Available online at www.sciencedirect.com
ScienceDirect
British Journal of Oral and Maxillofacial Surgery 57 (2019) 1032–1038
BRITISH Journal of Oral and Maxillofacial Surgery
www.bjoms.com

Relations between mandible-only advancement surgery, the extent of the posterior airway space, and the position of the hyoid bone in Class II patients: a three-dimensional analysis

T. Rückschloß[a,*], O. Ristow[a], M. Berger[b], M. Engel[a], C. Freudlsperger[a], J. Hoffmann[a], R. Seeberger[c]

[a] *University of Heidelberg, Department of Oral and Maxillofacial Surgery, Im Neuenheimer Feld 400, D-69120 Heidelberg, Germany*
[b] *Oral Surgery Practice, Hindenburgstraße 1, D-67433 Neustadt an der Weinstraße, Germany*
[c] *Practice Clinic of Oral and Maxillofacial Surgery, Darmstädter Str. 7, D-64625 Bensheim, Germany*

Accepted 2 September 2019
Available online 26 September 2019

Abstract

The objective of the present study was to evaluate the relation between mandibular advancement, the three-dimensional extent of the posterior airway space (PAS), and the position of the hyoid bone, using cone-beam computed tomography (CT). Twenty-eight Class II patients (21 women (mean (SD) age 29 (9) years) and seven men (mean (SD) age 23 (6) years)), who had had mandibular-only advancement surgery (Obwegeser-Dal Pont) were included in the study. In each case, cone-beam CT scans were taken one week before and six months after operation, and a retrospective analysis made of the alterations of several airway variables (volume, mean cross-sectional area, and diameter) and the three-dimensional extent of mandibular and hyoid movement, by using IPlan® cranial software. A linear regression was also done to correlate mandibular advancement, the movement of the hyoid bone, and airway variables. There were significant postoperative increases in all volumetric PAS variables, and in most diametric and spherical variables ($p < 0.05$). There was also a significant linear relation between forward displacement of the mandible and the movement of the hyoid bone ($p < 0.05$). These results show that mandible-only advancement surgery causes an increase in most dimensions of the PAS. This intervention can be assumed to reduce airway resistance and therefore might be a suitable treatment option for patients with obstructive sleep apnoea syndrome.

Keywords: PAS; Class II patients; mandibular advancement; OSAS; hyoid bone

Introduction

Obstructive sleep apnoea (OSA) has become a major public health issue with a prevalence between 4% and 9% in women and between 9% and 24% in men.[1] It is a breathing disorder that is characterised by repetitive episodes of apnoea or hypopnea, or both, during sleep, as a result of partial or total collapse of the pharyngeal airway space more than five times/hour of sleep.[2,3] Predisposing factors include all those that cause a narrowing of the pharyngeal airway space and a shortening of the mandible or maxilla.[4] Cephalometric analyses have established that it is associated with a mandibular deficiency with or without maxillary hypoplasia, and the hyoid being lower than the mandibular plane.[5–7] This is certainly the case in patients with Angle Class II malocclusion. The use of continuous positive airway pressure (CPAP) machines is the first choice remedy in severe cases.[8] Never-

* Corresponding author. Tel.: +49 6221 56 39716; Fax: +49 6221 56 4375.
E-mail address: Thomas.rueckschloss@med.uni-heidelberg.de (T. Rückschloß).

https://doi.org/10.1016/j.bjoms.2019.09.001
0266-4356/

Table 1
Measurement and reference points, reference planes, volumes, mean cross-sectional area, diameters (taken in part form Kochel et al. and previous projects of our working group).

Measurement points	Abbr.	Definition
Left lesser horn of the hyoid	Hyol	Tip of the lesser horn on the left side
Right lesser horn of the hyoid	Hyor	Tip of the lesser horn on the right side
Hyoid body	Hyo	Dorsocranial point of the hyoid body on the median plane
Left mental foramen	Fml	Central point of the mental foramen on the left side
Right mental foramen	Fmr	Central point of the mental foramen on the right side
Menton	Me	Inferior point of bony chin
Reference points		
Orbitale left	Orl	Inferior point of the orbital margin on the left side
Orbitale right	Orr	Inferior point of the orbital margin on the right side
Porion right	Po	Superior point of external auditory meatus
Basion	Ba	Posterior inferior point of occipital bone
Nasion	Na	Anterior point of frontonasal suture
Posterior nasal spine	PNS	Posterior point of the hard palate
Soft palate	SP	Posterior inferior point of the soft palate
Epiglottis tip	Ep	Superior point of epiglottis
Reference planes		
FH plane		Frankfort horizontal plane, constructed on Po, Orr, and Orl
Midsagittal plane		Midsagittal reference plane, perpendicular to Frankfort horizontal plane, passing through Na and Ba
Coronal plane		Perpendicular to Frankfort horizontal plane and midsagittal plane
A plane		Perpendicular to Frankfort horizontal plane and midsagittal plane, passing through PNS
B plane		Parallel to Frankfort horizontal plane, passing through PNS
C plane		Parallel to Frankfort horizontal plane, passing through SP
D plane		Parallel to Frankfort horizontal plane, passing through Ep
Volumes (mm^3)		
Superior posterior airway volume	PAV_S	Volume of upper PAS third delimited by the A and B planes
Middle posterior airway volume	PAV_M	Volume of middle PAS third between the B and C planes
Inferior posterior airway volume	PAV_I	Volume of lower PAS third between the C and D planes
Mean cross-sectional areas (mm^2)		
Superior cross-sectional area	MCA_S	Mean cross-sectional area of superior posterior airway volume
Middle cross-sectional area	MCA_M	Mean cross-sectional area of middle posterior airway volume
Inferior cross-sectional area	MCA_I	Mean cross-sectional area of inferior posterior airway volume
Anteroposterior diameters (mm)		
Superior anteroposterior distance	AP_B	Midsagittal PAS length on the B plane
Middle anteroposterior distance	AP_C	Midsagittal PAS length on the C plane
Inferior anteroposterior distance	AP_D	Midsagittal PAS length on the D plane
Transversal diameters (mm)		
Superior longest transversal diameter	$Trans_B$	Largest transversal PAS width on the B plane
Middle longest transversal diameter	$Trans_C$	Largest transversal PAS width on the C plane
Inferior longest transversal diameter	$Trans_D$	Largest transversal PAS width on the D plane

theless, a wide range of operations is available, all of which aim to alleviate the symptoms.

In this context, maxillomandibular advancement (MMA) is a highly effective but invasive operation.[9] Many authors have reported consistently favourable effects, and the volumetric changes of the upper airway space have been well described.[10–12] However, the evidence about the effects of mandible-only advancement on the upper airway space is poor.[13,14] One detriment of all the existing studies is that most of them do not describe the bony displacement of the jaw segments or, if they do, only by means of cephalometric measurements.

Our aim, therefore, was to assess the effects of mandibular advancement on the upper airway space by using cone-beam computed tomography (CT). We hypothesised that mandibular advancement provokes an increase in most dimensions of the posterior airway space (PAS), and that there is a linear correlation between mandibular movement and the change in airway measurements.

Patients, material, and methods

This retrospective study was organised according to the principles of the Declaration of Helsinki, and the standardised measurement protocol was approved by the local Ethics Committee (Ethics number S131/2009).

The inclusion criteria were: bilateral mandibular advancement surgery (bilateral sagittal split osteotomy, Obwegeser-Dal Pont[15]) in Class II patients with no facial asymmetry done between 1 January 2015 and 31 December 2017; facial skulls had finished growing; and preoperative and postoperative cone-beam CT scans were available.[13,16] The exclusion criteria were: cleft lip and palate, congenital craniofacial anomalies or adenoidal hypertrophy; and a history of adenoidectomy or tonsillectomy, or genioplasty.[13,16]

Twenty-eight patients had bilateral sagittal split osteotomy (Obwegeser-Dal Pont[15]) with mandibular advancement, 21 of whom were women (mean (SD) age 29 (9) years) and seven of whom were men (mean (SD) age 23 (6) years) in the Department of Oral and Maxillofacial Surgery of the University Hospital Heidelberg by the same surgeon (RS).

Each patient had a cone-beam CT (Galileos Comfort, isotopic voxel size 0.25 mm) scan one week preoperatively and six months postoperatively, and these datasets were analysed retrospectively. All records were anonymised, and identified by a code for the respective subject.

During the scans the patients stood upright with the head in the natural head position and stabilised by a head support. For the preoperative scan a wax bite was used to position the condyles centrically. For the postoperative scan the patients kept their mouths closed with habitual tooth contact. They were instructed not to swallow, to keep the lips and tongue in a resting position, and to breathe evenly.[13] All datasets were examined and analysed by one investigator (TR) using the software tool IPlan® cranial software (Brainlab).[16]

To guarantee reliable and reproducible measurements, the preoperative datasets were aligned to a three-dimensional Cartesian coordinate system, and oriented based on three reference planes: the Frankfort horizontal plane, the mid-sagittal plane, and the coronal plane (Table 1). Further planes (A–D) (Table 1) were then constructed in the dataset running through the points (PNS, SP, Ep). The reference points for their construction are also given in Table 1.

We correlated the preoperative datasets (Fig. 1), and then the measurement points (as defined in Table 1), were drawn on both preoperative and postoperative records.

IPlan® cranial offers the opportunity of specifying the exact displacement of each measurement point in the coordinate system by a vector, which consists of a triple number (x, y, z) that gives the three-dimensional displacement of each point perpendicular to the reference planes.[13,16]

The three PAS segments were defined by the planes (A–D) mentioned above: the upper (PAV_S), middle (PAV_M), and lower (PAV_I) segments (Table 1, Fig. 2).[17] We then measured the cross-sections of the airway on the reference planes B, C, and D, on which the anteroposterior and the transverse width of the PAS could be measured in the sectional views (axial) (Table 1).

Based on the preoperative and postoperative datasets, three-dimensional airway models were created by using the region growing algorithm supplied by IPlan® cranial. A volumetric analysis of these airway segments was then made. In addition, the mean cross-sectional areas of each airway segment were calculated (Table 1).

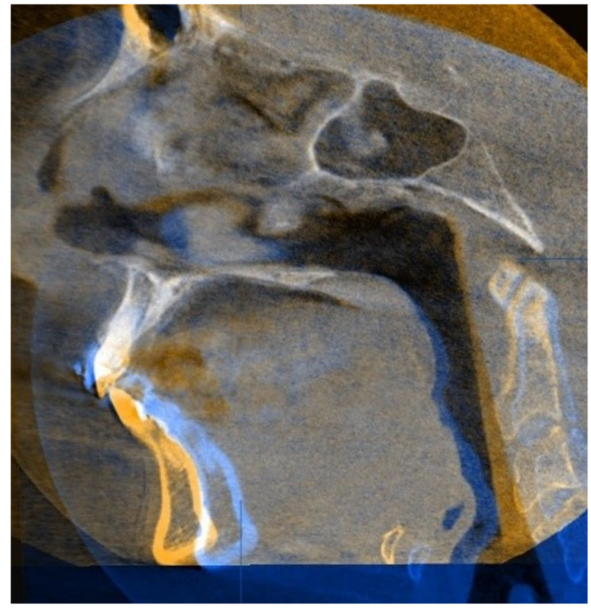

Fig. 1. Voxel-wise recording of the preoperative (blue) and postoperative (orange) datasets based on the skull base (white).

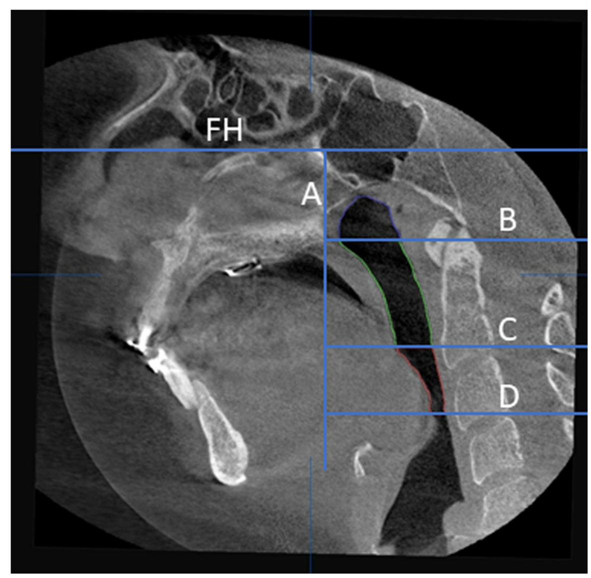

Fig. 2. Sagittal view showing the reference planes and the segments of airway.

Statistical analysis

The software IBM SPSS Statistics for Windows (version 25, IBM Corp) was used for statistical analysis. In addition to the descriptive evaluation (arithmetic mean and SD), we used the Wilcoxon signed-rank test for paired samples to assess the significance of differences between the preoperative and

Table 2
Three-dimensional movement of all measurement points [mm]; Craniocaudal: Cranial movements are indicated by a positive value; Transversal: Movements to the right (from patient's point of view) are indicated by a positive value, movements to the left are indicated by a minus sign.

		Anterior		Craniocaudal		Transversal	
	N	Mean	SD	Mean	SD	Mean	SD
Me	28	5.54	2.51	0.67	2.43	0.23	1.3
Fml	28	5.34	2.39	1.08	1.64	−0.16	1.21
Fmr	28	5.31	2.35	1.01	1.35	0.09	1.17
Hyo	27	1.74	5.02	3.43	4.7	0.27	1.15
Hyor	28	1.37	4.78	2.29	4.01	0.48	1.51
Hyol	28	1.65	4.53	2.89	3.93	0.17	1.34

postoperative values. We also did a linear regression to calculate the degree of significance between the movement of the measurement points and the changes in the other airway variables. The significance level was set at 5%.

Results

As previous studies have showed no differences between the sexes for these measurements, the subjects were combined for subsequent analysis.[13,17–19]

Movement of measurement points

Table 2 shows the movements of our measurement points. A mean mandibular advancement of 5.54 (2.51) mm for the measurement point menton was found to be typical for class II one-jaw orthognathic surgery. We also found advancement of the hyoid bone (Hyo(anterior) = 1.74 (5.02) mm).

Three-dimensional airway assessment

Volume
Table 3 shows the variables for the 3-dimensional airway assessment. The Wilcoxon signed-rank test indicated that mandible-only advancement resulted in significant increases in the pharyngeal airway volume of each segment ($\Delta PAV_I = 936.82$ (1955.81) mm^3, $Z = -2.391$, $p = 0.017$). The largest increase was seen in the middle part of the posterior airway volume ($\Delta PAV_M = 2884.86$ (3575.99) mm^3, $Z = -3.689$, $p = 0.000$*), whereas the smallest increase was seen on the upper part of the posterior airway volume ($\Delta PAV_S = 246.00$ (746.25) mm^3, $Z = -2.015$, $p = 0.044$).

Mean cross-sectional area
There were significant gains for the mean cross-sectional areas of the middle and inferior airway volumes, with increases of $\Delta MCA_M = 99.82$ (140.19) mm^2 ($Z = -3.735$, $p = 0.000$) and $\Delta MCA_I = 85.89$ (172.66) mm^2 ($Z = -2.869$, $p = 0.004$), respectively. We found no significant difference between the preoperative and postoperative values in the mean cross-sectional areas of the superior airway volume ($\Delta MCA_S = 17.30$ (65.11) mm^2, $Z = -1.844$, $p = 0.065$) (Table 3).

Diameter
Increases in linear measurements of the cross sections were measured in both the anteroposterior and transverse directions. In the anteroposterior direction, the Wilcoxon signed-rank test indicated significant increases on the C and D planes ($\Delta AP_C = 3.31$ (3.50) mm, $Z = -3.894$, $p = 0.000$* and $\Delta AP_D = 1.96$ (4.61 mm), $Z = -2.319$, $p = 0.020$, respectively). In comparison, in the transverse direction, significant increases could be seen only on the B and C planes ($\Delta Trans_C = 4.13$ (4.68) mm, $Z = -4.054$, $p = 0.000$* and $\Delta Trans_B = 0.40$ (2.12) mm, $Z = -2.238$, $p = 0.025$, respectively).

Relations

Table 4 shows the result of the linear regression between the movement of the measurement points and the changes of other airway measurements. As can be seen for the linear regression of "Me" (predictor) and "Hyo" (dependent variable), the overall regression model is significant ($R^2 = 0.187$, $p = 0.024$). "Me" is therefore a predictor for "Hyo" ($B = 0.871$, $t(26) = 2.395$). Interestingly, we found no significant linear regressions of "Me" and any other airway measurement. Contrary to this, "Hyo" turned out to be a significant predictor for many airway measurements (but with negative B values) (Table 4).

Discussion

A thorough search of the relevant published papers yielded only four related ones that dealt with the effect of mandibular advancement surgery on the upper airway space based on a three-dimensional analysis.[13,17–19] All studies clearly showed a significant increase in the volume of the pharyngeal airway. Unfortunately, only Ristow et al[13] stated the distance of mandibular advancement. Two other research groups[17,19] made a cephalometric analysis of the patients before and after operation, but gave only limited information regarding the extent of the advancement. Their methods, in contrast to the procedures in this study, do not show the 3-dimensional reality of the mandibular movement. Except for Kochel et al,[17] all the authors measured the whole volume of one airway, and made no additional subdivisions.[13,17–19] However, the findings of these other groups[13,17–19] seem to be consistent with our results.

A detailed comparison of our results with other studies is difficult. Even though we used several variables for assessment of the upper airway (as previously described by other research groups) the reference planes used by the above-mentioned authors differ from each other or have not been stated. In addition, we measured a little-known variable, the

Table 3
Three-dimensional parameters for the PAS analysis before (pre) and after (post) surgery (*$p \leq 0.05$).

	Pre	Post		Δ		Wilcoxon			
	N	Mean	SD	Mean	SD	Mean	SD	Z	p
Volumes (mm^3)									
PAV_S	28	6455.75	1587.24	6701.75	1700.94	246	746.25	−2.015	0.044*
PAV_M	28	10701.39	4696.77	13586.25	4673.13	2884.86	3575.99	−3.689	0.000*
PAV_I	28	4640.04	2786.44	5576.86	2970.87	936.82	1955.81	−2.391	0.017*
Mean cross-sectional areas (mm^2)									
MCA_S	28	523.73	106.74	541.03	103.95	17.3	65.11	−1.844	0.065
MCA_M	28	323.75	122.95	423.57	151.26	99.82	140.19	−3.735	0.000*
MCA_I	28	263.94	185.4	349.83	170.61	85.89	172.66	−2.869	0.004*
Anteroposterior diameters (mm)									
AP_B	28	20.68	3.33	20.93	3.26	0.26	1.39	−0.915	0.36
AP_C	28	10.6	4.14	13.91	4.01	3.31	3.5	−3.894	0.000*
AP_D	28	11.67	4.27	13.63	3.72	1.96	4.61	−2.319	0.020*
Transversal diameters (mm)									
$Trans_B$	28	30.02	4.05	30.43	4.43	0.4	2.12	−2.238	0.025*
$Trans_C$	28	27.2	7.24	31.32	7.15	4.13	4.68	−4.054	0.000*
$Trans_D$	28	31.34	4.72	32.19	4.16	0.85	3.53	−1.082	0.279

Table 4
Linear regression (*$p \leq 0.05$).

Depending variable	Predictor	B	β	df	T	R^2	p
Hyo	Me	0.871	0.432	26	2.395	0.187	0.024*
ΔPAV_M	Hyo	−313.653	−0.433	26	−2.404	0.188	0.024*
ΔPAV_I	Hyo	−195.988	−0.508	26	−2.948	0.258	0.007*
ΔMCA_I	Hyo	−16.71	−0.477	26	−2.715	0.228	0.012*
ΔAP_D	Hyo	−0.453	−0.487	26	−2.784	0.237	0.010*
$\Delta Trans_D$	Hyo	−0.425	−0.595	26	−3.697	0.353	0.001*

so-called “mean cross-sectional area of the airway volumes” (volume of each segment of airway divided by its height) that was first described by Abramson et al.[20] Simple cross-sectional areas are insufficient if a statement is to be made about total airway resistance to airflow, an important variable in the pathogenesis of OSA. This is because the total airway resistance is calculated as the sum of all obstructions along its length.[20] The mean cross-sectional area therefore seems to be an appropriate measurement if conclusions are to be drawn about upper airway resistance and if a diagnosis of OSAS is to be made.[13,20] Nevertheless, other authors measured only the smallest cross-sectional areas.

We have also calculated the amount of three-dimensional movement of the hyoid bone, and our results underline its importance in affecting the PAS. Linear regression analysis established, first, the significant linear association between the mandibular advancement and hyoid displacement and, secondly, the great influence that the hyoid bone has on the PAS. It must be pointed out, though, that the R^2-values for each model are low and for this reason the explanatory power is also low, so it seems that the influence of mandibular advancement on the PAS is more complex than we thought, and various unknown factors play a part. To date, the effect of orthognathic surgery on the hyoid bone has been little studied, and only a few authors have used 3-dimensional measures[21] or adequate statistical methods. The hyoid bone seems to be a key element in the condition of the PAS.

Nevertheless, cephalometry remains an essential imaging tool for the planning and follow-up of orthognathic surgery. Because of the oval or elliptical cross-section of the upper airway, many scientific groups have emphasised that accurate expression of it is impossible with only cephalometric measurements. For this reason, modern three-dimensional imaging is recommended.[22] We used cone-beam CT because of its low radiation exposure, its low costs compared with conventional CT, and its accuracy in visualising the pharyngeal airway spaces.

As we used retrospective imaging data, the patient’s head posture during cone-beam CT could not be controlled as this involves changes in the pharyngeal dimensions.[23] For example, there is a strong correlation between the upper airway variables and the craniocervical angle.[24] The position of the head also affects the position of the hyoid bone.[25] Unfortunately, reproduction of the position of the patient’s head during the postoperative cone-beam CT scan is almost impossible. We should point out that orthognathic surgery significantly affects the postoperative position of the patient’s head.[23] In our standardised in-house procedures for cone-beam CT for planning and follow-up of orthognathic surgery the patient’s head is in it natural position, as we think that this is the best option for obtaining realistic data of the usual airway dimension in a patient when awake. Nevertheless, OSAS is a phenomenon that happens in patients who are sleeping and normally lying down.

The pathomechanism of OSAS has been shown to be grounded in the morphological changes in the pharyngeal airway spaces caused by gravity and posture. In patients who are lying supine this leads to a narrowing of the airway,[26] which is possible only because of the relaxation of the airway dilating muscles during sleep. These muscles are unable to counter the negative airway pressure on inspiration effectively. Consequently, the airway collapses.[2] The data from this study (and all those mentioned above[13,17–19]) give only limited information about the development of OSA, as the patients are scanned awake, and standing. Further studies that take these circumstances into account, and that therefore should measure the upper airway with the patient lying down, are needed.

Notwithstanding the limitations of all existing studies on this topic, orthognathic surgery, and MMA in particular, has been established as a viable and effective treatment option in patients with OSA.[10–12] Our results give valuable information concerning the efficacy of mandible-only advancement. We can reasonably presume that mandible-only advancement is equal to MMA with respect to its effect on the upper airway space. Conceivably, the main effect of MMA results from the mandibular movement. To examine this aspect, further studies are needed that should also examine isolated maxillary advancement surgery.

We think that mandible-only advancement is effective in appreciably widening the posterior airway space. Future studies aimed at the evaluation of the PAS should involve three-dimensional imaging, particularly for OSA diagnosis or planning of treatment. Standard imaging protocols that assure a reproducible supine position for the patient are therefore necessary.

Conclusions

The main goal of the study was to describe the relations between MMA, the extent of the PAS, and the position of the hyoid bone in a homogeneous cohort of Class II patients (n = 28) using cone-beam CT. Our retrospective analysis shows that there are significant gains in almost all airway measurements six months' postoperatively. We confirm previous findings and contribute additional evidence that suggests that bilateral MMA might be a suitable alternative to established methods for widening the posterior airway in patients with skeletal Class II malocclusions.

Conflict of interest

We have no conflicts of interest.

Ethics statement/confirmation of patients' permission

The standardised measurement protocol was approved by the Ethics Committee (Ethics number S131/2009) of the University Hospital Heidelberg. We have obtained written informed consent for publication in print and electronic form from patients.

Funding

This work was supported by the Medical Faculty of Heidelberg as part of the Physician Scientist programme.

References

1. Srijithesh PR, Aghoram R, Goel A, et al. Positional therapy for obstructive sleep apnoea. *Cochrane Database Syst Rev* 2019;**5**:CD010990.
2. Costa C, Santos B, Severino D, et al. Obstructive sleep apnea syndrome: An important piece in the puzzle of cardiovascular risk factors. *Clin Investig Arterioscler* 2015;**27**:256–63.
3. Kapur VK, Auckley DH, Chowdhuri S, et al. Clinical practice guideline for diagnostic testing for adult obstructive sleep apnea: an American Academy of Sleep Medicine Clinical Practice Guideline. *J Clin Sleep Med* 2017;**13**:479–504.
4. Mbata G, Chukwuka J. Obstructive sleep apnea hypopnea syndrome. *Ann Med Health Sci Res* 2012;**2**:74–7.
5. Lowe AA, Fleetham JA, Adachi S, et al. Cephalometric and computed tomographic predictors of obstructive sleep apnea severity. *Am J Orthod Dentofacial Orthop* 1995;**107**:589–95.
6. Riha RL, Brander P, Vennelle M, et al. A cephalometric comparison of patients with the sleep apnea/hypopnea syndrome and their siblings. *Sleep* 2005;**28**:315–20.
7. Cistulli PA. Craniofacial abnormalities in obstructive sleep apnoea: Implications for treatment. *Respirology* 1996;**1**:167–74.
8. Giles TL, Lasserson TJ, Smith BH, et al. Continuous positive airways pressure for obstructive sleep apnoea in adults. *Cochrane Database Syst Rev* 2006;**1**:CD001106.
9. Sundaram S, Bridgman SA, Lim J, et al. Surgery for obstructive sleep apnoea. *Cochrane Database Syst Rev* 2005;**4**:CD001004.
10. Serra MM, Greenburg D, Barnwell M, et al. Maxillomandibular advancement as surgical treatment for obstructive sleep apnea in active duty military personnel: a retrospective cohort. *Mil Med* 2012;**177**:1387–92.
11. Ronchi P, Novelli G, Colombo L, et al. Effectiveness of maxillo-mandibular advancement in obstructive sleep apnea patients with and without skeletal anomalies. *Int J Oral Maxillofac Surg* 2010;**39**:541–7.
12. Jaspers GW, Booij A, de Graaf J, et al. Long-term results of maxillomandibular advancement surgery in patients with obstructive sleep apnoea syndrome. *Br J Oral Maxillofac Surg* 2013;**51**:e37–9.
13. Ristow O, Rückschloß T, Berger M, et al. Short- and long-term changes of the pharyngeal airway after surgical mandibular advancement in Class II patients-a three-dimensional retrospective study. *J Craniomaxillofac Surg* 2018;**46**:56–62.
14. Turnbull NR, Battagel JM. The effects of orthognathic surgery on pharyngeal airway dimensions and quality of sleep. *J Orthod* 2000;**27**:235–47.
15. Dal Pont G. Retro-molar osteotomy for correction of prognathism. *Minerva Chir* 1959;**14**:1138–41 (paper in Italian).
16. Freudlsperger C, Rückschloß T, Ristow O, et al. Effect of occlusal plane correction on lip cant in two-jaw orthognathic surgery - A three-dimensional analysis. *J Craniomaxillofac Surg* 2017;**45**:1026–30.
17. Kochel J, Meyer-Marcotty P, Sickel F, et al. Short-term pharyngeal airway changes after mandibular advancement surgery in adult class

II-patients—a three-dimensional retrospective study. *J Orofac Orthop* 2013;**74**:137–52.
18. Hernández-Alfaro F, Guijarro-Martinez 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**:e395–400.
19. Dalla Torre D, Burtscher D, Widmann G, et al. Long-term influence of mandibular advancement on the volume of the posterior airway in skeletal Class II-patients: A retrospective analysis. *Br J Oral Maxillofac Surg* 2017;**55**:780–6.
20. Abramson Z, Susarla SM, Lawler M, et al. Three-dimensional computed tomographic airway analysis of patients with obstructive sleep apnea treated by maxillomandibular advancement. *J Oral Maxillofac Surg* 2011;**69**:677–86.
21. Shin JH, Kim MA, Park IY, et al. A 2-year follow-up of changes after bimaxillary surgery in patients with mandibular prognathism: 3-dimensional analysis of Pharyngeal airway volume and hyoid bone position. *J Oral Maxillofac Surg* 2015;**73**(340):e1–9.
22. Schulze R, Deppe H, Betz W, et al. German S2k-Guidelines for Dental Cone beam computed tomography (Document in German). Available from URL: http://www.dgzmk.de/uploads/tx_szdgzmkdocuments/083- Last accessed 1 September 2019.
23. Kim MA, Kim BR, Youn JK, et al. Head posture and pharyngeal airway volume changes after bimaxillary surgery for mandibular prognathism. *J Craniomaxillofac Surg* 2014;**42**:531–5.
24. Muto T, Takeda S, Kanazawa M, et al. The effect of head posture on the pharyngeal airway space (PAS). *Int J Oral Maxillofac Surg* 2002;**31**:579–83.
25. Winnberg A, Pancherz H, Westesson PL. Head posture and hyo-mandibular function in man. A synchronized electromyographic and videofluorographic study of the open-close-clench cycle. *Am J Orthod Dentofacial Orthop* 1988;**94**:393–404.
26. Sutthiprapaporn P, Tanimoto K, Ohtsuka M, et al. Positional changes of oropharyngeal structures due to gravity in the upright and supine positions. *Dentomaxillofac Radiol* 2008;**37**:130–5.