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Prospective randomized comparison of impedance-controlled auto-continuous positive airway pressure ($APAP_{FOT}$) with constant CPAP

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Abstract

Background: The measurement of impedance permits reliable detection of obstructive apneas, hypopneas and upper airways resistance syndrome.

Objective: To establish whether impedance-controlled self-adjusting positive airway pressure therapy ($APAP_{FOT}$) is equally as good as constant continuous positive airway pressure (CPAP) in the treatment of sleep apnea syndrome (OSAS).

Methods: Twenty men and five women with OSAS (age 52.8 ± 9.0 years, body mass index (BMI) 31.4 ± 5.0 kg/m^2, AHI 32.2 ± 18.1/h (mean ± SD)) underwent baseline polysomnography, manual CPAP titration and two nights of treatment, one with $APAP_{FOT}$, one with constant CPAP.

Results: With both modes, a significant reduction in respiratory disturbances was seen (apnea/hypopnea index (AHI) baseline 32.2 ± 18.1/h, constant CPAP 6.6 ± 8.7, $APAP_{FOT}$ 5.5 ± 3.8/h, $P < 0.001$ baseline vs. each treatment mode). Under $APAP_{FOT}$, the sleep profile was normalized (S3/4 baseline 16.3 ± 13.9% total sleep time (TST), $APAP_{FOT}$ 21.6 ± 10.9% TST, $P < 0.05$, rapid eye movement (REM) 14.2 ± 6.7% TST vs. 20.3 ± 7.3% TST, $P < 0.01$), while with constant CPAP, a tendency towards improvement was found. The mean treatment pressure with $APAP_{FOT}$ was significantly lower than the constant CPAP (5.7 ± 2.1 vs. 8.3 ± 1.6 mbar, $P < 0.001$).

Conclusion: We conclude that $APAP_{FOT}$ is at least as effective as constant CPAP in normalizing sleep and breathing in OSAS. © 2001 Elsevier Science B.V. All rights reserved.

Keywords: Impedance; Forced oscillation technique; Automatic continuous positive airway pressure; Impedance-controlled self-adjusting positive airway pressure; Constant continuous positive airway pressure; Pressure reduction; Sleep apnea syndrome

1. Introduction

Continuous positive airway pressure (CPAP) employing a constant pressure, is the method of choice for the treatment of the obstructive sleep apnea syndrome (OSAS) [1]. Nevertheless, up to 30% of the patients discontinue treatment within the first months because of local side effects and discomfort, related to the mask and pressure. With the aim of reducing pressure-associated side effects, automatic CPAP devices were developed that continuously match the treatment pressure to the actual obstruction

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in the upper airways. In this way, mean pressure should theoretically be reduced, and treatment failures due to non-compliance avoided. The detection of respiratory disturbances is effected on the basis of the respiratory pattern, flow characteristics and acoustic signals of the airflow [2–8].

In the present study we have used a self-adjusting system for nasal CPAP treatment which is based on impedance measurement by forced oscillation technique (FOT). This technology is a non-invasive means of detecting complex resistances. It was first described by DuBois in 1956, and has, since then, been experimentally investigated in various modifications, and has been employed at various levels of the airway system [9,10].

In 1995, Rühle and colleagues used impedance to detect obstructions in the upper airways occurring during sleep [11–13]. In the case of OSAS, increases of the impedance correlated with apneas and hypopneas, the upper airway resistance syndrome and snoring. Besides the obstructive events, central apneas with and without obstruction of the upper airways could be distinguished [11–13]. In 1997, Farré et al. described the prototype of a system for the simultaneous generation of oscillatory measuring pressure and continuous constant positive treatment pressure [14]. Subsequently this group was also able to show that manual CPAP titration on the basis of impedance measurement permitted an adequate therapeutic effect to be achieved [15,16]. Using impedance, however, the mean CPAP pressure did not differ significantly from that of conventional titration which suggested the possibility of impedance-controlled self-adjusting CPAP treatment.

In two recent investigations aimed at establishing the optimal pressure variation range using an impedance-controlled self-adjusting CPAP device ($APAP_{FOT}$) we were able to demonstrate the adequacy of this treatment for OSAS [17,18]. The present study compares this self-adjusting CPAP treatment with the previous standard treatment using constant CPAP.

2. Methods

2.1. Patients

The patients were recruited consecutively from among persons referred for primary evaluation and treatment of OSAS. All subjects underwent a baseline examination of lung function and gave their written informed consent to participate in the study. The study protocol was approved by the ethics committee of the University Witten/Herdecke, Germany. The patients did not have any kind of treatment of OSAS before, in particular no corrective upper airways surgery, (e.g. UPPP) and no positive airway pressure treatment. Only patients with OSAS with a history of hypersomnia and apnea/hypopnea index (AHI) >10/h were included in the study. Patients with the following concomitant diseases or intercurrent treatments were excluded: obstructive airway diseases, medications with a central stimulating or suppressive effect and neurological/ psychiatric diseases. Study participants comprised 20 men and five women. Their anthropometric data and the results of lung function tests are shown in Table 1.

2.2. CPAP system on the basis of the forced oscillation technique ($APAP_{FOT}$)

Generation of the oscillatory pressure signal and application of the CPAP pressure was effected with the Somnosmart® device (Weinmann, Hamburg, Germany), as previously described [17,18]. Impedance designates a complex resistance: in addition to the real component (resistance, R) it also includes an 'imaginary' component (reactance). The patients breathe through a mass-produced nasal mask which is connected in parallel to a treatment pressure genera-

Table 1
Anthropometric data and baseline measurements[a]

n	25
Male/female	20/5
Height (cm)	174.3 ± 8.0
Age (years)	52.8 ± 9.0
Weight (kg)	95.5 ± 16.1
BMI (kg/m^2)	31.4 ± 5.0
AH1 (1/h)	32.2 ± 18.1
FEV1 (l)	3.3 ± 1.1
FEV1% pred. (%)	98.3 ± 23.4
FVC (l)	4.4 ± 1.3
FVC% pred. (%)	98.6 ± 15.8
TLC (l)	6.8 ± 1.3
TLC% pred. (%)	102.3 ± 13.3

[a] Mean ± SD, BMI, body mass index; AHI, apnea/hypopnea index; TLC, total lung capacity.

tor, a pump for generating an oscillating flow (frequency 20 Hz), and a sensor to record the mask pressure. The pressure signal is passed on to the processor which calculates the impedance and regulates the CPAP generator. At the start of the measurement, impedance was recorded over a period of 5 min. The patients were advised to stay awake and not to speak or to eat during this period. An individual mean value was then obtained from these values and served as a reference for regulation purposes during the operating time of the machine. The device re-evaluates the establishment of the reference value at every new start.

Figs. 1 and 2 show the time course of the impedance with the variation of the treatment pressure and examples of single events in the impedance signal, respectively. Based on the experimental data by Reisch et al. [19] an obstructive event was identified when the current impedance value measured over a period of 10 s exceeded the reference value by a factor of 1.6. In the case of hypopneas these increases of the impedance varied through inspiration and expiration (Fig. 2a). In the case of apneas the impedance signal showed persistently high level without variations during the respiratory cycle (Fig. 2a). The apneic events can either be obstructive apneas or central apneas with closed airways as described in endoscopical studies by Badr et al. [20]. A central event with open airways was identified when the current impedance measured over 10 s equaled or was up to 10% smaller than the reference value. The definition of snoring in the algorithm was based on the analysis of the impedance signal during periods of snoring in prestudy patients. 'Snoring' was identified when the impedance signal varied between 1.6 times the reference value and any point equal to the reference within a period of 3–12 s. That indicates a rapid change in the degree of obstruction [18].

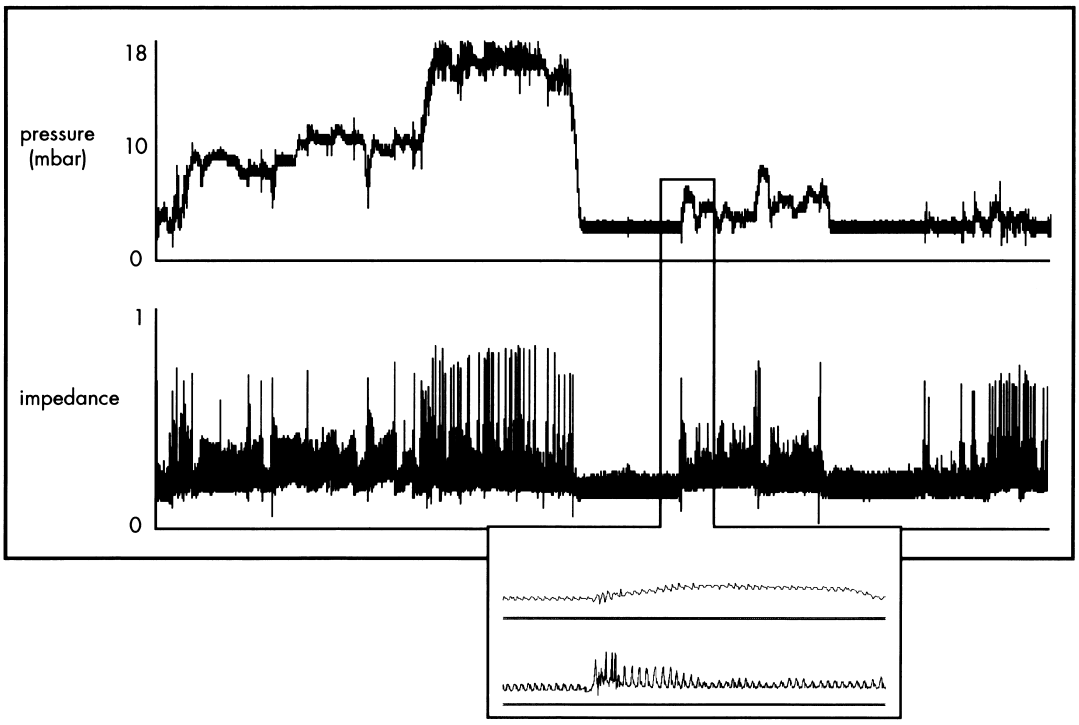

Fig. 1. Time course of the impedance and the treatment pressure. The figure shows the compressed time course of a treatment night with $APAP_{FOT}$ and a short period of the study in a higher resolution. Increases of the impedance (lower line) result in increases of the treatment pressure (upper line). The treatment pressure reaches the highest technically possible level of 18 mbar until the obstruction has been overcome and is reduced thereafter to the lowest level of 4 mbar. The small box demonstrates a short period of breathing with the variations of the impedance and the consecutive reactions of the pressure.

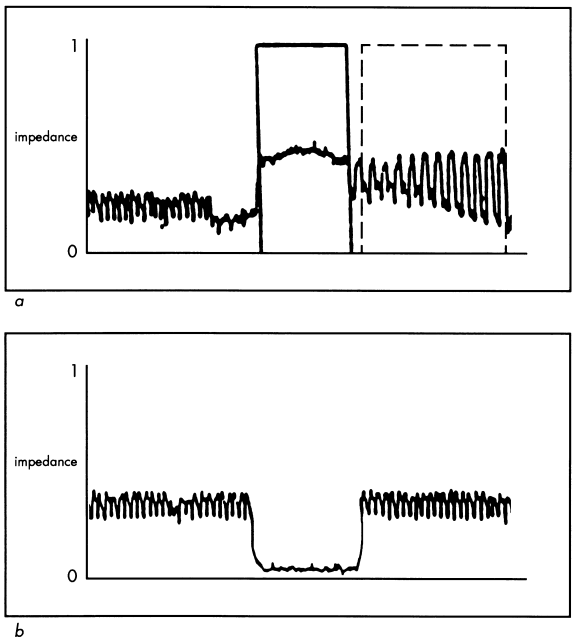

Fig. 2. Examples of disturbances as measured with the impedance. After a period with a low level of the impedance (normal breathing) the figure shows a complete obstruction of the airways ((a) first box). This can either be an obstructive apnea or a central apnea with closed airways. During the last period (interrupted box in (a)) the amplitude of the impedance reaches the same level as in the apneic event but it varies with the respiratory cycle indicating an obstructive hypopnea. (b) Gives an example of a period of leakage. The impedance value reaches the level of '0'. The normal breathing before and after the leakage indicates the reference level.

The rate of pressure increase was selected to be 0.2 mbar/s. An increase in pressure was triggered when an increase in the impedance value of more than 1.6 times the reference value was detected. The rate of pressure decrease following an obstructive respiratory event was 0.1 mbar/s at maximum, but differed as a function of the prior signal (single obstructive event: pressure decrease 0.1 mbar/s, cluster of obstructions: 0.05–0.1 mbar/s). The system is designed to permit pressure variations between 4 and 18 mbar.

2.3. Lung function

Measurements of the functional-analytical basic data (FEV1, FEV1% pred., R_{tot}, R_{tot}% pred., FVC, FVC% pred.) were carried out using a standard bodyplethysmograph. As reference values for FVC and FEV1, the European Community standard values were employed.

2.4. Polysomnographic evaluation criteria

The equipment was identical in the baseline and both treatment studies.

2.4.1. Sleep parameters

For the establishment of the hypnogram, the following parameters were derived: electroencephalograph (EEG) (C4A1 or C3A2), a submental and a pretibial electromyogram (EMG), and two electrooculograms (EOGs). An analysis of sleep stages was carried out in accordance with the guidelines of Rechtschaffen and Kales, analysis of arousal and periodic limb movements using the ASDA criteria [21–23]. Arousals were interpreted to be respiration-related when they occurred at the earliest at the onset, at the latest two s after the end, of an apnea or hypopnea.

2.4.2. Respiratory parameters

The following parameters were recorded: respira-

tory effort via thoracic and abdominal impedance plethysmography, respiratory flow via an oronasal thermistor, CPAP pressure picked up at the mask with a pressure sensor, snoring signals picked up via a laryngeal microphone, and oxygen saturation by pulse oximetry.

2.4.3. Definition of respiratory disturbances

We used standard definition of obstructive and central apneas. Hypopnea was defined as a 50% reduction in respiratory flow or respiratory effort compared with baseline (last period of normal breathing) for at least 10 s and a decrease in oxygen saturation of at least 4%. The number of epochs (30 s/page) with evidence of microphone signals (snoring) over a period of at least 2 s not associated with movement artefacts were counted.

2.4.4. Oxygen saturation

Desaturations were defined as a decrease in oxygen saturation of at least 4%. SaO_{2min} designates the minimal oxygen saturation during the total sleep time (TST).

2.5. Treatment pressure

P_{man} is the designation for the CPAP value established by means of manual titration. The aim of titration was to minimize snoring, obstructive apneas and hypopneas. P_{min} is the lowest CPAP, P_{max} the highest CPAP, P_{mean} the integrated and average CPAP over the TST.

2.6. Statistics

All data are given in mean ± standard deviation (SD). The statistical calculations for significant differences with rejection of the null hypothesis at a $P < 0.05$ was carried out using the Wilcoxon test [24].

2.7. Study design

The investigations were carried out in accordance with the following protocol: In the first night, diagnostic polysomnography (baseline measurement, *B*) was performed. When OSAS was diagnosed, the CPAP pressure was titrated manually in the next night. The pressure value derived from manual titration (P_{man}) served as a basis for the setting of CPAP. On the third and fourth nights polysomnographically monitored treatment using both modes was carried out: mode 1: $APAP_{FOT}$: pressure variation within the range 4–18 mbar, mode 2: constant CPAP, using the manually titrated pressure.

The order of the application of mode 1 and mode 2 was effected in randomized fashion. Twelve patients started with $APAP_{FOT}$, 13 with constant CPAP. The technicians did not intervene during the auto CPAP trial. The studies were scored by persons who were not involved in the supervision of the patients during the night. The scorers were not informed about the treatment modes and were not able to determine the treatment mode as the pressure channel was blinded during scoring.

Patients were asked to fill in a questionnaire on side effects and subjective parameters of the outcome (sleep quality, daytime sleepiness, physical and mental fitness, concentration) after both treatment nights.

3. Results

During the baseline polysomnography an AHI of 32.2 ± 18.1/h (all data: mean ± SD) and a minimal oxygen saturation of 81.6 ± 6.1% were measured. In addition, 35.1 ± 36.7 snoring epochs/h were recorded (Table 2). Both under constant CPAP and $APAP_{FOT}$, a highly significant improvement ($P < 0.001$ in each case) in the AHI to 6.6 ± 8.7 and 5.5 ± 3.8/h, respectively, in snoring to 4.2 ± 5.7 and 3.8 ± 6.0 epochs/h, respectively, and in minimal oxygen saturation 87.9 ± 4.5 and 87.0 ± 4.2%, respectively, was observed. No significant differences were found between the two treatment modes (Table 2).

Although the total sleep time (TST) and the wake phase after sleep onset (WASO) were slightly reduced as compared with baseline for both CPAP modes, these differences did not reach significance (Table 2). With $APAP_{FOT}$, in comparison with baseline values, slow-wave sleep (16.3 ± 13.9 vs. 21.6 ± 10.9%TST, $P < 0.05$), and rapid eye movement (REM) sleep (14.2 ± 6.7 vs. 20.3 ± 7.3%TST, $P < 0.01$) significantly increased, while with constant CPAP only a tendency to improve was observed (S3/4: 16.3 ± 13.9 vs. 19.0 ± 11.0%TST, n.s.; REM: 14.2 ± 6.7 vs. 17.1 ± 7.4%TST, n.s.). The two modes did not differ significantly (Table 2).

Table 2
Polysomnography[a]

Parameter	Baseline (B)	$APAP_{FOT}$ (1)	CPAP cst. (2)	*P*-value of B/1	*P*-value of B/2	*P*-value of 1/2
AHI	32.2 ± 18.1	5.5 ± 3.8	6.6 ± 8.7	< 0.001	< 0.001	n.s.
Snor. (ep.)	183.2 ± 195	19.8 ± 33.5	20.6 ± 35.1	< 0.001	< 0.001	n.s.
Snor. (ep./h)	35.1 ± 36.7	3.8 ± 6.0	4.2 ± 6.7	< 0.001	< 0.001	n.s.
Min. SaO_2 (%)	81.6 ± 6.1	87.0 ± 4.2	87.9 ± 4.5	< 0.01	< 0.001	n.s.
TST (min)	323.4 ± 75.5	307.1 ± 53.9	308.4 ± 71.3	n.s.	n.s.	n.s.
WASO (min)	50.9 ± 42.8	60.2 ± 39.9	53.6 ± 37.1	n.s.	n.s.	n.s.
S1 (min)	56.2 ± 36.5	37.9 ± 14.5	40.2 ± 16.2	< 0.05	n.s.	n.s.
S2 (min)	177.2 ± 87.9	140.0 ± 45.2	152.0 ± 54.0	n.s.	n.s.	n.s.
S3/4 (min)	47.5 ± 35.2	65.2 ± 32.1	58.8 ± 39.5	< 0.05	n.s.	n.s.
REM (min)	47.4 ± 25.3	63.4 ± 27.2	55.8 ± 28.6	< 0.05	n.s.	n.s.
S1 (%TST)	18.0 ± 11.2	12.5 ± 5.2	14.3 ± 7.6	< 0.05	n.s.	n.s.
S2 (%TST)	55.6 ± 24.7	45.3 ± 11.2	49.1 ± 12.1	n.s.	n.s.	n.s.
S3/4 (%TST)	16.3 ± 13.9	21.6 ± 10.9	19.0 ± 11.0	< 0.05	n.s.	n.s.
REM (%TST)	14.2 ± 6.7	20.3 ± 7.3	17.1 ± 7.4	< 0.01	n.s.	n.s.
Arousal abs	155.3 ± 73.5	80.8 ± 40.7	87.1 ± 42.1	< 0.001	< 0.001	n.s.
Arous./h	28.9 ± 9.0	16.5 ± 9.4	18.4 ± 10.4	< 0.001	< 0.001	n.s.
Ar. resp. abs	102.6 ± 11.8	18.5 ± 19.5	19.0 ± 28.1	< 0.001	< 0.001	n.s.
Ar. resp./h	17.8 ± 15.8	3.7 ± 3.9	4.5 ± 8.2	< 0.001	< 0.001	n.s.

[a] Mean ± SD, CPAP cst., constant continuous positive airways pressure treatment; $APAP_{FOT}$, self-adjusting positive airway pressure treatment based on measurement of impedance; AHI, apnea/hypopnea index; Snor., snoring; ep., epochs; ep./h, epochs/h; Min. SaO_2, minimal oxygen saturation; TST, total sleep time; WASO, wake after sleep onset; S1, 2, 3/4, sleep stages 1, 2, 3/4; REM, rapid eye movement; arousal abs, total number of arousals in accordance with ASDA criteria in TST; Arous./h, arousals per h TST; Ar. resp. abs, total number of respiration-related arousals in TST; Ar. resp./h, respiratory-related arousals during TST.

Both the indices of arousals measured during TST, and respiration-related arousals, showed a highly significant decrease with both modes in comparison with baseline, with no significant differences between the two modes (arousal index: baseline 28.9 ± 9.0/h, $APAP_{FOT}$ 16.5 ± 9.4/h, constant CPAP 18.4 ± 10.4/h; index of respiratory arousals: baseline 17.8 ± 15.8/h, $APAP_{FOT}$ 3.7 ± 3.9/h, constant CPAP 4.5 ± 8.2/h, baseline vs. treatment, each $P < 0.001$, Table 2).

The mean treatment pressure with $APAP_{FOT}$ was significantly lower than with constant CPAP (5.7 ± 2.2 vs. 8.3 ± 1.6 mbar, $P < 0.001$). For 95% of the time, the treatment pressure with $APAP_{FOT}$ was ≤9.3 ± 4.4 mbar. This figure was not significantly higher than the mean pressure under constant CPAP. The maximum pressure under $APAP_{FOT}$ reached 12.6 ± 4.6 mbar, which significantly exceeded the value under constant pressure ($P < 0.001$, Table 3).

Sixteen of 25 patients filled in the questionnaire on side effects and subjective outcome measures after both treatment nights. There were no significant differences in the evaluation of side effects but the patients rated the quality of sleep with $APAP_{FOT}$ significantly higher than with constant CPAP ($APAP_{FOT}$: 6.8 ± 2.6, constant CPAP: 5.4 ± 1.9, $P < 0.05$; scale 0: very bad quality of sleep, 10: very good).

Table 3
Pressures during constant and $APAP_{FOT}$ treatment[a]

Parameter	$APAP_{FOT}$	CPAP constant	*P*
P_{mean} (mbar)	5.7 ± 2.1	8.3 ± 1.6	< 0.001
P_{min} (mbar)	3.8 ± 0.1		
P_{max} (mbar)	12.6 ± 4.6		
P_t 95% (mbar)	9.3 ± 4.4		

[a] Mean ± SD, P_{mean}, mean treatment pressure during TST; P_{max}, maximum treatment pressure during TST; P_{min}, minimum treatment pressure during TST; P_t 95%, 95% percentile of the treatment pressure related to time (for 95% of the TST, the pressures are smaller than, or equal to, the measured value).

4. Discussion

4.1. Comparison of the efficacy of $APAP_{FOT}$ and constant CPAP

With both treatment modes, a highly significant improvement in AHI, minimal oxygen saturation, snoring, the total number of arousals and respiration-related arousals was observed without significant differences between these two modes. While, however, under $APAP_{FOT}$, a significant increase in, and normalization of, the amounts of slow-wave and REM sleep occurred, the improvement in these parameters under constant CPAP did not reach significance. However, no impairment of the sleep profile was seen under $APAP_{FOT}$. Teschler et al. and Scharf et al. also failed to find any impairment of the sleep profile or arousal index caused by automatic CPAP titration with flow analyzing systems [4,25]. Teschler et al. and Behbehani et al. [2] reported a significant increase in slow-wave and REM sleep phases under automatic and constant-pressure modes, with no differences between them. Scharf et al. [4] also found a significant increase with both modes, but the percentage of slow wave sleep remained under 10% TST. However, the number of patients in the latter study was smaller. Berthon-Jones et al. were also able to show a marked reduction in the arousal index under CPAP treatment using an automatic device based on flattening [26]. With $APAP_{FOT}$, the arousals in our own studies were 16.5 ± 9.4/h, and with constant CPAP 18.4 ± 10.4/h, and were thus comparable with the figures reported by Berthon-Jones (18/h). The figures for arousals are similar to those for healthy subjects of the age group investigated [27]. Teschler et al. [25] reported a lower figure for the overall number of arousals (8.9 ± 0.9/h) and comparable figures for respiratory arousals (1.5 ± 0.6/h). These figures are lower than those measured by Berthon-Jones using the identical system, and are also below the figures found in normal populations. These differences might be due to differences in ambient conditions and differences in the study populations, e.g. the severity of OSAS before treatment [26–28].

4.2. Pressure profile

In a direct comparison with constant CPAP (8.3 ± 1.6 mbar), a decrease in mean pressure to 5.7 ± 2.1 mbar was achieved with $APAP_{FOT}$. This confirms also quantitatively the results of our earlier studies showing that decreases to figures of between 5 and 6 mbar could be achieved [17,18]. For 95% of the time, an $APAP_{FOT}$ pressure not exceeding 9.3 ± 4.4 mbar proved to be adequate – a figure that did not differ significantly from that found with constant CPAP.

In the present study, the actual pressure range extended from 3.8 ± 0.1 to 12.6 ± 4.6 mbar, under $APAP_{FOT}$. In most patients, the mean pressure was (up to 7 mbar) less with $APAP_{FOT}$ than with constant CPAP therapy. However, there were two patients in whom the mean treatment pressure exceeded the constant CPAP pressure (Fig. 3). The presumable reason for these differences are variations in pressure requirements from one night to another. Therefore, it was found that clearly higher peak pressures than those derived with manual titration were necessary to achieve an optimal effect [17–18].

Our results confirm the data reported by Scharf et al., who found that the automatically titrated pressure was below the manually derived pressure for 63.1 ± 34.2% of TST [4]. Using a system responsive to pharyngeal wall vibrations, Behbehani et al. were able to show a reduction in mean treatment pressure of 3.1 mbar [2]. However, the mean treatment pressure at 8.4 ± 3.3 mbar, was clearly higher than with $APAP_{FOT}$. Possible reasons for these differences may include differences in the technology of the systems employed, or differences in patient populations (higher body mass index (BMI), higher manual treatment pressure (11.5 ± 3.3 mbar)) [2]. In our present investigation, too, a wide range of applied pressures was observed.

The mean pressures for manual titration shown by our present data were of the same order of magnitude as in the studies done by Teschler et al. (Teschler: 8.6 ± 0.4 mbar, Randerath: 8.3 ± 1.6 mbar). Employing automatic titration using a device based on flattening, Teschler's working group derived higher 'recommended pressures' (95% percentile) than the manual titrated pressure [25]. In a subsequent investigation an attempt was also made to suppress snoring by manual titration during which the manual CPAP pressure increased to above the value titrated using the automatic system [28]. The 95% percentile in our own

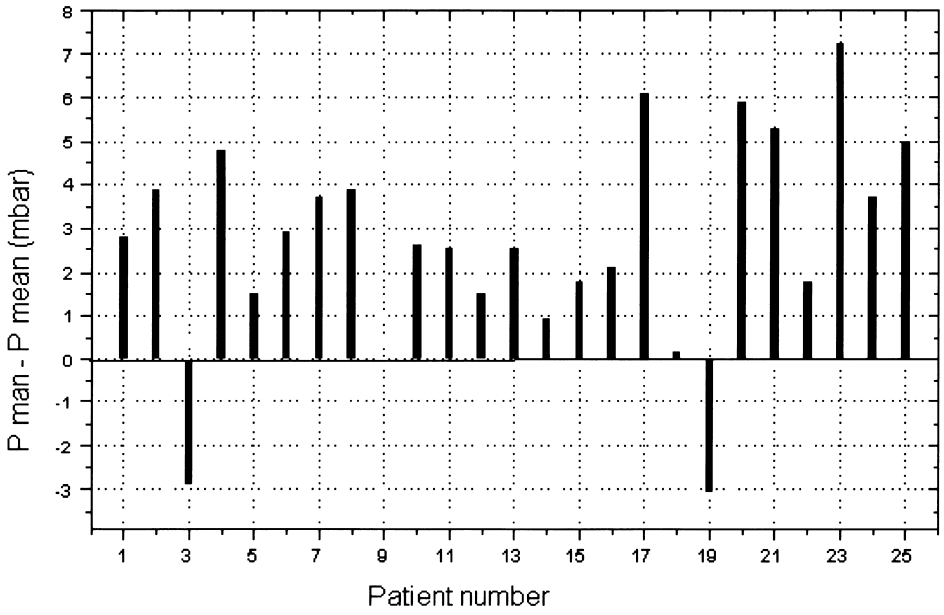

Fig. 3. Pressures measured in individual patients. The figure shows the differences between the manually titrated pressure which was used as constant CPAP and the mean pressure with $APAP_{FOT}$ in the 25 patients investigated. In 22 patients the mean pressure in the automatic mode was lower than with the constant CPAP. Only in two patients (no. 9 and 18) the manually titrated pressure was almost equal to the self-adjusted mean pressure.

study did not differ significantly from that titrated manually. The number of epochs in which snoring was recorded in our study, was highly significantly reduced both under $APAP_{FOT}$ and constant CPAP. The reports by Teschler provide no comparable data on snoring epochs.

The subjective parameters can only be interpreted with caution because not all patients filled in the questionnaire after both nights and the differences between the two treatment modes were small. Furthermore, our study does not present any data on long-term use. However, preliminary results from studies on the long-term treatment with the system showed that most patients preferred $APAP_{FOT}$ for home therapy [29]. The reduction in the mean treatment pressure with $APAP_{FOT}$ and its more flexible response to higher pressure requirements as compared to constant CPAP may be a reason for this preference.

4.3. Methodological problems and open questions

At the present time, a number of questions still remain unanswered with regard to the algorithm of the $APAP_{FOT}$ system. If the patients fall asleep during the reference period obstructive events might disturb respiration. Therefore, the reference could be defined incorrect. Furthermore the detection of, and reaction to, leakages need to be discussed. In the event of a leakage, the impedance decreases to values below the reference, since the airway resistance is abruptly reduced. The device cannot unequivocally differentiate this from a central apnea, although in most cases of the former the impedance is reduced to zero, and most cases of the latter are associated with minimal variations in the impedance signal caused by intrathoracic pressure fluctuations (cardiac actions). In both cases, however, the CPAP generator aims to keep the pressure constant, provided that the leakage is not too large to be compensated for. As described by Badia et al. in a recent study using a different system the measurement of the airflow would be necessary both to define leakages accurately and to measure the impedance in absolute figures [30]. Furthermore, Badia et al. addressed the problem of the obstruction of the nasal airway in periods of mouth leakage. This leads to increases of the impedance value which cannot be

differentiated from pharyngeal obstructions. Although these nasal obstructions may result in increases of the treatment pressure the mean pressure with $APAP_{FOT}$ could be reduced substantially as compared to the manually titrated pressure in our present and other studies with $APAP_{FOT}$ [17,18,29].

Measurement of impedance makes it possible to differentiate between central apneas with open and occluded upper airways, the latter giving rise to a higher impedance value with no respiratory fluctuations [11]. Closed central apnea had been described in an invasive experiment by Badr et al. [20]. $APAP_{FOT}$ interprets a central apnea to be present only when the impedance signal decreases to the reference level, with the result that closed central apneas are evaluated as obstructions and elicit a pressure increase response. In the case of our investigations, these problem were not found to have any clinical relevance.

5. Conclusions

Self-adjusting CPAP treatment on the basis of the forced oscillation technique ($APAP_{FOT}$) permitted normalization of the respiratory and sleep parameters in patients with OSAS. For all the parameters investigated, $APAP_{FOT}$ was at least equally as good as treatment employing constant CPAP pressure. This effect was achieved with a significantly reduced mean treatment pressure. The postulated disturbance of the patient by the variations in pressure under treatment was not observed. It may be concluded that the system represents a satisfactory implementation of the forced oscillation technique for automated CPAP treatment, and is suitable for use in long-term studies on compliance.

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