Clinical evaluation of a computer-controlled pressure support mode

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Abstract

We designed a computerized system allowing a closed-loop control of the PSV level. The system reaches the lowest level of PSV to keep respiratory rate (RR), tidal volume (Vt) and end-tidal pressure of CO_2 within a certain range (i.e. 12<RR<28 cycles/min, Vt>300 ml or 250 if weight < 55 Kg, $P_{et}CO_2$ < 55 mmHg or 65 if chronic CO_2 retention), defining acceptable ventilation. Ten patients were randomly ventilated during 2 periods of 24 hours with the computer-controlled (automatic) PSV or with physician-controlled (standard) PSV, where PSV was modified by the clinician in charge. An estimation of the occlusion pressure (P0.1) was continuously recorded. The average time spent with the defined acceptable ventilation was found to be 66±24% of the total duration of ventilation with standard PSV and 93±8% with automatic PSV (p<0.05), while the level of support was similar in the two periods (17±4 cmH_2O and 19±6 cmH_2O). The time spent with an estimated P0.1 above 4 cmH_2O amounted to 34±35% of the time with standard PSV and decreased to 11±17% with automatic PSV (p<0.01). The automatic PSV system allowed the patient to spend more time within physician predefined limits and presumably could reduce periods of excessive workload.

MESH Keywords Aged ; Computers ; Female ; Humans ; Male ; Monitoring, Physiologic ; Respiration, Artificial ; methods ; Respiratory Insufficiency ; therapy ; Ventilator Weaning ; Ventilators, Mechanical

Mechanical Ventilation ; Weaning ; Ventilation Controller ; Closed Loop System ; Knowledge-Based System

Pressure support ventilation (PSV) is a mode of partial respiratory support that is widely used to assist patients, especially during gradual withdrawal from mechanical ventilation (1, 2, 3, 4). Because PSV is not a volume-controlled mode, any change in respiratory mechanics modifies the delivered volume. Also, changes in respiratory demand may require adjustment of the PSV level, depending on the time course of the recovery of the patient's respiratory status. The PSV level must be adjusted for each patient to assist his/her spontaneous activity within a reasonable range of effort (3). Because adjustments are often based on objective data, the automatic control of ventilator settings via a computerized system is conceivable. The expected advantages of the use of such a system include the continuous delivery of an optimized mechanical assistance and the rationalization of the weaning process based on predefined guidelines. We previously have described a knowledge-based system working in closed-loop, which uses simple indexes to appreciate the patient's needs and adjusts accordingly the level of mechanical assistance (5, 6). We have shown that this system can be used successfully during the weaning period to determine the right time for extubation and can advantageously replace the classical battery of preweaning tests and 2 hour T-piece trial (7).

The objective of the present clinical study was to test, during the ventilation process and before the weaning period has clearly started, the capability of such an autonomous system to efficiently ventilate patients and prevent respiratory failure. To assess the benefits obtained when using an automatic regulation of the PSV level, we compared this computer-controlled PSV mode (automatic PSV) to physician-controlled PSV mode (standard PSV). In particular, we specifically assessed the efficacy of the automatic PSV to avoid periods with high breathing workload. We used the occlusion pressure as a surrogate for work of breathing (8, 9).

PATIENTS AND METHODS

Patients

Ten patients were selected for the study. All patients were ventilated with PSV mode after they recovered from the initial cause of acute respiratory failure. Main patients characteristics are shown in Table 1. Criteria for including the patients in the study were: 1) a high likelihood of requiring mechanical ventilation for the next 48 hours; 2) mechanical ventilation delivered with PSV alone with a level of 10 cmH_2O or more; 3) hemodynamic stability; 4) patient's (or next of kin's) agreement to participate in the study.

Material

All patients were ventilated with a Veolar ventilator (Hamilton Medical, Bonaduz, Switzerland) set in the PSV mode. For the computer-controlled PSV mode, a computer was connected via two RS-232 digital outputs to the Veolar, to directly control the ventilator settings and to receive information about the patient, assessing RR, Vt and the PSV level through the ventilator. Another serial port

connected to a main stream gas monitor (Novametrix 1260, Wallingford, CT) assessed end-tidal PCO_2 ($P_{et}CO_2$). All data were sampled every 10 seconds and averaged over 2 minutes. Evaluation of the current respiratory status of the patient was based on these measurements and their time-course. The functionalities of the system relied on clinician's knowledge modeled using forward chaining production rules. Details about the medical knowledge representation can be found in a previous report (6). Briefly, the working principle is based on two goals: 1) to keep the ventilation in an "acceptable range" by periodically adjusting the PSV level and 2) to use the lowest PSV level compatible with ventilation. Definition of acceptable ventilation was: a respiratory rate (RR) between 12 and 28 breaths per minute, a tidal volume above a minimum threshold (250 ml, or 300 ml if patient's weight > 50 Kg), and a $P_{et}CO_2$ below a maximum threshold (55 mmHg, or 65 mmHg for patients with chronic CO_2 retention, like chronic obstructive pulmonary disease (COPD)). When the respiratory rate was above 28 breaths/min and both $P_{et}CO_2$ and tidal volume were acceptable (intermediate RR), the assistance was increased by 2 cmH_2O; if respiratory rate exceeded 35 breaths/min (high RR), pressure support was increased by 4 cmH_2O. When respiratory rate was less than 12 breaths/min, PSV was decreased by 4 cmH_2O (low RR). When tidal volume or $P_{et}CO_2$ were outside the defined limits (low Vt or High $P_{et}CO_2$), the level of pressure support was increased by 2 cmH_2O. In case of persistent apnea (duration > 30 seconds) the ventilatory mode was automatically switched to assist-control as a safety feature. The level of pressure support level was modified taking into account the patient's breathing pattern history, and what is referred to as transient instabilities. For example, a PSV level below 15 cmH_2O was automatically decreased by 2 cmH_2O in case of adequate ventilation for 30 minutes, whereas a PSV level higher than 15 cmH_2O was decreased by 4 cmH_2O in case of acceptable ventilation for 60 minutes. In addition, to avoid unnecessary modifications of PSV, the system tolerated transient instabilites for 2 min or 4 min with a PSV level lower or higher than 15 cmH_2O. PSV level was increased by 2 cmH_2O in case of tachypnea or insufficient ventilation during 2 minutes with a PSV level lower than 15 cmH_2O and was increased by 4 cmH_2O with a PSV level higher than 15 cmH_2O. The patient's status was evaluated every 2 min. Following a change of the PSV level of 4 cmH_2O, an observation lasting 4 min was introduced before performing a new evaluation of patient's status. A message could be displayed on the computer screen when unacceptable ventilation persisted for more than 3 expertises (12 minutes) despite modifications of the PSV level. This situation has never been encountered during this study.

Eventually, when a low level of PSV (equal to 9 cmH_2O, or 5 cmH_2O in case of tracheotomized patient) was tolerated by the patient for 2 hours, a proposal about ventilator disconnection was displayed on the computer screen. Again, transient instabilities were tolerated. The specific efficacy of this aspect has been assessed in a previous work (7).

All ventilator alarms remained available throughout the period of automatic control. The computer-controlled mode did not require any external intervention, except before connection of the patient, where relevant information about the patient needed to be entered (e.g., name, weight, intubation or tracheotomy, presence of COPD). The system was able to differentiate apnea from disconnection and thus, the computer-controlled PSV mode did not interfere with usual patient management, such as endotracheal suctioning.

For standard PSV mode (physician-controlled) the same computer was connected to the ventilator but was only used for recordings of the physiological parameters and ventilator settings, which could be modified at any time by the physician in charge. We thought it was important to tell as little as possible to the clinicians in charge, in order to keep the management as standard as possible. The clinicians in charge were not aware about the details of the algorithm used by the computer controlled system. A message displayed on the computer screen indicated if the automatic control was active or not. For safety purposes, when the system was active the clinician could stop at any time the system and manually control the ventilator. When the computer was not active, the clinician in charge could modify freely the assistance. The physicians were thus relatively naive about the system and it is likely that the presence of the computer did not change their behavior.

In addition to the above mentioned parameters, the occlusion pressure (P0.1) defined as the airway pressure (Paw) generated 100 ms after the onset of an occluded inspiration, and previously used as an estimate of the neuromuscular drive of respiration (10), was continuously measured to provide an indirect assessment of patient's effort (8, 9). New ventilators or monitors integrate functions that provide measurements of P0.1, essentially during an on-demand end-expiratory pause. Although this method of measurement is reliable, it is not convenient for on-line monitoring, and a direct method applicable when patients are assisted with partial support seemed preferable. Because the presence of a closed triggering system generates a short pause related to the patient's effort to trigger the ventilator, P0.1 can be estimated from the measurement of the negative airway pressure (Paw) generated by the inspiratory patient's effort to open the demand valve of the ventilator (11, 12). Because the duration of the occlusion may often be shorter than 100 ms, P0.1 was obtained from an extrapolation of Paw measured during 50 ms before the opening of the ventilator demand valve. In our study, P0.1 (referred to as « estimated P0.1 ») was measured using the computerized system B-analyzer (Hamilton, Switzerland). This system used the pressure and flow analog signals measured with the sensors attached to the ventilator as inputs, and a PCO_2 analog signal measured directly with the main stream gas monitor. The B-analyzer system calculated in real-time the estimated P0.1 with an algorithm that uses the flow and PCO_2 signals to determine accurately the end-of expiration, and performs a linear regression with six Paw values and an extrapolation to determine the value at 100 ms. Similarly to the other physiological parameters measured, estimated P0.1 was sampled every 10 seconds

and averaged over 2 minutes. Estimated P0.1 could not be recorded in one patient (#9) for technical reasons. Estimated P0.1 was used as a surrogate for work of breathing (8, 9). We were interested to compare the time spent with high P0.1 values with each system. We choose a threshold value of 4 cmH_2O as proposed by Conti et al. during pressure support ventilation (13).

Protocol

The protocol was approved by the local Ethics Committee. Each patient was ventilated during two consecutive periods of 24 hours with the computer-controlled PSV mode (automatic PSV) and with physician-controlled PSV mode (standard PSV), in a randomized order. In standard PSV, the physician in charge modified the value of pressure support as judged necessary. The initial level of PSV in the two modes was set by the physician in charge.

Statistics

We studied the differences between the two modes of ventilation regarding the different parameters and the time spent having these parameters out of predefined boundaries, using a Wilcoxon test for paired values. A p level lower than 0.05 was considered as significant.

RESULTS

All ten patients were ventilated with the two modes. Table 1 summarizes the characteristics of the patient population studied. The average duration of ventilation for the patients was 27±17 days.

Patients were ventilated 23±3 hours and 24±4 hours with the standard and the automatic PSV respectively. In Table 2, the average values of the physiological parameters recorded during the two periods of ventilation are reported, as well as the average values of the PSV level. There was no significant difference ($p > 0.05$) for all the parameters shown on Table 2 between the two modes, and the average PSV level was similar with the two modes (17±4 cmH_2O and 19±6 cmH_2O for standard and automatic PSV respectively).

For all the patients, the time spent in acceptable ventilation, i.e., when RR was 12<RR<28 cycles/min, Vt>300 ml or 250 if weight < 55 Kg, and $P_{et}CO_2$ < 55 mmHg or 65 if COPD, was increased, and the duration of critical situations was decreased when using automatic PSV, as shown on Table 3. The average time spent with acceptable RR, Vt and $P_{et}CO_2$ parameters was 64 ± 23% of the total duration of ventilation with standard PSV and 91± 8% with automatic PSV (p=0.003). Three patients spent twice or more time with an acceptable ventilation using the automatic PSV. The number of changes in the pressure support level were considerably higher with automatic PSV (56±40) than the number of physician or personnel interventions during standard PSV (1±2).

The duration of inadequate ventilation was divided as follows: 1) Ventilation with Intermediate RR when RR was inside the interval [28, 35] and Vt and $P_{et}CO_2$ were within the limits and 2) Critical ventilation when a) RR was lower than 12 breaths/min (Low RR), b) RR was superior to 35 breaths/min (High RR), c) Vt was lower than the threshold (Low Vt) or d) $P_{et}CO_2$ was superior to the threshold (High $P_{et}CO_2$). The time spent in critical ventilation was 23 % of the total duration of ventilation with standard PSV and 3 % with automatic PSV ($p<0.05$). The main cause of inadequate ventilation, i.e., outside the acceptable range, was due to respiratory rate values outside the defined limits. When ventilated with standard PSV, patients spent respectively 12% of the total duration of ventilation with a RR > 28 and · 35, and 4% when using automatic PSV (p=0.02). Patients spent 14% of the total duration of ventilation with a RR > 35 breaths/min with standard PSV and 1% with automatic PSV (p=0.03). For all patients, the automatic PSV mode decreased the duration of the ventilation with high RR. These results appear on Figures 1 and 2.

Lastly, the time spent with estimated P0.1 · 4 cmH_2O was compared between the two periods. It decreased in 8 of the 9 patients studied with automatic PSV, and went from 34· 35% of the time with standard PSV to 11 · 17% ($p< 0.01$). Results are shown on Table 4.

DISCUSSION

One of the main goals of mechanical ventilation is to reduce the patient's effort or work to breathe. In our computer-controlled PSV mode, we use three parameters to automatically control the level of assistance: RR, Vt and $P_{et}CO_2$. The respiratory rate, which seems to reflect how well the respiratory muscles are adapted to the imposed workload (14), was the main parameter used to adapt the level of mechanical assistance, while Vt and $P_{et}CO_2$ were used as safety limits. With the standard PSV, the period spent with inadequate ventilation was mainly due to respiratory rate above the defined limits, which confirms the results of our preliminary study (5). To counteract high respiratory rates, the computer-controlled system increased the level of pressure. This could lead to an increase in tidal volume as observed in patients #7, #8 and #5. In parallel when the ventilation was acceptable during a certain period of time depending of the current PSV level, the system automatically decreased the level of PSV. The PSV level was also decreased in case of hyperventilation (RR < 12 cycles/min). The system tried to use the lowest level of PSV tolerated by the patient. Consequently, the automatic PSV mode prevented critical situations. The average PSV level, however, was not significantly different than in standard PSV, because in some patients the

level of PSV was increased in APSV, to counteract episodes of tachypnea. It is conceivable, however, that specific additional automatic maneuvers may be introduced into the system, in order to test intermittently whether the PSV level could be more drastically reduced and then hasten for some patients the weaning process.

The hypothesis we had in designing our computer-controlled PSV mode, was that the continuous adaptation of the PSV level to maintain an acceptable ventilation would facilitate the recovery of the patient's status and the future withdrawal of mechanical ventilation (5, 7). High values of P0.1 and RR/VT are associated with poor weaning success. For at least two patients (cases 4 and 6) the work to breathe reflected by estimated P0.1, was substantially higher with the standard PSV (respectively 4.5 cmH_20 and 6.2 cmH_20 compared to 2.9 cmH_20 and 3.5 cmH_20 with the automatic PSV). The rapid shallow breathing index was 82 and 91 breaths/min/L in standard PSV compared to 51 and 56 breaths/min/L in automatic PSV. For these patients automatic PSV directly improved the overall breathing workload during assisted ventilation. In standard PSV, patient 3 was hyperventilated during 49% of the duration of the ventilation. In the same situation the automatic system would decrease the level of assistance by 4 cmH_20 as soon as hyperventilation would be detected.

Overall, the time spent with high estimated P0.1 values was significantly decreased with automatic PSV. The percent of the duration of ventilation spent with an estimated P0.1 higher than 4 cmH_20, was mainly influenced by four patients (#2, #4, #6 and #10) who spent >50% of the time with high P0.1 values in standard PSV. If a threshold for P0.1 equal to −3 cmH_20 had been chosen, the difference would not remain significant (51 ± 43 with SPS vs 34 ± 41 % with APS). However, the lower is the threshold, the lesser one can expect to find differences. Indeed, the system is not designed to constantly reduce respiratory rate, and presumably respiratory effort, compared to standard PSV, but only to avoid unnecessary episodes of tachypnea and high P0.1. It is therefore very likey that differences will be found only if we consider specifically these out-of-range periods. Both Alberti et al. (8) and Mancebo et al. (9) have shown good correlations between P0.1 and the work of breathing. This suggests that the automatic PSV prevented from prolonged periods with excessive levels of work. This could have important implications to facilitate recovery from or avoid respiratory muscle fatigue (15). P0.1 could be used to improve the PSV regulation loop. This parameter was introduced in a servo-controlled system by Iotti et al. (16). Determining the optimal P0.1 value for an individual patient is still empirical, however, and optimal threshold values for weaning are still a matter of debate (17, 18 , 19, 20). Whether P0.1 could be used as a second line parameter and for safety purposes needs to be determined.

The comparison between the days with or without APS allow to understand why the system increased the PSV level and the tidal volume in some patients. It is interesting to see that the system succeeded to reach the predetermined goals. For instance, figure 3 shows the evolution of the breathing pattern and the PSV level for patient #7. This patient had a f/Vt ratio frequently around or above 100 (probably a very high value under PSV) without the system and, intuitiveley, it seems that the response of the APS was very adequate, i.e., to increase the PSV level. In patient 8, frequent episodes of transient tachypnea were avoided by the APS. In patient #5, the patient was very frequently at the upper limit for RR without the APS, which probably explains the higher PSV and Vt levels with APS. In addition very short periods of tachypnea (RR > 35 cycles/min) also participated to an increase in PSV. One could argue that in such a patient, the threshold for RR could have been kept slightly higher and that a much lower level of PSV would have been required. It is conceivable to decide on an individual basis what could be the upper threshold for RR, based on the patient's history and his/her clinical tolerance.

PetCO2 was not different between SPS and APS and there are probably at least two reasons why mean PetCO2 may be the same with the two systems despite a different amount of time spent with rapid shallow breathing. First, to assess the ventilatory status of the patient, our system used one main parameter, the Respiratory Rate. Tidal Volume and end-tidal PCO2 were mainly used for safety purposes. The constraints set on this last parameter were mainly to check that it remained below PetC02= 55 mmHg or 65 for COPD patients. So there was no precise goal on this parameter. More importantly, there was a number of situations where the system could help to avoid hypocapnia: this could happen indirectly, when the system decreased the pressure support level because the Respiratory Rate was below the lower limit, or in case of apnea associated with a high tidal volume and a low PetCO2 value. Therefore for several patients, the PetCO2 could be higher with the APS because of these adaptative functions.

Computers will be more and more present in hospitals and especially in intensive care departments for automatic patient monitoring. Only few systems exist in the literature that control in closed-loop the ventilator settings. Recent knowledge-based systems for patient monitoring analyze the time course of the ventilation and advise physicians about the best therapy to apply. They deal in general with complex problems such as ventilation of newborn infants (21) or design of general architectures for intensive-care monitoring (22, 23) and explore sophisticated techniques coming from Artificial Intelligence. They do not act on the ventilator and their clinical evaluation is difficult. Another direction for research is to propose new modes of ventilation based on algorithms that integrate physiological models to facilitate the weaning process. ARIS (24) or ALV (25) implemented in prototype ventilators are good examples of this type of research. In ALV, automatic ventilation adjustments are based on measurements of the patient's lung mechanics and series dead space, and designed to achieve minimal work of breathing and avoid intrinsic PEEP. With the main goals of avoiding hyperinflation and restoring progressively spontaneous ventilation, ARIS allows the patient to determine his/her own RR, Vt and inspiratory/expiratory ratio compatible with an optimal level of minute ventilation and minimal tidal volume fixed by the clinician. Because the introduction in the clinical environment of a new mode of ventilation is a time-consuming process, we have chosen −1) to ventilate patients with PSV, a mode widely used during weaning and −2) to add specific empirical knowledge to improve the use of this mode and facilitate the weaning process. We benefited

from a large clinical experience and from the literature. This accumulated knowledge allowed us to design a computer-controlled PSV mode working at the patient's bedside. Our work is close to the work of Strickland and Hasson (26, 27). They proposed a closed-loop system that modifies the setting of synchronized intermittent mandatory ventilation and of the pressure support for the intervening breaths based on RR, Vt and pulse oxymeter oxygen saturation measurements. One main technical difference between the two approaches is that our system implemented a specific 14 temporal reasoning (6) to take into account the time-course of the ventilation. The system observes the ventilation history to adjust the pressure support level. Our system is designed to adapt the PSV level whatever the stage of the weaning process. Consequently, this clinical study compared the evolution of patients placed under PSV at an early stage before the weaning period has clearly started. This differs from the clinical evaluation presented by Strickland and Hasson (27) where only candidates for weaning were studied.

The main result of this study was that the automatic system was able to keep the patient within predefined limits for physiological respiratory parameters. We believe that this may advantageous in terms of breathing workload and energy expenditure, as suggested by the results of estimated P0.1 measurements. One may argue, however, that the limits were arbitrarily defined and that they may need to be individually tailored. The use of knowledge-based systems allows the user to easily understand the basic rules of the system. It is therefore easy to imagine that such limits could be tailored to individual patients. We choose the upper acceptable frequency to be 35 breaths/min, but started to react when the respiratory rate was above 28 breaths/min. It is conceivable that these limits may be increased for some patients with chronic respiratory disorders accustomed to breathe at higher frequencies for instance.

The automatic PSV system used in this study maintains RR, Vt and $P_{et}CO_2$ in acceptable ranges compared to physician-controlled mode. A future study might be to compare in a large randomized controlled trial, the effects on weaning duration and outcome of patients placed under pressure support mode at an early stage of their respiratory failure, with either the computer controlled system or using the standard approach of the ICU staff.

Ackowledgements:

We thank Josef X. Brünner and Hamilton Medical AG for providing us the B-analyzer system for physiological measurements and Florence Picot for typing the manuscript.

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Figure 1

Contributions to inadequate ventilation of Intermediate RR (28< RR · 35 breaths/min,) High RR: (RR >35 cycles/min), Low RR: (RR <12 breaths/min), Low Vt: (Vt<300 ml or 250 ml if weight >55 Kg), and High $P_{et}CO_2$ ($P_{et}CO_2$ < 55 mmHg or 65 if COPD) during 24h of standard PSV in the 10 patients studied. For ventilation in standard PSV, inadequate ventilation represented 36% of the total duration of ventilation in this mode whose 24% were spent with critical ventilation. Definition of abbreviations: SPS: standard pressure support ventilation (physician-controlled), APS: automatic pressure support ventilation (computer-controlled).

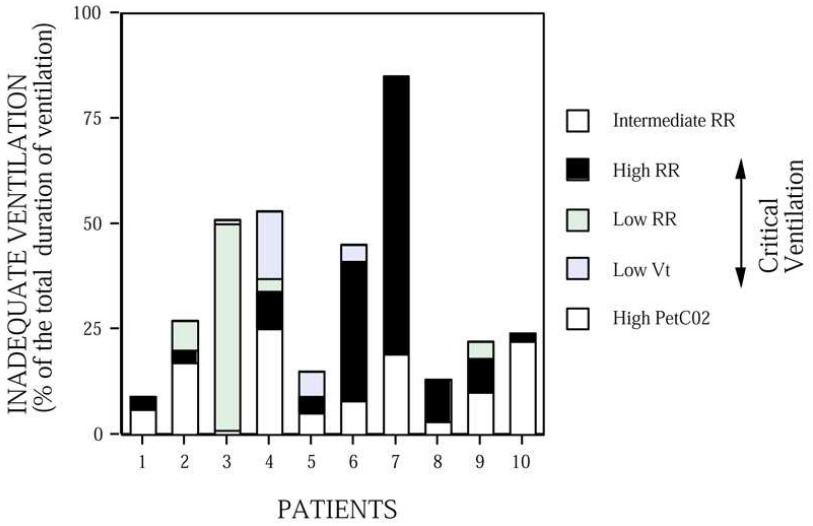

Figure 2

Contributions to inadequate ventilation of Intermediate RR (28< RR ·35 breaths/min,) High RR: (RR >35 cycles/min), Low RR: (RR <12 breaths/min), Low Vt: (Vt<300 ml or 250 ml if weight >55 Kg), and High $P_{et}CO_2$ ($P_{et}CO_2$ < 55 mmHg or 65 if COPD) during 24h of automatic PSV in the 10 patients studied. For ventilation in automatic PSV, inadequate ventilation represented 9% of the total duration of ventilation in this mode whose 5% were spent with critical ventilation. Definition of abbreviations: SPS: standard pressure support ventilation (physician-controlled). APS: automatic pressure support ventilation (computer-controlled).

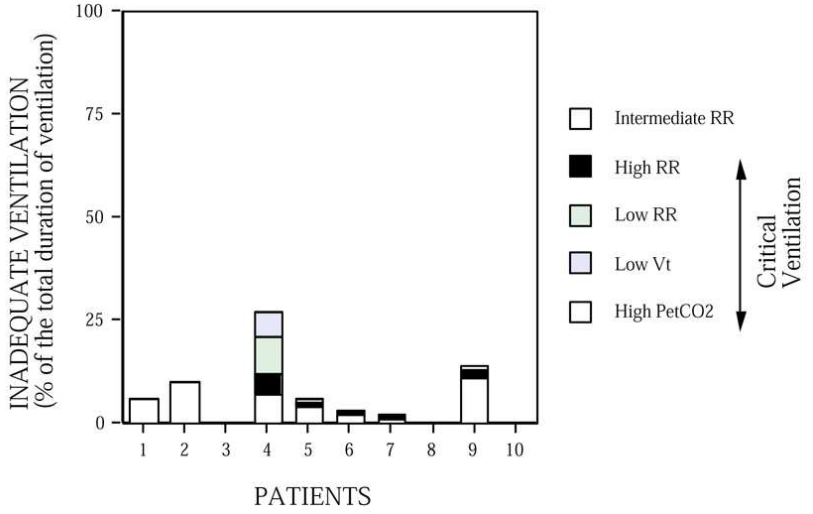

Figure 3

These two figures show for patient #7 the evolution of both the PSV and the RR levels (left panel), and the evolution of RR/Vt (right panel) over the two periods of 24 hours of ventilation either with (APS) or without (SPS) the automated system. Note that the very high values of the rapid shallow breathing index (f/Vt) during SPS were no more present during APS.

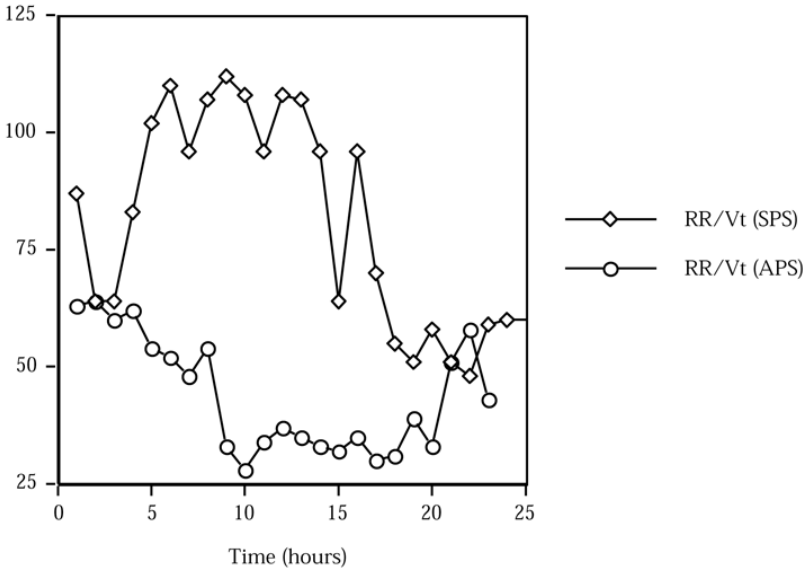

Table 1

Characteristics of the 10 study patients

	Age	Sex	SAPSII (28)	Diagnosis	Duration of ventilation (d)	Outcome
1	71	M	57	Stroke	28	D
2	75	F	31	Cardiac surgery-DD	18	S
3	63	F	30	Esophageal resection - Pneumonia	37	D
4	84	F	54	Obesity-Chronic Respir Failure	15	S
5	81	F	60	Obesity-Chronic Respir Failure	19	D
6	75	F	48	Cardiac surgery-Obesity	70	S
7	49	F	23	Cardiac surgery-DD	17	S
8	76	M	68	Cardiac surgery-Septic Shock	16	D
9	80	F	32	Cardiac surgery-Pneumonia	15	S
10	61	M	53	Liver transplant-DD	32	S
Mean (SD)	72 (11)	-	46 (15)	-	27(17)	-

Abbreviations: SAPS = Simplified Acute Physiology Score; Duration of ventilation = total duration of mechanical ventilation in days; S = survived; D = died; COPD = chronic obstructive pulmonary disease, DD = Diaphragmatic dysfunction

Table 2

Mean values of the physiological parameters and PSV level during automatic PSV and standard PSV

	RR (breaths/min)		Vt (ml)		RR/Vt (breaths/min/L)		$P_{et}CO_2$ (cmH_2O)		estimated P0.1 (cmH_2O)		Mean PSV level (cmH_2O)	
Patient#	**sPSV**	**aPSV**	**sPSV**	**aPSV**	**sPSV**	**aPSV**	**sPSV**	**aPSV**	**sPSV**	**aPSV**	**sPSV**	**aPSV**
1	23	23	471	406	49	59	32	37	−1.2	−1.7	19	12
2	24	23	418	439	59	54	39	35	−4.2	−4	17	17
3	14	21	508	434	30	48	30	32	−3	−3.7	10	10
4	27	20	341	434	82	51	52	46	−4.5	−2.9	25	22
5	23	19	440	631	55	31	38	28	−2.1	−2.2	15	24
6	33	23	379	463	91	56	35	34	−6.2	−3.5	11	13
7	35	27	398	665	94	44	NA	NA	−1	−1.3	18	27
8	28	27	638	813	45	34	NA	NA	−1.7	−1	17	24
9	21	23	658	659	36	36	25	31	NA	NA	17	21
10	29	23	607	687	48	36	24	24	−3.8	−3	19	22
Mean (SD)	**26 ± 6**	**23 ± 3**	**486 ± 113**	**564 ± 144**	**59 ± 23**	**45 ± 10**	**34 ± 9**	**33 ± 7**	**−3.1 ± 1.7**	**−2.6 ± 1.1**	**17 ±4**	**19 ± 6**

Abbreviations: RR, Respiratory Rate; Vt, tidal volume; RR/Vt, rapid shallow breathing; P0.1, estimated occlusion pressure,
$P_{et}CO_2$, end-tidal expired CO_2 pressure; PSV, pressure support ventilation; NA: not available continuously; sPSV, standard pressure support ventilation; aPSV, automatic pressure support ventilation
No statistical differences were found between aPSV and sPSV for any of the study parameters.

Table 3

Time spent with an acceptable ventilation during automatic PSV and standard PSV

	Duration of ventilation (min)		Period with acceptable ventilation		Period with acceptable RR		Period with acceptable Vt		Period with acceptable $P_{et}CO_2$		Changes in PSV Level	
	sPSV	**aPSV**	**sPSV**	**aPSV**	**sPSV**	**aPSV**	**sPSV**	**aPSV**	**sPSV**	**aPSV**	**sPSV**	**aPSV**
1	1483	1441	91	94	91	94	100	100	100	100	3	67
2	1437	1281	73	90	74	90	99	100	100	100	0	87
3	1441	902	49	100	50	100	99	100	100	100	4	10
4	1420	1681	47	74	63	79	84	91	100	100	0	120
5	1542	1345	85	94	90	94	95	100	100	100	2	41
6	1485	1433	54	97	59	97	96	100	100	100	0	41
7	1039	1445	15	99	15	99	100	100	100	100	0	20
8	1465	1582	88	100	87	100	100	100	100	100	0	9
9	1160	1703	78	86	78	87	100	100	100	99	1	110
10	1409	1468	76	100	76	100	100	100	100	100	4	58
Mean (SD)	**1388 ± 159**	**1428 ± 229**	**66 * ± 24**	**93 ± 8**	**68 * ± 23**	**94 ± 7**	**97 ± 5**	**99 ± 3**	**100**	**100**	**1 * ± 2**	**56 ± 40**

Periods are expressed as the percentages of the total duration of ventilation with the corresponding mode. Acceptable ventilation is defined as: 12<RR<28 breaths/min, Vt>300 ml (250 if weight < 55 kg), and $P_{et}CO_2$ < 55 mmHg (65 if COPD).

Abbreviations: RR, respiratory Rate; Vt, tidal volume; $P_{et}CO_2$, end-tidal expired CO_2 pressure; PSV, pressure support ventilation; sPSV, standard pressure support ventilation; aPSV, automatic pressure support ventilation

* indicates a significant difference ($p < 0.05$) between aPSV and sPSV

Table 4

Percentage of the total duration of ventilation spent with a high level of estimated P0.1 (≥ 4 cmH_2O) with automatic PSV and standard PSV

	Period with estimated P0.1≥4 cmH_2O	
Patient *	**sPSV**	**aPSV**
1	2	0
2	64	48
3	27	22
4	61	0.1
5	2	2
6	95	22
7	0.1	1
8	4	0.1
10	52	1
Mean (SD)	**34 * ± 35**	**11 ± 17**

Abbreviations: P0.1, occlusion pressure; sPSV, standard pressure support ventilation; aPSV, automatic pressure support ventilation

* $p<0.01$ versus aPSV