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Does using pressure-controlled ventilation to rest respiratory muscles improve sleep in ICU patients?

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Summary
Purpose: Sleep is commonly altered in critically ill patients. Ventilatory mode may impact on quality of sleep. The aim of our study was to evaluate the effect on sleep of pressure-controlled ventilation (PCV) to spontaneous ventilation with 6 cm H_2O inspiratory pressure (low-PSV).
Methods: Thirty-five patients intubated and mechanically ventilated for acute-on-chronic respiratory failure were included in this prospective randomized cross-over study. Nine were discarded, 13 received PCV first (10 p.m.–2 a.m.) and then low-PSV (2–6 a.m.) and 13 patients received low-PSV first and then PCV.
Results: Sleep architecture was altered (50.4% of the night was spent in wakefulness). PCV was associated with significantly improved sleep quality and quantity compared to low-PSV: sleep efficiency (total sleep time/total recording time) was 63% (range: 9–100) vs. 37% (0–96; $p = 0.0002$), stage 2 NREM sleep was 33% vs. 13% ($p = 0.0005$), stages 3 and 4 NREM sleep were 9% vs. 3.5% ($p = 0.003$) and REM sleep was 6.5% vs. 0% ($p = 0.003$).
Conclusions: Sleep quantity and quality were significantly improved with PCV compared to low-PSV. Nocturnal respiratory muscles rest through PCV is recommended to improve sleep in ICU patients with acute-on-chronic respiratory failure.

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Introduction

Patients in intensive care unit (ICU) are known to have disrupted sleep, reduced sleep efficiency, and decreased non-rapid eye movement (NREM) and rapid eye movement (REM) sleep. Recent data suggest there is a reciprocal influence between sleep and mechanical ventilation in patients who are intubated for acute respiratory failure.[1–3] Parthasarathy and Tobin found that sleep fragmentation was significantly greater during "high" pressure-support ventilation (PSV) (with a mean pressure-support level of 16.8 $\pm$ 1.5 cm H_2O) when compared to assist-controlled ventilation (ACV), and that sleep disruption was related to "high" PSV-induced central apnea.[2] More recently, our group has shown that ACV is also associated with significantly improved sleep quality, even when PSV was used at "low" levels of pressure-support (6 cm H_2O).[3] In our previous study, sleep disruption observed with low-PSV could not be attributed to central apnea (not registered); the improved sleep quality with ACV was related to respiratory muscles being able to rest.

Nowadays, because patients are mostly weaned with pressure modes according to ERS/ATS guidelines,[4] we decided to study the impact of enabling respiratory muscles to rest using pressure-controlled ventilation (PCV) to improve sleep quantity and quality compared to using low levels of pressure-support ventilation (PSV). The amount of stage 3 and 4 NREM sleep recorded with each mode was defined as the main outcome.

Patients and methods

Patients

This prospective randomized, crossover, simple, blinded study was designed to assess adult patients with chronic lung disease. Obstructive lung diseases[5] were defined using spirometric data obtained during a previous clinically stable period according to GOLDE criteria (irreversible chronic airflow limitation with forced expiratory volume (FEV_1)/forced vital capacity (FVC) $<$ 70% and a FEV_1 $<$ 80% of the predicted).[6] Most patients had chronic bronchitis that had been clinically defined as a cough producing sputum for at least 3 months per year for a 2 consecutive years; only some patients had bronchiectasis that had been identified clinically by computed-tomography scan.

Restrictive lung diseases were defined using spirometric data obtained during a previous clinically stable period with a total lung capacity (TLC) $<$ 80% of predicted values. Obesity was defined by having a body-mass index of $\geq$30 kg/m^2. Restriction caused by sequelae of tuberculosis was defined by the appropriate clinical and radiological findings. Patients with asthma or interstitial lung disease were excluded from this study.

To be included in the study, patients had to be orally intubated with a tube wider than 7.5 mm ID and had to have been mechanically ventilated for an episode of acute-on-chronic respiratory failure. They were invited to participate in this study near the end of their weaning period, during the last night preceding the planned extubation, when the cause of respiratory failure was controlled and when patients were able to sustain low levels of PSV (absence of respiratory acidosis in arterial blood gases sampled after 1 h of low-PSV levels). Patients also needed to be hemodynamically stable without any vasopressive, sedative, narcotic, or analeptic drugs administered for the previous 48 h. Patients with central apnea syndrome, narcolepsy, or metabolic encephalopathy were excluded from the study, as well as patients considered unstable by their primary physician.

Design

The study's protocol was designed to compare sleep quality between pressure-controlled ventilation (PCV) and low levels (6 cm H_2O) of pressure-support ventilation (low-PSV). All patients were monitored by standard polysomnography (Medatec, Belgium) and their respiratory parameters (respiratory rate, tidal volume, inspiratory pressure) were obtained with a Puritan Bennett B840 respirator (USA). In order to lower noise pollution, patients were transferred to an isolated single room for the recording night.

The polysomnographic recordings were performed during a single night from 10 p.m. to 6 a.m. The night was divided into two segments, each lasting 4 h: from 10 p.m. to 2 a.m. and from 2 a.m. to 6 a.m. Each patient was recorded while receiving PCV for 4 h and low-PSV for 4 h. Because sleep architecture is known to differ from the beginning to the end of the night, the sequence of experimental interventions (PCV vs. low-PSV) was randomly assigned to each patient using the closed-envelope method. Patients, therefore, received either PCV first and then low-PSV, or vice versa (Fig. 1).

During PCV, inspiratory pressure support was set at 20 cm H_2O with the respirator-frequency set to provide complete disappearance of spontaneous inspiratory efforts: this was assessed by an absence of triggered breaths (i.e., respirator frequency $\geq$12/min). Inspiratory time was set to provide an *I/E* ratio of between 1/1.2 and 1/1.5. During low-PSV,

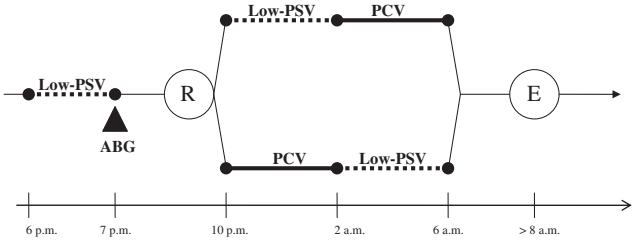

Figure 1 Study protocol. The study was proposed to patients who were able to sustain low levels of pressure-support ventilation (6 cm H_2O) from 6 to 7 p.m. If arterial blood gas (ABG) data were correct (absence of any respiratory acidosis with a pH value $>$7.38), patients were randomized into two groups (R): one group received low levels of pressure-support ventilation (6 cm H_2O) during the first part of the night (from 10 p.m. to 2 a.m.) and then pressure-controlled ventilation (from 2 to 6 a.m.), whereas the other group received pressure-controlled ventilation first and then low-level pressure-support ventilation (6 cm H_2O). At the end of the night, the patients were proposed for extubation (E).

patients breathed spontaneously via the respirator's circuitry, with pressure-support level of 6 cm H_2O and a trigger sensitivity of 0.5 cm H_2O. This is the lowest level needed to compensate for resistances imposed by the circuitry.[7,8] When prescribed (for patients with severe chronic obstructive pulmonary disease [COPD]), no changes in positive end-expiratory pressure are made between PCV and low-PSV.[9] The inspired oxygen fraction (FiO_2) was adjusted to maintain SaO_2 at $\geq$92%.

During the night, the nurses carried out the patients' care activities at 2 a.m. during the change in ventilatory mode to minimize disturbance. At the end of the night, the patients were proposed for extubation.

All patients were monitored with standard polysomnography and the recorded variables were included in a three-channel electroencephalography (Fp1/C3, C3/T3 and T3/O1). The A1 reference electrode was fixed over the patient's mastoid process. Polysomnography also recorded right and left electro-oculograms and bipolar electrodes were used for a submental electromyogram. Electrocardiographs were recorded continuously. Arterial oxygen saturation was monitored by pulse oximetry (Hewlett Packard M1020A, USA). In addition to the usual medical staff working in the ICU, a physician was present in the ward to care for the patient and monitor the quality of polysomnographic recordings, which were scored according to the criteria of Rechtschaffen and Kales in 20-s periods.[10]

Each period was attributed to wakefulness, stages 1—4 NREM sleep, REM sleep, or movement time according to the characteristics of $\geq$50% of the period. Arousal was defined as an abrupt shift in EEG frequency that occurred during sleep and lasted between a minimum of 0.5 and a maximum of 14.9 s.[11] All polysomnographic data were analyzed by a single neurophysiologist blinded to the randomization. Total recording time (TRT) was defined as the time from the beginning to the end of the study period (10 p.m.—6 a.m.). Durations of sleep stages were expressed in minutes and as a percentage of TRT. The arousal index was defined as the number of arousals per hour of sleep.

In addition to polysomnographic and respiratory parameters, demographic data (age, gender, comorbidities, smoking habits), baseline spirometric data, baseline blood gas, and data on the acute event (etiology of acute failure, duration of mechanical ventilation, size of the endotracheal tube, chest X-ray) were collected. The Acute Physiology Score Chronic Health Evaluation II was calculated for the initial 24 h ICU period for each patient.

The study was approved by our institution's ethics committee (North West of France Patients Protection Committee n° DGS 2007-0388) and all patients gave their written informed consent prior to participation.

Statistical analyses

In our previous study,[3] stage 3 and 4 NREM represented 14.2% of TRT during ACV vs. 0% during low-PSV ventilation. For an expected difference of 14% between PCV and low-PSV, with a power of 80% and an alpha risk of 5%, 26 patients were required. All data were expressed as means $\pm$ standard deviations.

Quantitative differences between the two groups were detected by the Wilcoxon's non-parametric test. When the entire night was considered, the two ventilatory modes were compared using the Wilcoxon's non-parametric paired test (patients acted as their own control) and we also compared, within the same test, the two periods of the night whichever ventilatory mode was used. An interaction test between sequence and ventilatory mode was realized. Qualitative data were analyzed using Fisher's exact test. Correlations between stages 3—4 NREM sleep and respiratory rate tidal volume ratio were tested using Spearman's rank correlation test. A probability of $\leq$0.05 was considered statistically significant. Statistical analyses were performed using SAS version 9.1.

Results

Patients

We included 35 patients in our study. Five patients were not included because it was impossible to obtain accurate data (excessive electrical artefacts on their polysomnographic records) and four because no respiratory parameters were recorded (no or too late backup from the B840 PB respirator). Thus, the data from 26 patients, with a mean age of 67 $\pm$ 11 years, were available for analyses. The patients' characteristics are shown in Table 1.

All patients were successfully extubated after the study night (no need to re-intubate in the 48 h following extubation). The two groups (PCV—low-PSV and low-PSV—PCV) were similar in terms of anthropometric data, pulmonary-function tests, and data on arterial blood gas sampled just before randomization (Tables 1 and 2). No significant differences in heart rate or blood pressure were observed between the two groups (Table 2).

Polysomnographic results

The total recording time (TRT) was 473 $\pm$ 17 min. Regardless of the mode of mechanical ventilation used, total sleep time (TST) was altered, with a median of 50.4% of the night spent in wakefulness. There was a predominance of stage 1 and 2 NREM sleep (43.5 $\pm$ 21.5% of TRT) whereas stage 3 and 4 NREM sleep was rare (6.2 $\pm$ 7.5% of TRT). REM sleep was also extremely low (2.2 $\pm$ 3.8% of TRT). No apnea was recorded during low-PSV or PCV.

Effect of night-time period on sleep quality and quantity

Comparisons between the two night-time periods (10 p.m.—2 a.m. vs. 2—6 a.m.) showed that, irrespective of the mechanical-ventilation mode used, the duration of polysomnographic recordings was similar between the first and second part of the night: 244 $\pm$ 22 min vs. 238 $\pm$ 10 min, respectively (NS). No significant differences in sleep architecture were observed.

Effect of mechanical ventilation on sleep quality (PCV vs. low-PSV)

When considering the whole night, irrespective of the order of ventilator settings, the duration of polysomnographic recordings was similar between PCV and low-PSV: 241 $\pm$ 17 min vs. 241 $\pm$ 19 min, respectively (NS). Sleep

Table 1 Anthropometric, clinical characteristics, and pulmonary-function tests of patients; pulmonary-function data were obtained during a stable period preceding an episode of acute respiratory failure.

	Age (years)	Gender	BMI	Cause of acute respiratory failure	Chronic respiratory disease	FEV_1/ VC (%)	FEV_1 (% pred)	VC (% pred)
1	70	M	27	Pulmonary infection	COPD, silicosis	25	21	63
2	61	M	23	Pulmonary infection	COPD	35	20	54
3	47	M	20	Pulmonary infection	COPD	62	45	58
4	87	M	17	Pulmonary infection	COPD	59	50	62
5	79	M	19	Pulmonary infection	COPD	60	45	79
6	60	F	27	Treatment interruption	COPD	42	28	58
7	55	M	24	Pulmonary infection	COPD	40	23	60
8	69	M	18	Pulmonary infection	COPD, bronchiectasis	58	29	61
9	56	M	27	Pulmonary infection	COPD, bronchiectasis	48	28	60
10	81	M	23	Pulmonary infection	COPD	NA	NA	NA
11	84	M	22	Pulmonary infection	COPD	60	34	65
12	72	M	18	Pulmonary infection	COPD	45	32	70
13	70	F	27	Pulmonary infection	COPD, obesity	60	50	70
14	69	M	23	Pulmonary infection	COPD	62	47	62
15	39	M	21	Pulmonary infection	COPD	60	53	80
16	59	M	18	Pulmonary infection	COPD	34	21	61
17	61	M	23	Pulmonary infection	COPD	38	30	75
18	78	M	21	Pulmonary infection	COPD	42	42	88
19	55	M	23	Pulmonary infection	COPD	43	22	52
20	67	F	23	Pulmonary infection	COPD	55	48	81
21	74	M	35	Heart failure	COPD	46	48	89
22	69	M	26	Pulmonary infection	COPD	40	32	75
23	57	F	23	Pulmonary infection	COPD	37	30	80
24	72	M	25	Pulmonary infection	COPD	NA	NA	NA
25	79	M	27	Pulmonary infection	COPD	54	73	85
26	65	M	40	Pulmonary infection	COPD	52	34	68

Abbreviations: BMI, body-mass index; COPD, chronic obstructive pulmonary disease; FEV, forced expiratory volume; VC, vital capacity; M, male; F, female.
Six COPD patients received long-term domiciliary oxygen therapy (GOLD stage IV).
For patients #10 and #24, spirometric data were not available, but these patients were previously on long-term oxygen therapy and were ex-smokers.

quantity was higher with PCV than with low-PSV, (wakefulness: 37.7 ± 24.7% of TRT in PCV vs. 58.3 ± 28.8% of TRT in low-PSV, $p = 0.006$) (Fig. 2). The sleep-efficiency index (sleep quantity divided by respective TRT) was better with PCV than with low-PSV (respectively: 61.5% ± 25.1 and 39.2% ± 29.1, $p = 0.0003$). Stage 3 and 4 NREM sleep (main outcome) was greater during PCV than with low-PSV (respectively: 8.9% ± 10.1 of TRT and 3.5% ± 8.9 of TRT, $p = 0.003$; Fig. 2) without any period effect (Fig. 3).

Stage 2 NREM and REM sleep were greater during PCV than during low-PSV (respectively for stage 2 NREM sleep: 35.3% ± 23.3 vs. 20% ± 21.9, $p = 0.0005$; and for REM sleep: 3.4% ± 6.4 vs. 0.8% ± 2.1, $p = 0.003$). No significant differences were found in quantity of stage 1 NREM sleep between PCV and low-PSV. These results are summarized in Table 3, and Fig. 4 displays a typical example of sleep improvement with PCV in patient #24.

No interaction was found between the two parts of the night and ventilatory mode (PCV vs. low-PSV) for stages 2 NREM, 3 and 4 NREM, or REM.

Respiratory parameters

By design, tidal volume (TV) was greater during PCV than during low-PSV (876 ml ± 179 ml vs. 568 ml ± 153, respectively; $p < 0.0001$) with a lower respiratory rate (RR) (13.3 ± 2.2 vs. 23.2 ± 7, respectively; $p < 0.0001$) and a higher inspiratory pressure (24.1 ± 3.1 vs. 12.4 ± 2.3 cm H_2O, respectively; $p < 0.0001$). The RR—TV ratio was lower during PCV than during low-PSV (16.1 ± 5.6 vs. 45.9 ± 23.0, respectively; $p < 0.0001$). Fig. 5 shows the relationships between TV and RR for the two ventilation modes. Stage 3 and 4 NREM sleep was significantly related to breathing pattern with a higher amount observed under PCV (lower RR/higher TV) than under low-PSV (higher RR/lower TV) ($p < 0.005$).

Discussion

This study of ICU patients with acute-on-chronic respiratory failure and near to being weaned off mechanical ventilation

Table 2 Characteristics of the two groups: those receiving PCV first and then low-PSV (6 cm H_2O) vs. those receiving low-PSV first and then PCV. Arterial blood gases were sampled after 2 h of low-level PSV, just before randomization.

	PCV—low-PSV group ($n = 13$)	Low-PSV—PCV group ($n = 13$)
Age (years)	64 ± 12	68 ± 11
Gender (M/F)	11/2	12/1
Smokers, *n*	13	13
Previous respiratory failure, *n*	7	7
Previous intubations, *n*	6	5
Mechanical ventilation (days)	10 ± 5	10 ± 6
Tracheal-tube diameter (mm)	8 ± 0.1	7.9 ± 0.2
APACHE score	24 ± 9	23 ± 5
BMI (kg/m^2)	23.1 ± 3.4	24.9 ± 7.1
PaO_2/FiO_2	237.6 ± 55.6	222.9 ± 64.1
$PaCO_2$ (mmHg)	42.3 ± 7.8	43.5 ± 8.2
pH	7.43 ± 0.02	7.44 ± 0.04
SAP/DAP at 10 p.m. (mmHg)	124 ± 24/68 ± 16	131 ± 18/66 ± 10
SAP/DAP at 2 a.m. (mmHg)	126 ± 18/73 ± 11	129 ± 18/64 ± 12
SAP/DAP at 6 a.m. (mmHg)	133 ± 19/71 ± 9	117 ± 21/63 ± 10
HR at 10 p.m. (bpm)	89 ± 12	95 ± 14
HR at 2 a.m. (bpm)	89 ± 13	88 ± 12
HR at 6 a.m. (bpm)	87 ± 11	84 ± 9
First part of PSG recording (min)	240.8 ± 7.6	234.4 ± 11.8
Second part of PSG recording (min)	233.7 ± 10.0	218.4 ± 2.7

Quantitative variables are expressed as means ± standard deviations.
PSG, polysomnography; SAP, systolic arterial pressure in mmHg; DAP, diastolic arterial pressure in mmHg; HR, heart rate; bpm, beat per minute; BMI, body-mass index in kg/m^2; APACHE, Acute Physiology and Chronic Health Evaluation.

shows that enabling respiratory muscles to rest during the night using pressure-controlled ventilation was associated with improved sleep quantity and quality compared to being kept under a weaning mode using low-level of PSV. PCV resulted in more stage 3 and 4 NREM sleep, increased REM sleep, and improved the sleep-efficiency index. These results were found for the whole night and for each part of the night.

This study only included patients with severe COPD (24 patients with Global Initiative for Chronic Obstructive Lung Disease, stages 3 and 4). In such patients, sleep is known to be altered during stable states (home recordings)[12] and during acute failure (ICU recordings).[13] In ICUs, sleep is commonly altered with sleep fragmentation and decreased NREM and REM sleep.[13–15] In our study, all patients slept during the night of the study but sleep quantity and architecture were severely impaired. Indeed, we found low sleep efficiency, large decreases in stages 3 and 4 NREM sleep (6.2 ± 7.5% of TRT), and scarce REM sleep (2.2 ± 3.8% of TRT), as also previously described by Toublanc et al.[3] and Freedman et al.[15]

The reason for sleep deprivation in ICU patients is still debated. In the study of Freedman et al., which was conducted in a medical ICU (patients in single rooms, enclosed on three sides), sleep could occur during the daytime; thus, total sleep time could be normal, although of poor quality.[15] Because we did not conduct a 24-h recording, we cannot exclude the possibility that there was a normal duration of sleep overall. In addition, we may have overestimated the total quantity of sleep during the 8-h recording as our patients were studied in a single room with reduced environmental noise pollution, which does not correspond to real life in ICUs.

The main objective of our study was to assess the effect of ventilation mode on sleep quality. A previous study performed by our team showed that when ACV is compared to low-level PSV, there is a significant decreased wakefulness, significant increased in stage 1 and 2 NREM sleep during the first part of the night, and significant increased

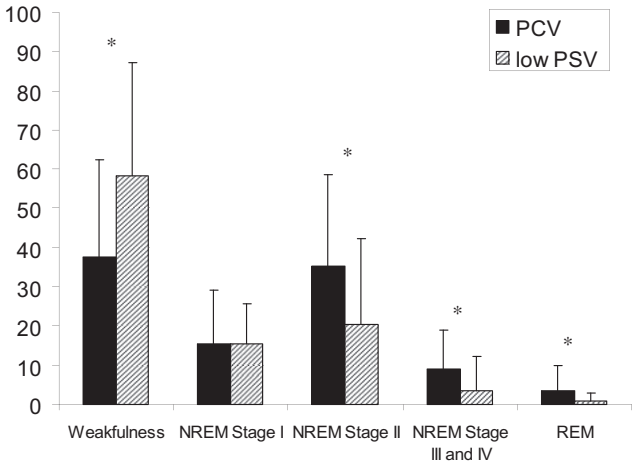

Figure 2 Comparison of quantity of sleep stages expressed as a percentage of total recording time during the entire night between pressure-controlled ventilation (PCV) and low-level of pressure-support ventilation (low-PSV). *$p < 0.01$.

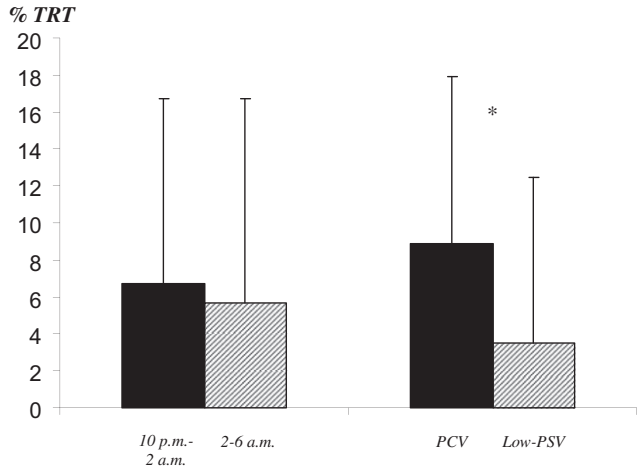

Figure 3 Quantity of stage 3 and 4 NREM sleep, expressed as a percentage of the total recording time (TRT), according to the night period and the ventilation mode (pressure-controlled ventilation (PCV) or low-level of pressure-support ventilation (low-PSV)). *$p < 0.01$.

in stage 3 and 4 NREM sleep during the second part of the night.[3] As our patients were weaned during the day with a "pressure" mode, according to the 2007 ERS/ATS guidelines,[4] we decided to evaluate sleep quantity and quality by resting the respiratory muscles using PCV. To control for circadian variations in sleep, a crossover study design was used, with patients randomized to both modes of ventilation.

Our results showed a clear significant improvement in the quantity and quality of sleep with PCV compared to low-level PSV, particularly for our main outcome (stage 3 and 4 NREM sleep). We also found improved sleep efficiency with PCV, with significantly increased REM sleep. No difference was found in sleep quality and quantity between the two parts of the night. Ventilation mode undoubtedly influenced sleep quality and this is even more remarkable as stage 3 and 4 NREM sleep is usually reduced in older people (mean age of our population was 67 ± 11 years).

Few studies have focused on the impact of ventilatory mode on sleep in ICUs[2,3,16,17] and no recommendations have been proposed for the nights of the weaning period. Although PSV is the recommended mode to wean patients during the daytime, Pathasarathy and Tobin found worse sleep under PSV when compared to ACV in 11 patients (ventilated through endotracheal tubes or tracheostomies connected to the ventilator) recorded during the night in single-occupancy ICU rooms.[2] Because the sleep fragmentation they observed was mainly caused by central apnea, we used low-level PSV to avoid sleep fragmentation induced by central apnea. No central apnea occurred with such a low level and the poor sleep we observed using low-PSV could thus not be attributed to apnea.

In contrast to our results, Cabello et al. did not find any differences between three different ventilatory modes: ACV, automatic adjusted PSV, and clinically adjusted PSV, in 15 medical ICU patients ventilated through an endotracheal tube or a tracheostomy.[17] In the study of Cabello et al., their objectives for clinically adjusted PSV were a tidal volume of $\geq$300 ml and a respiratory rate of between 15 and 30 per min. Although central apnea occurred during PSV at a mean level of 14 cm H_2O in nine patients, they did not report more sleep fragmentation. Probably the main difference between Cabello et al.'s study and ours is the inclusion criteria as we only included patients with acute-on-chronic respiratory failure, and particularly COPD patients. These patients are known to have reduced muscle endurance, which could explain the greater impact of enabling respiratory muscle to rest on sleep quality and quantity.

Some data gathered during acute failure suggest that oxygen consumption of the respiratory muscles is dramatically increased; thus, oxygen available to other tissues is significantly reduced.[18,19] We suggest that unloading respiratory muscles with PCV (this study) (or with ACV: our previous study[3]), results in a decreased need for oxygen of the respiratory muscles. Thus, this leaves more oxygen available for other organs, particularly the brain. This opinion is supported by the correlations we found in this study between the amount of stage 3 and 4 NREM sleep (our main outcome) and the breathing pattern (RR/TV ratio). Low-PSV is associated with a poor breathing pattern (rapid shallow breathing with low TV and high RR) and poor sleep quality. The use of PCV, which enables respiratory muscles to rest, improves both the breathing pattern and sleep quality.

By improving sleep quality and quantity, PCV may influence the weaning period and reduce its duration. Indeed, it has been shown that sleep deprivation alters pulmonary mechanics and breathing control, reduces

Table 3 Characteristics of the different sleep stages according to ventilatory mode and recording period.

	PCV		Low-PSV		*p*
	%TRT	%TST	%TRT	%TST	
Wakefulness	38 ± 25: 36 [0—91]		58 ± 29: 57 [3.5—100]		0.0006
Stage 1	15 ± 14: 14 [1—50]	31 ± 26: 24 [1—93]	15 ± 10: 16 [0—39]	60 ± 33: 56 [6—100]	0.25
Stage 2	35 ± 23: 33 [0—84]	51 ± 21: 59 [6—85]	20 ± 21: 13 [0—67]	35 ± 29: 36 [0—79]	0.0005
Stage 3—4	8.9 ± 10: 6.55 [0—39]	13 ± 14: 12 [0—64]	3.5 ± 9: 0 [0—40]	4 ± 10: 0 [0—46]	0.003
REM	3.46 ± 6: 0 [0—23.4]	4 ± 8: 0 [0—34]	0.7 ± 2: 0 [0—8.9]	1.4 ± 3: 0 [0—12]	0.003
Sleep efficiency	61 ± 25: 63 [9—100]		39 ± 29: 37 [0—96]		0.0002

Data are expressed as means ± standard deviations, median and [extremes] as the percentage of the total recording time (TRT), or total sleep time (TST). PCV, pressure-controlled ventilation; low-PSV, low level of pressure-support ventilation; REM, rapid eye movement. First part of the night = 10 p.m.—2 a.m., second part of the night = 2—6 a.m.
*p for %TRT between PCV vs. the low-PSV group.

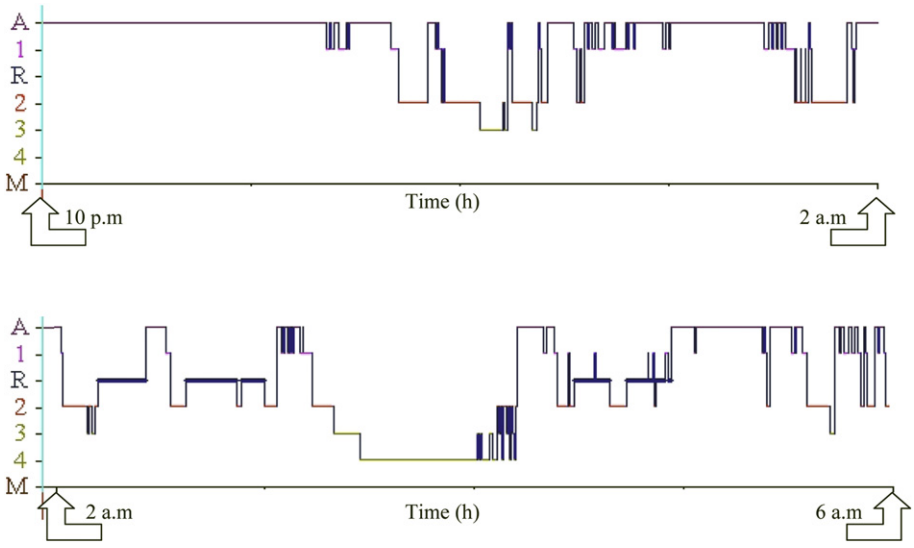

Figure 4 Typical examples of sleep quality, recorded in patient #24. Top: First part of the night (10 p.m.—2 a.m.) recorded under low-level pressure-support ventilation (low-PSV). The beginning of the night was spent in wakefulness and when the patient was asleep, his sleep was mainly represented by stage 1 and 2 NREM, without any REM sleep. Bottom: Second part of the night (2—6 a.m.) recorded under pressure-controlled ventilation (PCV). The patient fell asleep as soon as low-PSV was changed to PCV. Pressure-controlled ventilation was associated with better sleep quality (predominance of stage 3 and 4 NREM sleep and REM sleep) when compared to the first part of the night with low-PSV. A, wakefulness; 1, stage 1 NREM sleep; R, REM sleep; 2, stage 2 NREM sleep; 3, stage 3 NREM sleep; 4, stage 4 NREM sleep; M, time (in hours).

inspiratory muscle strength,[20] maximum voluntary ventilation,[20] and the ventilatory response to hypercapnia.[21,22] Moreover, Heller et al. found more delirium in patients with lower quantities of sleep[23] (though we do not know if sleep deprivation is a cause or a consequence of delirium).

Our results are quite disturbing: resting the respiratory muscles in ICU patients has been shown to be hazardous. Levine et al. found, in humans, that diaphragmatic inactivity (>18 h), when induced by mechanical ventilation was associated with marked atrophy of both slow-twitch and fast-twitch diaphragmatic fibers.[24] Animals studies have also found that shorter periods of mechanical ventilation (6 h) are enough to initiate oxidative diaphragmatic muscle injury.[25,26] Thus, if respiratory muscles are rested during the night to favor restorative sleep, this must not exceed 6—8 consecutive hours per day.

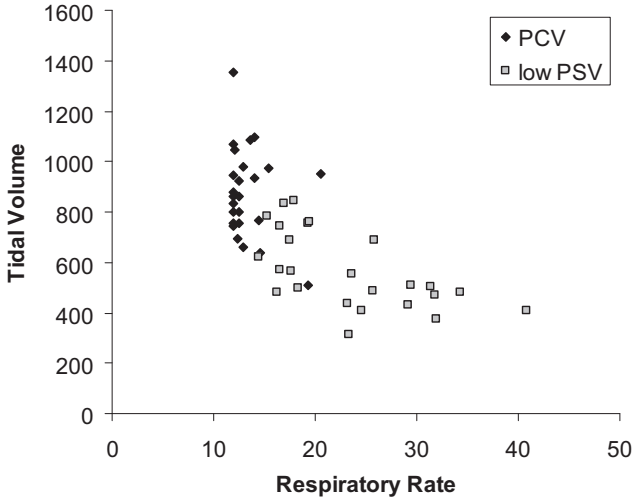

Figure 5 Tidal volume (expressed in ml) according to respiratory rate (per minute), as a function of ventilation mode: pressure-controlled ventilation (PCV) and low-level of pressure-support ventilation (low-PSV) in 26 patients.

In summary, we found that 26 intubated and mechanically ventilated patients with acute-on-chronic respiratory failure, near the end of their weaning periods, had significantly improved sleep quality and quantity when respiratory muscles were rested at night using PCV compared to using low-level PSV. In this highly selected population, weaning periods using PSV (with a progressive decrease in PSV levels) could be proposed during the day (6 a.m.—10 p.m.) whereas respiratory muscles could be rested with PCV during the night (10 p.m.—6 a.m.) to improve sleep quality and quantity.

Authors' contributions

- C. Andréjak contributed to the conception and design, the acquisition of data, the analysis and interpretation of data, drafted the article, and gave the final approval for this version to be published.
- J. Monconduit contributed to acquisition of data, the analysis of data, carefully revised the article, and gave final approval for this version to be published.
- D. Rose contributed to the conception and design, the analysis and interpretation of data, carefully revised the article, and gave final approval for this version to be published.
- B. Toublanc contributed to the conception and design, the acquisition of data, carefully revised the article, and gave final approval for this version to be published.

- Mayeux contributed to the acquisition of data, carefully revised the article, and gave final approval for this version to be published.
- D. Rodenstein contributed to the conception and design, the interpretation of data, carefully revised the article, and gave the final approval for this version to be published.
- V. Jounieaux contributed to the conception and design, the interpretation of data, drafted the article, and gave final approval for this version to be published.

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Conflict of interest

None.

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