Automated Continuous Positive Airway Pressure Titration for Obstructive Sleep Apnea Syndrome

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This study tested the effectiveness of the AutoSet™ self-titrating nasal continuous positive airway pressure (nCPAP) system in treating obstructive sleep apnea (OSA), and choosing a suitable pressure for subsequent conventional fixed-pressure nCPAP therapy. Twenty-one adult men with untreated OSA were studied with full polysomnography on each of four nights: diagnostic, manual and AutoSet nCPAP titration (in random order), and conventional fixed-pressure nCPAP at the pressure recommended by the AutoSet titration. Titration was satisfactorily performed in 20 of 21 subjects. Severe mask leak prevented automated titration in one subject and caused transient unnecessary increases in pressure in three subjects. In the 20 subjects, respiratory disturbance index (RDI) was 60.3 ± 5.7 events/h (mean ± SEM) on the diagnostic night. RDI was lower with manual titration (10.1 ± 3.0, $p < 0.001$), and lower still with AutoSet (2.8 ± 0.9, $p < 0.01$) and fixed pressure (2.5 ± 0.7, p = ns versus AutoSet) nCPAP. There were similar changes in the arousal index, which was 52.7 ± 4.6 events/h on the diagnostic night, 14.2 ± 2.4 with manual titration and 8.9 ± 0.9 with AutoSet titration, and 9.5 ± 1.0 on the night of conventional fixed-pressure CPAP ($p < 0.001$ versus diagnostic). We conclude that the AutoSet system is suitable for automated nCPAP pressure titration. Teschler H, Berthon-Jones M, Thompson AB, Henkel A, Henry J, Konietzko N. Automated continuous positive airway pressure titration for obstructive sleep apnea syndrome. AM J RESPIR CRIT CARE MED 1996;154:734–40.

Continuous positive airway pressure applied through the nose (nCPAP) is currently recommended as the treatment of choice for obstructive sleep apnea syndrome (OSAS). It prevents upper airway obstruction by acting as a pneumatic splint, thereby maintaining an open airway (1). The critical nCPAP level necessary to prevent the collapse of the upper airways during sleep varies among patients over a wide range, from 5 to 20 cm H_2O (1). High pressures are associated with increasing side effects (2–4), including machine noise and mask tightness, ribcage and abdominal discomfort, discomfort from air swallowing, and difficulty in exhaling. High pressures also lead to annoying mask leaks, and more important, to leakage of air through the mouth, causing discomfort from nasal and oral mucosal drying. Therefore, the determination of the minimum pressure needed to eliminate apneas and hypopneas becomes of crucial importance. The minimal effective nCPAP level is usually empirically determined with full polysomnography by increasing the pressure in a stepwise manner to the level that prevents most apneas and hypopneas in all sleep stages and body positions. Titration of nCPAP by this method is both expensive and time consuming.

We conducted a study with the central goal of testing whether the AutoSet™ (ResMed, Sydney, Australia) self-setting CPAP device produced an adequate improvement in sleep and breathing when used in the autosetting mode. This question was addressed in two ways: (*1*) by comparison of sleep and breathing, using the device in autosetting mode versus the untreated state; and (*2*) by comparison with sleep and breathing during a night of manually titrated nCPAP.

A possible practical use for the AutoSet device is to determine a single fixed pressure for subsequent home use. This question was again addressed in two ways: (*1*) by comparison of sleep and breathing at the fixed pressure determined automatically from the autosetting night with sleep and breathing on the diagnostic and autosetting nights; and (*2*) by comparing hours of use at 3 mo home treatment at this fixed pressure versus hours of use for historical controls.

METHODS

Subjects

The study population consisted of 20 men with OSAS confirmed at a diagnostic all-night sleep study. The subjects' ages ranged from 36 to 76 yr (mean ± SEM: 52 yr ± 2 yr). Body mass index (BMI) ranged from 25 to 48 kg/m² (33.8 ± 1.3 kg/m²). No subject had signs or symptoms of nasal deformity, allergic rhinitis, or upper airway infection. Subjects with daytime respiratory failure or nocturnal myoclonus (> 5/h) were excluded. In one additional subject it was impossible to obtain an adequate seal with the nose mask, and this subject was excluded from the study. The project was approved by the institutional review board of the University of Essen, and informed consent was obtained from each participating subject.

Self-setting Device

The AutoSet device increases pressure in response to apneas lasting longer than 10 s, snoring, and changes in the inspiratory flow–time curve suggestive of inspiratory airflow limitation. A maximum pressure limit of 20 cm H_2O is provided. If there are no further abnormalities detected, the pressure decreases toward 4 cm H_2O with a time constant of 20 min for snore and flow limitation and 40 min for apneas. Airflow is measured using a pneumotachograph located between the mask and the ex-

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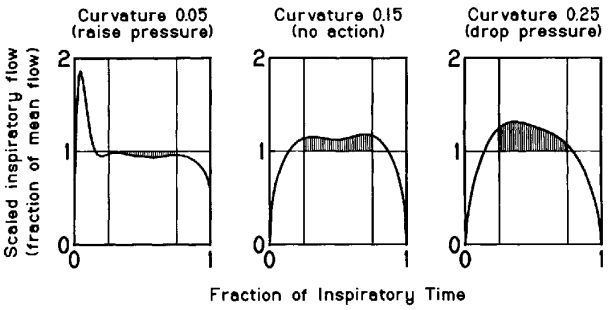

Figure 1. Software response to various flow versus time curves (schematic). Inspiratory airflow is scaled so that mean inspiratory flow is one unit, and time is expressed as a fraction of inspiratory duration. The curvature index is a measure of the deviation from unit scaled flow over the middle 50% of inspiratory time (indicated schematically by shading). *Left:* a severely flattened curve typical of inadequate CPAP pressure (curvature index = 0.05). The software responds by increasing the CPAP pressure at 0.2 cm H_2O per breath. *Center:* a breath showing slight flattening (curvature index = 0.15). The CPAP pressure remains unchanged. *Right:* a typical awake breath (curvature index = 0.25). The software assumes that this breath represents hyperadequate CPAP pressure, and reduces the flattening-induced component of the CPAP pressure exponentially to zero with a time constant of 20 min.

haust port. The blower starts (at 4 cm H_2O) at the onset of breathing. Removal of the mask is detected when the mask pressure goes to zero; the blower then stops automatically. Leak is considered as mean mask flow as estimated with a low-pass filter (time constant: 20 s). This works because over any sufficiently long period, inspiratory and expiratory flow approximately cancel: any large net flow through the mask is not going into the lungs, and must therefore be exiting via a leak.

Figure 1 shows the software response to some typical flow-time curves. The software derives a curvature index, such that normal breaths have a large index and flattened breaths have a small index. If the index is below a threshold, the pressure is increased by an amount depending on both the degree of curve flattening and the existing CPAP pressure. Moderate to severe flattening will cause the CPAP pressure to increase at 1.5 cm H_2O per minute. Therefore, if flattening were to continue unabated until the correct pressure were reached, effective pressure would be reached in less than 10 min.

Snoring is measured semiquantitatively from the bandpassed audio and subsonic components of the airflow signal. Snoring causes the pressure to rise by up to 1 cm per breath (depending on the loudness of the snoring). Therefore, if snoring were to continue unchanged until the correct pressure were reached, effective CPAP pressure would be reached in less than 1 min.

The AutoSet software does not attempt to classify apneas as central versus obstructive, but rather classifies apneas as having open versus closed airways. This is done as follows: At 6 s into an apnea, the AutoSet device modulates the mask pressure at high frequency and low amplitude, measures the resultant induced airflow, and calculates airway conductance. If the conductance is above a threshold, the airway is assumed to be open. If the conductance is below threshold at any time during the apnea, the airway is assumed to be closed, and the pressure is increased at 1 cm H_2O per 15 s of apnea. Thus, pressure will increase for obstructive apneas and for those central apneas in which the airway is closed. (These are the events that are likely to benefit from an increase in pressure). There should therefore be no increase in pressure for open-airway central apneas, such as at high existing CPAP pressure (because the airway is already open, and further increases in pressure would be counterproductive. No attempt is made to distinguish central versus obstructive hypopneas; instead, the underlying snoring and airflow limitation is detected.

Study Design

Each subject underwent 4 nights of full polysomnography. On the first night (diagnostic night), the diagnosis and severity of OSAS were determined. On the manual titration night, the critical nCPAP pressure was determined by the polysomnographic technician. The critical pressure just eliminated apneas and obstructive hypopneas in all sleep stages and body positions. There was no attempt to eliminate snoring or airflow limitation. On the AutoSet night the subject slept using the automatic titration device. The two types of titration (manual and AutoSet) were performed on consecutive nights in random order, and within 5 d of the diagnostic night. On the fourth, fixed-pressure night, the subject slept with a conventional CPAP machine set at a fixed pressure determined from the results of the AutoSet night. This pressure was chosen as the pressure exceeded only 5% of the time, after first excluding periods in which the total leak (reported by the software) exceeded 0.4 L/s. This calculation was made by an investigator blinded to the results of the manual titration. The technician intervened whenever the leak recorded by the AutoSet software exceeded 0.4 L/s for more than a few minutes, or if the patient required assistance (e.g., to urinate). In the former case, the technician adjusted the mask. The number of interventions was logged.

Sleep Studies

Nocturnal polysomnography was begun at the patient's usual bedtime and terminated after final waking or at 6:00 A.M. Standard polysomnography was performed using the Madaus ED24 sleep recorder (Madaus, Munich, Germany). Paper speed was 10 mm/s. Surface electroencephalography (EEG) (C3-A2 and C4-O1), submental electromyography (EMG), and left and right electrooculography (EOG) were used to stage sleep according to Rechtschaffen and Kales (5). Anterior tibial EMG was recorded to screen for periodic leg movements. Ear oximetry (Biox III; Bioximetry Technology, Boulder, CO) was used to record oxyhemoglobin saturation (Sa_{O_2}). Desaturations were defined as a decline in the oxyhemoglobin saturation of > 4%. Mean nadir saturation was calculated. Delta saturation (the difference between saturation at the end of an apnea and the subsequent recovery saturation) was calculated, and mean delta saturation was calculated as the average delta saturation over all apneas and hypopneas during sleep. Oronasal airflow was monitored with a thermistor. Respiratory effort and pattern were monitored with thoracic and abdominal strain gauges.

Polysomnograms were scored by the Ruhrlandklinik sleep-unit staff for disordered breathing episodes and for changes in Sa_{O_2} using the following criteria: (*1*) Obstructive apneas were identified as episodes of cessation of airflow lasting more than 10 s and associated with paradoxical movements of the chest wall and abdomen. (*2*) Hypopneas were defined as episodes of airflow cessation lasting more than 10 s and during which the thermistor signal was reduced to less than 50% of its magnitude during normal unobstructed breathing, and Sa_{O_2} dropped by at least 4%. The apnea index, obstructive apnea index, and hypopnea index were calculated as the numbers of apneas, obstructive apneas, and hypopneas respectively per hour of sleep. The numbers of apneas and hypopneas per hour of sleep were added to define the respiratory disturbance index (RDI). The respiratory arousal index was calculated as the number of respiratory disturbances per hour associated with EEG arousals. The nonrespiratory arousal index was the total arousal index minus the respiratory arousal index, and therefore represented arousals that were not immediately preceded by an apnea, hypopnea, or snoring, as determined by laryngeal microphone.

Follow-up

The patients were sent home with conventional CPAP, set to the pressure used on the fourth (fixed pressure) study night. Average daily use of nasal CPAP (for the first 3 mo) was calculated from hour-meter recordings. This was compared with average daily use (for 1 yr) for 100 conventionally titrated historical controls.

Statistical Analysis

All values are given as mean ± SEM unless stated otherwise. For the sleep staging, nadir and delta saturation, and nonrespiratory arousal index, within-group variances were homogeneous and the data were approximately normally distributed. Therefore, comparisons between the

TABLE 1

RESPIRATORY, SLEEP STAGE, AND AROUSAL RESULTS*

	Diagnostic	Manual	AutoSet	Fixed
Resp. disturbance index, events/h	60.3 ± 5.7	10.1 ± 3.0	2.8 ± 0.9 m**	2.5 ± 0.7 d***
Obstr. apnea index, events/h	44.4 ± 5.3	3.0 ± 1.0	0.38 ± 0.15 m**	0.36 ± 0.20 d*
Hypopnea index, events/h	14.1 ± 3.1	5.8 ± 2.0	1.1 ± 0.2 m**	1.4 ± 0.5 d***
Apnea index, events/h	46.2 ± 5.5	4.2 ± 1.2	1.7 ± 0.7 m*	1.2 ± 0.4 d***
Mean nadir saturation, %	70.9 ± 2.2	84.8 ± 1.4	90.4 ± 0.8 m**	90.0 ± 0.9 d***
Mean delta saturation, %	23.6 ± 1.9	10.8 ± 1.3	5.4 ± 0.7 m***	6.1 ± 0.7 d***
Apnea duration, s	34.7 ± 2.1	22.4 ± 1.5	16.1 ± 1.9 m*	16.1 ± 2.2 d***
Hypopnea duration, s	29.3 ± 2.1	21.0 ± 3.0	17.8 ± 2.5	19.2 ± 2.2 d**
Total sleep time, min	357 ± 4.6	366 ± 4.3	344 ± 5.8 m***	358 ± 4.3 a**
Wake, %	3.1 ± 0.6	3.8 ± 0.6	7.3 ± 1.3 m*	5.1 ± 1.1
Stage 1, %	28.6 ± 4.0	14.7 ± 1.9	13.8 ± 1.6	12.9 ± 1.5 d**
Stage 2, %	46.9 ± 2.9	25.8 ± 2.4	26.0 ± 2.3	29.0 ± 2.4 d***
Slow wave, %	8.1 ± 2.2	30.5 ± 4.2	29.8 ± 3.1	32.5 ± 2.9 d***
REM, %	10.3 ± 1.6	22.9 ± 1.5	21.0 ± 1.3	20.4 ± 1.8 d***
Total arousal index, events/h	52.7 ± 4.6	14.2 ± 2.4	8.9 ± 0.9 m*	9.5 ± 1.0 d***
Resp. arousal index, events/h	49.6 ± 4.9	7.9 ± 2.4	1.5 ± 0.6 m**	1.3 ± 0.4 d***
Nonresp. arousal index, events/h	3.1 ± 0.6	6.3 ± 0.7	7.4 ± 0.8	8.2 ± 1.0 d***

* Diagnostic = diagnostic study without CPAP. Manual = manual titration night. AutoSet = AutoSet automatic titration night. Fixed = conventional fixed pressure treatment at pressure recommended from AutoSet night.

d*, d**, d*** Significantly different from diagnostic, $p < 0.05$, 0.01, 0.001.

a*, a**, a*** Significantly different from AutoSet, $p < 0.05$, 0.01, 0.001.

m*, m**, m*** Significantly different from manual titration, $p < 0.05$, 0.01, 0.001.

4 study nights were made with repeated measures analysis of variance (ANOVA), followed, if the omnibus F-test was significant, by planned linear comparisons of diagnostic versus fixed, manual versus AutoSet, and AutoSet versus fixed data. For the RDI (variances inhomogeneous, outliers present), the repeated measures ANOVA was preceded by rank transform. For the other respiratory and arousal parameters, the within-group variance was high on the diagnostic night but comparable within the other nights. Therefore, the manual versus AutoSet and AutoSet versus fixed-pressure comparisons were made using repeated measures ANOVA. The diagnostic versus fixed pressure comparison was made using a paired *t* test after rank transform.

With one subject, it was not possible to achieve an adequate mask fit, resulting in a very high leak. The AutoSet responded by increasing the pressure inappropriately to the preset maximum of 20 cm H_2O, and it was not possible to determine a suitable fixed pressure for home use. This subject was eliminated from further calculations.

RESULTS

Respiratory, sleep stage, and arousal data are shown in Table 1. Individual results for RDI and total arousal index are shown in Figures 2 and 3.

AutoSet Night

Figure 4 shows pressure versus time and leak versus time for a typical subject. Mask leak was below 0.4 L/s for an average of 96% of the study (range: 83 to 100%). In all subjects it was possible to determine a fixed pressure for subsequent conventional treatment. However, in four subjects the AutoSet pressure increased inappropriately for short periods, owing to false-positive detection of snoring and/or closed airway apneas in the presence of transient large leaks, requiring reseating of the mask.

Comparison of Fixed and AutoSet Nights

There was an average 4% decrease in total sleep time on the AutoSet night compared with the fixed-pressure night ($p < 0.01$). There were no other important or statistically significant differences between these nights. In particular, there was no difference in the number of respiratory or nonrespiratory arousals.

Fixed Pressure Night versus Diagnostic Night

On the fixed-pressure night, the subjects were treated conventionally, using a single pressure calculated from the AutoSet study. There was a 24-fold average improvement in RDI (Figure 2; $p < 0.001$) and a 5-fold improvement in total arousal index (Figure 3; $p < 0.001$). On average, 86% of the arousals on the fixed-pressure night were nonrespiratory. There was a large increase in the percentage of slow-wave and rapid eye movement (REM) sleep, and a corresponding reduction in the percentage of Stage 1 and 2 sleep.

Comparison of Manual and AutoSet Nights

On the AutoSet night, there was an approximately 3-fold reduction in the RDI compared with the manual titration night (Table 1). One subject responded particularly poorly on the manual titration night (outlier in Figure 2), owing chiefly to a large number of central apneas. Median values for RDI (Table 3) confirm that the improvement on the AutoSet night was typical and not due to this outlier ($p < 0.01$, repeated measures ANOVA after rank transform). Similarly, there was a 5-fold reduction in respiratory arousals (Table 1). The nonrespiratory arousal index was com-

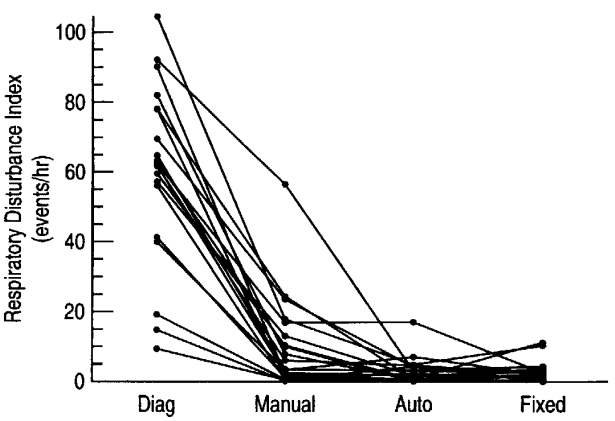

Figure 2. Effect of nasal CPAP on respiratory disturbance index. Diag = diagnostic night without CPAP. Manual = manual titration night. Auto = AutoSet automatic titration night. Fixed = conventional fixed pressure treatment at pressure recommended from AutoSet night.

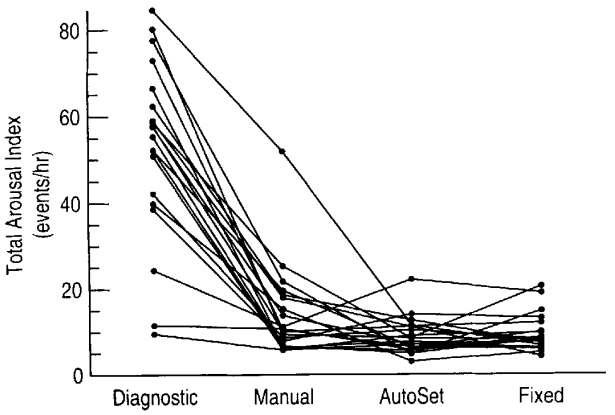

Figure 3. Effect of nasal CPAP on total arousal index. Diagnostic = diagnostic night without CPAP. Manual = manual titration night. AutoSet = AutoSet automatic titration night. Fixed = conventional fixed-pressure treatment at pressure recommended from AutoSet night.

parable on the two nights (Table 1). Using analysis of covariance (with the diagnostic-night total arousal index as a covariate), the total arousal index on the AutoSet night was higher by only 1.8 ± 1.9 events/h in the 10 patients who had the AutoSet study after the manual study than in those in whom these studies were performed in the reverse order. This difference was not statistically significant ($p = 0.38$).

Technician Intervention

The technician reseated the mask on the AutoSet night on an average of 1.9 ± 0.4 occasions per patient per night. On the manual titration night there were 2.3 ± 0.3 entries per night, and on the fixed-pressure night there were 0.7 ± 0.2 entries per night. There was no significant or important difference between the AutoSet and manual nights, but there were fewer entries on the fixed-pressure night ($p < 0.01$, repeated measures ANOVA).

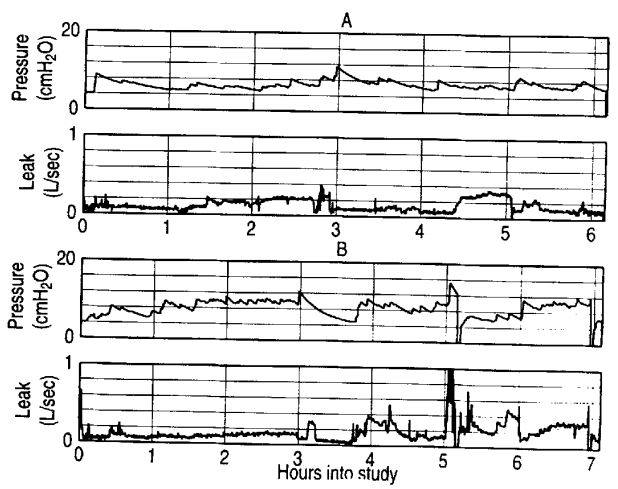

Figure 4. Masked pressure and total leak during two AutoSet automatic pressure titration studies. (*A*) Pressure started at default of 4 cm H_2O. There was a brisk rise in pressure approximately 10 min into study, corresponding to sleep onset. Thereafter pressure varied between 4 and 12 cm H_2O. Recommended pressure is 9.0 cm H_2O. Mask leak remained minimal throughout this study. (*B*) A period of high mask leak at 5 h into the study was associated with a brief inappropriate rise in pressure, corrected by the subject reseating the mask. Recommended pressure is 10 cm H_2O.

Sleep Staging Across the Three Treatment Nights

Across the three treatment nights, there was no important or significant difference in the percentages of time in slow-wave sleep or in the percentages of time in REM sleep (Table 1). Furthermore, there was no important difference in the percentage of total sleep time in supine REM sleep, which was 16.3 ± 2.0% (mean ± SEM) with manual tritation, 13.9 ± 2.2% with AutoSet, and 13.2 ± 2.7% with fixed pressure (differences not significant, repeated measures ANOVA).

Comparison of Fixed Pressures Recommended by AutoSet and Technician

The relationship between the fixed pressure determined from the AutoSet study and the manually determined pressure is shown in Figure 5. The mean pressure prescribed manually was 8.6 ± 0.4 cm H_2O. The fixed pressure prescribed from the AutoSet study was on average 1.3 ± 0.3 cm H_2O higher ($p < 0.001$, paired *t* test). There was a 73% correlation between the two pressures ($p < 0.001$).

Overall Adequacy of Treatment

Adequacy of treatment is shown in Figures 2 and 3. In general, the improvement in the RDI was excellent, and the improvement in the total arousal index was good. All subjects reported that they were still using the AutoSet machine at 3 mo. The average daily usage (hour-meter recording at 3 mo) was 4.9 ± 0.3 h (mean ± SEM). Among 100 conventionally titrated historical controls, the dropout rate was 10% per annum, and mean hourly usage at 1 yr was 4.7 ± 0.16 h. The 95% confidence interval (CI) for the difference in usage is therefore 0.2 ± 0.4 h.

DISCUSSION

This study demonstrates that the AutoSet device produces an excellent improvement in sleep and breathing in subjects with uncomplicated OSAS. The study (Table 2) also demonstrates that the device can be used to automatically titrate a fixed CPAP pressure in such subjects, and that when retested at this fixed pressure, subjects continue to show excellent improvement in sleep and breathing, and good medium-term compliance.

Theoretical Basis for Autotitration

Sullivan and Issa (6) have shown that a lower pressure is required to treat apneas than is required to treat all respiratory disturbances. Consequently, there is a tradeoff between increasing pressure to yield increasing effectiveness and decreasing pressure to reduce side effects. The aim of titration is to produce both an acceptable improvement in RDI and an acceptable improvement in arousal index.

The rationale for the use of the flow limitation parameter, rather than relying on the more traditional apneas and snoring, is as follows. Guilleminault and others (7) have drawn attention to the upper airway resistance syndrome, in which a subject can have repeated arousals associated with high esophageal pressure swings but without apneas or hypopneas. These high pressure swings are due to a high pressure drop across the upper airway. Such subjects have daytime sleepiness that resolves with CPAP treatment. This suggests that it is of benefit to eliminate severe upper airway flow limitation and that the increase in pressure needed to do so will be rewarded with improved sleep architecture. We might speculate that an autotitrating device that attempts

TABLE 2

EFFECT OF FIXED PRESSURE NASAL CPAP ON APNEA-HYPOPNEA INDEX: STUDIES FROM RECENT LITERATURE

	Subjects	Untreated (*events/h*)	CPAP (*events/h*)	AutoSet (*events/h*)
Hoffstein and colleagues (15)	79	not given	9.0	–
McEvoy and colleagues (16)	12	35.1	5.7	–
Prosise and colleagues (17)	7	58.3	7.2	–
Riley and colleagues (18)	30	72.0	8.6	–
Sanders and colleagues (19)	30	76.5	4.3	–
Yamashiro and colleagues (20)	107	23.6	3.0	–
Present study	20	60.3	10.1	2.8

to normalize the degree of upper airway flow limitation may do better than one that does not. The present work does not try to address the question of whether this is the optimum algorithm; rather, it tests whether this algorithm produces acceptable results.

It was suggested by Berthon-Jones that the shape of the inspiratory flow-time curve could be used to detect inspiratory airflow limitation caused by inadequate CPAP pressure, in order to automatically adjust CPAP pressure (8, 9). The relationship between inspiratory airflow limitation and the shape of the flow-time curve has been confirmed by elegant catheter studies conducted by Condos and coworkers (10). The AutoSet derives a "curvature" index, such that a value of zero represents a square-wave flow-time curve (complete airflow limitation), whereas normal awake breathing produces an index of about 0.3 units. The device increases CPAP pressure if the index falls below 0.15 units, a value achieved approximately 20% of the time by normal subjects during sleep (Berthon-Jones, unpublished data). Consequently, the AutoSet device is able to increase CPAP pressure preemptively, before respiratory disturbances occur.

Does Varying Pressure Cause Arousal?

It was anticipated that a constantly changing pressure might cause arousal. However, there were no important differences between the AutoSet night and the fixed-pressure night. The AutoSet night preceded the fixed-pressure night by either 1 or 2 d. Consequently, the number of arousals on the AutoSet night might be somewhat reduced by residual sleep deprivation. However, the AutoSet night total arousal index in the 10 patients who had the AutoSet study after the manual titration study was neither importantly nor significantly higher than in those in whom the study was performed in the reverse order. Therefore, we conclude that the improvement on the AutoSet night was genuine.

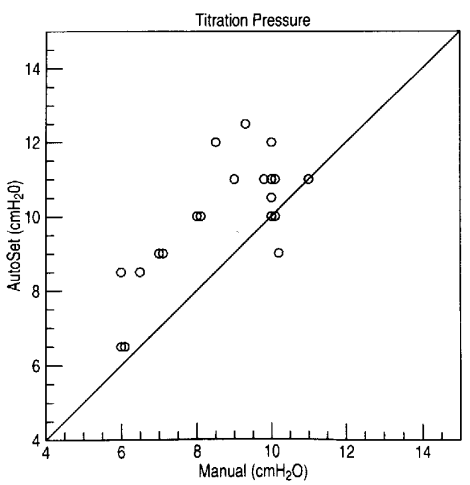

Figure 5. Pressure derived from AutoSet automatic pressure titration study versus manual titration pressure. AutoSet pressure was taken as 95th centile of pressure distribution, after elimination of periods in which mask leak exceeded 0.4 L/s. Manual titration pressure was the pressure that eliminated most apneas and obstructive hypopneas.

Mask Leak

In one subject, very high leak precluded automatic titration. Availability of a wider selection of masks, or instructing the subject in how to reseal the mask at the time of the study, may have prevented this problem. In three of the remaining 20 patients, the AutoSet increased pressure inappropriately for short periods (up to 15 min) in response to high mask leak. This did not interfere with determination of a suitable fixed pressure, because the leak was low (< 0.4 L/s) for at least 85% of the night.

Comparison with Manual Titration

It is of interest to compare results achieved with the AutoSet device with those achieved with fixed pressure from manual titration. For economic and logistic reasons, we did not restudy the subjects at the manually determined fixed pressure. However, some idea of how subjects would have performed at this pressure can be obtained from the manual titration night itself. Since standards for manual titration vary, we have also tabulated results for manual titration from the literature. The apnea-hypopnea index with the AutoSet was better than during manual titration, and arousal index was comparable.

The pressure recommended by the AutoSet device was on average 1.3 cm H_2O higher than that chosen by the technician. Conversely, there were 80% fewer respiratory arousals than on the manual titration night, despite the manual titration being performed by a skilled technician in full-time attendance on each individual patient. We speculate that this could be due to the AutoSet responding to snore and airflow limitation as well as to apneas and obstructive hypopneas. The difference was not due to an order effect, because the manual and AutoSet nights were performed in random order. The good compliance data (*see the subsequent discussion*) also suggest that the pressure was acceptable to the patient.

Problems with Study Design

There are two objections to the AutoSet versus manual titration comparison. One objection is that the AutoSet uses a potentially very sensitive index (silent inspiratory airflow limitation) not available to most existing laboratories, where airflow is measured only indirectly using thermistors, respibands, or other devices, and that the comparison is therefore unfair. However, there was no *a priori* reason to assume that the potentially more sensitive AutoSet algorithms would actually work in practice, or that they would give both an excellent apnea-hypopnea index (AHI) and an adequate improvement in sleep architecture.

The second objection is that the present design did not include a fifth sleep study with measurement of the number of arousals at the fixed pressure recommended by the technician. This renders it impossible to make a direct comparison with how the patient would have slept at this fixed pressure. It is probable that the number of events would have been less than on the manual titration night.

Another possible objection is that if the subjects had no REM sleep on the AutoSet night, or had spent the night in the lateral position, the airway may have been more stable, and this could have explained the good results seen with the AutoSet. However, percentages of time in slow-wave sleep, REM sleep, and in particular supine REM sleep were very comparable across the three treatment nights.

Compliance

The dropout rate at 3 mo was zero, and the mean hourly CPAP machine usage was virtually identical to that in our historical controls. These preliminary results suggest that the automatically determined titration pressure is adequate for subsequent fixed-pressure use at home. Meter readings can overestimate compliance if the subject runs the machine without using it. It is therefore possible that the compliance was lower than measured. However, there is no reason to believe that subjects would selectively run their machines (without using them) after an automatic titration night as opposed to after a manual titration night.

Comparison with Other Devices

We are unaware of any comparable study using another self-setting device in previously untreated subjects. The improvement in RDI on the AutoSet night over the diagnostic night was comparable with results in other subjects reported briefly by Berthon-Jones and colleagues (9), but manual and fixed-pressure nights were not included. A brief report by Burke and associates (11) of 10 patients described comparable improvement in RDI with an automatic device, but arousal indices were not presented. Another brief report, by Scharf and coworkers (12), described results with five patients who had been on preexisting long-term CPAP, and were presumably habituated to the use of CPAP. Again, respiratory results were roughly comparable with those of the present study, but pressure results and nonrespiratory arousal results were not described. Miles and colleagues (13) reported automated titration by stepwise adjustment of the pressure up and down over multiple cycles. Their device was not intended to provide adequate therapy in its own right. Furthermore, no respiratory or arousal indices were provided for the treatment night. Hoffstein and coworkers (14) reported a formula for calculating ideal CPAP pressure based on AHI, neck circumference, and body mass. Their AHI fell from 48.3 ± 4.4 to 11 ± 2.5 with their method. AutoSet clearly performed better.

Applications

Automated titration. Automatic titration produced a pressure yielding very satisfactory respiratory and arousal indices on subsequent fixed-pressure treatment. In 17 of 21 patients, performance on the AutoSet night itself was also very satisfactory. Titration is currently very labor expensive. One approach to making treatment more cost effective has been to use split-night studies, with diagnosis in the first half and titration in the second half of the night. This has its own disadvantages: the severity of disease at 5:00 A.M. is unknown, the subject is introduced to CPAP when sleepy and hypoxic, and titration is based on only half a night's experience. Automated titration provides a way of reducing labor costs without the above disadvantages. Indeed, it is conceivable that automated titration of nCPAP could be performed outside the formal sleep laboratory.

Long-term home autotitration. In 17 of 21 patients, AutoSet behaved correctly at all times, and we infer cautiously that the device would have worked well unattended in these subjects. We speculate that long-term home autotitration could be advantageous: the median pressure in autosetting mode was on average 85% of the fixed pressure chosen for subsequent conventional home therapy. Furthermore, in autosetting mode, the pressure remains at or near 4 cm H_2O prior to sleep onset. These features could help with compliance in some subjects.

Conclusion

When used in the autosetting mode, AutoSet produced an excellent improvement in sleep and breathing as compared with the untreated state and produced results equivalent or superior to those during manual titration. Good results were also obtained at the fixed pressure recommended by the AutoSet study, and compliance at 3 mo was comparable with that obtained using manual titration in historical controls. Hence it appears practicable to use the device to determine a single fixed pressure for subsequent home use.

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