

POSITIVE PRESSURE THERAPY

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Since its first description in 1981, considerable advances have been made in systems used to deliver positive airway pressure for the treatment of patients with obstructive sleep-disordered breathing (OSDB).¹⁰¹ The present generation of machines uses microprocessors and are small, quiet, and easily portable to facilitate their use while traveling. The software in many of the newer generation machines allows for the objective assessment of patient compliance by monitoring both the total time on and time at the prescribed pressure. Positive pressure can be delivered at a fixed pressure throughout the breathing cycle, as in the case of continuous positive airway pressure (CPAP), at two different fixed pressures in response to inspiration and expiration, as in bilevel pressure, or at a variable positive pressure in response to changes in airflow or snoring sounds, as is the case in autotitrating systems.⁹⁸

Most machines can be run on European or North American electrical current, and off alternate power sources such as a car battery. The nasal and oronasal interfaces that are available incorporate a variety of materials and designs. The newer masks provide pa-

tients with improved fit and comfort. Positive airway pressure remains the initial medical treatment of choice for the sleep apnea/hypopnea syndromes.⁹⁸ It has essentially eliminated the need for emergency tracheostomy in patients with obstructive sleep apnea (OSA).

In this article we discuss the utility of positive airway pressure in OSDB—its mechanism of action, benefits, and complications. We review the important topic of compliance and discuss current approaches to improve the long-term use of this highly effective treatment modality. Finally, we will offer our perspective on the future of positive airway pressure therapy for OSDB.

NASAL CONTINUOUS POSITIVE AIRWAY PRESSURE

Mechanism of Action

CPAP systems consist of a blower unit that generates and directs airflow downstream to the patient. The positive pressure is generated by variations in delivered airflow and resistance in the system. When CPAP is delivered by way of a nasal interface, the soft palate *seals* against the tongue, resulting in a pressurized upper airway (Fig. 1). Pressure is

Supported in part by Department of Veterans Affairs Medical Center and NHLBI Training Grant NHLBI2T32HL075631A2.

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Figure 1. A, The sites of airway closure during sleep. Note that the soft palate and the base of the tongue are involved. B, Pressurization of the upper airway with continuous positive airway pressure (CPAP). Note that the soft palate moves against the base of the tongue to seal the upper airway and as a result reduce the possibility of a mouth leak. (©1997, American Sleep Disorders Association, reprinted by permission.)

maintained by increasing airflow in response to small leaks, involving the mask or mouth. The collapsible region of the upper airway is pneumatically splinted open, an effect that represents the primary mechanism of therapeutic action.

The effect of CPAP may be mediated by additional factors. Some authors^{10, 33, 91} have speculated that nasal CPAP maintains upper airway patency during sleep by a reflex mechanism involving an increase in end-expiratory lung volume. In contrast, several investigators^{2, 67, 97} have demonstrated that the administration of nasal CPAP depresses electromyographic activity of the upper airway dilator muscles, which argues against a reflex-mediated reduction in upper airway resistance. Alternatively, a mechanism involving a "tracheal tug" has been suggested; traction of neck structures in response to lung inflation has been demonstrated to affect upper airway patency favorably.^{5, 106} Although upper airway resistance varies directly with lung volume, that effect is relatively small.⁹⁰ Series and coworkers⁸⁹ demonstrated that there is no sig-

nificant reduction of CPAP's impact on upper airway resistance when the increase in lung volume is prevented by the concomitant application of positive extrathoracic pressure. In addition, Abby et al¹ observed that CPAP eliminated obstructive apnea, whereas application of continuous negative extrathoracic pressure did not, despite comparable augmentation of lung volume.

Regardless of the mechanism, nasal CPAP has been documented to be effective in eliminating both mixed and obstructive apneas.⁷³ Some "central" apneas, particularly those observed in patients with predominantly obstructive events, are also eliminated by nasal CPAP.^{36, 73} That finding strongly supports the contention of Sanders and coworkers that the central portion of mixed apneas and many central apneas may actually represent delayed inspiratory effort caused by prolongation of the preceding expiration.⁷⁹ Those investigators hypothesized that the increase in expiratory time is related to expiratory upper airway instability with augmented upper airway resistance and slowing of expiratory airflow.^{75, 79}

Clinical Benefits

Objective improvements in neuropsychiatric function and daytime sleepiness have been demonstrated repeatedly in patients treated with nasal CPAP.^{15, 18, 41, 44, 63, 65} Nocturnal desaturation, ventilatory-related arousals, nocturnal dysrhythmias, pulmonary hypertension, and right heart failure often are treated effectively.⁶⁸ Nocturia may improve, particularly if it is associated with atrial natriuretic peptide release in response to hypoxic pulmonary vasoconstriction.⁴² Preliminary data suggest that diurnal hypertension control may be improved presumptively by correcting nocturnal desaturation and lowering nocturnal catecholamine release.^{25, 46} Those results parallel those previously observed with tracheostomy, while avoiding its morbidity and disfigurement.^{24, 26, 58, 105, 109} Both nasal CPAP and tracheostomy have been associated with improved survival compared with patients who were not treated or were treated with uvulopalatopharyngoplasty alone.²⁷

Side Effects and Complications

Side effects reported by the patient usually, but not exclusively, are related to pressure or airflow or the mask–nose interface.⁶¹ Possible side effects related to positive pressure therapy and potential management strategies are listed in Table 1. Significant complications of nasal CPAP therapy are extremely rare and represent isolated case reports in the literature, including pulmonary barotrauma and pneumocephalus (Sanders MH, personal communication, 1993).³⁷ It appears that side effects are important for the clinician to address: Engleman et al¹⁹ reported that patients who complained of side effects used CPAP less frequently than those devoid of side effects.

Ill-fitting masks may result in leaks, causing conjunctivitis.⁹⁶ Occasionally, patients develop a contact dermatitis from the mask material. Poor mask fit can also lead to skin breakdown, particularly at the nasal bridge, where the skin is thin. In addition, a poor mask fit may cause air leaks, resulting in ineffective pressurization of the upper airway, persistent OSDB, and sleep fragmentation.

Optimal treatment with nasal CPAP can be compromised by mouth leaks that cause pressure loss or nasal congestion refractory to medical therapy. In our experience, chin straps frequently are not effective in control-

ling mouth leaks. Using a mask that covers both the nose and the mouth can effectively address that problem.⁶⁴ Oronasal masks have been used for chronic therapy in the outpatient setting without adverse consequences.⁷⁸ Although precautions regarding aspiration are warranted with such interfaces, concerns regarding increased carbon dioxide retention because of elevated dead space with the mask appear to be unfounded.⁵¹

Richards et al⁷¹ demonstrated that increased nasal flow because of a mouth leak increases nasal resistance. Previous work by Hayes et al²⁹ and a recent report by Fleury et al²⁰ questioned the utility of cold passover humidification of the CPAP circuit. Those investigators found that only heated humidification of the CPAP circuit was effective in providing effective relative humidity and decreasing nasal resistance caused by mouth leak.

Patients may complain of nasal congestion, dryness, or, occasionally, rhinorrhea.⁶¹ Nasal congestion can be treated with antihistamines or topical steroids. Topical saline sprays or humidification of the circuit improve nasal dryness. Intranasal ipratropium bromide can be helpful in abating CPAP-induced rhinorrhea.

Aerophagia, increased intraocular pressure, and musculoskeletal chest discomfort (presumably related to increased lung volumes) have also been reported.^{3, 32, 107} Other significant but rare complications of CPAP involve epistaxis and tympanic membrane rupture.^{76, 100}

Intolerance

Proper mask fit and comfort impact on acceptance of positive pressure therapy.⁷² A number of commercially available masks with varied material and construction are available (Fig. 2). In our experience, it is helpful to allow patients to try a variety of different masks prior to the initial CPAP titration to find the most comfortable fit. Patients who cannot obtain a proper seal or fit can have a custom mask made. The wide variety of interfaces now available commercially substantially decreases the need to resort to a custom mask. A Comfort Flap (Respironics, Inc., Murrysville, PA) or a Bubble Mask (ResMed Corp., San Diego, CA) may provide an adequate seal without needing to tighten the headgear excessively. Certain patients become claustrophobic when using nasal CPAP. Changing the interface prescription from a nasal mask to less-confining nasal prongs

Table 1. SIDE EFFECTS OF NASAL CONTINUOUS POSITIVE AIRWAY PRESSURE

Problem	Management Strategy
Mask related Skin abrasion or rash Conjunctivitis from air leak	• Optimize mask fit from wide selection of commercially available types of masks, select nonallergenic material • Protective skin covering • Customized mask • Reinforce hygienic care of device • Eye patch
Pressure or airflow related Chest discomfort Aerophagia Sinus discomfort Smothering sensation Difficulty exhaling Difficulty initiating and/or maintaining sleep Pneumothorax or pneumomediastinum Pneumoencephalus	• Pressure ramp • Reduce pressure with bilevel positive airway pressure • Try to reduce requisite pressure using oral appliance + CPAP (no published data)
Problems related to the nasal route Rhinorrhea Nasal congestion, nasal or oral dryness Epistaxis (may be massive, especially in anticoagulated patients)	• Heated humidification • Saline nasal spray • Topical nasal steroid preparation • Consider trial of nasal aerosol of ipratropium bromide solution • Chin strap for oral dryness • Desensitization over time • Oralnasal mask interface
Other Noise Cumbersomeness or inconvenience Spousal intolerance	• Longer tubing to move device further from bedside • Intensify education of patient and spouse • Recommend attending a patient support group (A.W.A.K.E. Network of the American Sleep Apnea Association)

may correct that problem. If a proper seal at the nares is achieved, there appears to be no significant difference between nasal prongs and mask in the pressure prescription^{28, 52} (a CPAP prescription consists of the pressure that maintains satisfactory upper airway patency and oxyhemoglobin saturation during sleep, as well as provides satisfactory sleep continuity using an interface that is well-tolerated by the patient). If this intervention is not effective, progressive desensitization to the mask may be helpful.¹⁷

Some patients may complain of increased resistance to expiration or the sensation of too much pressure in the nose. If that is the case, a CPAP unit with a ramp feature may be worth considering. The ramp allows the pressure to increase to the optimal CPAP pressure gradually over a set time interval (usually 15 to 30 minutes). No published data indicate that a ramp feature improves acceptance or compliance with CPAP, however. If that approach is not effective, a bilevel positive airway pressure system, in which inspiratory positive airway pressure and expiratory positive airway pressure can be adjusted indepen-

dently, lowers mean airway pressure and resistance to expiration.⁷⁴

Patients occasionally find the air generated by the CPAP unit too warm or too cold. If moving the machine from the floor to a bedside table does not correct the problem, incorporating a heated humidifier into the circuit may help. This complaint is encountered most commonly when high flows or pressures are prescribed.

Another uncommon complaint is that the CPAP machine generates too much noise.³² That usually is the bed partner's, and not the patient's, complaint. Removing the machine from the bedside or placing it in a closet may remedy the problem. We have had patients travel all over the world with nasal CPAP systems. Although the units are compact, lightweight, and easily transported, however, a small number of patients find them too cumbersome to travel with.

Acceptance and Compliance

Treatment with CPAP is "unique" in that it involves the nightly, volitional use of a me-

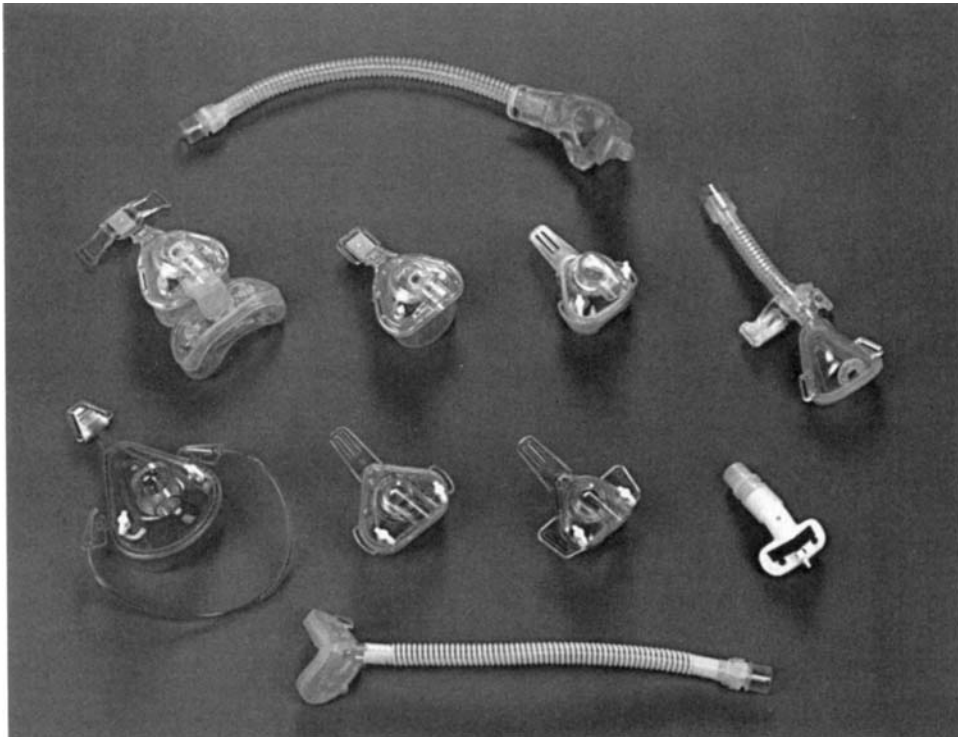


Figure 2. A sampling of the masks that are currently available. The interfaces are designed to cover either the nose alone (nasal prongs/nasal masks) or the nose and the mouth. These masks are made of a number of different materials.

chanical device to treat OSDB. The first obstacle to treatment is the *acceptance* of CPAP, defined as the patient's willingness to be set up in the home after the titration night. *Compliance* with CPAP is defined as the adherence to treatment with CPAP once the patient has agreed to initiate therapy.

Acceptance of CPAP therapy may be influenced by the manner in which the treatment is introduced. Because of the "unique" nature of the treatment, as opposed to taking a medication, proper patient preparation, with appropriate educational interventions before treatment, may facilitate acceptance. That should start in the physician's office and continue in the sleep laboratory on the titration night. Brochures and video tapes explaining what OSA is and how CPAP works can be useful. If CPAP is introduced outside the laboratory, using an unattended home titration or, more recently, autotitrating devices (discussed subsequently), the technician will not be available to educate the patient and assist him or her with adjustment of the mask.

Limited subjective reports using unattended in-home titrations with help of the

bed partner are favorable.¹⁴ To date, no controlled study has examined the success of this approach to therapy compared with traditional, attended, in-laboratory titrations.

Hoffstein and colleagues^{31, 56} developed a prediction equation to estimate the minimal CPAP pressure required. The equation, $CPAP_{min} = -5.12 + 0.13 \times BMI + 0.16 \times NC + 0.04 \times AHI$, incorporates the apnea-hypopnea index (*AHI*), body mass index ($BMI = \text{weight in kilograms} \div \text{height in meters squared}$) and neck circumference ($NC = \text{circumference in centimeters at the cricothyroid membrane}$). Calculations from the predictive equation lack sufficient accuracy to replace a CPAP titration for OSDB but may be useful for selecting a starting point for the titration in the laboratory.³¹ There are no data examining the impact on acceptance or compliance when titration protocols using the predictive equation are employed with either in-laboratory, attended studies or in home, unattended studies.

Many sleep laboratories have adopted the use of "split-night" attended polysomnograms to expedite initiation of therapy and

control costs related to polysomnography. Previous reports indicate that with using split-night protocols, it is possible to obtain satisfactory CPAP prescription in approximately 60% to 80% of patients.^{21, 34, 77} Yamashiro et al¹¹¹ identified a subset of patients for whom a split-night study provides insufficient time for CPAP titration to achieve a satisfactory prescription. Patients with milder degrees of OSDB (AHI<20) in whom the titration is initiated later in the night (because prolonged monitoring was required to establish a diagnosis) are more likely to have unsuccessful split-night titrations. The potential impact of such abbreviated titrations on acceptance and compliance requires consideration. An uncontrolled study by Fleury et al²¹ suggested that compliance may not be altered by using a split-night protocol. A small case-controlled study ($n=12$) previously reported by our group indicated that acceptance may be reduced following a split-night. In addition, there was a trend for lower therapeutic compliance in the patients who had undergone a split-night compared with those who had undergone a full-night titration.⁹⁹ Those data indicate the need for further examination of the impact of split-night polysomnography on acceptance and compliance with CPAP.

When compliance is assessed by subjective means, a 65% to 90% compliance rate with positive airway pressure therapy has been reported.^{32, 61, 66, 72, 76, 107} Those and other studies demonstrate that the patient's perception of improvement and not the severity of OSDB predicts acceptance of and compliance with CPAP.^{18, 19} Kribbs et al⁴⁰ reported that, when compliance was assessed objectively by covertly measuring use with an hour meter incorporated into the unit, compliance with nasal CPAP was substantially less than in previous studies when compliance was reported on the basis of subjective patient data. Their study indicated that nasal CPAP was used 46% of the time, equal to or greater than 4 hours, for 70% of the observed nights, and compliance at 1 month predicted compliance at 3 months. A subsequent study by Reeves-Hoché et al⁷⁰ reported similar results using objective monitoring of compliance. Their data indicate that (1) patients subjectively overestimate CPAP use and (2) long-term compliance may be less than desirable when use is monitored objectively.

Weaver et al¹⁰⁸ recently reported that irregular use of CPAP can be identified during the first week of therapy. Simple interventions by way of telephone contacts or written material

aimed at improving compliance have been reported to be effective,¹³ highlighting the need for close follow-up in the first week of treatment to identify patients at high risk for noncompliance and to intervene appropriately, if necessary. How that is best accomplished requires further study.

Must CPAP be used every night? Existing data suggest that optimal relief of daytime sleepiness requires nightly use of CPAP. Kribbs et al³⁹ and Sforza et al⁹² reported that sleeping one night without CPAP results in increased objectively measured daytime sleepiness. Does CPAP need to be used throughout the entire sleep period? Hers et al³⁰ reported that, when CPAP was discontinued after 4 hours, there was a persistent beneficial effect on oxyhemoglobin saturation and sleep continuity during the remainder of the night. The investigators postulated that the persistent improvement was attributed to improved sleep continuity achieved during the initial portion of the night, while on CPAP, favorably influencing upper airway stability during the latter portion of the night, after the CPAP was removed. It has been suggested that at least some OSDB patients use CPAP for only part of the night because they derive a satisfactory degree of symptomatic benefit from that limited application.^{30, 55} That observation would be in keeping with previous observations that sleep restriction of greater than 4 hours has precipitous effects on objective measurement of sleep propensity by multiple sleep latency testing, and that 4 hours of adequate sleep may be the minimum requirement for acceptable daytime performance.¹¹ The software incorporated into the newer generation CPAP devices that allows monitoring more precise patterns of use (i.e., time at pressure on individual nights) undoubtedly will give us insight into the minimal duration of CPAP use that is "acceptable" to decrease daytime sleepiness and possibly, to modify vascular consequences of OSDB.

BILEVEL POSITIVE AIRWAY PRESSURE

Previous work by a number of investigators^{75, 79, 85, 94} has shown that upper airway resistance increases during expiration despite the absence of negative intrapharyngeal pressure accompanying inspiration. Sanders et al⁷⁹ subsequently speculated that the instability of the upper airway during expiration is the initial event in the sequence leading to

obstructive apnea. Mahadevia et al⁴⁹ further substantiated that concept by demonstrating that apnea frequency could be reduced by the application of expiratory positive airway pressure. It was hypothesized by Sanders et al⁷⁴ that the splinting action of positive pressure in the upper airway, during *both* inspiration and expiration, was necessary to eliminate obstructive events, and that *less* pressure would be needed to maintain upper airway patency during expiration than during inspiration. They reasoned that, during expiration, inherent upper airway instability represents the primary factor that favors airway closure, whereas, during inspiration, airway patency is determined by two factors—(1) the collapsing influence of negative intraluminal pressure and (2) the inherent instability of the upper airway. The pressure requirement to maintain upper airway patency therefore may be less during expiration than inspiration. That leads to the development of a bilevel positive airway pressure system for the treatment of OSDB. More recent work by Schwab et al,^{81–84} employing CT and MR imaging, confirms the presence of expiratory narrowing of the upper airway during expiration.

Mechanism of Action

Unlike CPAP, in which a constant pressure is maintained during inspiration and expiration, bilevel positive airway pressure systems, such as Bi-PAP (Respironics, Inc., Murrysville, PA), allow independent adjustment of inspiratory and expiratory pressures. Inspiratory positive airway pressure (IPAP) is initiated in response to low-level, patient-generated inspiratory airflow (≈ 40 mL/second). The pressure cycles to the set expiratory positive airway pressure (EPAP) when inspiratory airflow falls below a threshold level. Bilevel devices are adjusted to deliver EPAP at a level sufficient to prevent upper airway closure during expiration; at the initiation of inspiratory effort, minimal inspiratory airflow triggers the delivery of a predetermined level of IPAP to prevent airway closure associated with inspiration.⁷⁴ As a result, IPAP would offset the negative intrapharyngeal pressure generated during inspiration and the subsequent airway collapse or closure. In addition to simply preventing complete upper airway closure, delivery of a sufficient level of IPAP would augment airway patency, eliminating partial airway clo-

sure (hypopnea) with desaturations or arousals from sleep. If the upper airway closes during expiration, IPAP cannot be triggered and an apnea occurs, highlighting the need for proper titration of both IPAP and EPAP in the laboratory.

Indications and Clinical Benefits

Bilevel positive airway pressure can effectively treat patients with OSDB. Because of differences in cost, it is generally reserved for patients with OSDB who cannot tolerate or have had complications related to CPAP. We have found bilevel positive airway pressure to be useful for “salvaging” treatment with positive airway pressure. Mean mask pressures are usually lower on bilevel positive airway pressure than CPAP, so air leakage around the interface may be less pronounced. In patients who experience nasal congestion or rhinorrhea not treated adequately with conservative measures, switching to a bilevel system may be worthwhile. It is believed that these nasal side effects may be precipitated or exacerbated by the stimulation of pressure-sensitive nasal mucosal receptors. The lower mean airway pressure tends to minimize chest discomfort because, when the expiratory pressure is lower, end-expiratory lung volume is not increased to the same degree as it is with CPAP. In addition, some patients complain of discomfort exhaling against positive pressure, or a smothering sensation that makes it difficult for them to initiate or maintain sleep. In those individuals, the ability to minimize expiratory positive pressure using bilevel positive airway pressure may improve acceptance of therapy. Finally, the risk of hypoventilation caused by increased mechanical impedance on CPAP is probably reduced with the lower expiratory pressures on bilevel pressure.⁵⁰

Side Effects and Complications

The side effects and complications are similar to those seen with CPAP (see Table 1). The risk of barotrauma may be less than with CPAP because of the lower mean airway pressures used with bilevel systems.

Acceptance and Compliance

Sanders et al⁷⁷ found that 7 of 50 patients (14%) required a change from CPAP to a bi-

level system when undergoing a split-night polysomnography. Patients were placed on a bilevel device for the following reasons: intolerance of the CPAP system pressure (four patients), development of central apneas on CPAP, resulting in sleep fragmentation (one patient), mask leaks at a high CPAP pressure (one patient on 17.5 cm H₂O of CPAP), and persistent alveolar hypoventilation on CPAP (one patient). Although acceptance of treatment with positive airway pressure may be improved with bilevel positive airway pressure, a recent report indicated that, in patients who do accept therapy for home use, compliance is the same with both CPAP and bilevel systems.⁶⁹ Reeves-Hoché et al⁷⁰ randomized 83 patients to receive CPAP or bilevel positive airway pressure and objectively followed compliance for 1 year with covert monitors incorporated into the devices. Overall, there was no significant difference between CPAP and bilevel positive airway pressure use. There was a greater drop-out rate in the CPAP group and greater compliance with therapy in the bilevel positive airway pressure group when the differences between IPAP and EPAP were greater than 6 cm H₂O. The study had a methodologic flaw in randomization, resulting in an uneven distribution of patients in the two groups (26 bilevel versus 36 CPAP); it is uncertain how that impacted the investigator's conclusions. Nonetheless, even if compliance is comparable on CPAP and bilevel positive airway pressure, the ability to increase acceptance may be useful. Further study is required to support that notion.

VARIABLE (AUTOTITRATING) CPAP

The pressure required to stabilize the upper airway during sleep is influenced by several factors, including body position, sleep stage, sleep deprivation, sedatives, and alcohol.* It would appear to be theoretically advantageous to use a positive-pressure device that would raise and lower the pressure delivered in response to those conditions. A number of positive-pressure devices that provide variable (autotitrating) CPAP recently were developed. They are designed to respond dynamically to changes in the patient's upper airway resistance by variably increasing or decreasing the pressure in response to changes in

pressure, flow, or reflections of snoring sounds.^{6, 9} Unlike fixed CPAP machines that are titrated to a level that maintains upper airway patency under the conditions of greatest collapsibility, autotitrating devices, at least theoretically, are capable of responding to changing physiologic conditions and provide the lowest required pressure (Fig. 3). That has the potential to be useful for the initiation of CPAP therapy and perhaps favorably influence long-term therapeutic compliance.

Several recently published studies^{8, 47, 48, 80, 93, 103} suggest that a variety of autotitrating CPAP devices compare favorably with fixed CPAP devices with respect to reducing the mean AHI and arousal frequency, as well as improving nocturnal oxygenation. In those reports, comparable beneficial effects were obtained with lower mean overnight levels of CPAP with autotitrating CPAP compared with fixed CPAP therapy.^{80, 93}

It should be noted that virtually all of the investigations assessing the effectiveness of autotitrating CPAP that have been published in peer-reviewed journals have examined the devices in an attended, monitored environment. In most of the investigations, a technologist was permitted to intervene and adjust the mask position if significant leaks were detected. In addition, manual readjustment of the device was permitted by the technician if inadequate sensing of airway events occurred.^{38, 47, 80, 93, 103} In some instances, data collected during periods of mouth-mask leaks were excluded from analyses, potentially biasing the results.^{47, 103} The current literature also suggests that mouth breathing or leaks may prove particularly troublesome for autotitrating devices.^{8, 48} In these reports,^{8, 38, 47, 93, 104} some patients were unable to tolerate the rapid changes in pressure or for whom the device performed in a less-than-optimal manner.

One possible application of autotitrating CPAP would be to facilitate in-laboratory positive-pressure titrations. That would enable a titration to be performed in an attended environment but without requiring the technologist to manually adjust the level of CPAP. Post study, a single "best" CPAP pressure could be selected (typically defined as the pressure at which 90% to 95% of the events are treated adequately). "De-intensifying" the technologist's responsibilities may permit a lower technologist-to-patient ratio, with a resultant reduction in cost. That concept has been examined by several investigators.^{47, 95, 103}

*References 12, 16, 23, 35, 43, 45, 53, 54, 57, 60, 62, 86, 88, 102, 104.

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Figure 3. An example of a printout of an overnight study using an auto-CPAP system. Note the variation in the pressure delivered over the titration and that the pressure is decreased intermittently from 20 cm H₂O to 10 cm H₂O. (From Polo O, Berthon-Jonis M, Douglas NJ, et al: Management of obstructive sleep apnea/hypopnea syndrome. *Lancet* 344:656–660, 1994; with permission.)

The investigations indicate that the selection of a single best therapeutic pressure by visually examining the range of CPAP delivered by an autotitrating device across a night resulted in a pressure that was comparable to or slightly greater than that obtained by manual titration of “fixed” CPAP during polysomnography.

There are no published studies comparing the acceptance rate (as we have defined) of autotitrating versus fixed CPAP. Compliance at 3 weeks with an autotitrating CPAP device versus fixed CPAP has been found to be equivalent.⁸⁷ In that study, the autotitrating unit was set so the system could vary 3 cm H₂O above or 4 cm H₂O below a reference pressure. The reference pressure was determined either by an in-laboratory titration or by way of the CPAP prediction equation developed by Hoffstein.³¹ Of note, there were a number of exclusion criteria for entry into the study, including severe OSA, periodic breathing, hypoventilation, nonrespiratory sleep disorders (i.e., narcolepsy and periodic limb

movements), and an estimated pressure above 15 cm H₂O.

In summary, autotitrating CPAP shows promise, but its role has yet to be clearly defined. Initiating positive-pressure therapy with autotitrating CPAP, unattended, in the home, is technically feasible. When proceeding in that manner, the “value added” by a technician with regard to patient education and reassurance and the opportunity to optimize the interface may be compromised. In addition, it is unclear whether auto-CPAP should be used: (1) only to determine the “best” level for a “fixed” CPAP prescription, (2) with pre-set maximum and minimum pressure limits in conjunction with a reference CPAP pressure (predetermined empirically or in the laboratory), or (3) in a completely automatic (ungoverned) mode. At the present time, if autotitrating CPAP is to be used, it may be most prudent to initiate it in a laboratory environment to facilitate the CPAP titration and subsequently establish the single “best” level for a “fixed” CPAP prescription.

SPECIAL CONSIDERATIONS

Patients with OSDB treated with positive airway pressure should be re-evaluated at regular intervals to reinforce the importance of continued treatment, assess compliance and response to treatment, and address any side effects or complications of the therapy. In patients who complain of persistent daytime sleepiness, an objective evaluation of machine use should be obtained prior to repeat polysomnography. That can be accomplished easily by securing an hour "meter read" of machine use. Most CPAP and bilevel positive airway pressure units now have an hour meter incorporated into the machine. The latest generation of positive-pressure systems allows for the analysis of time at pressure and use on individual nights.

It is our practice to obtain a meter reading prior to the initial follow-up visit. If the patient complains of persistent daytime sleepiness and the meter reading reflects poor compliance, the treatment strategy is directed at improving compliance with therapy. If, on the other hand, the meter reading reveals good compliance and continued daytime sleepiness, repeat polysomnography, with or without a multiple sleep latency test, may be indicated. If repeat polysomnography is performed, the adequacy of the positive airway pressure prescription should be confirmed, with particular attention to sleep architecture and continuity.

Coexistent periodic limb movements of sleep (PLMS) should be ruled out. Although Fry and colleagues²² suggested that PLMS are an independent entity commonly seen in patients with OSDB on CPAP, and that CPAP worsens PLMS, work by our group and others^{4, 110} has found this not to be the case. In 51 consecutive patients with OSDB studied in our laboratory, seven patients (14%) had PLMS that elicited arousal from sleep. In all seven patients, the application of positive airway pressure was associated with a decrease in the PLMS (mean PLMS/hour = 21 ± 14.2 without positive pressure versus 8.3 ± 5.8 on positive pressure). We have hypothesized that the emergence of PLMS on positive pressure may be related to converting the sleep apnea-hypopnea syndrome into an upper airway resistance syndrome (i.e., converting complete or partial upper airway obstruction into flow limitation associated with arousal and leg movements secondary to the arousal). The differences in the observation of the "emer-

gence of PLMS" on positive airway pressure by Fry et al²² and our group may be attributable to differences in the way the positive airway pressure titration was accomplished with regard to monitoring airflow (in our laboratory, a pneumotachograph flow signal is incorporated into the polysomnographic montage). Further study is required to clarify that issue.

Occasionally, the CPAP or bilevel positive airway pressure system cannot generate enough pressure to overcome upper airway obstruction. That problem is encountered most frequently in morbidly obese patients with OSDB. Positioning the patient laterally or with the head elevated may slightly lower the pressure requirement, allowing successful *splitting* of the upper airway.⁵⁹ We have also used an oral appliance in conjunction with positive airway pressure in some of those individuals, with good results. If body positioning or the addition of an oral appliance is ineffective or not tolerated, a home ventilator can be used to generate the higher required pressures for upper airway stabilization. The recent availability of bilevel systems that generate pressures up to 35 cm H₂O has decreased the need to resort to a home ventilator for the treatment of OSDB.

As previously mentioned, alcohol and sedatives destabilize the upper airway during sleep. It appears that modest intake of alcohol (1.5–2.0 mg/kg) does not significantly change the CPAP prescription for patients treated with positive pressure.^{7, 104} Chronic alcohol use or abuse most assuredly will impact negatively on daily compliance with therapy. If alcohol abuse is identified, appropriate counseling should be provided.

FUTURE DIRECTIONS

Considerable advances have been made in our understanding of positive airway pressure therapy for OSDB. A wide variety of masks are available that improve patient comfort and acceptance of the interface. The current generation of CPAP and bilevel positive airway pressure systems is relatively quiet, highly portable, and durable. Compliance should be monitored objectively in all patients treated chronically with positive airway pressure. As is the case with any chronic disease, it is clear that ongoing patient education must be provided to enhance understanding

of the condition and reinforce the reasons treatment is important.

What does the future hold? On the horizon is the routine use of auto-CPAP systems in which adjustments in pressure and flow are made automatically throughout the night in response to physiologic changes in upper airway stability and function, such as those that may occur with changes in body position and sleep stage, and other factors that influence the CPAP prescription (i.e., sleep deprivation, hormone status, blood alcohol level, or nasal congestion). Exactly how such systems will be employed remains unclear. It seems likely that they will ultimately evolve to the point at which reliable "hands off" in-laboratory titrations can be accomplished. Appropriate subsets of outpatients undoubtedly will be identified as candidates for unattended in-home titrations. Problems related to the interface (i.e., mouth and mask leaks) must be solved before auto-CPAP protocols can reliably replace technician-attended studies.

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