REVIEW ARTICLE

Acoustic Reflection: Review and Clinical Applications for Sleep-Disordered Breathing

John S. Viviano, D.D.S.[1]

ABSTRACT

Sleep-disordered breathing (SDB) affects more than 4% of the adult population with an even higher prevalence within high-risk groups. Nasal continuous positive air pressure, although considered the current gold standard treatment for SDB, demonstrates poor patient compliance. Alternative therapies, such as palatal surgeries and airway orthotics, lack validated candidacy selection protocols, resulting in varying success rates. Although much has been published over the last several years regarding the effect of these therapies on the upper airway, no publication has presented an accounting of the use of acoustic reflection (AR) to evaluate airway characteristics pre- and post-treatment with these alternative therapies. This article will review AR and our current knowledge base of the pathological airway characteristics that can be assessed through AR. It will include the advantages, limitations, and potential clinical usefulness of this diagnostic modality in the treatment of patients with SDB.

KEYWORDS: Nasal patency, pharyngeal patency, acoustic reflection, palatal surgery, airway orthotic, obstructive sleep apnea

Sleep-disordered breathing (SDB) affects more than 4% of the adult population[1,2] with certain groups, such as commercial truck drivers, demonstrating a much higher prevalence.[3] Moderate to severe levels of obstructive sleep apnea (OSA), a component of SDB, are associated with cardiovascular diseases,[1,4] daytime somnolence,[5] and increased mortality and morbidity. The cost of sleep-related accidents has been estimated to range from $43.15 to $56.02 billon per year.[6] Although nasal continuous positive airway pressure (nCPAP), the current gold standard of treatment, is highly effective and safe, its long-term compliance rate has been reported to be 50 to 80%.[7] Alternative therapies,

Sleep and Breathing, volume 6, number 3, 2002. Address for correspondence and reprint requests: John S. Viviano, D.D.S., SnoreSolutions.com, 4099 Erin Mills Parkway, Mississauga, Ontario, Canada, L5L 3P9. E-mail: SnoreSolutions@aol.com. [1]Private practice, SnoreSolutions.com, Mississauga, Ontario, Canada. 1520-9512,p;2002,06,03,129,150,ftx,en;sbr00213x.

such as palatal surgical procedures and airway orthotics, successfully increase airway caliber[8–12] but report a variable success rate.[13–18] In addition, they lack validated selection protocols that triage patients to the therapeutic approach ensuring the best outcome.

This article will review acoustic reflection (AR), first described over 25 years ago,[19] and how it relates to our knowledge of the airway dynamics associated with SDB and their therapies, much of which we have learned in only the last several years. Advantages, limitations, and potential clinical usefulness of AR will also be discussed.

ACOUSTIC REFLECTION

AR technology provides an objective measurement of the nasal (rhinometry) and pharyngeal (pharyngometry) cavities. Many papers have established its accuracy,[19–27] reproducibility,[21,25,28–30] and application.[31–35] A technical explanation of the modus operandi of the Eccovision Rhinometer and Pharyngometer™ (E. Benson Hood Labs, Pembroke, MA) can be found in various publications.[19–21,35] These citations along with the manufacturer's manual[36] adequately review the technology in general and its technique of use. Therefore, we will limit our discussion in this regard to current and supplemental findings (Fig. 1).

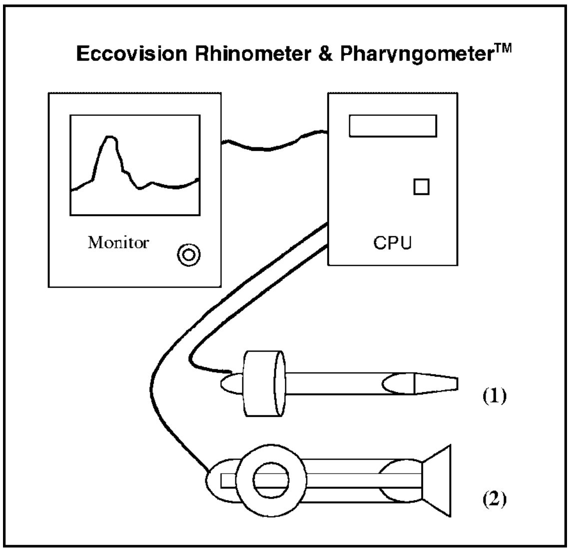

Figure 1 (1) Rhinometer wave tube and nosepiece; (2) Pharyngometer wave tube and mouthpiece. Sound generated by wave tubes is reflected in the airway and then recorded by microphones in the wave tubes, then processed by the CPU. The monitor displays both cross-sectional area and distance along the airway.

Rhinometry

Accuracy Acoustically derived measurements of nasal anatomy have compared favorably to those derived by both computerized tomography (CT)[23,37] and magnetic resonance imaging (MRI).[24,38] Studies evaluating their accuracy and usefulness in comparison to rhinomanometry[22,34] have also compared favorably and have demonstrated superiority in that AR has the ability to precisely localize and quantify the most resistive area of the nasal passage and is not dependent on nasal airflow; this allows for its use in severely constricted nasal airways. However, acoustic and CT-derived measurements relate more favorably in the anterior nasal cavity,[23,37] indicating that acoustic measurements beyond the second notch may be of limited clinical significance.[37]

Reproducibility Lenders and Pirsig[34] investigated 255 subjects and established the standard of deviation of repeated measurements of mean cross-sectional area, in the same patient, under constant conditions, to be consistently less than 7%.

Normative Standards Shemen and Hamburg[33] demonstrated the utility of AR for evaluating nasal patency before and after nasal septal surgery, demonstrating a 25% improvement in resistance, a 21% improvement in nasal volume, and a 15% improvement in minimal cross-sectional area postsurgery. They also established postoperative norms under the assumption that patients demonstrating a patent nasal cavity clinically and physically after surgery would be ideal for determining these values.

In another study, Corey et al[30] investigated 106 healthy adult subjects and established nasal caliber norms and a standard rhinometry curve useful in the evaluation of nasal patency. All measurements were made before and after application of topical nasal decongestant to eliminate the effects of the nasal cycle. Data analysis considered race, sex, height, and weight.

Pharyngometry

Accuracy The accuracy of pharyngometry-derived measurements has been evaluated extensively in the literature.[19,20,25,26] Due to the influences that lung volume, body posture, and phase of respiration have on the pharyngeal structures, these early studies evaluated only the trachea in human subjects, demonstrating that acoustic derived measurements compared favorably to measurements obtained through both anterior/lateral chest radiographs and CT. In a subsequent study, D'Urzo and associates[27] demonstrated excellent agreement between glottic area measurements of pharyngeal cross-sectional area derived acoustically (1.8 ± 0.8 cm^2) as compared to those obtained through CT (1.7 ± 0.9cm^2). All of these early studies followed a protocol first described by Fredberg et al,[20] which involved the use of helium/oxygen gas rather than room air in order to reduce the effect of nonideal airway wall characteristics on accuracy outcome.

More recently, Marshall et al[21] acoustically evaluated the pharyngeal dimensions of 10 normal human subjects using room air rather than helium/oxygen gas and compared these measurements to those obtained through MRI. They superimposed the acoustic and MRI-derived pharyngeal area profiles aligned at the vocal cords, demonstrating no significant difference in pharyngeal and glottal cross-sectional areas. Due to the "smoothing" effect and resulting loss in anatomical detail associated with AR, a 35% underestimation of maximal hypopharyngeal area was observed. However, this was the only measure that was statistically different between the two modalities. Minimal areas at the oropharyngeal junction and the glottis were similar (within 20%) and estimates of pharyngeal volume also showed agreement (within 10%). Integrating over the whole airway appeared to minimize the effect of "smoothing" and increased agreement in measurements between these two modalities.

Reproducibility In an early study utilizing helium/oxygen gas, Brooks and colleagues[25] determined that pharyngometry intrasubject, day-to-day coefficient of variation (CV) (9 ± 4%) is similar to within-run measurements performed on the same day (10 ± 4%) and similar to variability experienced with conventional measurements of pulmonary function. In a later study evaluating mean pharyngeal area, also using helium/gas, Brooks and associates[29] demonstrated a within-run CV of 8 ± 4%. They also compared acoustic measurements taken with a custom-made mouth piece versus a rubber pulmonary function mouthpiece, demonstrating differences between the mouthpieces but an excellent CV within 10% for the rubber mouthpiece, which is similar to the mouthpiece in use today. Using room air, Marshall et al.[21] found equally favorable results: same-day within-run CV for one individual and in 10 naïve subjects was 10%, and day-to-day CV in 5 subjects over 21 days was 13 ± 3% at the oropharyngeal area minimum and 11 ± 3% at the hypopharyngeal maximum and glottal minimum areas. Using the most current version of the pharyngometer, which uses room air, Kamal[28] recently investigated 350 normal adult subjects and established a CV for intrasubject pharyngeal volume of 5 to 7%.

Normative Standards Kamal's[28] investigation of 350 normal adult subjects documented sex-specific norms for airway caliber at various pharyngeal sites and a standard normal pharyngometry curve.

Limitations in Comparing Measurement Modalities

There are inherent problems regarding comparing acoustic measurements to other measurement techniques. Although AR provides an instantaneous measurement of the airway, MRI requires several minutes, requiring data to be averaged over many breaths including changes that occur with the respiratory cycle. MRI also has its inherent drawbacks. Relative to AR, MRI is expensive, time-consuming, and has a level of uncertainty in identifying airway walls in cases of poor image quality. Also, technical limitations in accurately establishing the exact location of the airway wall on the image at a “pixel level of contrast” leads to an intrinsic uncertainty in area estimation, resulting in an irreducible area of uncertainty[21] of ± 19% for an area of 1 cm^2 and ± 14% for an area of 2 cm^2.

Comparison to the CT technique is also not without problems. Although CT provides accurate transverse images free of distortion, inaccuracies can arise from the airway not being perpendicular to the plane of the scanner, improper selection of the window width and level, and inaccuracies in determining the air-tissue interface.[26] Finally, both CT and MRI are conducted in the supine position, the importance of which will be discussed below.

Limitations of Acoustic Technology

Although studies have demonstrated a strong correlation between measurements derived by rhinometry, pharyngometry, and other modalities such as MRI[21,24,38] and CT[23,26,27,37], unlike these anatomic imaging modalities, the acoustic rhinometer and pharyngometer are physiological tools, limited to providing a measurement of cross-sectional area according to distance along the airway; they do not provide high resolution of anatomic representation or soft-tissue structures. Therefore, there are limitations to each of the studies on AR that relate to specific anatomical regions. Acoustic derived cross-sectional measurements are used to establish volume, mean cross-section, and local area maximums and minimums with pharyngometry, and volume, local area minimums, and a substantially underestimated physiological flow resistance with rhinometry. Notwithstanding this technology’s inability to provide high-resolution anatomic representation of the airway and soft-tissue structures, the favorable correlation between measurements derived through AR, CT, and MRI, and the noninvasiveness, low cost, and ease of use of AR make it an ideal physiological tool useful in contributing to our understanding of both structural and functional characteristics of the airway in health and disease.

Awake versus Sleeping Airway

One of the most challenging aspects of investigating issues pertaining to sleep is that some data are very difficult to obtain during the sleep state, and in many instances data collected during wakefulness are of questionable value. AR performed during wakefulness has been criticized regarding its meaningfulness once the patient falls asleep.

Using the acoustic technique, Rivlin et al[39] demonstrated that patients with OSA have a smaller pharyngeal area than controls. They also found a significant correlation between the number of apneas per hour of sleep and the pharyngeal cross-sectional area during wakefulness. One patient in this particular study experienced a remarkable decrease in apnea and increase in pharyngeal cross-sectional area after a drastic weight loss of 68 kg. Many other studies have demonstrated a significant relationship between acoustic pharyngeal measurements of the awake airway and characteristics of that airway during sleep.[21,40–45]

The existence of a relationship between the awake and sleeping airway has also been demonstrated using other techniques. Suratt et al[46] measured nasopharyngeal resistance in the awake airway and found that it correlated significantly with both the apnea index and number of desaturation episodes observed per hour of sleep. They demonstrated that the number of apneic events and arterial oxygen desaturations increased with increasing flow resistance in the upper airway during wakefulness.

Malhotra and associates[47] recently published a study evaluating two collapsibility measurement techniques in normal and apneic subjects during wakefulness and sleep: negative pressure pulses (NPPs) and inspiratory resistive loading. Their findings revealed (1) a significant correlation between these two measures of collapsibility, and that (2) collapsibility during wakefulness as measured by NPPs correlated significantly with collapsibility during sleep. Although both controls and apneics demonstrated a significant increase in pharyngeal collapsibility during sleep as compared to wakefulness, apneics were found to demonstrate significantly greater pharyngeal collapsibility than controls while awake. The authors suggested that "upper-airway collapsibility measured during wakefulness does provide useful physiologic information about pharyngeal mechanics during sleep and demonstrates clear differences between individuals with and without sleep apnea."

Exam Technique

An adequate description of the exam techniques for both rhinometry and pharyngometry can be found in the manufacturer's manual[36] for the devices. The following is supplemental information intended to validate and further clarify that information.

Pharyngometry Readings Using nasopharyngoscopy in the sleeping patient, it has been demonstrated that there is a progressive reduction in end-expiratory cross-sectional pharyngeal area prior to obstructive apnea.[48] Since end-expiration is the point at which the pharyngeal airway is most compromised and susceptible to suction collapse, pharyngometry acoustic readings are taken at that point. Recording acoustic readings consistently in this manner helps to ensure reproducibility.

Caliber and Compliance In order to facilitate the reading of this document, an explanation of the terms airway caliber and compliance is warranted. Airway caliber, documented at end-expiration during regular tidal breathing at functional residual capacity (FRC), is representative of cross-sectional area of the airway. Airway compliance is documented at end-expiration following exhalation from total lung capacity (TLC) to residual volume (RV). The acoustic reading at RV when compared to FRC documents airway compliance associated with lung volume-related changes and is representative of airway collapsibility.

Supine versus Upright Posture Body position is also an important factor when evaluating the upper airway. For rhinometry, in order to make comparisons to the norms established in the upright position by Corey and colleagues,[30] the exam is conducted upright as per the manufacturer's instructions. However, in a study using positional rhinomanometry to evaluate the importance of nasal resistance in OSA patients, De Vito et al[49] demonstrated that 9 of 36 subjects had normal nasal resistance in the seated position and pathological resistance in the supine position, suggesting that it may be useful to evaluate changes in supine nasal patency as compared to norms established in the upright position.

In a study evaluating the effect of posture on pharyngeal airway caliber, Martin et al[50] demonstrated that sleep apnea hypopnea syndrome (SAHS) patients have a smaller upper airway area at the oropharyngeal junction (OPJ) than either snorers or normal subjects in the seated upright position while awake. However, these same patients demonstrated no statistical difference in airway cross-sectional areas in the supine or lateral recumbent positions. Also, these individuals demonstrated a significantly smaller decrease in OPJ cross-sectional area from the seated to either the supine or lateral recumbent positions. The authors concluded that these findings are compatible with SAHS patients defending their upper airway more upon lying down than do snorers or normal subjects while awake. Another study designed to evaluate the effect of posture on the upper airway dimensions of normal subjects provided supporting results; Jan and associates[31] demonstrated through AR that the pharyngeal areas of normal awake patients are smaller when supine than while sitting, and that this difference persisted in the lateral recumbent position.

Further support for the conclusion that SAHS patients defend their airway more than normal subjects in the supine position can be found in studies evaluating neuromuscular function: genioglossal electromyographic activation is increased in awake apneics while in semi-recumbent and supine positions in comparison with normal subjects.[51,52] It is generally accepted that airway dynamics differ between sleep and wakefulness. Although patients susceptible to airway collapse demonstrate increased activation of these muscles while awake, this compensatory muscle response is lost with the loss of muscle tonus that accompanies onset of sleep, leaving the airway susceptible to collapse. Evaluation of the awake airway must consider these state-dependent muscular differences and the extent to which they manifest themselves in supine versus upright positions during wakefulness.

The literature demonstrates that SAHS patients differentiate themselves from normal subjects more distinctly in the seated upright position while awake. However, to date much research has been conducted in the supine state on awake patients with the belief that the supine awake airway more closely resembles the sleeping airway.

Pharyngometry Mouthpiece and Baseline Readings Over the years, a variety of mouthpiece designs have been utilized with the acoustic pharyngometer. The Free Flow™ mouthpiece (SensorMedics Corporation, Yorba Linda, CA), currently in use, is designed to aid in patient tongue orientation, allowing the operator to acquire reproducible data with minimal patient compliance. This mouthpiece has a patented restraint bat that gently positions the patient's tongue downward and away from the wave tube opening, virtually eliminating proximal tongue interference. In a recent review on upper airway imaging, Schwab[53] expressed concerns regarding the alteration in upper airway anatomy that accompanies mouth opening associated with use of a mouthpiece, thus potentially compromising the ability to compare area calculations obtained through AR with other imaging modalities. The Free Flow™ mouthpiece has noncompliant bite-pads which in fact open the vertical dimension up to several mm, potentially altering upper airway anatomy as Schwab[53] describes. However, this anatomical alteration is patient-specific due to the fact that some individuals will experience a vertical opening consistent with their habitual rest posture, which can vary greatly between patients.

The temporomandibular joint allows the mandible to assume various postures. Habitual or rest posture of the mandible has been described as that assumed while muscles that elevate or depress it are at rest, while the subject is in the seated upright or standing position.[54] During rest posture, the mandible is held in a muscular sling with the teeth slightly out of contact (creating space between them referred to as freeway space), usually 1 to 3 mm in the anterior region, but as much as 10 mm or more.[54] This is the posture in which acoustic baseline readings should ideally be performed; when the orofacial musculature is relaxed and in balance and in a state of minimal tonic contraction; minimally influencing upper airway anatomy.

The bite-pads on the Free Flow™ mouthpiece are easily reduced by scalpel to a wafer-thin compliant pad approximately 1 mm in thickness. With this reduction, the purpose of this pad is no longer for the teeth to bite down on, but rather a way to retain the tongue positioning restraint bat described above. This reduced thickness and resulting increased compliance allow the pads to pass through the freeway space, minimally interfering with the assumption of habitual rest posture of the mandible. It is then possible to obtain an acoustic reading at true habitual rest posture and evaluation of the upper airway, uninfluenced by mouth opening and muscle contraction not normally present at true baseline.

Standard Operating Procedure (SOP) The patient is asked to sit comfortably upright in a straight-backed chair, fixing his or her gaze at a point straight ahead. Posture is maintained throughout the exam during the breathing exercises, particularly head, neck, and shoulder posture. For rhinometry, have the patient take a relaxed oral breath, exhale half way, then stop breathing or swallowing during the test. For pharyngometry, take the reading at FRC or RV as described above and have the patient assume a comfortable habitual rest posture with the mouthpiece in place. This will avoid any increase in muscle tonus associated with heavy occlusion on the bite-pads.

NASAL AIRWAY PATENCY

Although the relationship between nasal obstruction and SDB is poorly understood, evidence of this relationship can be found throughout the literature.

Effect of Nasal Obstruction

Daytime nasal obstruction has been demonstrated to be an independent risk factor for obstructive sleep apnea syndrome (OSAS) .[55] Numerous studies involving the creation of an artificial nasal obstruction have demonstrated the creation of polysomnography-verified obstructive apneic events in normal subjects.[56–59] A population study involving close to 5000 subjects found that patients with a symptomatic nasal obstruction were statistically more likely to report snoring and chronic daytime somnolence.[60] Taking the opposite approach, Rubin et al[61] demonstrated improvement in daytime somnolence, sleep quality, and polysomnography-verified apneic events after surgical correction of nasal obstruction. Finally, Loth and Petrusen[62] demonstrated a remarkable reduction in snoring and morning tiredness through dilation of the nasal valve region with a nostril dilator in snorers.

Notwithstanding these citations, the existence of a relationship between nasal obstruction and SDB has also been refuted in the literature. In a study evaluating the relationship between snoring and nasal resistance during sleep, Miljeteig and colleagues[63] failed to demonstrate a relationship between nasal resistance, which varied significantly between patients, and both the number of snores and snore sound intensity.

Nasal Acoustic Evaluation

Acoustic rhinometry has been documented extensively in the literature. It has been demonstrated to objectively compare nasal patency to normative data established by Corey et al,[30] to confirm improvement in nasal patency after nasal septal/turbinate surgery,[33] and to establish the degree of improvement in nasal patency with medical treatment of nasal allergies.[22,34]

PHARYNGEAL AIRWAY PATENCY

A great deal of information has been published regarding the characteristics of both the healthy and pathological pharyngeal airway, both in the awake and sleeping states. In recent years, much has also been written about how palatal surgery and manipulation of the mandible with an airway orthotic affects these characteristics. The subject of pharyngeal airway patency can be subdivided into site of collapse/narrowing, caliber/volume, and compliance. These parameters, along with the effect of palatal surgery and airway orthotics on the pharyngeal airway, have been evaluated through AR.[9,19–21,29,31,44,45]

Collapse (Narrowing)

Site analysis for the location of airway collapse can be technically elusive. Airway closure in OSA has been demonstrated to occur at multiple levels: velopharynx, oropharynx, and/or hypopharynx.[64,65] Complicating the issue further, the majority of OSA patients exhibit more than one site of upper airway obstruction during sleep and the pattern of these obstructions varies with sleep stage and body position.[66] Studies to date have utilized many techniques in both the awake and sleeping states, all with their own limitations. However, relationships between the site of obstruction and ultimate therapeutic success do exist and warrant investigation.[67–70] It is generally accepted that dynamic studies during sleep should be employed to accurately determine the site of airway obstruction.[71] This may be possible in the research setting, but it may not be practical in the clinical setting. Using multiple modalities to evaluate the specifics of airway collapse, the literature confirms that patients with OSA demonstrate structural narrowing/collapse of the upper airway which is usually focal and located at the velopharynx, but extends downward to the oropharynx and hypopharynx in approximately 50% of individuals.[72]

Over 15 years ago, Katsantonis and Walsh[68] demonstrated through the use of somnofluoroscopy a 67% response to uvulopalatopharyngoplasty (UPPP) when maximal narrowing and/or airway collapse occurred above the midpoint of the second cervical vertebra. This compared to a 9% successful surgical outcome when it extended below this level. A few years later, Launois et al,[69] using fiber optic pharyngoscopy and a pressure catheter to evaluate the sleeping airway of OSA patients, demonstrated similar findings. They reported a successful response to UPPP in 6 of 7 patients demonstrating upper airway collapse confined to the velopharyngeal segment, compared to 2 of 11 in whom collapse occurred caudal to the velopharynx. In spite of the fact that the existence of a relationship continues to be demonstrated in the current literature,[70] attempts to date have failed to develop an empirical protocol to select surgical candidates.

A study involving mandibular advancement with an airway orthotic and propofol-induced sleep reported a remarkable relationship between closure of the airway below the velopharynx and successful treatment outcome.[67] It was discovered that although some patients obtained therapeutic relief when the closure occurred at the velopharynx exclusively, successful reduction of the apnea-hypopnea index to below 10 events per hour was less common when airway closure was confined to this site. In contrast, all of the patients that experienced closure caudal to the velopharynx experienced a drop in apnea-hypopnea index to fewer than 6 events per hour. The technique used to determine the site of airway closure involved a pressure catheter that detected the lowest site of closure. As a result, individuals demonstrating closure below the velopharynx may have also had undetected closure at the velopharynx, suggesting that an airway orthotic works best when dealing with closure caudal to the velopharynx, regardless of whether there is additional closure at higher levels.

Rubinstein and associates[43] used AR to evaluate upper airway function in awake OSA patients both before and after weight loss. They demonstrated a paradoxical inspiratory narrowing of the glottis in some patients and complete resolution of this glottic narrowing in 2 of the 3 afflicted patients after weight loss, implying that cross-sectional area at the glottis during wakefulness may be a particularly important indicator of airway pathology during sleep.

Although closure during sleep cannot be documented through AR, abnormal sites of upper airway narrowing during wakefulness can be documented and compared to established norms for the nasal cavity, oropharynx, OPJ, hypopharynx, and glottis.[19–23,28,30,33]

Pharyngeal Caliber (Volume)

In an effort to explain what happens during an apneic event, Remmers et al[73] proposed that upper airway collapse occurs when the negative pressure generated in the airway during inspiration is inadequately opposed by the pharyngeal dilator musculature. Horner,[74] in his review of motor control of the pharyngeal musculature as it relates to OSA, discussed the concept of a pressure-volume relationship, whereby decreasing airway volume results in a decrease in the negative pressure required to collapse the airway. He concluded that if airway caliber entered a critical region of narrowing (particularly at end-expiration), it would become susceptible to collapse with a minimum of inspiratory negative pressure, or even at pressures above atmospheric.

Mandibular advancement through the use of an airway orthotic has been demonstrated to be effective in enlarging airway caliber.[8,10,11] Isono and colleagues,[10] using videoendoscopy, demonstrated widening of the retropalatal airway as well as that at the base of the tongue with mandibular advancement in 13 OSA patients under general anesthesia with total muscle paralysis. They also demonstrated that a more negative pressure was required to cause collapse of the airway when the mandible had been advanced. These authors postulated that tension transmitted along the palatoglossus muscles to the soft palate may have been responsible for the airway stabilization demonstrated in their study.

In contrast, videoendoscopy evaluation of awake airway caliber with mandibular advancement, while supine, demonstrated an increase in caliber at the velopharynx and hypopharynx, but no significant increase at the oropharynx or tongue-base level.[12] However, one must consider the fact that this study was conducted in the awake, supine patient. As discussed above, Martin et al[50] demonstrated through AR that the airway caliber of awake apneics differentiates itself from normal subjects more distinctly in the upright position, possibly due to compensatory muscle tonus in the awake patient while supine. This suggests that the above oropharyngeal findings may have been different had the patient been evaluated in the upright position.

Through the use of AR, Rivlin and associates[39] demonstrated that the mean cross-sectional pharyngeal area is smaller in awake patients with OSA when compared with controls. They also found a significant correlation between the number of apneas per hour of sleep and pharyngeal cross-sectional area during wakefulness. Katz et al.[40] used AR to further confirm these findings; they concluded that a reduced cross-sectional area of the awake hypopharynx was a risk factor for both OSA and snoring.

Videoendoscopy,[10,12] MRI,[11] and AR[44] have all been used successfully to evaluate and document the effect an orthotic has on the caliber of a pathologically small airway. AR, along with the airway caliber norms established by Kamal,[28] may be useful to evaluate the ability of an orthotic to normalize the caliber of a pathological airway during wakefulness.

Pharyngeal Compliance (Collapsibility)

Stienhart et al[75] analyzed pharyngeal collapsibility at the palatal and tongue-base levels during propofol-induced sleep using endoscopy. They found that patients with OSA syndrome demonstrated significantly stronger collapsibility compared with snorers and that it was most evident at the tongue-base level. Collapsibility at the tongue base was also found to have a strong correlation to higher values of RDI (respiratory disturbance index) as recorded by standard polysomnography.

Airway compliance during wakefulness has been demonstrated to distinguish apneics from non-apneics. Hoffstein and colleagues[42] found that the awake airway of obese apneics was smaller in caliber and collapsed to a greater degree during lung volume-related changes in comparison to nonapneic obese controls. This increase in airway collapse from 30 to 54% implies increased compliance for the apneic airway of obese patients. Increased pharyngeal compliance of the awake airway of obese apneics was also demonstrated by Brown and associates[45] and then further confirmed in a study evaluating the relationship between pharyngeal area and weight loss, which demonstrated through AR that the post-weight-loss airway became statistically less compliant.[43] Of particular note, although these patients demonstrated the anticipated increase in FRC after weight loss, they did not experience a significant change in pharyngeal caliber at either FRC or RV; this suggests that the improvement in OSA after weight loss was associated with airway function rather than solely with airway structure.

The existence of obesity seems to play a role in the presentation of the apneic airway as measured through AR. Bradley et al,[41] in their acoustic study of awake, nonobese normal subjects, snorers, and apneics, also demonstrated a reduction of airway caliber in the pathological airway, but found variable compliance in differentiating these patients. These authors demonstrated that patients with OSA and simple snoring have abnormalities of anatomical and mechanical features of the pharynx that distinguish them from each other and from normal subjects. They found that the nonapneic snorer, when compared to the apneic snorer, had similar airway caliber at FRC but smaller lung volume-related changes at RV, implying a less compliant airway and allowing for maintenance of airway patency during sleep. They also demonstrated that although snorers had a smaller airway caliber than controls at FRC, they experienced less compliance with lung volume-related changes at RV, resulting in no difference in caliber at RV than controls. This differentiated those airways as being susceptible to snoring due to narrow airway caliber, but not statistically narrower enough than controls' airways at RV to compromise airway patency. Finally, in contrast to the findings of Hoffstein et al[42] in their study of obese apneics, although the nonobese apneics in this study also demonstrated a smaller airway than controls at both FRC and RV, they experienced a similar level of compliance with lung volume-related changes. This suggests that airway structure may be more significant than function when evaluating nonobese apneics.

The ability to repeat AR readings at 0.2-second intervals allows for the dynamic study of airway characteristics and measurements associated with lung volume-related changes, thus facilitating the evaluation of airway compliance.

Site of Collapse/Narrowing versus Caliber/Volume versus Compliance

The relative importance of these variables is difficult to ascertain. Regarding site of collapse/narrowing, a study utilizing AR to evaluate improvement in upper airway function after weight loss demonstrated a post-weight-loss improvement in apnea accompanied by normalization of abnormal narrowing at the glottis.[43] Site of collapse/narrowing has been confirmed by many other studies to play a significant role in the pathogenesis of SDB.[67–70] However, the existence of multiple sites of obstruction[64,65] and variability based on sleep position and stage of sleep[66] make it difficult to study.

Regarding caliber and compliance, their relative importance appears to be quite elusive in the literature. It has been demonstrated that the critical pressure at which airway collapse occurs can be altered by either an increase in airway caliber or a decrease in airway wall compliance.[74] However, using AR to evaluate the airways of nonobese apneics as compared with nonobese normal subjects, the apneics differentiated themselves as having a smaller airway caliber, but not through a difference in compliance.[41] On the other hand, another acoustic study involving obese apneics and studies using other modalities, in both the sleeping and awake airway, have demonstrated that apneic airways are more compliant than normal ones.[42,47,75] The inconsistent interstudy variable of obese versus nonobese participants may play a role in the differences observed in the significance of compliance.

Although the importance of compliance seems to vary in the literature, caliber at end-

	Calibre at FRC (cm^2)	Calibre at RV (cm^2)	Compliance
Normals	#1 4.9-5.9	#2 4.1-4.9	Similar to Apneics
Snorers	#3 2.8-4.6	#3 3.3-4.1	Less than Normals & Apneics
Apneics	#3 3.9-4.3	#3 3.2-3.6	Similar to Normals

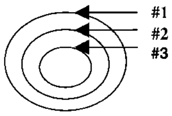

Figure 2 Relative airway caliber and compliance for nonobese normal subjects, snorers, and apneics. (Reprinted with permission of Bradley TD, Brown IG, Grossman RF, et al.[41])

expiration is consistently found to be important. A study by Issa and Sullivan[76] demonstrated that the smaller caliber of the pathological airway at end-expiration makes it more susceptible to suction collapse upon inspiration. This disposition to collapse becomes more pronounced during REM sleep with further loss of muscle tonus. This corresponds with the pressure-volume relationship discussed above, whereby a decrease in airway volume results in a decrease in the negative pressure required for airway collapse. Acoustic studies have demonstrated that apneics demonstrate a reduction in airway caliber at both FRC and RV; however, the role of compliance appears to be associated with the existence of obesity (see Figs. 2 and 3).

The literature demonstrates that site of abnormal airway narrowing, airway caliber, volume, and compliance all have the potential to be critical parameters in the evaluation of airway patency. Airway patency seems to be dependent on both the anatomical factors of site of narrowing, caliber, and volume, and the physiological factor of compliance.

AIRWAY DYNAMICS AND CRITICAL PARAMETERS

Critical Parameters and the Asleep Airway

There have been many attempts to validate parameters that must be maintained in order to ensure airway patency. One example is "critical pressure." Airway patency has been found to be dependent on maintaining a differential of 4 cm H_2O between atmospheric pressure and the "critical pressure" required to collapse the airway.[77] This parameter operates on a continuum, with a differential of 8 cm H_2O required to eliminate snoring. Individuals with a differential of less than 4 cm H_2O can increase it

	Calibre at FRC (cm^2)	Calibre at RV (cm^2)	Compliance
Controls	#1 4.2-5.0	#2 3.6-4.2	Less than Apneics
Apneics	#3 3.2-3.6	#4 2.0-2.6	More than Controls

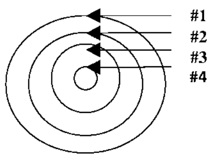

Figure 3 Relative airway caliber and compliance for obese controls and apneics. (Reprinted with permission of Hoffstein V, Zamel N, Phillipson EA.[42])

in one of two ways: increasing atmospheric pressure as is accomplished with nCPAP, or decreasing the critical pressure required to collapse the airway. It has been established that any therapy intended to maintain airway patency must maintain this differential.[77–79]

In a study designed to evaluate the relationship between critical pressure and the response to UPPP, Swartz and associates[78] found a 100% correlation between apneics who responded favorably to UPPP and reduction in critical pressure following surgery. Those individuals not experiencing a decrease in critical pressure to at least −4 cm H_2O postsurgery were found to be nonresponders.

In a second study involving weight loss,[79] a direct relationship to critical pressure was also demonstrated, resulting in the conclusion that weight loss affects OSA by reducing the collapsibility of the pharyngeal airway in proportion to the amount of weight lost. The authors also proposed an explanation for why post-weight-loss individuals have variable success in the reduction of their RDI. Although a direct relationship was demonstrated between weight loss and critical pressure; they found that regardless of the amount of weight loss and resulting reduction in critical pressure, if the end critical pressure was above −4 cm H_2O, the patients' RDI would not be eliminated. Therefore, an individual experiencing a substantial weight loss would still experience airway collapse during sleep if his or her critical pressure remained above −4 cm H_2O.

Critical Parameters and the Awake Airway

Many studies that validated relationships regarding both the "awake" and "sleeping" airway have been discussed. Upper airway collapsibility measured during wakefulness provides useful physiologic information about pharyngeal mechanics during sleep.[47] Weight loss results in a reduction in RDI,[80] in critical pressure,[79] in compliance of the sleeping airway,[79] and in compliance of the awake airway.[43] Elimination of RDI with weight loss occurs only when the critical pressure resulting from the weight loss is at or below −4 cm H_2O.[79] The critical pressure at which airway collapse occurs can be lowered by either an increase in airway caliber or a decrease in airway wall compliance.[74] Finally, airway compliance in the "awake" airway has been found to be related to airway collapse during sleep in apneics as verified by polysomnography.[42]

In their presentation of pharyngeal critical pressure, Gold and Schwartz[77] discuss a correlation between increasing levels of critical pressure and increasing levels of sleep-related airflow obstruction. They propose that different levels of critical pressure on a continuum results in a range of symptoms commencing with normal subjects, to snorers, to apneics. Horner[74] reports the existence of a pressure-volume relationship whereby once a reduction in airway volume to a critical level takes place, the airway will collapse during sleep. In a study using AR to evaluate the pharyngeal size of awake normal subjects, snorers, and apneics, Bradley and colleagues[41] describe a continuum regarding pharyngeal size that includes a critical level of pharyngeal narrowing during wakefulness, below which one will tend to snore, and another more severe level, below which airway occlusion occurs during sleep. See Figure 4.

The above suggests that both critical pressure[77] and critical volume[74] during sleep are parameters that must be maintained to ensure airway patency during sleep. The relationship between these parameters and airway compliance and/or caliber/volume during wakefulness suggests that there may be airway parameters during wakefulness that are also critical to the maintenance of patency during sleep.

Critical Parameters and Acoustic Reflection

As discussed above, the literature supports the concept of "critical pressure" as a parameter necessary to maintain airway patency. We also discussed the relationship between "critical pressure" in the sleeping airway and parameters that can be evaluated through AR in the awake airway. Hoffstein et al[42]

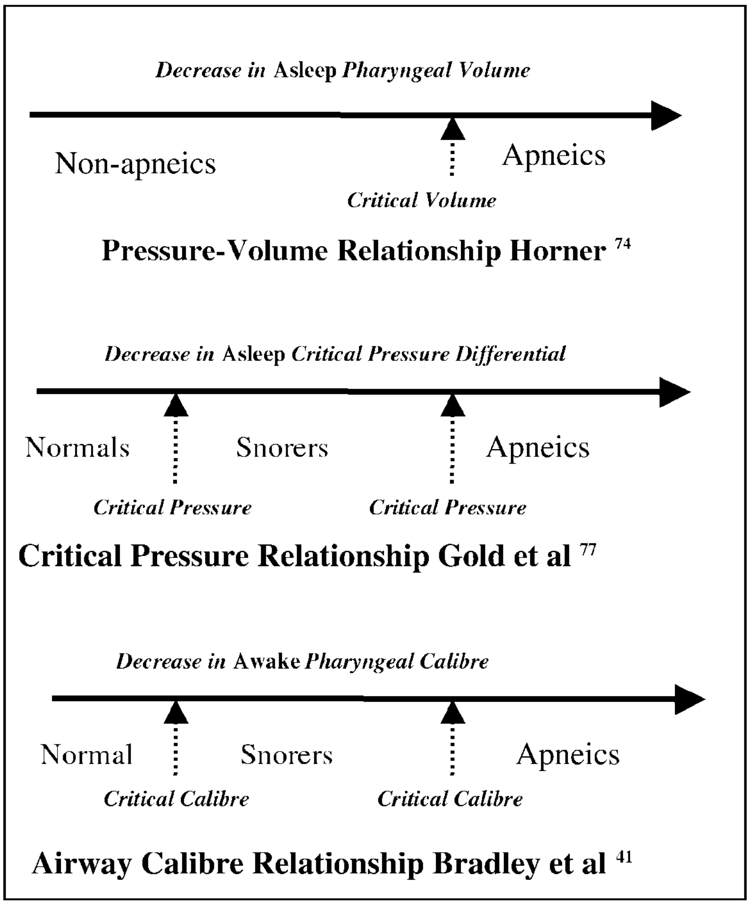

Figure 4 Critical parameters during wakefulness and sleep.

demonstrated that the apneic airway of obese patients is more compliant than controls'. Bradley et al[41] found that the apneic airway of nonobese patients does not demonstrate more compliance than controls but rather a reduced caliber. Rubinstein and associates[43] found that apneic airways of obese patients that do not demonstrate increased compliance demonstrate abnormal narrowing at the glottis which resolves with weight loss and reduction in apnea. All of these studies involved assessment of the awake airway, measured in the sitting upright position using AR.

Site of pharyngeal narrowing, airway caliber, volume, and compliance can all be accurately evaluated, documented, and compared with norms through AR.[19–21,28,39–43,45] However, the relative importance of each of these variables is difficult to ascertain; it is not known if their effects are cumulative or independent. The fact that a decrease in pharyngeal compliance has been observed in the absence of any meaningful change in pharyngeal caliber indicates that airway caliber alone may not provide all the information required to predict airway stability.[43] Perhaps it is not airway caliber at FRC that is critical, but the caliber established after maximum compliance has occurred. In other words, airway narrowing to a critical caliber may in fact be critical to maintaining airway patency. Perhaps, as long as this caliber remains larger than the critical caliber required for maintenance of patency, the airway does not collapse, regardless of the degree of compliance.

Factors Influencing Acoustic Critical Parameters

Gender, age, and obesity have been demonstrated to influence airway structure and function. These influences must be understood and considered when evaluating the airway through AR.

In his evaluation of the normal pharynx through AR, Kamal[28] demonstrated a smaller airway caliber in normal females versus males. This gender difference is supported by other investigations of normal subjects[81,82] and recently in a study evaluating obese apneic males and females.[83] Greater compliance has also been demonstrated in males versus females.[81,82,84] However, these differences in structure and function were all demonstrated in upright posture through AR and become less distinguishable when investigated in supine subjects.[82]

One possible explanation for these gender differences may involve the relationship between female hormones (progesterone) and increased genioglossus muscle activity.[85] Further support for this explanation lies in the fact that although females experience less severe OSA during nonREM sleep, both genders demonstrate a similar severity of OSA during REM sleep, suggesting that the loss in muscle tonus that accompanies REM sleep leaves females as susceptible as males to airway obstruction.[86] In contrast, although a recent study[87] evaluating airway response to resistive loading during nonREM sleep found that males exhibit markedly greater pharyngeal collapsibility in response to externally applied load, no significant difference in either tensor palatini or genioglossus muscle activity was noted for either gender. These authors suggested that gender differences may be better explained by a fundamental difference in upper airway anatomy and/or tissue characteristics.

The literature demonstrates conflicting data regarding the affect of age on the airway. Although Martin et al[84] demonstrated that airway caliber decreases with increasing age for both genders, Huang and colleagues[82] found no change for either gender with age. However, this group did find that males demonstrate an increase in compliance with age, suggesting that airway function may play a role in the increased incidence of OSA in older males.

As discussed above, obesity seems to affect the relevance of caliber and compliance in OSA patients. See Figures 2 and 3.

The literature suggests that acoustic evaluation of the upper airway must consider gender, age, and obesity when developing normative standards and evaluating both pathology and normalization of the airway. The fact that gender differences disappear when the airway is investigated in the supine subject provides further support for evaluating the awake airway in the upright position.

Table 1 summarizes our current knowledge regarding assessment of the pharyngeal airway through AR. The literature supports a distinct con-

Table 1 Acoustic Verified Relationships[39,40–43,81,82,84]

	Airway Caliber	Airway Compliance	Glottic Dysfunction
Nonobese Snorers versus Controls	Smaller	Smaller	Not Investigated
Nonobese Apneics versus Controls	Smaller	Equal	Not Investigated
Nonobese Apneics versus Nonobese Snorers	Equal	Greater	Not Investigated
Obese Apneics versus Controls	Smaller	Greater	Not Investigated
Obese Apneics Pre- versus Post-Weight Loss	Equal	Greater	Greater*
Males versus Females	Larger	Greater	Not Investigated
Older Males versus Younger Males	Smaller	Greater	Not Investigated

*Glottic dysfunction: witnessed in obese apneics who demonstrate normal compliance.

tinuum of airway characteristics from apnea to snoring to controls, whereby both caliber and compliance alternate in their role to distinguish patients at each level. In keeping with the multifactorial nature of the pathogenesis of SDB, the variables of gender, age, and obesity appear to influence airway dynamics in the awake airway as documented through AR.

AIRWAY ASSESSMENT BY ACOUSTIC REFLECTION

Advantages

Although lateral cephalographs are limited to providing a two-dimensional view, they have been used extensively to assess the upper airway. Schwab et al,[11] using MRI on awake snorers, demonstrated a specific pattern of airway dilation with mandibular advancement; increase in caliber was greater in the lateral than the anterior-posterior (AP) dimension. Another study evaluating the effect of CPAP on soft-tissue structures demonstrated a similar airway dilation pattern.[88] Evaluation of the lateral pharyngeal walls of normal and apneic airways demonstrated that narrowing in the apneic airway was predominantly in the lateral dimension.[89] It is of significant importance that no difference in the AP dimension of normal and apneic subjects was demonstrated. Unlike cephalographs, *AR accurately evaluates the airway in three dimensions, allowing for documentation of caliber and volume over a given length of airway.* [21]

Demonstrated to be noninvasive, accurate, and reproducible, AR provides an objective measurement of the upper airway from the nasal valve to the glottis in three dimensions.[19–30] The exam is quick and inexpensive to perform and as a result, easily repeatable. Although it requires patient cooperation, it results in a high patient acceptance. Because the exam makes it possible to take readings at 0.2-second intervals, it allows for dynamic assessment of the airway.

Limitations

For both rhinometry and pharyngometry, AR provides a measurement of cross-sectional area according to distance along the airway. However, it does not provide high resolution anatomic representation of the airway or soft-tissue structures.

Acoustic rhinometry accurately documents the nasopharynx.[22–24,34,37,38] However, values may be influenced by a significant constriction,[90] movement of the soft palate,[91] perforations in the nasal septum causing an acoustic leak,[24] or asymmetric branching of the nasal cavity at the epipharynx.[24]

Regarding acoustic pharyngometry, although upper airway collapse occurs most often at the level of the velopharynx, extending caudally as low as the hypopharynx approximately 50% of the time,[64,65,72] conventional pharyngometry provides a calculated approximation of the velopharynx and an accurate assessment of the remaining upper airway commencing at the oropharynx moving caudal to the glottis.[19–21,25–27]

The conventional AR technique cannot be used during sleep. However, Huang and associates[92] recently published a new AR technique which involves introduction of the acoustic waves into the nostrils during spontaneous nasal breathing while asleep. The authors claim accuracy in measuring not only the oro- and hypopharynx, but also the nasopharynx, which is not possible using the conventional technique. They also suggest that this new technique can be used as a monitor of upper airway dimensions during standard nocturnal polysomnography.

Potential Clinical Usefulness

The literature establishes a clear relationship between acoustic derived measurements of the awake airway and pathological airway behavior during sleep.[39–43,45] This sleep-wake relationship of airway dynamic characteristics has also been demonstrated through other modalities.[47] Shown to be accurate[19–27,34,37,38] and reproducible[21,25,28–30,34] in the assessment of the upper airway, the potential for clinical usefulness of AR will be discussed based on our current understanding of upper airway dynamics and the unique characteristics afforded us by this imaging modality.

Patient Screening As a result of insufficient public and professional awareness,[93] only a small portion of individuals afflicted with SDB have been diagnosed and treated. With increase in awareness, the development of a validated protocol designed to facilitate the initial screening process would help to control the resulting increase in patient load at facilities already working to full capacity. Acoustic assessment of nasal patency and pharyngeal characteristics of individuals in the general population, or perhaps in high-risk groups, could isolate those that warrant further evaluation through polysomnography, ultimately reducing the burden on current medical facilities all the while increasing the number of individuals isolated for treatment.

Positional Therapy Evaluation AR has been used to evaluate airway response to positional therapy. Hsu et al.[94] used acoustic technology to assess the effect head extension through cervical repositioning has on airway caliber. They demonstrated a significantly increased caliber with cervical repositioning through the use of a patented special pillow.

Surgery Candidacy Relationships between the site of obstruction and therapeutic success with UPPP have been established.[68–70] The need for a preoperative investigation of the upper airway in order to establish candidacy for UPPP prior to surgery has been emphasized in the literature.[70] Although site of airway closure is impossible to demonstrate in the awake patient using AR, the acoustic pharyngometer accurately documents the cross-sectional area and abnormal upper airway narrowing caudal to the velopharynx.[21] Research by Kamal[28] documenting acoustic derived pharyngeal cross-sectional minimum area norms provides normative standards for evaluation of the airway regarding caliber and sites of abnormal narrowing.

Postsurgery Evaluation AR has been used to evaluate changes in pharyngeal structure and function after UPPP surgery. Wright et al[9] demonstrated a postsurgical increase in pharyngeal area as well as a reduction in lung volume-related changes. It has also been demonstrated to be useful in the evaluation of postsurgical nasal patency[33] and postmedical treatment of nasal allergies.[22,34]

Orthotic Candidacy It is difficult to determine whether an airway orthotic stabilizes the pharyngeal airway by increasing caliber or by decreasing compliance. A small airway cannot tolerate as much compliance without collapsing as a large airway, and a large airway may be less likely to be challenged to comply due to the fact it would experience a lower critical pressure.[74,76] Horner[74] discussed the concept of a critical airway volume below which airway collapse occurs. However, although caliber has differentiated apneics from nonapneics when investigating nonobese patients,[41] it was compliance and not caliber that improved after weight loss in a study involving obese apneics.[43] Even so, in the absence of abnormal compliance in obese apneics, abnormal narrowing at the glottis has been documented.[43] The literature suggests that airway pathology manifests itself through a variety of variables when assessed through AR, possibly due to the multifactorial etiology of SDB. See Table 1.

Loube[44] used AR to evaluate hypopharyngeal changes produced by mandibular advancement in the awake patient. He found that no change in volume was 95% predictive of failure and that an increase in volume was 60% predictive of a successful treatment outcome. Airway area was less accurate than volume as an outcome predictor. Although Loube's study indicates a very strong association between airway volume and treatment outcome, the 60% predictive value for success associated with airway dilation indicates that variables other than volume may play a role in determining success.

The theory postulated by Isono and colleagues,[10] that mandibular advancement increases airway muscle tonus, may explain those instances in which a decrease in compliance in the absence of airway dilation is observed with mandibular advancement. Since Loube's investigation was limited to changes in airway caliber/volume, improvement or the absence of improvement in compliance went unnoticed. Notwithstanding this, the fact that nonresponse to mandibular advancement is 95% predictive of orthotic failure is useful information when considering candidacy for airway orthotic therapy. However, as discussed above, when investigated through AR, the apneic airway differentiates itself from normal airways more readily in the upright position; that these patients were investigated in the supine position could have potentially altered this studies outcome.

That an airway orthotic works best when dealing with closure caudal to the velopharynx, regardless of whether there is additional closure at higher levels,[67] could be a useful consideration when evaluating airway narrowing through AR. Comparison to established norms[28] could aid in assessing the beneficial effects of an airway orthotic on the caliber of a pathological airway.

The use of AR to predict successful orthotic therapy may be enhanced by further investigation of the relationship between airway patency during sleep and the effect on the airway of an orthotic during wakefulness. The literature suggests that the following variables warrant evaluation: critical minimum caliber, minimum volume, maximum compliance, and/or site specific area norms. Much in the same way that violation of "critical pressure" discussed above results in airway collapse, violation of one or more of these parameters as measured through AR may also result in collapse. Considering the correlation between nasal patency and SDB, it would also be of value to investigate the effect untreated nasal blockage has on the success of orthotic therapy.

Orthotic Construction A degree of mandibular vertical displacement is unavoidable with mandibular protrusion. Anterior and downward movement of the mandibular condyle occurs due to the anatomy of the anterior wall of the mandibular fossa, which dictates condyle movement as it glides forward during protrusion (Fig. 5). Also, the mandibular anterior teeth are guided downward by the lingual surface of the maxillary anterior teeth as the mandible is translated forward (Fig. 6).

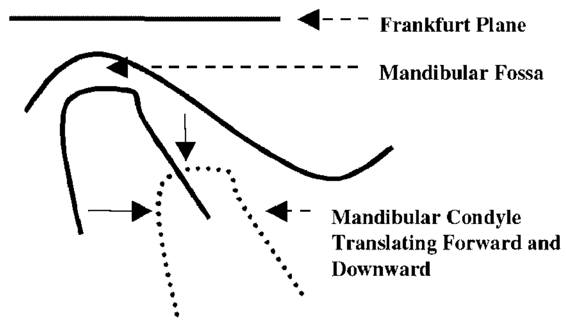

Figure 5 Mandibular condyle is displaced vertically as it is advanced with an airway orthotic due to guidance of anterior wall of mandibular fossa.

The effect on the airway of this vertical displacement of the mandibular apparatus and associated musculature is not clear. Consequently, the degree of benefit derived from an airway orthotic that results from anterior repositioning as opposed to this accompanying vertical displacement is unknown. To date, it has been popular to minimize vertical opening when using an airway orthotic. However, an anecdotal finding in my own clinical practice, which I have verified through personal communication with other practitioners and case studies,[95] is that some patients benefit from the varying of vertical posture of the mandible beyond that associated with mandibular protrusion.

The vertical and protrusive settings that best stabilize the airway with an oral bite-jig may play a role in the construction of an airway orthotic. Through the use of a chair-side constructed bite-jig, the mandible could be manipulated in both the AP and vertical dimensions, providing an opportunity to evaluate through AR the various critical airway parameters discussed thus far; aiding the clinician in determining ideal construction parameters.

Orthotic Titration The current protocol involves advancing the mandible until subjective relief of symptoms is experienced and then verified objectively through standard polysomnography. It is not

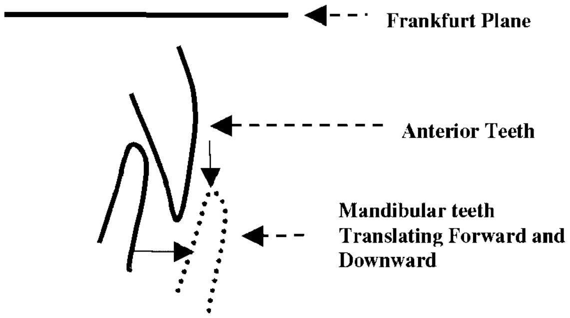

Figure 6 Mandibular teeth are displaced vertically as mandible is advanced with an airway orthotic due to guidance of the lingual surface of the maxillary anterior teeth.

uncommon for an orthotic to be advanced further than therapeutically necessary in order to ensure a successful outcome with the polysomnogram. However, from a neuromuscular point of view, it is important that an airway orthotic not advance the mandible so much as to result in hyperextension of the masticatory and cervical muscles. Unnecessary mandibular advancement may lead to increased patient discomfort and ultimately lower compliance to therapy.

Mandibular advancement past the point of therapeutic effectiveness to ineffectiveness has been reported. L'Estrange and associates,[96] demonstrated that although the airways of most patients increase in caliber with mandibular advancement, reduction in caliber occurs in some patients with advancement past 75% of full protrusive position, possibly due to skeletal differences in the subjects.

Once the orthotic has been constructed, it could be optimized further through acoustic evaluation of the airway's response to mandibular manipulation with the orthotic in place, thus ensuring orthotic titration that results in the most ideal management of the airway. This would help to minimize the possibility of inadvertent advancement past the ideal point of effectiveness into a position that would unnecessarily strain the masticatory and cervical muscles and/or reduce the effectiveness of the orthotic.

Orthotic Maintenance The importance of regular follow-up is generally regarded as mandatory whenever ongoing therapy is prescribed; its value regarding orthotic therapy was highlighted in a recent publication[97] demonstrating that patients returning regularly for adjustments and follow-up visits experienced a better long-term effect than patients continuing to use their original orthotic. Orthotic effectiveness may be affected by factors such as weight gain, development of allergies, medication use, and so on. A yearly examination of the orthotic and dentition along with subjective evaluation through patient consultation is considered standard protocol; an acoustic exam at these visits could objectively substantiate that the orthotic is still ideally titrated to maintain airway patency during sleep.

SUMMARY AND CONCLUSIONS

The potential clinical usefulness of AR in the treatment of patients with SDB involves all stages of treatment: initial screening of patients, establishing patient candidacy, evaluating nasal patency, determining mandibular posture that optimizes airway patency, determining orthotic titration settings, and verifying continued efficacy of orthotic settings at follow-up. The use of AR could facilitate front-line efforts in isolating afflicted individuals; ensure a higher level of success for surgical, positional, and airway orthotic therapies; eliminate the possibility that an undiagnosed nasal obstruction could interfere with successful treatment; establish orthotic construction parameters; and objectively verify the orthotics' continued effectiveness. Although much evidence is currently found in the literature, continued research to evaluate critical parameters of the awake airway as documented through acoustic reflection would further validate the use of this diagnostic modality in the treatment of patients with SDB.

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