± 13.93	34.19 ± 21.53	0.957	0.047	0.559
C3CA	62.58 ± 44.41	31.05 ± 29.99	0.001§	27.89 ± 19.91	41.90 ± 28.31	0.252	0.015‡	0.375

Data are shown as mean ± standard deviation (linear: mm, area: mm^2).
Abbreviations: T0, before surgery; T1, 6 months after surgery.
* Postoperative change (T1 to T0) were compared by paired *t* test.
† Intergroup comparison was tested by the independence *t* test.
‡ Statistically significant at FDR-adjusted $P < .05$.
§ Statistically significant at FDR-adjusted $P < .01$.

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Table 6. SKELETAL CHANGES AFTER BIMAXILLARY SURGERY IN GROUP A AND GROUP B

Landmark	Coordinate	Group A		Group B		Sig. (2-Tailed)†
		Mean ± SD	P*	Mean ± SD	P*	
A point	Δx	0.72 ± 1.68	0.118	0.91 ± 1.39	0.069	0.770
	Δy	1.00 ± 1.88	0.036	0.68 ± 1.45	0.172	0.654
	Δz	0.31 ± 1.62	0.466	0.10 ± 2.63	0.907	0.804
PNS	Δx	0.57 ± 1.17	0.083	−0.04 ± 0.99	0.901	0.192
	Δy	0.90 ± 1.20	0.011	−2.16 ± 0.91	0.000§	0.000§
	Δz	4.19 ± 1.52	0.000§	3.84 ± 1.69	0.000§	0.591
Jugular (Deviated side/right side)	Δx	0.46 ± 0.25	0.166	0.00 ± 2.31	1.000	0.522
	Δy	1.03 ± 1.05	0.002‡	−0.62 ± 2.22	0.401	0.049
	Δz	1.79 ± 0.89	0.000§	0.76 ± 2.02	0.264	0.155
Jugular (Nondeviated side/left side)	Δx	0.25 ± 0.63	0.153	1.49 ± 1.78	0.027	0.059
	Δy	0.81 ± 1.08	0.012	−1.00 ± 1.36	0.045	0.001§
	Δz	2.16 ± 1.54	0.000§	1.07 ± 1.71	0.080	0.111
B point	Δx	5.12 ± 2.36	0.000§	−0.36 ± 1.57	0.487	0.000§
	Δy	5.60 ± 2.38	0.000§	8.26 ± 2.66	0.000§	0.016
	Δz	2.34 ± 1.05	0.000§	3.39 ± 2.26	0.001§	0.195
Me	Δx	6.10 ± 2.58	0.000§	−0.12 ± 1.31	0.778	0.000§
	Δy	6.00 ± 2.93	0.000§	9.58 ± 2.62	0.000§	0.005‡
	Δz	2.65 ± 1.10	0.000§	5.18 ± 2.41	0.000§	0.009
Gonion (Deviated side/right side)	Δx	−0.39 ± 1.39	0.300	1.28 ± 2.20	0.099	0.029
	Δy	0.65 ± 1.32	0.079	1.18 ± 3.82	0.354	0.680
	Δz	2.65 ± 1.99	0.000§	2.93 ± 1.31	0.000§	0.679
Gonion (Nondeviated side/left side)	Δx	0.65 ± 1.70	0.159	−0.84 ± 1.72	0.157	0.043
	Δy	0.70 ± 1.40	0.073	0.32 ± 3.17	0.757	0.728
	Δz	4.02 ± 1.80	0.000§	2.61 ± 1.49	0.000§	0.052
Hyoid	Δx	0.79 ± 1.52	0.064	0.49 ± 3.04	0.623	0.775
	Δy	3.87 ± 1.69	0.000§	4.45 ± 2.00	0.000§	0.439
	Δz	0.56 ± 1.43	0.148	0.57 ± 2.28	0.450	0.994
Measurements						
Mandibular body length	Deviated side/right side	−5.07 ± 3.64	0.000§	−9.31 ± 2.90	0.000§	0.005‡
	Nondeviated side/left side	−10.15 ± 1.79	0.000§	−9.20 ± 2.76	0.000§	0.306
Ramus length	Deviated side/right side	−3.15 ± 2.73	0.002‡	−1.57 ± 2.38	0.067	0.884
	Nondeviated side/left side	−1.69 ± 1.74	0.001§	−1.61 ± 2.36	0.060	0.000§

Data are shown as mean ± standard deviation (linear: mm, area: mm^2).

Abbreviations: T0, before surgery; T1, 6 months after surgery.

Positive value indicates to the left, posterior, and superior of maxilla and mandible in the horizontal (x), anteroposterior (y), or vertical (z) direction at the indicated reference points. In Group A, to determine the movement of skeletal in x-axis, the positive values indicated to the nondeviated side.

* Postoperative change (T1 to T0) were compared by paired *t* test.

† Intergroup comparison was tested by the independence *t* test.

‡ Statistically significant corrected by Bonferroni's method at $P < .0055$.

§ Statistically significant corrected by Bonferroni's method at $P < .0011$.

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affected the reshaping of airway morphology. The evaluation of pharyngeal airway function in a large sample would be required in a further study.

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Table 7. PEARSON'S CORRELATION ANALYSIS BETWEEN THE CHANGES OF AIRWAY PARAMETERS AND THE SKELETAL MOVEMENTS AFTER BIMAXILLARY SURGERY IN GROUP A

	Maxillary Posterior Impaction		Mandibular Setback		Mandibular Asymmetry Correction	
	Pearson's Correlation	*P* Value	Pearson's Correlation	*P* Value	Pearson's Correlation	*P* Value
C1AP	0.339	.141	0.129	.646	0.268	.335
C2AP	−0.072	.779	−0.458	.086	0.386	.155
C3AP	0.116	.682	−0.239	.390	0.250	.370
C1LW	0.464	.082	0.146	.603	−0.006	.984
C2LW	0.054	.849	0.256	.356	−0.362	.185
C3LW	0.121	.666	0.344	.210	0.084	.765
C1C	0.493	.062	0.316	.252	0.189	.499
C2C	0.226	.418	0.291	.292	0.045	.874
C3C	−0.137	.627	0.120	.671	0.098	.730
MinC1C	0.325	.327	0.235	.399	−0.027	.925
MinC2C	0.117	.679	0.077	.786	0.613	.015*
MinC3C	0.083	.770	0.101	.720	0.172	.541
V1	0.572	.026*	0.210	9.452	−0.075	.792
V2	0.519	.048*	0.201	.473	−0.128	.649
V3	0.343	.211	0.116	.679	0.075	.792
V	0.568	.027*	0.209	.456	−0.058	.839
C1APA	−0.171	.541	0.092	.745	0.320	.245
C2APA	0.472	.076	−0.100	.723	0.048	.865
C3APA	0.123	.662	−0.130	.644	0.260	.349
C1LWA	0.278	.316	−0.042	.883	−0.087	.757
C2LWA	0.092	.746	0.245	.380	−0.619	.014*
C3LWA	0.501	.057	0.221	.429	−0.134	.633
C1CA	0.121	.667	0.109	.700	−0.587	.021*
C2CA	−0.225	.421	0.241	.387	−0.538	.039*
C3CA	−0.005	.985	0.207	.460	0.048	.866

* Statistically significant at $P < .05$.

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Table 8. LINEAR REGRESSION ANALYSIS BETWEEN MANDIBULAR ASYMMETRY CORRECTION AND AIRWAY ASYMMETRY INDEX CHANGES

Response Variable (Airway Parameter and Asymmetry Index Changes)	Explanatory Variable (Skeletal Movement)	95% CI for Beta Unstandardized Coefficients			
		Beta	SE	Adjusted R^2	*P* Value
MinC2C	B(x)	25.492	9.106	0.328	.015*
C2LWA	B(x)	−0.387	0.136	0.335	.014*
C1CA	B(x)	−5.058	1.934	0.294	.021*
C2CA	B(x)	−6.221	2.706	0.234	.039*

R^2, coefficient of determination.

Abbreviations: CI, Confidence interval; SE, Standard error.

* $P < .05$.

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Supplementary Data

Supplementary data associated with this article can be found in the online version, at https://doi.org/10.1016/j.joms.2021.01.001.

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