Otolaryngol Clin N Am
36 (2003) 539–561

OTOLARYNGOLOGIC
CLINICS OF
NORTH AMERICA

Evidence-based medicine in sleep apnea surgery

K. Christopher McMains, MD,
David J. Terris, MD, FACS*

Department of Otolaryngology–Head and Neck Surgery, Medical College of Georgia, 1120 Fifteenth Street, Augusta, GA 30912-4060, USA

Historical perspective

Guilleminault et al [1] coined the term *obstructive sleep apnea* (OSA) to describe patients with disrupted nocturnal breathing. Kuhlo et al [2] performed the first tracheotomy to bypass upper airway obstruction in 1969, which represented the first definitive surgical procedure to treat OSA. Fujita et al [3] introduced the uvulopalatopharyngoplasty (UPPP) for treatment of OSA in 1979. Sullivan et al [4] published the first study of continuous positive airway pressure (CPAP) for nonsurgical treatment of OSA in 1981. As with tracheotomy, CPAP eliminates excessive daytime sleepiness (EDS) and cardiopulmonary sequelae of OSA [5], including normalization of blood pressure [6]. Only complete compliance was shown to be sufficient to confer treatment benefits from CPAP [7], and incomplete compliance with CPAP proved prevalent [8–10]. Despite increased compliance with autotitrating CPAP, a substantial proportion of patients remained ineffectively treated on CPAP [11]. This finding led to a shift in focus toward surgical treatment of OSA. In a meta-analysis, Sher et al [12] noted success of UPPP in 41% of all patients, whereas in patients with tongue base obstruction, success was achieved in only 6% of cases. This finding is supported further by Isono et al [13], who demonstrated that collapsibility at the level of the retroglossal airway is the most significant determinant of UPPP outcome.

In the wake of objective failure of UPPP in many patients, it became clear that multiple anatomic sites contribute to obstruction [14–16]. Methods for evaluating levels of obstruction were sought to improve preoperative assessment and surgical outcomes. The methods the studies used included

* Corresponding author.
E-mail address: dterris@mcg.edu (D.J. Terris).

doi:10.1016/S0030-6665(02)00182-2

the Müller maneuver, cephalometric analysis, CT, and volumetric MRI. The Müller maneuver offers some insight into the level of obstruction and dimensions of obstruction, although it does not accurately predict surgical success [17]. Cephalometric analysis correlates with three-dimensional CT analysis [18]. CT provides good airway and bony resolution, although it does not provide delineation of the upper airway soft tissue as well as the MRI [19]. Sagittal MRI allows evaluation of the palate and tongue base to the posterior pharyngeal wall [20]. MRI provides good soft tissue resolution and supine evaluation in multiple dimensions; however, weight, claustrophobia, pacemaker placement, and expense can limit its application.

In response to the limitations of UPPP, Riley et al [21] introduced the Stanford Protocol (Fig. 1), which involved inferior sagittal osteotomy of the mandible and hyoid myotomy and suspension. Later, Riley et al [22] published results from a two-phase protocol, which involved UPPP for palatal obstruction and genioglossus advancement with hyoid myotomy or suspension for tongue base obstruction in phase I. This method achieved success as measured by polysomnography in 70% to 80% of patients with mild to moderate OSA, although success was obtained in only 42% of patients with severe OSA. Additionally, surgical treatment improved sleep architecture and increased lowest oxygen-saturation levels to those achieved by CPAP.

For patients with residual OSA as determined by postoperative sleep study who were interested in further treatment, phase II involved maxillary-mandibular advancement osteotomy and achieved a 97% success rate [22]. Updates on clinical outcomes from the Stanford group continue to report similar outcomes for phase I [23] and phase II [24].

Recent years have seen a proliferation of procedures aimed at a surgical cure for OSA. Laser-assisted uvuloplasty has been investigated and proved to be an effective treatment for snoring [25], but there are conflicting data on its efficacy in the treatment of OSA [26]. Preliminary studies on tongue-base suspension sutures demonstrate a modest effect on objective measures [27] and small improvement in functional outcomes, sleepiness, and snoring [28]. Radiofrequency energy has been used to decrease the volume of palatal tissue [29], turbinate tissue [30,31], and tongue base [32–34], with mixed results. Bariatric surgery also has been used to affect the degree of obesity and, secondarily, OSA. This tremendous assortment of treatment modalities and methods of reporting outcomes raises two fundamental questions: What constitutes failure or success and why do specific interventions succeed or fail by these measures?

Pathologic features of obstructive sleep apnea

To fully understand treatment approaches to OSA, a thorough understanding of the pathologic features of OSA is necessary. Current understanding suggests that obstruction and cessation of ventilation result from anatomic and neurologic factors working to collapse the airway,

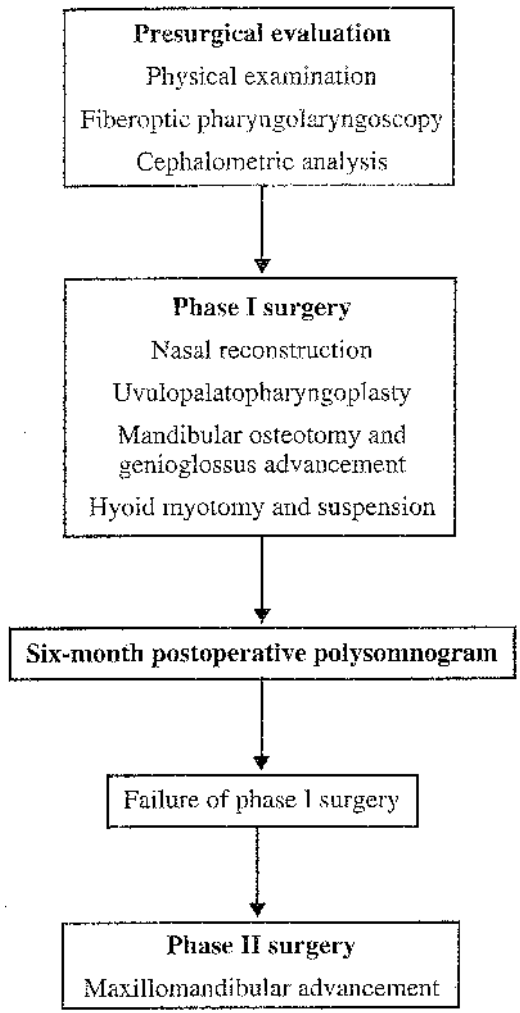

Fig. 1. Staged surgical protocol. *From* Likk, Powell NB, Riley RW, Troell R, Guilleminault C. Overview of phase I surgery for obstructive sleep apnea syndrome. Ear Nose Throat J 1999;78:836–45; with permission.

overriding those working to dilate the airway. This effect is known as the "balance-of-forces" model [35]. In OSA, these events include apneas, complete cessation of ventilation, hypopneas, significantly reduced ventilation secondary to partial obstruction, or respiratory effort–related arousal, which are defined as inspiratory efforts against increased upper airway resistance that cause transient arousals but do not reach the threshold for either apnea or hypopnea [36]. Formerly, it was believed that hypersomnolence resulted from hypoxemia or hypercapnea associated with

these events. It is now understood that hypersomnolence results from sleep fragmentation [37].

Respiratory drive and tonic control of airway musculature differ in the sleep and awake states. A "wakefulness drive," which responds to nonmetabolic inputs, modulates changes during the awake state. When this influence is removed during sleep, respiratory drive relies solely on metabolic inputs to chemoreceptors that allow a higher pCO_2 set point. Transition from wakefulness to sleep results in an immediate decrease in respiratory drive. This decrease is followed sequentially by hypoxemia, a brisk respiratory response, arousal, and a large compensatory breath. Therefore, the transition between states represents a time of considerable importance for the patient with OSA because of the vulnerability of the upper airway [38,39]. Additionally, rapid-eye-movement–phase sleep constitutes a higher percentage of sleep during the last third of the night [40] and is associated with decreased muscle tone. The effect of this change in tonic control is increased collapsibility during this phase of sleep.

Anatomically, resistance can occur intranasally or at the level of the palate (type I), at both the palate and the base of the tongue (type II), or at the base of the tongue alone (type III) [41]. As compared with control patients, there is increased pharyngeal resistance during wakefulness in patients with OSA [42–45]. As compared with the wakeful state, pharyngeal airway resistance triples during sleep [42–48]. With arousal and concomitant return of the wakefulness drive, dilator muscle activity increases, airway resistance decreases, and airflow resumes [42–49].

Several specific anatomic differences exist between control patients and patients with sleep apnea. Smaller upper airways have been observed in patients with OSA [15,47,50]. The cross-sectional area of the pharynx has been shown to be inversely proportional to the severity of OSA [15]. Pharyngeal anterior-posterior axis length greater than lateral axis length predisposes to airway collapse [51]. In contrast to the pharynx in control patients, the pharynx in patients with OSA is collapsible to a greater degree [52] and collapses under subatmospheric pressure conditions [53]. Lateral walls are the structures most likely to collapse in all subject groups. Thickness of the lateral pharyngeal muscular walls is cited as being responsible for collapse [54]. The palate of patients with OSA has significantly increased muscle and fat mass as compared with control patients [55]. Evidence suggests that there is a relationship between OSA and local pharyngeal fat deposits. Additionally, increased fat load in the collapsible pharyngeal segment has been demonstrated when compared with control patients [47]. These anatomic and physiologic tendencies lead to poor sleep efficiency and downstream physiologic effects. As a result, much of the available data suggest that OSA negatively affects several measures of health.

Several authors have shown an association between OSA and cardiovascular disease. The National Commission on Sleep Disorders Research

estimates that there are 38,000 cardiovascular deaths per year in the United States secondary to OSA [56]. Obstructive sleep apnea is believed to lead to pulmonary and systemic hypertension [57,58]. In individuals with an apnea-hypopnea index (AHI) greater than or equal to 15, increased systolic and diastolic blood pressure was noted during both sleep and wakefulness when compared with individuals with AHIs less than 15 [59]. Hung et al [60] showed increased cardiovascular mortality in patients with apnea indices (AIs) greater than 5.3. Obstructive sleep apnea has been implicated in cor pulmonale, arrhythmia, cerebrovascular accident (CVA), and polycythemia as well [56].

Obstructive sleep apnea has been implicated as a causal factor in motor vehicle accidents. In one study, an AHI greater than 5 yielded a three-fold increase in motor vehicle accidents, whereas an AHI greater than 15 yielded a seven-fold increase [33,61]. It is worth noting that an AHI greater than 15 falls within the definition of clinical success used by several authors. Reaction times of motorists with OSA were compared with and found to be worse than those of alcohol-impaired drivers [62].

Obstructive sleep apnea has been linked to increased mortality. In middle-aged patients with sleep-disordered breathing (SDB), decreased survival was demonstrated, regardless of disease severity [63]. He et al [64] showed increased mortality in patients with AIs greater than 20. Despite similarity in overall mortality in the post-uvulopalatopharyngoplasty (UP3) population, there is a relative risk of three for hypertension and subsequent death from cardiovascular disease (CVD) in patients with OSA as compared with control patients [65].

In a review published in 1997, Wright et al [66] contravened conventional wisdom by questioning the health effects of OSA. They found contradictory evidence regarding SDB and cardiovascular disease or CVA. They regarded the evidence linking OSA to EDS as stronger but still inconclusive. Since that time, much work has been done to further examine the role of OSA in cardiovascular and overall health, most notably through the Framingham and Sleep Heart Health Study. In the Framingham study, SDB was associated with increased right ventricular wall thickness, although neither right atrial dimensions, right ventricular dimensions, or right ventricular systolic function was affected [67]. Obstructive sleep apnea is associated with overall increased health care use [68]. Nieto et al [69] demonstrated an association between hypertension and SDB, as defined by AHI and percent time with oxygen saturation in arterial blood below 90%. Obstructive sleep apnea was shown to have mild to moderate effects on ''heterogeneous manifestations of CVD'' with even a slight increase in AHI. A stronger association with congestive heart failure (CHF) and stroke was shown [70]. In a recent review, Young and Peppard [71] wrote of the data: ''collectively they provide evidence that we cannot dismiss the hypothesis that SDB causes CVD.'' Other authors argue that correlations among respiratory disturbance index (RDI) and body mass index (BMI), hypertension diabetes mellitus (HTN, DM), and lipid

levels cloud any conclusions as to whether increased risk of CVD results from SDB or concomitant risk factors [72]. Despite mounting evidence, debate about the true effect of OSA on health continues.

Measures of success and failure

Several mechanisms have been used for diagnosing OSA, assessing its severity, and assessing the response to treatment. These mechanisms include purely subjective patient-reported measures, subjective physician-graded measures, and objective monitoring. A brief review of the major modalities follows.

Epworth sleepiness scale

Principal among the symptoms resulting from OSA is EDS. Using EDS in assessment of disordered sleep presents the difficulties of subjective reporting. Additionally, EDS is not limited to patients with OSA. It was found in 21% in patients with RDIs less than 5 versus 35% of patients with RDIs greater than 30 [73]. The Epworth sleepiness scale (ESS), first described by Johns, is an instrument used to evaluate severity of symptoms from OSA in a semiquantitative way [74]. The ESS is a self-administered survey of a patient's likelihood of dozing during eight activities. For each activity, the patient rates his or her chances of falling asleep while engaged in the activity. Scores range from 0 (never dozing in a situation) to 3 (always dozing).

Quality-of-life scales (general and disease-specific)

In early work, global measures of health were used to assess the effect of OSA. These measures originally were designed to measure aggregate health characteristics and to provide synoptic information regarding a patient's own perception of health. The Medical Outcome Survey Short Form (SF-36) includes eight domains to measure health and well-being [75]. Briones et al [76] showed a correlation among the ESS score and vitality, role-emotional, and general health domains, whereas the multiple sleep latency test correlated with the vitality domain. Another study using the SF-36 showed improvement in energy and vitality and mental and physical functioning domains, although another measure used in the study failed to identify these effects [77]. Mild to moderate SDB was associated with a decreased vitality measure on the SF-36, whereas severe SDB was associated with a global decrease in quality of life (QOL) [78]. Oxygen desaturation negatively affects the QOL measured by SF-36 as well [79]. All dimensions of QOL were diminished significantly on the SF-36 in patients with OSA as compared with control patients. Improvement in QOL was related more to the degree of perceived disability than to the RDI or arousal index [80].

The Nottingham Health Survey demonstrated significant differences in energy, pain, sleep, social isolation, and physical mobility in patients with OSA as compared with control patients; however, no difference in EDS between these groups was noted. No difference in QOL was identified among patients with different levels of severity with OSA [81].

Concern about the ability of nonspecific measures to elucidate subtle QOL changes specific to OSA led to development of disease-specific measures of QOL. The Calgary Sleep Apnea Quality-of-Life Index demonstrated validity in assessment of OSA. It also demonstrated a higher responsiveness index and effect size than did the SF-36 [82]. The Functional Outcomes Sleep Questionnaire was designed to assess the effect of sleep-related symptomatology on five daily activities. It demonstrated validity in evaluating functional disability as it relates to sleep disturbance and response to treatment [83].

The Obstructive Sleep Apnea Patient-Oriented Severity Index (Table 1) was designed for use in the OSA Treatment Outcome Pilot Study. It involves responses to questions regarding five subscales to which importance and magnitude of effect are assigned. A symptom impact score is generated from the product of the importance and the magnitude. The OSA Treatment Outcome Pilot Study study demonstrated worse QOL in all domains except bodily pain [84]. A revised version, the SNORE-25, excluded seven items from the first and dispensed with symptom-impact scoring, reporting average magnitude score instead. This instrument correlates well with the patient's subjective response to treatment [85].

Multiple sleep latency test

The multiple sleep latency test (MSLT) evaluates degree of impairment of daytime alertness [86]. This test involves recording the time of sleep initiation for multiple naps separated by at least 2 hours during a patient's normal waking period. This instrument can be used to diagnose upper airway resistance syndrome (UARS) [87] or as an assessment of treatment effect. In the absence of UARS, the MSLT is used to diagnose narcolepsy. It generally is considered the "gold standard" for evaluating daytime somnolence and sleep latency. Moderate correlation exists between "irresistible sleepiness," which describes the sensation of being overcome by sleep, and MSLT; however, "irresistible sleepiness" failed to identify pathologic MSLT in patients with SDB [88].

Müller maneuver: palate, base of tongue, and lateral walls

The Müller maneuver originated from attempts to evaluate various levels of upper airway obstruction. The examiner views the upper airway through the nasopharyngoscope at rest and with maximal inspiratory effort against closed nose and mouth. The base of tongue, lateral pharyngeal walls, and

Table 1
Items on the Obstructive Sleep Apnea Patient-Oriented Severity Index

Sleep problems
1. Trouble falling asleep
2. Waking during sleep
3. Loud/excessive snoring
4. Restlessness during sleep
5. Waking "too early" in morning
6. Waking up feeling tired
7. Bed wetting
Awake problems
8. Fatigue or tiredness
9. Frequent yawning
10. Sleepiness while driving
11. Memory and/or concentration problems
12. Productivity limited at certain times of day
13. Often late for meetings or appointments
14. Participation in community, volunteer, religious, or spiritual activities limited
Medical problems
15. Amount of medical care required for OSA
16. Interaction of OSA with other medical problems
17. Travel by automobile to other regions or parts of country limited because of fear of medical problem
18. Unable to have sexual relations because of medical problem
19. Financial burden as a result of illness
Emotional and personal problems
20. Dread/fear going to bed
21. Nerves are "right on surface"
22. Inability to relax, always anxious
23. Marital strain, stress, and tension
24. "Foul" mood
25. Unable to experience closeness with spouse and/or others
26. Lack of desire for sexual relations
27. Feeling that future is hopeless
Occupational impact
28. Competence questioned
29. Reliability questioned
30. Inability or difficulty getting new job
31. Loss of job
32. Modification in job because of excessive sleepiness

From Piccirillo JF, Gates GA, Schectman KB. Obstructive sleep apnea treatment outcomes pilot study. Otolaryngol Head Neck Surg 1998;118:833–44; with permission.

palate are examined for collapse. The examiner rates collapsibility of each structure from 0 (minimal collapse) to 4+ (complete collapse). Müller maneuver score was shown to be correlated moderately with preoperative SDB severity, and its reproducibility was verified between examiners [27]. Collapse of the palate was correlated highly with RDI, whereas lateral wall

collapse was correlated moderately, and base-of-tongue collapse was not correlated [89].

P close

P close is the pressure at which the upper airway collapses. This value is a significant discriminating feature between normal subjects and patients with abnormal collapsibility, as is seen in OSA [90]. In apneics, P close tends toward higher values than in control subjects. Airway collapse can occur at the level of the palate or tongue base. Positive P close predicted treatment effect in patients with OSA. For patients with positive P close, nocturnal oxygenation was normalized after UPPP in 27%, whereas oxygenation corrected 73% of OSA in patients with negative P close [13]. Tracheal traction [91], UPPP, and palatal advancement result in a decrease in closing pressure [92].

Cephalometrics

Cephalometric radiographs are obtained and evaluated in a standardized manner [93]. Relationships of different structures to one another have been assessed for predictive value in diagnosing OSA and evaluating surgical outcome. Changes in ANB and SNB angles were correlated with postoperative changes in AHI [94]. Other studies correlated postoperative outcomes with increased posterior airway length, increased hyoid-mandibular length, and increased posterior airway space (PAS) [95,96]. Li et al [97] report an increase in pharyngeal length and depth of 48% and 53%, respectively, after maxillomandibular advancement and report a high success rate for these procedures. Conflicting data were described by Yao et al [89], who found that cephalometric radiographs reflect anatomic changes postoperatively, but these changes did not correlate with efficacy as measured by improvements in the AHI.

Polysomnogram

The polysomnogram (PSG) was first described in 1974 by Holland et al [98]. Since that time, PSG has become the ''gold standard'' in diagnosis and follow-up of sleep apnea because it provides objective data on sleep and respiratory status. Originally, the only events evaluated were apnea; however, analysis has expanded to include hypopneas and respiratory event-related arousals (RERAs), as described previously. The diagnosis most frequently is made on the basis of the sum of these events per hour or RDI. In the level I study, information gathered includes pulse oximetry, electrocardiography, nasal or oral airflow, respiratory effort, extremity electromyography, submental electromyography, electro-oculogram, positionally dependent sleep changes, and electroencephalographic evidence of arousal [99]. Despite

collecting information on oxygen desaturation, arousals, limb movements, sleep architecture, and cardiac events, diagnosis most often is made by RDI alone. With the pressures of medical economics, other less costly studies have been explored that endeavor to adequately diagnose OSA without incurring similar costs. These studies range from fully monitored home studies to overnight oximetry, although each has limitations in the data collected. In a nap study, the AHI and oxygen desaturation index detected correlates with the severity of OSA as determined by PSG [100]. Data reported from portable PSG correlated with those obtained with a laboratory-based control for AHI and diagnosis, although there was reduced confidence in respiratory scoring secondary to signal quality [101]. Parra et al [102] showed 89% concordance between AHI measured by a home device and traditional PSG. Kapur et al [103] reported that unattended home sleep studies were acceptable for the evaluation and diagnosis of OSA in 90.6% of cases.

Why surgical procedures fail

The complex interacting factors causing dysfunction in OSA make it difficult to guarantee effective treatment in an individual patient. The perfect treatment for OSA would eliminate sleep disturbance, reverse dangerous physiologic changes, restore restful sleep, eliminate symptoms, and be well tolerated by patients. The principal failure of CPAP is the patient's inability to tolerate treatment. Tracheotomy bypasses airway obstruction at all levels, yielding objective results comparable to CPAP, but it also is poorly tolerated by many patients owing to inconvenience and social stigma. Paradoxically, UPPP may, in some cases, decrease the maximal pressure tolerated by way of CPAP by creating oral air escape and decreasing the effectiveness of treatment [104]. The importance of patient selection based on careful examination affects the likelihood of success. In early work, Sher et al [17] showed that selecting patients with pharyngeal changes isolated to the region of the tonsillar fossae and soft palate increased the success rate of UPPP. For patients completing phase II surgical treatment, more than 90% have a successful surgical result as measured by RDI; however, many patients who do not have successful surgery as defined by PSG do not elect to complete phase II surgery, limiting the generalizability of results reported in OSA surgery [105]. Answers to the questions "What prevents a successful result in earlier stages of surgical treatment?" and "How does one maximize the likelihood of a given patient achieving a cure for his or her disease?" may lie in the variability of OSA.

The association of OSA and obesity cannot be disputed. Major weight gain was associated with surgical failures, although there was no negative effect from aging and minor weight gain [106]. Failure after UP3 was related to preoperative BMI and postoperative weight gain [107]. Bariatric surgery

has been explored in the treatment of OSA, with variable results. Several authors report that bariatric surgery provides significant long-term reduction in weight and OSA severity [108–110], whereas other reports suggest a considerable relapse rate among treated patients [111]. Aggressive weight-reduction programs represent an important component of comprehensive OSA treatment.

Significant differences in disease presentation and characteristics are seen between male and female patients with OSA. Presenting symptoms for men included snoring and stoppage of breathing, whereas women reported headache on awakening [112]. In another study of SDB, both genders presented with similar symptoms of snoring and EDS. This same study showed that, despite having significantly smaller oropharyngeal airways, women had much milder disease than men. Additionally, upper airway size correlated with severity of disease only for men [113]. A higher death rate is noted among women with AHIs greater than five than in similarly affected men [114]. In a study of obese patients, Vgontzas et al [115] reported OSA in 40% of men and only 3% of women. The association between BMI and RDI is weaker in women than in men. Another study of morbidly obese patients showed that 77% of men and only 7% of women had OSA [116]. Taken together, these observations suggest important gender differences in sleep disorders. Further exploration of the nature of these differences may result in a higher percentage of surgical successes.

Collapse of the lateral pharyngeal wall contributes significantly to obstruction. Bettega et al [117] wrote, ''No data are available on the effects of phase I surgical techniques on dilator muscle activity, contraction efficiency, and upper airway collapsibility.'' This view is disputed by Schwab et al [93], who reported that skeletal advancement surgery increased tension on constrictors, thereby decreasing lateral wall collapse. Li et al [24] found that maxillomandibular osteotomy improves the tension and collapsibility of the suprahyoid and velopharyngeal musculature. In a later study, Li et al [118] reported that maxillomandibular osteotomy improves retrodisplacement of the tongue and more dramatically improves lateral wall stability. Thut et al [119] showed that elongation of the airway had the greatest effect on collapsibility. Pharyngeal length increases significantly in patients with OSA as compared with control patients when changing from the upright to the supine position [120]. A distance of less than 21 mm from the mandibular plane to the hyoid was associated significantly with UPPP failure [121]. Exploration of airway-lengthening procedures may exploit the insight gained through Thut's research to the benefit of patients with OSA.

Recognition of the influence exerted by other diseases and syndromes may contribute to the challenge of effective OSA treatment. ''Disproportionate anatomy'' among the base of the tongue, narrow mandible, and hypoplastic mandible affect upper airway dynamics [16]. This disproportion can be seen in syndromic patients and in isolation from other abnormalities.

Allergy also may play a role in the pathogenesis of OSA [122]. Allergic response not only increases airway resistance intranasally, it may result in edema of pharyngeal segments and predispose to collapse. Hypoventilation syndrome can occur concomitantly with OSA and cause continued sleep disturbance despite treatment of obstruction. Recognizing and addressing these and other comorbidities may affect surgical outcomes positively.

Best current metrics

Despite using RDI as a standard for diagnosis and treatment effectiveness, there is some suggestion that RDI may not completely describe all aspects of the disease. Piccirillo elucidates the principal limitations in the use of PSG for diagnosis and evaluation of response in OSA [123]:

1. *Assignment of severity based on RDI, not oxygen desaturation index (ODI), sleep fragmentation, or patient symptoms.* This criticism is supported by Kingshott et al [124], who demonstrated that neither apneas nor hypopneas account for more than a small percentage of the variation in objective or subjective sleepiness. Respiratory disturbance index showed poor correlation with EDS, neuropsychologic functioning, or rates of motor vehicle accidents [61]. Oxygen desaturations negatively affect QOL measured by SF-36 as well [79]. This finding suggests an influence from desaturation independent of RDI; however, ODI has been shown to be specific for OSA diagnosed by PSG [125], whereas ODI coupled with CT90 (percentage of time saturation levels remain below 90%) and oximetry is both sensitive and specific for OSA by PSG [126]. Sleep fragmentation results from short-alpha electroencephalogram arousals during sleep that correlate with increased work of breathing [127]. Although RDI and minimum oxygen saturation in arterial blood were improved on therapeutic CPAP, no significant difference in sleep architecture was seen between therapeutic CPAP and placebo CPAP [128]. Therefore, patients "effectively" treated as assessed by RDI alone may not receive the physical benefits of restored sleep architecture.

Patient perception of treatment may differ dramatically from objective data provided by PSG. The fact that tracheotomy and CPAP can decrease QOL secondary to inconvenience, discomfort, and social stigma despite effective bypass or splinting of obstruction highlights the distinction between PSG data and patient perception [129]. This disparity has been demonstrated for laser assisted uvulopalatoplasty [26], UPPP [130], and dental appliances [131]. Epworth sleepiness scale shows correlation with patient-identified sleepiness but does not correlate with MSLT [132], AHI, or minimum oxygen saturation in arterial blood [133]. In contrast, other studies have found an association between RDI and QOL measures [134]. Li et al [129] showed correlation among RDI, minimum oxygen saturation in arterial blood, and visual analog scale reporting of symptoms. Most patients report subjective improvement in symptoms after UP3, although this subjective improvement does not correlate with AI or sleep architecture for many patients. One suggestion regarding the

difficulty in obtaining postoperative sleep studies is that symptomatic improvement decreases a patient's desire to undergo additional testing [130]. In a study of patients with mild OSA, no additional benefit was seen with CPAP treatment compared with placebo on SF-36 or functional outcomes of sleep questionnaire, suggesting that the placebo effect may obscure subjective reporting of findings [135]. Additionally, snorers without OSA have decrements in QOL to almost the same degree as patients who carry the diagnosis of OSA as measured on the Nottingham Health Profile [136]. Response bias has been shown to affect medical outcomes survey data [137]. Differing data on PSG data and subjective data are competing and cloud conclusions on the relationship among these measures.

2. *There is a lack of correlation between AHI and overall health status [81] or QOL [138].* The conflicting data regarding the relationship to OSA defined by PSG and various measures of health are presented in a previous section (''Pathologic features of obstructive sleep apnea''). Data addressing the relationship between PSG results and QOL also are presented previously in this section. Although not uniformly disproved, questions about the strength of each of these relationships persist.

3. *Apneas and hypopneas are not reported in a uniform way*. Although efforts to standardize definitions of these occurrences have been made [86], considerable variability in definition, evaluation, and reporting continues to cloud comparisons [139]. Various cutoffs are used in individual studies for diagnosis, benefit, and cure, which further complicate interpretation of PSG data. Different methods of recording AHI yield dramatically different diagnosis and assignment of severity [140]. For example, thermistors have the potential to be less sensitive to hypopneas than other methods of recording [116]. Sher [141] states that intraesophageal manometry is the most effective method of distinguishing apnea from hypopnea. In contrast, Skatvedt et al [142] showed no statistical difference between patients undergoing PSG with and without pressure monitoring in any sleep-quality parameter except duration of non–rapid-eye-movement sleep with oxygen saturation below 90%. The use of different definitions for respiratory disturbance, criteria for diagnosis, and measures of success is perhaps the most significant limitation in evaluating and comparing outcomes from different treatments.

4. *Frequency of apneas and hypopneas may vary from night to night.* Because sleep quality may vary from night to night owing to myriad physical and psychosocial influences, a one-night study may be inaccurate [143]. A corollary to this contention is that monitoring may cause considerable arousal artifact secondary to mask placement or perception of other monitoring devices. This criticism has been refuted by some studies that show no significant difference between first- and second-night sleep studies [144] and reclassification of disease or severity in only a few patients based on subsequent night-sleep studies [145]. Although data conflict on this point as well, attention to this possibility may guide decisions regarding repeating sleep studies or proceeding with surgical treatment in cases that fall close to diagnostic cutoffs.

Steps have been taken already to incorporate some of these principles in diagnosis and treatment of OSA. The composite clinical-severity index, described by Piccirillo et al [84], includes ESS, BMI, presence of redundant pharyngeal tissue, RDI, and minimum oxygen saturation in assignment of disease severity (Figs. 1 and 2). A second generation of this instrument, the SNORE-25, has been developed, and an initial study has been reported [85]. Although exploration of this type of multidimensional analysis is in its infancy, this approach represents a significant step toward thorough assignment by considering both objective and subjective measures.

Future strategies

Future strategies for OSA treatment will involve the evolution of methods of assessment and treatment. Although related, these areas are distinct fields of endeavor. Much progress has been made already in the field of assessment. Clear definition of respiratory disturbances will help establish uniform reporting and more reliable, valid comparisons among different studies. To date, relative contributions of apneas, hypopneas, and RERAs have not been well defined. Research into the relative contributions of different types of respiratory disturbance to symptomatology and downstream health effects may provide insight into the true effect of treatment. Despite its utility as an objective measure, traditional PSG reported in terms of RDI alone has limitations. Recognition of these limitations has already motivated the development of instruments that include multiple pertinent variables. Additionally, continued exploration of the neural interface between sleep and awake states may provide new frontiers in OSA treatment.

Future advances in treatment will likely parallel those made in assessment. On the nonsurgical front, vigorous educational efforts on the part of the medical community to raise public awareness of OSA will affect health behaviors and social stigmata assigned to various treatment modalities. Such educational efforts have been reported to increase compliance with CPAP treatment [146]. Finding new and unique approaches to prevent collapse while decreasing morbidity will likely drive additional treatment advances. Continued work on lateral wall collapse offers one area of potential improvement. Procedures designed to lengthen the airway may provide a breakthrough in prevention of collapse. Early success has been reported in electrical stimulation of the genioglossus, resulting in decreased pharyngeal critical pressure [147]. Work will likely continue on application of radiofrequency energy in OSA. Other devices also may demonstrate utility in treatment of OSA. Jokic et al [148] reported decreasing surface tension and, as a result, AHI by applying a topical lubricant to upper airway tissues. Further work in these areas will likely add to the armamentarium of OSA treatment.

A

Redundant pharyngeal tissue	BMI <30	30-40	>40
Absent	Alpha	Beta	Gamma
Present	Alpha	Gamma	Gamma

B

ESS	Physical-severity index Alpha	Beta	Gamma
<9	A	A	B
9-16	A	B	C
>16	B	C	C

C

Minimum O_2 saturation (%)	RDI 0-33	34-65	>65
>84	1	2	2
84-65	1	2	3
<65	2	2	3

D

Functional-severity index	PSG-severity index 1	2	3
A	I	I	III
B	II	II	III
C	II	III	III

Fig. 2. Creation of clinical-severity staging system. Panels A through C demonstrate the sequential conjunction and consolidation of key physical examination variables, ESS, and PSG variables to ultimately create the clinical severity index. (A) Pattern of consolidation of redundant pharyngeal tissue and BMI to form composite physical-severity index. Categories of BMI and redundant pharyngeal tissue are conjoined to create the three-category (alpha, beta, and gamma) physical-severity index. (B) Pattern of consolidation of ESS and physical-severity index to form composite functional-severity index. Categories of physical-severity index (alpha, beta, and gamma) are conjoined with three categories of the ESS (<9, 9–16, >16) to create the functional-severity index. (C) Pattern of consolidation of minimum O_2 saturation during apnea and RDI to form the composite PSG-severity index. Categories of the two key PSG variables, minimum O_2 saturation during apnea and RDI, are conjoined to create the three-category (1, 2, and 3) PSG-severity index. (D) Pattern of consolidation of functional-severity index and PSG-severity index to form the composite clinical-severity index. The three categories (A, B, and C) of the functional-severity index and the three categories (1, 2, and 3) of the PSG-severity index are conjoined to create the three-category (I, II, and III) composite clinical-severity index. (*From* Piccirillo JF. Outcomes research and obstructive sleep apnea. Laryngoscope 2000;110(3 Pt 3):16–20; with permission.)

The complexity of OSA and its variability of expression within individuals make identification of one "best method" of assessment and treatment difficult. As new techniques for treatment continue to evolve, methods of reporting will continue to evolve to more thoroughly illuminate the complex relationships at work in OSA.

References

[1] Guilleminault C, van den Hoed J, Mitler MM. Clinical overview of the sleep apnea syndrome. In: Guilleminault C, Dement WC, editors. Sleep apnea syndromes. New York: Alan R Liss; 1978. p. 1–12.
[2] Kuhlo W, Doll E, Franck MC. Successful management of Pickwickian syndrome using long-term tracheostomy. Dtsch Med Wochenschr 1969;94:1286–90.
[3] Fujita S, Conway W, Zorick F, Roth T. Surgical correction of anatomic abnormalities in obstructive sleep apnea syndrome: uvulopalatopharyngoplasty. Otolaryngol Head Neck Surg 1981;89:923–34.
[4] Sullivan CE, Issa FG, Berthon-Jones M, Eves L. Reversal of obstructive sleep apnoea by continuous positive airway pressure applied through the nares. Lancet 1981;1:862–5.
[5] Sullivan CE, Berthon-Jones M, Issa FG. Remission of severe obesity-hypoventilation syndrome after short-term treatment during sleep with nasal continuous positive airway pressure. Am Rev Respir Dis 1983;128:177–81.
[6] Guilleminault C, Stoohs R. Arousal, increased respiratory efforts, blood pressure and obstructive sleep apnoea. J Sleep Res 1995;4(S1):117–24.
[7] Collop NA, Block AJ, Hellard D. The effect of nightly nasal CPAP treatment on underlying obstructive sleep apnea and pharyngeal size. Chest 1991;99:855–60.
[8] Sanders MH, Moore SE, Eveslage J. CPAP via nasal mask: a treatment for occlusive sleep apnea. Chest 1983;83:144–5.
[9] Waldhorn RE, Herrick TW, Nguyen MC, O'Donnell AE, Sodero J, Potolicchio SJ. Long-term compliance with nasal continuous positive airway pressure therapy of obstructive sleep apnea. Chest 1990;97:33–8.
[10] Kribbs NB, Pack AI, Kline LR, Smith PL, Schwartz AR, Schubert NM, et al. Objective measurement of patterns of nasal CPAP use by patients with obstructive sleep apnea. Am Rev Respir Dis 1993;147:887–95.
[11] Series F, Marc I. Efficacy of automatic continuous positive airway pressure therapy that uses an estimated required pressure in the treatment of the obstructive sleep apnea syndrome. Ann Intern Med 1997;127(8 Pt 1):588–95.
[12] Sher AE, Schechtman KB, Piccirillo JF. The efficacy of surgical modifications of the upper airway in adults with obstructive sleep apnea syndrome. Sleep 1996;19:156–77.
[13] Isono S, Shimada A, Tanaka A, Tagaito Y, Utsugi M, Konno A, et al. Efficacy of endoscopic static pressure/area assessment of the passive pharynx in predicting uvulopalatopharyngoplasty outcomes. Laryngoscope 1999;109:769–74.
[14] Crumley RL, Stein M, Gamsu G, Golden J, Dermon S. Determination of obstructive site in obstructive sleep apnea. Laryngoscope 1987;97(3 Pt 1):301–8.
[15] Rivlin J, Hoffstein V, Kalbfleisch J, McNicholas W, Zamel N, Bryan AC. Upper airway morphology in patients with idiopathic obstructive sleep apnea. Am Rev Respir Dis 1984;129:355–60.
[16] Rojewski TE, Schuller DE, Clark RW, Schmidt HS, Potts RE. Videoendoscopic determination of the mechanism of obstruction in obstructive sleep apnea. Otolaryngol Head Neck Surg 1984;92:127–31.
[17] Sher AE, Thorpy MJ, Shprintzen RJ, Spielman AJ, Burack B, McGregor PA. Predictive value of Muller maneuver in selection of patients for uvulopalatopharyngoplasty. Laryngoscope 1985;95:1483–7.

[18] Riley RW, Powell NB. Maxillofacial surgery and obstructive sleep apnea syndrome. Otolaryngol Clin North Am 1990;23:809–26.
[19] Schwab RJ, Goldberg AN. Upper airway assessment: radiographic and other imaging techniques. Otolaryngol Clin North Am 1998;31:931–68.
[20] Dundar A, Gerek M, Ozunlu A, Yetiser S. Patient selection and surgical results in obstructive sleep apnea. Eur Arch Otorhinolaryngol 1997;254(Suppl 1):S157–61.
[21] Riley RW, Powell NB, Guilleminault C. Inferior sagittal osteotomy of the mandible with hyoid myotomy-suspension: a new procedure for obstructive sleep apnea. Otolaryngol Head Neck Surg 1986;94:589–93.
[22] Riley RW, Powell NB, Guilleminault C. Obstructive sleep apnea syndrome: a review of 306 consecutively treated surgical patients. Otolaryngol Head Neck Surg 1993;108:117–25.
[23] Li KK, Powell NB, Riley RW, Troell R, Guilleminault C. Overview of phase I surgery for obstructive sleep apnea syndrome. Ear Nose Throat J 1999;78:836–45.
[24] Li KK, Riley RW, Powell NB, Troell R, Guilleminault C. Overview of phase II surgery for obstructive sleep apnea syndrome. Ear Nose Throat J 1999;78:851–7.
[25] Mickelson SA. Laser-assisted uvulopalatoplasty for obstructive sleep apnea. Laryngoscope 1996;106(1 Pt 1):10–3.
[26] Ryan CF, Love LL. Unpredictable results of laser assisted uvulopalatoplasty in the treatment of obstructive sleep apnoea. Thorax 2000;55:399–404.
[27] Terris DJ, Hanasono MM, Liu YC. Reliability of the Muller maneuver and its association with sleep-disordered breathing. Laryngoscope 2000;110:1819–23.
[28] Woodson BT, Derowe A, Hawke M, Wenig B, Ross EB Jr, Katsantonis GP, et al. Pharyngeal suspension suture with repose bone screw for obstructive sleep apnea. Otolaryngol Head Neck Surg 2000;122:395–401.
[29] Powell NB, Riley RW, Troell RJ, Li K, Blumen MB, Guilleminault C. Radiofrequency volumetric tissue reduction of the palate in subjects with sleep-disordered breathing. Chest 1998;113:1163–74.
[30] Back LJ, Hytonen ML, Malmberg HO, Ylikoski JS. Submucosal bipolar radiofrequency thermal ablation of inferior turbinates: a long-term follow-up with subjective and objective assessment. Laryngoscope 2002;112:1806–12.
[31] Utley DS, Goode RL, Hakim I. Radiofrequency energy tissue ablation for the treatment of nasal obstruction secondary to turbinate hypertrophy. Laryngoscope 1999;109:683–6.
[32] Li KK, Powell NB, Riley RW, Guilleminault C. Temperature-controlled radiofrequency tongue base reduction for sleep-disordered breathing: long-term outcomes. Otolaryngol Head Neck Surg 2002;127:230–4.
[33] Powell NB, Riley RW, Guilleminault C. Radiofrequency tongue base reduction in sleep-disordered breathing: a pilot study. Otolaryngol Head Neck Surg 1999;120:656–64.
[34] Woodson BT, Nelson L, Mickelson S, Huntley T, Sher A. A multi-institutional study of radiofrequency volumetric tissue reduction for OSAS. Otolaryngol Head Neck Surg 2001;125:303–11.
[35] Woodson BT, Naganuma H. Comparison of methods of airway evaluation in obstructive sleep apnea syndrome. Otolaryngol Head Neck Surg 1999;120:460–3.
[36] Loube DI, Andrada TF. Comparison of respiratory polysomnographic parameters in matched cohorts of upper airway resistance and obstructive sleep apnea syndrome patients. Chest 1999;115:1519–24.
[37] Kryger MH. Sleep apnea: from the needles of Dionysius to continuous positive airway pressure. Arch Intern Med 1983;143:2301–3.
[38] Dempsey JA, Skatrud JB, Safwan BM, et al. Effects of sleep on the regulation of breathing and respiratory muscle function. In: Crystal RG, West JB, editors. The lung: scientific foundations. New York: Raven Press; 1991.
[39] Khoo MC. Periodic breathing. In: Crystal RG, West JB, editors. The lung: scientific foundations. New York: Raven Press; 1991.

[40] Troell RJ, Riley RW, Powell NB, Li K. Surgical management of the hypopharyngeal airway in sleep disordered breathing. Otolaryngol Clin North Am 1998;31:979–1012.
[41] Fujita S. Pharyngeal surgery for obstructive sleep apnea and snoring. In: Fairbanks DNF, Fujita S, Ikematsu T, et al, editors. Snoring and obstructive sleep apnea. New York: Raven Press; 1987. p. 101.
[42] Anch AM, Remmers JE, Bunce H 3rd. Supraglottic airway resistance in normal subjects and patients with occlusive sleep apnea. J Appl Physiol 1982;53:1158–63.
[43] Kuna ST, Remmers JE. Neural and anatomic factors related to upper airway occlusion during sleep. Med Clin North Am 1985;69:1221–42.
[44] Stauffer JL, Zwillich CW, Cadieux RJ, Bixler EO, Kales A, Varano LA, et al. Pharyngeal size and resistance in obstructive sleep apnea. Am Rev Respir Dis 1987;136:623–7.
[45] Suratt PM, McTier RF, Wilhoit SC. Collapsibility of the nasopharyngeal airway in obstructive sleep apnea. Am Rev Respir Dis 1985;132:967–71.
[46] Winakur SJ, Smith PL, Schwartz AR. Pathophysiology and risk factors for obstructive sleep apnea. Seminars in Respiratory and Critical Care Medicine 1998;19:999–1112.
[47] Horner RL, Mohiaddin RH, Lowell DG, Shea SA, Burman ED, Longmore DB, et al. Sites and sizes of fat deposits around the pharynx in obese patients with obstructive sleep apnoea and weight matched controls. Eur Respir J 1989;2:613–22.
[48] Mezzanotte WS, Tangel DJ, White DP. Waking genioglossal electromyogram in sleep apnea patients versus normal controls (a neuromuscular compensatory mechanism). J Clin Invest 1992;89:1571–9.
[49] Tangel DJ, Mezzanotte WS, White DP. Influence of sleep on tensor palatini EMG and upper airway resistance in normal men. J Appl Physiol 1991;70:2574–81.
[50] Suratt PM, Dee P, Atkinson RL, Armstrong P, Wilhoit SC. Fluoroscopic and computed tomographic features of the pharyngeal airway in obstructive sleep apnea. Am Rev Respir Dis 1983;127:487–92.
[51] Leiter JC. Upper airway shape: is it important in the pathogenesis of obstructive sleep apnea? Am J Respir Crit Care Med 1996;153:894–8.
[52] Malhotra A, Pillar G, Fogel R, Beauregard J, Edwards J, White DP. Upper-airway collapsibility: measurements and sleep effects. Chest 2001;120:156–61.
[53] Suratt PM, Wilhoit SC, Cooper K. Induction of airway collapse with subatmospheric pressure in awake patients with sleep apnea. J Appl Physiol 1984;57:140–6.
[54] Schwab RJ, Gupta KB, Gefter WB, Metzger LJ, Hoffman EA, Pack AI. Upper airway and soft tissue anatomy in normal subjects and patients with sleep-disordered breathing: significance of the lateral pharyngeal walls. Am J Respir Crit Care Med 1995;152(5 Pt 1): 1673–89.
[55] Stauffer JL, Buick MK, Bixler EO, Sharkey FE, Abt AB, Manders EK, et al. Morphology of the uvula in obstructive sleep apnea. Am Rev Respir Dis 1989;140:724–8.
[56] National Commission on Sleep Disorders Research. Wake up America: a national sleep alert. Washington (DC): Government Printing Office; 1993.
[57] Fletcher EC, DeBehnke RD, Lovoi MS, Gorin AB. Undiagnosed sleep apnea in patients with essential hypertension. Ann Intern Med 1985;103:190–5.
[58] Kales A, Bixler EO, Cadieux RJ, Schneck DW, Shaw LC 3rd, Locke TW, et al. Sleep apnoea in a hypertensive population. Lancet 1984;2:1005–8.
[59] Young T, Peppard P, Palta M, Hla KM, Finn L, Morgan B, Skatrud J. Population-based study of sleep-disordered breathing as a risk factor for hypertension. Arch Intern Med 1997;157:1746–52.
[60] Hung J, Whitford EG, Parsons RW, Hillman DR. Association of sleep apnoea with myocardial infarction in men. Lancet 1990;336:261–4.
[61] Young T, Blustein J, Finn L, Palta M. Sleep-disordered breathing and motor vehicle accidents in a population-based sample of employed adults. Sleep 1997;20:608–13.
[62] Beninati W, Harris CD, Herold DL, Shepard JW Jr. The effect of snoring and obstructive sleep apnea on the sleep quality of bed partners. Mayo Clin Proc 1999;74:955–8.

[63] Noda A, Okada T, Yasuma F, Sobue T, Nakashima N, Yokota M. Prognosis of the middle-aged and aged patients with obstructive sleep apnea syndrome. Psychiatry Clin Neurosci 1998;52:79–85.
[64] He J, Kryger MH, Zorick FJ, Conway W, Roth T. Mortality and apnea index in obstructive sleep apnea: experience in 385 male patients. Chest 1988;94:9–14.
[65] Lysdahl M, Haraldsson PO. Long-term survival after uvulopalatopharyngoplasty in nonobese heavy snorers: a 5- to 9-year follow-up of 400 consecutive patients. Arch Otolaryngol Head Neck Surg 2000;126:1136–40.
[66] Wright J, Johns R, Watt I, Melville A, Sheldon T. Health effects of obstructive sleep apnoea and the effectiveness of continuous positive airways pressure: a systematic review of the research evidence. BMJ 1997;314:851–6.
[67] Guidry UC, Mendes LA, Evans JC, Levy D, O'Connor GT, Larson MG, et al. Echocardiographic features of the right heart in sleep-disordered breathing: the Framingham Heart Study. Am J Respir Crit Care Med 2001;164:933–8.
[68] Kapur VK, Redline S, Nieto FJ, Young TB, Newman AB, Henderson JA. The relationship between chronically disrupted sleep and healthcare use. Sleep 2002;25:289–96.
[69] Nieto FJ, Young TB, Lind BK, Shahar E, Samet JM, Redline S, et al. Association of sleep-disordered breathing, sleep apnea, and hypertension in a large community-based study. Sleep Heart Health Study. JAMA 2000;283:1829–36.
[70] Shahar E, Whitney CW, Redline S, Lee ET, Newman AB, Javier Nieto F, et al. Sleep-disordered breathing and cardiovascular disease: cross-sectional results of the Sleep Heart Health Study. Am J Respir Crit Care Med 2001;163:19–25.
[71] Young T, Peppard P. Sleep-disordered breathing and cardiovascular disease: epidemiologic evidence for a relationship. Sleep 2000;23(Suppl 4):S122–26.
[72] Newman AB, Nieto FJ, Guidry U, Lind BK, Redline S, Pickering TG, et al. Relation of sleep-disordered breathing to cardiovascular disease risk factors: the Sleep Heart Health Study. Am J Epidemiol 2001;154:50–9.
[73] Gottlieb DJ, Whitney CW, Bonekat WH, Iber C, James GD, Lebowitz M, et al. Relation of sleepiness to respiratory disturbance index: the Sleep Heart Health Study. Am J Respir Crit Care Med 1999;159:502–7.
[74] Johns MW. A new method for measuring daytime sleepiness: the Epworth sleepiness scale. Sleep 1991;14:540–5.
[75] Stewart AL, Ware JE Jr. Measuring functioning and well-being. The Medical Outcomes Study Approach. Duke University Press; Durham, NC: 1991.
[76] Briones B, Adams N, Strauss M, Rosenberg C, Whalen C, Carskadon M, et al. Relationship between sleepiness and general health status. Sleep 1996;19:583–8.
[77] Jenkinson C, Stradling J, Petersen S. Comparison of three measures of quality of life outcome in the evaluation of continuous positive airways pressure therapy for sleep apnoea. J Sleep Res 1997;6:199–204.
[78] Baldwin CM, Griffith KA, Nieto FJ, O'Connor GT, Walsleben JA, Redline S. The association of sleep-disordered breathing and sleep symptoms with quality of life in the Sleep Heart Health Study. Sleep 2001;24:96–105.
[79] Akashiba T, Kawahara S, Akahoshi T, Omori C, Saito O, Majima T, et al. Relationship between quality of life and mood or depression in patients with severe obstructive sleep apnea syndrome. Chest 2002;122:861–5.
[80] D'Ambrosio C, Bowman T, Mohsenin V. Quality of life in patients with obstructive sleep apnea: effect of nasal continuous positive airway pressure—a prospective study. Chest 1999;115:123–9.
[81] Fornas C, Ballester E, Arteta E, Ricou C, Diaz A, Fernandez A, et al. Measurement of general health status in obstructive sleep apnea hypopnea patients. Sleep 1995;18:876–9.
[82] Flemons WW, Reimer MA. Measurement properties of the Calgary sleep apnea quality of life index. Am J Respir Crit Care Med 2002;165:159–64.

[83] Weaver TE, Laizner AM, Evans LK, Maislin G, Chugh DK, Lyon K, et al. An instrument to measure functional status outcomes for disorders of excessive sleepiness. Sleep 1997;20:835–43.
[84] Piccirillo JF, Gates GA, White DL, Schectman KB. Obstructive sleep apnea treatment outcomes pilot study. Otolaryngol Head Neck Surg 1998;118:833–44.
[85] Piccirillo JF. Outcomes research and obstructive sleep apnea. Laryngoscope 2000;110 (3 Pt 3):16–20.
[86] American Sleep Disorders Association Standards of Practice Committee Indications for Polysomnography Task Force. Practice parameters for the indications for polysomnography and related procedures: an American Sleep Disorders Association report. Sleep 1997;20:406–22.
[87] Chervin RD, Guilleminault C. Obstructive sleep apnea and related disorders. Neurol Clin 1996;14:583–609.
[88] Rinaldi R, Vignatelli L, D'Alessandro R, Bassein L, Sforza E, Plazzi G, et al. Validation of symptoms related to excessive daytime sleepiness. Neuroepidemiology 2001;20: 248–56.
[89] Yao M, Utley DS, Terris DJ. Cephalometric parameters after multilevel pharyngeal surgery for patients with obstructive sleep apnea. Laryngoscope 1998;108:789–95.
[90] Isono S, Remmers JE, Tanaka A, Sho Y, Sato J, Nishino T. Anatomy of pharynx in patients with obstructive sleep apnea and in normal subjects. J Appl Physiol 1997; 82:1319–26.
[91] Rowley JA, Permutt S, Willey S, Smith PL, Schwartz AR. Effect of tracheal and tongue displacement on upper airway airflow dynamics. J Appl Physiol 1996;80:2171–8.
[92] Woodson BT. Retropalatal airway characteristics in uvulopalatopharyngoplasty compared with transpalatal advancement pharyngoplasty. Laryngoscope 1997;107:735–40.
[93] Schwab RJ, Gefter WB, Hoffman EA, Gupta KB, Pack AI. Dynamic upper airway imaging during awake respiration in normal subjects and patients with sleep disordered breathing. Am Rev Respir Dis 1993;148:1385–400.
[94] Vilaseca I, Morello A, Montserrat JM, Santamaria J, Iranzo A. Usefulness of uvulopalatopharyngoplasty with genioglossus and hyoid advancement in the treatment of obstructive sleep apnea. Arch Otolaryngol Head Neck Surg 2002;128:435–40.
[95] Ryan CF, Dickson RI, Lowe AA, Blokmanis A, Fleetham JA. Upper airway measurements predict response to uvulopalatopharyngoplasty in obstructive sleep apnea. Laryngoscope 1990;100:248–53.
[96] Woodson BT, Conley SF, Dohse A, Feroah TR, Sewall SR, Fujita S. Posterior cephalometric radiographic analysis in obstructive sleep apnea. Ann Otol Rhinol Laryngol 1997;106:310–3.
[97] Li KK, Troell RJ, Riley RW, Powell NB, Koester U, Guilleminault C. Uvulopalatopharyngoplasty, maxillomandibular advancement, and the velopharynx. Laryngoscope 2001;111:1075–8.
[98] Holland J, Dement W, Raynall D. Polysomnography: a response to a need for improved communication. Presented at the 14th Annual Meeting of the Association of Psychophysiological Study of Sleep, Jackson Hole, WY, June 1974.
[99] Coleman J. Sleep studies: current techniques and future trends. Otolaryngol Clin North Am 1999;32:195–210.
[100] Sergi M, Rizzi M, Greco M, Andreoli A, Bamberga M, Castronovo C, et al. Validity of diurnal sleep recording performed by an ambulatory device in the diagnosis of obstructive sleep apnoea. Respir Med 1998;92:216–20.
[101] Mykytyn IJ, Sajkov D, Neill AM, McEvoy RD. Portable computerized polysomnography in attended and unattended settings. Chest 1999;115:114–22.
[102] Parra O, Garcia-Esclasans N, Montserrat JM, Garcia Eroles L, Ruiz J, Lopez JA, et al. Should patients with sleep apnoea/hypopnoea syndrome be diagnosed and managed on the basis of home sleep studies? Eur Respir J 1997;10:1720–4.

[103] Kapur VK, Rapoport DM, Sanders MH, Enright P, Hill J, Iber C, et al. Rates of sensor loss in unattended home polysomnography: the influence of age, gender, obesity, and sleep-disordered breathing. Sleep 2000;23:682–8.
[104] Mortimore IL, Bradley PA, Murray JA, Douglas NJ. Uvulopalatopharyngoplasty may compromise nasal CPAP therapy in sleep apnea syndrome. Am J Respir Crit Care Med 1996;154(6 Pt 1):1759–62.
[105] Schechtman KB, Sher AE, Piccirillo JF. Methodological and statistical problems in sleep apnea research: the literature on uvulopalatopharyngoplasty. Sleep 1995;18:659–66.
[106] Li KK, Powell NB, Riley RW, Troell RJ, Guilleminault C. Long-term results of maxillomandibular advancement surgery. Sleep Breath 2000;4:137–40.
[107] Larsson LH, Carlsson-Nordlander B, Svanborg E. Four-year follow-up after uvulopalatopharyngoplasty in 50 unselected patients with obstructive sleep apnea syndrome. Laryngoscope 1994;104(11 Pt 1):1362–8.
[108] Charuzi I, Lavie P, Peiser J, Peled R. Bariatric surgery in morbidly obese sleep-apnea patients: short- and long-term follow-up. Am J Clin Nutr 1992;55(2 Suppl):594S–6S.
[109] Scheuller M, Weider D. Bariatric surgery for treatment of sleep apnea syndrome in 15 morbidly obese patients: long-term results. Otolaryngol Head Neck Surg 2001;125: 299–302.
[110] Sugerman HJ, Fairman RP, Sood RK, Engle K, Wolfe L, Kellum JM. Long-term effects of gastric surgery for treating respiratory insufficiency of obesity. Am J Clin Nutr 1992;55(2 Suppl):597S–601S.
[111] Wittels EH, Thompson S. Obstructive sleep apnea and obesity. Otolaryngol Clin North Am 1990;23:751–60.
[112] Walker RP, Durazo-Arvizu R, Wachter B, Gopalsami C. Preoperative differences between male and female patients with sleep apnea. Laryngoscope 2001;111:1501–5.
[113] Mohsenin V. Gender differences in the expression of sleep-disordered breathing: role of upper airway dimensions. Chest 2001;120:1442–7.
[114] Young T. Analytic epidemiology studies of sleep disordered breathing—what explains the gender difference in sleep disordered breathing? Sleep 1993;16(8 Suppl):S1–2.
[115] Vgontzas AN, Tan TL, Bixler EO, Martin LF, Shubert D, Kales A. Sleep apnea and sleep disruption in obese patients. Arch Intern Med 1994;154:1705–11.
[116] Rajala R, Partinen M, Sane T, Pelkonen R, Huikuri K, Seppalainen AM. Obstructive sleep apnoea syndrome in morbidly obese patients. J Intern Med 1991;230:125–9.
[117] Bettega G, Pepin JL, Veale D, Deschaux C, Raphael B, Levy P. Obstructive sleep apnea syndrome: fifty-one consecutive patients treated by maxillofacial surgery. Am J Respir Crit Care Med 2000;162(2 Pt 1):641–9.
[118] Li KK, Guilleminault C, Riley RW, Powell NB. Obstructive sleep apnea and maxillomandibular advancement: an assessment of airway changes using radiographic and nasopharyngoscopic examinations. J Oral Maxillofac Surg 2002;60:526–30; discussion, 531.
[119] Thut DC, Schwartz AR, Roach D, Wise RA, Permutt S, Smith PL. Tracheal and neck position influence upper airway airflow dynamics by altering airway length. J Appl Physiol 1993;75:2084–90.
[120] Pae EK, Lowe AA, Fleetham JA. A role of pharyngeal length in obstructive sleep apnea patients. Am J Orthod Dentofacial Orthop 1997;111:12–7.
[121] Millman RP, Carlisle CC, Rosenberg C, Kahn D, McRae R, Kramer NR. Simple predictors of uvulopalatopharyngoplasty outcome in the treatment of obstructive sleep apnea. Chest 2000;118:1025–30.
[122] Boehlecke BA. Epidemiology and pathogenesis of sleep-disordered breathing. Curr Opin Pulm Med 2000;6:471–8.
[123] Piccirillo JF. More information needed about the long-term health consequences of mild to moderate obstructive sleep apnea. Arch Otolaryngol Head Neck Surg 2001;127: 1400–1.

[124] Kingshott RN, Vennelle M, Hoy CJ, Engleman HM, Deary IJ, Douglas NJ. Predictors of improvements in daytime function outcomes with CPAP therapy. Am J Respir Crit Care Med 2000;161(3 Pt 1):866–71.
[125] Douglas NJ, Thomas S, Jan MA. Clinical value of polysomnography. Lancet 1992; 339:347–50.
[126] Gyulay S, Olson LG, Hensley MJ, King MT, Allen KM, Saunders NA. A comparison of clinical assessment and home oximetry in the diagnosis of obstructive sleep apnea. Am Rev Respir Dis 1993;147:50–3.
[127] Troell RJ, Riley RW, Powell NB, Li K. Long-term results of surgical management of sleep disordered breathing: are our patients really benefiting? Otolaryngol Clin North Am 1998;31:1031–5.
[128] Loredo JS, Ancoli-Israel S, Dimsdale JE. Effect of continuous positive airway pressure vs placebo continuous positive airway pressure on sleep quality in obstructive sleep apnea. Chest 1999;116:1545–9.
[129] Li KK, Riley RW, Powell NB, Gervacio L, Troell RJ, Guilleminault C. Obstructive sleep apnea surgery: patient perspective and polysomnographic results. Otolaryngol Head Neck Surg 2000;123:572–5.
[130] Simmons FB, Guilleminault C, Miles LE. The palatopharyngoplasty operation for snoring and sleep apnea: an interim report. Otolaryngol Head Neck Surg 1984;92:375–80.
[131] Walker-Engstrom ML, Wilhelmsson B, Tegelberg A, Dimenas E, Ringqvist I. Quality of life assessment of treatment with dental appliance or UPPP in patients with mild to moderate obstructive sleep apnoea: a prospective randomized 1-year follow-up study. J Sleep Res 2000;9:303–8.
[132] Benbadis SR, Mascha E, Perry MC, Wolgamuth BR, Smolley LA, Dinner DS. Association between the Epworth sleepiness scale and the multiple sleep latency test in a clinical population. Ann Intern Med 1999;130(4 Pt 1):289–92.
[133] Chervin RD, Aldrich MS. The Epworth Sleepiness Scale may not reflect objective measures of sleepiness or sleep apnea. Neurology 1999;52:125–31.
[134] Moore P, Bardwell WA, Ancoli-Israel S, Dimsdale JE. Association between polysomnographic sleep measures and health-related quality of life in obstructive sleep apnea. J Sleep Res 2001;10:303–8.
[135] Barnes M, Houston D, Worsnop CJ, Neill AM, Mykytyn IJ, Kay A, et al. A randomized controlled trial of continuous positive airway pressure in mild obstructive sleep apnea. Am J Respir Crit Care Med 2002;165:773–80.
[136] Reda M, Ullal U, Wilson JA. The quality of life impact of snoring and the effect of laser palatoplasty. Clin Otolaryngol 2000;25:570–6.
[137] Bardwell WA, Ancoli-Israel S, Dimsdale JE. Response bias influences mental health symptom reporting in patients with obstructive sleep apnea. Ann Behav Med 2001; 23:313–7.
[138] Weaver EM, Kapur VK, Yueh B. Correlations between polysomnography parameters and quality of life measures in sleep apneics [abstract]. Sleep 2000;23:A59.
[139] Moser NJ, Phillips BA, Berry DT, Harbison L. What is hypopnea, anyway? Chest 1994;105:426–8.
[140] Series F, Marc I. Nasal pressure recording in the diagnosis of sleep apnoea hypopnoea syndrome. Thorax 1999;54:506–10.
[141] Sher AE. An overview of sleep disordered breathing for the otolaryngologist. Ear Nose Throat J 1999;78:694–5698–700, 703–6.
[142] Skatvedt O, Akre H, Godtlibsen OB. Nocturnal polysomnography with and without continuous pharyngeal and esophageal pressure measurements. Sleep 1996;19:485–90.
[143] Pitman SD, Pillar G, Malhotra A, Fogel R, White DP. Night-to-night variability of apnea severity abstract. Sleep 2000;23:A373.
[144] Young T, Palta M, Dempsey J, Skatrud J, Weber S, Badr S. The occurrence of sleep-disordered breathing among middle-aged adults. N Engl J Med 1993;328:1230–5.

[145] Mendelson WB. Use of the sleep laboratory in suspected sleep apnea syndrome: is one night enough? Cleve Clin J Med 1994;61:299–303.
[146] Zozula R, Rosen R. Compliance with continuous positive airway pressure therapy: assessing and improving treatment outcomes. Curr Opin Pulm Med 2001;7:391–8.
[147] Schwartz AR, Eisele DW, Hari A, Testerman R, Erickson D, Smith PL. Electrical stimulation of the lingual musculature in obstructive sleep apnea. J Appl Physiol 1996; 81:643–52.
[148] Jokic R, Klimaszewski A, Mink J, Fitzpatrick MF. Surface tension forces in sleep apnea: the role of a soft tissue lubricant: a randomized double-blind, placebo-controlled trial. Am J Respir Crit Care Med 1998;157(5 Pt 1):1522–5.