Objective Measurement of Patterns of Nasal CPAP Use by Patients with Obstructive Sleep Apnea

NANCY BARONE KRIBBS, ALLAN I. PACK, LEWIS R. KLINE, PHILIP L. SMITH, ALAN R. SCHWARTZ, NORMAN M. SCHUBERT, SUSAN REDLINE, JOHN N. HENRY, JOANNE E. GETSY, and DAVID F. DINGES

Center for Sleep and Respiratory Neurobiology, University of Pennsylvania School of Medicine, Philadelphia, Pennsylvania; the Department of Medicine, Division of Pulmonary Medicine, Johns Hopkins University School of Medicine, Baltimore, Maryland; and Case Western Reserve University, Cleveland, Ohio

Obstruction of the upper airway during sleep (OSAS) is widely treated by having patients self-administer nasal continuous positive airway pressure (CPAP). To obtain objective evidence of the patterns of CPAP use, information was gathered from two urban sites on 35 OSAS patients who were prescribed CPAP for a total of 3,743 days. Patients were given CPAP machines that contained a microprocessor and monitor that measured actual pressure at the mask for every minute of each 24-h day for an average of 106 days per patient. They were not aware of the monitor inside the CPAP machines. Monitor output was compared with patients' diagnostic status, pretreatment clinical and demographic characteristics, and follow-up self-reports of CPAP use, problems, side effects, and aspects of daytime fatigue and sleepiness. Patients attempted to use CPAP an average of 66 ± 37% of the days monitored. When CPAP was used, the mean duration of use was 4.88 ± 1.97 h. However, patients' reports of the duration of CPAP use overestimated actual use by 69 ± 110 min (p < 0.002). Both frequency and duration of CPAP use in the first month reliably predicted use in the third month (p < 0.0001). Although the majority (60%) of patients claimed to use CPAP nightly, only 16 of 35 (46%) met criteria for regular use, defined by at least 4 h of CPAP administered on 70% of the days monitored. Relative to less regular users, these 16 patients had more years of education (p = 0.05), and were more likely to work in professional occupations. At pretreatment they tended to report more episodes of daytime sleepiness (p = 0.062) and less ability to perform tasks (p = 0.069), and at follow-up after CPAP use they reported greater satisfaction with CPAP (p = 0.025) and an improved level of daytime energy (p = 0.046). The most frequently cited problems with CPAP were "inconvenience" (54%) and "stuffy nose" (46%), although the complaint that the mask caused "claustrophobia" was the only problem identified significantly more often by the 19 patients who used CPAP less regularly (p < 0.02). Surprisingly, only 2 of the 35 patients studied used CPAP for at least 7 h on ≥ 70% of days, suggesting that frequent, long-duration, quality sleep is a relatively rare occurrence in OSAS patients treated with CPAP. We conclude that actual CPAP use by OSAS patients falls short of the therapeutic goal of providing quality sleep all night, every night, and that patients' self-reports are rather poor estimates of actual use within and between nights. Efforts to enhance CPAP use are needed, especially early in treatment.

Since its introduction in 1981 (1), nasal continuous positive airway pressure (CPAP) has become the treatment of choice for obstructive sleep apnea syndrome (OSAS). When used at the appropriate pressure during sleep, nasal CPAP effectively eliminates apneas and hypopneas due to upper airway obstruction (2-4), thereby reducing the disturbance of sleep and the subjective hypersomnolence during wakefulness that patients experience before treatment (5-7).

Although CPAP is therapeutically effective for OSAS, concerns have remained regarding patients' acceptance of the treatment and the likelihood that they will apply it daily throughout major sleep periods (8). It appears that among unselected OSAS patients, 50 to 90% accept CPAP therapy (9-16). Studies of nasal CPAP use based upon patients' self-reports have found that more than 75% of patients who started therapy indicated that they use the therapy every day during the period from 1 to 30 months posttreatment (13, 14, 17), although use has also been reported to decline over time (10). To circumvent the problems inherent in patients' self-reports (influence from expectation, social desirability, and limitations of memory), investigators have also studied CPAP use by the output of a counter that records the cumulative time that power is turned on to a CPAP unit (9, 18-20). This approach has yielded daily use rates comparable to those derived from patient report data. Because it allowed patients to be aware that CPAP use was being monitored by an external clock, however, even these ostensibly objective results may not reflect actual use of CPAP.

Moreover, neither the self-report studies nor the studies based on external counters have provided information on the actual time of day and duration CPAP is used each 24-h period. In fact, no study has yet evaluated the extent to which CPAP is actually used in a manner consistent with the prescription that it be applied throughout the major daily sleep period, virtually every day, to permit adequate quality of sleep. Such information could be extremely valuable to physicians when evaluating treatment effectiveness.

Thus, despite widespread prescription of nasal CPAP for treatment of OSAS, it remains unknown just when and how often patients actually use the therapy. The goal of this study was to provide the first data on CPAP use by unselected OSAS patients who were unaware of the presence of a microprocessor-based monitor discretely located inside the CPAP machines, to obtain natural usage data without interference from researchers. An additional goal was to test the hypotheses that actual CPAP use would be less than prescribed and less than patients' self-reports of use and that patients who used CPAP frequently would report fewer problems with CPAP side effects and more improved daytime sleepiness.

METHODS

Subjects

A group of 42 patients were recruited for this protocol, the only inclusionary criteria being consent to participate and that nasal CPAP had been prescribed by their physician for treatment of OSAS. The therapy decision was made by the physician independently of the knowledge of whether the patient would be involved in the protocol. The availability of a specialized CPAP monitor, described subsequently, at the time of treatment onset was a determining factor in whether a particular patient was studied. At the time of enrollment, the patients were given informed consent in which they agreed to provide information regarding their health and CPAP use; they agreed to use the CPAP machine provided to them; they were not informed of the monitor inside the CPAP unit; and they were not paid for their participation (those enrolled at the Johns Hopkins site were provided free monthly follow-up visits after the 1-month follow-up). Permission to conduct this protocol and approval of the consent forms were received from the institutional human studies review boards of the two sites, the University of Pennsylvania Committee on Studies Involving Human Beings and the Johns Hopkins University Institutional Review Board (IRB) for Human Research. There were some differences mandated by the different IRB in the wording of the informed consents. Notably, the Johns Hopkins IRB required that patients be informed that there were aspects of the study that could not be made known to them at the time they enrolled.

CPAP Use Monitor

The CPAP microprocessor monitor was developed at the University of Pennsylvania to record the use of the Sleep Easy® III (Respironics) CPAP system. The monitor consists of a Vitrax® IX microcontroller single-board computer (Motorola 6502 CPU) equipped with a 32K nonvolatile standard random access memory (SRAM) chip (Dallas semiconductor), a 10 bit A/D converter, battery backup, real-time clock, power on reset circuit (CWE, Inc.), and a Sensym 142-SC-01D pressure transducer. For programming, the microcomputer acts as a functional slave via an integral RS232 serial port to an IBM-compatible personal computer through which program storage and data retrieval were conducted. The software for programming and data retrieval consisted of three main parts: the menu setup, a CPAP monitor program, and an analysis program to perform data reduction that calculates indices reflecting pattern of use as well as provides graphic summaries. The events detected and logged by the monitor using internal programmed algorithms were power on, power off, mask on, and mask off. The CPAP monitor uses a power-on reset circuit when switched on, which logs the date and time. A solid-state pressure transducer mounted on the air outflow circuit of the Sleep Easy III detects that the mask is

in use by recording the characteristic rise in pressure, as measured by the pressure transducer, that occurs when the mask is worn on the face. The pressure transducer was precalibrated, linear (within 0.2% at 70 cm H_2O full-scale output), and repeatable (variance < 0.2%). The microprocessor digitized the signal from the pressure transducer at a rate of 10 Hz and compared this to a predetermined threshold level chosen by the investigator to be below the prescribed level of pressure. Pressure maintained above the threshold level for more than 60 s logged a *mask on* event; pressure below the threshold for more than 60 s logged a *mask off* event. Detected events were stored in nonvolatile SRAM along with the time and date read from the system clock. Up to 8,000 events can be recorded in the nonvolatile SRAM for later retrieval; thus data acquisition for at least a month could be obtained before downloading of information was required. Data were retrieved as an ASCII file, and the ASYST (Keithley) program developed for data reduction calculated the exact amount of CPAP use in each 24-h period (from 1800 to 1759 h) and the daily CPAP use in minutes for each day recorded. The software also provided graphic output of the period of CPAP use on each day and summary information on use across days.

Validity testing of the monitor was conducted at the University of Pennsylvania; 15 patients were studied as part of routine clinical care either during all-night polysomnography (n = 9) or during daytime training session naps (n = 6) for acclimating patients to CPAP therapy. There was 97% agreement between monitor data and the technicians' logs and a correlation of r = 0.99 between clock time on the monitor and the technician's log sheet. Subsequent field testing of the monitor was done with two apnea patients who completed daily log sheets while using CPAP machines with the monitor, yielding coefficients of r = 0.99 for one patient and r = 0.84 for the second patient (the lower coefficient was due to mask leaks detected by the monitor but missed by the patient).

Pretreatment Questionnaire

All the patients completed a pretreatment questionnaire, which is an initial survey given to all patients regarding patient demographics, overall health, sleep hygiene, daytime sleepiness, and ability to perform various tasks at work and at home.

Follow-up Questionnaire

The follow-up questionnaire was designed to measure patients' self-reports of CPAP use and experiences with treatment on a monthly basis. The seven-page questionnaire included questions about current daily use of CPAP by day of the week and hour of use, followed by a series of questions regarding side effects associated with CPAP use. The portion of the questionnaire that contained these 21 questions about CPAP side effects and problems is shown in table 1, along with the four response options for each item. Following this section of the questionnaire were questions regarding overall satisfaction with treatment. The next section, also given as part of the pretreatment baseline questionnaire, asked about general health, sleep hygiene, problems sleeping, excessive daytime sleepiness, and the ability to perform various tasks over the past 1-month period.

Procedure

Patients were introduced to the research protocol and were given informed consent by a research staff member at the end of the initial visit to one of the two sleep centers. All 42 patients had an initial diagnostic clinical polysomnogram, and many (n = 26) had a multiple sleep latency test (MSLT). This was followed by a night of polysomnography to establish the therapeutic level of CPAP. Patients who enrolled in the protocol were then given a CPAP machine that included the monitor for use at home. Normal treatment instruction, follow-up, and payment procedures for CPAP machine rentals were maintained by the individual sleep centers and the patient's home health care companies. At both sites, there was a clear instruction to patients by their physicians to use CPAP therapy whenever they slept, for the duration of their normal sleeping periods.

The protocols differed somewhat between the two sites with respect to the initiation of CPAP. At the University of Pennsylvania, potential apnea patients had OSAS and CPAP treatment explained to them first by the sleep physician during the initial assessment and then were scheduled for a diagnostic polysomnogram. Patients were given a CPAP educa-

TABLE 1

QUESTIONS REGARDING SIDE EFFECTS FROM THE CPAP FOLLOW-UP QUESTIONNAIRE

	Not a Problem	Sometimes a Problem	A Problem	A Serious Problem
1. CPAP is too inconvenient to use	____	____	____	____
2. The CPAP mask irritates my face	____	____	____	____
3. I can't sleep because of the noise CPAP makes	____	____	____	____
4. My eyes are irritated by CPAP	____	____	____	____
5. The CPAP mask makes me feel claustrophobic (closed in)	____	____	____	____
6. My ears are irritated by CPAP	____	____	____	____
7. I have chest pains when I use CPAP	____	____	____	____
8. I am embarrassed to use my CPAP	____	____	____	____
9. My nose bleeds when I use CPAP	____	____	____	____
10. I have difficulty operating the CPAP machine	____	____	____	____
11. The CPAP mask makes the bridge of my nose hurt	____	____	____	____
12. I have trouble putting on the CPAP mask	____	____	____	____
13. CPAP disturbs my sleep	____	____	____	____
14. CPAP gives me headaches	____	____	____	____
15. CPAP results in less intimacy with my bed partner	____	____	____	____
16. CPAP makes my nose stuffy or dry	____	____	____	____
17. I toss and turn more with CPAP	____	____	____	____
18. I sleep poorly with CPAP	____	____	____	____
19. CPAP is too expensive	____	____	____	____
20. My bed partner sleeps worse when I use CPAP	____	____	____	____
21. I sleep worse when I use CPAP	____	____	____	____

tional session before the night during which the therapeutic level of CPAP was established. During the educational session they were shown the CPAP unit, given instruction in its purpose by a sleep technician, and allowed to sleep for about 20 min while wearing the CPAP unit. At Johns Hopkins University, patients were seen in initial follow-up after the laboratory diagnosis of OSAS was made. Various forms of therapy were reviewed, and if CPAP was selected as a mode of treatment, an overnight sleep study was scheduled during which CPAP pressure was titrated. Following this, an instructional session in the use of the CPAP machine was given by the home care company representative.

As part of routine clinical care at both sites, a follow-up visit was scheduled for 1 month after CPAP treatment initiation. To collect data after the second and third months of treatment, it was necessary to engage in further patient contact that would not necessarily be the usual experience for CPAP patients. The two sites accomplished this phase of the protocol in different ways. At Penn the participating home health care company made a visit to the patient's home to administer the follow-up questionnaire and exchange the CPAP machine, which was returned to the hospital for data downloading. Patients were not always seen by their sleep physicians at 2- and 3-month follow-ups, but they were encouraged to participate in a patient support group. At Hopkins, patients returned to the sleep center to have the CPAP units downloaded, to complete the follow-up questionnaire, and to be seen by the sleep physician.

Sleep and Respiratory Scoring Criteria

Criteria for record interpretation were standardized, and sleep technicians from each of the two sites underwent common training sessions, which included review of independently determined interpretation of sleep records obtained at each clinical site. Clinical polysomnograms (PSG) were recorded and scored by standardized criteria (21). PSG recording procedures for both sites have been published elsewhere (22, 23). Airflow during sleep was measured by oral-nasal thermistors. An obstructive apnea was scored when airflow cessation was accompanied by respiratory effort lasting at least 10 s. Hypopnea was recorded when there was at least a 50% reduction in airflow lasting at least 10 s accompanied by at least a 4% decrease in Sa_{O_2} or an arousal. A respiratory disturbance index (RDI) was calculated (number of apneas and hypopneas per hour of sleep; that is, apneas + hypopneas/total sleep time $\times$ 60) for each night of clinical PSG assessment.

Calculation of CPAP Usage

The average daily use of CPAP in minutes was calculated, as was use

efficiency, which refers to the proportion of time the mask was on relative to the total time the CPAP unit power was on [(mask on/power on) 100]. CPAP duration of use was quantified in three ways to yield metrics for comparison with self-report data. The first criterion was met whenever the CPAP monitor logged mask on for at least 20 min. This criterion permitted an estimate of patients' *attempts* to use CPAP and therefore provided a frequency of use parameter that was largely independent of duration of use. The second criterion considered only CPAP use of at least 4 h in a 24-h period. Based on what is known about the need for sleep (24–26), this criterion provided a minimal acceptable duration of use for a therapy prescribed for use during sleep. The third criterion provided an estimate of optimal use by considering only CPAP use of at least 7 h in a 24-h period. A total daily sleep duration criterion of at least 7 h was selected based on what is known about the average daily sleep duration of middle-aged adults (25, 26). Stratification into three duration criteria provided valuable information about the number of patients who were receiving acceptable treatment. For example, in previous self-report studies, a patient who used CPAP only 20 min to less than 4 h per night may have correctly reported nightly use, but we would argue that this is not adequate to derive treatment benefit.

The frequency with which each patient used CPAP according to the minimal and optimal duration criteria was also calculated. The criterion used as an acceptable level for frequency was an average of 5 of 7 days or $\geq$ 70% of all days monitored, determined by expert clinical opinion (consensus of the authors). Some support for this same frequency criterion was expressed in a previously published abstract (12). Thus, patients were stratified into those who used CPAP at least 4 h a day on at least 70% of all days, versus those who failed to meet these frequency and duration criteria. The former were designated *regular users* of CPAP, and the latter were considered *irregular users* of CPAP.

Data Analyses

Unless otherwise stated, statistical comparisons between sites and between regular and irregular CPAP users were carried out using t tests. Comparisons of CPAP use across months were done with analysis of variance. Pearson correlation coefficients were also used for evaluating changes in CPAP over time. For all analyses, statistical significance required $p \leq 0.05$, two-tailed.

RESULTS

Data from 7 of the 42 patients had to be excluded because of tech-

TABLE 2

PRETREATMENT AND POSTTREATMENT CPAP USE VARIABLES FOR 35 PATIENTS AT THE
UNIVERSITY OF PENNSYLVANIA AND JOHNS HOPKINS UNIVERSITY (MEAN AND SD)

	Penn ($n = 14$)	Hopkins ($n = 21$)	Total ($n = 35$)
Pretreatment			
Sex, male/female	11/3	18/3	29/6
Age, yr	48.6 (9.8)	44.6 (9.3)	46.2 (9.6)
Body mass index	37.7 (7.6)	40.7 (7.8)	39.5 (7.7)
Minimum SaO_2, %	67.4 (12.1)	68.3 (18.3)	67.9 (15.9)
RDI, events/h	45.6 (27.4)	78.1 (27.4)[†]	65.1 (31.5)
MSLT, min	3.7 (2.2) ($n = 8$)	4.1 (3.9) ($n = 18$)	3.9 (3.5) ($n = 26$)
CPAP pressure, cm H_2O	13.4 (4.2)	12.6 (3.0)	12.9 (3.5)
Posttreatment			
Days CPAP monitored	137.3 (68.9)	86.7 (32.7)[†]	106.9 (55.4)
Days ≥ 20 min CPAP use, %	65.2 (38.9)	67.1 (37.7)	66.3 (37.6)
Days ≥ 4 h CPAP use, %	53.1 (39.4)	49.8 (37.4)	51.1 (37.7)
Days ≥ 7 h CPAP use, %	18.9 (25.0)	15.1 (19.6)	16.6 (21.6)
CPAP duration, min/day*	316.5 (122.8)	277.6 (115.7)	293.2 (118.4)
Use efficiency, %	94.8 (9.3)	88.5 (17.0)	90.9 (14.7)

* Based on days with ≥ 20 min CPAP use.
[†] Difference between Penn and Hopkins at $p < 0.05$.

nical problems with the monitor, most of which occurred with the early versions of the device. These 7 patients did not differ from the remaining 35 patients in gender, age, RDI, body mass index, MSLT, or SaO_2 nadir. In the 35 patients CPAP was monitored for a grand total of 3,743 days. Of these 35 patients, 14 were from the Penn sleep center and 21 were from the Hopkins center. The means (and standard deviations, SD) of the characteristics of these two groups at the time of initial study are shown in table 2, along with the average number of days CPAP use was monitored and the extent to which CPAP was used. Patients at the two sites were similar, with the exception that those from the Hopkins site had a higher mean RDI ($p < 0.001$). Although fewer patients were monitored at Penn, the period of covert monitoring was longer than at Hopkins ($p < 0.05$).

Despite differences in RDI and duration of covert monitoring, patients' patterns of CPAP use were very similar between sites (table 2). Thus, there were no statistically reliable differences between sites in the proportion of days that patients used CPAP for 20 min (Penn M = 65%; Hopkins M = 67%), for ≥ 4 h (Penn M = 53%; Hopkins M = 50%), and for ≥ 7 h (Penn M = 19%; Hopkins M = 15%). Not surprisingly, at both sites, the longer the criterion for duration of use, the fewer was the proportion of days on which CPAP was used (table 2).

Overall, attempted use of CPAP (> 20 min criterion) occurred on an average of 66 ± 37% of days, with a mean duration of use of 4.88 h per night (293 ± 118 min) and a mean efficiency of use (mask on/power on) of 91 ± 14.7%. Thus, overall, 9% of the time the machine was on the mask was not being used. As the standard deviations suggest, these averages were the result of a wide range of individual differences in days used (2 to 100%) and in durations of CPAP use (60 to 540 min) when an attempt was made to use it. Only six patients had an overall use efficiency of less than 80%, two patients had a use efficiency of 86%, and the rest ($n = 27$) had a use efficiency of greater than 93%. Mask leaks likely accounted for less than perfect use efficiencies in these patients, as the lower efficiencies were primarily characterized by interruptions in mask use throughout the sleep period rather than continuous mask off time.

The inter- and intrapatient variability in CPAP monitor results from four selected patients are shown in figure 1. Two were regu-

lar CPAP users at night (left two panels). A third patient was a rotating shift worker who regularly used CPAP when he slept (top right panel). The fourth patient made an initial attempt at therapy but soon became noncompliant, using CPAP only very infrequently (bottom right panel). Interestingly, on his follow-up questionnaires, this last patient reported using CPAP every night!

CPAP Use by Hour of Day and Day of Week

Not surprisingly, 82% of the time CPAP was used occurred between the hours of 10 p.m. and 9 a.m., when nocturnal sleep is common, the modal hour of use being 2 to 3 a.m. Daytime naps, weekend oversleeping, and shift work accounted for the 18% of CPAP use at other hours of the day. All analyses of subgroups of patients according to combined criteria for frequency and duration of use yielded the same result; the great majority of time that CPAP was used was during the nocturnal sleep period.

There was also little systematic variation in either frequency of CPAP use or duration of use by day of the week. Analysis of the amount of CPAP use by day of the week revealed the longest duration of CPAP use to be on Saturday nights (353 ± 116 min) and the shortest on Monday nights (318 ± 89 min) ($p < 0.01$; this analysis was based on results from 24 of the 35 patients who used CPAP often enough to permit evaluation of use by day of the week). An analysis of day of the week when CPAP was most likely to be skipped revealed no significant differences, although Friday had the highest percentage of missed therapy nights (M = 12%).

CPAP Use over Time

The reliability of both the frequency and duration of CPAP use over time was assessed by comparing covert monitor data from 20 of the patients who were monitored for at least 3 months. The mean (and SD) of monthly duration of CPAP use and the mean (and SD) of number of days CPAP was used by these patients for each of the three duration of use criteria are displayed in table 3. As revealed by the F ratios, there were no statistically significant differences in use across the 3 months.

Correlational analyses between the first and third months for each of the variables listed in table 3 were conducted to determine the extent to which patients maintained their patterns of use over time. By any criterion, frequency of CPAP use was very sta-
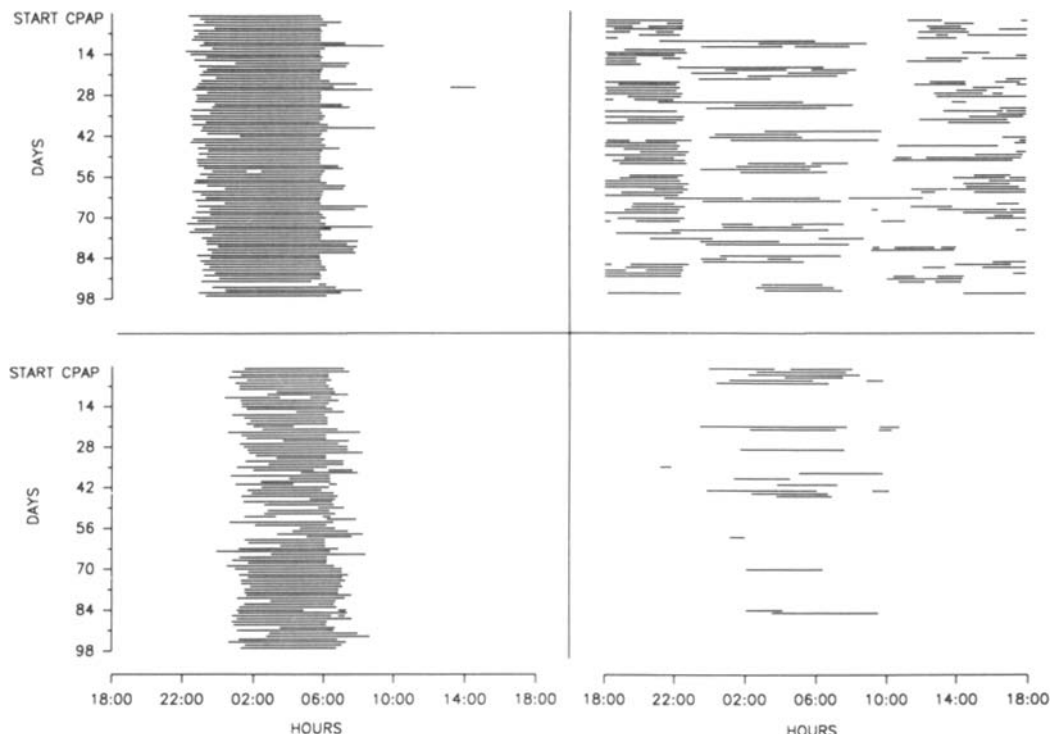
Figure 1. CPAP use in four patients. The horizontal black lines indicate the times when the CPAP machine was used by the patient, with Day 1 starting at the top. Each patient is represented in one quadrant.

ble from Month 1 to Month 3 (> 20 min, $r = 0.94$; > 4 h, $r = 0.91$; > 7 h, $r = 0.83$; all $p < 0.0001$). The mean percentage of days CPAP was used in Months 1 and 3 for each of the three duration of use criteria is shown in figure 2. Average daily minutes of use (when CPAP was used) in Month 3 was also reliably related to average minutes of use in Month 1 ($r = 0.77$, $p < 0.0001$).

Objective Monitor Versus Subjective Reports of CPAP Use

Patients' reports of CPAP use from questionnaires administered at the first follow-up were compared to actual CPAP monitor output data collected during the time period in question. Of the 35 patients 21 reported using CPAP every day on the first follow-up questionnaire. The covert monitor showed that 15 of them used it at least 20 min on $\geq 90\%$ of the total days measured, 3 patients used it on 47 to 73% of the days, and 3 patients used it on 0 to 27% of the days. On average, patients also overestimated the duration of CPAP use. Although 7 patients actually underestimated the daily duration of CPAP use between 11 and 121 min, 23 patients overestimated their daily use between 8 and 319 min (5 patients did not provide subjective estimates of daily use). Thus, patients reported an average of 69 ± 110 min *more* CPAP use

per night than was objectively recorded by the monitor ($t = 3.43$, $p < 0.002$); the average duration of CPAP use reported by patients was 376 ± 88 min, compared to the covert monitor mean duration of 306 ± 112 min. The correlation between self-reported duration of CPAP use and actual use was rather low but statistically significant ($r = 0.41$, $p < 0.02$).

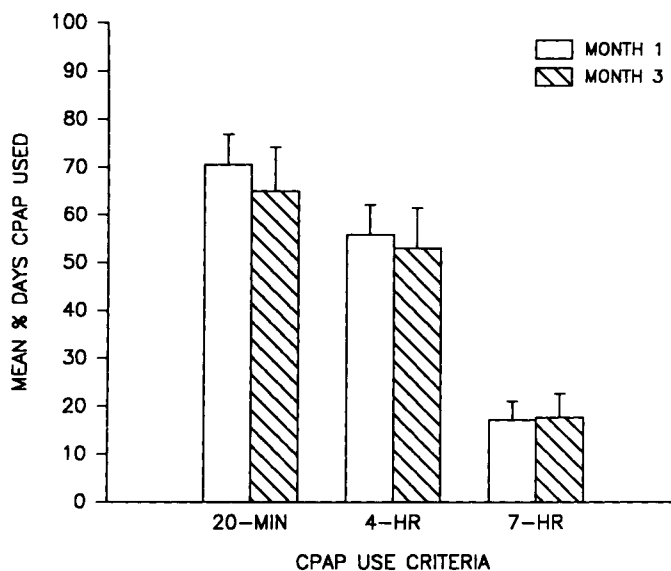On the follow-up questionnaire, patients were also asked if they

TABLE 3

DURATION OF CPAP USE (WHEN IT WAS USED) AND NUMBER OF DAYS CPAP WAS USED FOR THE THREE CRITERION LEVELS ACROSS MONTHS 1, 2, AND 3*

	Month 1	Month 2	Month 3	$F_{2,38}$
Duration of use, min	330.7 (101.8)	308.0 (107.3)	320.5 (93.2)	2.26
Use $\geq$ 20 min, days	21.2 (11.5)	20.7 (11.9)	19.5 (12.3)	2.16
Use $\geq$ 4 h, days	17.0 (11.5)	16.5 (12.0)	15.9 (11.5)	0.34
Use $\geq$ 7 h, days	5.1 (6.6)	4.9 (6.4)	4.8 (6.6)	0.16

* Values given as the mean with SD in parentheses; n = 20.

Figure 2. Mean percentage (and standard error of the mean) of days CPAP was used in Months 1 (*open bars*) and 3 (*hatched bars*), according to three duration of use criteria: use defined as $\geq$ 20 min, use defined as $\geq$ 4 h, and use defined as $\geq$ 7 h. Data are from 20 OSAS patients in whom at least 3 months of CPAP monitoring occurred.

used CPAP for only a portion of the time they spent sleeping. Of the 31 patients who answered the question, 25 indicated they used CPAP throughout their sleep, and the remaining 6 reported they did not use CPAP the entire time they slept. The latter group reported that they slept an average of 1.42 h longer each night *after* turning their CPAP machine off. The CPAP monitor appeared to support this claim. The average CPAP use time of the 25 patients who reported using CPAP all night was 1.5 h more per night (M = 5.3 h) than the average for the 6 patients who did not use CPAP all night (M = 3.8 h).

Regular Versus Irregular CPAP Users

Patients were segregated into two groups based on whether the covert monitor showed that they used CPAP at least 4 h per day on at least 5 days per week ($\geq$ 70% of the time). Of the 35 patients 16 (46%) met these criteria and were designated regular users of CPAP. The remaining 19 patients were considered irregular users. The mean (and SD) pretreatment characteristics and CPAP follow-up questionnaire results for these two groups are listed in table 4. The 16 regular users of CPAP had more years of education (p = 0.050). These regular users were also more likely to be employed in what would be considered professional "white-collar" occupations (chi square = 5.43, p = 0.02) rather than "blue-collar" technical jobs. [Occupations were categorized into professional (n = 14; 10 regular users, 4 irregular users) and nonprofessional (n = 17; 5 regular users, 12 irregular users) by seven independent raters for those patients who responded to the occupation question (n = 31). Examples of professional occupations were attorney, banker, and engineer. Nonprofessional occupations were, for example, plumber, longshoreman, and nurse's aide.] Otherwise the two groups were similar at the pretreatment baseline with respect to clinical, laboratory, and demographic variables, such as race, marital status or living arrangement, and use of drugs or alcohol.

There was a trend for differences between groups in two pretreatment self-report parameters relevant to daytime functioning: regular users reported more frequent excessive daytime sleepiness (EDS) before treatment (p = 0.062) and less ability to perform tasks (p = 0.069). At the first follow-up after CPAP prescription, regular users reported significantly more satisfaction with CPAP treatment (p = 0.025) and a better level of daytime energy (p = 0.046). A separate two-way analysis of variance on self-reported daily energy level at pretreatment baseline and follow-up revealed that although both groups had a statistically significant improvement in the reported energy level with CPAP prescription, this change was much greater for regular users ($F_{1,30}$ = 57, p = 0.0001).

Correlational analyses between the parameters listed in table 4 and the rate of attempted use of CPAP (> 20 min/day criterion) for all 35 patients confirmed the results of between-group comparisons. Only satisfaction with CPAP treatment (r = 0.44, p = 0.006) and daily energy level (r = 0.39, p = 0.01) ratings at follow-up correlated with objective frequency of CPAP use. There were no significant correlations between CPAP use and baseline pretreatment measures of apnea severity (RDI, Sa_{O_2} nadir) or the objective measure of sleepiness (MSLT; n = 26).

Analyses were also conducted between the regularity of CPAP use and ratings of CPAP side effects or problems at the first follow-up. Regular CPAP users were not different from less regular users in subjective complaints in the first monthly follow-up questionnaire regarding maintenance of alertness, with the severity of 20 to 21 potential side effects or problems from CPAP, or on a global score for frequency of side effects or problems in which each subject's ratings for all questions were added together (table 4). However, 1 of the 21 questionnaire items considered CPAP side effects and problems reliably discriminated regular users of CPAP from irregular users. This item was "The CPAP mask makes me feel claustrophobic (closed in)." Of the 16 regular CPAP users, 14 answered the claustrophobia question. Only 1 of the 14 regular users who responded to this item rated it as a problem, compared to 8 of 18 irregular users who rated this item as a problem (χ^2 = 5.4, p = 0.02). Data from the follow-up questionnaire revealed that for all 35 patients the most frequently rated side effect or problem with CPAP was inconvenience (54.5% of respondents), followed by stuffy nose (46.9%), sleep poorly (32.3%), disturbs sleep (31.3%), less intimacy with bed partner (31.3%), claustrophobia (28.1%), irritates face (28.1%), and expense (27.6%). All 13 remaining categories of side effects and problems (see table 1) were rated as problematic by fewer than 25% of respondents.

Optimal CPAP Use

To assess the extent to which CPAP was actually used by patients at a level consistent with the prescription that it be used daily throughout sleep, the covert monitor results scored by the minimal acceptable use criterion ($\geq$ 4 h use per 24-h period) were compared to the optimal use criterion ($\geq$ 7 h use per 24-h period). Results in table 2 show that although CPAP was used for at least 4 h on 51.1% of days monitored, it was used for at least 7 h on only 16.6% of days. These values do not convey the full picture, however, since they confound differences between patients with differences within patients. The covert monitor results for both the $\geq$ 4 and $\geq$ 7 h use duration criteria for all 35 patients during the first 60 days monitored are displayed in figure 3 (although the analyses were conducted on all available days for each patient). Whereas 16 of the 35 patients (46%) used CPAP for at least

TABLE 4

PRETREATMENT AND FOLLOW-UP CHARACTERISTICS OF 16 REGULAR USERS OF CPAP ($\geq$ 4 H ON $\geq$ 70% OF DAYS) AND 19 IRREGULAR USERS (MEAN AND SD)

	Regular Users (n = 16)	Irregular Users (n = 19)
Age, yr	47.9 (9.3)	44.8 (9.9)
Body mass index	39.5 (9.3)	39.5 (6.3)
Respiratory disturbance index, events/h	62.8 (33.5)	67.1 (30.4)
MSLT, min	4.6 (4.6)	3.4 (2.0)
Sa_{O_2} nadir, %	67.7 (17.6)	68.2 (14.9)
CPAP pressure level, cm H_2O	12.7 (3.9)	13.1 (3.2)
Pretreatment questionnaire		
Employed, % yes	93.7	78.9*
Main complaint of sleepiness, %	50.0	31.6*
Education, yr	15.3 (2.4)	13.3 (3.1)†
Energy level (1 = high, 5 = low)	3.7 (1.0)	3.5 (1.1)
Daytime sleepiness, episodes/wk	3.6 (0.6)	3.0 (1.2)‡
Times fallen asleep driving, past month	1.1 (1.8)	1.4 (3.7)
Times fallen asleep on job, past month	5.8 (9.9)	12.2 (23.2)
Ability to perform tasks (1 = high, 5 = low)	3.7 (0.8)	3.0 (1.2)‡
Quality of life (1 = high, 5 = low)	2.8 (1.1)	2.5 (0.7)
Hopeful quality of life will improve		
(1 = high, 5 = low)	1.8 (0.8)	1.8 (0.8)
Follow-up questionnaire		
Global CPAP side effects (0 = no problems,		
63 = serious problem for all questions)	5.7 (4.6)	6.7 (6.8)
Satisfaction with CPAP (0 = very		
unsatisfactory, 3 = very satisfactory)	2.5 (0.6)	1.7 (1.0)†
Energy level (1 = high, 5 = low)	2.1 (0.7)	2.8 (1.0)†

* Chi-square analysis.
† Difference between groups at p < 0.05.
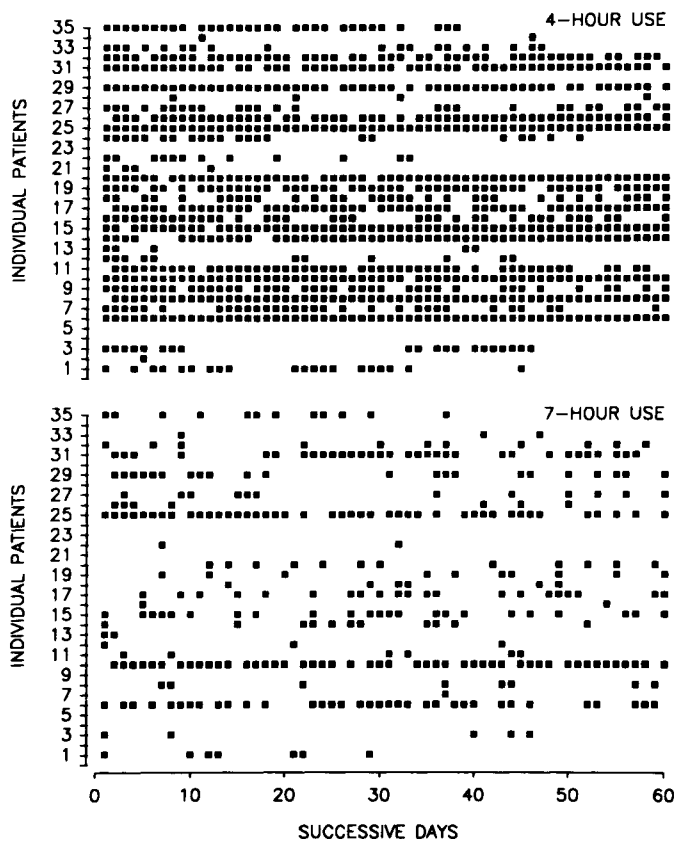‡ Difference between groups at p < 0.07.

Figure 3. Pattern of day-to-day CPAP use for each of the 35 patients for as many as 60 days, plotted according to two duration of use criteria. The black squares are days when CPAP was used for at least 4 h (upper panel) or for at least 7 h (lower panel). Blank areas between the squares represent days when CPAP either was not used or not used long enough to meet this duration of use criterion.

4 h on 70% of days, only 2 of the 35 patients (5.7%) used CPAP for 7 h per day on at least 70% of days. Both were female patients, ages 49 and 54 yr, one each from the two sleep centers; one used CPAP at least 7 h per day on 73.6% of days, and the other on 85.2% of days. Two male patients averaged the next highest frequency of CPAP use by optimal criteria ($\geq$ 7 h per day 52 to 53% of the time).

DISCUSSION

Since no patient volunteers returned CPAP, the results of this study generalize to that portion of apnea patients who accept CPAP treatment. By covert monitor records, patients attempted to use CPAP for at least 20 min per day on the majority of days (66%), for an average of less than 5 h, generally at night (10 p.m. to 9 a.m.), throughout the approximately 100-day period they were monitored. Not surprisingly, these averages were the product of large individual differences. When very liberal (minimal) criteria were applied for what might be accepted as a regular use of CPAP ($\geq$ 4 h/day on at least 70% of days), fewer than half the patients (46%) could be considered regular users. Despite rather wide differences among patients, there was surprisingly little variation across time in the use of CPAP. Neither frequency nor duration of CPAP use changed from Month 1 to Month 3, and correlations between use in Months 1 and 3 were very high, suggesting that the extent to which a patient uses CPAP is likely determined in

the first few weeks after prescription. If so, this appears to be the best time to focus efforts to enhance patient's use of the therapy. It remains unknown, however, to what extent CPAP use may change beyond the 3-month time frame of this study.

Although stable in their patterns of CPAP use over time, patients' self-reports of use at follow-up were inflated relative to actual use. Their claims were consistent, however, with findings from other studies that relied solely on patients' reports. Thus, it is not uncommon to find reports that between 68 and 80% of OSAS patients use CPAP (12, 17) and that duration of use is at least 6 h every night (14, 18). In the current study, 60% of the patients (21 of 35) reported nightly use of CPAP, but of these only 71% (15 of 21) actually did so 90% or more of the time, which reduces the proportion actually using CPAP "daily" (independent of duration of use) to fewer than half (15 of 35). Similarly, patients consistently overestimated, usually by more than an hour, the duration of time each day that they used CPAP. Finding that CPAP is used less than patients claim to use it is not unexpected for a therapy that requires patient self-administration. For example, using a covert objective monitor of inhaler use for chronic obstructive pulmonary disease, it was found that during the first 4 months of the multisite study only 52% of patients used their inhalers twice daily as prescribed, compared to 87% who claimed to do so by self-report (27). Nasal CPAP therapy requires much more time and effort than inhaler therapy, and consequently it is not surprising that our percentages for objective use are even lower than those for inhalers.

The discrepancies we observed between the record of use from the covert monitor and what patients reported on follow-up pose a problem for determining when and how to use patients' reports of compliance with CPAP. Of the 21 patients who reported using CPAP every day, the covert monitor revealed that 29% of them (6 of 21) did not, in fact, use it on even three-quarters of the days. Moreover, the vast majority of patients (76%) reported a daily duration of use in excess of actual use. This discrepancy, which was on average slightly more than 1 h, is likely due to some patients' inability to accurately estimate their nocturnal sleep time. The range of discrepancy between actual duration and reported duration of CPAP use was so great, however, that we believe it is problematic to rely too heavily on patients' retrospective reports of use when estimating the extent to which CPAP is accepted and utilized as prescribed. It is likely that we would have observed somewhat better agreement between objective monitoring and self-reports of CPAP use had we asked patients to complete daily logs of sleep and use rather than monthly retrospective reports. We opted not to use daily logs because these require patient compliance and they emphasize concern over CPAP use, which are two factors that could easily influence actual CPAP usage.

Although this study did not measure any objective outcomes as a result of patients using CPAP therapy, there were indications from self-report data on the first follow-up questionnaire that those patients who used CPAP more regularly not only tended to experience greater levels of fatigue and daytime sleepiness before treatment but also derived greater relief from these symptoms during the therapy period. This positive association between patient-reported excessive daytime sleepiness and CPAP acceptance and use has been observed by others (13, 17). However, there was no objective evidence that regular CPAP users were sleepier by objective criteria (MSLT) or more severely impacted (RDI, Sao_2 nadir) by OSAS before CPAP prescription. No follow-up MSLT was conducted because this is not the usual practice in our sleep centers and we did not wish to alter normal patient use of treatment. Therefore, we do not know whether regular CPAP users were objectively less sleepy than irregular users. (This is the fo-

cus of a new study.) It is possible that the greater complaint of sleepiness exhibited by these patients resulted in an increased willingness to use CPAP, which in turn led to their greater satisfaction with the therapy. Interestingly, these patients also had more years of education and were more likely to have a professional occupational status than those who used CPAP less regularly, which may have played a role in their apparent sensitivity to daytime sleepiness and its effects on their work.

Some indication of why CPAP was used much less frequently by some patients derived from the follow-up questionnaire ratings on side effects or problems. As expected, stuffy nose and inconvenience were the most frequently cited problems with CPAP, a finding consistently found in self-report studies (for example, references 12 and 17). However, only feelings of claustrophobia discriminated less regular CPAP users from more regular users. Claustrophobia has also been identified as a major reason for nonacceptance of CPAP in other studies (10). It is a psychologic factor that, unlike physical side effects, which can vary from night to night as a function of many variables, is likely to be a problem every time a patient attempts to use CPAP. Much is made of the physical side effects of CPAP as adversely impacting its use, yet the follow-up data from this study suggest that nonphysical factors (inconvenience, expense, claustrophobia, and less intimacy with bed partner) are the major problems for patients. Sleep disturbance from the therapy was also commonly reported as a problem, a result that has been noted in other studies of CPAP (28). Thus, CPAP use might be enhanced if more emphasis were given to efforts designed to reduce the fear of, and intrusiveness of, the therapy. Advances on both fronts will likely require new approaches to CPAP delivery or new therapies for OSAS altogether. In this regard, it is important to acknowledge that since this study was implemented on the Respironics Sleep Easy III model, newer CPAP devices, such as the ramp CPAP, continue to appear on the market. Among other changes, these devices are commonly smaller and quieter, factors that may or may not improve patient use.

When CPAP was used by patients, the average duration of use was 4.88 ± 1.96 h. This result is consistent with studies of CPAP use that relied on an external counter that accumulates the time the power is on to the unit (9, 18, 20), especially if one adjusts for use efficiency. For example, a study using a time counter in the CPAP machine that recorded only power on found a mean daily duration of use of 5.14 ± 0.31 h (9). If this average is adjusted downward by 9%, based on our finding that appropriate use of the mask occurs on average 90.9% of the time power is on, the average daily use of CPAP from the counter timer study (9) is 4.68 h. A similar use efficiency adjustment for average data from a study in which patients called in their power on counter numbers (20) yields a mean daily use of 5.54 h. These adjusted means are remarkably close to our average daily duration of use at 4.88 h (actual mask on time). This average duration of use hides a disturbing outcome, however. Only 2 of the 35 patients actually used CPAP for at least 7 h an average of at least 5 of 7 days. We selected 7 h as a conservative criterion for typical daily sleep duration based on what is known about the average daily sleep durations of middle-aged adults (25, 26). Based on these normative data, we expected that between one-third and one-half of the patients who used CPAP at least 70% of the time would use it for a duration of at least 7 h, assuming they used it throughout sleep. Yet the results illustrated in figure 3 make it clear that although 16 of the patients used CPAP for at least 4 h on 70% of days, only 2 of them used it at least 7 h a day. It seems highly unlikely that these are the only 2 patients of the 35 we monitored who needed 7+ h of undisturbed sleep per day. This provocative finding raises

questions about the extent to which patients use CPAP throughout sleep, the degree to which patients can sleep "normal" durations and maintain good sleep hygiene wearing CPAP, and the effects of chronic sleep disruption associated with untreated OSAS on sleep need. These questions are all beyond the scope of the current study, because we did not have an independent objective measure of total sleep time or time in bed. The decision not to use an actigraph or similar device for monitoring sleep was made to ensure that nothing was done that would artificially impact on CPAP use. Nevertheless, if we assume that the period of actual CPAP use reflects the amount of uninterrupted quality sleep obtained by our patients, then the results raise concerns about whether CPAP is only a partially effective treatment (as in reference 29) and lead us to question how well daytime functioning is normalized for patients using CPAP for only a few hours a day on only a portion of days.

References

1. Sullivan CE, Berthon-Jones M, Issa FG, Eves L. Reversal of obstructive sleep apnoea by continuous positive airway pressure applied through the nares. Lancet 1981; 1:862–5.
2. Sullivan CE, Issa FG, Berthon-Jones M, McCauley VB, Costos LJV. Home treatment of obstructive sleep apnea with continuous positive airway pressure applied through a nose mask. Bull Eur Physiopathol Respir 1984; 20:49–54.
3. Sullivan CE, Grunstein RR. Continuous positive airways pressure in sleep-disordered breathing. In: Kryger MH, Roth T, Dement WC, eds. Principles and practice of sleep medicine. Philadelphia: W. B. Saunders, 1989; 559–70.
4. Smith PL, Wise RA, Gold AR, Permutt S. Upper airway pressure-flow relationships in obstructive sleep apnea. J Appl Physiol 1988; 64:789–95.
5. Zorick F, Merlotti L, Conway W, Fujita S, Rosenthal L, Roth T. Patient response to various treatments for sleep apnea. Sleep Res 1988; 17:270.
6. Issa FG, Sullivan CE. The immediate effects of nasal continuous positive airway pressure treatment on sleep pattern in patients with obstructive sleep apnea syndrome. Electroencephalogr Clin Neurophysiol 1986; 63:10–7.
7. Rajagopal KR, Bennett LL, Dillard TA, Tellis CJ, Tenholder MF. Overnight nasal CPAP improves hypersomnolence in sleep apnea. Chest 1986; 90:172–6.
8. Wagner DR, Pollak CP, Weitzman ED. Nocturnal nasal-airway pressure for sleep apnea. N Engl J Med 1983; 308:461–2.
9. Krieger J, Kurtz D. Objective measurement of compliance with nasal CPAP treatment for obstructive sleep apnoea syndrome. Eur Respir J 1988; 1:436–8.
10. Katsantonis GP, Schweitzer PK, Branham GH, Chambers G, Walsh JK. Management of obstructive sleep apnea: comparison of various treatment modalities. Laryngoscope 1988; 98:304–9.
11. Rauscher H, Popp W, Wanke T, Zwick H. Acceptance of CPAP therapy for sleep apnea. Chest 1991; 100:1019–23.
12. Issa FG, Costas LJV, Berthon-Jones M, McCauley VJ, Bruderer J, Sullivan CE. Nasal CPAP treatment for obstructive sleep apnea (OSA): long term experience with 117 patients (abstract). Am Rev Respir Dis 1985; 131:A108.
13. Waldhorn RE, Herrick TW, Nguyen MC, ODonnell AE, Sodero J, Potolicchio SJ. Long-term compliance with nasal continuous positive airway pressure therapy of obstructive sleep apnea. Chest 1990; 978:33–8.
14. Sanders MH, Gruendl CA, Rogers RM. Patient compliance with nasal CPAP therapy for sleep apnea. Chest 1986; 90:330–3.
15. Anand VK, Ferguson PW, Schoen LS. Obstructive sleep apnea: a comparison of continuous positive airway pressure and surgical treatment. Otolaryngol Head Neck Surg 1991; 105:382–90.
16. Nino-Murcia G, McCann CC, Bliwise DL, Guilleminault C, Dement WC. Compliance and side effects in sleep apnea patients treated with nasal continuous positive airway pressure. West J Med 1989; 150:165–9.
17. Rolfe I, Olson LG, Saunders NA. Long-term acceptance of continuous positive airway pressure in obstructive sleep apnea. Am Rev Respir

Dis 1991; 144:1130–3.

18. Idatna R. A multicentric survey of long term compliance with nasal CPAP treatment in patients with obstructive sleep apnea syndrome (abstract). Am Rev Respir Dis 1990; 141:A863.

19. Reeves-Hoche MK, Meck R, Zwillich CW. An objective trial of nasal continuous positive airway pressure treatment compliance (abstract). Am Rev Respir Dis 1990; 141:A862.

20. Fletcher EC, Luckett RA. The effect of positive reinforcement on hourly compliance in nasal continuous positive airway pressure users with obstructive sleep apnea. Am Rev Respir Dis 1991; 143:936–41.

21. Rechtschaffen A, Kales A. A manual of standardized techniques and scoring system for sleep stages of human subjects. Los Angeles: Brain Information Service, 1968.

22. Knight H, Millman RP, Gur RC, Saykin AJ, Doherty JU, Pack AI. Clinical significance of sleep apnea in the elderly. Am Rev Respir Dis 1987; 136:845–50.

23. Smith PL, Haponik EF, Allen RP, Bleecker ER. The effects of protripty-line in sleep-disordered breathing. Am Rev Respir Dis 1983; 127:8–13.

24. Horne JA. Why we sleep. New York: Oxford University Press, 1988.

25. Tune GS. Sleep and wakefulness in 509 normal human adults. Br J Med Psychol 1969; 42:75–80.

26. Williams RL, Karacan I, Hursch CJ. EEG of human sleep. New York: John Wiley, 1974.

27. Tashkin DP, Rand C, Nides M, Simmons M, Wise R, Coulson AH, Li V, Gong H. A nebulizer chronolog to monitor compliance with inhaler use. Am J Med Sci 1991; 91:33S–6S.

28. Hoffstein V, Viner S, Mateika S, Conway J. Treatment of obstructive sleep apnea with nasal continuous positive airway pressure. Am Rev Respir Dis 1992; 145:841–5.

29. Sforza E, Krieger J, Weitzenblum E, Apprill M,Lampert E, Ratamaharo J. Long-term effects of treatment with nasal continuous positive airway pressure on daytime lung function and pulmonary hemodynamics in patients with obstructive sleep apnea. Am Rev Respir Dis 1990; 141:866–70.