



# Surgical evaluation for reconstruction of the upper airway

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Surgical reconstruction of the upper airway is designed to reduce collapsibility and optimize stability of the airway. A universally accepted protocol for reconstruction of the upper airway does not exist. The philosophy of identifying the anatomic site of airway compromise and surgically correcting it, however, is generally accepted. A successful surgical outcome should be equivalent to successful continuous positive airway pressure (CPAP) treatment. Contributing factors for airway collapse can be complex and involve physiologic, neurogenic, and anatomic findings that demand a comprehensive evaluation before embarking on the reconstructive process. This article discusses evaluation considerations and surgical staging protocols that may be beneficial in achieving a successful surgical outcome.

## The consultation

Polysomnography identifies the severity of the disease and is usually the first objective data used to assess the patient; however, a detailed history from the patient and bed partner is crucial in identifying behavioral factors contributing to poor sleep architecture and excessive daytime somnolence. Attention to and correction of psychologic dysfunction such as clinical depression only enhances the possibility of a successful surgical outcome [1].

The medical status of the patient is assessed during the initial consultation and determines if the patient is a surgical candidate. The medical considerations for preoperative evaluations are covered in another article in this issue.

Preoperative evaluation must include a thorough review of a recent nocturnal polysomnography (NPSG). The apnea hypopnea index (AHI), or the number of apneas and hypopneas per hour of sleep, indexes the severity of the condition. This categorization alone with oxygen desaturation classifies the patient as having mild, moderate, or severe obstructive sleep apnea (OSA). Normal values for the AHI range from 5 to 10 apneas or hypopneas per hour [2,3]. An AHI of 10 to 20 is considered indicative of mild OSA, 20 to 35 apneas or hypopneas per hour is considered moderate OSA, and greater than 40 apneas or hypopneas per hour is considered severe. There is a significant increase in morbidity associated with an AHI greater than 20 per hour [4], and those patients with higher AHI values have been linked to a greater incidence of perioperative airway complications [5]. The Sao<sub>2</sub> data as stated previously should be examined to determine the awake base line and mean Sao<sub>2</sub> sleep desaturations because lower values are indicative of potential perioperative respiratory compromise [5].

Surgical staging consideration is determined by analysis of the preoperative sleep study and the evaluation of the anatomic airway. For example, a surgical candidate with a relatively high AHI classified as moderate to severe OSA may receive recommendations for a bimaxillary advancement as the first stage of surgical reconstruction even in the

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absence of craniofacial abnormality, whereas the patient with a mild to moderate OSA diagnosis may receive recommendation for a uvulopalatopharyngoplasty (UPPP) and anterior mandibular osteotomy with genioglossus muscle advancement as the first stage if the craniofacial anatomy is normal. Surgical staging is discussed in detail later.

### Examination of the upper airway

Clinical examination of the upper airway is designed to identify compromised anatomic sites that are susceptible to collapse and to identify characteristics that directly contribute to the pathophysiology of OSA [6].

The goals of examination are to (1) identify sites of anatomic upper airway pathology, (2) predict the site and levels of obstruction during sleep, and (3) identify areas where surgery may reduce resistance, increase size, or decrease collapsibility of the upper airway and thereby improve OSA. Staged surgical treatment may then be directed at appropriate segments of the upper airway. [7].

The upper airway performs several physiologic functions including deglutition, vocalization, and respiration. The upper airway is subdivided into three regions on the basis of sagittal imaging nomenclature: (1) nasopharynx (region between the turbinate and hard palate); (2) oropharynx, subdivided into the retropalatal (the level of the hard palate to the caudal margin of the palate) and retroglottal (the caudal margin of the soft palate to the base of the epiglottis) regions; and (3) hypopharynx (region from the base of the tongue to the cervical esophagus) [8–10].

The pathogenesis associated with upper airway obstruction is complex, involving muscular, neurologic, anatomic, and developmental anomalies as well as other etiologic factors. This multifactorial picture is impossible to capture with the awake assessment of the upper airway and may not have a direct correlation to obstruction during sleep [11]. Nevertheless, sites of potential collapse and identification of pathologic comprises in the upper airway are useful in directing a definitive surgical plan to improve the stability of the upper airway.

#### *The nose*

The nasal airway is the beginning of the airway conduit, and resistance in nasal airflow can play a major role in snoring and sleep apnea. The greatest increase in resistance occurs at the nasopharyngeal/

retropalatal portion of the upper airway [12]. Therefore, because the upper airway is a collapsible tube, the Starling resistor principle exists. Specifically, proximal resistance determines the critical closure and location of obstruction at distal pharyngeal sites [12]. Therefore, a patent nasal airway with minimal resistance is important to the overall stability of the upper airway. The external examination of the nose can identify compromises in nasal airflow such as a deviated dorsum, constricted nasal width, tip ptosis, and soft tissue asymmetries. Nasal speculum and fiber optic examination is necessary to diagnose rhinitis, septal deviation, hypertrophic turbinates, nasal masses, and polyps. Most nasal pathology can be treated pharmacologically; therefore, medication should be the first line of treatment.

#### *The oral cavity*

The position of the maxilla and mandible relative to the cranial base is manifested by the categorization of the dental occlusion. The skeletal position of the maxilla and mandible is best determined by cephalometric imaging; however, the dental occlusion (class II or class III) may suggest hypoplasia or hyperplasia of the maxilla or mandible and is an important indication of the relative position of soft palate and base of tongue to the posterior pharynx. Maxillary and mandibular hypoplasia is associated with a retropositioning of upper airway soft tissue. The dental health of the periodontium is also important and should be noted in the clinical assessment. The presence of mandibular tori could potentially displace the base of the tongue posteriorly, thus compromising the retrolingual airway space.

The oral examination of the palate is significant in determining the overall stability the oropharyngeal airway. The overall length of the soft palate, thickness of the soft palate, and anatomic findings associated with the lateral tonsillar pillars and size of the tonsils if present are important in surgical treatment planning.

Relative macroglossia is rare; however, the position of the posterior third of the tongue base relative to the posterior pharyngeal wall and epiglottis should be noted. Again, cephalometric analysis of the posterior airway space is helpful in evaluating the base of tongue relative to the soft palate and posterior pharynx.

The circumference of the neck should be measured. Flemmons and colleagues have noted that neck circumference increases are associated with the presence of hypertension, and increased witnessed gasping, therefore, the percentage incidence of OSA increases [13].

### *Endoscopic pharyngoscopy*

Direct visualization of the upper airway aids in the identification of anatomic compromise and potential areas of airway collapse. The accurate determination of the site of obstruction in the upper airway is vital to selecting the appropriate surgical procedure. Most OSA patients have clearly identifiable pathology [14]. Therefore, awake endoscopic pharyngoscopy in the supine position, mouth closed, and at rest obviously is not the same neuromuscular situation as sleep; however, it is a reliable modality to evaluate the anatomic airway. Comparison of endoscopy during pharmacologically induced sleep and physiologic sleep has been controversial and not universally accepted [15].

After the application of a topical anesthetic and a decongestant, nasopharyngoscopy can be performed comfortably. The nasal airway is evaluated for nasal pathology including septal deviation, turbinate hypertrophy, polyps, or nasal masses that may be responsible for partial obstruction of the upper airway. The nasopharynx is then examined to rule out obstruction from adenoids, polyps, masses, or cysts. The nasal aspect of the soft palate is evaluated to determine possible obstruction from tonsillar tissue, base of the uvularis muscle, or a thickened posteriorly positioned palate. The patient is then asked to perform a Muller's maneuver, which is forced inspiratory effort with the mouth and nose closed, to determine if there is obstruction at the level of the soft palate. A positive Mueller's maneuver and the degree of obstruction or partial obstruction is quantified subjectively. There is still controversy associated with the clinical significance associated with collapse of the airway during the Mueller's maneuver. The use of the Mueller's maneuver and fiber optic endoscopy on the awake patient was first reported by Borowiecki and Sassion [16] and Walsh and Datsantonis [17] who utilized somnofluoroscopy to demonstrate that patients with partial collapse at the level of the soft palate only were more likely to benefit from UPPP alone. Sher et al [18] subjectively quantified the degree of collapse at the level of the soft palate as follows: (1) Minimal movement of the components of the circumference of the pharyngeal cross section toward the center. (2) Movement toward the center diminishing cross-sectioned area of the pharynx by 50%. (3) Movement toward the center diminishing cross-sectioned area of the pharynx by 75%. (4) Inward motion obliterating the airway [18]. They concluded that the Mueller's maneuver provided a simple means of assessing pharyngeal dynamics in relationship to OSA. The endoscopic examination proceeds to the

level of the oropharynx, and the base of the tongue is evaluated along with the tonsillar tissues. The relationship of the base of tongue to the posterior pharyngeal wall and epiglottis should be noted. Retrolingual positioning is subjective; however, it is identifiable, as is redundant lateral tonsillar tissue. Because most obstruction during sleep occurs at the retropalatal and retroglottal areas [19], this portion of the examination is important to rule out or diagnose multiple sites of airway compromise.

The patient is asked to perform another Mueller's maneuver as the endoscope is passed into the hypopharynx. The position of the base of tongue to the epiglottis and posterior pharyngeal wall is observed to assess a more accurate degree of closure and repositioning of the base of tongue. The larynx and vocal cords are also evaluated to rule out any supraglottic, glottic, or subglottic pathology.

The clinical examination, endoscopic pharyngoscopy, and imaging of the upper airway serve as a guide to select the appropriate surgical procedure or procedures to reconstruct the upper airway adequately without overtreatment. As the level of understanding of the upper airway collapse increases, so too will the sophistication of the diagnostic evaluation. The ultimate goal is to predict success in the selection of the appropriate surgical procedure, which is so elusive today.

### **Imaging**

The biomechanics of upper airway collapse in OSA remains complex. Modern imaging techniques have provided much information in assessing the anatomic characteristics of the soft tissue and bony structure of the upper airway. Dynamic and static imaging techniques are useful in evaluating the function of the upper airway in both pretreatment and posttreatment states. Various imaging techniques such as the cephalometric radiograph with and without barium, MRI, CT, and dynamic somnofluoroscopy have also promoted understanding of the efficacy of treatment. The cephalometric radiograph, however, is the most inexpensive widely used technique to evaluate the upper airway. This section reviews the efficacy and associated diagnostic capability of each technique.

#### *The cephalometric radiograph*

The cephalometric radiograph is a static two-dimensional interpretation of a three-dimensional upper airway. The cephalogram, however, has stand-

ards that make the interpretation uniform. Each exposure has a standard position and distance of the central beam to the target. One clinician can be responsible for the interpretation, and the exposure is always at end expiration. Radiographs are inexpensive and readily available, which makes this technique attractive for the diagnostic evaluation. DeBerry-Borowiecki et al concluded that cephalometric analysis could be useful in conjunction with the head and neck examination, polysomnographic, and endoscopic studies to evaluate OSA patients and in planning surgical treatment for improvement of upper airway patency. [20]

The cephalometric radiograph offers a unique quantification of craniofacial anatomy necessary in the treatment of craniofacial deformities and OSA. The method of interpretation that is most accepted in OSA is the technique of Riley et al, which demonstrates a positive correlation to volumetric analysis of the upper airway by CT [21]. The following cephalometric landmarks are primarily used in interpreting the upper airway in OSA: S: sella; N: nasion; A: subspinale; B: supramental; Pg: pogonion; ANS: anterior nasal spine; PNS: posterior nasal spine; Gn: gnathion; Go: gonion; Mp; mandibular plane; H: hyoid; Ba: basion. The following angles are also primarily used in interpreting the upper airway in OSA patients: SNA; SNB; GoGn-SN; NSBa (cranial base flexure); MP-H; mandibular plane to hyoid) PNS-P (distance from posterior nasal spine to soft palate); PAS (posterior airway space)(Fig. 1).

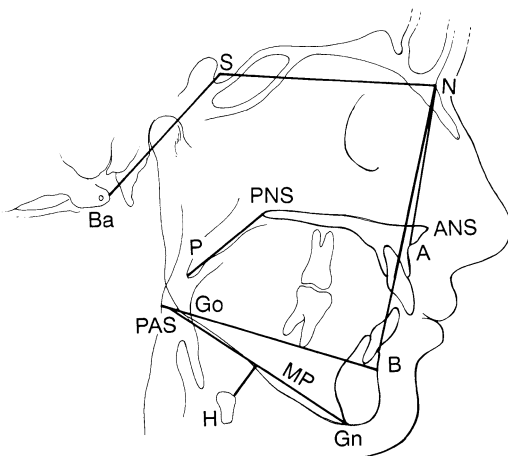


Fig. 1. Cephalometric analysis screening measurements identify the position of the maxilla and mandible, and the relationship of the PAS. (From Waite PD, Shettar SM. Maxillomandibular advancement surgery: a cure for obstructive sleep apnea syndrome. Oral Maxillofac Surg Clin North Am 1995;7:327–36; with permission.)

Jamieson et al demonstrated that OSA patients had the following characteristics: (1) a normally positioned maxilla, (2) a retroposition of the mandible, and (3) different cranial base flexure with a nasion-sella-basion angle smaller than expected (ie, more acute) [22]. The combined effect of a normally positioned maxilla and a retroposition of the mandible reduces the space occupied by soft tissue anchored on the skull and mandible [21].

Barium has been used with the cephalometric radiograph to enhance the soft tissue interpretation. Little additional information, however, is gained with the use of barium and it is not widely used. There are limitations of the cephalogram, and they should be noted. The cephalogram remains a two-dimensional study of three-dimensional anatomy, and thus accurate volumetric analysis of the upper airway is not possible. The effects of tonsillar hypertrophy or other lateral soft tissue on the function of the upper airway cannot be accurately accessed. The cephalogram, however, should be included in the diagnostic armamentarium for evaluating the upper airway anatomy in the OSA patient.

#### CT

CT has been used extensively to study the soft tissue and bony structures of the upper airway. CT scanning provides excellent imaging capabilities; however, the soft tissue contrast resolution is not as superior as with MRI. One of the distinct advantages of CT scanning in the supine position is the accurate measurement of upper airway cross-sectional area. Images from CT scanning are only obtained in the axial plane, but volumetric analysis reconstruction of the soft tissue and bony images of the upper airway can be performed [23]. Lowe et al studied a sample of 25 men with OSA using CT volumetric analysis of the upper airway at the base of tongue; volumetric analysis provided an excellent overview of the interaction between these structures [24]. Volumetric analysis can also be accomplished with helical CT scanners, whereas dynamic imaging of the upper airway is possible using electron beam CT scanning.

CT scanning does have limitations: it is relatively expensive, there are patient weight limitations, excessive radiation exposure limits repeat studies, and there is poor contrast resolution of upper airway adipose tissue [25]. Despite these relative disadvantages, CT scanning has been and will continue to provide knowledge necessary to understand the impact of soft tissue and bony structures of the upper airway in the pathogenesis of OSA.

## MRI

The ideal upper airway imaging modality for patients with OSA should be inexpensive and non-invasive and be performed in the supine position without radiation. In addition, such an imaging technique should provide high-resolution anatomic representation of the airway and surrounding soft tissue structures with the capability of performing dynamic images during wakefulness and sleep. Such an imaging technique does not exist, although MR scanning is an excellent method to access the upper airway. Moreover, MRI maybe the ideal modality for OSA because it provides excellent upper airway soft tissue resolution, accurately determines cross-sectional area and volume, allows imaging in the axial, sagittal, and coronal planes, and can be performed during wakefulness and sleep without radiation [26–29].

MR is not without its disadvantages, however. The procedure is expensive and not widely available. Claustrophobia can be a problem and there are patient weight limitations of approximately 300 pounds. Patients with ferromagnetic clips or pacemakers are not candidates for this technique. When indicated MR, however, is an excellent tool to assess the upper airway preoperatively and the technique has been very successful in the understanding of the role of soft tissue and bony anatomy in the pathogenesis of OSA.

## Surgical staging

Selection of the appropriate surgical procedures and the protocol for reconstruction of the upper airway remains one of the more controversial subjects in the treatment of OSA. Although a universally accepted protocol for reconstruction of the upper airway does not exist, much knowledge has been gained in understanding the pathogenesis of OSA and effectiveness of the advancements in surgical treatment modalities. Surgical treatment of snoring and mild OSA are addressed in another article in this issue. This section discusses surgical staging for adults with moderate and severe OSA.

It is universally accepted that the nasal airway must be patent and functional before addressing collapse of the airway at the retropalatal or retrolingual region. Most nasal airway pathology may be treated pharmacologically; however, septoplasty, turbinate reduction, or both may be necessary to achieve airway stability.

Kuhlo and colleagues described the earliest surgical method for successful treatment of OSA by bypassing the upper airway with the tracheostomy

[30]. Later, Fujita et al [31] advocated UPPP, which was a modification of the procedure described by Ikematsu for the treatment of snoring [32]. Further retrospective studies concluded that successful treatment of OSA with UPPP was at best approximately 50% [5]. Riley, Powell, and Guilleminault reviewed UPPP failures and concluded that base of tongue obstruction contributed to airway collapsibility [33,34]. Additional published data established that fact that the soft palate, base of tongue, and pharyngeal walls of the hypopharynx contribute to the collapsibility of the airway [35].

Riley and Powell were the first to describe a staged surgical protocol for addressing a site-specific surgical correction to obstruction of the upper airway. For type II obstructions (soft palate and base of tongue) Riley and Powell performed stage I surgery, a UPPP and anterior mandibular osteotomy (AMO) with genioglossus muscle advancement and hyoid suspension (GAHM), which yielded a 97.8% elimination of OSA [34,36]. Whereas Riley and Powell were the first to advocate a two-stage surgical reconstruction of the upper airway, other authors published data on the technique of site specific correction of the upper airway. Johnson and Chinn reported an elimination of OSA (postoperative respiratory disturbance index [RDI] less than 10 and 50% reduction in preoperative RDI) in 77.8% of OSA patients with a UPPP and AMO and genioglossus muscle advancement (GMA) without hyoid suspension [37]. Lee et al [20] reported a review of 35 patients treated with stage I reconstruction, UPPP and AMO/GMA. Most patients responded positively to stage I reconstruction with a postoperative RDI < 20, with oxygen saturation 95<sup>+</sup>%. Twenty-four patients (69%) had postoperative RDIs of 20 or less. Of these, 11 patients (31%) had an RDI of 5 or less; 7 patients (20%) had an RDI between 6 and 10, and 6 patients (17%) had an RDI between 10 and 20. The mean preoperative RDI was 53, and the mean postoperative RDI was 19. Of the 3 patients who elected to proceed to stage II reconstruction, all had a postoperative RDI of 10 or less (2 patients [67%] had a RDI of 5 or less, and 1 patient [33%] had an RDI of 6 to 10). This study showed that properly selected patients with OSA syndrome benefit from a staged reconstruction of the upper airway.

Other authors have advocated bimaxillary advancement as the first stage of treatment for OSA. Hochban and colleagues [38] reported on a series of 20 patients treated primarily with maxillomandibular advancement (MMA). All patients treated with MMA alone (20) had a postoperative RDI less than 10. One patient required a UPPP to complete reconstruction of the upper airway.

Waite et al [39] reported on a series of 23 patients treated with MMA alone with a surgical success rate of 65% (RDI less than 10). The failed patients became a surgical success after adjunctive procedures to reconstruct the upper airway.

Prinsell [40] reported on a series of 50 patients treated with MMA and a modified anterior inferior mandibular osteotomy for reconstruction of the upper airway. All of these patients had diffusely complex or multiple sites of disproportionate upper airway anatomy. Prinsell reported a 100% surgical success rate (AHI of less than 10) in this group of patients.

It is clear that MMA and other adjunctive procedures are effective in the reconstruction of the upper airway; however, the pathogenesis of airway collapse is not as clearly understood. All factors, the AHI, body mass index, length of apneic episodes, neck circumference, oxygen desaturations, presence of craniofacial abnormalities, and sites of disproportionate upper airway anatomy together with consideration of the medical status of the patient are critical in the selection of the surgical procedure to reconstruct the upper airway. Surgical procedures are also selected dependent upon the experience and knowledge of the surgeon performing them.

In cases of failed stage I procedures (UPPP, AMO, or GAHM) or in the presence of craniofacial deformities, the decision to proceed with MMA is without question. In addition, in cases of moderate to severe OSA without significant medical compromise, the decision to select MMA as the first procedure for reconstruction of the upper airway is well supported by the literature. Selection of surgical procedures for reconstruction of the upper airway has been an evolutionary process over the past several decades, and MMA has evolved as an effective first line treatment for moderate and severe OSA. After MMA, site-specific correction of disproportionate anatomy may still be necessary especially if the patient gains weight.

The future remains bright for innovative research and acquisition of knowledge to understand better the pathogenesis of airway instability and the biomechanics of successful surgical outcomes. The oral and maxillofacial surgeon is a vital team member and a leader in the discipline of surgical correction of sleep disordered breathing. It is an exciting time for the oral and maxillofacial surgeon as the multidisciplinary approach to the treatment of OSA continues to evolve.

## References

[1] Reynolds CF, Coble PA, Kupfer DJ. Depressive patients and the sleep laboratory. In Guilleminault C,

editor. Sleep and waking disorders: indications and techniques. Menlo Park, CA: Addison-Wesley; 1982. p. 245–164.

- [2] American Thoracic Society. Indications and standards for cardiopulmonary sleep studies. *Am Rev Respir Dis* 1989;139:559.
- [3] Guilleminault C, Van Den Hoed J, Mitler MM. Clinical overview of the sleep apnea syndrome. New York: Alan R. Liss; 1978.
- [4] Ballard RD, Irvin CG, Martin RJ, et al. Influence of sleep on lung volume in asthmatic patients and normal subjects. *J Appl Physiol* 1989;68:2034.
- [5] Fujita S, Conway W, Zorick F, et al. Uvulopalatopharyngoplasty: one year follow up. *Chest* 1985;88:385.
- [6] Schwab RJ, Goldberg AN. Upper-airway assessment. *Otolaryngol Clin North Am* 1998;31:931–68.
- [7] Woodson BT. Examination of the upper airway. *Oral Maxillofacial Surg Clin North Am* 1995;7:257–69.
- [8] Hudgel DW. The role of upper airway anatomy and physiology in obstructive sleep apnea. *Clin Chest Med* 1992;13:383.
- [9] Schwab RJ, Grupta KB, Gefter WB, et al. Upper airway soft tissue anatomy in normals and patients with sleep disordered breathing: significance of the lateral pharyngeal walls. *Am J Respir Crit Care Med* 1995;152:1673.
- [10] Van Lunteren E. Muscles of the pharynx: structural and contractile properties. *Ear Nose Throat J* 1993;72:27.
- [11] Horner RL, Sher SA, McIvor J, et al. Pharyngeal size and shape during wakefulness and sleep in patients with obstructive sleep apnea. *Q J Med* 1989;72:719–35.
- [12] Kuna ST, Bedi DG, Ryckman C. Effects of nasal airway positive pressure on upper airway size and configuration. *Am Rev Respir Dis* 1988;138:969–75.
- [13] Flemmons WW, Whitelaw WA, Brant R, Remmers JE. Likelihood ratios for a sleep apnea clinical prediction rule. *Am J Respir Crit Care Med* 1994;150:1279–85.
- [14] Rojewski TE, Schuller DE, Clark RW, et al. Video endoscopic determination of mechanism of obstruction in obstructive sleep apnea. *Otolaryngol Head Neck Surg* 1984;92:127.
- [15] Sadaoka T, Kakitsuha N, Fujiwara W, et al. The value of sleep nasendoscopy in the valuation of patients with suspected sleep related breathing disorders. *Clin Otolaryngol-HNS* 1996;21:485–9.
- [16] Borowiecki B, Sassion J. Surgical treatment of sleep apnea. *Arch Otolaryngol-HNS* 1983;109:508.
- [17] Walsh JK, Datsantonis GP. Somnofluoroscopy as a predictor of UPPP efficacy. *Sleep Research* 1984;13:21.
- [18] Sher AE, et al. Predictive values of Mueller's maneuver in selection of patients for uvulopalatopharyngoplasty. *Laryngoscope* 1985;95:1483–7.
- [19] Lee NR, Givens CD Jr, Wilson J, Robins RB. Staged surgical treatment of obstructive sleep apnea syndrome: a review of 35 patients. *J Oral Maxillofac Surg* 1999;57:382–5.
- [20] DeBerry-Borowiecki B, Kukwa A, Blanks RH. Analysis for diagnosis and treatment of obstructive sleep apnea. *Laryngoscope* 1998;98.

- [21] Riley R, Guilleminault C, Herran J, Powell N. Cephalometric analysis and flow volume loops in obstructive sleep patients. *Sleep* 1983;6:304–17.
- [22] Jamieson A, Guilleminault C, Partinen M, et al. Obstructive sleep apneic patients have craniomandibular abnormalities. *Sleep* 1986;9:469–477.
- [23] Ryder CF, Lowe AH, Li D, et al. Three dimensional upper airway computed tomography in obstructive sleep apnea. *Am Rev Respir Dis* 1984;129:355.
- [24] Lowe A, et al. Three dimensional CT reconstructions of tongue and airway in adult subjects with obstructive sleep apnea. *Am J Orthod Dentofacial Orthop* 1986; 90:364–74.
- [25] Esclamado RM, Glenn MG, McCulloch TM, et al. Perioperative complications and risk factors in the surgical treatment of obstructive sleep apnea syndrome. *Laryngoscope* 1989;99:1125.
- [26] Schwab RJ. Upper airway imaging. *Clin Chest Med* 1998;19:33–51.
- [27] Abbey NC, Block AJ, Green D, et al. Measurement of pharyngeal volume by digitalized magnetic resonance imaging. *Am Rev Respir Dis* 1989;140:717.
- [28] Ryan CF, Lowe AA, Li D, et al. Magnetic resonance imaging of the upper airway in obstructive sleep apnea before and after chronic nasal continuous positive airway pressure therapy. *Am Rev Respir Dis* 1991; 144:939.
- [29] Soto Y, Matsuo T, Kato T, et al. Evaluation of the pharyngeal airway in patients with sleep apnea: value of ultra fast MR imaging. *AJR Am J Roentgenol* 1993;160:311.
- [30] Kuhlo W, Doll E, Frank MD. Erfolgreiche behandlung eines Pickwick-syndromes durch eine dauertrachealkanule. *Dtsch Med Wochenschr* 1969;94:1286.
- [31] Fujita S, Conway W, Zorick F, et al. Surgical correction of anatomic abnormalities of obstructive sleep apnea syndrome: uvulopalatopharyngoplasty. *Otolaryngol Head Neck Surg* 1981;89:923.
- [32] Ikematsu T. Study for snoring- fourth report: snoring. *J Jpn Otolaryngol* 1964;64:434.
- [33] Riley R, Guilleminault C, Powell N. Palatopharyngoplasty failure, cephalometric roentgenograms and obstructive sleep apnea. *Otolaryngol Head Neck Surg* 1985;93:240.
- [34] Riley R, Powell N, Guilleminault C. Maxillary, mandibular and hyoid advancement for treatment of obstructive sleep apnea: a review of 40 patients. *J Oral Maxillofacial Surg* 1990;48:20–6.
- [35] Crumley RL, Stein S, Ganser G, et al. Determination of obstructive sites in obstructive sleep apnea. *Laryngoscope* 1987;97:301.
- [36] Sher AE, et al. the efficacy of surgical modifications of the upper airway in adults with obstructive sleep apnea syndrome. *Sleep* 1996;19:156–77.
- [37] Johnson NT, Chinn J. Uvulopalatopharyngocopy and inferior sagittal mandibular osteotomy with genioglossus muscle advancement for treatment of obstructive sleep apnea. *Chest* 1994;105:278–83.
- [38] Hochban W, Brandenburg U, Peter JH. Surgical treatment of obstructive sleep apnea by maxillomandibular advancement. *Sleep* 1994;17:624–9.
- [39] Waite PD, Wooten V, Lachner J, et al. Maxillomandibular advancement surgery in 23 patients with obstructive sleep apnea syndrome. *J Oral Surg* 1989;47: 1256–61.
- [40] Prinsell JR. Maxillomandibular advancement surgery in a site-specific treatment approach for obstructive sleep apnea in 50 consecutive patients. *Chest* 1999; 116:1519–29.