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Comparison between intermittent mandatory ventilation and synchronized intermittent mandatory ventilation with pressure support in children

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Abstract

Objective: To compare intermittent mandatory ventilation (IMV) with synchronized intermittent mandatory ventilation plus pressure support (SIMV+PS) in terms of time on mechanical ventilation, duration of weaning and length of stay in a pediatric intensive care unit (PICU).

Methods: This was a randomized clinical trial that enrolled children aged 28 days to 4 years who were admitted to a PICU between October of 2005 and June of 2007 and put on mechanical ventilation (MV) for more than 48 hours. These patients were allocated to one of two groups by drawing lots: IMV group (IMVG; n = 35) and SIMV+PS group (SIMVG; n = 35). Children were excluded if they had undergone tracheotomy or had chronic respiratory diseases. Data on oxygenation and ventilation were recorded at admission and at the start of weaning.

Results: There were no statistical differences between the groups in terms of age, sex, indication for MV, PRISM score, Comfort scale, use of sedatives or ventilation and oxygenation parameters. The median time on MV was 5 days for both groups (p = 0.120). There were also no statistical differences between the two groups for duration of weaning [IMVG: 1 day (1-6) vs. SIMVG: 1 day (1-6); p = 0.262] or length of hospital stay [IMVG: 8 days (2-22) vs. SIMVG: 6 days (3-20); p = 0.113].

Conclusion: Among the children studied here, there was no statistically significant difference between IMV and SIMV+PS in terms of time on MV, duration of weaning or time spent in the PICU.

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Introduction

Intermittent mandatory ventilation (IMV), which was first described in 1955 and is still used to provide ventilatory support for children with respiratory failure, is a ventilator mode in which predetermined mechanical cycles are provided while the patient breathes spontaneously between cycles with continuous flow.[1,2]

Ventilators that offer IMV mode are easy to operate, offer simple adjustment of ventilator parameters and cost less than more modern ventilators. Despite these advantages, since the patient does not interact with the ventilator, spontaneous breathing may clash with mechanical respiration cycles. Under these conditions, additional pulmonary distension occurs, with increased frequency of barotrauma, reduced cardiac output, reduced oxygenation, increased respiratory work and a

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greater need for sedatives, with the possibility of longer periods on mechanical ventilation (MV) and increased length of hospital stay.[3]

As a result of these difficulties, over recent years attempts have been made to improve ventilators. The mechanical cycles, which were initially time-controlled, began to be triggered by respiratory effort, making it easier for children to adapt to the ventilator.[4] This mode was named synchronized intermittent mandatory ventilation (SIMV). The SIMV system includes a demand valve which allows gas to flow in response to the patient's respiratory effort. If the child does not breathe, predetermined mandatory cycles are produced by the ventilator. This ventilator mode is also not free from problems, the most significant being auto-cycling and an increase in the work required of the respiratory musculature.[5]

Recently, another ventilator mode, known as pressure support (PS), has been combined with SIMV. The PS mode is a form of flow cycled assisted ventilation, designed to maintain constant and predetermined positive airway pressure, during spontaneous inspiration. The PS mode maintains and supports the patient's in respiratory effort, reducing the respiratory work of spontaneous breathing and allows respiratory muscles to be trained.[6]

There are studies with newborn infants that have compared IMV with SIMV, with SIMV producing more favorable results.[4,7,8] However, SIMV combined with PS has not been evaluated. Furthermore, as far as we can ascertain, there are no studies that have compared SIMV+PS with IMV in children more than 28 days old in terms of duration of mechanical ventilation, weaning and hospital stay.

Our hypothesis is that, for children between 28 days and 4 years old suffering from the most common types of acute respiratory failure, the IMV and SIMV+PS are interchangeable.

The objective of this study was to compare mechanical ventilatory support in IMV mode with SIMV+PS mode in children from 28 days to 4 years of age in terms of length of time on MV, time taken for weaning and length of hospital stay.

Methods

This study was approved by the Research Ethics Committee at the Faculdade de Medicina de Botucatu-UNESP, SP, Brazil and written consent was obtained from parents or guardians before children were enrolled on the study.

This prospective randomized clinical trial was carried out at the PICU at the Pediatrics Department of the Faculdade de Medicina de Botucatu, between October of 2005 and June of 2007, throughout which time the team of health professionals responsible for caring for these patients remained unchanged. This PICU has eight beds and has a historical mean mortality of 12%. Children aged 28 days to 4 years were enrolled consecutively on admission to the PICU if they required MV. It was considered that a minimum period of 48 hours on MV would be necessary to compare the two groups, since shorter periods of MV do not generally alter respiratory mechanics, making it difficult to evaluate the outcomes chosen.[9,10] The 4-year age limit was defined on the basis that the SIMV+PS mode is already well-established in older children.

A protocol was filled out with identification details, age, sex, date of admission, diagnoses on admission and discharge, indication for ventilatory support, ventilator used, date weaning started, date of extubation, success or failure of extubation (and reason for failure), time on mechanical ventilation in days, reintubation and complications. Before data collection began, all daytime and on-call staff were trained to fill out this study protocol.

Children were excluded if they had chronic respiratory disease or had been tracheostomized because such patients generally need longer periods in hospital and on MV and it is also difficult to study weaning in this group of children.[11]

Randomization

The patients were systematically randomized by lots into two groups: an IMV group (IMVG) and an SIMV+PS group (SIMVG). The patients were divided on the basis of 70 pieces of paper, on 35 of which was written IMV, while the other 35 were marked as SIMV+PS, and which were placed in a closed box and drawn out, one per patient, as soon as patients were intubated, so that the lottery was exclusive and finite. The interior of the box was dark, preventing prediction of which ventilation mode each patient was allocated to. If a patient came to meet one of the exclusion criteria, their paper was returned to the box and eventually allocated to another patient. The treating team and the professionals evaluating the patients were the same for both groups.

Mechanical ventilation

The IMV mode ventilation was provided by time cycled and pressure regulated ventilators (Inter 3®, Intermed, São Paulo, Brazil). The SIMV+PS mode ventilation was provided by ventilators with a sensitivity control for triggering by flow and/or pressure and with the option of administering pressure support at the desired level (Inter 5®, Intermed, São Paulo, Brazil).

The fraction of inspired oxygen (FiO_2) and positive end-expiratory pressure (PEEP) were adjusted to the lowest FiO_2 that maintained arterial oxygen saturation (SaO_2) at 90 to 95% with a minimum PEEP of 5 cmH_2O. Respiratory rate (RR), inspiratory time (I), expiratory period (E) and the ratio of I to E (I:E ratio) were set to maintain arterial partial pressure of CO_2 ($PaCO_2$) between 35 mmHg and 45 mmHg, with a flow rate sufficient to provide a maximum tidal volume (Vt) of 8 mL/kg, and inspiratory pressure (Pip) limited to 35 cmH_2O.

Patients in both groups were given sedation and analgesia with midazolam at dosages from 5 to 10 µg/kg/min and/or fentanyl citrate at dosages from 0.02 to 0.05 µg/kg/min. The Comfort scale was used to asses the degree of sedation.[12]

Weaning off mechanical ventilation

The weaning technique varied depending on the ventilation mode employed. Briefly, when $FiO_2 \leq 60\%$ and Pip < 25 cmH_2O were reached (start of weaning, T = 0), RR was gradually reduced (3-5 cycles per reduction) down to 10 cycles per minute. From this point, PEEP was reduced in decrements of 2 centimeters of water until 7 cmH_2O was reached. These ventilator settings were maintained for a period of 12 to 24 hours, when patients were assessed for their capacity to take up spontaneous respiration by means of the extubation readiness test described by Randolph et al.,[13] which was applied daily. Patients were considered ready for extubation if they exhibited spontaneous respiratory effort, functioning gag reflex, pH between 7.34 and 7.45 on most recent blood gas analysis, adequate level of consciousness, no need for increased ventilator support in the last 12 to 24 hours and would undergo no operations requiring sedation in the next 12 hours. The test consisted of reducing FiO_2 to 0.5 (unless the patient was already at $FiO_2 < 0.5$, maintaining $SaO_2 \geq 95\%$), reducing PEEP to 5 cmH_2O and PS to 16 cmH_2O (in SIMVG), for 2 hours while verifying the patient's ability to maintain $SaO_2 \geq 95\%$. Children unable to maintain this saturation level were considered to have failed the test and were put back on their previous respiratory settings. Patients in IMVG who maintained $SaO_2 \geq 95\%$ for 2 hours were then extubated. In SIMVG, a minimal PS was set according to the diameter of the cannula (3.0-3.5 = PS 10 cmH_2O; 4.0-4.5 = PS 8cmH_2O; ≥ 5 = PS 6cmH_2O) and children were kept under observation for 2 hours. Any children who exhibited $SaO_2 \leq 95\%$ and/or whose RR increased were considered to have failed the test.

Data collection

The following ventilation and oxygenation data were recorded on the day that MV was started and on the first day of weaning: the highest $PaCO_2$, the best PaO_2/FiO_2 ratio, the greatest Pip, the highest RR and the greatest PEEP. Extubation was considered successful if the patient remained without ventilatory support for more than 48 hours. The emergence of any type of barotrauma was noted (pneumothorax, pneumomediastinum, pneumoperitoneum, pneumopericardium and/or subcutaneous emphysema). Pediatric Risk of Mortality (PRISM) scores were calculated for all patients on admission.[14]

Statistical analysis

Student's *t* test was used to compare variables with normal distribution and the Mann-Whitney U test was applied when this was not the case. The Goodman test was used to compare sex distribution and diagnoses on admission.[15] Variables with normal distribution are given as mean ± standard deviation (x ± SD) and those without as median (variation). The level of statistical significance was 5%.

Results

During the study period 375 patients were admitted to the PICU. Figure 1 illustrates the inclusion and exclusion of patients in the form of a flow diagram.

The groups did not differ statistically in terms of age, sex or disease severity as assessed by the PRISM score (Table 1). The median dose of midazolam was 10 µg/kg/min [IMVG: 10 (7.5-10) vs. SIMVG: 10 (7.5-10); p = 0.491] and for fentanyl it was 0.02 µg/kg/min [IMVG: 0.02 (0.0-0.02) vs. SIMVG: 0.02 (0.0-0.02); p = 0.702], with no statistical difference between the groups. Midazolam was administered without fetanyl to 15 patients in each group. There was no statistical difference between the groups in terms of Comfort scores [IMVG: 17 (17-20) vs. SIMVGG: 18 (17-19); p = 0.113].

There was no statistical difference between the two groups in terms the frequencies of different diagnoses on admission (IMVG: Pneumonia = 26, Shock = 6, Neuro = 2, Others = 1 vs. SIMVG: Pneumonia = 23, Shock = 7, Neuro = 3, Others = 2; p = 0.302).

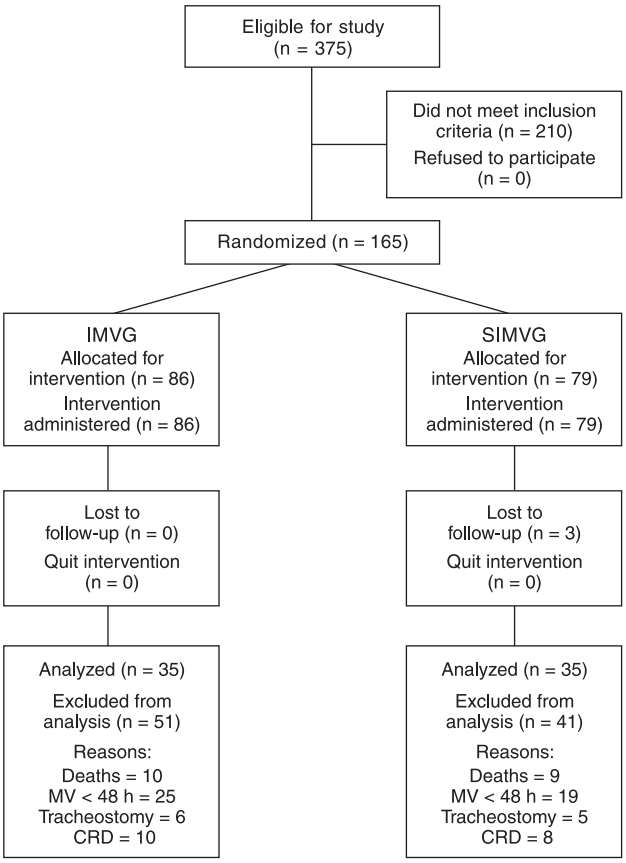
Comparison of the groups in terms of ventilator and gasometry parameters on admission and at the start of weaning detected no statistically significant differences between them (Table 2).

There was no statistically significant difference between the groups in terms of time on MV, with a median of 5 days in both groups, with a variation of 2 to 20 days in IMVG and of 2 to 18 days in SIMVG (p = 0.120). There was also no statistical difference between the groups in time taken for weaning [IMVG: 1 day (1-6) vs. SIMVG: 1 day (1-6); p = 0.262] or length of stay in the PICU [IMVG: 8 days (2-22) vs. SIMVG: 6 days (3-20); p = 0.113]. No cases of barotrauma were observed in any of the patients in either of the groups. The frequency of extubation failure was 5.7% (two in each group), both due to upper respiratory distress.

Discussion

As far as we have been able to ascertain, this is the first study that has compared the SIMV mode combined with PS with the IMV mode in post-neonatal children. We observed that IMV and SIMV+PS were no different in relation to duration of MV, time taken for weaning or length of stay in the PICU.

Studies with newborn infants that have compared conventional IMV with other assisted ventilation modes, other than SIMV+PS, have found similar results to ours for time on MV and length of stay.[4,7,8,16-19] Furthermore, neither Chan & Greenough[20] nor Dimitrou et al.[21] observed differences in time taken for weaning when comparing conventional assist-control ventilation with SIMV without PS.



CRD = chronic respiratory disease; MV = mechanical ventilation; IMVG = intermittent mandatory ventilation group; SIMVG = synchronized intermittent mandatory ventilation + pressure support group.

Figure 1 - Flow diagram for inclusion and exclusion of patients

Table 1 - Comparison between IMVG and SIMVG by age, sex and PRISM score

Variables	IMVG (n = 35)	SIMVG (n = 35)	p
Age in months	11.70 (1.33-35.46)	9.06 (1.47-48.33)	0.356
1-12	20	19	
13-24	8	13	
25-48	7	3	
Sex, n (%)			0.127
Male	16 (46)	18 (51)	
Female	19 (54)	17 (49)	
PRISM	9 (1-23)	10 (1-19)	0.120

IMVG = intermittent mandatory ventilation group; PRISM = Pediatric Risk of Mortality; SIMVG = synchronized intermittent mandatory ventilation + pressure support group.
Mann-Whitney U test and Goodman test.

The lack of studies of children in this age group makes discussion of our results difficult. Nevertheless, there are certain factors that may have had an influence on our results:

- The sedation protocol used may have affected the time on MV and duration of weaning. Our patients were sedated in accordance with the protocol in force at the unit and no

Table 2 - Ventilation and oxygenation parameters on admission and at the start of weaning for IMVG and SIMVG

	IMVG (n = 35)		SIMVG (n = 35)		
Parameters	**Admission**	**Weaning**	**Admission**	**Weaning**	**p**
RR (mpm)	29.71±0.1	19.09±6.6	27.96±6.6	17.06±5	0.251
PEEP (cmH_2O)	6±1.4	5.41±1	6.14±1.4	5.31±0.8	0.665
PIP (cmH_2O)	20.14±3.9	18.66±3	20.54±3	17.97±2	0.703
PaO_2/FIO_2	246.37±143	301.31±140.9	252.14±115.2	302.40±93	0.465
$PaCO_2$ (mmHg)	33.73±10	38.75±7.2	34.72±9.4	38.14±6.3	0.297

FiO_2 = fraction of inspired oxygen; IMVG = intermittent mandatory ventilation group; mpm = movements per minute; $PaCO_2$ = arterial partial pressure of carbon dioxide; PaO_2 = arterial partial pressure of oxygen; PEEP = positive end-expiratory pressure; PIP = peak inspiratory pressure; RR = mechanical respiratory rate; SIMVG = synchronized intermittent mandatory ventilation + pressure support group.
Student's *t* test.

statistical differences were observed in terms of sedation level or dosage.

- It should be considered that although this was a homogenous group in terms of age, disease severity and diagnoses on admission, there was a large percentage of children, in both groups, without lung disease, which could result in similar results in terms of outcomes. Additionally, it was not possible to stratify our sample for analysis by age and there was a wide range of variation in age and, consequently, weight and muscle mass, which are possible causes of statistical rejection errors (false negatives).
- The trigger sensitivity adjustment of the ventilator for SIMV and PS varies depending on the model, which could affect how ventilatory support is provided. For this study we chose ventilators that are widely used in our country in order to increase the applicability of our results to a large number of services, despite being aware of the variations in the ventilator's sensitivity control.

Specifically with relation to weaning, it is possible that, by establishing criteria to indicate the time to start weaning and by including an extubation readiness test, we have managed to study this stage of ventilatory support better, in contrast with other studies. Nevertheless, enrolling patients without lung disease, i.e. patients without altered respiratory mechanics, may have masked possible effects of one or other ventilator mode on weaning. Furthermore, in many patients in our sample, mean inspiratory pressure levels were low (below 20 cmH_2O), which could indicate late weaning; although this may have been minimized by the daily extubation readiness tests.

The literature reports extubation failure frequencies varying from 2.7 to 22%.[22] Four studies that assessed extubation failure in the context of a comparison between SIMV with IMV were subjected to a meta-analysis published in 2006,[23] which did not detect any significant effect on this variable from using one or other of the modes. In order to compare assist-control with SIMV in terms of extubation failure, two studies were selected for meta-analysis[20,21] and once more there was no significant difference between the two modes. In common with these findings, we did not observe any differences between our two groups in terms of the frequency of extubation failure.

Study limitations

It is worth pointing out that during MV the professionals treating these children were aware of the ventilation mode being used, which could have caused bias in terms of the treatment proposed. However, the treatment plan is discussed daily by the medical team and nothing was carried out differently for the study patients.

In addition to the aspects discussed above, another important limitation factor is the small number of patients enrolled. The sample size analysis indicated that in order to have 80% test power and a 95% confidence interval it would be necessary to include approximately 90 extra patients per group in order to detect a difference of 20% in the time on mechanical ventilation and length of hospital stay outcomes. With relation to time taken for weaning, the number of patients to be included would be even greater, more than 1,000. There is clearly a need to carry out collaborative multicenter studies in order to obtain more consistent results.

Study implications and conclusions

This is the first study that has compared IMV with SIMV+PS in children more than 1 month old in terms of time on MV, duration of weaning and length of stay, and has important implications for the design of future investigations in which researchers could investigate different groups and outcomes from ours with larger numbers of patients and involving other conditions and cost benefit analyses. This last factor is extremely important since, in a period during which rationalization of costs is imperative, many PICU in Brazil are still using cheaper, lower technology equipment that offers IMV, but which is still capable of providing MV that is adequate for

a significant proportion of the children admitted. When planning a PICU, a certain number of lower technology machines can be given priority in order to increase the total number of mechanical ventilators available, in combination with more complex equipment reserved for more severe lung conditions.

We conclude that there was no statistically significant difference between IMV and SIMV+PS in terms of time on MV, duration of weaning or length of hospital stay in this group of children.

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