Effects of orthognathic surgery on pharyngeal airway space: A literature review

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Abstract

Pharyngeal airway changes after orthognathic surgery have been concerned because of the effects on breathing function of the patients. Moreover, sleep quality of patients can be improved or worsened by these changes. Obstructive sleep apnea is a disorder characterized by episode of pharyngeal airway collapse. It may be better following a maxillomandibular advancement surgery or may be worsened or developed after mandibular setback surgery. The purpose of this study is to review the changes of pharyngeal airway and its important related structure such as hyoid bone, the tongue and soft palate after orthognathic surgery in dentofacial deformity patients. The change of the head posture, the adaptation and the stability of the pharyngeal airway are also considered. Moderate evidence was found to support a significant decrease in the oropharyngeal airway after mandibular setback surgery. Bimaxillary surgery in class III patients has less unfavorable effects and should be considered when setback the mandible a large extent. Maxillomandibular advancement widens the airway in many levels and has high success rate in treatment of OSA.

Key words: orthognathic surgery, obstructive sleep apnea, pharyngeal airway, cephalometry, cone beam computed tomography, bilateral sagittal split ticenus ostiotamy, maxillomandibular advancement

How to cite: Truong Nguyen M, Visutivatanakorn S, Manh Truong D, Wongsirichat N. Effects of orthognathic surgery on pharyngeal airway space: A literature review M Dent J 2014; 34: 165-173.

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Received: 1 October 2013
Accepted: 26 December 2013

Introduction

Orthognathic surgery is a common method to treat dentofacial deformities. Orthognathic surgery by changing the position of facial skeletons has effects on the morphology of the pharynx.[1, 2] Since soft palate, tongue, hyoid bone and associated tissues are attached directly or indirectly to the mandible and maxilla, movement of the jaws by orthognathic surgery affects those tissues, causing changes in the pharyngeal area. Mandibular setback surgery can reduce the volume of pharyngeal airway space (PAS)[3-13] and change the position of the hyoid bone and tongue.[5-7, 10, 11, 14] Moreover, mandibular setback has been reported to be associated with PAS decrease and in some patients can develop Obstructive sleep apnea (OSA).[4, 7, 9, 15, 16] On the contrary, maxillomandibular advancement has been used successfully in the treatment of OSA due to the effect of PAS increase.[17]

The pharyngeal airway is a complicated structure. It cooperates with surrounding structures to perform the physiologic processes of swallowing, speech, and respiration.[18] The pharyngeal airway is subdivided into 3 regions: nasopharynx, oropharynx which contains retropalatal region and retrolingual region, and hypopharynx. The walls of pharyngeal airway consist only of soft tissue so the mechanism that maintains the patent airway results from tension and contraction of the surrounding muscles.

OSA is a condition characterized by recurring episodes of pharyngeal airway obstruction during sleep that results from collapse of the surrounding soft tissues.[19] Prevalence of OSA is approximately 3 to 7 percent for adult men and 2 to 5 percent for adult women in the general population.[20] Therefore, OSA is not infrequent in the age range that the patients commonly seek orthognathic procedures. Especially for class II patients who may already have snoring or OSA, as this deformity has been shown to be related to the clinical appearance of OSA patients. The symptoms of OSA include loud snoring, choking sensation, sudden awakening and especially daytime sleepiness. Other consequences are also significant: cardio metabolic disorder, cognitive dysfunction, anxiety, and increased risk of automobile accidents.[21]

Airway analysis

Cephalometric is still used widely in many studies. Cephalometric can provide a linear or area measurement in sagittal plane of pharyngeal airway. Common methods are used to measure the pharyngeal airway using cephalometric:

1) Linear measurements across the airway at defined points. Several studies have used the method popularized by Riley et al [22] in which the PAS is measured by a line through B-point and Gonion, with the linear measurement from the base of the tongue to the posterior pharyngeal wall. (Figure 1)

However, this linear measurement does not provide consistent anatomic segmentation of the airway that represents 3 regions i.e. nasopharynx, oropharynx and hypopharynx.

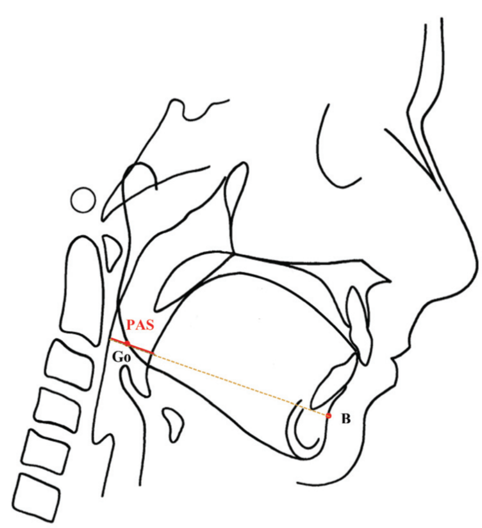

Fig. 1 PAS measurement by Riley

2) Linear measurement across the point of greatest constriction of the airway. Some authors stated that the two sites which are most reported to be narrowed in OSA patients are the retrolingual and retropalatal airway.[8] (Figure 2)

Five different anteroposterior airway measurements were found to be common amongst studies. These measurements were: posterior nasal spine to pharyngeal wall; uvula to pharyngeal wall; base of tongue to pharyngeal wall; vallecula to pharyngeal wall; and minimal pharyngeal airway space. (Figure 3)

However, pharyngeal airway is 3D structure so cephalometric give no information about the lateral width, the cross sectional area and the volume of the airway. Therefore, recently, some authors have used Cone beam computed tomography (CBCT) to analyze the pharyngeal airway. CBCT can provide measurement of axial section area at different plane and volumetric analysis.

Orthognathic Surgery and Airway

One issue of orthognathic surgery, which has gained notice recently, is the effect of jaw movements on the pharyngeal airway. Many researches have showed the correlation between the PAS and OSA. Riley et al [22] found that a PAS less than 11 mm was a risk of OSA. Literature has shown the possibility of potential airway changes after orthognathic surgery and the development of OSA.

Class III deformity surgery

Class III skeletal deformity is the result of mandibular prognathism or maxillary deficiency.[23] Class III malocclusion is more common in Asia than in Caucasian.[24] The class III malocclusion affects around 22.4% of Asia population.[25] Accordingly, class III malocclusions is one of the main cause of seeking orthodontic treatment in these countries, for example, 33% of orthodontic patients in Japan and 20% in China.[26] The orthognathic surgeries commonly used to treat the deformity are mandibular setback osteotomy and Lefort I maxillary advancement osteotomy.

Mandibular Setback

Bilateral sagittal split ramus osteotomy (BSSRO) is the most common procedure. It is due to the versatility in treating mandibular deformities.

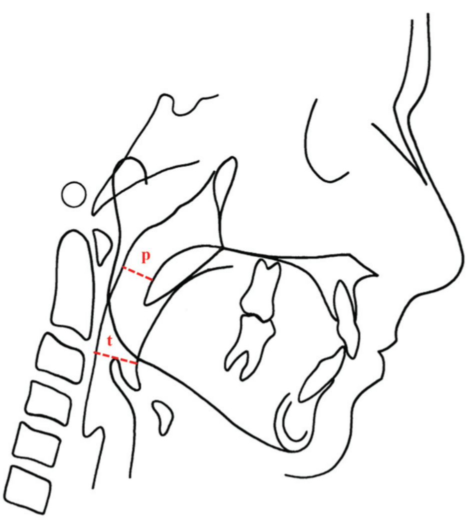

Fig. 2 p: narrowest dimension in retropalatal airway, t: narrowest dimension in retrolingual airway.

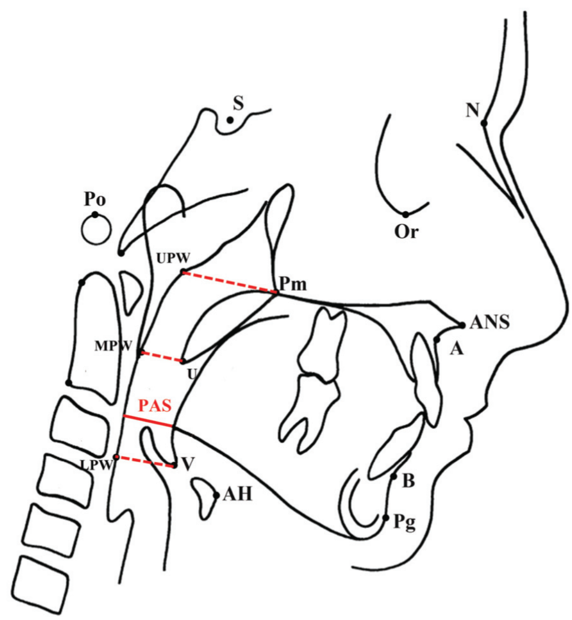

Fig. 3 Common measurement of pharyngeal airway in cephalometry

The comparison of anteroposterior changes after mandibular setback surgery showed a significant decrease in oropharyngeal airway in retropalatal dimension (mean -2.57 mm)[9, 27-30] and in retrolingual (mean -2.99 mm).[6, 9, 12, 28-32] The lateral width of the oropharyngeal airway also decreased after surgery (mean -2.37 mm).[6, 28] Comparison of studies on mandibular setback surgery in CBCT showed a significant decrease in the axial section area of oropharyngeal airway at the level of the base of tongue (mean -46.23 mm^2).[28, 30] However, Park et al. [30] found no significant changes in the volume of the oropharyngeal airway.

The hyoid bone may be considered as the skeleton of the tongue. The hyoid bone serves as an indicator of the position of the tongue. Studies also showed downward and backward displacement of the hyoid bone post operation, which moved the tongue in the similar direction.[3, 6, 33] The posteriorly displaced tongue narrows the retrolingual dimension of the airway and decreases the PAS.[5-7, 9] Tongue's displacement also causes the palatoglossus muscle to become less upright, increases the length of the soft palate and pushes the soft palate posteriorly and narrows the PAS.[29]

Liukkonen et al[9] noted that the degree of clockwise rotation of the mandible during the BSSRO is associated with the degree of airway narrowing. Another observation was the adaptive increased craniocervical inclination or counter clockwise rotation of the face after BSSRO setback.[13, 34] The extension of the head serves as a compensatory mechanism in pulling the hyoid bone away from the posterior pharyngeal wall and pulling the tongue and soft palate from interfering with the upper airway.[35] Muto et al [34] reported that the PAS correlated with the head posture (inclination at the cervical vertebrae). They concluded that 10° rise in the inclination will result in an increase in PAS about 4 mm. Kawamata et al [6] using 3D CT, found a positive correlation between the extent of mandibular setback, reduction in the lateral width of the pharyngeal airway, and the extent of hyoid bone displacement. Muto et al [36] developed a formula to predict the change of PAS on the cephalometric after mandibular setback surgery. The postoperative anteroposterior PAS dimension was calculated from the change of C3-Me (distance between the anteroinferior point of the third cervical vertebra and Menton) using 2 cephalometric taken before and after surgery 1 year. The equation used was PAS = -21.105 + 0.402 C3-Me (r =0.854).

There are controversies about the degree and stability of the postoperative changes in the PAS. Some studies suggested that the changes are temporary as the tissues readapt, resulting in partial or total resolution.[3, 14, 27, 33] However, most of the other studies showed that the changes of the airway are stable over the long time.[2, 5-7, 11, 33]

Bimaxillary Surgery

Some studies stated that Lefort I advancement would not produce an increase in retro-palatal airway space. On the other hand, there was a significant decrease in retropalatal airway dimension.[8, 14] This was may be due to 2 reasons. Firstly, after maxillary advancement, there is adaptation of the soft palate to maintain velopharyngeal seal and palatal function.[37] Secondly, the tongue moved posteriorly and superiorly from the mandibular setback and come into contact and displaces the soft palate backwards and upwards.[38] As a result, the soft palate will be longer and thinner and the palatal angle increases.

Mattos et al [31] stated that there is a significant decrease in retropalatal dimension (mean -0.91 mm)[16, 27, 28, 39, 40] and a highly significant decrease in retrolingual dimension (mean -2.83 mm)[28, 40] but no significant change in the minimal PAS. The axial section areas in retropalatal and retroligual level show no significant change.[28, 39] Jakobsone et al [39] observed a substantial increase in volume in the oropharyngeal and hypopharyngeal areas but no statistically significant changes in the total volume.

Class II Deformity Surgery

The prevalence of class II malocclusion in Asian population is about 29.5%.[25] This is less than that of Caucasian population (35%).[41] This deformity is due to mostly mandibular deficiency and less frequent maxillary protrusion.[42] The patients in this group should be examined carefully as they may already have snoring or OSA. This is due to the fact that this deformity has been shown to be a potential clinical feature of an OSA patient.

Mandible advancement is the most popular treatment whereas maxillary setback is of lesser extent. Mandibular advancement improved the retropalatal and retrolingual dimensions of the airway significantly.[8, 43] Furthermore, there was increased intermaxillary space and decreased tongue proportion. As the tongue area remained unchanged after surgery, this indicates a more functional space for the tongue, which adopts a more anterior position.[8]

Besides mandibular advancement, there are also other procedures that could benefit OSA patients, like genioglossus advancement (GGA), uvulopalatopharyngoplasty (UPPP) and maxillomandibular advancement (MMA). UPPP is a surgical procedure in which the tissues of the soft palate, including the uvula and possibly the tonsils, are removed to improve upper airway obstruction. UPPP is widely used as a first-step procedure for the surgical management of OSA but only at oropharynx level.[44] GGA advances genioglossus muscle to reposition the tongue in a forward position away from the back of the airway. This procedure is a safe and rapid method for improving retrolingual obstruction in OSA.[45] However, the most successful orthognathic procedure that has been documented is MMA.

Maxillomandibular advancement (MMA)

MMA is described as the advancement of the maxilla and mandible via the LeFort I and BSSRO. MMA is the most successful acceptable surgical treatment for OSA, with a therapeutic efficacy equal to that of CPAP.[46]

MMA have traditionally been considered when non-surgical therapies and single-site surgeries, such as UPPP, GGA have been unsuccessful.[46] Some authors now recommend MMA as a first surgical option in patients who have been diagnosed with multiples levels of airway collapse and those with craniofacial skeletal abnormalities.[46] MMA is able, in 80 percent of cases, to bring the AHI index to normal or close to normal value (surgical success outcome AHI <20 and 50% reduction of preoperative AHI).[47]

MMA has been shown to be efficacious in the elimination of OSA because it enlarges the PAS and tightens the upper airway muscles and tendons, by advancement of their bony origin.[48-50] The rationale for this treatment is the advancement of the skeletal attachment of the suprahyoid and velopharyngeal muscles and tendons, so increase the volume of the nasopharynx, oropharynx and hypopharynx.[51]

MMA is so successful because it actually increases the space of the upper airway at many levels. A statistically significant increase was found in all the airway dimensions in the linear, area, volumetric analysis performed after surgery.[52] The average increases were 34% for PAS area, 56% for PAS volume and 112% for the PAS minimum axial area.[53] Some studies showed that the airway gain after MMA is stable.[53, 54] Souza Carvalho stated that there is a partial relapse after 6 months and the airway gain after 6 months is only 80% that of immediate post operation.[52]

Counterclockwise rotation of the maxillomandibular complex

Bimaxillary surgery with counterclockwise rotation of the maxillomandibular complex and mandibular advancement significantly increases the postsurgical PAS and velopharyngeal anatomy.[40] Moreover, the genial tubercles advance further than the teeth, so maximizing the advancement of the hyoid bone, the base of the tongue and the genioglossus and geniohyoid muscles.[55]

The esthetical important point is that the anteroposterior position of the maxilla stays almost the same in contrast to the MMA technique, where the maxilla has to be anteriorly repositioned up to10 mm.[56] This procedure resulted in resolution of the apneic condition in 93.9% of OSA patients, and all the patients were satisfied with their appearance.[57]

Discussion

Most studies that examine changes in the pharyngeal airway by using lateral cephalometric radiograph. Although the fact that lateral cephalometric radiograph provides only two-dimensional information of the pharyngeal airway, it is still a popular method in the assessment of craniofacial structures and sleep apnea. The advantages of cephalometry consist of its availability, simplicity, low cost, easily comparison with other studies. Moreover, cephalometry is a routine diagnosis material for orthodontic and orthognathic surgery treatment. However, CBCT has significant advantages because it allows better delineation of soft tissue and air. Skeletal maxillary and mandibular changes may be described by the change in the sagittal dimension only, but soft tissue pharyngeal changes should be considered in all three dimensions.[4] Some studies reported significant correlation between the PAS measured with cephalometric and the volume of the pharyngeal airway on CBCT[58], but cephalometric provides no information about the lateral structures and cross sectional area of the upper airway. Sears et al found a weak, but statistically significant, correlation between the linear and volumetric measurements in nasophayrnx and oropharynx but not in hypopharynx.[59]

The size and morphology of upper airway structures differs in men and women.[60] Women have greater genioglossal muscle tone than men, suggesting greater defense of the upper airway.[61] Furthermore, OSA is more common in men than in women, despite their smaller pharyngeal airway size.[62] It is still controversy whether changes in pharyngeal airway are different for each gender. Some studies assessed only subjects of the same gender.[5, 16, 50] Samman et al [14] showed a reduction in the minimal airway dimension after mandibular setback surgery only in males. Whereas Degerliyurt et al [63]did not observe any difference between the two genders.

Modern trend in orthognathic surgery is the increase in bimaxillary surgery in treatment of class III deformities. It is due to the refinement of Lefort I down fracture technique and the increased diagnostic awareness of maxillary hypoplasia.[8] In mandibular setback surgery, the main finding is the significant decrease in pharyngeal airway in all dimensions. However, there are controversies about the PAS changes after bimaxillary surgery. Some studies reported a significant decrease in linear measurements and in the retrolingual axial section area, whereas Jakobsone[39]observed a substantial increase in volume in the oropharyngeal and hypopharyngeal areas.

OSA is associated with the presence of a narrowed PAS, inferiorly positioned hyoid, long soft palate, and narrowed nasopharyngeal airway.[22] Mandibular setback surgery changes oropharyngeal characteristics to morphology similar to OSA. However, OSA after mandibular setback was rare and almost the patients have sleep study result within normal range.[3] But it maybe risk in the long term, especially when these patients get older and are more likely to have other risk factors for OSA.[8] Therefore, it is recommended caution when planning mandibular setback of 10 mm or more, especially when the PAS was less than 10 mm. For these patients, it might be better to consider bimaxillary surgery.[14]

The increase in the pharyngeal airway in all the measurement in individuals submitted to MMA surgery seems to confirm the indication of this type of surgery for patients with OSA.[31] Analysis of the literature reveals that the increase in PAS after MMA is greater than that offered by other surgical techniques such as UPPP, GGA because they are only effective at one level of airway obstruction.[49] However, Small proportion of patients (10-20%) failed to respond to MMA even if the anatomic goals of MMA have been achieved.[64] According to recent advance of understanding of the pathophysiology of OSA, besides anatomic constriction of the airway, central nervous system regulation of breathing (ventilator control) is now recognized as a significant contributor to the pathogenesis of OSA.[65]

Funding: None
Competing interests: None
Ethical approval: None (Review article)

References

1. Greco JM, Frohberg U, Van Sickels JE. Cephalometric analysis of long-term airway space changes with maxillary osteotomies. *Oral Surg Oral Med Oral Pathol* 1990; 70: 552-4.
2. Greco JM, Frohberg U, Van Sickels JE. Long-term airway space changes after mandibular setback using bilateral sagittal split osteotomy. *Int J Oral Maxillofac Surg* 1990; 19: 103-5.
3. Enacar A, Aksoy AU, Sencift Y, Haydar B, Aras K. Changes in hypopharyngeal airway space and in tongue and hyoid bone positions following the surgical correction of mandibular prognathism. *Int J Adult Orthodon Orthognath Surg* 1994; 9: 285-90.
4. Hochban W, Schurmann R, Brandenburg U, Conradt R. Mandibular setback for surgical correction of mandibular hyperplasia--does it provoke sleep-related breathing disorders? *Int J Oral Maxillofac Surg* 1996; 25: 333-8.
5. Achilleos S, Krogstad O, Lyberg T. Surgical mandibular setback and changes in uvuloglossopharyngeal morphology and head posture: a short- and long-term cephalometric study in males. *Eur J Orthod* 2000; 22: 383-94.
6. Kawamata A, Fujishita M, Ariji Y, Ariji E. Three-dimensional computed tomographic evaluation of morphologic airway changes after mandibular setback osteotomy for prognathism. *Oral Surg Oral Med Oral Pathol Oral Radiol Endod* 2000; 89: 278-87.
7. Tselnik M, Pogrel MA. Assessment of the pharyngeal airway space after mandibular setback surgery. *J Oral Maxillofac Surg* 2000; 58: 282-5; discussion 85-7.
8. Turnbull NR, Battagel JM. The effects of orthognathic surgery on pharyngeal airway dimensions and quality of sleep. *J Orthod* 2000; 27: 235-47.
9. Liukkonen M, Vahatalo K, Peltomaki T, Tiekso J, Happonen RP. Effect of mandibular setback surgery on the posterior airway size. *Int J Adult Orthodon Orthognath Surg* 2002; 17: 41-6.
10. Eggensperger N, Smolka W, Iizuka T. Long-term changes of hyoid bone position and pharyngeal airway size following mandibular setback by sagittal split ramus osteotomy. *J Craniomaxillofac Surg* 2005; 33: 111-7.
11. Guven O, Saracoglu U. Changes in pharyngeal airway space and hyoid bone positions after body ostectomies and sagittal split ramus osteotomies. *J Craniofac Surg* 2005; 16: 23-30.
12. Kawakami M, Yamamoto K, Fujimoto M, et al. Changes in tongue and hyoid positions, and posterior airway space following mandibular setback surgery. *J Craniomaxillofac Surg* 2005; 33: 107-10.
13. Muto T, Yamazaki A, Takeda S, et al. Relationship between the pharyngeal airway space and craniofacial morphology, taking into account head posture. *Int J Oral Maxillofac Surg* 2006; 35: 132-6.
14. Samman N, Tang SS, Xia J. Cephalometric study of the upper airway in surgically corrected class III

skeletal deformity. ***Int J Adult Orthodon Orthognath Surg*** 2002; 17: 180-90.
15. Riley RW, Powell NB, Guilleminault C, Ware W. Obstructive sleep apnea syndrome following surgery for mandibular prognathism. ***J Oral Maxillofac Surg*** 1987; 45: 450-2.
16. Marsan G, Cura N, Emekli U. Changes in pharyngeal (airway) morphology in Class III Turkish female patients after mandibular setback surgery. ***J Craniomaxillofac Surg*** 2008; 36: 341-5.
17. Waite PD, Vilos GA. Surgical changes of posterior airway space in obstructive sleep apnea. ***Oral Maxillofac Surg Clin North Am*** 2002; 14: 385-99.
18. Schwab RJ, Goldberg AN. Upper airway assessment: radiographic and other imaging techniques. ***Otolaryngol Clin North Am*** 1998; 31: 931-68.
19. Goodday RH, Percious DS, Morrison AD, Robertson CG. Obstructive sleep apnea syndrome: diagnosis and management. ***J Can Dent Assoc*** 2001; 67: 652-8.
20. Punjabi NM. The epidemiology of adult obstructive sleep apnea. ***Proc Am Thorac Soc*** 2008; 5: 136-43.
21. Marin JM, Carrizo SJ, Vicente E, Agusti AG. Long-term cardiovascular outcomes in men with obstructive sleep apnoea-hypopnoea with or without treatment with continuous positive airway pressure: an observational study. ***Lancet*** 2005; 365: 1046-53.
22. Riley R, Guilleminault C, Herran J, Powell N. Cephalometric analyses and flow-volume loops in obstructive sleep apnea patients. ***Sleep*** 1983; 6: 303-11.
23. Samman N, Tong AC, Cheung DL, Tideman H. Analysis of 300 dentofacial deformities in Hong Kong. ***Int J Adult Orthodon Orthognath Surg*** 1992; 7: 181-5.
24. TM G. ***Current Principles and Techniques***; 2005.
25. Soh J, Sandham A, Chan YH. Occlusal status in Asian male adults: prevalence and ethnic variation. ***Angle Orthod*** 2005; 75: 814-20.
26. Fu M, Zhang D, Wang B, et al. The prevalence of malocclusion in China--an investigation of 25,392 children. ***Zhonghua Kou Qiang Yi Xue Za Zhi*** 2002; 37: 371-3.
27. Chen F, Terada K, Hua Y, Saito I. Effects of bimaxillary surgery and mandibular setback surgery on pharyngeal airway measurements in patients with Class III skeletal deformities. ***Am J Orthod Dentofacial Orthop*** 2007; 131: 372-7.
28. Degerliyurt K, Ueki K, Hashiba Y, Maru Kana K, Na Kagana K, Yamamoto E. A comparative CT evaluation of pharyngeal airway changes in class III patients receiving bimaxillary surgery or mandibular setback surgery. ***Oral Surg Oral Med Oral Pathol Oral Radiol Endod*** 2008; 105: 495-502.
29. Muto T, Yamazaki A, Takeda S, Sato Y. Effect of bilateral sagittal split ramus osteotomy setback on the soft palate and pharyngeal airway space. ***Int J Oral Maxillofac Surg*** 2008; 37: 419-23.
30. Park JW, Kim NK, Kim JW, Kim MJ, Chang YI. Volumetric, planar, and linear analyses of pharyngeal airway change on computed tomography and cephalometry after mandibular setback surgery. ***Am J Orthod Dentofacial Orthop*** 2010; 138: 292-9.
31. Mattos CT, Vilani GN, Sant'Anna EF, Ruellas AC, Maia LC. Effects of orthognathic surgery on oropharyngeal airway: a meta-analysis. ***Int J Oral Maxillofac Surg*** 2011; 40: 1347-56.
32. Chen F, Terada K, Hanada K, Saito I. Predicting the pharyngeal airway space after mandibular setback surgery. ***J Oral Maxillofac Surg*** 2005; 63: 1509-14.
33. Gu G, Gu G, Nagata J, et al. Hyoid position, pharyngeal airway and head posture in relation to relapse after the mandibular setback in skeletal Class III. ***Clin Orthod Res*** 2000; 3: 67-77.
34. 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.
35. Solow B, Skov S, Ovesen J, Norup PW, Wildschiodtz G. Airway dimensions and head posture in obstructive sleep apnoea. ***Eur J Orthod*** 1996; 18: 571-9.
36. Muto T, Yamazaki A, Takeda S, Sato Y. Accuracy of predicting the pharyngeal airway space on the cephalogram after mandibular setback surgery. ***J Oral Maxillofac Surg*** 2008; 66: 1099-103.
37. Schendel SA, Oeschlaeger M, Wolford LM, Epker BN. Velopharyngeal anatomy and maxillary advancement. ***J Maxillofac Surg*** 1979; 7: 116-24.
38. Lye KW. Effect of orthognathic surgery on the posterior airway space (PAS). ***Ann Acad Med Singapore*** 2008; 37: 677-82.
39. Jakobsone G, Neimane L, Krumina G. Two- and three-dimensional evaluation of the upper airway after bimaxillary correction of Class III malocclusion. ***Oral Surg Oral Med Oral Pathol Oral Radiol Endod*** 2010; 110: 234-42.
40. Mehra P, Downie M, Pita MC, Wolford LM. Pharyngeal airway space changes after counterclockwise rotation of the maxillomandibular complex. ***Am J Orthod Dentofacial Orthop*** 2001; 120: 154-9.
41. McLain JB, Proffitt WR. Oral health status in the United States: prevalence of malocclusion. ***J Dent***

Educ 1985; 49: 386-97.
42. McNamara JA, Jr. Components of class II malocclusion in children 8-10 years of age. *Angle Orthod* 1981; 51: 177-202.
43. Yu LF, Pogrel MA, Ajayi M. Pharyngeal airway changes associated with mandibular advancement. *J Oral Maxillofac Surg* 1994; 52: 40-3; discussion 44.
44. Senior BA, Rosenthal L, Lumley A, Gerhardstein R, Day R. Efficacy of uvulopalatopharyngoplasty in unselected patients with mild obstructive sleep apnea. *Otolaryngol Head Neck Surg* 2000; 123: 179-82.
45. Lewis MR, Ducic Y. Genioglossus muscle advancement with the genioglossus bone advancement technique for base of tongue obstruction. *J Otolaryngol* 2003; 32: 168-73.
46. Prinsell JR. Maxillomandibular advancement surgery for obstructive sleep apnea syndrome. *J Am Dent Assoc* 2002; 133: 1489-97; quiz 539-40.
47. Blumen MB, Buchet I, Meulien P, et al. Complications/adverse effects of maxillomandibular advancement for the treatment of OSA in regard to outcome. *Otolaryngol Head Neck Surg* 2009; 141: 591-7.
48. Hochban W, Conradt R, Brandenburg U, Heitmann J, Peter JH. Surgical maxillofacial treatment of obstructive sleep apnea. *Plast Reconstr Surg* 1997; 99: 619-26; discussion 27-8.
49. Prinsell JR. Maxillomandibular advancement surgery in a site-specific treatment approach for obstructive sleep apnea in 50 consecutive patients. *Chest* 1999; 116: 1519-29.
50. Marsan G, Vasfi Kuvat S, Oztas E, Cura N, Siisal Z, Emkli U. Oropharyngeal airway changes following bimaxillary surgery in Class III female adults. *J Craniomaxillofac Surg* 2009; 37: 69-73.
51. Li KK, Powell NB, Riley RW, Troell RJ, Guilleminault C. Long-Term Results of Maxillomandibular Advancement Surgery. *Sleep Breath* 2000; 4: 137-40.
52. de Souza Carvalho AC, Magro Filho O, Garcia IR, Jr., Araujo PM, Nogueira RL. Cephalometric and three-dimensional assessment of superior posterior airway space after maxillomandibular advancement. *Int J Oral Maxillofac Surg* 2012; 41: 1102-11.
53. Raffaini M, Pisani C. Clinical and cone-beam computed tomography evaluation of the three-dimensional increase in pharyngeal airway space following maxillo-mandibular rotation-advancement for Class II-correction in patients without sleep apnoea (OSA). *J Craniomaxillofac Surg* 2013.
54. Goncalves JR, Buschang PH, Goncalves DG, Wolford LM. Postsurgical stability of oropharyngeal airway changes following counter-clockwise maxillo-mandibular advancement surgery. *J Oral Maxillofac Surg* 2006; 64: 755-62.
55. Wolford LM, Chemello PD, Hilliard F. Occlusal plane alteration in orthognathic surgery--Part I: Effects on function and esthetics. *Am J Orthod Dentofacial Orthop* 1994; 106: 304-16.
56. Zinser MJ, Zachow 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* 2012; 42: 569-78.
57. Brevi BC, Toma L, Pau M, Sesenna E. Counterclockwise rotation of the occlusal plane in the treatment of obstructive sleep apnea syndrome. *J Oral Maxillofac Surg* 2011; 69: 917-23.
58. Riley RW, Powell NB. Maxillofacial surgery and obstructive sleep apnea syndrome. *Otolaryngol Clin North Am* 1990; 23: 809-26.
59. Sears CR, Miller AJ, Chang MK, Huang JC, Lee JS. Comparison of pharyngeal airway changes on plain radiography and cone-beam computed tomography after orthognathic surgery. *J Oral Maxillofac Surg* 2011; 69: e385-94.
60. Nakagawa F, Ono T, Ishiwata Y, Kuroda T. Morphologic changes in the upper airway structure following surgical correction of mandibular prognathism. *Int J Adult Orthodon Orthognath Surg* 1998; 13: 299-306.
61. Popovic RM, White DP. Influence of gender on waking genioglossal electromyogram and upper airway resistance. *Am J Respir Crit Care Med* 1995; 152: 725-31.
62. Mohsenin V. Effects of gender on upper airway collapsibility and severity of obstructive sleep apnea. *Sleep Med* 2003; 4: 523-9.
63. Degerliyurt K, Ueki K, Hashiba Y, et al. The effect of mandibular setback or two-jaws surgery on pharyngeal airway among different genders. *Int J Oral Maxillofac Surg* 2009; 38: 647-52.
64. Goode RL. Success and failure in treatment of sleep apnea patients. *Otolaryngol Clin North Am* 2007; 40: 891-901.
65. Susarla SM, Thomas RJ, Abramson ZR, Kaban LB. Biomechanics of the upper airway: Changing concepts in the pathogenesis of obstructive sleep apnea. *Int J Oral Maxillofac Surg* 2010; 39: 1149-59.