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Correlation study of increase of pharyngeal airway space after mandibular advancement, taking natural head position into consideration

Xiaozhen Lin *

Department of Oral and Maxillofacial Surgery, University of Michigan Hospital, 1500 E. Medical Center Dr., Ann Arbor, MI, 48109-0012, USA

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Abstract

The increase in the pharyngeal airway space after mandibular advancement has not been well explained, and in this study we aimed to show whether there is a correlation in the increase of pharyngeal airway space as a consequence of the mandibular advancement or of the relative change between the mandibular position and the natural head position (NHP). Fifteen patients who had bilateral sagittal split osteotomy for mandibular advancement with or without genioplasty were studied retrospectively. The primary variables of mandibular position, NHP, and pharyngeal airway space were measured in three dimensions using preoperative and postoperative cone-beam computed tomographic datasets and were compared using the paired *t* test. The secondary variable of pharyngeal airway space was defined as the square root of the mean cross-sectional area ($CSA^{1/2}$) of the pharyngeal airway space. Pearson's correlation coefficient was used to find out whether there was a correlation between the change in $CSA^{1/2}$ and the change in mandibular position, or the relative change between the mandibular position and the NHP. Volumes and minimal cross-sectional areas were increased in the pharyngeal airway space, and lengths of airways decreased. Correlation existed only between the increase in $CSA^{1/2}$ and the relative change between the mandibular position and NHP. The increase in pharyngeal airway space after mandibular advancement correlated with the relative changes between the mandibular position and the NHP.

Keywords: pharyngeal airway space; natural head position; mandibular advancement; three-dimensional; bilateral sagittal split osteotomy

Introduction

Mandibular advancement surgery has been shown to increase the pharyngeal airway space, offering a potential therapeutic benefit to many patients with skeletal Class II dysgnathia.[1] It has long been assumed that the changes measured are purely the result of the advancement of the mandible and its traction on the oral and pharyngeal soft tissues. The sources of these measured changes have not been investigated.

The natural head position (NHP), which describes the position of the cervical spine in relation to the cranial base when a person stands upright, balancing to his or her best ability, and is reliable over a lifetime.[2,3] However, our previous studies have shown that, following mandibular advancement, the NHP changes by decreasing the craniocervical inclination.[4,5] In other words, after the mandible has been advanced patients tend to tip their heads down, which effectively closes the angle between the head and cervical spine (Fig. 1). Because the cervical spine is essentially the posterior pharyngeal airway, this may be a source of change in the recorded shape and dimensions of the airway, and may be a factor in the characterisation of those changes in a single patient between two time points. A question is there-

* Corresponding author at: Department of Stomatology, Hainan Hospital of Chinese People's Liberation Army General Hospital, 80 Jianglin Rd., Sanya, Hainan Province, 572013, People's Republic of China.
E-mail address: dentlin@hotmail.com

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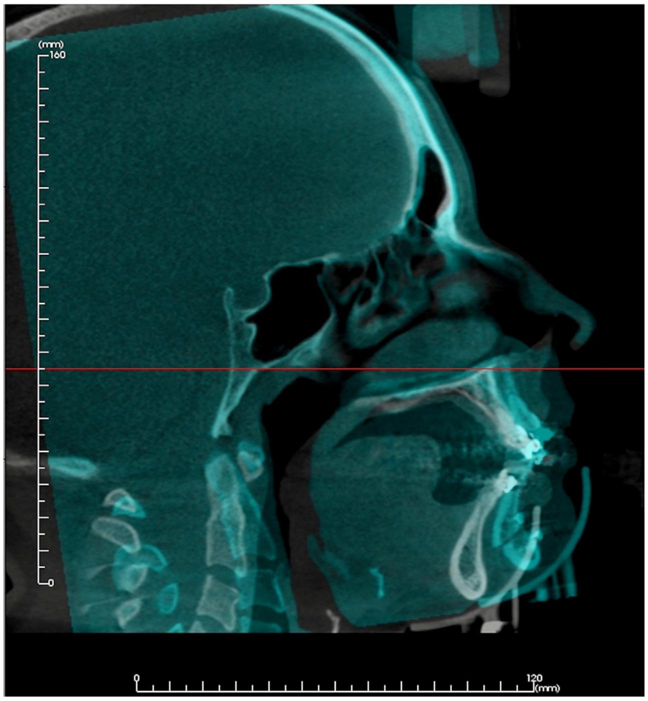

Fig. 1. Changes in natural head position in response to mandibular advancement. Compared with the preoperative image (grey), the postoperative (green) cervical vertebrae rotated forwards in response to mandibular advancement.

fore raised: does the increase of pharyngeal airway space result only from mandibular advancement or from the relative change between the mandibular position and the NHP?

To answer this question, we have designed a retrospective study to find out whether there is a stronger correlation between the increase in pharyngeal airway space and mandibular advancement or in the relative change between the mandibular position and the NHP.

Patients and methods

Fifteen patients - 5 men and 10 women, mean (SD) age 25 (13) years - who had been treated by bilateral sagittal split osteotomy for mandibular advancement with or without genioplasty between November 2010 and May 2012 in the Department of Oral and Maxillofacial Surgery at the University of Michigan Hospital, were entered into the study. They met the following criteria: they had non-syndromic skeletal malocclusion; were free of any pain or dysfunction in the head and neck region; had normal balancing ability; were not taking muscle relaxants; had no symptoms of obstructive sleep apnoea; had had both preoperative and postoperative cone-beam computed tomographic (CT) scans; and all the scans had reached the level of the hyoid bone. All the procedures were completed by the same senior surgeon, and mandibular advancement was more than 2 mm in all cases. The study was approved by the institutional review board of the University of Michigan Hospital (HUM00050381).

Cone-beam CT scans of each patient standing with the head in its natural position were taken before, and six weeks after, operation with the mandibles occluding at the centric relation. Before scanning, the patients were asked to stand upright balanced as well as they could with their eyes looking horizontally at the mirror image in the cone-beam CT machine. Once the NHP had been confirmed, the head was fixed with a head support and chin rest to secure the position. They were required not to move or swallow during the scan, and all the NHP were checked by the same radiological technician.

For mandibular position and NHP measurements, the cone-beam CT datasets were imported to InVivoDental 5.0 (Anatomage Inc.) for three-dimensional measurements (Fig. 2). A three-dimensional coordinate system was established based on the four coordinate system points (N, OrR_, Po_L, and Po_R) by picking these points on volume, and the rest of the landmarks were recorded in the same manner. The NHP was measured using the cranial-cervical angle (SNC2) and the horizontal distances from the second vertebra to the frontal plane (CIP-FP and CSP-FP). The mandibular position was measured using the craniomandibular angle (SNL) and the horizontal distance from the mandible to the frontal plane (L-FP). SNL measures to the lingual portion of the mandibular alveolus and obviates errors of measurement that would be encountered in patients who had a genioplasty if SNB were used instead. Measurements were recorded on volume and then projected on to the mid-sagittal plane for comparison. For the relative change between mandibular position and NHP, variables were calculated using the variables of mandibular position and subtracting the corresponding variables of NHP - for example, the relative angle between mandibular position and NHP was calculated as SNL minus SNC2.

Cone-beam CT datasets were imported to Dolphin Imaging 11.0 (Dolphin Imaging and Management Solutions) for assessment of the pharyngeal airway (Fig. 3). The zone of interest for analysis was set from the level of the posterior nasal spine point down to the most superior point of the hyoid bone – that is, the oropharynx. Primary variables including volume, minimal cross-sectional area, and length of airway were measured. A secondary variable was defined as the square root of the volume divided by its length, which indicates the linear dimension of the mean cross-sectional area of airway ($CSA^{1/2}$).

Statistical analysis

All the measurements were repeated three times every other week by the same investigator, and the mean values were used to decrease errors of measurement. The preoperative and postoperative variables were tabulated and then tested using the D'Agostino-Pearson omnibus normality test before they were tested using parametric statistical methods. The paired *t* test was used to assess the significance of differences in the postoperative changes of mandibular position, NHP, and

Table 1
Paired *t* test of preoperative and postoperative three-dimensional measurements of mandibular position, natural head position, and pharyngeal airway space (N = 15).

	SNL	L-FP	SNC2	CIP-FP	CSP-FP	Volume	Length	CSA_{min}
Preoperative	68.97	22.59	74.00	100.2	96.79	21159	64.28	207.6
	(3.00)	(6.23)	(10.12)	(8.07)	(4.46)	(7933)	(7.78)	(97.55)
Postoperative	72.05	15.97	81.04	95.65	96.90	24437	62.07	272.1
	(2.26)	(5.82)	(8.58)	(7.05)	(4.04)	(8757)	(62.07)	(124.8)
p value	<0.0001	<0.0001	0.0006	0.0004	0.043	0.0296	0.0233	0.0139

* All the columns passed the test for normality. The significance level of the paired *t* test (two-tail) was set at 0.05.

Fig. 2. Three-dimensional measurements of the mandibular position (SNL and L-FP) and natural head position (SNC2, CIP-FP and CSP-FP). N = the midpoint of the frontonasal suture; Or_R = the most inferior point of the right orbital rim; Po_L = the most superior point of the left external auditory meatus; Po_R = the most superior point of the right external auditory meatus; S = the midpoint of sella; L = the most lingual point of the mandibular symphysis; CSP = the most superoposterior point of the second cervical vertebral body; CIP = the most inferoposterior point of the second cervical vertebral body; SN = the line passing the points of S and N; C2=the line passing the points of CIP and CSP; FH = the Frankfurt horizontal plane, passing Po_L, Po_R and Or_R; MSP = the mid-sagittal plane passing N and perpendicular to the line passing bilateral porions; FP = the frontal plane, passing N and perpendicular to FH and MSP; SNL = the angle formed by points S, N and L, projected on to the MSP.
L-FP = distance from points CIP to FP, projected on to the MSP; SNC2=the angle formed by line SN and C2, projected on to the MSP; CIP-FP = distance from point CIP to FP, projected onto MSP; and CSP-FP = distance from point CSP to FP, projected on to FP.

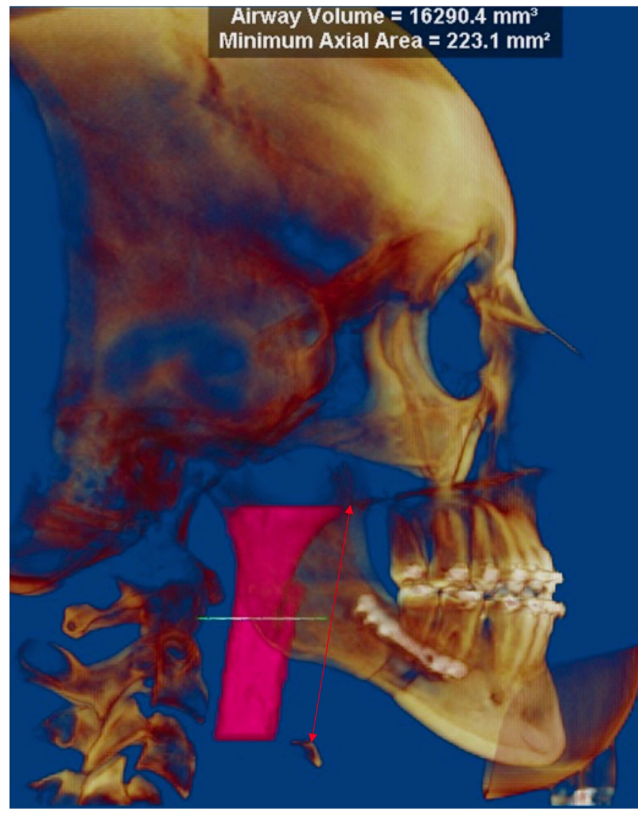

Fig. 3. The volume and minimal cross-sectional area were automatically calculated; airway length was as indicated on the mid-sagittal slice from the posterior nasal spinal point down to the most superior point of the hyoid bone (red-arrowed line).
EES 687 (18) Tables

pharyngeal airway space compared with their corresponding preoperative ones. Pearson's correlation coefficient was used to investigate whether there were significant differences in the change in the $CSA^{1/2}$, the change in the mandibular position, and the relative change between the mandibular position and the NHP. The statistical calculations were processed using Prism 6 (GraphPad Software Inc.).

Results

The paired *t* test showed that the NHP had changed after mandibular advancement, while the pharyngeal airway space, the volume, and the minimal CSA increased and the airway

Table 2
Correlation in the change $CSA^{1/2}$ compared with the change of mandibular position and the relative changes between the mandibular position and natural head position.

	△SNL	△L-FP	△LNC2	△L-CIP	△L-CSP
r	0.2978	0.5256	−0.4367	0.6487	0.6331
p value	0.2810	0.0592	0.0442	0.0089	0.0113

LNC2 = SNL - SNC2, L-CIP = (CIP-FP) - (L-FP), L-CSP = (CSP-FP) - (L-FP), r = correlation coefficient. The significance level of the Pearson correlation test (two-tailed) was set at 0.05.

length decreased (Table 1). Pearson's correlation coefficient showed significant changes only between the $CSA^{1/2}$ and the relative change between the mandibular position and the NHP (Table 2).

Discussion

After mandibular advancement, the pharyngeal airway space changed by increasing the volume and the minimal cross-sectional area, and shortening the length of the airway. However, these morphological changes correlated significantly only with those variables that indicated the relative changes between the NHP and the mandibular position. This may suggest that the morphological change in the pharyngeal airway results from the inter-relational change between the mandibular position and the NHP, rather than mandibular advancement being the only factor.

This may suggest that if a further correlation study that focuses on the association between the pharyngeal airway and orthognathic surgery is to be done, the NHP should be taken into consideration. This has not been an important issue in conventional 2-dimensional cephalometric analysis because the pharyngeal airway is basically measured as the posteroanterior linear distance using the cervical vertebrae as a reference, which automatically counts in the change of NHP. In 3-dimensional measurement, however, distances are measured independently in the world coordinate system, and if the potential bearing of the NHP on the pharyngeal airway were to be neglected, contradictory conclusions would be likely to be drawn.[6–8]

Another important aspect of this study may be that it provides a hypothetical explanation of why an advancement of the mandible has a potential therapeutic effect on respiratory function. According to Poiseuille's law, the airflow resistance is proportional to the length of the airway and inversely proportional to the fourth power of the radius of the airway.[9] If the pharyngeal airway could be considered as a cylinder, such morphological changes - from long, narrow, and leaning forwards to shorter, wider, and straighter - would decrease the airflow resistance. However, its true effect on respiratory function should be evaluated using pulmonary function tests such as spirometry, and it would be interesting to investigate such a correlation in the future.

One limitation of this study was the small sample size. These patients were drawn from a larger sample that included bimaxillary cases from a single surgeon's academic cases. These cases are an important part of the overall sample, as they would be in any contemporary orthognathic surgical practice. We chose to omit them in an effort to make the sample more homogeneous. On the one hand, the displacement of the maxilla is much smaller compared with that of the mandible, and not as dominant in the anteroposterior direction. On the other hand, however, reliable volumetric measurement of the maxillary sinus and nasal cavity is difficult, because the region of interest is difficult to define and the respiratory mucosa are vulnerable to oedema – particularly postoperatively.

Solow and Sandham have proved that facial development, NHP, and airway are inter-linked through neuromuscular feedback.[10] We agreed with their findings as we showed that, in patients with mandibular hypoplasia, such an interlinkage also exists dynamically if one part is operated on. This may expand our understanding about the remodelling effect of orthognathic surgery from the maxillofacial region to the cervical region, as well as the geometry of the airway between them. Future work will be focused on patients with skeletal Class II and III disease, and those who have had bimaxillary orthognathic surgery, to judge whether the impact of NHP on changes in pharyngeal dimensions are consistent across the range of orthognathic surgical patients.

Conflict of interest

We have no conflicts of interest.

Ethics statement/confirmation of patients' permission

The study was approved by the institutional review board of the University of Michigan Hospital (HUM00050381). The patients' permission was obtained.

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