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Effects of patient-triggered automatic switching between mandatory and supported ventilation in the postoperative weaning period

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Abstract *Objective*: To compare two ventilator settings in the postoperative weaning period. Patient-triggered automatic switching between controlled ventilation and supported spontaneous breathing (Automode, AM) was compared to synchronised intermittent mandatory ventilation (SIMV) with stepwise manual adjustment of mandatory frequency according to the breathing activity.
Design: Prospective clinical investigation.
Setting: Eighteen-bed intensive care unit in a university hospital.
Patients: Forty postoperative patients with healthy lungs who had undergone brain tumour surgery.
Interventions: Randomisation either to the AM or SIMV weaning procedure after entering the ICU.
Measurements and results: Total weaning time and number of manipulations on the ventilator were observed. Cardiocirculatory and respiratory parameters were measured consecutively at five points during the weaning period. No significant differences were seen for cardiocirculatory parameters, airway pressures and oxygenation between the two groups. There was a trend to shorter weaning times with AM (136 ± 46 min vs 169 ± 68 min, n.s.), the average number of manipulations on the ventilator was lower (0.55 ± 0.69 vs 5.05 ± 1.19, $p < 0.001$) and arterial partial pressure of carbon dioxide ($PaCO_2$) levels showed fewer variations in the late phase of the weaning period (39.5 ± 3.1 vs 38.3 ± 7.2, $p < 0.001$ for differences in variance).
Conclusions: Automatic, patient-triggered switching between controlled and supported mode of ventilation can be used for postoperative weaning of neurosurgical patients with healthy lungs. Compared to a SIMV weaning procedure, fewer manipulations on the ventilator are necessary and individual adaptation of ventilation seems to be more accurate.

Key words Automatic weaning · Interactive ventilation · Clinical study

Introduction

Since the 1950s respirator therapy has been almost synonymous with mechanical control of breathing. The underlying philosophy was to put the patient at rest in order not to interfere with the ventilatory pattern delivered. With the development of more sophisticated ventilators and improved triggering devices, the work of breathing can nearly be eliminated by delivering an adequate degree of support to the patient [1, 2, 3], even though the patient initiates the breath and controls the breathing pattern to a large degree. Synchronisation of ventilation with the patient's spontaneous inspiratory efforts is associated with lower airway pressures, im-

Table 1 Data measured once: patient characteristics, duration of surgical procedures and cumulative doses of anaesthetics before randomisation, weaning time (from randomisation to extubation) and number of necessary manipulations on the ventilator and/or automatic switches (AM) during the weaning period given as mean ± SD (except sex, age). Cumulative values for all patients of a group are given in parentheses (*AM* Automode, *SIMV* synchronised intermittent mandatory ventilation, *PSV* pressure support ventilation, *PCV* pressure controlled ventilation)

Parameter	AM	SIMV	*p*
Sex	15 m/5 f	8 m/12 f	–
Age (years)	24–87	23–84	
Mean age (years)	55.1 ± 16.1	53.8 ± 15.7	0.68
Duration of anaesthesia (min)	248 ± 79	248 ± 50	0.79
Duration of surgery (min)	166 ± 67	180 ± 45	0.50
Cumulative doses of anaesthetics			
Vecuronium (mg)	13.1 ± 5.3	11.6 ± 3.8	0.44
Fentanyl (mg); AM: 10, SIMV: 9	1.6 ± 0.9	1.4 ± 0.3	0.82
Sufentanil (μg); AM: 10, SIMV: 11	157 ± 54	140 ± 37	0.42
Propofol (mg)	437 ± 153	405 ± 134	0.59
Midazolam (mg); AM: 7, SIMV: 7	16.8 ± 14.1	9.3 ± 3.5	0.30
Weaning time (min)	136 ± 46	169 ± 68	0.18
Number of ventilator manipulations			
Total	0.55 ± 0.69 (11)	5.05 ± 1.19 (101)	< 0.001
Adjustment of mandatory rate	0.55 ± 0.69 (11)	3.75 ± 1.19 (75)	–
Switching to PSV	–	1.15 ± 0.37 (23)	–
Switching back to SIMV	–	0.15 ± 0.37 (3)	–
Automatic switching PCV → PSV	9.1 ± 3.2 (182)	–	–
Automatic switching PCV → PSV	8.1 ± 3.2 (162)	–	–

proved haemodynamics and a reduced rate of ventilator-induced lung injury [4, 5, 6, 7, 8]. Additionally, muscular activity of the diaphragm prevents atelectasis in the dependent lung regions [9]. Because the ventilator is adapted to the patient and not vice versa, there is less need for sedation or even relaxation with their well known side effects [10].

As a result of these considerations, spontaneous breathing should be established whenever, and as early as, possible. Nevertheless, the transition from a controlled to a spontaneous mode of ventilation is still regulated by switching the patient manually, often through the use of SIMV. In times of shortage of personnel the ICU staff members are not able to observe the patient's breathing activities permanently. Changes in breathing activity can therefore lead to struggling with the SIMV mode and repeated alarm beeps due to either hyperventilation or hypoventilation (depending on the pre-set alarm levels). To prevent such a phenomenon AM, an algorithm for an automated switch between control and support mode of ventilation according to the patient's breathing activity, was developed. In contrast to complex closed-loop systems, which automatically calculate respiratory rate (RR), pressure limits and background mandatory rate by measuring lung mechanics [11, 12, 13], AM simply uses the following algorithm: whenever the patient triggers two consecutive breaths, the mode switches from a control mode to a support mode of ventilation and back to control mode in the event of apnoea for more than 12 s.

In this study the combination of a pressure control mode (PCV) with a pressure support mode (PSV) was used in both groups. In contrast to SIMV, where the rate of mandatory breaths was reduced stepwise with increasing spontaneous breathing activity, AM switched between completely controlled ventilation and supported ventilation in the event of spontaneous breathing activity and back in the event of apnoea. The objective of this study was to assess if AM (a) really works and (b) effects weaning time, number of required manipulations on the ventilator or cardiocirculatory and respiratory parameters when compared to a manually regulated weaning procedure with the use of SIMV/PSV.

Materials and methods

Patients and study design

Forty patients with healthy lungs who underwent brain tumour surgery were consecutively randomised either to the SIMV or the AM weaning procedure after entering the ICU. The patients' characteristics are shown in Table 1. Included were those patients who required controlled ventilation and who were expected to show spontaneous breathing efforts during the first 24 h after admission to the ICU. Patients with central depression of breathing drive expected to last for more than 24 h as well as patients with mechanical or neural damage making spontaneous breathing efforts impossible were excluded from the study.

Equipment, ventilator settings and criteria for extubation

A Siemens Servo Ventilator 300 (Siemens Elema, Sweden) with AM function was used for both groups. The SIMV group was ventilated with the AM function in the OFF position. A Servo Screen 390 with an attached printer was used for documentation. Immediately after admission to the ICU a stabilisation phase with pressure controlled ventilation (PCV) was performed in both groups for

Table 2 Data measured consecutively: respiratory and cardiocirculatory parameters (mean ± SD shown except $PaCO_2$ range where minimum/maximum is shown) during the weaning period. RR, MV and P_{aw} are not measured at T_{post} because the patients were extubated before (*RR* respiratory rate, *MV* minute ventilation, P_{aw} mean airway pressure, *MAP* mean arterial pressure, *Ox* oxygenation index, $PaCO_2$ arterial carbon dioxide partial pressure, $PaCO_2$ *range* difference between maximum and minimum $PaCO_2$ value) (0.133 kPa = 1 mmHg, 0.1 kPa = 1 mbar)

Parameter	Group	T_0	T_{20}	T_{140}	T_{ex}	T_{post}
RR (breaths/min)	SIMV	9.1 ± 1.4	9.9 ± 2.4	8.1 ± 1.7	8.6 ± 2.9*	-
	AM	9.0 ± 1.5	9.3 ± 1.8	9.8 ± 0.5	9.8 ± 2.2*	-
MV (l/min)	SIMV	5.8 ± 1.4	5.9 ± 1.9*	6.3 ± 1.8	8.0 ± 2.4	-
	AM	5.6 ± 1.3	7.1 ± 2.2*	6.5 ± 0.9	8.5 ± 2.9	-
P_{aw} (mbar)	SIMV	8.6 ± 0.6	8.4 ± 1.2	7.5 ± 1.0	9.1 ± 1.3	-
	AM	8.8 ± 0.7	8.7 ± 0.9	9.0 ± 1.2	9.5 ± 1.3	-
HR (beats/min)	SIMV	58 ± 15	63 ± 15	67 ± 15	66 ± 16	70 ± 14
	AM	57 ± 12	67 ± 16	67 ± 15	76 ± 17	77 ± 16
MAP (mmHg)	SIMV	101 ± 16	108 ± 19	107 ± 13	108 ± 16	106 ± 15
	AM	106 ± 16	110 ± 15	104 ± 20	110 ± 15	106 ± 14
Ox (PaO_2/FIO_2)	SIMV	391 ± 74	403 ± 76	402 ± 88	428 ± 25	334 ± 99
	AM	364 ± 86	381 ± 72	430 ± 43	408 ± 86	311 ± 92
$PaCO_2$ (mmHg)	SIMV	38.8 ± 2.7	41.9 ± 4.2	40.4 ± 6.0	38.3 ± 7.2**	39.3 ± 5.2
	AM	39.7 ± 3.7	40.9 ± 4.8	40.8 ± 2.9	39.5 ± 3.1**	40.4 ± 3.8
$PaCO_2$ range	SIMV	12 (31–43)	17 (32–49)	17 (33–50)	24 (22–48)	16 (30–46)
	AM	12 (33–45)	14 (34–48)	7 (38–45)	11 (34–45)	14 (34–48)

*$p < 0.05$ for differences between the two groups
**$p < 0.001$ for differences of variances between the two groups

20 min. Pressure levels were adjusted within a range of 10–15 cmH_2O to reach a tidal volume of 10 ml/kg body weight. RR was adjusted to reach normoventilation. Inspiratory to expiratory (I:E) ratio was set to 1:2, FIO_2 was set to 0.35–0.4 (PaO_2 > 90 mmHg) at a PEEP level of 5 cmH_2O. For pressure support ventilation (PSV), the flow trigger was activated and the pressure support level was adjusted to the same value as the pressure control level. Pressure support level, PEEPand FIO_2 were kept constant during the whole protocol until extubation. After randomisation, AM was activated in the AM group by automatically switching from PCV to PSV in cases of repeated triggering of the ventilator, and back in cases of apnoea of more than 12 s. In the SIMV group, mandatory frequency was initially reduced by 2 breaths/min if the ventilator indicated triggering by the patient. Mandatory frequency was further decreased in cases of stability and/or an increase in minute ventilation (MV) over the pre-set alarm levels. If MV dropped below the pre-set alarm levels, the mandatory rate was increased again. Adjustments were made by the nurses, supervised by a physician. Manual switching to PSV was done in cases of stable spontaneous breathing. Alarm levels for MV were set to 80 % and 120 % of the values measured in the stabilisation phase. Patients were considered to be ready for extubation when there was stable spontaneous breathing without switching back to controlled ventilation (AM) or the need for mandatory background frequency (SIMV). Additionally, the patient should have regained consciousness, be able to open his/her eyes, press a hand and lift up his/her head.

Data acquisition

Respiratory rate, MV, mean airway pressure (P_{aw}), heart rate (HR), mean arterial pressure (MAP), PaO_2/FIO_2 (Ox) and $PaCO_2$ were consecutively measured at five points: at randomisation (T_0), 20 min after the first spontaneous breathing activity (T_{20}), 2 h after T_{20} (T_{140}), before extubation (T_{ex}) and 1 h after extubation (T_{post}, without RR, MV, P_{aw}). RR, MV and P_{aw} were taken from the display of the Siemens Servo 300 A ventilator (Siemens Elema, Solna, Sweden), whereby desynchronisation had been excluded, HR and MAP were measured with a Sirecust 1281 monitor (Siemens Medical Electronics, Danvers, Mass.) and a Novotrans II (Medex, Hilliard, Ohio) pressure transducer referenced to atmospheric pressure at the mid thorax level. T_{140} was reached only by a subgroup of the patients (AM: 5; SIMV: 9), because the others could be extubated earlier. Total weaning time (from T_0 to extubation) and the number of necessary manipulations on the ventilator during the weaning period for each patient were measured.

Statistical analysis

Mann-Whitney-Wilcoxon test was used for differences between the two groups for total weaning time, number of manipulations and all consecutive parameters (RR, MV, P_{aw}, HR, MAP, Ox, $PaCO_2$) at T_0, T_{20}, T_{140}, T_{ex} and T_{post}. To compare variability of ventilation, the *F* test was used to detect differences in the variance of $PaCO_2$ levels between the two groups at T_0, T_{20}, T_{140}, T_{ex} and T_{post}.

Results

All patients could be weaned successfully in both groups. No malfunction or phases of undetected apnoea occurred in the AM group. No differences in cardiocirculatory parameters, P_{aw} and oxygenation could be observed between the two groups, MV and RR were slightly higher under AM at T_{20} and T_{ex}, respectively (Table 2, $p < 0.05$). The average number of manipulations required on the ventilator during the weaning period was reduced from 5.05 ± 1.19 with SIMV to 0.55 ± 0.69 with AM (Table 1; $p < 0.001$). There was only a trend to

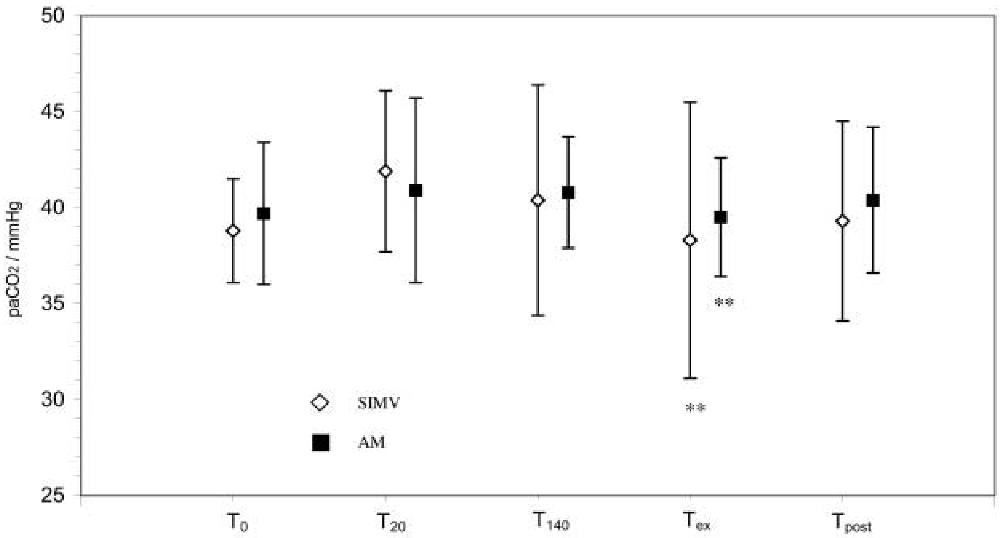

Fig. 1 Arterial partial pressure of carbon dioxide values during the weaning period (T_0–T_{ex}) and after extubation (T_{post}). Values are means ± SD (**$p < 0.001$ for differences in variance = SD^2 between the two groups)

shorten weaning time with AM (136 ± 46 vs 169 ± 68 min, Table 1). Variability of ventilation, described by the range of $PaCO_2$ levels, showed differences between the two groups: While variance of $PaCO_2$ values increased in the SIMV group until extubation, it was lower in the AM group during the whole weaning period. These differences reached a level of statistical significance at T_{ex} (Table 2 and Fig. 1; $p < 0.001$). Additionally, because almost no alarm beeps were heard in contrast to SIMV, weaning with AM was quiet and comfortable for both patients and staff.

Discussion

The AM function allows the patient to change from controlled mode to support mode of ventilation and back according to his/her breathing activity. In contrast to complex closed-loop systems [11, 12, 13], the software has been commercially available since 1998. This study shows a possible benefit of use of the mode in clinical routine when compared with manual stepwise reduction of mandatory frequency with SIMV. The advantage of the technology seems to be clear: by detecting the patient's breathing activity at every moment, adaptation can take place without any delay. In times of low budgets for staff, the tasks of those taking care become more and more complex and do not allow them to detect the patient's breathing activity at all times, so that manual adjustment of the ventilator setting often happens with a certain delay. The results of our study show that this can lead to episodes of hyper- or hypoventilation. As indicated by Fig. 1, variations in $PaCO_2$ increased with increasing spontaneous breathing activity (T_{140}, T_{ex}) in SIMV compared to AM. These differences were significant for T_{ex}, even if existing differences did not reach a level of statistical significance with the small number of patients at T_{140}. The assimilation of the $PaCO_2$ variances of the two groups after extubation (T_{post}) underlines the hypothesis that these differences were due to the ventilator settings and not caused by differences in the study population. AM seems to provide more accuracy in the individual adaptation of ventilation in this subgroup of patients. Stable $PaCO_2$ levels during the weaning period are especially important in our neurosurgical study group (all patients had undergone brain tumour surgery), because variations can cause alterations of the intracranial pressure.

Weaning with AM also seems to be more comfortable, because almost no changes in ventilator settings are necessary (Table 1) and acoustic alarms disappear. Total time on ventilator was shorter in the AM group, i.e. extubation was performed earlier as compared with SIMV. Because of the variations in weaning time, these differences did not reach a level of statistical significance and must be seen as a trend ($p = 0.18$).

It has to be pointed out that only postoperative patients with healthy lungs were included. The results cannot be transferred to patients after long-term ventilation with muscular atrophy or parenchymal lung injury without limitation. In these patients, in whom long-term weaning procedures with step-by-step reduction of ventilatory support and PEEP are necessary, ventilator adjustments should still be made manually by an experienced physician. Nevertheless, AM represents the first simple interactive mode of ventilation because the ventilator setting is controlled by the patient's breathing activity. Recent developments including modes that facilitate spontaneous breathing on the ventilator by compensating the elastance and resistance of the respiratory system, like proportional assist ventilation and automatic tube compensation [14, 15, 16, 17, 18, 19], may be a further step in optimising the interaction between patient and ventilator. An implementation of these new modes in the AM algorithm, instead of static PSV, will be an interesting further step to evaluate.

In conclusion we found that AM is safe, efficient and comfortable in weaning postoperative patients with healthy lungs. Especially patients after long operations who received high cumulative doses of opiates should have a benefit because they often show phases of spontaneous breathing that alternate with apnoea during the weaning period. Those patients will interfere with a rigid SIMV mode and better fit with the AM algorithm. These findings may be of clinical importance.

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