Cephalometric analysis of the pharyngeal airway space after maxillary advancement surgery

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Abstract: This study evaluated the effect of maxillary advancement surgery on the size of the pharyngeal airway space (PAS). Lateral cephalometric radiographs were collected for 90 patients (29 men and 61 women; average age, 27.2 ± 8.1 years) before (T1) and 1 year after (T2) maxillary advancement surgery. Horizontal and vertical changes in the maxilla and PAS were measured and classified by distance. The maxilla was advanced horizontally by 2.9 ± 1.7 mm and vertically by 2.7 ± 1.4 mm. Upward maxillary movement of ≥4 mm significantly increased PAS (mean change horizontally by 2.9 ± 1.7 mm and vertically by 2.7 ± 1.4 mm). Upward movement is believed to have a large effect on PAS, it is suggested that upward vertical movement is more effective for improving PAS. Both the extent and direction of maxillary movement should be considered. Future studies should use cone-beam computed tomography to evaluate the effect of axial direction and differences in PAS.

Materials and Methods

This study retrospectively reviewed data from 90 patients who had undergone maxillary advancement with forward or backward mandibular movement surgery to correct malocclusion at the Department of Oral and Maxillofacial Surgery at Nihon University School of Dentistry during the 2-year period from May 2012 to June 2014. All study participants provided written informed consent. The study was approved by the Ethical Review Board Committee of Nihon University School of Dentistry (Tokyo, Japan; approval no. 2012-12), and the research was conducted in accordance with the Declaration of Helsinki.

Le Fort I osteotomy was performed for the maxilla, and sagittal split ramus osteotomy was performed for the mandible. The angulation of the osteotomy was designed in accordance with patients’ esthetic requirements. T1 (before surgery) and T2 (1 year after surgery) lateral cephalometric radiographs of all patients were acquired. All patients were positioned by using a cephalostat, with the median sagittal plane perpendicular to the ground, the Frankfort horizontal plane parallel to the ground, teeth in occlusion, and lips at rest. Patients were allowed to exhale.

All cephalometric radiographs were traced and analyzed by the same examiner. The following orthodontic and skeletal landmarks were identified (Fig. 1): sella (S), nasion (N), posterior nasal spine (PNS), A-point (A), B-point (B), gonion (Go), and maxillary molar mesiobuccal cusp tip (Mx MBT). To guarantee standardization of the assessed images, the SN plane (the line connecting the sella and nasion) was used. Cephalometric analysis has been used to evaluate the position of facial bone structures and soft tissues and to measure PAS. PAS has been measured with several methods: at the narrowest dimension in the hypopharynx; as the distance between the base of the tongue and posterior pharyngeal wall, derived from a line connecting the B-point to Go in millimeters; and at the levels of the nasopharynx, oropharynx, and hypopharynx. In this study, cephalography was performed according to Esaki’s method [9], in which the Frankfort horizontal plane was regarded as the standard horizontal plane for head position and for determination of the following PAS parameters: the superior posterior airway space (SPAS), middle airway space (MAS), and inferior airway space (IAS). The anteroposterior dimensions of the PAS were measured at three points at the oropharynx level. The following PAS parameters were measured at three levels: SPAS was measured as the distance between the posterior pharyngeal wall and the median point of the line of the PNS and P-point (the lowest point of the soft palate); MAS was measured as the distance between the posterior pharyngeal wall and the P-point; and IAS was measured as the distance from the base of the tongue to the posterior pharyngeal wall and was derived from a line connecting the B-point to Go. The soft palate was traced, and the length was measured between the PNS and the P-point (PNS-P). The thickness of the soft palate (MPT) was also measured.

To measure maxillary movement, the midpoint between the Cusps of the upper first molar was used. Horizontal and vertical changes in the maxilla and the PAS (SPAS, MAS, IAS) were measured and classified by distance as 0, 1, 2, 3, 4, 5, or ≥6 mm. Statistical analyses were performed with the Statistical Package for the Social Sciences for Windows software version 24.0 (IBM Corp., Armonk, NY, USA). Statistical significance was defined as a P value <0.05. The t-test was used to compare average cephal-
lometric measurements between the T1 and T2 examinations.

Results

Table 1 shows the characteristics of the 90 participants. There were 29 men and 61 women (ratio 1:2.1), and average age was 27.2 ± 8.1 years. Average body mass index was 20.7 ± 2.5 kg/m². The maxilla was advanced horizontally by 2.9 ± 1.7 mm and vertically by 2.7 ± 1.4 mm.

Figure 2 shows changes in the study parameters with each millimeter of horizontal maxillary advancement. The difference in SPAS was 2.3 mm with 0 mm of horizontal advancement (n = 8), 4.8 mm with 1 mm of advancement (n = 2), 3.2 mm with 2 mm of horizontal advancement (n = 30), 2.2 mm with 3 mm of horizontal advancement (n = 25), 2.6 mm with 4 mm of horizontal advancement (n = 6), 2.4 mm with 5 mm of horizontal advancement (n = 14), and 1.2 mm with ≥6 mm of horizontal advancement (n = 5). The mean difference in SPAS for the entire patient population was 2.6 mm. Horizontal advancement of the maxilla by 2, 3, and 5 mm resulted in statistically significant increases in SPAS. In addition, SPAS significantly increased without horizontal advancement. In contrast, there was a significant difference in MAS only after 2 mm of advancement, and IAS, PNS-P, and MPT did not significantly differ after horizontal advancement. Therefore, factors other than horizontal advancement might have influenced changes in these parameters. Changes in these parameters after vertical upward movement of the maxilla were thus investigated (Fig. 3).

Table 1 Patient characteristics (n = 90)

| Characteristic                                      | No. of patients (%) | Mean ± S.D. (Range) |
|-----------------------------------------------------|---------------------|---------------------|
| Sex                                                 |                     |                     |
| Male                                                | 29 (32)             |                     |
| Female                                              | 61 (68)             |                     |
| Operative characteristics                           |                     |                     |
| MMA                                                 | 35 (39)             |                     |
| Maxillary advancement + mandibular setback          | 55 (61)             |                     |
| Maxillary horizontal advancement                     | 3.0 ± 1.7 mm (0 - 8 mm) |                     |
| Maxillary vertical advancement                      | 2.7 ± 1.4 mm (0 - 6 mm) |                     |
| Skeletal class                                       |                     |                     |
| I                                                    | 9 (10)              |                     |
| II                                                   | 24 (27)             |                     |
| III                                                  | 57 (63)             |                     |

MMA, maxillomandibular advancement; S.D., standard deviation

Fig. 1 Cephalometric landmarks and measurements. B, most concave point on the mandibular symphysis; N, most anterior point on the frontonasal suture; S, midpoint of the fossa hypophysialis; Go, midplane point at the gonial, located by bisecting the posterior borderline of the mandible; ①SPAS, superior posterior airway space; ②MAS, middle airway space; ③IAS, inferior airway space; ④PNS-P, posterior nasal spin and P-point; ⑤MPT, thickness of soft palate

Fig. 2 Changes in parameters in relation to maxillary advancement, before (T1) and 1 year after (T2) maxillomandibular or maxillary advancement surgery. *P < 0.05, t-test. Data are expressed as mean ± standard deviation. SPAS, superior posterior airway space; MAS, middle airway space; IAS, inferior airway space; PNS-P, posterior nasal spin and P-point; MPT, thickness of soft palate

Fig. 3 Changes in parameters after vertical upward movement of the maxilla (data not shown). Mean difference in SPAS for the entire patient population was 2.6 mm. Horizontal advancement of the maxilla by 2, 3, and 5 mm resulted in statistically significant increases in SPAS. In addition, SPAS significantly increased without horizontal advancement. In contrast, there was a significant difference in MAS only after 2 mm of advancement, and IAS, PNS-P, and MPT did not significantly differ after horizontal advancement. Therefore, factors other than horizontal advancement might have influenced changes in these parameters. Changes in these parameters after vertical upward movement of the maxilla were thus investigated (Fig. 3). After analysis of vertical maxillary advancement per millimeter (data not shown), a ≥4-mm upward movement of the maxilla significantly increased SPAS, MAS, and IAS, as compared with movement of <4 mm. In addition, upward movement of ≥4 mm resulted in a significant decrease in PNS-P.

Next, changes in these parameters after vertical upward movement of ≥4 mm and <4 mm were analyzed in relation to horizontal advancement (Figs. 4, 5). Only patients with ≥4 mm of vertical movement and 3 mm of horizontal advancement had significant increases in SPAS, MAS, and IAS. The mean SPAS of patients with ≥4 mm of vertical movement was 12.7 ± 0.83 mm at T1 and 16.4 ± 0.61 mm at T2. The mean SPAS of patients with
<4 mm of vertical movement was 14.7 ± 0.42 mm at T1 and 16.9 ± 0.44 mm at T2. The mean difference was 3.7 mm in patients with ≥4 mm of movement and 2.2 mm in patients with <4 mm of movement. The PNS-P was significantly decreased in patients with ≥4 mm of movement.

Vertical movement of <4 mm was not associated, at any extent of horizontal advancement, with a significant difference in any measured parameter, except for SPAS in patients with 2 mm of vertical advancement (Fig. 5).

The effect of mandibular movement on improving PAS in patients with ≥4 mm of vertical movement and 3 mm of horizontal advancement was analyzed (Fig. 6). This group included five cases of mandibular advancement and five cases of mandibular setback. The mean difference in SPAS was 4.84 mm in the mandibular advancement group and 5.16 mm in the setback group. The mean difference in MAS was 5.02 mm in the mandibular advancement group and 2.02 mm in the setback group. As expected, SPAS, MAS, and IAS greatly improved after mandibular advancement (Fig. 6A). Furthermore, PAS improved after mandibular setback in all groups (Fig. 6B).

Discussion

The maxilla was advanced horizontally by 2.9 ± 1.7 mm and vertically by 2.7 ± 1.4 mm. SPAS increased by an average of 2.6 mm. Ubaldo et al. [10] reported a mean advancement of 5.2 mm in the maxilla and 8.3 mm in the mandible and a 4-mm increase in the posterior airway in patients with OSA treated by MMA. Current indications indicate that an advancement of 10 mm in both the maxilla and mandible is adequate [11]. Faria et al. [12]...
reported that mean change in PAS was 6-10 mm. Ronchi et al. [3] reported successful treatment of OSA with MMA surgery (mean change in PAS, 4.4 mm). Despite the much smaller maxillary advancement in the present study, and the fact that the procedures included both mandibular advancement and mandibular setback, nevertheless there was noted improvement in PAS.

Maxillary advancement affects muscles of the soft palate, and the PAS is expanded by each of these muscles. All extents of upward maxillary movement, especially ≥4 mm upward movement, significantly changed PAS parameters. This vertical maxillary movement increased oropharynx volume. In addition, vertical movement of ≥4 mm resulted in a thicker, shorter uvula. Upward maxillary movement affects the uvula and palatoglossus muscles, which can increase the size of the velopharynx. The present patients with <4 mm of vertical movement showed changes in the velopharynx but not in the oropharynx, which suggests that improvement of the oropharynx requires adequate oral cavity volume. The velopharynx significantly improved after horizontal maxillary advancement. This effect is attributable to the pulling of the uvula levator and uvula sagittal muscles. Although forward maxillary movement is believed to have a large effect on PAS, upward vertical movement of the maxilla was more effective for PAS improvement in this study. Furthermore, ≥4 mm of vertical movement combined with 3 mm of horizontal advancement resulted in the greatest improvement in PAS and is thus effective. In addition, PAS improved in patients with ≥4 mm of vertical movement and 3 mm of horizontal maxillary advancement, regardless of mandibular movement.

Cephalography, computed tomography (CT), and magnetic resonance imaging (MRI) have been used to study the morphologic characteristics of persons with OSA [13-15]. Previous studies reported that CT and MRI may be more effective for understanding two-dimensional images. However, conventional lateral cephalography was reported to be easy to interpret when assessing the nasopharyngeal airway and was the most cost effective method [16]. Lateral cephalography remains the radiographic standard for airway assessment. Previous studies consistently reported that persons with OSA tend to be obese and to have an excessively long soft palate, a very large tongue, micrognathia, and marked narrowing of the upper airway. Esaki [9] reported that micrognathia is a morphologic characteristic of Japanese patients with OSA. The prevalence of obesity in Japanese patients with OSA is low [17,18], and obesity is not as frequent in Japanese as in other populations. They suggested that micrognathia and obesity-related enlargement of the tongue and soft palate might be involved in narrowing of the airway in persons with OSA. A systematic review [19] of cephalometric data highlighted the role of soft-tissue abnormalities in patients with OSA: skeletal-only halfway, mandibular plane to hyoidal (MP-H), and SPAS were the most reliable parameters for evaluation. Reduced SPAS width might be a prognostic variable for patients with suspected OSA. In that systematic review, SPAS was reduced by 4.53 mm. In the present study of SPAS, maxillary advancement distance had an effect on PAS regardless of mandibular movement. These results could be useful for reducing OSA risk in patients with unsatisfactory facial esthetics and malocclusion. In addition, the authors suggested that, for diagnosis of OSA, lateral radiographs should be taken in the natural head position. In addition, head position should be considered when collecting lateral radiographs before and after MMA surgery for OSA. Although cephalographic measurement is limited to a lateral viewing angle, it is effective for analysis of facial morphology and OSA diagnosis and as a basis for guiding therapy [20].

In conclusion, the extent and direction of maxillary advancement should be considered. Additionally, cone-beam CT was reported to be a practical technique for quantitative assessment in evaluating three-dimensional morphologic changes of the pharyngeal airway [19,21]. Future studies should use cephalography and cone-beam CT to compare the effect of axial direction and differences in PAS.

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Conflict of interest
The authors have no conflict of interest to declare.

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