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Auto-adjusting CPAP Titrations at Home and Correlation between an Automatic Algorithm and the Hoffstein Formula

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Abstract

Introduction: Continuous positive airway pressure (CPAP) has proven to be effective in the treatment of obstructive sleep apnea/hypopnea syndrome (OSAHS). Effective pressure is traditionally acquired with a polysomnography (PSG). The performance of unconventional strategies, such as auto-adjusting positive airway pressure (APAP) and titration formulas (T_f) varies according to the population where they are applied.

Objective: To describe the APAP titration and correlate the mean airway pressure ($Mean_p$), the Eff_p and the Hoffstein and Mateika T_f pressure ($Hoff_f$).

Results: We included 192 patients, 52 female (27%) and 140 male; age, 60.2 years old ± 11.7 and BMI (body mass index) of 33.8 ± 6.7 kg/m^2. The apnea-hypopnea index (AHI) was: 33.1 ± 16.6 in females and 36.5 ± 16 in males ($p > 0.24$); and 190 cases (98.9%) had an AHI > 15 ev/hour. Mean compliance with APAP was: 380 minutes ± 101 in females and 370 ± 91.2 in males ($p > 0.54$). Less than 10% of the population presented unacceptability criteria.

We found a correlation between the $Mean_p$ and the Eff_p; *rho*: 0.73 (95% CI [confidence interval] 0.57-0.84) $p < 0.001$. However, between the Eff_p and the $Hoff_f$ β: 0.519 and r^2: 0.269 ($p < 0.001$) there was an underestimation by $Hoff_f$: - 1.98 cm H_2O (95% CI, 1.48-2.49) and intraclass correlation index: 0.60 (95% CI: 0.47-0.80) $p < 0.0001$.

Conclusions: A high proportion of patients titrate at home with APAP without supervision and with acceptability criteria. We did not find a suitable correlation between the $Hoff_f$ and the Eff_p in our population.

Key words: titration, CPAP, Hoffstein and Mateika

Introduction

The obstructive sleep apnea/hypopnea syndrome (OSAHS) is a clinical condition characterized by recurrent episodes of upper airway obstruction during sleep. The evidence gathered up to now demonstrates that the OSAHS without a suitable treatment is associated with arterial hypertension, stroke, deterioration in quality of life, traffic accidents and a higher risk of dying due to cardiovascular events[1-5]. Continuous positive airway pressure (CPAP) has proven to be the most effective treatment modality, since it corrects obstructive events during sleep and intermittent hypoxemia, and improves the sleep structure and quality of life of the affected individuals[6-8].

Once the OSAHS diagnosis has been established by means of polysomnography (PSG) or respiratory polygraphy (RP), if the patient complies with the criteria to use the CPAP, some method shall be used to define the pressure values to be set in the equipment that will be used by the patient at home (titration procedure).

The effective pressure is traditionally acquired with a second nocturnal PSG[7-11] or during the same night in which the diagnosis is established with the known split-night PSG[12-14].

The proposal to use auto-adjusting or automatic CPAP equipment (APAP) as an unconventional titration method comes from centers with a great demand of sleep studies and long waiting lists. Though the auto-adjusting equipment was not originally designed to this end, the method has spread thanks to its capacity to register in its memory working pressure variations throughout the night in response to airway obstruction phenomena, making it possible to analyze the behavior of that variable according to the requirements of the patient during sleep.

APAP titration can be used at the patient´s home for several nights, thus increasing the range of registered data, making it possible to observe variations night after night, and reducing the waiting list and operational costs of the conventional titration procedure[15-19].

The last update of the American Academy of Sleep Medicine (AASM) recommendations considers the APAP titration as a valid option for patients with no significant comorbidities, but it recommends manual data analysis by experienced personnel[20]. The practical guidelines of the Argentinian Association of Respiratory Medicine (AAMR, by its acronym in Spanish) acknowledge the usefulness of this procedure to titrate the pressure level at the sleep lab or "during one or several nights at the patient´s home with no supervision or additional monitoring"[21].

There are remarkable differences among the different algorithms validated and proposed by the manufacturers of different equipment brands, so it is necessary to use the algorithms that have been compared with conventional titration PSG[20-21].

On the other hand, experience with predictive titration formulas (T_f) based on anthropometric or clinical parameters varies according to the population where it is applied[22]. Since there are no validations of a T_f in our country, we recommended the correlation of pressures suggested by the algorithm of an APAP model in relation to predictive formulas and to the final recommendation of effective pressure (Eff_p).

Objective

To describe our experience with APAP titration in patients with OSAHS who have no experience in the use of CPAP, and to establish the relationship between the airway mean pressure ($Mean_p$) calculated by the APAP, the Eff_p defined by experts, and pressures calculated by the Hoffstein and Mateika titration formula[22] ($Hoff_f$).

Study Design

Prospective, correlational study at a single center.

Materials and Methods

Population

Prospective study based on home APAP titrations of systematic collection made between August, 2015 and August, 2016 (one year) in patients with OSAHS referred to the Sleep Unit for interface demonstration and unsupervised home titration. We only considered the records of patients with no previous experience in the use of the device. The authors did not participate in the indication of the CPAP, which was made by the respective attending pulmonologists.

Patients diagnosed with obesity hypoventilation syndrome, periodic breathing or central apneas on the baseline study and those who required other treatment modalities (ventilation with two pressure levels, servo-controlled ventilation, concomitant oxygen use) were not included in the study.

The baseline apnea-hypopnea index (AHI) was obtained from the PSG or RP records and anthropometric parameters; the body mass index (BMI) and neck circumference (N_{circ}) were calculated before delivery of the CPAP device.

Auto-adjusting CPAP titration

The mask type, size and model were selected after an interface demonstration carried out by physiotherapists with experience in sleep medicine. The final selection of the mask depended on the patient´s preferences and the leakage test with the APAP equipment after a ≈ 30 minutes test. Every patient received basic instructions regarding the operation of the CPAP device together with their partner or roommate. The patients were also invited to participate in the educational program called "CPAP school".

System One (Philips-Respironics) auto-adjusting devices were used. Unlike the conventional CPAP, which operates with a positive pressure fixed value, this algorithm automatically modifies

pressures with a built-in flow sensor and adjusts working pressure according to the presence of apneas, limitation to inspiratory flow and snoring until a normal breathing pattern is allowed[23]. The minimum pressure was set to 4 cm of H_2O and the maximum pressure to 15 cm of H_2O. No ramp features, expiratory pressure relief or thermohumidifiers were used.

The titration period coincided with the current processes of the Sleep Unit (3 to 7 days), depending on the appointment and device availability.

Titration data were obtained after downloading the information from the CPAP memory (*SD card*) with the Encore pro II Philips-Respironics software.

The effective pressure data were obtained after the subjective visual analysis of the pressure/time curve night after night made by physicians and physiotherapists with experience in sleep medicine, excluding leakage periods of more than 25 liters/minute (compensation limit of the equipment). The resulting final effective pressure was selected taking into account the nights with greater use and less leakages.

> 6500 hours of APAP use recording were analysed. Compliance, mean leakage and residual apnea-hypopnea index (rAHI) data were gathered. Minimum compliance (Min_c) was defined as the use of at least 4 hours per night, taking into account the total number of nights with effective use of CPAP, and optimum titration (OPT_t) was defined as that with rAHI < 5 events per hour (ev/hour) and minimum compliance. When the rAHI was between 5 and 10 ev/hour, the titration was considered as acceptable. Finally, the titration was considered inadequate ($Inad_t$) when there was a rAHI of more than 10 ev/hour, with a compliance of < 4/hours per night, or when there were leakages above the compensation limit > 50% of the nights.

The data of the EFF_p reading made by experts in relation to the automatic data of the APAP ($Mean_p$ of the first day, $Mean_p$ of every day) were compared with the pressure previously stated by the $Hoff_f$ [(22)], namely: (0.16 x BMI + 0.13 x N_{circ} in centimeters + 0.04 x baseline AHI – 5.12 = effective pressure).

Statistical Analysis

Results were presented as percentages for the categorical variables or as mean and standard deviation (±) for the numerical variables. For the comparison of differences, we used the Mann-Whitney or Fisher tests or □2. For the comparison of titration pressures we carried out Bland and Altman plot representation, linear regression analysis and calculation of the intraclass correlation coefficient (ICC). For the statistical analysis, STATA 12 and Graph Pad Prism-5™ software were used.

Results

During 12 moths, we included 192 patients; 52 females (27%) and 140 males; mean age, 60.2 years old ± 11.7 and mean BMI of 33.8 ± 6.7 kg/m². Table 1.

57.7% of females and 70% of males were obese (BMI > 30 kg/m²); and 58.8% of females and 45% of males had a subjective Epworth sleepiness scale (ESS) value of > 11 points ($p > 0.96$). Table 2.

141 cases (73.5%) were diagnosed through RP, and 25.5% through PSG. The mean AHI was 33.1 ± 16.6 in females and 36.5 ± 16 in males ($p > 0.24$); and 190 cases (98.9%) presented an AHI > 15 ev/hour.

The use of the APAP was 3.4 nights ± 1.2 (range between 2 and 8). 83.8% (163) used the device for 3 nights. Mean compliance with APAP treatment of the whole population was 373 minutes (6.05 hours ± 1.55), with no gender differences; 380 minutes ± 101 in females and 370 ± 91.2 in males ($p > 0.54$). Seventeen patients used full face masks (8.8%) and minimal contact nasal pillows (3%), whereas most patients used 14 different models of nasal masks (88.2%).

Mean pressure values at 90th percentile (P90), Eff_p, day 1 $Mean_p$ and every day $Mean_p$ are detailed in table 2. Both for males and females, there were differences regarding the rAHI but not in airway pressures. Less than 10% of the population presented unacceptability criteria, and the Opt_t proportion was lower in males (78.9% versus 65.7%) $p < 0.001$. Table 2.

There was a good correlation between the $Mean_p$ and the titration pressure (Eff_p) that was finally indicated; *r* Spearman (*rho*): 0.73 (95% CI,

TABLE 1. Demographic variables of the population

Variable	Value
n	192
Males	140 (83%)
Age (years)	60.2 ± 11.7
BMI (kg/m²)	33.8 ± 6.7
ESS	10.25 ± 5.83

TABLE 2. Clinical variables and auto-adjustable CPAP titration data according to gender

Variables	Females (n 52)	Males (n 140)	p value
Age (years)	61.1 ± 10.7	59.7 ± 12.1	0.33
BMI (kg/m^2)	34.8 ± 7.9	33.5 ± 6.1	0.21
Epworth scale	10.3 ± 5.2	10.2 ± 5.8	0.96
Neck (Ncirc)	40.6 ± 4.3	44.8 ± 4.2	*0.0001*
Baseline AHI	33.1 ± 16.6	36.5 ± 16	0.24
P90 (cm of H_2O)	8.9 ± 2.7	9.2 ± 3.5	0.5
Meanp (cm of H_2O))	7.5 ± 1.9	7.5 ± 1.9	0.73
Meanp of the first day (cm of H_2O)	7.5 ± 1.8	7.40 ± 2	0.70
Effective pressure (Effp)	8.5 ± 1.7	8.6 ± 1.9	0.87
rAHI (ev/hour)	3.8 ± 3.4	5.3± 4.3	*0.02*
Total mean leakage	8.9 ± 16	10.1 ± 8	0.23
rAHI > 5 (ev/hour)	21.1%	34.3%	*0.001*
rAHI > 10 (ev/hour)	5.7%	10.7%	*0.05*

0.57-0.84) $p < 0.001$, y-axis (*intercept*); 0.1 to -0.1 (Figure 1 and 2). In a similar way, the $Mean_p$ of the first night correlated with the Eff_p; *rho*: 0.73 (95% CI, 0.56-0.85) p < 0.001, *intercept*; 0.2 to -0.3 (Figure 3). The Bland and Altman representation between the Eff_p and the $Hoff_f$ showed: *intercept*: 3.96, β: 0.519 and r^2: 0.269 ($p < 0.001$) (Figure 4). 26% of titrations showed absolute concordance between both methods, and pressure underestimation by $Hoff_f$ was frequent, with a negative mean difference: - 1.98 cm of H_2O (95% CI, 1.48-2.49). The ICC was 0.60 (95% CI: 0.47-0.80) $p < 0.0001$, showing a low degree of correlation.

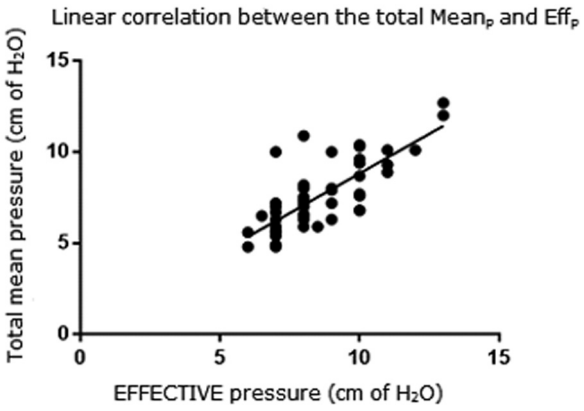

Figure 1. Correlation between the $Mean_p$ of all the titration nights and the effective pressure (Eff_p).

Discussion

Our work summarizes a one year experience of unsupervised unconventional titrations with auto-adjusting CPAP in patients not previously adapted to the therapy.

This strategy seems to be useful for acquiring working pressures; it facilitates interface selection and the initial training of the patient, and makes it possible to gather data from multiple nights at the place where the patient usually sleeps with a low $Inad_t$.

The use of auto-adjustable equipment as a titration method has been validated in the literature and represents an interesting option[18-21], for it simplifies the procedure and it is not necessary to make sleep laboratory appointment dates, giving priority to patients with initial home titration failure.

We use the visual reading of the pressure/time and leakage/time chart to define the final Eff_p

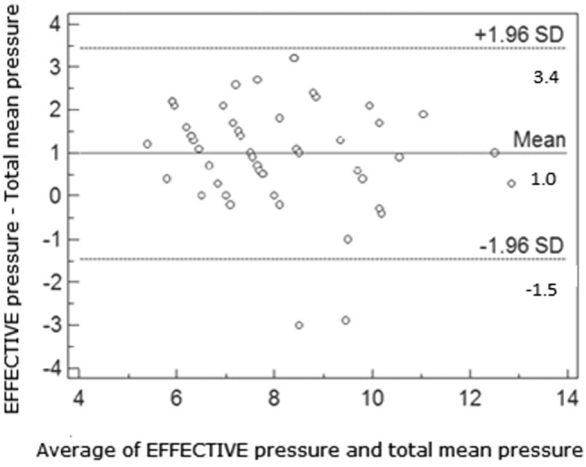

Figure 2. Distribution of the $Mean_p$ of all the titration nights in relation to the effective pressure.

value. The values showed by the statistical analysis derived from the automatic algorithm (P90) used in this study tend to be higher in bench studies,

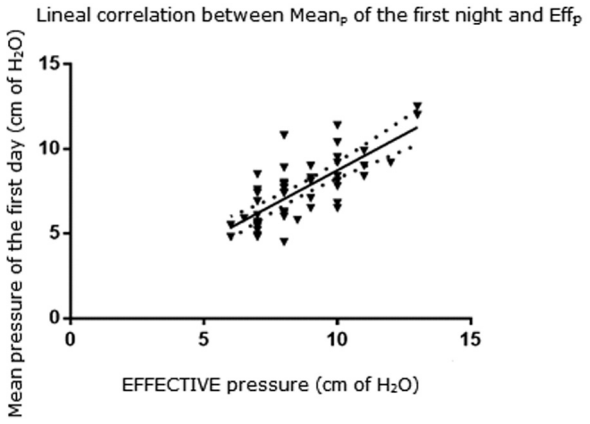

Figure 3. Correlation between the Mean$_p$ of the first night and the effective pressure.

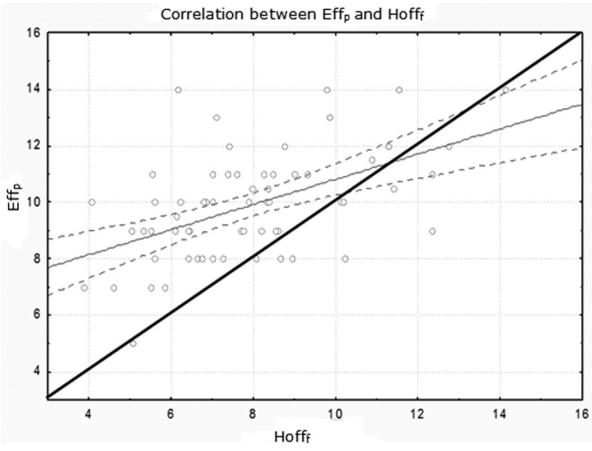

Figure 4. Correlation of the Eff$_p$ in relation to the Hoff$_f$.

since the software can´t exclude in the calculation the moments in which the mask is not adequately adjusted[24]. In this case, visual reading can discriminate and exclude pressure values shown under that circumstance. Also, the Eff$_p$ is determined after several nights, excluding periods of no use or with leakages that imply a not yet corrected rAHI. We found that 5 to 10 % of APAP titrations have residual AHIs between 5 and 10 ev/hour with a greater proportion in males (Table 2). Some definitions consider an acceptable reduction of the AHI with an APAP of < 10 ev/hour for patients with OSAHS, though these definitions have not been evaluated in patients with upper airway resistance syndrome (UARS) or individuals who remain sleepy with the use of CPAP[25].

Additionally, in our experience, the total Mean$_p$ and the Mean$_p$ of the first night have a good correlation between themselves and with the Eff$_p$ (Figures 1 and 3), serving as a guide when there is great variability of pressures during the night/s. The rAHI of this kind of devices is reliable information when it is < 10 ev/hour in comparison with the manual titration by PSG[23]. However, our results can´t be extrapolated to other algorithms since there may be an evident variation in the performance of each device[24].

The influence of the kind of mask on the Mean$_p$ and Eff$_p$ has been previously described. The values are higher with full face masks, which represented the minority in our series[26]. The analysis of our data shows that careful interface selection and initial supervision allows ≈ 90% of patients with no previous experience to use the CPAP > 4 hours per night with AHI correction.

The compliance figures vary and fluctuate between 50% and 70%, if a criterion of at least 4 hours/night[27-28] is used, although we know that adherence to the treatment is gradually lost with time. In the same way, a good initial experience in the implementation of the treatment is very important, in such a way that the first CPAP week is determinant of long-term compliance[29-30].

A higher socio-economic level and the increase in patient age determine a better compliance and could partly explain the results, since it is an adult population (≈ 60 years) of a private place[21, 32-34] referred to home titration (possible selection bias). On the other hand, clinical management carried out by trained personnel and the influence of the use of cognitive-behavioral strategies can´t be ignored as a possible incentive to improve short-term compliance[(35-36)]

Remarkably, some studies showed that APAP titration improves mean compliance in approximately one hour, compared to PSG titration at the sleep laboratory, when compliance was evaluated three months later[37, 38].

On the other hand, the existence of waiting lists or the delays in the titration have generated predictive formulas based on coefficients according to anthropometric and functional parameters as the desaturation index[39] or the AHI[22, 40]. An interesting study that compared acquired pressures by means of unsupervised titrations with a different APAP model (P_{95} of the Autoset II algorithm) and three titration formulas, did not find a good correlation (r^2 between 0.66-0.71) and concluded that such equations must be used carefully[41, 42]. One strength

of our analysis is that we use the Eff_p of the manual edition of several nights (finally recommended pressure) without finding an adequate correlation.

The indices we used (AHI) differ from those of the PSG (AHI or RDI [respiratory disturbance index]), since in the RP they result from the quotient between the events and the total recorded time[21, 43, 44], an underestimation factor[43, 44] that shall be taken into account when interpreting the performance of coefficients in the titration formulas.

Conclusions

A high proportion of patients without experience in the use of CPAP titrate at home with APAP without surveillance and with acceptability criteria.

We did not find an adequate correlation between the prediction by Hoffstein and Mateika formula and the effective pressure in our population.

Conflicts of interest: The authors of this work declare there is no conflict of interest related to this publication.

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