Effect of Mono- and Bimaxillary Advancement on Pharyngeal Airway Volume: Cone-Beam Computed Tomography Evaluation

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Purpose: To evaluate pharyngeal airway volume changes after forward movements of the maxilla or mandible, or both, using cone-beam computed tomography.

Patients and Methods: A retrospective evaluation of 30 patients who underwent maxillomandibular advancement, maxillary advancement, or mandibular advancement was performed. Three groups of 10 subjects each were established: group 1, bimaxillary surgery (Le Fort I maxillary osteotomy and mandibular bilateral sagittal split osteotomy with maxillomandibular advancement); group 2, maxillary advancement (Le Fort I maxillary osteotomy); and group 3, mandibular advancement (bilateral sagittal split osteotomy). Pre- and postoperative cone-beam computed tomography scans were taken in each case, and the changes in pharyngeal airway volume were compared.

Results: A statistically significant increase in the pharyngeal airway volume occurred systematically. The average percentage of increase was 69.8% in group 1 and 78.3% in group 3. Group 2 exhibited a lower magnitude of increase (37.7%).

Conclusion: Cone-beam computed tomography provides a new method for airway evaluation using a noninvasive, rapid, low-radiation, cost-effective scan. It seems the influence of mandibular advancement on the pharyngeal airway volume is greater than the effect of the forward movement of the maxilla.

J Oral Maxillofac Surg xx:xxx, 2011

Orthognathic surgery aims to restore proper dental occlusion and facial harmony through the modification of the position, shape, and size of the facial bones. Bone movement implies secondary positional and tensional changes in the attached soft tissues. These new soft tissue relationships introduce significant changes in the facial appearance and, in addition, in the pharyngeal airway space (PAS) dimensions, especially when a significant anteroposterior component is present.[1]

The tongue, soft palate, hyoid bone, and related musculature are directly or indirectly attached to the maxilla and mandible; therefore, the dimensions of the oral cavity and pharyngeal airway will change depending on the direction and magnitude of the skeletal movements.[1-3] Several investigators have reported the induction of sleep-related breathing disorders after isolated mandibular setback procedures.[4-7] Research has shown postoperative narrowing of the retrolingual and hypopharyngeal airway[1,4,5,7-10] and posteroinferior displacement of the hyoid bone and tongue.[10-12] This is an issue receiving increasing attention during the past 2 decades owing to the potentially serious adverse systemic consequences of obstructive sleep apnea (OSA).

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0278-2391/11/xx0x-0$36.00/0
doi:10.1016/j.joms.2011.02.138

In contrast, favorable improvement of OSA can be achieved with maxillomandibular advancement.[2,13-18] An increase in the PAS is achieved by the advancement of the skeletal attachment of the suprahyoid and velopharyngeal muscles and tendons.[13,16,17,19] Moreover, when a counterclockwise rotation of the maxillomandibular complex is performed in patients with high occlusal plane morphology, the genial tubercles move forward more than the teeth, thereby maximizing the advancement of the hyoid bone, base of the tongue, and related soft tissues.[15,20]

In the medical field, airway evaluation is possible using several techniques, including magnetic resonance imaging,[21] cine-magnetic resonance imaging,[22] computed tomography (CT),[23] endoscopy,[24] and optical coherence tomography.[25] However, the advent of cone-beam CT (CBCT) has provided the chance to evaluate the airway using a noninvasive, rapid, low-radiation scan. In their study to measure the human airway with CBCT, Tso et al[26] demonstrated this appliance achieves highly correlative linear, cross-sectional area and volumetric measurements in addition to morphometric analysis of the airway. They found the narrowest region in an awake subject, sitting upright and breathing quietly, is located chiefly in the oropharynx.[26] Although several investigators have studied pharyngeal airway and soft tissue changes after orthognathic surgery procedures using lateral cephalometry[4-9,11,12,27] and CT,[10,13,19,28] no previous studies have reported on CBCT evaluation. To our knowledge, this is the first study to assess the effects of orthognathic surgery, in particular mono- and bimaxillary advancement, on the PAS using CBCT.

Patients and Methods

A retrospective analysis of 30 patients who underwent orthognathic surgery during 2009 at the Institute of Maxillofacial Surgery and Implantology, Teknon Medical Center (Barcelona, Spain) was performed. The Helsinki Declaration guidelines were followed. As a retrospective analysis, the study was exempt from institutional review board approval. The patients were randomly selected from the Institute's database according to the orthognathic procedure performed. Three groups of 10 subjects each were established: group 1, bimaxillary surgery (Le Fort I maxillary osteotomy and mandibular bilateral sagittal split osteotomy with maxillomandibular advancement); group 2, maxillary advancement (Le Fort I maxillary osteotomy); and group 3, mandibular advancement (bilateral sagittal split osteotomy). Patients undergoing procedures involving changes in the transverse dimensions (ie, segmented Le Fort I osteotomy, surgically assisted rapid palatal expansion, mandibular midline expansion) or isolated or combined genioplasty, were excluded for evaluation with the aim of analyzing "pure" sagittal advancements without changes in hard palate inclination. All patients provided written informed consent. All procedures were performed by the same surgeon using rigid fixation and postoperative box elastics for 2 to 6 weeks. The patients received routine preoperative and postoperative orthodontic treatment.

Every patient underwent pre- and postoperative CBCT with the IS i-CAT, version 17-19 (Imaging Sciences International, Hatfield, PA). A 7-second scan was taken with the patient breathing quietly and sitting upright, with the clinical Frankfort horizontal plane parallel to the floor, the tongue in a relaxed position, and the mandible in centric relation with a wax bite in place. The radiologic parameters used were 120 kV and 5 mA. The axial slice distance for each scan was 0.300 mm^3. The facial mode with the 23-cm field of view was used. Primary images were stored as 576 Digital Imaging and Communications in Medicine data files.

Each CBCT scan was processed using the SimPlant Pro Crystal software (Materialise, Leuven, Belgium). Special attention was paid to the correspondence of the hard palate and cervical vertebrae between the pre- and postoperative scans to minimize the influence of the head and cervical posture on the airway evaluation. It was established that if this correspondence was not achieved despite having followed our head posture protocol, the patient would be excluded from evaluation.

To digitally excise the airway, a distinctive high-contrast border was defined using threshold segmentation. In the resulting set of masks (highlighted areas representing the region of interest within each slice), the areas occupied by air corresponded to a range of CT units below the ranges for the denser soft tissue and bone. The threshold limits were modified to an appropriate range that adequately captured all spaces filled by air within the volume of each particular CBCT scan. Therefore, other areas, in addition to the PAS, were defined, including the oral cavity, maxillary sinuses, nasal cavity, and trabecular matrix within dense bones. These undesired structures, together with any artifacts or background scatter, were eliminated manually from each slice by using the tools "Edit Mask in Single Slice" and "Edit Mask in Multiple Slices." Similarly, the air space above the palatine plane and below the plane tangent to the superior border of the body of the fourth cervical vertebra was eliminated from the evaluation (Fig 1).

The volume of the segmented region was calculated from the "Masks List Window." A 3-dimensional display of the excised area was attained. Thus, a pair of values (pre- and postoperative PAS volume) and the

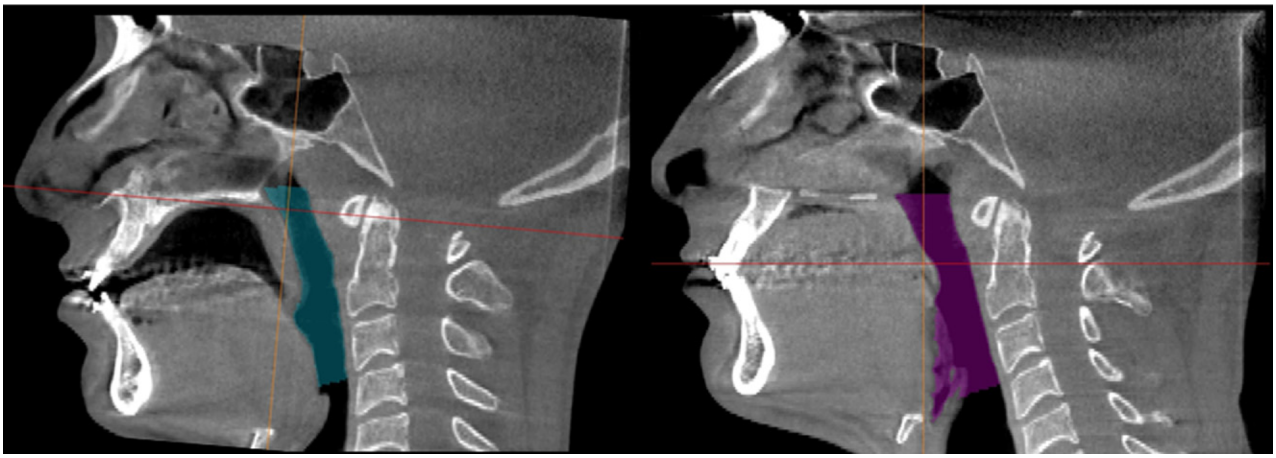

FIGURE 1. Digital excision of the pharyngeal airway space in patient 3 (bimaxillary surgery). Pre- (*left*) and postoperative (*right*) CBCT scans.

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corresponding pair of airway reconstructions was obtained for each patient (Fig 2).

Statistical analysis was performed using the Statistical Package for Social Sciences for Windows, version 15.0.1 (SPSS, Chicago, IL). Descriptive statistics were used for quantitative analysis. Each patient's percentage of variation in volume was calculated as follows: (postoperative volume × 100/preoperative volume) − 100. Student t test for paired samples was used to compare pre- and postoperative PAS volumes. The α level was set at 0.05.

Results

The studied sample included 22 women and 8 men (ratio 2.75:1), with a median age at surgery of 32 years. Preoperative scans were taken the day before surgery. The average period elapsed between the pre- and postoperative scans was 146.3 days for group 1, 132.9 days for group 2, and 121.4 days for group 3 (average for all 3 groups 133.5 days).

The pre- and postoperative volumetric measurements and percentage of variation in the airway volume in each group are presented in Figure 3 and Table 1. The average variation was positive in all 3 groups (ie, an average increase in airway volume occurred systematically). The average increase was 68.4% in group 1 and 78.3% in group 3. Group 2 exhibited a lower magnitude of increase (37.7%). For an α level of 0.05, these positive variations were statistically significant ($t_o = 8.07$, 29 degrees of freedom).

Discussion

To our knowledge, the present study is the first to evaluate the changes in the PAS after orthognathic surgery using CBCT technology. Cephalometric radiography has been commonly used to evaluate the postoperative pharyngeal airway and soft tissue changes.[4-9,11,12,27] This method was chosen because it is an essential imaging tool for orthodontic treatment

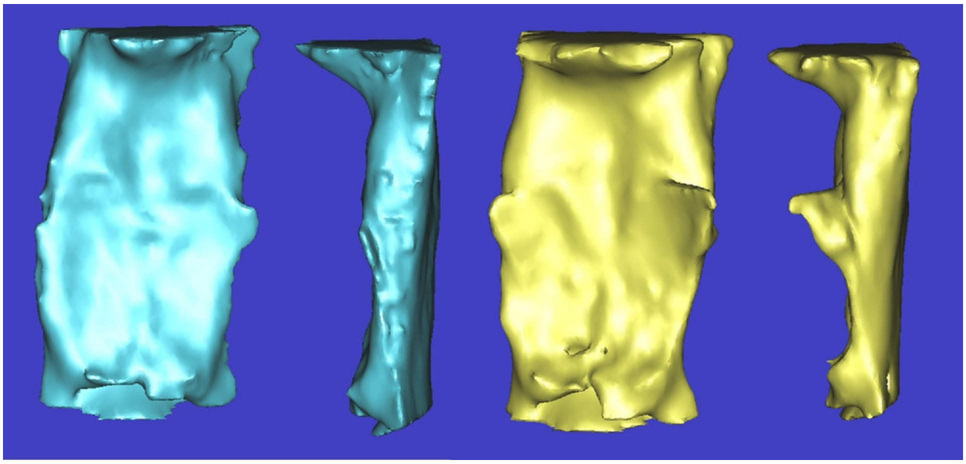

FIGURE 2. Three-dimensional pharyngeal airway space of patient 3 (bimaxillary surgery). Pre- (*left*) and postoperative (*right*) volumes.

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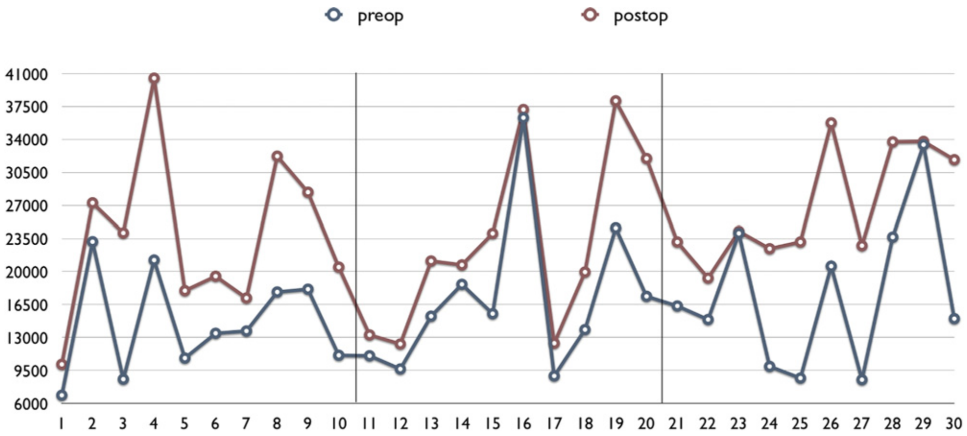

FIGURE 3. Pre- and postoperative volumetric measurements and percentage of variation in airway volume in the studied sample.

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planning and follow-up.[10] Although airway changes are only assessed 2-dimensionally, a significant correlation between the PAS measured on the cephalographs and the volume of the airway calculated from the CT studies was demonstrated.[2,29] Therefore, the results are still relevant. However, it is difficult to evaluate the airway 3-dimensionally using conventional cephalometric radiography, and the hard tissue structures often overlap.[10] In contrast, CT, especially with 3-dimensional reconstruction, permits excellent visualization of the pharyngeal airway without hard tissue superimposition and can create various types of images repeatedly.[10,13,18,19,28]

Table 1. PRE- AND POSTOPERATIVE MEASUREMENTS AND PERCENTAGE OF VARIATION IN AIRWAY VOLUME

Pt. No.	Preoperative Volume (mm^3)	Postoperative Volume (mm^3)	Percentage of Variation (%)
1	6,851.61	10,136.67	47.9
2	23,173.56	27,270.36	17.7
3	9,077.91	24,296.35	167.6
4	21,225.29	40,517.03	90.9
5	10,803.17	17,975.48	66.4
6	13,439.98	19,508.32	45.2
7	13,683.65	17,190.77	26.6
8	17,832.68	32,224.76	80.7
9	18,131.64	28,395.94	56.6
10	11,100.53	20,478.20	84.5
11	11,051.06	13,265.68	20.0
12	9,644.50	12,301.71	27.6
13	15,260.35	21,125.43	38.4
14	18,647.53	20,711.63	11.1
15	15,526.51	24,050.31	54.9
16	36,309.92	37,187.14	2.4
17	8,905.06	12,381.79	39.0
18	13,831.24	19,953.76	44.3
19	24,620.72	38,109.47	54.8
20	17,371.64	31,979.38	84.0
21	16,345.32	23,145.30	41.6
22	14,904.35	19,313.97	29.6
23	24,058.36	24,264.57	0.9
24	9,918.28	22,432.04	146.3
25	8,677.63	23,141.80	166.7
26	20,580.04	35,766.55	73.8
27	8,504.14	22,756.92	167.6
28	23,662.25	33,746.96	42.6
29	33,442.49	33,792.43	1.0
30	14,996.70	31,847.19	112.4

Abbreviation: Pt. No., patient number.

Group 1, bimaxillary advancement, patients 1-10; group 2, maxillary advancement, patients 11-20; group 3, mandibular advancement, patients 21-30.

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Recently, CBCT has proved to be a practical technique for the quantitative assessment of the PAS, with important advantages over other current scanning systems. It is a noninvasive, low-radiation, fast scanning (<60-second) technique that is more cost-effective than other systems such as spiral CT or magnetic resonance imaging.[26,30] The system is highly accurate in its measurements, the images are not distorted, and the relative range of the CT units for different tissues provides a method to rapidly segment the airway.[26]

However, CBCT does have some inherent deficiencies, in particular its static evaluation of the PAS. Airway imaging studies have shown that the airway dimensions change at different levels with breathing,[21,23] especially in the lateral dimension.[31] One weakness of our study was that the patient was scanned while breathing normally, suggesting that both inspiration and expiration contribute to the final calculated airway volume. It is essential that the patient does not swallow, cough, speak, or do any motor response other than breathe quietly during the scanning process.[26] Accordingly, in addition to standardizing a repeatable head posture protocol in our study, the patient was carefully instructed to breathe normally during the 7-second scan and to avoid any other motor reaction.

Muto et al[32] reported a strong correlation (r = 0.807) between the PAS and the head posture, defined as the craniocervical angulation at the uppermost part of the cervical spine. A change of 10° in craniocervical angulation produced a 4-mm change in the PAS.[32] Taking into account these findings, the head posture correspondence between each patient's pre- and postoperative CBCT scans was checked before airway volume measurement in our study. Using the SimPlant software, it was ensured that the hard palate plane and cervical vertebrae coincided at the superimposed sagittal midline in the pre- and postoperative scans. No significant discrepancy was found to exclude any subject from evaluation. A possible explanation to this is that particular care was taken to correctly position the patient for the scan (patient sitting upright, with the clinical Frankfort horizontal plane parallel to the floor, tongue in a relaxed position, and mandible in centric relation with the help of a wax bite).

Our results support other investigators' findings that maxillomandibular advancement can achieve an increase in the PAS.[13,16,17,19] A systematic increase in the PAS volume occurred in all cases. On average, bimaxillary and mandibular advancement achieved an increase in the airway volume of 69.8% and 78.3%, respectively. Maxillary advancement also increased the PAS volume but to a lesser extent (37.7%). These results suggest the influence of mandibular advancement on the PAS is greater than the effect of the forward movement of the maxilla. Thus, the advancement of the skeletal attachment of the suprahyoid muscles and tendons could play a major role in the widening of the PAS. An ongoing study will seek to determine whether any correlation exists between the magnitude of skeletal forward movement and the increase in PAS volume.

A possible limitation of the present study was that the hypothetical influence of substantial postoperative weight loss on the dimensions of the PAS was not evaluated. Although this possibility has not been confirmed, it should be considered for future investigation.

The relationship between OSA and a narrow PAS has been emphasized by numerous studies.[4-7] Patients with OSA have a retropositioned mandible and maxilla, short mandibular body length, and long anterior facial height compared with age- and gender-matched controls.[33,34] These craniofacial abnormalities can be minimized with maxillomandibular advancement, thereby improving OSA symptoms.[2,13-18] In the present study, patients 1, 3, 10, and 25 reported subjective significant improvement of OSA symptoms postoperatively. Moreover, patient 10 stopped requiring continuous positive airway pressure nocturnal support after a bimaxillary advancement procedure. Therefore, forward movements of the mandible and/or maxilla in the context of orthognathic surgery procedures can be aimed at correcting malocclusion, restoring facial harmony, and improving OSA symptoms because of PAS volume enlargement.

Acknowledgment

The authors thank Tomás Charles for his invaluable assistance in image processing and technical support.

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