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Pharyngeal airway evaluation after isolated mandibular setback surgery using cone-beam computed tomography

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Introduction: In this study, we investigated volumetric and dimensional changes to the pharyngeal airway space after isolated mandibular setback surgery for patients with Class III skeletal dysplasia. **Methods:** Records of 28 patients who had undergone combined orthodontic and mandibular setback surgery were obtained. The sample comprised 17 men and 11 women. Their mean age was 23.88 ± 6.57 years (range, 18-52 years). Cone-beam computed tomography scans were obtained at 3 time points: before surgery, average of 6 months after surgery, and average of 1 year after surgery. Oropharyngeal, hypopharyngeal, and total volumes were calculated. The lateral surface and anteroposterior dimensions at the minimal axial areas for oropharyngeal and hypopharyngeal volumes and mean mandibular setback were determined. **Results:** The mean mandibular setback was 9.93 ± 5.26 mm. Repeated measures analysis of variance determined an overall significant decrease between the means for 6 months and up to 1 year after surgery for oropharyngeal and hypopharyngeal volumes, anteroposterior at oropharyngeal, lateral surface at oropharyngeal, and anteroposterior at hypopharyngeal. No strong correlation between mandibular setback surgery and pharyngeal airway volumes or dimensions was determined. **Conclusions:** After mandibular setback surgery, pharyngeal airway volume, and transverse and anteroposterior dimensions were decreased. Patients undergoing mandibular setback surgery should be evaluated for obstructive sleep apnea and the proposed treatment plan modified according to the risk for potential airway compromise. (Am J Orthod Dentofacial Orthop 2018;153:46-53)

In patients with severe skeletal Class III dysplasia, combined orthodontic-orthognathic surgical treatment provides an esthetic and functional solution. Isolated mandibular setback surgery is a treatment option for the correction of this dysplasia. An important aspect of this surgical correction is that it causes changes in the position of the hyoid bone and the base of tongue.[1-4] The posterior shift of the tongue base creates an increase in contact length between the soft palate and the tongue base and can decrease the pharyngeal airway space.[1,4-6] The resultant changes in hard and soft tissues after mandibular setback surgery have been shown to produce a shift in oropharyngeal characteristics to a morphology associated with sleep-disordered breathing, typical of obstructive sleep apnea (OSA).[7]

OSA is characterized by repeated increases in resistance to airflow in the upper airway, causing obstruction.[8] It is also characterized by the periodic partial or complete collapse of the upper airway that results in episodes of hypopnea (diminished airflow of at least 30%, lasting at least 10 seconds) or apnea (absent airflow).[8-10] The collapse of soft tissues in the upper airway, including the retropalatal and retroglossal regions of the oropharynx, play a role in the etiology of OSA.[11] Epidemiologic estimates of OSA prevalence are about 4% for men and 2% for women in the age group of 30 to 60 years in the United States when considering subjective daytime sleepiness.[12-16] Approximately 1 in 5 adults has at least mild OSA, and 1 in 15 adults has OSA of moderate or worse severity.[12,17,18]

Initial research performed to evaluate the effect of mandibular setback surgeries on the pharyngeal airway space have been evaluated with lateral cephalograms.[7,19-24] The limitations of a lateral cephalogram are that it is a static, 2-dimensional image that does not adequately represent the 3-dimensional volumetric

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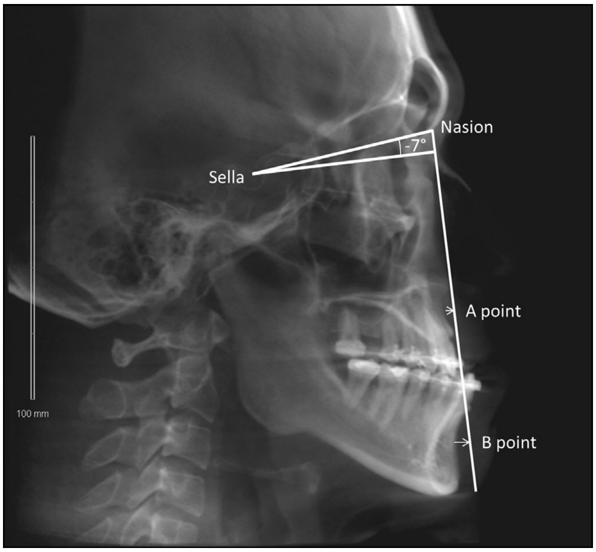

Fig 1. Lateral cephalogram demonstrating measurement of surgical movement.

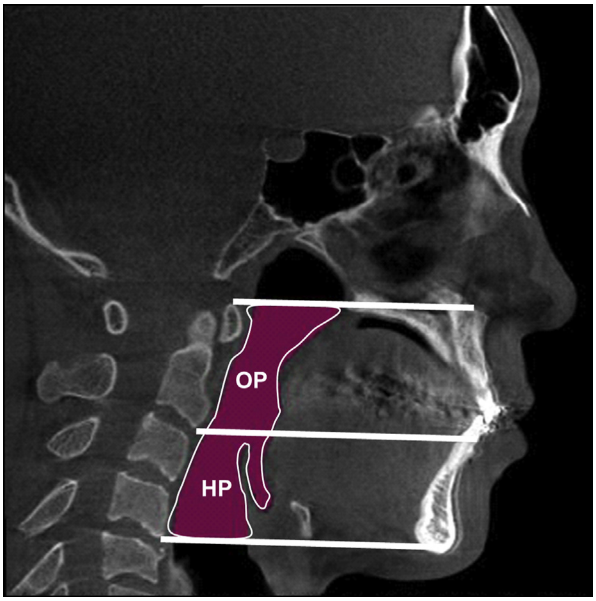

Fig 2. Segmentation of OP and HP volumes.

data.[25] Recently, cone-beam computed tomography (CBCT) has been used to evaluate the airway changes 3 dimensionally.[26] The majority of CBCT studies examining pharyngeal airway volume changes have patients undergoing a combination of maxillary advancement and mandibular setback surgery.[27-30] Thus, there is limited evidence in the literature describing the effect of isolated mandibular setback surgeries on pharyngeal

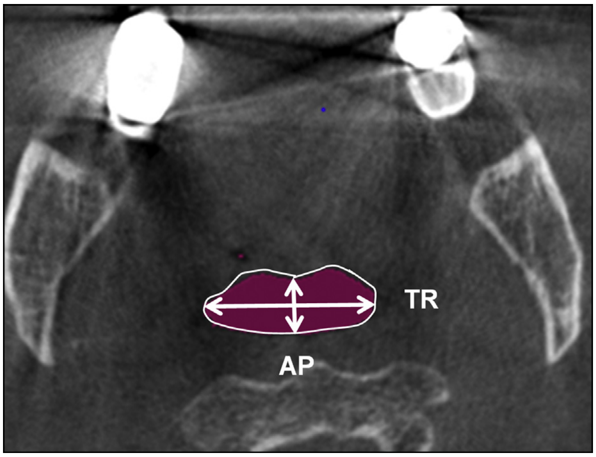

Fig 3. Segmentation of TR and AP.

airway space using CBCT. Further research may elucidate whether a setback alone contributes to a negative impact on the airway and possibly exacerbate OSA.

The aims of this study were to evaluate volumetric and dimensional changes in the pharyngeal airway space for patients who have undergone isolated mandibular setback surgery with CBCT, and also to determine whether a relationship exists between mandibular setback surgery and pharyngeal airway volumes or dimensions.

MATERIAL AND METHODS

For this study, the records of 28 patients who had undergone combined orthodontic and isolated mandibular setback surgery to correct Class III skeletal dysplasia were obtained. The sample included 17 men and 11 women. Their mean age was 23.88 ± 6.57 years, with a range of 18 to 52 years. The sample was retrieved from the Department of Orthodontics at Pusan National University Hospital, Busan, South Korea. The setback surgery consisted of sagittal split ramus osteotomy of the mandible with rigid fixation. CBCT scans were obtained at 3 time points: T1 (before surgery), T2 (an average of 6 months after surgery), and T3 (an average of 1 year after surgery). The inclusion criteria for this study were adults with Class III skeletal deformities who had undergone mandibular setback surgery and orthodontic treatment. The exclusion criteria were severe facial asymmetry or syndrome, and symptoms of temporomandibular disorders or respiratory disease.

The presurgical and postsurgical apnea-hyponea index values and the body mass index values of the subjects were not available for this study.

Table I. Descriptive statistics for oropharyngeal volume (OP), hypopharyngeal volume (HP), total volume (TV), anteroposterior at oropharyngeal (AP at OP), lateral surface at oropharyngeal (TR at OP), anteroposterior at hypopharyngeal (AP at HP), and lateral surface at hypopharyngeal (TR at HP)

Variable	*T1*	*T2*	*T3*
OP (mm^3)	16279.31 ± 4627.48	11868.04 ± 5600.73	12317.64 ± 5595.85
HP (mm^3)	14199.36 ± 4246.32	11049.49 ± 4969.84	11943.75 ± 4154.69
TV (mm^3)	30478.67 ± 8319.83	22917.53 ± 9824.03	24261.40 ± 8916.27
AP at OP (mm)	13.50 ± 3.34	9.77 ± 3.49	10.25 ± 3.72
TR at OP (mm)	29.06 ± 5.46	24.10 ± 6.12	24.74 ± 6.01
AP at HP (mm)	14.50 ± 3.34	11.35 ± 4.04	11.78 ± 4.30
TR at HP (mm)	28.60 ± 9.03	27.20 ± 6.59	27.85 ± 7.31

T1, Before surgery; *T2*, 6 months after surgery; *T3*, 1 year after surgery. n = 28.

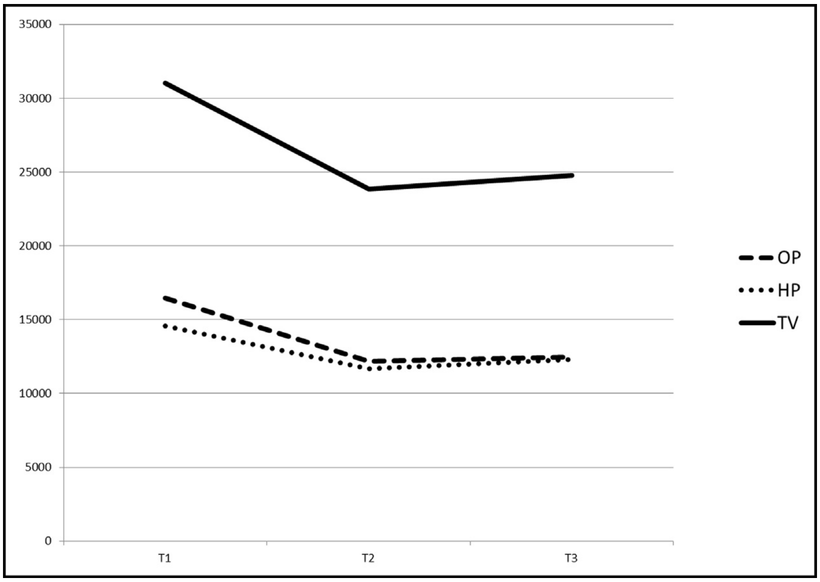

Fig 4. Graph representing changes in mean volumes at T1, T2, and T3.

All patients underwent a CBCT examination (DCTpro; Vatech, Seoul, Korea) for assessment of upper airway volume and skeletal changes. The patients were seated in the upright position with maximum intercuspation. The Frankfort horizontal plane was parallel to the floor. Head orientation was the same for each CBCT image performed by the same experienced operator. The patients were asked not to swallow during the scan. The maxillofacial regions were scanned for 24 seconds using a CBCT machine with a voxel size of 0.3 mm, a field of view of 20 × 19 cm, a tube voltage of 90 kV(p), and a tube current of 4.0 mA. Images were imported into imaging software (version 11.5; Dolphin Imaging and Management Systems, Chatsworth, Calif) and used to view, analyze, and manipulate the CBCT scans.

The calculation of the anteroposterior surgical movement was measured by converting the CBCT scan from a 3-dimensional volume to a lateral cephalogram image. A reference plane was drawn through sella and nasion, and then 7° was subtracted. A perpendicular line was drawn through the corrected horizontal plane from nasion, and then the distance to B-point was measured and compared before and after surgery (Fig 1).

To isolate the pharyngeal airway and volumetric measurements, orientation of the CBCT scan included the horizontal reference plane that was defined bilaterally by porion with right orbitale. This condition was verified on the midsagittal plane. The transporionic plane was oriented vertically, defined bilaterally by porion and perpendicular to the horizontal reference plane. The midsagittal plane was oriented vertically, defined by nasion, and perpendicular to the other reference planes. The 2 defined volumes included the oropharyngeal (OP) and hypopharyngeal (HP) volumes. The superior border of OP was bounded by a line from the most superior anterior point of cervical vertebrae 1 to the posterior tip of the hard palate. The inferior border was defined by a line parallel to the superior border from the most inferior anterior point of cervical vertebrae 2 to the base of the tongue. This inferior border also formed the superior border of the HP, and the inferior border of the HP was a line parallel to the superior border from the most inferior anterior point of cervical vertebrae 4 to the anterior border. The anterior border comprised the posterior soft palate and the base of tongue. The posterior border was the posterior pharyngeal wall (Fig 2).

After isolation, the volume of each segment and total volume (TV) were calculated. In addition, the minimum axial area was determined, and then the lateral surface length (TR) and the anterior posterior lengths (AP) were measured (Fig 3).

Statistical analysis

Data analysis was performed using SPSS software (version 23.0; IBM, Armonk, NY). Descriptive statistics calculated the means and standard deviations for mandibular setback and relapse, as well as the OP and HP volumes and TV, TR, and AP at each time point. The Shapiro-Wilk test demonstrated normal distribution of the data. Paired *t* tests were used to verify significant differences in the mean airway volumes, and the TR and AP measurements. The Pearson correlation was used to determine whether a relationship existed between the amount of mandibular setback and pharyngeal volumes and dimensions.

Multiple linear regressions were conducted at each time point interval (T2-T1, T3-T2, T3-T1) using all variables that evaluated the airway volumes or dimensions. The forward method was used to include or exclude variables in the adjusted model. The significance level for the statistical tests was set at 0.05.

For reliability testing, 10% of the variables were randomly selected and remeasured after 2 weeks. Cronbach alpha interitem correlation was the statistic used to determine reliability. As a general rule, intraclass correlations greater than or equal to 0.80 are considered adequate. A Cronbach value of 0.8 or greater was met for all measurements.

RESULTS

From the cephalometric data, the mean mandibular setback was 9.93 ± 5.26 mm, and the mean mandibular relapse from T3 to T2 was 1.13 ± 3.11 mm.

From the volumetric data, means and standard deviations for OP and HP volumes, TV, and TR and AP are presented in Table I.

Thus the null hypothesis can be rejected and the alternative hypothesis accepted. There was a significant difference in the pharyngeal airway (OP and HP volumes and TV, TR at OP, and AP at HP) after mandibular setback surgery (Fig 4).

Paired *t* tests (after Bonferroni correction to control the family-wise error) identified the intervals during which there were significant changes for the OP and HP volumes and TV, in addition to the TR and AP. Generally, significant decreases were noted from T2 to T1 and from T3 to T1, but no significant changes were noted from T3 to T2. The only exception was for TR at HP (lateral surface length at hypopharyngeal), where there was no statistically significant change over time (Table II).

Calculations were done to determine the volume percentage change. All 3 volumes showed statistically significant percentage decreases from T2 to T1 and T3 to T1. However, T3 to T2 showed a nonsignificant percentage change (Table III).

The Pearson correlation was used to determine whether a relationship existed between the amount of mandibular sagittal displacement and the pharyngeal airway volumes or dimensions between the time points.

Table II. Paired *t* tests denoting significant changes between T1 and T2, and T1 and T3, but not T2 and T3, for all evaluated variables, except for TR at HP where no differences were noticed between all time points

Variable	*Time point*	*Time point*	*Mean difference*	*SE*	*Significance*
OP (mm^3)	T1	T2	4411.26	806.63	<0.001
		T3	12304.14	1057.24	<0.001
	T2	T3	−449.60	545.71	0.417
HP (mm^3)	T1	T2	3149.87	763.16	<0.001
		T3	2255.60	705.77	0.001
	T2	T3	−894.26	540.17	0.109
TV (mm^3)	T1	T2	7561.13	1497.01	<0.001
		T3	6217.27	1566.01	<0.001
	T2	T3	−1343.86	974.16	0.179
AP at OP (mm)	T1	T2	3.72	0.61	<0.001
		T3	3.25	0.73	<0.001
	T2	T3	−2.18	1.64	0.196
TR at OP (mm)	T1	T2	4.96	1.14	<0.001
		T3	4.32	0.82	0.001
	T2	T3	−0.63	1.24	0.478
AP at HP (mm)	T1	T2	3.14	0.83	0.001
		T3	2.71	0.79	0.001
	T2	T3	−0.42	0.66	0.524
TR at HP (mm)	T1	T2	1.40	1.53	0.369
		T3	0.75	1.31	0.555
	T2	T3	−0.65	1.08	0.570

OP, Oropharyngeal volume; *HP*, hypopharyngeal volume; *TV*, total volume; *AP at OP*, anteroposterior at oropharyngeal; *TR at OP*, lateral surface at oropharyngeal; *AP at HP*, anteroposterior at hypopharyngeal; *TR at HP*, lateral surface at hypopharyngeal.

Table III. Volume percent change over the 3 time points

Percent change	*T2−T1*	*T3−T2*	*T3−T1*
Oropharyngeal volume	−26.2% ± 2.4%*	6.2% ± 2.5%	−22.3% ± 3.3%*
Hypopharyngeal volume	−21.7% ± 2.4%*	7.5% ± 3.1%	−14.0 % ± 2.3%*
Total volume	−24.0% ± 2.2%*	10.5% ± 2.7%	−18.4% ± 2.7%*

*P <0.05, a statistically significant decrease.

Pearson correlations with an r greater than 0.7 are considered strong. A correlation with an r between 0.5 and 0.7 is considered moderate in strength, whereas a weak correlation will yield an r of 0.3 to 0.5. Although this study presented some statistically significant correlations at some time point intervals between the amount of mandibular sagittal displacement and the pharyngeal volumes or dimensions, it did not yield any correlation in a strong or moderate range. The significant Pearson correlations are presented in Table IV.

Regarding the multiple linear regression analysis, the only statistical significance was observed for the variable TR at HP at the interval T3-T1, with a P <0.03 (Table V). Age and sex were not significant (P <0.35 and P <0.25, respectively). Collinearity diagnostics were greater than 1.0, showing that collinearity was not a problem in the regression models.

Table IV. Significant correlations between the sagittal movement of the mandible and airway dimension changes

Time point interval	*Variable correlated to mandibular movement*	*r value*	*P value*
T2-T1	TR at HP (mm)	0.330	0.043
T3-T2	OP (mm^3)	0.357	0.031
T3-T2	TV (mm^3)	0.368	0.027
T3-T2	TR at OP (mm)	0.341	0.038
T3-T1	OP (mm^3)	0.351	0.034
T3-T1	TR at OP (mm)	0.362	0.029
T3-T1	AP at HP (mm)	0.325	0.046
T3-T1	TR at HP (mm)	0.344	0.036

P <0.05 (2-tailed).
TR at HP, Lateral surface at hypopharyngeal; *OP*, oropharyngeal volume; *TV*, total volume; *TR at OP*, lateral surface at oropharyngeal; *AP at HP*, anteroposterior at hypopharyngeal; *T1*, before surgery; *T2*, 6 months after surgery; *T3*, 1 year after surgery.

DISCUSSION

In this study, we evaluated pharyngeal airway volume changes, and lateral surface and anteroposterior dimensional changes using CBCT for 28 patients who had undergone combined orthodontic and isolated mandibular setback surgery to correct Class III skeletal dysplasia. Correlation and linear regression analyses were performed to ascertain a relationship between the amount of mandibular setback and pharyngeal airway volumes or dimensions.

Statistical analysis determined that there were significant decreases for OP and HP volumes and TV for T2 to T1 and T3 to T1, but not for T3 to T2. Similar significant decreases were noted for AP at OP, TR at OP, and AP at HP. For TR at HP, the changes over time were not significant.

Reductions in the dimensions of the retrolingual and hypopharyngeal airways after mandibular setback surgery have been shown in several studies.[2,3,5,6,20,22,31] Similar to our study, other CBCT studies have also reported decreases in OP and HP volumes after mandibular setback surgery in short-term and long-term follow-up studies.[27-29,32] After mandibular setback surgery, there is a posteroinferior displacement of the hyoid bone, which moves the tongue in a similar direction.[2-4,31] The posteriorly displaced tongue can then narrow the retrolingual (part of the oropharyngeal) region and decrease the pharyngeal airway space.[4-6,31] This can lead to an increase in the contact angle between the soft palate and the tongue and contribute to the decrease in the OP volume.[4]

The significant decreases in AP and TR at the OP region and the decrease in AP at the HP region in this study have also been corroborated.[27,29] Hong et al[30] examined CBCT scans before surgery and 2 months after surgery and determined that the anteroposterior dimension, cross-sectional area, and pharyngeal volume were all decreased in the patients with mandibular setback. Mattos et al[33] in a meta-analysis conducted to study the effects of orthognathic surgery on the oropharyngeal airway determined that anteroposterior changes after mandibular setback surgery had a highly significant decrease in the oropharyngeal airway at the levels of the soft palate (−2.7 mm) and the base of the tongue (−2.99 mm). There was also a significant decrease in the lateral width of the oropharyngeal airway after mandibular setback surgery. However, we did not find significant changes in the lateral surface dimension at the hypopharyngeal region after mandibular setback surgery.

Concerns over the effect of mandibular setback surgery have received more attention as the epidemic

Table V. Beta coefficients and *P* values for the multiple linear regressions at each time point interval using the variables included in the adjusted model

	Mandibular sagittal displacement, T2-T1		*Mandibular sagittal displacement, T3-T2*		*Mandibular sagittal displacement, T3-T1*	
Variable	*β coefficient*	P *value*	*β coefficient*	P *value*	*β coefficient*	P *value*
OP (mm^3)	0.206	0.747	0.174	0.642	0.016	0.970
HP (mm^3)	0.377	0.360	0.565	0.177	0.161	0.672
TV (mm^3)	0.273	0.488	0.225	0.342	0.127	0.458
AP at OP (mm)	0.162	0.649	0.129	0.531	0.054	0.740
TR at OP (mm)	0.587	0.208	0.264	0.490	0.508	0.121
AP at HP (mm)	0.205	0.528	0.246	0.484	0.218	0.210
TR at HP (mm)	0.506	0.072	0.521	0.077	0.620	0.021*

OP, Oropharyngeal volume; *HP*, hypopharyngeal volume; *TV*, total volume; *AP at OP*, anteroposterior at oropharyngeal; *TR at OP*, lateral surface at oropharyngeal; *AP at HP*, anteroposterior at hypopharyngeal; *TR at HP*, lateral surface at hypopharyngeal; *T1*, before surgery; *T2*, 6 months after surgery; *T3*, 1 year after surgery.
*Statistical significance at $P < 0.05$.

of obesity continues to rise, leading to more middle-aged adults with OSA. Surgeons first noticed that some patients developed OSA after mandibular setback and published case reports about this potential complication.[5,7] Riley et al[7] reported on 2 women with OSA after mandibular osteotomy for treatment of mandibular prognathism. Before surgery, neither patient had any signs or clinical symptoms of airway obstruction. These 2 patients were diagnosed with OSA. Hasebe et al[34] conducted polysomnography before and 2 months after surgery and determined no change in the patients' apnea-hypopnea index values. However, 2 patients were diagnosed with mild OSA because the setbacks were large. These patients were not obese and had undergone mandibular setback surgeries only. In consecutive cephalometric studies, Hochban et al[19] noted a decrease in pharyngeal airway space after surgery, but the polysomnographs taken before and after surgery showed no significant changes, and the surgery did not perpetuate sleep-related breathing disorders.

Correlation analysis for this study showed some significant correlations between mandibular sagittal displacement and pharyngeal airway volumes or dimensions, but with weak correlations. Similar to our findings, Kawamata et al[1] found a correlation ($r = 0.54$) between the amount of mandibular setback and the reduction in lateral pharyngeal width 3 months after surgery using computed tomography to study the effect of mandibular setback surgery. In addition, Hochban et al[19] determined a correlation ($r = 0.5$) between mandibular setback and reduction in pharyngeal airway space. These correlation values do not substantiate a strong causation or association. In another study, Panou et al[28] used CBCT and found no correlation between the amount of surgical movement and the change in the pharyngeal volume.

The weak correlation that we found in this study can be corroborated by the absence of significance in the majority of the variables analyzed by the multiple linear regression analyses. The only significance for the regression analyses was observed for the variable TR at HP at the interval between T3 and T1. For all other variables, there was no significance between the amount of mandibular sagittal displacement and the pharyngeal volumes or dimensions.

This statistical significance for the variable TR at HP at the interval T3 to T1 found in the regression analysis means that the amount of mandibular setback from T3 to T1 could predict the change for the lateral surface dimension at the HP region at this same time interval. However, this was the only analyzed variable that did not show statistically significant changes over the 3 time point intervals. Therefore, for a clinical standpoint, this significance in the regression analysis has limited value.

The limitations of this study include a small sample size, and lack of control of tongue position and the inspiratory or expiratory phase during acquisition of the CBCT scans. It would have been helpful to have more long-term data and to compare the results between patients with smaller initial airways volumes. Additionally, patients with OSA could have been compared with nonapneic patients to determine whether a difference exists between the groups after mandibular setback surgery. Changes in the amount of surgical repositioning may also influence results.

The literature continues to evolve about the effect of mandibular setback surgery on the posterior airway. The evidence points to a detrimental effect on the airway, and further CBCT studies are needed to elucidate the relationship between airway volume changes after setback surgery and its implications in terms of airway resistance, obstruction, collapsibility, and the effect on OSA. After screening for excessive daytime somnolence, snoring, increased body mass index, and medical conditions related to OSA, and results from a polysomnograph, surgical treatment recommendations for patients pursuing Class III surgical correction need to be made to determine whether a mandibular setback or a combination with maxillary advancement would provide the best esthetic and functional results and in turn prevent OSA, a life-threatening outcome.

CONCLUSIONS

1. There are significant decreases in all pharyngeal airway volumes from before surgery to 6 months and 1 year after isolated mandibular setback surgery.
2. There are significant decreases in the anteroposterior and lateral surface dimensions at oropharyngeal for up to 1 year after isolated mandibular setback surgery.
3. There is a significant decrease in the anteroposterior dimension at hypopharyngeal for up to 1 year after isolated mandibular setback surgery.
4. No strong correlation exists between the amount of mandibular setback surgery and pharyngeal airway volumes or dimensions.
6. The amount of mandibular sagittal displacement for up to 1 year after isolated mandibular setback surgery could not predict the volumetric changes in the pharyngeal airway.

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