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Changes in position of the hyoid bone and volume of the pharyngeal airway after mandibular setback: three-dimensional analysis

Jin Hoo Park, Hee-Sung Kim, Sung-Hwan Choi, Young-Soo Jung, Hwi-Dong Jung *

Department of Oral & Maxillofacial Surgery, Oral Science Research Institute, Yonsei University College of Dentistry, Seoul, Korea

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Abstract

Important aspects of orthognathic surgery are the effects of skeletal movement and changes in the position of the hyoid bone, tongue, soft palate, and dimensions of the pharyngeal airway. Our aims were to evaluate the 3-dimensional changes in the pharyngeal airway and in the position of the hyoid bone after mandibular setback in 30 patients who were diagnosed with mandibular prognathism and were treated by intraoral vertical ramus osteotomy (IVRO). Three-dimensional cone-beam computed tomographic (CT) images were obtained preoperatively, one month postoperatively, and one year postoperatively. The total pharyngeal volume decreased between the preoperative state and one month and one year afterwards. The hyoid bone had moved 2.0 mm posteriorly and 3.15 mm superiorly by one month postoperatively. The position of the hyoid bone was affected by changes in posterior and superior movement of the B point at one month ($r = 0.44$, $p = 0.015$ and $R = 0.63$, $p = 0.000$, respectively) and also by superior movement of the B point at one year ($r = 0.57$, $p = -0.001$). There was an advantageous relation between posterior positional changes in the B point (mandibular setback), and volumetric changes in the hypopharyngeal and total pharyngeal airway, so maxillofacial surgeons should consider the reduction in airway when planning excessive mandibular setback.

Keywords: hyoid bone; pharyngeal airway; mandibular setback surgery; three-dimensional analysis; Intraoral vertical ramus osteotomy

Introduction

The effects of skeletal movement and changes in the position of the hyoid bone, tongue, soft palate, and dimensions of the pharyngeal airway are important aspects of orthognathic surgery. [1] The upper pharyngeal airway has attracted much attention because a decrease in its volume is known to be closely associated with snoring and sleep apnoea.[2,3]

The hyoid bone is unique in that it does not articulate with any other bone and its position is governed by a number of muscles and ligaments.[4] Its position may be affected by the muscles connected to the mandible and may affect the pharyngeal airway so it plays an important part in studies of orthognathic surgery and the airway.[5]

Many investigators have reported a reduction in the dimensions of the airway after Class III orthognathic surgery,[6–10] but most previous studies have focused on the changes to the bony and soft tissue structures after sagittal split ramus osteotomy (SSRO). Changes in the pharyngeal airway after intraoral vertical ramus osteotomy (IVRO) setback have not to our knowledge been studied to date, and these may not be the same as after SSRO.

Traditionally, postoperative changes in the upper airway have been analysed using two-dimensional lateral

* Corresponding author at: Department of Oral & Maxillofacial Surgery, College of Dentisty, 134 Shinchon-Dong, Seodaemoon-Gu, Seoul, 120-752, Korea, Tel.: +82-2-2228-3138, Fax: +82-2-2227-7825.

E-mail addresses: wlsgnek@yuhs.ac (J.H. Park), for4ever@naver.com (H.-S. Kim), YUSUNG16@yuhs.ac (S.-H. Choi), ysjoms@yuhs.ac (Y.-S. Jung), cancer7@yuhs.ac (H.-D. Jung).

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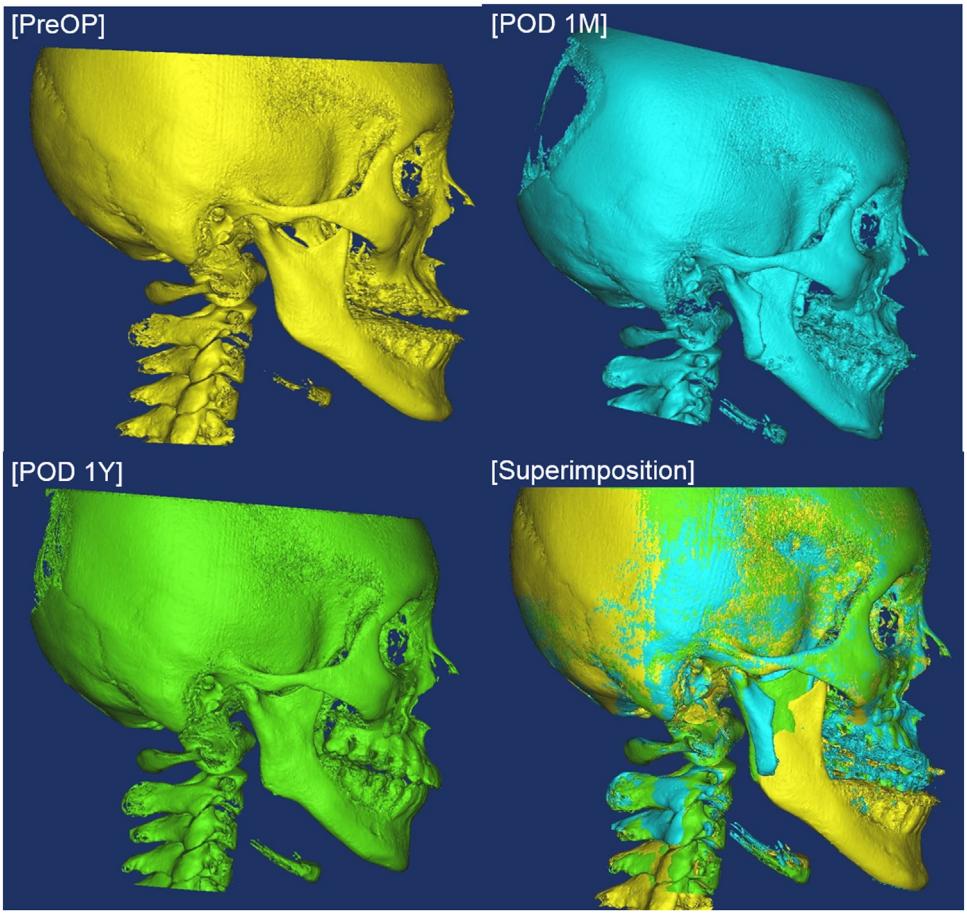

Fig. 1. Three-dimensional reconstructed skulls and a superimposition of those skulls.

cephalograms.[11–14] However, although lateral cephalograms have been used extensively as a diagnostic tool in the study of craniofacial morphology, they do not offer unique potential for assessment of the 3-dimensional anatomy of the airway.[15] Cone-beam computed tomography (CT), however, can distinguish the boundaries between the soft tissue and the airway, and offers a more precise anatomical assessment from reconstructed 3-dimensional models and multiplanar reformatted views.[16] Three-dimensional volumetric images also enable visualisation of the internal structures by eliminating the external structures, as well as allowing measurement of the volume of the airway.[17]

The aims of this study were to evaluate the 3-dimensional changes in the pharyngeal airway and in the position of the hyoid bone after IVRO setback.

Patients and methods

The protocol was approved by the institutional review board of Yonsei University Dental Hospital (approval number 2-2016-0037) and the study was done in accordance with the Declaration of Helsinki.

The study group comprised 30 patients (7 men and 23 women), mean (SD) age 21 (8) years (range 18–34) with mandibular prognathism, who had had bimaxillary Le Fort 1 advancement, or impaction, or both, with associated IVRO mandibular setback, from 2013–14. The exclusion criteria were previous orthognathic surgery, additional genioplasty, previously-diagnosed obstructive sleep apnoea, and craniofacial anomalies such as cleft lip and palate.

IVRO in each case was done to set back the mandible without internal fixation, and followed by intermaxillary fixation for two weeks. The fixation was released after two weeks and subsequent physiotherapy was provided according to the protocol described by Jung et al[18] using the fixation devices placed intraoperatively. Active physiotherapy was continued until an adequate range of movement (more than 40 mm) and stable occlusion had been achieved.[1] Orthodontic treatment was started four weeks postoperatively.[18] Cone-beam CT was done preoperatively, and one month and one year postoperatively (Fig. 1). At the time of cone-beam CT the patient's head was placed in the natural position, the patient was in centric occlusion, and the lips were naturally separated. The cone-beam CT images were extracted as DICOM files. Three-dimensional rendered images of the skull and pharyngeal

airway was reconstructed and superimposed using Mimics version 16.0 software (Materialise Dental n.v.).

The Frankfort horizontal (FH) plane was drawn as the horizontal reference plane and defined as the plane passing through the left and right porion and left and right orbitale. The midsagittal plane was drawn as a plane perpendicular to the FH plane passing through the nasion and the centre of the foramen magnum. A vertical reference plane was drawn perpendicular to the FH plane and midsagittal plane (Fig. 2).

Mandibular movement was evaluated by measuring the distance between the FH plane-B point (vertical movement) and the vertical reference plane-B point (horizontal movement). The hyoid point was defined as the most anterosuperior point of the hyoid bone. The position of the hyoid bone was evaluated by measuring the distance between the FH plane-hyoid point (vertical position) and the vertical reference plane-hyoid point (horizontal position). These lines were measured using the Mimics software.

The total pharyngeal airway was defined as the area between the upper pharyngeal wall and the epiglottis plane (a plane parallel to the FH plane passing through the base of the epiglottis). The anterior border of the upper pharyngeal wall was divided by the plane that was the pharyngeal intersection of a plane perpendicular to a plane that connected with the FH plane at the posterior nasal spine. The total pharyngeal airway was divided by the hard palatal plane (a plane parallel to the FH plane that passed through the point of the posterior nasal spine) and soft palatal plane (a plane parallel to the FH plane that passed through the most inferior point of the soft palate, Fig. 3).

The nasopharyngeal airway was defined as the area between the upper pharyngeal wall and the hard palatal plane. The oropharyngeal airway was defined as the area between the hard palatal plane and the soft palatal plane. The size of the hypopharyngeal airway was defined as the area between the soft palatal plane and the epiglottis plane.

Statistical analysis

The volume of the space of the pharyngeal airway was measured using 3-matic software (Materialise Dental). To ensure that the measurements were accurate, they were made twice on each image by the same clinician. The intraclass correlation was used to assess the consistency of the measurements. The significance of changes in volume of the airway and movement of reference points (B point, hyoid bone) preoperatively, one month postoperatively, and one year postoperatively were also tested using repeated-measures one-way analysis of variance (ANOVA). The relations between changes in the volume of the airway and movement of the reference points (B point, hyoid bone) were evaluated using Pearson's correlation analysis. The statistical analysis was made with the aid of the PASW Statistics for Windows software (version 18.0, SPSS Inc).

Results

The intraclass correlation coefficient was ≥ 0.9, indicating excellent intraobserver reliability of the measurements. Comparisons for all of the study items gave p values of < 0.001. There was a tendency for relapse of the hyoid bone in the superior direction but this was not significant (Table 1).

The total pharyngeal volume decreased considerably between its preoperative level and one month and one year postoperatively (Fig. 4). The nasopharyngeal and hypopharyngeal airway volumes were decreased at one month and one year postoperatively, while the volume of the nasopharyngeal airway increased slightly between one month and one year. However, there was no significant change in the volume of the oropharyngeal airway postoperatively ($p = 0.15$, Table 1).

We used Pearson's correlation analysis to assess the relations between mandibular changes, airway volumes, and the position of the hyoid bone (which was affected by changes in posterior and superior movement of the B point at one month, $p = 0.000$, respectively) and also by superior movement of the B point at one year ($r = 0.57$, $p = 0.001$). Although the hyoid bone is not articulated with the mandible, there seemed to be a relation between vertical and horizontal movement of the mandible and movement of the hyoid bone (Table 2).

There was an advantageous relation between posterior positional changes in the B point (mandibular setback) and volumetric changes in the hypopharyngeal and total pharyngeal airway at one month and one year postoperatively. However, there was no significant relation between the vertical positional changes in the B point (mandibular superior movement) and changes in the volume of the pharyngeal airway, and there was no significant relation between vertical or horizontal movement of the hyoid bone and change in pharyngeal airway volume.

Discussion

We have made a 3-dimensional analysis of the positional changes in the hyoid bone and changes in the volume of the pharyngeal airway after IVRO setback. Mandibular relapse has been reported after IVRO in the clockwise and counter-clockwise directions, but the amount of horizontal relapse is smaller than that with SSRO.[11,19,20] We found that the mandible relapsed in a counter-clockwise direction, and the hyoid bone moved posteriorly and superiorly when measured a month and a year postoperatively. Most of the superior and posterior movement of the hyoid bone occurred during the first month postoperatively but, unlike in a previous study,[10] there was no tendency for the hyoid bone to return towards its original position. Gu et al suggested that movement of the hyoid bone reflects the tendency of the mandible to relapse in the anteroposterior position,[23] but our results show that the postoperative position of the hyoid bone did not change significantly by the one year follow up.

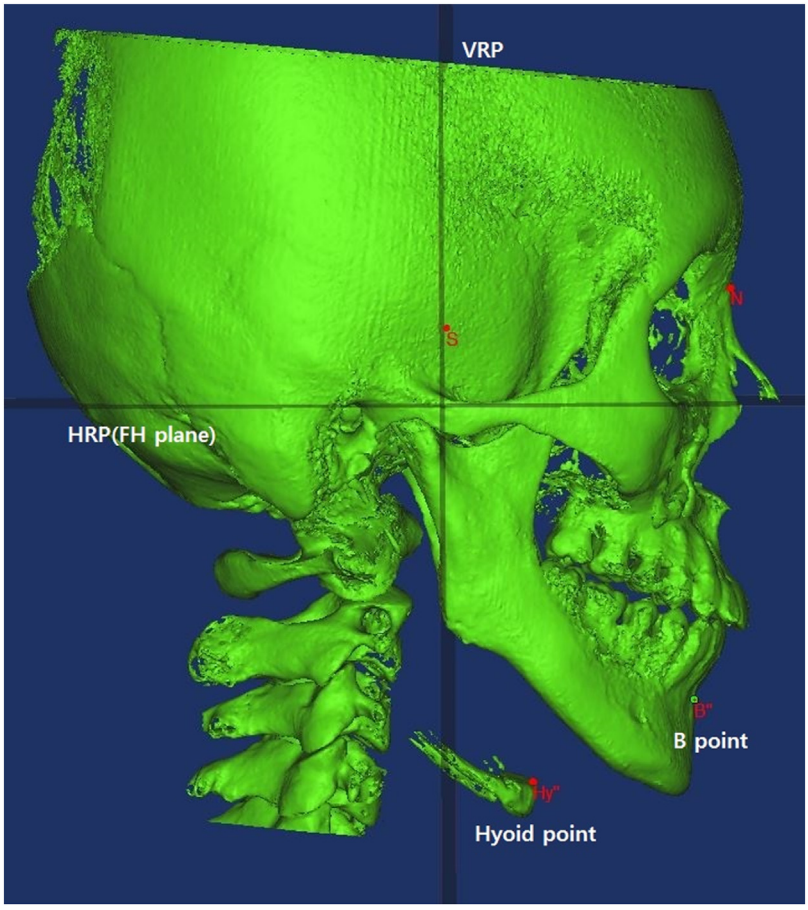

Fig. 2. Reference plane and points: HRP = horizontal reference plane (Frankfort horizontal plane), VRP = vertical reference plane, B = B point, Hy = hyoid point, N = Nasion, S = Sella turcica.

Table 1
Postoperative changes in skeletal, hyoid bone, and pharyngeal airway volume. A negative value indicates a mandibular setback, a hyoid bone upward and a reduction in airway volume.

	Change in displacement at one month compared with preoperatively		Change in displacement at one year compared with preoperatively		Change in displacement at one month compared with one year postoperatively	
	Mean (SD)	p value	Mean (SD)	p value	Mean (SD)	p value
B point horizontal (mm)	−9.72 (3.89)	0.000*	−8.76 (2.90)	0.000*	0.96 (2.54)	0.049*
B point vertical (mm)	−2.40 (4.17)	0.011*	−4.05 (3.48)	0.000*	−1.65 (2.40)	0.002*
Hyoid bone horizontal (mm)	−2.00 (4.92)	0.048*	−2.01 (3.87)	0.024*	−0.01 (6.20)	1.000
Hyoid bone vertical (mm)	−3.15 (5.30)	0.009*	−3.45 (6.77)	0.027*	−0.30 (6.03)	1.000
Nasopharyngeal volume (mm^3)	−4440.13 (2285.77)	0.000*	−3829.70 (1975.14)	0.000*	610.43 (855.98)	0.002*
Oropharyngeal volume (mm^3)	78.00 (2270.52)	1.000	−745.37 (2514.61)	0.346	−823.37 (2207.02)	0.151
Hypopharyngeal volume (mm^3)	−2188.50 (3149.13)	0.002*	−2233.17 (4043.42)	0.015*	−44.67 (3742.85)	1.000
Total pharyngeal volume (mm^3)	−6552.10 (5975.36)	0.000*	−6801.07 (5814.24)	0.000*	−248.97 (5814.24)	1.000

*$p < 0.05$ (repeated measurement ANOVA).

The skeletal relapse pattern after IVRO differs from that after SSRO in both the short and long term as a result of differences in stabilisation, healing, and the postoperative relapse pattern. The positions of the hyoid bone and tongue may also differ after IVRO setback.[8] In previous studies, after mandibular setback with SSRO, the hyoid bone moved posteriorly at first, and then recovered to some extent anteriorly.[23] We found that the hyoid bone moved backwards after IVRO and could not be moved back to its original position. This is presumably attributable to the different directions of mandibular anterior relapse achieved after setback with SSRO and IVRO. Anterior relapse of more than 2 mm is likely to be found in at least 30% of patients after SSRO, whereas IVRO has a posterior relapse pattern.[18,24] It is thought, therefore, that the anterior and posterior position of the hyoid bone

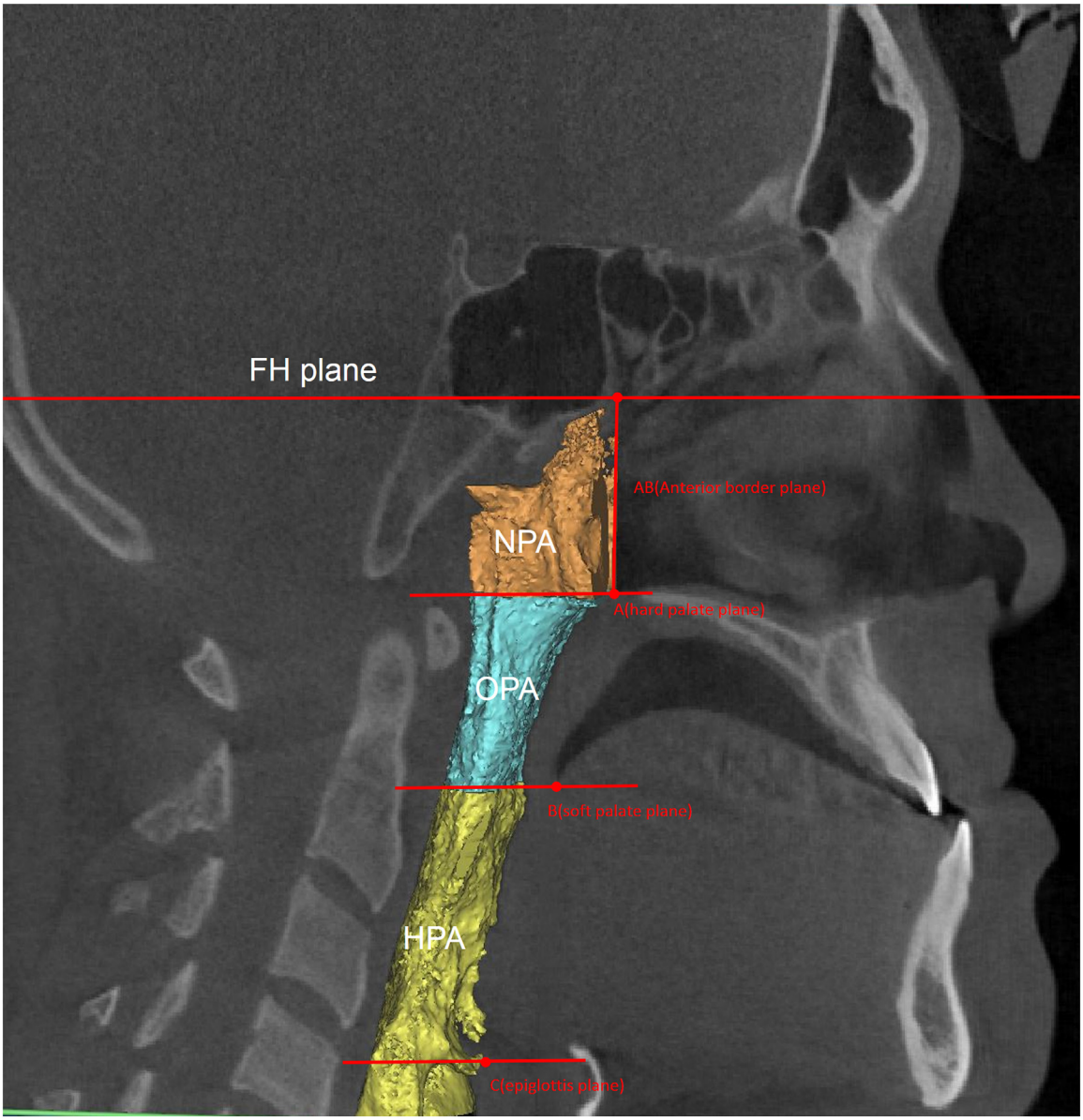

Fig. 3. Volumetric measurements of the space in the pharyngeal airway. NPA = nasopharyngeal airway, OPA = oropharyngeal airway, HPA = hypopharyngeal airway, AB = anterior border plane, A = hard palate plane; B = soft palate plane, C = epiglottis plane.

Table 2
Pearson correlation analysis between skeletal movement and change of hyoid bone, pharyngeal airway volume.

Volume	One month postoperatively compared with preoperatively: B horizontal		One year postoperatively compared with preoperatively: B horizontal		One month postoperatively compared with preoperatively: B vertical		One year postoperatively compared with preoperatively: B vertical	
	r	p value	r	p value	r	p value	r	p value
Nasopharyngeal	0.12	0.539	0.32	0.083	0.23	0.226	0.19	0.324
Oropharyngeal	0.10	0.596	0.10	0.594	0.04	0.833	−0.01	0.958
Hypopharyngeal	0.55	0.002*	0.44	0.014*	-0.57	0.001*	−0.43	0.017*
Total pharyngeal	0.39	0.033*	0.48	0.007*	-0.20	0.294	−0.25	0.180
Hyoid bone	0.44	0.015*	0.01	0.942	0.63	0.000*	0.57	0.001*

"r" is coefficient of correlation.
* $p < 0.05$.

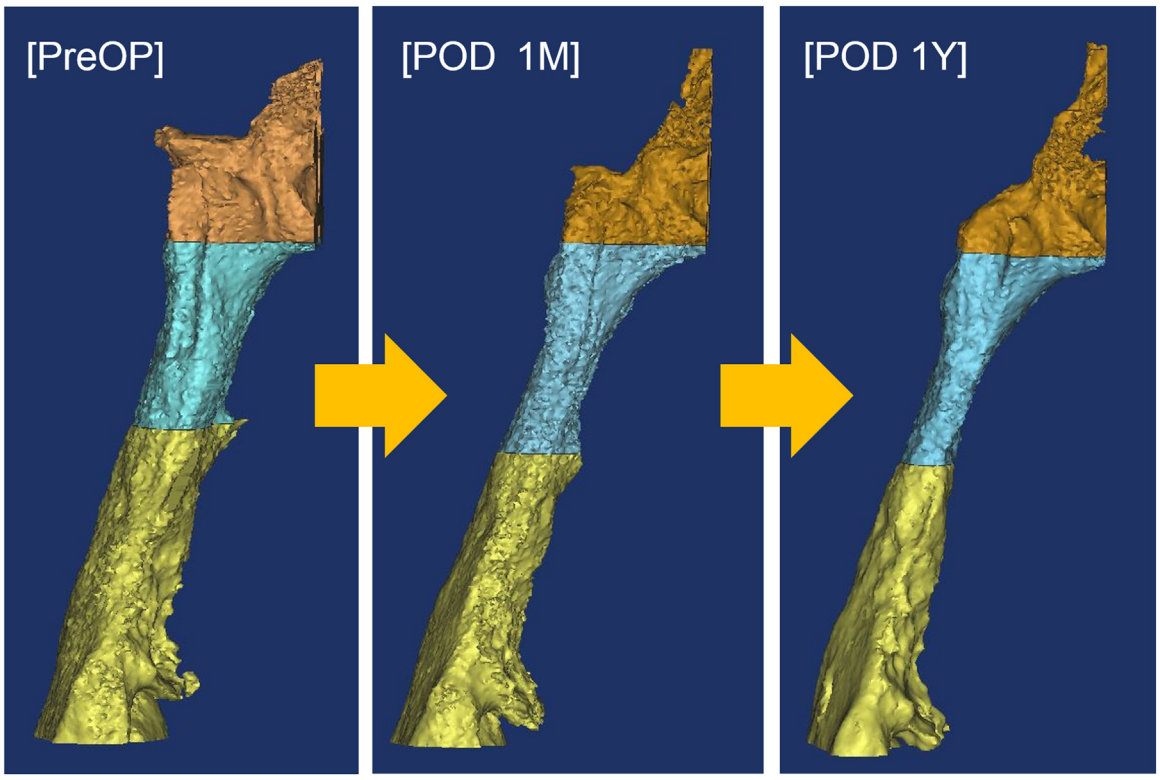

Fig. 4. Three-dimensional reconstruction of changes in volume of the pharyngeal airway.

after mandibular setback has a moderate correlation with the relapse pattern of the mandible.

The pharyngeal airway space often decreases immediately after mandibular setback, whether by IVRO or by SSRO. We found that it had significantly decreased by one month postoperatively, and that remained at one year. However, there was only a slight increase in the volume of the nasopharyngeal airway at one year. Park et al reported a significant change in the posterior maxilla after Le Fort 1 osteotomy,[25] but we found that the nasopharyngeal airway was enlarged and the oropharyngeal airway reduced when measured a year after the operation. This phenomenon is thought to be caused by inferior movement of the posterior maxilla postoperatively.

There was no significant relation between positional changes of the hyoid bone and changes in the volume of the pharyngeal airway space after IVRO, which is in contrast to the results of a previous two-dimensional study by Hwang et al who did not take into account the 3-dimensional structure of the airway and found a correlation between changes in the hyoid bone and airway in patients after IVRO.[9] Analysis of 3-dimensional reconstructed models allows more precise anatomical assessment of postoperative changes in the pharyngeal airway, so 3-dimensional CT is desirable in patients with airway problems having orthognathic surgery.

We did find changes in the pharyngeal airway after mandibular setback by IVRO, and confirmed that the decrease in the airway during the first month postoperatively was maintained at one year. A year after mandibular setback with IVRO, there was no anterior change in the position of the hyoid bone and no increase in the airway volume. Maxillofacial surgeons should therefore consider the reduction in the airway when planning excessive mandibular setback. Follow-up cone-beam CT was done for only one year postoperatively. We do not know whether or not there are long-term changes in the volume of the airway that would affect sleep patterns, so a study investigating the longer-term outcomes of mandibular setback with IVRO is needed.

Conflict of interest

We have no conflict of interest.

Ethics statement/confirmation of patient permission

This study was approved by the institutional review board of Yonsei University Dental Hospital (approval number 2-2016-0037). Patients' permission not required.

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