Int. J. Oral Maxillofac. Surg. 2019; 48: 1057–1065
https://doi.org/10.1016/j.ijom.2019.01.021, available online at https://www.sciencedirect.com

International Journal of Oral & Maxillofacial Surgery

Clinical Paper
Orthognathic Surgery

Influence of mandibular setback surgery on three-dimensional pharyngeal airway changes

S.-T. Lee, J.-H. Park, T.-G. Kwon
Department of Oral and Maxillofacial Surgery, School of Dentistry, Kyungpook National University, Daegu, Republic of Korea

S.-T. Lee, J.-H. Park, T.-G. Kwon: Influence of mandibular setback surgery on three-dimensional pharyngeal airway changes. Int. J. Oral Maxillofac. Surg. 2019; 48: 1057–1065.

Abstract. The aim of this study was to investigate the factors influencing three-dimensional changes in pharyngeal airway space after mandibular setback surgery. Airway changes in 48 skeletal class III patients who had undergone mandibular setback surgery alone ($n = 25$, group 1) or with maxillary surgery ($n = 23$, group 2) were analyzed. Linear parameters, cross-sectional area, and volumes of the pharyngeal airway were evaluated before (T0), immediately after (T1), and 1 year after surgery (T2) by cone beam computed tomography. Although the reduced airway volume and cross-sectional area recovered slightly in the long term after surgery, the total pharyngeal airway volume (TPV) was significantly reduced compared to baseline, by 15% in group 1 and 12% in group 2. Regression analysis showed that maxillary posterior impaction in two-jaw surgery had a protective effect on preserving TPV. A change in body mass index from T0 to T2 was an important predictor of decreased TPV in one-jaw surgery patients. Maxillary posterior impaction can be a reliable option for compensating the pharyngeal airway reduction after mandibular setback surgery. Postoperative weight gain can increase the risk of postoperative pharyngeal airway reduction. Therefore, these factors need to be considered before and after mandibular setback surgery.

Key words: airway; mandibular setback; mandibular prognathism; three-dimensional.

Accepted for publication 29 January 2019
Available online 15 February 2019

Introduction

Orthognathic surgery not only improves the aesthetic appearance of patients with dentofacial deformities, but also changes the function and physiology of occlusion, pronunciation, and respiration by affecting the various related anatomical structures. Recently, maxillomandibular advancement (MMA) surgery has been suggested as a reliable option for the treatment of severe obstructive sleep apnoea (OSA)[1]. MMA improves the upper airway patency by enlarging the transverse and anteroposterior airway dimensions[2]. However, the influence of reversing the direction of the mandibular movement on airway patency is one of the greatest concerns. If mandibular setback surgery reduces the airway, recurrent pharyngeal airway space obstruction during sleep can potentially cause symptoms of OSA[3,4].

Previous reports regarding the effects of mandibular setback surgery, with or without maxillary surgery, on three-dimensional (3D) and volumetric changes in the pharyngeal airway space have shown varying results. A recent systematic review of the literature showed that the total pharyngeal airway volume was decreased in the isolated mandibular surgery cases, while mandibular setback surgery with maxillary advancement did not have this effect[5]. However, another systematic review suggested that both one-jaw and two-jaw surgeries resulted in a significant decrease in airway volume[6]. Some studies have suggested that narrowing of the pharyngeal airway space may contribute to the development of OSA[7–10]. In contrast, other studies have concluded that there is insufficient evidence of the development of sleep disordered breathing after bimaxillary or mandibular surgery for skeletal class III patients[11,12].

As well as the skeletal movements, other surrounding soft tissue conditions and related parameters can also influence the condition of the pharyngeal airway. It has been reported that sleep disordered breathing is closely associated with various demographic factors such as age, sex, and body mass index (BMI)[13]. However, factors influencing pharyngeal airway changes related to mandibular setback have not been clearly demonstrated in previous reports because of the limited information on surgical movements, insufficient numbers of subjects, or lack of demographic data including BMI. Only a few comparative studies investigating 3D pharyngeal airway changes after one-jaw versus two-jaw surgery for skeletal class III patients have been reported[10,14–17].

The aim of this study was to investigate the factors influencing pharyngeal airway changes after isolated mandibular setback surgery versus bimaxillary surgery. An analysis was performed of the differences between groups, the correlation between skeletal movements, various demographic characteristics, and 3D changes in the pharyngeal airway space.

Materials and methods

Study subjects

This retrospective study included skeletal class III patients who had undergone orthognathic surgery at Kyungpook National University Dental Hospital between January 2014 and July 2016. The patients were divided into two groups according to the type of surgery: group 1 included patients who had undergone mandibular bilateral sagittal split ramus osteotomy (BSSRO) alone ($n = 25$), while group 2 included patients who had undergone two-jaw surgery consisting of BSSRO with Le Fort I osteotomy ($n = 23$). The Le Fort I osteotomy was performed with maxillary posterior impaction, with the centre of rotation at the maxillary incisor tip, A-point, or anterior nasal spine (ANS) as a rotational setback for skeletal class III patients[18]. Subjects with cleft lip and palate, a history of facial trauma or infection, hemifacial microsomia, or congenital muscular torticollis were excluded from the study. This study was approved by the Institutional Review Board of Kyungpook National University Dental Hospital.

Computed tomography image reconstruction

All patients had cone beam computed tomography (CBCT) imaging performed before surgery (T0), within 1 month after surgery (T1), and 1 year after surgery (T2). CBCT imaging was performed to assess the 3D skeletal and airway structures with a voxel size of 0.4 mm (CB MercuRay, Hitachi, Japan). The patients were scanned in a seated, upright position with relaxed facial musculature. The patients were instructed to maintain their bite in intercuspal position and to breathe lightly and not swallow or move the tongue during image acquisition[14,17,19].

The CBCT data were reconstructed into 3D images, and cross-sectional areas, linear and volumetric measurements were analyzed (OnDemand3D, Cybermed Inc., USA; Mimics, Materialise, Belgium). Two-dimensional cephalometric images were derived from 3D CBCT using the software, and conventional cephalometric landmarks were identified and measurements were investigated.

Volumetric, cross-sectional, and linear measurements of the pharyngeal airway space

To measure the various study variables, 3D-rendered skull images were designated to reference planes, as reported in a previous study[20]. The 3D images were superimposed by anterior cranial base overlapping using the maximization of mutual information[20]. The airway volume was automatically calculated by defining the upper and lower boundaries: (1) the velopharyngeal airway volume (VPV) was the region between posterior nasal spine (PNS) and uvula tip, (2) the oropharyngeal airway volume (OPV) was the region between uvula tip and epiglottis tip, (3) the hypopharyngeal airway volume (HPV) was the region between epiglottis tip and the most inferior and anterior points of the fourth cervical vertebra (C4). The sum of VPV, OPV, and HPV was defined as the total pharyngeal airway volume (TPV, cm^3) (Fig. 1A).

The most constricted axial level of the total pharyngeal airway was defined as the minimum cross-sectional area (Min-CSA, mm^2). Anteroposterior (Min-CSA-AP, mm) and transverse (Min-CSA-TV, mm) diameters of the Min-CSA were measured. The vertical distance from Frankfort horizontal (FH) plane to Min-CSA was also measured (Min-CSA-Ver, mm) (Fig. 1B).

The cross-sectional areas (CSA, mm^2) were calculated automatically using the 'smart pen' function of the software. The CSA at the four different axial planes that represent the axial level of the upper pharynx were established[21]: (1) Od-CSA: CSA at the odontoid process tip (Od) of the axis (level of nasopharynx), (2) C2-CSA: CSA at the midpoint of the second cervical vertebra (C2) (level of velopharynx), (3) C23-CSA: CSA at the most anterior and superior point of the junction of C2 and C3 (level of tongue base), (4) C34-CSA: CSA at the most anterior and superior point of the C3–C4 junction (level of epiglottis) (Fig. 1C).

Data analysis and statistics

The statistical analysis of the data was performed using SPSS software (version 12.0; SPSS Inc., Chicago, IL, USA). The bilateral differences between the different time points within groups were analyzed using the paired *t*-test. Intergroup differences were compared with the independent *t*-test. The statistical relationships between the study variables were evaluated by Spearman correlation analysis. To investigate the important predictors influencing postoperative airway changes, stepwise multiple linear regression analysis was performed. The dependent variable was TPV (ΔT2–T0) and the independent variables were the various skeletal changes (ΔT2–T0), age, sex, and BMI changes (ΔT2–T0).

To evaluate the reproducibility of the measurements, all landmarks and measurements were examined twice for the first 10 patients at an interval of 1 week, as shown in the analysis of errors in measurements[22]. The method error in the linear measurements ranged from 0.56 mm to 1.87 mm and in area measurements from 0.23 mm^2 to 2.92 mm^2. For the volumetric measurements, the error ranged from 0.35 cm^3 to 0.89 cm^3. The difference was not statistically significant.

Results

Demographic features and skeletal movements

There was no significant difference between the groups in terms of age, sex, or

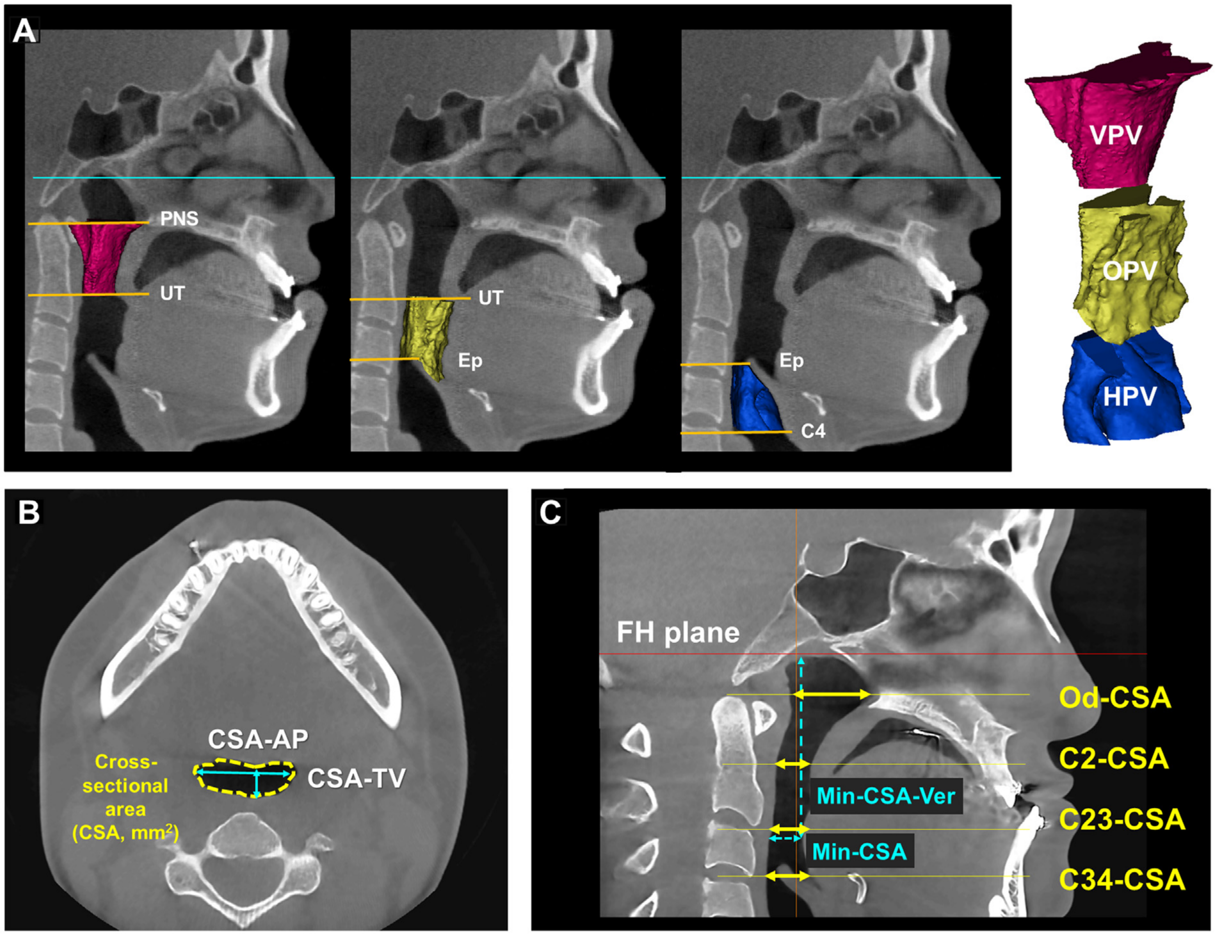

Fig. 1. Volumetric, area, and linear measurements of the pharyngeal airway. (A) Pharyngeal airway space volume: VPV (velopharyngeal airway volume): level of posterior nasal spine (PNS) to uvula tip (UT); OPV (oropharyngeal airway volume): level of UT to tip of epiglottis (Ep); HPV (hypopharyngeal airway volume): level of Ep to the most superior points of the fourth cervical vertebra (C4). (B) Cross-sectional area (CSA) measurements. Cross-sectional area (mm^2), anteroposterior diameter (CSA-AP), and transverse diameter (CSA-TV) were investigated. (C) The most constricted axial level in the total pharyngeal airway was defined as the minimum cross-sectional area (Min-CSA, mm^2). The vertical distance from Frankfort horizontal (FH) plane to Min-CSA was also measured (Min-CSA-Ver, mm). The cross-sectional area was investigated at the following levels: level at the odontoid process tip of the axis (Od-CSA), level of the midpoint of the second cervical vertebra on the sagittal plane (C2-CSA), the most anterior and superior point of the junction of the second and third cervical vertebrae (C23-CSA), the most anterior and superior point of the junction of the third and fourth cervical vertebrae (C34-CSA).

BMI before or after surgery. The change in BMI (ΔT2–T0) was -0.1 ± 1.8 (range -4.6 to 2.3) in group 1 and -0.4 ± 1.7 (range -4.8 to 3.2) in group 2, with no significant postsurgical changes or intergroup differences found. Average mandibular setback was -9.1 ± 2.6 mm in group 1 and -9.9 ± 4.0 mm in group 2 (intergroup difference, $P > 0.05$). In group 2, maxilla was impacted and rotated clockwise, and PNS moved in a posterior and superior direction. The average maxillary anterior movement at point A was 1.5 ± 2.2 mm ($P < 0.01$). PNS(y) moved more superiorly (-3.4 ± 1.7 mm) than point A (-0.6 ± 2.5 mm) (Table 1).

During the pre-surgical orthodontic period, 68% (17/25) of group 1 patients (one-jaw group) and 43% (10/23) of group 2 patients (two-jaw group) had premolars extracted for pre-surgical orthodontics ($p > 0.05$). Comparison of dentoskeletal cephalometric parameters between the two groups showed intergroup differences for angles SNA (sella–nasion–A-point) and SNB (sella–nasion–B-point) at T2. The occlusal plane angle, FH plane to upper incisor (U1) angle, and incisor mandibular plane angle (IMPA) did not differ significantly between the groups before (T0) or after (T2) the surgery (Table 2).

Volumetric, linear, and area parameter changes after mandibular setback surgery

The changes in the airway are illustrated as line graphs, representing absolute volume (cm^3), linear distance (mm), or area (mm^2), in Fig. 2. The relative values compared to T0 are also shown as percentage (%) values. There was a more significant reduction in TPV immediately postoperative in group 1 (25% reduction, 26.0 $cm^3 \rightarrow$ 19.6 cm^3) than in group 2 (18% reduction, 30.5 $cm^3 \rightarrow$ 25.0 cm^3). Although the reduced volume recovered slightly in the long term after surgery (T2), TPV was significantly decreased compared to the baseline value (T0), by 15% in group 1 and 12% in group 2 (Table 3, Fig. 2 upper right panel).

The Min-CSA-AP was significantly reduced (group 1, 11.5 mm at T0 and 9.3 mm at T2; group 2, 12.9 mm at T0 and 10.8 mm at T2). Group 1 showed a more significantly reduced AP dimension

Table 1. Demographic characteristics of the subjects[a].

Characteristics	Group 1 (one-jaw)	Group 2 (two-jaw)	*P*-value[b]
Number of subjects	25	23	
Female (%)	56% (*n* = 14)	35% (*n* = 8)	0.146
Age (years)	23.0 ± 4.4 (18 to 32)	23.3 ± 4.2 (19 to 38)	0.781
BMI (kg/m^2)			
T0	22.4 ± 3.5 (15.7 to 27.8)	24.5 ± 4.5 (18.0 to 34.1)	0.070
T2	22.2 ± 3.5 (18.0 to 34.1)	24.2 ± 4.5 (17.8 to 35.4)	0.106
ΔT2–T0	−0.1 ± 1.8 (−4.6 to 2.3)	−0.4 ± 1.7 (−4.8 to 3.2)	0.623
Change in maxillary position (mm)[c]			
A(*x*)	–	1.5 ± 2.2** (−3.7 to 5.6)	
A(*y*)	–	−0.6 ± 2.5 (−4.1 to 6.4)	
PNS(*x*)	–	3.1 ± 2.0** (−0.8 to 7.3)	
PNS(*y*)	–	−3.4 ± 1.7** (−5.9 to −0.5)	
Change in mandibular position (mm)[c]			
B(*x*)	−9.1 ± 2.6 (−14.3 to −4.0)**	−9.9 ± 4.0** (−16.1 to −2.0)	0.456
B(*y*)	−1.1 ± 2.1 (−4.9 to 3.3)*	−3.3 ± 4.1** (−9.6 to −9.4)	0.035

A, A-point; B, B-point; BMI, body mass index; PNS, posterior nasal spine; T0, before surgery; T2, 1 year after surgery.
[a] Data are presented as the mean ± standard deviation (range), unless stated otherwise.
[b] Intergroup comparisons were tested by independent *t*-test, except the sex distribution, which was tested by χ^2 test.
[c] Postoperative changes (ΔT2–T0) in each group; *$P < 0.05$, **$P < 0.01$. Positive value indicates anterior, inferior movement of maxilla or mandible in the horizontal (*x*) or vertical (*y*) direction at the indicated reference points.

Table 2. Intergroup comparison of cephalometric measurements obtained preoperatively (T0) and postoperatively (T2).

Measurements (°)	Group 1 (one-jaw)			Group 2 (two-jaw)			Intergroup difference	
	T0 Mean ± SD	T2 Mean ± SD	ΔT2–T0 *P*-value[a]	T0 Mean ± SD	T2 Mean ± SD	ΔT2–T0 *P*-value[a]	T0 *P*-value[b]	T2 *P*-value[b]
SNA	79.0 ± 4.0	79.1 ± 4.0	0.538	79.8 ± 5.1	81.8 ± 3.9	0.001	0.535	0.019
SNB	83.8 ± 5.6	77.6 ± 3.7	<0.001	86.5 ± 4.9	81.0 ± 4.9	<0.001	0.082	0.010
ANB	−4.8 ± 5.3	−1.4 ± 1.9	<0.001	−6.7 ± 4.5	−0.9 ± 2.9	<0.001	0.197	0.442
Occlusal plane[c]	9.6 ± 4.4	10.1 ± 4.2	0.215	7.1 ± 4.9	11.4 ± 5.0	<0.001	0.061	0.327
FH–U1[d]	118.9 ± 5.9	117.1 ± 6.1	0.009	121.9 ± 10.8	116.9 ± 9.0	<0.001	0.227	0.951
IMPA[e]	88.6 ± 9.0	84.2 ± 8.8	0.001	89.7 ± 8.7	89.9 ± 10.9	0.934	0.679	0.502

ANB, A-point–nasion–B-point angle; SNA, sella–nasion–A-point angle; SNB, sella–nasion–B-point angle; SD, standard deviation; T0, before surgery; T2, 1 year after surgery.
[a] Postoperative changes (ΔT2–T0) were compared by paired *t*-test.
[b] Intergroup comparisons were tested by independent *t*-test.
[c] The occlusal plane angle is the angle between the Frankfort horizontal (FH) plane and the maxillary occlusal plane.
[d] FH–U1 is the angle between the axis of the upper incisor and the FH line.
[e] IMPA (incisor mandibular plane angle) is the angle between the axis of the lower incisor and the mandibular plane angle.

in Min-CSA than group 2. Min-CSA (mm^2) showed a similar pattern: a significant reduction in cross-sectional area compared to the pre-surgical condition, to 77% in group 1 and 79% in group 2. A significant reduction in Min-CSA-TV was noted in group 2, but there was no intergroup difference. There was no change in Min-CSA-Ver after surgery in both groups. However, Min-CSA was located more superiorly in group 2 than in group 1 at T1 and T2 time points (both $P < 0.01$) (Table 4, Fig. 2 middle panel).

Cross-sectional areas (Od-CSA, C2-CSA, C23-CSA, and C34-CSA) showed that there was a significant reduction in airway space after surgery that remained decreased in the long term in both groups (ΔT2–T0, all $P < 0.05$) (Table 4, Fig. 2 lower panel).

Correlation between postsurgical (T2–T0) skeletal and BMI changes and pharyngeal airway parameters

In group 1, the degrees of mandibular movements B(*x*) and B(*y*) were not significantly correlated with any of volumetric, linear, or area pharyngeal airway parameters. However, in group 2, the degree of posterior movement of B(*x*) was significantly correlated with a reduction in HPV, TPV, and Min-CSA-AP ($r = 0.522$, 0.420, and 0.527, respectively; all $P < 0.05$). An increase in BMI was significantly correlated with narrowing of TPV in both group 1 and group 2 ($r = -0.498$ and -0.453, respectively; both $P < 0.05$). In group 2, the amount of maxillary posterior impaction (PNS (*y*)) was correlated with VPV, OPV, and TPV ($r = -0.506$, -0.474, and -0.530, respectively; all $P < 0.05$) (Table 5).

To identify the important predictor variables affecting TPV in each group, a stepwise linear regression analysis was performed. Demographic variables including age and sex did not influence the TPV changes in either group. In group 1, a change in BMI (ΔT2–T0) significantly influenced the TPV (ΔT2–T0) in the statistical model ($P < 0.01$). In group 2, the major predictor variable that affected TPV was the PNS(*y*) change (ΔT2–T0) ($P < 0.01$) (Table 6).

Discussion

Although very rare, there have been cases of sleep disordered breathing[3,4] or increased apnoea–hypopnoea index (AHI)

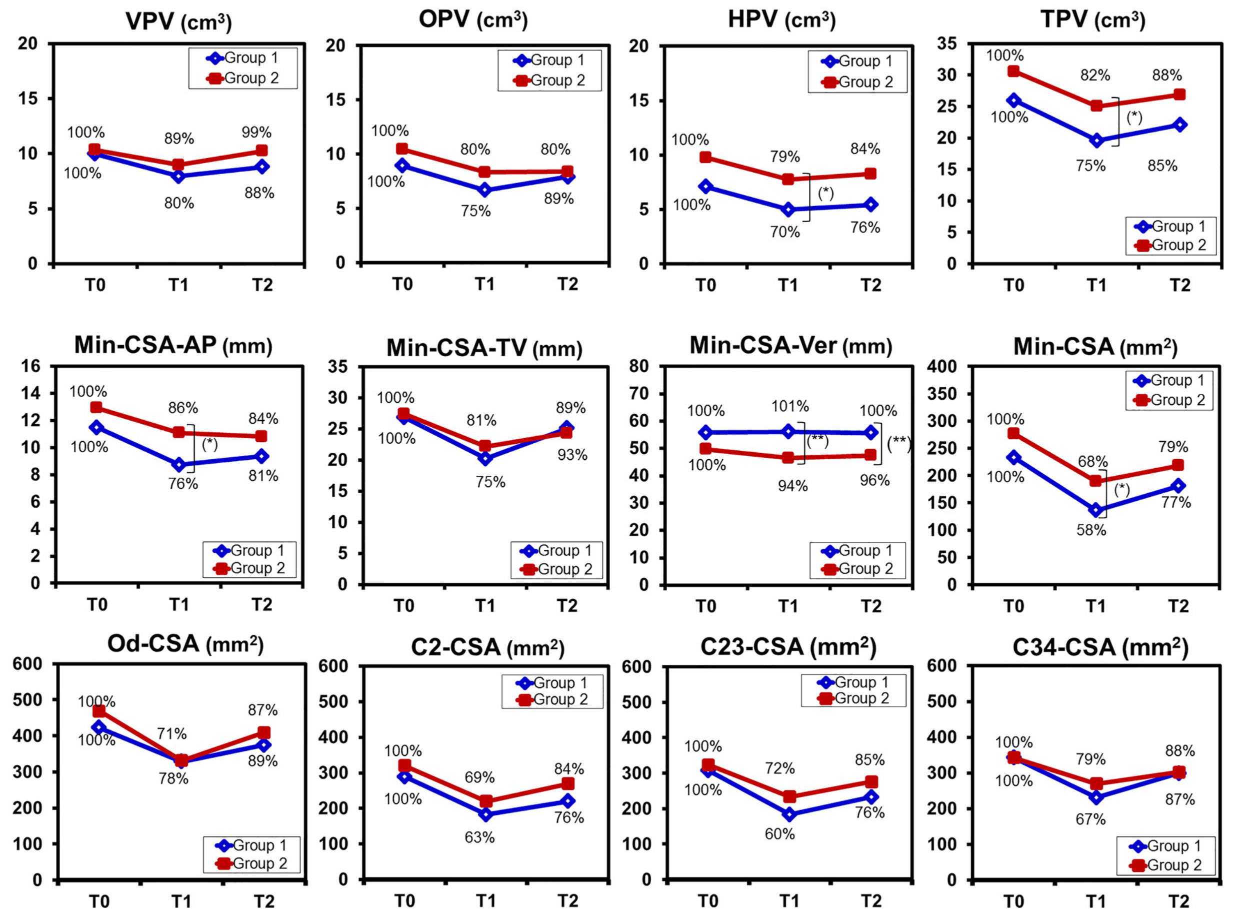

Fig. 2. Volumetric, linear, and area parameter changes after mandibular setback surgery. The airway measurements at each time point are illustrated as line graphs for absolute volume (cm^3), distance (mm), or area (mm^2). Relative values compared to T0 are also shown as percentage (%) values. Intergroup difference *P*-value: *<0.05, **<0.01.

after mandibular setback surgery[10]. In one report, six out of 67 patients who had undergone bimaxillary surgery for skeletal class III experienced postoperative snoring[9]. Therefore, the potential risk of OSA after mandibular setback surgery continues to be highlighted. To verify this risk scientifically, a comprehensive analysis of related factors using volumetric data from 3D computed tomography is required. However, the factors influencing airway changes in relation to the different directions and amounts of maxillomandibular structure movements have not been investigated fully. Some of the previously

Table 3. Volumetric changes in the pharyngeal airway after surgery.

Volumetric measurements (cm^3)[a]	Difference: ΔT1–T0 Mean ± SD	ΔT1–T0 *P*-value	ΔT2–T1 Mean ± SD	ΔT2–T1 *P*-value	ΔT2–T0 Mean ± SD	ΔT2–T0 *P*-value
VPV						
Group 1	−2.0 ± 2.8	0.001	0.8 ± 3.1	0.094	−1.2 ± 2.9	0.027
Group 2	−1.4 ± 3.3	0.029	1.3 ± 3.0	0.026	−0.1 ± 3.5	0.449
OPV						
Group 1	−2.2 ± 3.3	0.001	1.2 ± 2.9	0.023	−1.0 ± 3.0	0.054
Group 2	−2.1 ± 3.3	0.003	0.1 ± 2.4	0.451	−2.1 ± 3.2	0.003
HPV						
Group 1	−2.1 ± 4.0	0.007	0.5 ± 2.1	0.146	−1.7 ± 3.8	0.019
Group 2	−2.0 ± 2.9	0.001	0.5 ± 3.0	0.209	−1.5 ± 3.9	0.038
TPV						
Group 1	−6.4 ± 7.2	<0.001	2.5 ± 6.8	0.038	−3.9 ± 6.1	0.002
Group 2	−5.5 ± 7.0	<0.001	1.9 ± 5.9	0.073	−3.7 ± 8.5	0.025

SD, standard deviation; T0, before surgery; T1, immediately after surgery; T2, 1 year after surgery.
[a] VPV, velopharyngeal airway volume; OPV, oropharyngeal airway volume; HPV, hypopharyngeal airway volume; TPV, total pharyngeal airway volume.

Table 4. Changes in linear and area parameters of the pharyngeal airway after surgery.

	Difference					
	ΔT1–T0		ΔT2–T1		ΔT2–T0	
Linear and area measurements[a]	Mean ± SD	*P*-value	Mean ± SD	*P*-value	Mean ± SD	*P*-value
Min-CSA-AP (mm)						
Group 1	−2.7 ± 1.9	<0.001	0.6 ± 2.0	0.065	−2.1 ± 2.3	<0.001
Group 2	−1.8 ± 2.5	0.001	−0.3 ± 2.6	0.302	−2.1 ± 2.8	0.001
Min-CSA-TV (mm)						
Group 1	−6.7 ± 8.0	<0.001	4.9 ± 6.2	<0.001	−1.8 ± 6.4	0.090
Group 2	−5.2 ± 2.6	<0.001	2.1 ± 6.6	0.069	−3.1 ± 4.4	0.002
Min-CSA–Ver (mm)						
Group 1	0.3 ± 6.5	0.412	−0.3 ± 6.3	0.398	0.0 ± 3.4	0.479
Group 2	−3.1 ± 8.9	0.053	0.9 ± 9.2	0.322	−2.2 ± 6.3	0.051
Min-CSA (mm^2)						
Group 1	−96.9 ± 76.4	<0.001	44.2 ± 80.4	0.006	−52.7 ± 66.7	<0.001
Group 2	−87.8 ± 94.5	<0.001	29.1 ± 89.2	0.066	−58.7 ± 87.2	0.002
Od-CSA (mm^2)						
Group 1	−94.2 ± 115.5	<0.001	46.3 ± 90.9	0.009	−47.9 ± 84.5	0.005
Group 2	−137.2 ± 113.3	<0.001	77.3 ± 108.8	0.001	−59.9 ± 113.1	0.009
C2-CSA (mm^2)						
Group 1	106.0 ± 86.9	<0.001	36.8 ± 77.9	0.013	−69.2 ± 86.0	<0.001
Group 2	−100.5 ± 94.8	<0.001	49.9 ± 96.3	0.011	−50.6 ± 99.1	0.011
C23-CSA (mm^2)						
Group 1	−123.9 ± 96.1	<0.001	49.1 ± 75.1	0.002	−47.7 ± 122.3	<0.001
Group 2	−89.9 ± 19.8	0.001	42.2 ± 112.3	0.042	−47.7 ± 122.6	0.038
C34-CSA (mm^2)						
Group 1	−112.0 ± 102.4	<0.001	68.2 ± 84.6	<0.001	−40.3 ± 110.1	0.006
Group 2	−72.8 ± 135.3	0.009	32.5 ± 151.3	0.157	−40.3 ± 110.1	0.046

SD, standard deviation; T0, before surgery; T1, immediately after surgery; T2, 1 year after surgery.

[a] Min-CSA, minimum cross-sectional area; Min-CSA-AP, anteroposterior diameter of the Min-CSA; Min-CSA-TV, transverse diameter of the Min-CSA; Min-CSA-Ver, vertical distance from FH plane to Min-CSA; Od-CSA, cross-sectional area at the level of the odontoid process tip of the axis; C2-CSA, cross-sectional area at the midpoint of the second cervical vertebra height; C23-CSA, cross-sectional area at the most anterior and superior point of the junction of the second and third cervical vertebrae; C34-CSA, cross-sectional area at the most anterior and superior point of the junction of the third and fourth cervical vertebrae.

reported studies did not consider the direction of maxillary and mandibular movements, or had only 2–3 months of follow-up with a limited number of subjects[13,15,16].

Uesugi et al.[10] reported that the pharyngeal airway volume was decreased in the isolated mandibular setback surgery group (amount of setback, 4.9 ± 3.2 mm), but with maxillary advancement (average advancement, 2.1 ± 0.9 mm), the mandibular setback (amount of setback, 3.2 ± 3.2 mm) did not result in this airway volume change. Park et al.[15] reported that after mandibular setback, nasopharyngeal volume, OPV, and HPV were significantly reduced. In two-jaw surgeries with maxillary advancement (amount of advancement, 4.2 ± 1.7 mm) and mandibular setback (amount of setback, 7.2 ± 3.4 mm), only OPV was reduced. Yang et al.[17] reported that VPV, OPV, and HPV were significantly decreased after isolated mandibular setback surgery (amount of setback, 5.3 ± 2.7 mm), whereas only VPV was decreased and no changes occurred in OPV or HPV after maxillary advancement (amount of advancement, 2.8 ± 1.3 mm) with mandibular setback surgery (amount of setback, 4.8 ± 2.9 mm). However, these studies only focused on airway changes and did not clarify the potential influence of related factors on the airway.

In the present study, VPV was significantly decreased after one-jaw surgery, but not after two-jaw surgery. When the mandible moves posteriorly, the attached muscles and ligaments of the mandible change and a significant reduction occurs in the cross-sectional area and volume of the velopharyngeal region. The study results suggest that maxillary posterior impaction and anterior movement at PNS tended to elevate the soft palate and dilate the velopharynx. This movement might offset the influence of mandibular setback surgery on pharyngeal airway constriction. It has also been suggested that maxillary posterior impaction can improve the upper pharyngeal airway volume (nasopharynx and upper part of VPV)[23].

It has previously been reported that maxillary advancement and mandibular setback surgery does not cause a significant reduction in TPV[14,15,23]. Also, various reports have suggested that two-jaw surgeries can compensate the pharyngeal airway narrowing caused by an isolated mandibular setback surgery[10,13,15,16]. However, the results of the present study showed that both one-jaw surgery and bimaxillary surgery significantly reduced TPV. The differences between the studies might be attributable to the greater amount of setback in the current study (group 1: 9.1 ± 2.6 mm and group 2: 9.9 ± 4.0 mm) and the smaller amount of maxillary advancement (A(x) 1.5 ± 2.2 mm) than in any of the other previously published reports.

In addition to the volumetric information on the pharyngeal airway, the narrowest pharyngeal area (Min-CSA) is also important, because the resistance to air flow depends on the constriction point. Narrowing of the airway after mandibular setback surgery may potentially increase the airway flow velocity and the intraluminal pressure[13]. A previous report suggested that one-jaw surgery resulted in a decreased CSA, but that bimaxillary surgery did not affect the CSA[15]. Another study reported that bimaxillary surgery for mandibular prognathism decreased the anteroposterior distance and CSA after surgery[21], whereas no changes were reported in another study[24]. Park et al.[25] reported that isolated mandibular setback surgery constricted the sagittal dimension but enlarged the transverse width. The current study results showed that both Min-CSA-AP and Min-CSA-TV were decreased after surgery in both groups. This might be attributable to the different amount of mandibular setback. The previous study reported that the level of constriction was slightly superiorly located after two-jaw surgery[21]. In the present study it could also be seen that group 2 showed a more superior position of Min-CSA-Ver after surgery than group 1. Maxillary posterior impaction might be associated with these differences in the level of the constriction point after surgery.

The results of the correlation analysis and stepwise regression analysis showed that the parameter estimate of the predictor variable affecting the TPV changes after two-jaw surgery was the degree of maxillary posterior impaction. This result is similar to those of previous studies showing that the vertical movements of PNS were the determining factor in a lower pharyngeal airway volume[23], and that upward movements of PNS resulted in an increased airway volume[24]. Maxillary posterior impaction is frequently performed in skeletal class III patients to improve their aesthetic concerns of a protrusive upper lip, acute nasolabial angle, or lower occlusal plane, which are frequently seen in Asian skeletal class III patients[26]. This study result implies that if severe narrowing of the airway could be expected after mandibular setback surgery, maxillary posterior impaction can also be considered. In particular, in the case of a patient with aesthetic concerns regarding labioversed maxillary incisors and where a large amount of setback is needed, a two-jaw surgery with clockwise rotation of the maxillomandibular complex will be more beneficial than an isolated mandibular setback surgery.

Correlation between the amount of mandibular setback and the degree of airway narrowing is controversial. Some have reported a significant correlation between the amount of mandibular setback and oropharyngeal airway volume reduction[14,24], whereas others have found no correlation between these, similar to the present study[10,15,16]. The reason for this could include various environmental differences, such as the hard and soft tissue structures, the degree of elasticity of the soft tissues, the degree of obesity, and individual variations.

Table 5. Correlation (r) between postoperative variables and changes in airway parameters (ΔT2–T0)[a].

	ΔVPV	ΔOPV	ΔHPV	ΔTPV	ΔMin-CSA-AP	ΔMin-CSA-TV	ΔMin-CSA–Ver	ΔMin- CSA	ΔOd- CSA	ΔC2- CSA	ΔC23- CSA	ΔC34- CSA
Group 1												
ΔB(x)	0.115	0.059	−0.278	−0.120	0.174	−0.162	0.034	0.183	−0.028	0.025	−0.034	−0.031
ΔB(y)	−0.121	−0.250	0.194	−0.105	−0.138	0.033	0.209	−0.194	0.022	−0.065	−0.105	−0.241
ΔBMI	−0.387	−0.317	−0.310	−0.498*	−0.443*	−0.257	−0.132	−0.366	−0.293	−0.310	−0.356	−0.252
Age (T0)	0.277	0.144	−0.030	0.166	0.171	0.415*	0.193	0.376	0.457*	0.436*	0.244	0.196
Group 2												
ΔA(x)	−0.090	−0.120	−0.001	−0.169	0.115	−0.047	−0.061	0.292	0.337	−0.057	−0.100	−0.030
ΔA(y)	0.232	−0.057	−0.102	0.112	−0.182	0.184	−0.408	0.026	0.124	−0.186	−0.280	−0.268
ΔPNS(x)	0.096	0.019	0.015	−0.085	0.120	−0.152	−0.042	0.118	0.074	0.045	0.058	0.177
ΔPNS(y)	−0.506*	−0.474*	−0.263	−0.530**	−0.310	0.161	−0.220	−0.393	−0.190	−0.365	−0.138	−0.338
ΔB(x)	0.025	0.170	0.522*	0.420*	0.527*	0.020	0.335	0.357	0.248	0.384	0.060	0.254
ΔB(y)	0.099	−0.087	−0.403	−0.165	−0.263	−0.256	0.182	−0.397	−0.169	−0.183	−0.129	−0.163
ΔBMI	−0.080	−0.287	−0.386	−0.453*	0.024	0.321	−0.068	−0.209	−0.071	0.068	0.091	−0.112
Age (T0)	−0.184	0.026	0.393	0.200	0.041	−0.379	0.066	−0.128	−0.111	−0.074	−0.219	0.191

[a] r, Spearman's correlation coefficient.
* P-value: <0.05.
** P-value: <0.01.

Table 6. Stepwise regression analysis for parameter estimate of independent variables affecting the change in total pharyngeal airway volume after mandibular setback surgery.

Variables (ΔT2–T0)	Unstandardized coefficient		Standardized coefficient	95% CI for B		*P*-value
	B (cm^3)	SE	beta	Upper bound	Lower bound	
TPV change						
Group 1						
(constant)	−4.2	1.0		−2.0	−6.3	0.001*
ΔBMI	−2.0	0.6	−0.564	−7.3	−3.2	0.003*
Group 2						
(constant)	−1.4	3.1		−8.0	−20.7	0.000*
ΔPNS (*y*)	−3.2	0.8	−0.647	−1.5	−4.9	0.001*

BMI, body mass index; CI, confidence interval; PNS, posterior nasal spine; SE, standard error; T0, before surgery; T2, 1 year after surgery; TPV, total pharyngeal airway volume.
* *P*-value: <0.05 indicates a significant relationship.

It has been reported that there is a significant correlation between OSA and obesity (BMI), suggesting that patients with a high BMI and high neck circumference are at greater risk of OSA[17,27], and the severity of OSA has been positively correlated with the AHI and BMI[28]. It has been emphasized that the pharyngeal fat pad could have an important role in the development of OSA in overweight patients, and weight reduction is important for reducing central fat and pharyngeal adipose tissue to improve OSA[29]. After orthognathic surgery, some patients gain weight because their occlusal function has improved. However, none of the previous studies examined the relationship between the change in BMI and airway narrowing after mandibular setback surgery. In the present study, the pharyngeal airway space tended to be narrower in patients with an increased BMI after surgery (ΔT0–T2) in both groups. The results of the regression analysis showed the influence of BMI on the pharyngeal airway space. Therefore, the need for weight control after mandibular setback surgery needs to be emphasized.

Another consideration in the development of OSA is the age factor. The older patient exhibits decreased neuromuscular tone, including genioglossus tone, and shows gradual changes in sleep patterns[30]. In the present study, most of the patients were young and did not show a significant development of sleep disordered breathing after surgery. Further investigations with a larger number of subjects are needed.

There are some limitations to this study. The study did not include the AHI or physical examinations to assess sleep apnoea. Additional studies are required to determine the long-term changes in the pharyngeal airway space by comparison to an age and sex-matched normal control group; the relationship with polysomnography data also needs to be investigated. At the same time, there is a fundamental difference between patient positions during polysomnography (supine) and CBCT (upright). Future research using drug-induced sedation endoscopy would be needed to overcome the limitations in patient position of OSA study using CBCT[31].

Presurgical orthodontic treatment after premolar extraction may potentially influence the oral cavity volume. In this study, the preoperative CBCT scans were taken immediately before surgery and most of the extraction space was nearly closed before surgery. Potential influences of orthodontic movements (incisor retraction) on airway changes need to be investigated further.

Previous studies have claimed that two-jaw surgery with maxillary advancement causes a lesser decrease in pharyngeal airway space[5,12]. Although maxillary advancement can have a beneficial effect on the airway, maxillary advancement may result in a protrusive maxilla, which would not be an aesthetically pleasing profile in Asian populations. Therefore, bimaxillary rotational setback with maxillary posterior impaction could also be regarded as a reliable option for patients with a severe skeletal class III deformity who are at potential risk of airway compromise after mandibular setback. The study also suggests that postoperative weight gain is a risk factor for postoperative airway compromise and emphasizes the need for weight control after surgery. Therefore, these factors need to be considered before and after the surgery.

Funding

This research was supported by the Kyungpook National University Bokhyeon Research Fund, 2015.

Competing interests

None declared.

Ethical approval

This study was approved by the Institutional Review Board of Kyungpook National University Dental Hospital (KNUDH-2018-05-005).

Patient consent

Not required.

References

1. Zaghi S, Holty JE, Certal V, Abdullatif J, Guilleminault C, Powell NB, Riley RW, Camacho M. Maxillomandibular advancement for treatment of obstructive sleep apnea: a meta-analysis. *JAMA Otolaryngol Head Neck Surg* 2016;**142**:58–66.
2. Gokce SM, Gorgulu S, Gokce HS, Bengi AO, Karacayli U, Ors F. Evaluation of pharyngeal airway space changes after bimaxillary orthognathic surgery with a 3-dimensional simulation and modeling program. *Am J Orthod Dentofacial Orthop* 2014;**146**:477–92.
3. Guilleminault C, Riley R, Powell N. Sleep apnea in normal subjects following mandibular osteotomy with retrusion. *Chest* 1985;**88**:776–8.
4. Riley RW, Powell NB, Guilleminault C, Ware W. Obstructive sleep apnea syndrome following surgery for mandibular prognathism. *J Oral Maxillofac Surg* 1987;**45**:450–2.
5. He J, Wang Y, Hu H, Liao Q, Zhang W, Xiang X, Fan X. Impact on the upper airway space of different types of orthognathic surgery for the correction of skeletal class III malocclusion: a systematic review and meta-analysis. *Int J Surg* 2017;**38**:31–40.
6. Christovam IO, Lisboa CO, Ferreira DM, Cury-Saramago AA, Mattos CT. Upper air-

way dimensions in patients undergoing orthognathic surgery: a systematic review and meta-analysis. *Int J Oral Maxillofac Surg* 2016;**45**:460–71.

7. Chen F, Terada K, Hanada K, Saito I. Predicting the pharyngeal airway space after mandibular setback surgery. *J Oral Maxillofac Surg* 2005;**63**:1509–14.
8. Marsan G, Cura N, Emekli U. Changes in pharyngeal (airway) morphology in class III Turkish female patients after mandibular setback surgery. *J Craniomaxillofac Surg* 2008;**36**:341–5.
9. Park JE, Bae SH, Choi YJ, Choi WC, Kim HW, Lee UL. The structural changes of pharyngeal airway contributing to snoring after orthognathic surgery in skeletal class III patients. *Maxillofac Plast Reconstr Surg* 2017;**39**:22.
10. Uesugi T, Kobayashi T, Hasebe D, Tanaka R, Ike M, Saito C. Effects of orthognathic surgery on pharyngeal airway and respiratory function during sleep in patients with mandibular prognathism. *Int J Oral Maxillofac Surg* 2014;**43**:1082–90.
11. Fernandez-Ferrer L, Montiel-Company JM, Pinho T, Almerich-Silla JM, Bellot-Arcis C. Effects of mandibular setback surgery on upper airway dimensions and their influence on obstructive sleep apnoea—a systematic review. *J Craniomaxillofac Surg* 2015;**43**:248–53.
12. Canellas JV, Barros HL, Medeiros PJ, Ritto FG. Sleep-disordered breathing following mandibular setback: a systematic review of the literature. *Sleep Breath* 2016;**20**:387–94.
13. Ralls FM, Grigg-Damberger M. Roles of gender, age, race/ethnicity, and residential socioeconomics in obstructive sleep apnea syndromes. *Curr Opin Pulm Med* 2012;**18**:568–73.
14. Hong JS, Park YH, Kim YJ, Hong SM, Oh KM. Three-dimensional changes in pharyngeal airway in skeletal class III patients undergoing orthognathic surgery. *J Oral Maxillofac Surg* 2011;**69**:401–8.
15. Park SB, Kim YI, Son WS, Hwang DS, Cho BH. Cone-beam computed tomography evaluation of short- and long-term airway change and stability after orthognathic surgery in patients with class III skeletal deformities: bimaxillary surgery and mandibular setback surgery. *Int J Oral Maxillofac Surg* 2012;**41**:87–93.
16. Hatab NA, Konstantinovic VS, Mudrak JK. Pharyngeal airway changes after mono- and bimaxillary surgery in skeletal class III patients: cone-beam computed tomography evaluation. *J Craniomaxillofac Surg* 2015;**43**:491–6.
17. Yang Y, Yang K, Zhao Y. Three-dimensional changes in the upper airway of skeletal class III patients after different orthognathic surgical procedures. *J Oral Maxillofac Surg* 2018;**76**:155–64.
18. Hsieh YJ, Chen YC, Chen YA, Liao YF, Chen YR. Effect of bimaxillary rotational setback surgery on upper airway structure in skeletal class III deformities. *Plast Reconstr Surg* 2015;**135**:361–9.
19. Yamashita AL, Iwaki Filho L, Leite PCC, Navarro RL, Ramos AL, Previdelli ITS, Ribeiro MHDM, Iwaki LCV. Three-dimensional analysis of the pharyngeal airway space and hyoid bone position after orthognathic surgery. *J Craniomaxillofac Surg* 2017;**45**:1408–14.
20. Jeon EG, Lee ST, Kwon TG. Perioral soft tissue change after isolated mandibular surgery for asymmetry patients. *J Craniomaxillofac Surg* 2017;**45**:962–8.
21. Kim HS, Kim GT, Kim S, Lee JW, Kim EC, Kwon YD. Three-dimensional evaluation of the pharyngeal airway using cone-beam computed tomography following bimaxillary orthognathic surgery in skeletal class III patients. *Clin Oral Investig* 2016;**20**:915–22.
22. Houston WJ. The analysis of errors in orthodontic measurements. *Am J Orthod* 1983;**83**:382–90.
23. Lee Y, Chun YS, Kang N, Kim M. Volumetric changes in the upper airway after bimaxillary surgery for skeletal class III malocclusions: a case series study using 3-dimensional cone-beam computed tomography. *J Oral Maxillofac Surg* 2012;**70**:2867–75.
24. Hart PS, McIntyre BP, Kadioglu O, Currier GF, Sullivan SM, Li J, Shay C. Postsurgical volumetric airway changes in 2-jaw orthognathic surgery patients. *Am J Orthod Dentofacial Orthop* 2015;**147**:536–46.
25. Park JW, Kim NK, Kim JW, Kim MJ, Chang YI. Volumetric, planar, and linear analyses of pharyngeal airway change on computed tomography and cephalometry after mandibular setback surgery. *Am J Orthod Dentofacial Orthop* 2010;**138**:292–9.
26. Jeon HM, Choi JY, Baek SH. Soft tissue changes after posterior impaction and setback of the maxilla with Le Fort I osteotomy in skeletal class III patients. *J Craniofac Surg* 2014;**25**:1495–500.
27. Zeng F, Wang X, Hu W, Wang L. Association of adiponectin level and obstructive sleep apnea prevalence in obese subjects. *Medicine (Baltimore)* 2017;**96**:e7784.
28. Welch KC, Foster GD, Ritter CT, Wadden TA, Arens R, Maislin G, Schwab RJ. A novel volumetric magnetic resonance imaging paradigm to study upper airway anatomy. *Sleep* 2002;**25**:532–42.
29. Pahkala R, Seppa J, Ikonen A, Smirnov G, Tuomilehto H. The impact of pharyngeal fat tissue on the pathogenesis of obstructive sleep apnea. *Sleep Breath* 2014;**18**:275–82.
30. Lin J, Suurna M. Sleep apnea and sleep-disordered breathing. *Otolaryngol Clin North Am* 2018;**51**:827–33.
31. Wang Y, Sun C, Cui X, Guo Y, Wang Q, Liang H. The role of drug-induced sleep endoscopy: predicting and guiding upper airway surgery for adult OSA patients. *Sleep Breath* 2018;**22**:925–31.

Address:
Tae-Geon Kwon
Department of Oral and Maxillofacial Surgery
School of Dentistry
Kyungpook National University
2177 Dalgubeol-daero
Jung-gu
Daegu
41940
Republic of Korea
Tel.: +82 53 600 7574; Fax: +82 53 426 5365
E-mail: kwondk@knu.ac.kr