Autotitrating CPAP as a Tool for CPAP Initiation for Children

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Study Objectives: Few studies have assessed autotitrating positive airway pressure (autoPAP) for treatment of obstructive sleep apnea (OSA) in children. We aimed to review our use of autoPAP for initiation of continuous positive airway pressure (CPAP) therapy in children, and compare autoPAP-derived treatment pressures to CPAP treatment pressure determined by attended polysomnography (PSG).

Methods: Retrospective review of children initiated on autoPAP from 2013 to 2015. Mean autoPAP pressure (AutoMean pressure) and average device pressure ≤ 90% of time (Auto90 pressure) were taken from downloaded data and compared to the recommended treatment pressure following titration PSG (PSG pressure).

Results: Fifty-two children started CPAP, of whom 26 (age ± standard deviation 11.9 ± 3.4 years) used autoPAP and had titration PSG. AutoPAP was used on average 84% of nights (standard deviation 20%) in the first month, with a mean ± standard deviation 6.3 ± 2.0 hours of use on nights used. The median (interquartile range) obstructive apnea-hypopnea index decreased from 16.6 (11, 35) events/h before treatment to 2.2 (0.4, 3.8) events/h on the titration PSG. Median (interquartile range) PSG pressure was 9.0 cm H₂O (7.0, 10.0), AutoMean pressure was 6.3 cm H₂O (5.3, 7.5), and Auto90 pressure was 8.1 cm H₂O (7.1, 9.5). These were significantly different (P < .001), with the significant difference lying between AutoMean and the other two pressures. PSG pressure was greater than or equal to the AutoMean pressure in all cases, and greater than or equal to the Auto90 pressure in 20 out of 26 cases (77%).

Conclusions: AutoPAP is a safe and effective means of initiating CPAP in children. AutoMean and Auto90 pressures are usually below treatment pressure determined by titration PSG.

Keywords: autoPAP, compliance, obstructive sleep apnea, pediatrics


INTRODUCTION

Obstructive sleep apnea (OSA) is a common condition of childhood, affecting approximately 4% of otherwise healthy children. Most children with OSA are successfully treated with adenotonsillectomy, but a small number of children, particularly those with comorbid conditions such as obesity or Down syndrome, are at increased risk of OSA persisting after adenotonsillectomy. Many of these children are candidates for treatment with continuous positive airway pressure (CPAP) delivered noninvasively in the home using a facial mask. CPAP using a single pressure derived from manual titration in an attended sleep laboratory setting has been demonstrated as a safe and successful treatment of OSA in even very young children and infants, and the use of this therapy in children is increasing.

In more recent years, newer CPAP technologies have been developed to help improve compliance and efficacy of treatment. Autotitrating CPAP, or autoPAP, provides variable pressure delivery by constantly monitoring the patient’s airflow overnight using algorithms developed by each device company. This potentially results in different pressures being delivered during different sleeping conditions, such as rapid eye movement (REM) and non-rapid eye movement sleep, and supine and nonsupine sleeping positions, in response to differing degrees of upper airway obstruction in these states. AutoPAP for the treatment of OSA has been well documented and widely used in the adult population, particularly as a therapeutic option in the initiation phase of therapy. However, the majority of studies fail to demonstrate a clinically significant improvement in compliance and quality of life outcomes compared to fixed-pressure CPAP.

To date there have been few studies of autoPAP use in children. A study conducted by Palombini and colleagues in 2004 investigated a single treatment night of autoPAP in 14 children aged 8 months to 18 years in an attended setting. All patients tolerated the autoPAP throughout the night with no adverse effects reported. AutoPAP lead to resolution of OSA in 8 children, with 6 still demonstrating mild to moderate OSA, which the authors attributed to mask leak. A study by Marshall...
et al. in 2009 investigated the use of autoPAP in the home for 6 weeks in 12 children with sickle-cell anemia. Improvements in sleep-disordered breathing were documented between baseline and titration PSG, and no adverse effects were reported by children using the autoPAP at home. Neither of these studies compared the autoPAP pressure to the gold standard manually titrated pressure, utilizing experienced sleep technologists.

Over time, we have developed a successful program for home initiation of CPAP, whereby children and parents have an education session and mask fitting during the day, and are then sent home to begin treatment, supported by phone and face-to-face contact with sleep laboratory staff. We have shown that a key factor in adherence to CPAP treatment is establishing the correct treatment pressure for each child early in therapy, to avoid long periods of subtherapeutic treatment.

Therefore, we aimed to determine whether autoPAP was tolerated by CPAP-naïve children in an unattended setting, and examine which pressure parameters on the autoPAP compliance download data would be useful in optimizing therapy and the manual titration study using fixed pressure CPAP in a pediatric population.

**METHODS**

This study is a retrospective review of a convenience sample of all children who were initiated on autoPAP at the Melbourne Children's Sleep Centre between January 2013 and December 2015. We prospectively collected demographic and treatment details for all children undergoing CPAP initiation in our center over those 3 years. Parents gave consent for their child's data to be included in this study. The study was approved as a Quality Assurance Activity by the Monash Health Human Research Ethics Committee.

**CPAP Treatment**

Patients were selected to start on fixed-pressure CPAP or autoPAP by their referring physician and/or the noninvasive ventilation medical director. Formal inclusion criteria were not applied, but in general, infants and younger patients (younger than 5 years), those with medical conditions affecting the anatomy of the upper airway, and patients living in situations that may limit close follow-up (eg, remoteness, out-of-home care) were not thought to be candidates for autoPAP during this trial period (further details are given in the subsequent paragraphs). All patients starting autoPAP were treated with the RemStar Auto (Philips Respironics Inc, Murrysville, Pennsylvania, United States). The upper and lower pressure of the device was determined by the referring physician, based on the patient’s age and medical conditions.

The initial CPAP education involves a 1.5- to 2-hour out-patient session for both children and parents in the Melbourne Children's Sleep Centre during the daytime. During this session the families are provided with a CPAP information pack containing written material and a locally developed DVD that explains OSA and the principles of CPAP treatment. Mask fitting is completed by an experienced clinical nurse educator, with a range of masks (including nasal and full face masks) tested for every patient. The patient is given the final choice between masks that fit well, with the aim of optimizing acceptability and comfort. In all but one patient in this study, patients elected to take home only a nasal or only a full face mask, with the remaining patient taking one of each but subsequently found to prefer the full face mask. Therefore, titration polysomnography (PSG) was performed using the mask type usually used at home.

Families are shown how to fit the mask and use the machine, including care and maintenance of the equipment and ramp function if used. Families take all equipment home to start nocturnal CPAP. During the acclimatization period, families are supported with frequent phone calls from our experienced noninvasive ventilation staff (initially twice per week and then weekly for 2 to 4 weeks), with further face-to-face contact if required (for example, for repeat mask fitting or to troubleshoot poor adherence to treatment). After parents are reporting CPAP use of at least 1 to 2 hours a night, overnight in-laboratory PSG is arranged for manual CPAP titration.

After the titration PSG, families were required to purchase their CPAP machine for ongoing treatment. For cost reasons, most transitioned to fixed-pressure CPAP at this stage.

**Downloaded AutoPAP Data**

AutoPAP machines were downloaded using EncorePro Basic (Philips Respironics Inc, Murrysville, Pennsylvania, United States) each time the patient visited the sleep center. Two pressure parameters were taken from the standard report, including “auto CPAP mean pressure,” (the mean pressure across the session time, hereafter referred to as AutoMean pressure) and “average device pressure ≤ 90% of time,” (the pressure at which the device spent 90% of the session time at or below pressure, hereafter referred to as Auto90 pressure). The patient’s adherence data (percent days with device usage, and average usage for days used) were also downloaded for the acclimatization period (from the day of the initial education to the night prior to titration PSG in the laboratory). Subsequently, adherence data were downloaded for the first 30 days after the patient had been transferred to therapeutic fixed-pressure CPAP, with optimal pressure prescribed by the referring physician based on the CPAP titration PSG (referred to as the PSG pressure).

**Polysomnographic Studies**

All children underwent routine attended overnight PSG performed in the sleep laboratory, both for diagnosis of OSA and for titration of CPAP. The following parameters were measured using a commercially available PSG system (Grael system, Compumedics, Melbourne, Australia): electroencephalograms (central, frontal, and occipital), left and right electrooculograms, mental-submental and left and right tibial electromyogram, continuous electrocardiogram, body position, airflow (both nasal pressure and oronasal thermistor for diagnostic studies and mask pressure with the use of a pressure transducer for CPAP titration studies), and respiratory effort (uncalibrated respiratory inductance plethysmography using z-RIP belts, Pro-Tech Services Inc., Mukilteo, Washington, United States). Oxygen saturation was measured by pulse oximetry (Masimo Corporation, Irvine, California, United States) and
transcutaneous carbon dioxide (TCM4, Radiometer, Copenhagen, Denmark). Sleep technologists experienced with children performed the PSG and monitored the patients from an adjacent room via infrared camera. Parents were required to remain for the entire duration of the sleep study.

CPAP was manually titrated by an experienced sleep technologist using the Fisher & Paykel HC600 device with remote (Fisher & Paykel, Auckland, New Zealand). Starting pressure ranged from 4 cm H2O to the mean CPAP pressure from the autoPAP download (as instructed by the referring physician on the sleep request). Pressure titration followed the American Academy of Sleep Medicine (AASM) clinical guidelines for children younger than 12 years,9 with the goal of eliminating all obstructive apneas and hypopneas and minimizing respiratory event-related arousals and snoring.

Scoring Criteria

All polysomnograms were scored by sleep technologists trained in pediatric sleep scoring. Sleep studies were scored following AASM criteria.10 The obstructive apnea-hypopnea index comprised obstructive apneas, hypopneas, and respiratory event-related arousals. The need for treatment with CPAP was determined by the referring physician, taking into account the PSG result, symptoms, and clinical history/examination.

Respiratory events were scored using a pressure line that connected the pressure transducer as close to the mask as possible.9 The optimal CPAP pressure was determined by the referring sleep physician based on the CPAP titration PSG.

Statistical Analysis

Data were analyzed using Stata 10.0 (Stata Corporation, Irvine, California, United States). Normally distributed data are presented descriptively using mean ± standard deviation, and compared using Student t tests. Nonparametric data are described using median (interquartile range) and compared using the Wilcoxon matched-pairs signed-rank test. Because the pressure was not normally distributed, AutoMean, Auto90, and PSG pressures were compared using Friedman repeated-measures analysis of variance on ranks with the Tukey test for pairwise multiple comparisons between pairs of pressures. Bland-Altman plots are used to demonstrate the relationship between pairs of pressures across the range of pressures used. Linear regression was used to examine the relationship between the average pressure and the difference between pressures, and also between age and pressure difference.

RESULTS

A total of 52 children were started on CPAP during the study period, with 34 initiated on autoPAP. The other 18 children were started on fixed pressure CPAP as per provider preference, noting that 8 were younger than 5 years, 7 had an anatomically abnormal upper airway (eg, achondroplasia, Goldenhar syndrome, lymphangioma), and 3 lived in a home situation thought to potentially limit close follow-up. Eight children who underwent autoPAP education did not continue with treatment: six because of patient refusal, and two because of intervention with alternative treatments. Twenty-six children started autoPAP (20 male; mean age at commencement of CPAP 11.9 ± 3.4 years) and progressed to a manual CPAP titration PSG to determine optimal CPAP pressure. Of these, 11 (42%) were obese (body mass index z-score above 2.0) and 17 (65%) had another significant comorbidity other than or in addition to obesity (7 with Down syndrome, 5 with other congenital abnormalities, 2 with attention deficit hyperactivity disorder, and 3 with various other comorbidities). Thirteen children (50%) had undergone surgery for OSA (7 adenotonsillectomy, 2 lingual tonsillectomy, 1 mandibular distraction and 3 adenoidectomy ± tonsillectomy with coblation tongue channeling). All children had OSA at baseline, and all were successfully treated with CPAP as demonstrated on attended PSG (Table 1).

AutoPAP was used at home prior to the manual CPAP titration PSG for a median of 42.5 days (range 11, 262). Nineteen patients (73%) used an oronasal mask and the remainder used a nasal mask. Upper and lower pressure limits were individually selected by the treating physician. The lower pressure was usually 4 cm H2O (range 4–6 cm H2O) except for older teenagers and the very obese, where the pressure was 5 or 6 cm H2O. The upper pressure ranged from 8 to 20 cm H2O, with higher values again used for older children and obese patients (Figure 1). AutoPAP was used on average 84% of nights (standard deviation 20%) in the first month, with mean 6.3 ± 2.0 hours of use on nights used. Sixteen children (61%) used CPAP on more than 90% of nights. When compared to a historical cohort,8 hours of use per night used was not

### Table 1—PSG results at baseline and on manual titration PSG.

<table>
<thead>
<tr>
<th>Participant Characteristics</th>
<th>Diagnostic PSG</th>
<th>Titation PSG</th>
<th>P Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (y)</td>
<td>11.5 ± 3.4</td>
<td>12.1 ± 3.4</td>
<td>&lt; .001</td>
</tr>
<tr>
<td>RDI (events/h)</td>
<td>19.1 (11.8, 35)</td>
<td>3.4 (2, 5.6)</td>
<td>&lt; .001</td>
</tr>
<tr>
<td>SpO2 nadir (%)</td>
<td>86 (75, 90)</td>
<td>92.5 (90, 94)</td>
<td>&lt; .001</td>
</tr>
<tr>
<td>OAHI (events/h)</td>
<td>16.6 (11, 35)</td>
<td>12.0 (11.2, 14)</td>
<td>&lt; .001</td>
</tr>
<tr>
<td>CnAHI (events/h)</td>
<td>1.2 (0.3, 2.3)</td>
<td>0.8 (0.4, 1.2)</td>
<td>.04</td>
</tr>
<tr>
<td>Arousal index (events/h)</td>
<td>21.3 ± 7.4</td>
<td>12.0 (11.2, 14)</td>
<td>&lt; .001</td>
</tr>
<tr>
<td>SpO2 nadir (%)</td>
<td>86 (75, 90)</td>
<td>92.5 (90, 94)</td>
<td>&lt; .001</td>
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</table>

Note that as CPAP pressure is being titrated in the titration PSG, obstructive events may be present at lower pressures (and thus the overall obstructive apnea-hypopnea index may not be zero). CnAHI = central apnea-hypopnea index, CPAP = continuous positive airway pressure, OAHI = obstructive apnea-hypopnea index, PSG = polysomnography, RDI = respiratory disturbance index, SpO2 = oxygen saturation.
R Mihai, M Vandeleur, S Pecoraro, et al. AutoPAP in Children

significantly different (6.3 ± 2.0 h/night compared to previous results of 5.6 ± 2.5 h/night, \( P = .26 \)). The number of children using CPAP more than 90% of the time was 61% compared to 37% previously (\( P = .06 \)).

There was a significant improvement in all respiratory parameters on titration PSG (Table 1). OSA was resolved by CPAP at the optimal pressure in all but 1 patient who still had frequent obstructive events at the maximum pressure of 14 cm H\(_2\)O that was reached on the night of manual titration. This patient later had surgery for removal of lingual tonsils. Nineteen of 26 patients experienced REM sleep in the supine position recorded at the optimum pressure, with staff repositioning the patient when possible to achieve this.

Median (interquartile range) AutoMean pressure was 6.3 cm H\(_2\)O (5.3, 7.5), Auto90 pressure was 8.1 cm H\(_2\)O (7.1, 9.5), and PSG pressure was 9.0 cm H\(_2\)O (7.0, 10.0) (Table 2). These findings were significantly different (\( P < .001 \)). Pairwise testing showed a significant difference between AutoMean pressure and each of the other pressures, with no statistical difference between Auto90 and PSG pressure (\( P = .6 \)). As the average of the PSG pressure and the AutoMean pressures increased, the difference between the two increased (\( r^2 = 0.36, P = .001 \)) as shown in Figure 3. This pattern was less strong but still present for the Auto90 pressure (\( r^2 = 0.18, P = .03 \)). Interface type (nasal versus full face mask) did not affect the difference between PSG pressure and AutoMean pressure (\( P = .2 \)) or between PSG pressure and Auto90 pressure (\( P = .2 \)). Age was also not related to the difference between PSG pressure and Auto90 pressure (\( r^2 < 0.001, P = .9 \)).

The patient with the largest difference was subsequently found to have an enlarged lingual tonsil.

Twenty-one children transitioned to fixed-pressure CPAP following their titration PSG. The adherence to CPAP was not significantly different when the first month on autoPAP was compared to the first month on fixed-pressure CPAP: (CPAP use on average 84% of nights (standard deviation 20%) for autoPAP versus 74% (standard deviation 30%) for fixed pressure (\( P = .14 \); hours of use per night was 6.3 ± 2.0 hours for autoPAP versus 6.3 ± 2.7 hours for fixed pressure (\( P = .99 \)).

**DISCUSSION**

We have determined that autoPAP is a safe and effective way of quickly reaching close to therapeutic CPAP pressure.

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**Table 2—CPAP pressures derived from manual titration polysomnography and autoPAP downloaded data.**

<table>
<thead>
<tr>
<th></th>
<th>AutoMean pressure</th>
<th>Auto90 pressure</th>
<th>PSG pressure</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pressure (cm H(_2)O), median, IQR</td>
<td>6.3 (5.3, 7.5)</td>
<td>8.1 (7.1, 9.5)</td>
<td>9.0 (7.0, 10.0)</td>
</tr>
<tr>
<td>Difference from PSG pressure (cm H(_2)O), median, IQR</td>
<td>2.6 (~1.4, 3.7)</td>
<td>0.7 (~0, 1.8)</td>
<td>~</td>
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</tbody>
</table>

Auto90 pressure = average device pressure ≤ 90% of time, AutoMean pressure = mean autoPAP pressure, autoPAP = autotitrating positive airway pressure, IQR = interquartile range, PSG pressure = pressure determined by attended polysomnography.
during home initiation of CPAP treatment in children. This finding is consistent with previous findings in adults and the AASM practice parameters from 2007, although the AutoMean was on average 2.6 cm H2O below the treatment pressure recommended following a manual CPAP titration PSG (PSG pressure), the Auto90 was on average within 1 cm H2O of the recommended treatment pressure derived from manual titration (PSG pressure). This suggests that at home, the autoPAP algorithm is increasing pressure to an appropriate degree in response to obstructive events occurring for at least part of the night (eg, in REM sleep and/or the supine position) and returning to lower levels at other times. In this way, CPAP pressure that is very close to the pressure required to alleviate OSA is being reached from the first night of treatment at home.

We have previously published our clinic’s data on CPAP adherence. That study demonstrated that the difference in pressure between the initial starting treatment pressure (an arbitrary low pressure) and that derived at the time of titration PSG was a key determinant of early adherence to CPAP treatment. We hypothesized that the reason for this might be that subtherapeutic CPAP may be uncomfortable, or at least not result in the desired therapeutic effect (ie, alleviate symptoms), which may result in poor adherence. In the current study the average hours of use on nights used was 6.3 ± 2.0 hours, which is not statistically different from adherence in our previous group. The number of children using CPAP more than 90% of nights increased from 37% in our previous cohort to 61% in the current study (P = .06). Although the numbers are small, these results suggest that autoPAP use during the initiation process at least does not reduce adherence, and may contribute to improved adherence. We were concerned at the start of this study that patients, having become used to autoPAP, may find fixed-pressure CPAP difficult to tolerate when they were transitioned to fixed-pressure treatment at a later stage for reasons related to the cost of treatment. Anecdotally this was the case in two patients, but overall, there was no significant dropoff in adherence after the switch to fixed-pressure CPAP in this study.

The findings of our study do not necessarily support the abandonment of PSG to manually titrate CPAP. We have not specifically studied the treatment outcomes in terms of symptom resolution of our patient group. The larger difference in manually derived (PSG pressure) and the Auto90 pressure for some individual patients suggests that a manual CPAP titration study remains the best way of determining appropriate pressure for fixed-pressure CPAP. These patients could not be predicted by age or mask type, although the one with the largest difference was subsequently found to have a lingual tonsil, which may have been the explanation for the failure of CPAP to resolve that patient’s OSA. We have not tested PSG on autoPAP to determine adequacy of treatment, which would be an important focus of future studies before eliminating the need for a manual titration PSG can be recommended. Where standard manual titration PSG is used, our data support starting at the mean CPAP pressure derived from download of the autoPAP machine rather than 4 cm H2O as per the AASM recommendations, given that the mean download pressure was always below the manually derived recommended treatment pressure. This may save time during the titration PSG, optimizing the time available to determine the best treatment pressure. It should be considered, however, that autoPAP studies over several nights or longer periods in the home have the potential to assess the function of CPAP in a natural environment, with better sleep quality.

Figure 3—Bland-Altman plots.

Comparing (A) PSG pressure to AutoMean pressure; and (B) PSG pressure to Auto90 pressure. As the average of the two pressures increases, the difference between the two increases: \( r^2 = 0.36 \) for PSG pressure versus AutoMean pressure (\( P = .001 \)) and \( r^2 = 0.18 \) for PSG pressure vs Auto90 pressure (\( P = .03 \)). AutoMean pressure = mean autoPAP pressure, Auto90 pressure = average device pressure ≤ 90% of time, PSG pressure = pressure determined by attended polysomnography, SD = standard deviation.
and natural body positioning over several nights rather than 1 night while undergoing PSG.

Previous studies of autoPAP use in children have also supported the judicious use of the technology. The first, by Palombini and colleagues in 2004, investigated a single treatment night of autoPAP in 14 children aged 8 months to 18 years in an attended setting. Palombini and colleagues used a different autoPAP device (ResMed AutoSet-T, ResMed, Sydney, Australia) than the one used in the present study, and a standard pressure range of 4 to 15 cm H2O. They described a respiratory disturbance index (comparable to our obstructive apnea-hypopnea index based on their description of scoring methods) of 2.6 ± 2.7 events/h, the same as our result on the titration study of 2.8 ± 2.6 events/h. They reported persistence of some respiratory events, and imply that this is a failure of autoPAP to completely resolve events (attributed to leak). We would contend, however, that no device, whether controlled manually or according to an algorithm, could be expected to totally eliminate events during a titration study, given that the presence of breakthrough events and/or upper airway resistance is what triggers an increase in CPAP pressure over the study. The goal is resolution of OSA by the end of the night, but some events are inevitable even on a perfect titration PSG. We agree with their conclusion that autoPAP is effective and well tolerated in children. Another study of autoPAP investigated the use of autoPAP in the home for 6 weeks in 12 children with sickle-cell anemia, which again found that autoPAP was effective and well tolerated. Neither of these studies compared the autoPAP pressures to the gold standard manually titrated pressure utilizing experienced sleep technologists, and so our current study contributes to knowledge of the role of autoPAP in current pediatric practice.

A strength of our study is that we used a single device for all children. Different devices use different proprietary algorithms to adjust pressure, and the performance of one device should not be assumed to be equivalent to that of another. This limits the generalizability of our study to other autotitrating CPAP devices, which would need to be tested separately. As is common in many pediatric CPAP studies, our numbers are relatively low and the patient group heterogeneous. In addition, our patient group was selected based on provider preference and did not include all children commencing CPAP treatment. Staff performing manual titration and reporting the PSG on CPAP were also not blinded to the downloaded autoPAP data. Multicenter collaborative studies are needed to boost numbers, increase generalizability, and examine subsets of patient populations.

In summary, in 26 children aged 4.5 to 18 years, autoPAP was well tolerated and effective when used at home from the time of CPAP initiation. The 90th centile pressure derived from download of the autoPAP device was on average less than 1 cm H2O different from the pressure recommended following manual titration PSG, and for most children this is likely to result in satisfactory treatment of OSA from the first day of therapy. Manual CPAP titration remains the gold standard for establishment of treatment adequacy and fixed CPAP pressure prescription, but the use of autoPAP while waiting for such a test optimizes CPAP therapy over that period.

**ABBREVIATIONS**

AASM, American Academy of Sleep Medicine  
Auto90 pressure, average autotitrating continuous positive airway pressure device pressure ≤ 90% of time  
AutoMean pressure, autotitrating continuous positive airway pressure mean pressure  
autoPAP, autotitrating continuous positive airway pressure  
CnAHI, central apnea-hypopnea index  
CPAP, continuous positive airway pressure  
OAHI, obstructive apnea-hypopnea index  
OSA, obstructive sleep apnea  
PSG, polysomnography  
RDI, respiratory disturbance index  
REM, rapid eye movement  
SpO2, oxygen saturation

**REFERENCES**
