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ORIGINAL ARTICLE

# Obstructive pressure peak: a new method for differentiation of obstructive and central apneas under auto-CPAP therapy

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**Abstract**
*Purpose* Auto-CPAP devices (APAP) are controlled, e.g., by the respiratory flow and pressure to adjust the treatment pressure to the variable obstruction in sleep apnea syndromes. By obstruction of the upper airway during inspiration, a pressure difference between the lower airways and the mask can be measured. In case of an opening of the pharynx at the end of the obstruction, the pressure decreases immediately. This brief negative pressure, the so-called obstructive pressure peak (OPP) can be used to identify obstruction or open airways with the algorithm of an APAP device. Useless pressure increases, e.g., after central apneas without obstruction may be avoided. We therefore investigated the association of the OPP signal with respiratory events during APAP therapy.
*Methods* In this pilot study, 13 patients with obstructive sleep apnea syndrome were evaluated. Attended automatic CPAP titration (SOMNObalance, Fa Weinmann Hamburg/Germany) was performed. The OPP signal was recorded synchronously in parallel with the polysomnographic data. If the OPP signal was within a time range of ±5 s of the resumption of normal breathing, it was assigned to the event.
*Results* A total of 480 sleep-related breathing disorders events were studied. The most common were the mixed apneas associated with more than 90% of all cases with an OPP signal, followed by obstructive sleep apneas (66.7%) and central apneas (38%). The difference in OPP frequency distribution between central apneas and obstructive apneas was significant with $p<0.001$.
*Conclusions* The analysis of the pressure characteristics of APAP treatment with the registration of OPP allows a further differentiation in obstructed and not obstructed upper airways.

**Keywords** Sleep · Apnea · Obstructive · Pressure · Automatic · CPAP

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## Introduction

Auto-CPAP devices (APAP) are used to continuously and timely adjust the pressure corresponding to the patient's therapeutic needs. The experience with APAP devices has shown that the average treatment pressure can be reduced significantly if compared to CPAP [1]. At higher pressures, there may be a higher risk of adverse side effects such as symptoms associated with mask leakages. Comparing CPAP with APAP, most studies document similar compliance [2]. However it was also demonstrated that by this procedure at higher required pressures, the compliance of the patients was improved [3], and many patients report an improvement of subjective sleep quality [4]. The obstructive events are detected by the electronics of the device with various parameters [5]. The algorithms are mostly related to the properties of the flow and pressure signal, measured within the device [6–8]. To avoid the risk to increase the pressure treatment unnecessarily, the differentiation in obstructive and central sleep apnea, for example by forced oscillation technique (FOT) or obstructive pressure peak (OPP), is useful and provides therapeutic benefits [9–11].

*Obstructive pressure peak* The respiratory movement of the diaphragm creates a pressure difference between the lower

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airways and the mask at each inspiration during an obstructive event. In case of sudden opening of the oropharynx at the end of the obstruction, the pressure in the mask, the tube, and device falls rapidly (short negative pressure peak with a duration in the range of 50 ms), but is compensated by the blower of the APAP device. This signal (see Fig. 1) can be used to detect obstruction by the algorithm of the device. At the end of an open apnea, however, this short pressure peak occurring at the resumption of respiration is not observed (see Fig. 2).

We asked therefore how often OPP signals in association with a respiratory event are detected during APAP therapy. The aim of the study was to analyze the basic informations, which can be deduced of the OPP signal.

## Methodology

In this pilot study, 13 patients, including 10 men and 3 women with OSAS, were recruited (age 56.6±12.4 years, BMI 28.5± 4.1 kg/m$^2$). During the first night in the sleep laboratory, a diagnostic polysomnography (PSG) was performed. During the following night with attended titration, we used a new, commercially available automatic CPAP device (SOMNObalance, Fa Weinmann Hamburg/Germany).The algorithm of the APAP device was based on multiple parameters such as the OPP signal, respiratory flow, snoring, and relative minute volume. The sleep stages prior to and during APAP were scored according to the criteria of Rechtschaffen and Kales [12], arousals according to American Sleep Disorders Association criteria [13], and the respiratory events according to the American Academy of Sleep Medicine rules [14]; the results are shown in Table 1. The OPP signal of the APAP device was recorded synchronously in parallel with the polysomnographic data (Alice 4; Heinen & Loewenstein, Bad Ems/Germany) and analyzed manually. First, the respiratory events were scored. From this basis, we analyzed whether an OPP signal could be assigned to these events. The OPP events were only considered if they were preceded by an apnea. The OPP signal was derived from the pressure sensor of the device. The output signal of the device was calibrated so that 0.5 V corresponds to 10 mbar. An OPP signal was only evaluated if the amplitude attained at least 0.05 V corresponding to a pressure of 1 mbar over the baseline (threshold) and if the event could be assigned temporally, i.e., if the OPP signal was within a time window of 5 s prior to or after the resumption of breathing.

The study was approved by the local ethical committee. All patients agreed to the evaluation of the data and gave their written consent. The data were analyzed anonymously.

*Statistics* The anthropometric and polysomnographic data are presented as mean ± standard deviation. The analysis for significant differences in the frequency of the association of the OPP signal with obstructive and central apneas was performed using chi-square test.

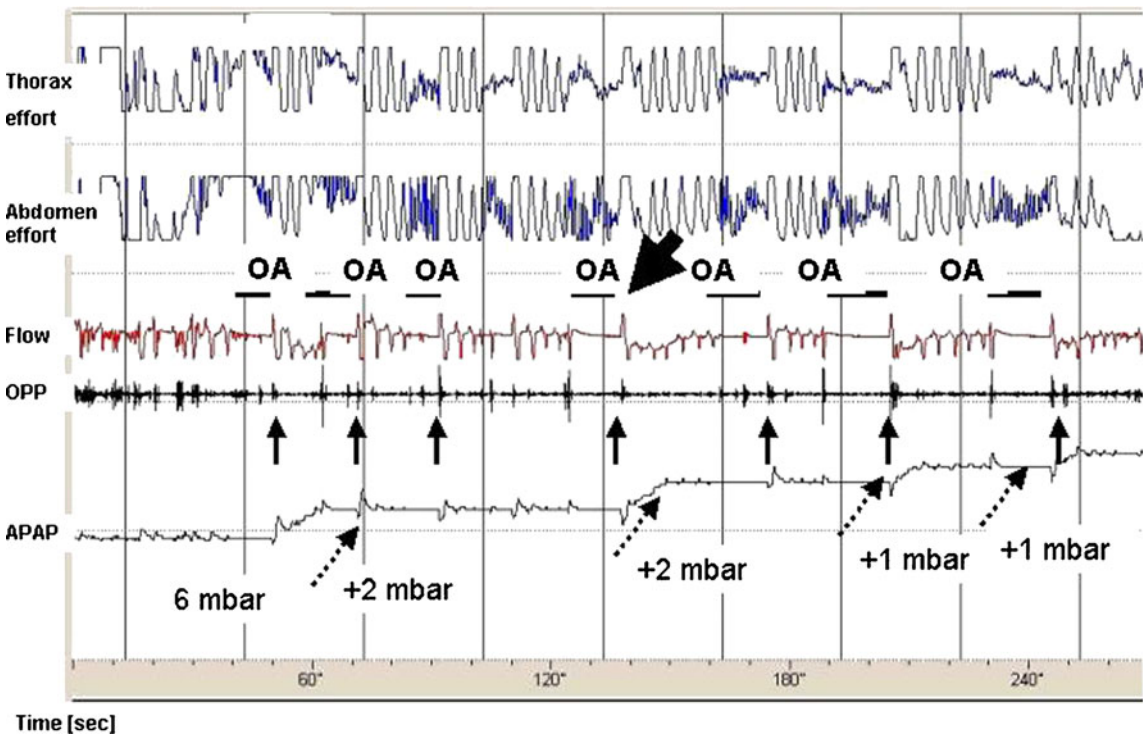


**Fig. 1** Identification of obstructive apneas (*OA*) by obstructive pressure peak (*OPP*, *arrows*) at termination of OA with consecutive pressure increase (*dotted arrows*). The OPP signals were only considered if they were preceded by an apnea

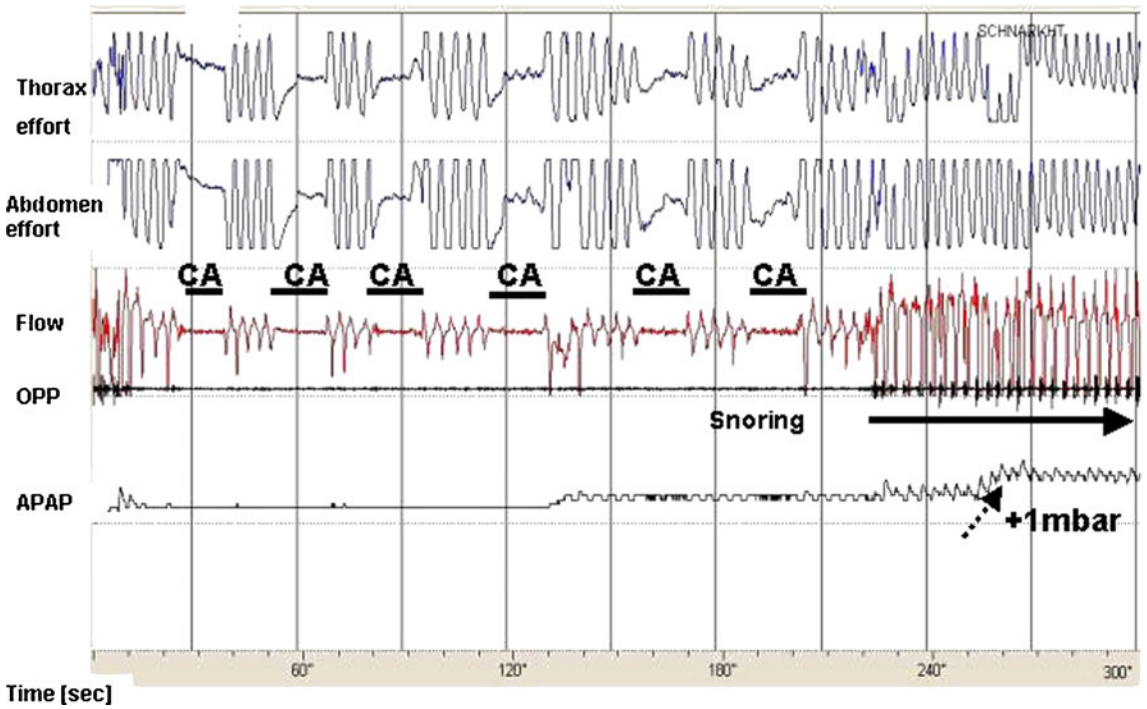


**Fig. 2** Identification of central, not obstructive apneas (*CA*) characterized by the lack of OPP (*arrows*) at termination of CA without consecutive pressure increase. During the last 70 s, OPP signals appear due to snoring (*dotted arrows*)

## Results

During the first night under the APAP treatment, the apnea/hypopnea index was already reduced to <10/h. The remaining 480 events were analyzed for the occurrence of the OPP signal (see Table 2).

Under the APAP treatment, we detected most frequently hypopneas with 69.4% of all respiratory events, which were not further differentiated in the PSG evaluation, followed by central apneas and obstructive apneas with 20.8% and 6.9%.

**Table 1** Polysomnographic data in the diagnosis night and during APAP therapy

| Scoring (Rechtschaffen and Kales) | Baseline | APAP | *p* value, *t* test |
|---|---|---|---|
| AHI (1/h) | 31.4±16.0 | 7.3±8.0 | 0.003 |
| Resp. arousal (1/h) | 21.2±14.1 | 4.7±6.5 | 0.007 |
| $SaO_2$ min (%) | 72.6±18.4 | 86.5±5.6 | 0.001 |
| S1 (% TST) | 19.0±12.6 | 12.5±5.4 | >0.05 |
| S2 (% TST) | 51.9±15.1 | 52.8±17.8 | >0.05 |
| S3/4 (% TST) | 14.9±12.1 | 19.4±15.8 | >0.05 |
| REM (% TST) | 14.3±6.9 | 16.1±8.2 | >0.05 |
| TST (min) | 344.4±32.5 | 294.0±71.8 | 0.011 |
| Sleep efficiency (%) | 89.0±9.0 | 84.5±11.6 | >0.05 |

Significant differences if $p<0.05$ (*t* test)

*AHI* apnea/hypopnea index; *$SaO_2$ min* lowest $O_2$ saturation; *S1*, *S2*, *S3/4* nonREM sleep stages; *TST* total sleep time

Mixed apneas occurred least often with a frequency of 2.9% (see Table 2).

The mixed apneas were associated with an OPP signal in more than 90% of all cases, followed by obstructive apneas (66.7%). OPP events occurred with lesser frequency in connection with central apneas (38%). Obstructive apneas were, as compared with central events, significantly more often associated with an OPP signal (chi-square test, $p<0.001$).

## Discussion

As a result of the proactive treatment effect of the APAP device, most of respiratory disorders were eliminated so we

**Table 2** Association between sleep-disordered breathing and OPP events

| | Respiratory events | OPP events | OPP events (% of respiratory events) |
|---|---|---|---|
| Hypopneas (not differentiated) | 333 | 204 | 61.3 |
| Obstructive apneas | 33 | 22 | 66.7* |
| Mixed apneas | 14 | 13 | 92.9 |
| Central apneas | 100 | 38 | 38.0 |

Obstructive apneas were—compared with central events—significantly more often associated with an OPP signal: 66.7% vs 38.0%

*$p<0.001$ (chi-squared test)

could analyze only a few obstructive and central events. Through analysis of the negative pressure peak (OPP), additional informations from the CPAP pressure behavior for the detection of open and closed apneas are available.

About two thirds of all obstructive events were associated with an OPP signal, but in central apnea an OPP signal in only one third of all cases were found. Thus in combination with other information such as snoring and flow limitation in connection with the event, an algorithm that differentiates between open and closed apneas instead of the FOT signal can be developed. There are a few limitations to this study: We cannot deduce sensitivity and specificity regarding detection of obstruction, since we did not register esophageal pressure.

Only through simultaneous registration a statement would be possible. In particular, if only effort and flow is registered, we cannot differentiate between open and closed central apneas. The piezoelectric signals of the thoracic and abdominal belts in combination with airflow will not provide adequate sensitivity to assess exactly the association between OPP and respiratory event. It could be that we scored an incorrect higher rate of central apneas due to the lower sensitivity of the effort belts compared to the induction plethysmography (RIP).

We found in a substantial percentage an association between central sleep apnea and the occurrence of OPP signals. This could also be explained by fiberoptic findings during central sleep apneas where a narrowing and complete collapse of the pharynx can be observed [15]. In a study of Badia et al. using the FOT method, central sleep apnea events with and without obstruction were also revealed [16]. We suspect, therefore, that central apneas associated with an OPP signal were obstructed (closed) apneas.

Our statement refers only to a threshold value of the OPP signal of >1 mbar in the recording. Other limits or individual adjustment of the threshold value to the patient, as implementable now in the investigated APAP device, have not been studied. The aim of the study was merely to analyze the basic advantages of the OPP signal. A reasonable use might be possible only in combination with other obstruction criteria. Adequate automatic therapy is based on the reliable detection and accurate differentiation of respiratory disorders, taking into account several parameters. Therefore in most APAP devices, different flow-derived signals are used.

In a study on 14 patients, the algorithm of the APAP device based on multiple parameters such as the OPP signal, respiratory flow, snoring, and relative minute volume proved to be effective [17]. However, the implemented algorithms are often not known, and cannot directly be derived from the polysomnographic recordings under APAP therapy.

For accurate comparison of APAP devices, simulators which generate different flow patterns are necessary [18–20]. Such comparative studies would also be desirable to get knowledge about their characteristics to use the APAP devices more specifically. If such comparison studies are conducted, it is necessary to simulate all phenomena (flow, obstruction of the upper airway, snoring, OPP) used by the APAP devices as otherwise the performance of the algorithm would be judged incorrectly.

## Conclusions

The analysis of the pressure behavior with detection and rapid pressure changes (OPP) during APAP therapy expands the diagnostic spectrum to differentiate between obstructed and not obstructed upper airways. In combination with other flow-derived signals, the usage of the OPP signal should increase the reliability of APAP therapy.

**Conflicts of interest** K.H. Rühle and G. Nilius received funding from Weinmann, Fisher & Paykel Healthcare, Heinen and Löwenstein, ResMed, and TNI. This money went to scientific projects of the clinic, including methodology in this work.

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