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ORIGINAL ARTICLE

Changes in posterior airway space and hyoid bone position after surgical mandibular advancement

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ABSTRACT

Objective: To evaluate cephalometric changes in posterior airway space (PAS) and in hyoid bone distance to mandibular plane (MP) 1–3 years after bilateral sagittal split osteotomy (BSSO).

Material and methods: The sample consisted of 36 females and 16 males who underwent mandibular advancement by BSSO. To observe sagittal changes in PAS and in hyoid bone distance to MP both pre- and postoperative cephalograms were analyzed using WinCeph® 8.0 software. For the statistical analyses paired T-test and multivariate logistic regression models were used.

Results: By the surgical-orthognathic treatment the sagittal dimension of PAS showed variable changes but it mainly diminished when the mandibular advancement exceeded 6 mm. In most cases the hyoid bone moved superiorly by BSSO. Logistic regression models showed that males, patients with narrow PAS at the baseline, and those with counterclockwise rotation of the mandible by the treatment gained more increase in PAS. However, an increase in sagittal PAS dimension tended to relapse over time. Concerning the movement of the hyoid it was found that the more PAS increased the less hyoid moved superiorly. In males the change in hyoid position was more obvious than in females.

Conclusion: Males, patients with narrow PAS at the baseline, and those whose mandible moved in the counterclockwise direction with moderate advancement gained more retrolingual airway patency by BSSO.

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Introduction

Among Caucasians, 15% have distal occlusion and approximately in one third of them the occlusal inconvenience is caused by retrognathic/micrognathic mandible.[1] If still present in adulthood, surgical-orthodontic treatment by bilateral sagittal split osteotomy (BSSO) is required to advance the mandible. Both maxillary and mandibular retrognathia, distal occlusion, and sagittal discrepancy between the jaws predispose to low-volume pharyngeal airways compared to subjects with orthognathic jaws and those with mandibular prognathism.[2,3] In order to increase the posterior airway space (PAS) it would be desirable to protrude the mandible. Besides elongating mandible BSSO alters structures of oropharyngeal complex, i.e. PAS and hyoid bone (HB) position via infra- and suprahyoidal musculature. This muscle and tendon intermitted change causes so called tonic neck reflex, and leads to a more forward head posture.[4,5]

Several studies report significant improvement in hard tissue dimensions postoperatively, but skeletal relapse especially in long-term exists.[6] The facial soft tissue profile follows the changes of the underlying hard tissue in general, but some of the effects are unpredictable.[7–9] The studies concerning changes in pharyngeal structures after BSSO are contradictory. Despite the contradictory findings in adaptation, and incompletely understood adaptation mechanisms, it is commonly believed, that mandibular advancement changes configuration and patency of PAS.[10–12] Due to the postoperative muscular adaptation, the hyoid bone is mostly observed to move superiorly and anteriorly.[12–16] Although the superior-anterior judgment dominates, in some cases the hyoid bone has been shown to move to the opposite direction or return towards its original position over time.[5,13,16–18] Altogether, dimensional changes are considered to be clinically significant if they exceed 2mm measured from the lateral cephalograms.[9,19,20]

The aim of this study was to evaluate the long-term changes in posterior airway space and in hyoid bone distance to mandibular plane one to three years after mandibular advancement by BSSO. The hypothesis was that the advancement surgery increases sagittal PAS dimension and causes superior movement of the hyoid bone.

Material and methods

The sample consisted of 88 consecutive patients who underwent surgical-orthodontic treatment by BSSO with rigid

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Table 1. Primary diagnoses of malocclusions in 36 females and 16 males who underwent mandibular advancement by BSSO.

Primary diagnosis	Females (*n*)	Males (*n*)	Total (*n*)
Mandibular retrognathia	10	4	14
Mandibular mikrognathia	7	2	9
Maxillary prognathia	3	0	3
Deep bite (≥5mm)	11	8	19
Large horisontal overjet (≥5mm)	5	2	7

internal fixation technique with osteosynthesis mini plates (*n* = 43) or bicortical screws (*n* = 9) at Kuopio University Hospital during the years 2004–2011. The surgeries were performed by three experienced senior surgeons. From the baseline sample 36 cases were excluded either due to additional surgery (i.e. genioplasty), poor quality of lateral cephalograms (i.e. lack of reference calibration scale and 'out of field' artifacts) or unavailability of the cephalograms at the time of this retrospective study. The final sample consisted of 36 females and 16 males, mean age of 37 years (SD 10.8). Primary clinical diagnoses of malocclusions are given in Table 1.

Lateral cephalograms were taken at the baseline and after the retention period, 1–3 years postoperatively. The cephalograms were analyzed by Winceph® 8.0 software in order to evaluate the sagittal PAS dimension and the hyoid bone distance to the mandibular plane. Posterior airway space was measured as the shortest distance between the tongue and the dorsal pharyngeal wall at the level of point B, and the hyoid bone vertical position was determined using a perpendicular distance from upper-front part of the hyoid bone to mandibular plane (Hb-MP). Skeletal landmarks S (sella), N (nasion), A (point A), B (point B) and the angles SNB (mandibular sagittal position to the anterior cranial base) and SN-MP (divergence of mandibular plane to the anterior cranial base) were traced and analyzed to indicate the hard-tissue changes. The digitalized landmarks and variables are shown in Figure 1. Furthermore, the amount of clinical mandibular advancement was determined preoperatively on plaster casts an average sagittal advancement of the left and right mandibular first permanent molars being 5.5 mm (SD 1.8). The Ethics Committee of the Kuopio University Hospital has approved the study in 2004 (9.3.2004, 24/2004).

Statistics

Intra-class correlation coefficients (ICC) with 95% CI were performed based on absolute agreement to determine the intra-examiner reliability for three repeated digitize measurements (interval of 3 weeks) of lateral cephalograms (*n* = 20). Paired *T*-test was used to analyze the differences between preoperative and postoperative cephalometric dimensions. The multivariate logistic regression models were used to determine the associations between postoperatively increased PAS dimension (0 = PAS decreased, 1 = PAS increased), as well as vertical movement of the hyoid bone (0 = hyoid bone moved inferiorly, 1 = hyoid bone moved superiorly) and the following variables: preoperative PAS (mm, at the baseline), preoperative hyoid bone distance to MP (mm, at the baseline), change in SNB angle (degrees), change in SN-MP angle (degrees), postoperative follow-up time (months, the time

Figure 1. The digitalized landmarks and variables of a preoperative lateral cephalogram.

between the osteotomy and the end of the postsurgical orthodontics and retention period). The effect of age at surgery (years) and gender (0 = male, 1 = female) were also considered. In addition, an association between the change in PAS (mm) and the amount of sagittal mandibular advancement (0 = less than 6mm, 1 = 6 mm or more) was determined using ANOVA variance analysis. Furthermore, the relationship between the change in PAS and the amount of sagittal mandibular advancement was demonstrated in a scatter plot with a regression line.

Results

The results showed that the sagittal dimension of PAS increased in 25 cases and decreased in 27 cases; the change in PAS varied from −9.8 mm to 9.1 mm. PAS tended to increase more in males than in females (Table 2). Interestingly, PAS seemed to decrease significantly ($p = .007$) when the mandibular advancement exceeded 6 mm. (Figure 2). The change in hyoid bone distance to mandibular plane was superior in 38 subjects and inferior in 13 subjects. In one case there was no detectable movement. Also this change was more obvious in men compared to women. In both genders the change in hyoid bone distance to MP was statistically significant.

Concerning the changes in mandibular position to the anterior cranial base by the treatment it seemed that SNB angle increased significantly in both genders, 2.5° in females and 1.9° in males, and SN-MP angle decreased 3.8° in females and 4.9° in males, this counterclockwise rotation being statistically significant in both genders.

Logistic regression models showed that an increase in sagittal PAS dimension was related to a narrow PAS at the baseline, to older age and to male gender. On the other hand, long follow-up time after surgery seemed to be related to a relapse in sagittal PAS dimension. In addition, decrease in mandibular vertical divergence was positively associated with an increase in PAS while the relationship between the change in sagittal PAS and the vertical change in hyoid position seemed to be reversed (Table 3). The only variables that were significantly related to superior movement to hyoid bone were male gender and decreased PAS (Table 4).

The intra-class correlation coefficient (ICC) concerning the cephalometric measurements varied from 0.985 (CI 0.969–0.994) for SNB, 0.991 (CI 0.981–0.996) for Hb-MP, 0.990 (CI 0.980–0.996) for SN-MP and 0.989 (CI 0.977–0.995) for PAS showing high intra-observer reproducibility.

Discussion

The present finding that those with narrow PAS at the baseline benefitted most from the mandibular advancement is in accordance with the finding of Yu et al.[10] Despite this positive trend, however, it has to be noted that approximately half of the present cases had postoperatively narrower sagittal PAS compared to the preoperative value.

Sagittal narrowing of the PAS over time has previously been presented by Eggensperger et al.[17] Indeed, the amount of mandibular advancement as a continuous variable, and thus an increase in SNB angle was not related to change in sagittal PAS dimension in the present study. The weakness of the present study is that it was carried out using lateral cephalometric images, which are two-dimensional (2D) descriptions of three-dimensional (3D) structures. Nowadays, in many surgical cases 2D lateral cephalograms are replaced by 3D cone beam tomography imaging. Concerning PAS

Table 2. Baseline cephalometric values and changes in them in 36 females and 16 males who underwent mandibular advancement by BSSO.

	Females mean (SD)	Change mean (SD) *p*-value[a]	Males mean (SD)	Change mean (SD) *p*-value[a]
PAS (mm)	9.96 (3.32)	−0.34 (3.69) .545	11.27 (4.76)	1.19 (3.81) .232
Hb-MP (mm)	13.74 (4.88)	−1.74 (3.43) .003	18.89 (6.59)	−2.95 (2.47) <.001
ANB (degrees)	6.56 (2.06)	−2.03 (2.19) <.001	6.23 (2.13)	−2.12 (1.60) <.001
SNB (degrees)	78.38 (3.93)	2.54 (1.73) <.001	78.79 (4.91)	1.89 (1.93) <.001
SN-MP (degrees)	27.08 (9.16)	−3.80(3.24) <.001	24.23 (7.55)	−4.89 (3.15) <.001

[a]By paired *T*-Test.

Table 3. Postoperatively increased posterior airway space (PAS) associated with preoperative and postoperative determinants.

	OR[a] (CI 95%)	*p*-value
Gender (0 = male, 1 = female)	0.01 (0.00–0.17)	.006
Age at surgery (years)	1.15 (1.02–1.31)	.025
Preoperative PAS (mm)	0.57 (0.36–0.91)	.018
Change in SN-MP[bc] angle (degrees)	1.62 (1.06–2.46)	.026
Postoperative follow-up time (months)	0.45 (0.25–0.82)	.009
Hyoid bone positional change from MP[c] (0 = increased, 1 = decreased)	0.02 (0.01–0.44)	.014

[a]The values are odds ratios (OR) and their 95% confidence intervals (CI) from logistic regression models in which all variables were entered simultaneously.
[b]S = sella, N = nasion.
[c]Mandibular plane.

Table 4. Postoperatively decreased hyoid bone (Hb) distance to mandibular plane (MP) associated with preoperative and postoperative determinants.

	OR[a] (CI 95%)	*p*-value
Gender (0 = male, 1 = female)	0.10 (0.01–0.87)	.037
Change in PAS (0 = decreased, 1 = increased)	0.19 (0.04–0.95)	.042

[a]The values are odds ratios (OR) and their 95% confidence intervals (CI) from logistic regression models in which all variables were entered simultaneously, adjusted for gender and age.

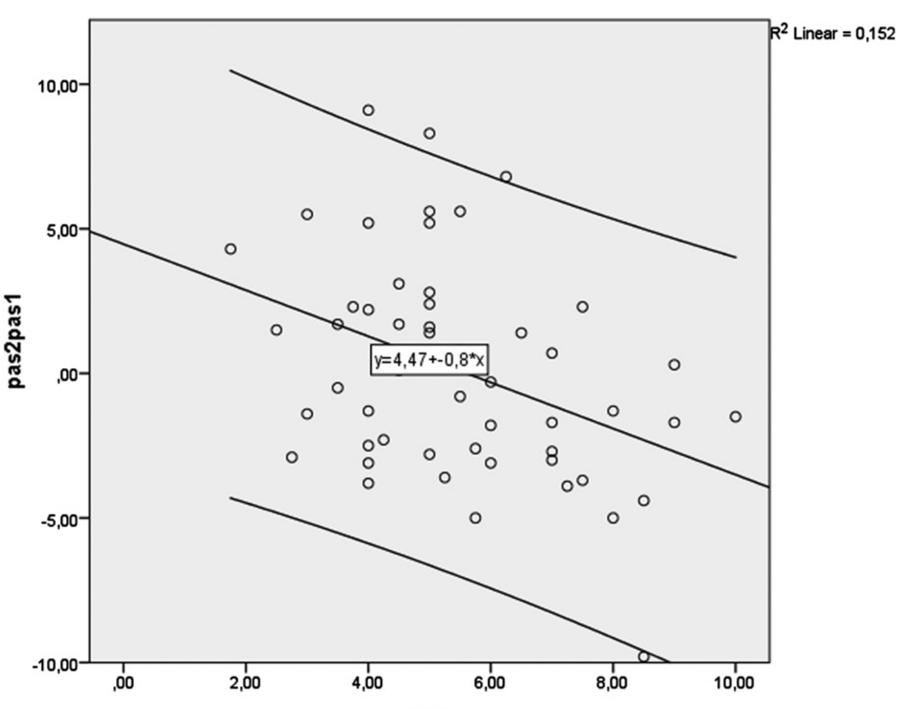

Figure 2. Changes in PAS (mm) following BSSO in relation to mandibular advancement (mm).

volume it has to be noted that the actual space of PAS is ellipsoid 3D cylinder that, according to recent studies, adapts post-surgically both in sagittal and transversal dimensions.[21,22] Anyhow 2D imaging is still justifiable in clinical research as correlations between 2D and 3D methods are strong enough, and long-term 3D data is not yet available or is inadequate.[23–26]

By the logistic regression model we also found that the more the SNB angle increased the more the hyoid bone moved towards the mandibular plane. This seems logical and is in accordance with the general finding of upward movement of the hyoid bone by BSSO advancement, the movement being caused by stretching in suprahyoidal musculature.[5,12–16] However, in approximately one fourth of the subjects in the present study hyoid bone moved away from the mandibular plane, which accompanies the findings of Gale et al.,[16] and Eggensperger et al.[17] This inferior movement tendency seemed to be related to increase in PAS dimension indicating that there is an adverse relationship between PAS and the hyoid bone, the positions of which are primarily determined by the respiratory demands and head posture. Altogether, the findings of unpredictable surgery outcomes both in PAS and in the position of hyoid bone are parallel with previous studies.[6,8,9]

The results also showed that an increase in PAS and a superior movement of the hyoid were more obvious in males than in females, which has not been previously reported. Concerning the change in the hyoid bone position Gale et al. [16] found that the vertical change was relatively smaller in males than in females. Variance between genders in normal pharyngeal structures has been reported, while some studies have found no difference between genders.[3,27,28]

Based on this and previous studies it seems that the achieved sagittal increase in posterior airway space tends to relapse over time.[7–12,17] The follow-up time of this study was 1–3 years, which conclusively eliminates the short-term error factors, e.g. swelling and postsurgical healing, and emphasizes the effect of physiological adaptation over time.[17,20] Long-term changes in pharyngeal airways may also be caused by ageing, weight gain and increase in pharyngeal fat pad.[3,17] What we know about aging is that natural pharyngeal structures reach their most stable position between 14 and 18 years and begin to narrow from 20 until 50 years.[3] With surgery more increase in sagittal PAS dimension was found in older subjects compared to younger ones.

The risk of post-operative hard tissue relapse is thought to be dependent on the amount of mandibular advancement, fixation technique, original mandibular plane angle, age, soft tissue response, postoperative follow-up period and surgeons' skills. The skeletal relapse rate is multifactorial. The amount of advancement is found to correlate positively with the relapse, among other factors.[6,8] The soft tissue relapse is most likely parallel to that of hard tissues, although some unpredictable, mostly adaptational variance exists both in facial soft tissues and pharyngeal airways.[7–12,17] In the present study additional surgery cases were excluded. In general, stability of BSSO procedure with RIF and mini plates is regarded high; 90% success rate in short term.[6,20,29] Hence we should rather talk about individual soft-tissue adaptation instead of surgical relapse.

Interestingly, in the present study retrolingual pharyngeal dimension seemed to increase up to 6 mm of mandibular advancement but then no more increase in PAS was gained although the advancement level increased. This finding is parallel to the volumetric 3D CT-study on patients with obstructive sleep syndrome treated by maxillomandibular advancement.[30] They found that in OSA-patients no further clinical improvement can be achieved after increasing the upper airway volume of 70% or more from the baseline.

As stated by Proffit et al. [20] the changes in cephalometric dimensions exceeding 2 mm or more are of clinical importance. This means that in the present study 62% of the changes in the hyoid bone distance to the mandibular plane (changes ±2 mm or more) and also 62% of the PAS changes (± 2 mm or more) are clinically relevant. This clinical relevance is meaningful especially in the treatment protocol of patients with obstructive sleep apnea (OSA). In general, the upper airway volume is essential to the development of OSA and in the treatment of it. Certain craniofacial features and oropharyngeal structures including mandibular micro- or retrognathia, low-hyoid bone position, short mandibular length and narrow pharyngeal airway space are associated with OSA.[31–33] Patients who have moderate-to-severe OSA, but do not adhere to CPAP therapy and have maxillary or mandibular retro- or micrognathia, can be treated with either mandibular advancement osteotomy or combined maxillo-mandibular advancement. The present sample did not represent OSA patients but the nonsignificant change in PAS sagittal dimension and unpredictable long-term surgery outcomes, both in PAS and in the hyoid bone vertical position, indicate that in OSA-patients BSSO alone might not be the only recommended osteotomy to improve upper airway volume, as far as 2D imaging of upper respiratory tract is concerned. More standardized long-term studies of the oropharyngeal changes using 3D methods in upright and supine positions should be performed.

Although the mandibular advancement by BSSO mainly elevates the position of the hyoid bone the sagittal change in the posterior airway space seems to be variable. There are adaptation changes in the soft tissue oropharyngeal structures over time, which are individually most likely determined by craniofacial anatomy, head posture and respiration. Baseline skeletal morphology has been found to affect the surgery outcome in BSSO.[34] In order to establish desirable occlusion, the mandible can be adjusted by clockwise or counterclockwise rotation, which may also affect the eventual adaptation and positioning of the pharyngeal structures. In this study patients with counterclockwise surgical rotation of the mandible seemed to gain more increase in PAS than those with clockwise rotation. A significant and relatively stable increase of PAS in sagittal and 3D is also observed in counterclockwise rotation by bimaxillary osteotomy.[35,36]

The hypothesis of this study concerning the increase in sagittal PAS dimension with BSSO should be partly rejected but the results mainly confirm the hypothesis that through alteration of jaw and tongue position by mandibular advancement osteotomy the hyoid bone moves superiorly.

These changes are supposed to improve upper airway configuration, increase the muscular tone of the m. genioglossus and thus to prevent the collapsibility of the upper airways, which would be advantageous especially for subjects with sleep-disordered breathing.

To conclude, males, patients with narrow PAS at the baseline, and those whose mandible moved in the counterclockwise direction with moderate advancement gained more retrolingual airway sagittal dimension by BSSO. However, BSSO alone to increase retrolingual airway space is questionable, because of the rather small amount of the clinically significant dimensional advantageous changes in airway patency and the contradictory sagittal outcomes of over 6 mm advancements.

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Disclosure statement

The authors report no conflicts of interest. The authors alone are responsible for the content and writing of this article.

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References

[1] McLain JB, Proffitt WR. Oral health status in the United States: prevalence of malocclusion. J Dent Educ. 1985;49:386–397.
[2] Muto T, Yamazaki A, Takeda S. A cephalometric evaluation of the pharyngeal airway space in patients with mandibular retrognathia and prognathia, and normal subjects. Int J Oral Maxillofac Surg. 2008;37:228–231.
[3] El H, Palomo JM. Airway volume for different dentofacial skeletal patterns. Am J Orthod Dentofacial Orthop. 2011;139:511–521.
[4] Carlson DS, Ellis E, Dechow PC. Adaptation of the suprahyoid muscle complex to mandibular advancement surgery. Am J Orthod Dentofacial Orthop. 1987;92:134–143.
[5] Valk JW, Zonnenberg AJ, van Maanen CJ, et al. The biomechanical effects of a sagittal split ramus osteotomy on the relationship of the mandible, the hyoid bone, and the cervical spine. Am J Orthod Dentofacial Orthop. 1992;102:99–108.
[6] Joss CU, Vassalli IM. Stability after bilateral sagittal split osteotomy advancement surgery with rigid internal fixation: a systematic review. J Oral Maxillofac Surg. 2009;67:301–313.
[7] Thüer U, Ingervall B, Vuillemin T. Stability and effect on the soft tissue profile of mandibular advancement with sagittal split osteotomy and rigid internal fixation. Int J Adult Orthodon Orthognath Surg. 1994;9:175.
[8] Joss CU, Thüer UW. Stability of the hard and soft tissue profile after mandibular advancement in sagittal split osteotomies: a longitudinal and long-term follow-up study. Eur J Orthod. 2008;30:16–23.
[9] Joss CU, Joss-Vassalli IM, Kiliaridis S, et al. Soft tissue profile changes after bilateral sagittal split osteotomy for mandibular advancement: a systematic review. J Oral Maxillofac Surg. 2010;68:1260–1269.
[10] Yu LF, Pogrel MA, Ajayi M. Pharyngeal airway changes associated with mandibular advancement. J Oral Maxillofac Surg. 1994;52:40–43.
[11] Achilleos S, Krogstad O, Lyberg T. Surgical mandibular advancement and changes in uvuloglossopharyngeal morphology and head posture: a short- and long-term cephalometric study in males. Eur J Orthod. 2000;22:367–381.
[12] Sahoo NK, Jayan B, Ramakrishna N, et al. Evaluation of upper airway dimensional changes and hyoid position following mandibular advancement in patients with skeletal class II malocclusion. J Craniofac Surg. 2012;23:623–627.
[13] LaBanc JP, Epker BN. Changes of the hyoid bone and tongue following advancement of the mandible. Oral Surg Oral Med Oral Pathol. 1984;57:351–356.
[14] Hayes RJ, Sarver DM, Jacobson A. The quantification of soft tissue cervicomental changes after mandibular advancement surgery. Am J Orthod Dentofacial Orthop. 1994;105:383–391.
[15] Chung DH, Hatch JP, Dolce C, et al. Positional change of the hyoid bone after bilateral sagittal split osteotomy with rigid and wire fixation. Am J Orthod Dentofacial Orthop. 2001;119:382–389.
[16] Gale A, Kilpeläinen PV, Laine-Alava MT. Hyoid bone position after surgical mandibular advancement. Eur J Orthod. 2001;23:695–701.
[17] Eggensperger N, Smolka K, Johner A, et al. Long-term changes of hyoid bone and pharyngeal airway size following advancement of the mandible. Oral Surg Oral Med Oral Pathol Oral Radiol Endod. 2005;99:404–410.
[18] Tan JL, Marshall SD, Kallal RH, et al. The relationship between presurgical hyoid bone position and 1-year postsurgical change in mandibular position following mandibular advancement surgery. Int J Adult Orthodon Orthognath Surg. 1995;10:263–268.
[19] Dolce C, Hatch JP, Van Sickels JE, et al. Rigid versus wire fixation for mandibular advancement: skeletal and dental changes after 5 years. Am J Orthod Dentofacial Orthop. 2002;121:610–619.
[20] Proffit WR, Turvey TA, Phillips C. The hierarchy of stability and predictability in orthognathic surgery with rigid fixation: an update and extension. Head Face Med. 2007;3:21.
[21] Hernández-Alfaro F, Guijarro-Martínez R, Mareque-Bueno J. Effect of mono- and bimaxillary advancement on pharyngeal airway volume: cone-beam computed tomography evaluation. J Oral Maxillofac Surg. 2011;69:395–400.
[22] Kochar GD, Chakranarayan A, Kohli S, et al. Effect of surgical mandibular advancement on pharyngeal airway dimensions: a three-dimensional computed tomography study. Int J Oral Maxillofac Surg. 2016;45:553–559.
[23] Riley R, Powell N, Guilleminault C. Cephalometric roentgenograms and computerized tomographic scans in obstructive sleep apnea. Sleep. 1986;9:514.
[24] Aboudara C, Nielsen I, Huang J, et al. Comparison of airway space with conventional lateral headfilms and 3-dimensional

reconstruction from cone-beam computed tomography. Am J Orthod Dentofacial Orthop. 2009;135:468–479.

[25] Sears CR, Miller AJ, Chang MK, et al. Comparison of pharyngeal airway changes on plain radiography and cone-beam computed tomography after orthognathic surgery. J Oral Maxillofac Surg. 2011;69:385–394.

[26] Bronoosh P, Khojastepour L. Analysis of pharyngeal airway using lateral cephalogram vs. CBCT images: a cross-sectional retrospective study. Open Dent J. 2015;31:263–266.

[27] Kollias I, Krogstad O. Adult craniocervical and pharyngeal changes – a longitudinal cephalometric study between 22 and 42 years of age. Part II: morphological uvulo-glossopharyngeal changes. Eur J Orthod. 1999;21:345–355.

[28] Whittle AT, Marshall I, Mortimore IL, et al. Neck soft tissue and fat distribution: comparison between normal men and women by magnetic resonance imaging. Thorax. 1999;54: c323–328.

[29] Proffit WR, Phillips C, Douvartzidis N. A comparison of outcomes of orthodontic and surgical-orthodontic treatment of Class II malocclusion in adults. Am J Orthod Dentofacial Orthop. 1992;101:556.

[30] Bianchi A, Betti E, Tarsitano A, et al. Volumetric three-dimensional computed tomographic evaluation of the upper airway in patients with obstructive sleep apnoea syndrome treated by maxillomandibular advancement. Br J Oral Maxillofac Surg. 2014;52:831–837.

[31] Miles PG, Vig PS, Weyant RJ, et al. Craniofacial structure and obstructive sleep apnea syndrome – a qualitative analysis and meta-analysis of the literature. Am J Orthod Dentofacial Orthop. 1996;109:163–172.

[32] Tangugsorn V, Krogstad O, Espeland, et al. Obstructive sleep apnoea: multiple comparisons of cephalometric variables of obese and non-obese patients. J Craniomaxillofac Surg. 2000;28:204–212.

[33] Hoekema A, Hovinga B, Stegenga B, et al. Craniofacial morphology and obstructive sleep apnoea: a cephalometric analysis. J Oral Rehabil. 2003;30:690–696.

[34] Mobarak KA, Espeland L, Krogstad O, et al. Mandibular advancement surgery in high-angle and low-angle class II patients: different long-term skeletal responses. Am J Orthod Dentofacial Orthop. 2001;119:368–381.

[35] Goncalves JR, Buschang PH, Goncalves DG, et al. Postsurgical stability of oropharyngeal airway changes following counter-clockwise maxillo-mandibular advancement surgery. J Oral Maxillofac Surg. 2006;64:755–762.

[36] Zinser MJ, Zachowb S, Sailer HF. Bimaxillary 'rotation advancement' procedures in patients with obstructive sleep apnea: a 3-dimensional airway analysis of morphological changes. Int J Oral Maxillofac Surg. 2013;42:569–578.