Upsala J Med Sci 102: 109–120, 1997

Trigger Delay in Infant Ventilators

A. Liubsys, T. Norsted, A. Jonzon and G. Sedin

Department of Pediatrics and Department of Physiology and Medical Biophysics, Uppsala University, Uppsala, Sweden, and Neonatal Clinic, Vilnius University Children's Hospital, Vilnius, Lithuania

ABSTRACT

In an experimental study we determined the response trigger delay time of three infant ventilators with a capacity to detect and support spontaneous breathing. We measured this in anaesthetized cats as the time between the start of phrenic nerve activity and the increase in airway pressure caused by the subsequent inflation. Two modes of ventilatory support were used, namely Assist/Control (A/C) and synchronised intermittent mandatory ventilation (SIMV). We found that ventilators equipped with flow sensors close to the free end of the endotracheal tube had a shorter trigger delay than a ventilator which detected breathing with an abdominal sensor. Further, the trigger delay was shorter in SIMV mode than in A/C mode of operation. A higher set sensitivity reduced the response time.

We conclude that triggered ventilation may be used in infants, at least when the spontaneous breathing rate is below 60 breaths per minute. This mode of ventilation could be useful when infants are to be weaned off the ventilator.

INTRODUCTION

In the past it has been very difficult to use patient-triggered ventilation in newborn infants, especially in those born preterm, as the sensors have required larger inspiratory volumes or pressure drops than the infants can produce. During recent years new sensors intended for patient-triggered ventilation have been introduced. One of these has been used to monitor changes in abdominal expansion (Graseby capsule). Also, measured changes in the oesophageal pressure have been utilised to trigger insufflation (3), but these systems were too slow and insufflation tended to take place in the expiratory phase. Changes in airway pressure (5, 6) have

also been used to trigger insufflation. With a faster patient-respirator interface, Bernstein and co-workers (1) found a short response time with use of a Graseby capsule. They also compared the response times of different ventilators (1) in rabbits, measuring the time that elapsed from the start of inspiratory flow to the start of insufflation from the ventilator, and observed differences between the available respirators.

The rationale for developing triggered ventilation techniques is the need to find modes of ventilation with a lower risk for inadvertent by high intratracheal pressures and subsequent barotrauma. Further, triggered ventilation may reduce the need for paralysis and sedation. If a safe and dependable patient-triggered technique is found, it should be possible to ventilate newborn term and preterm infants in a controlled way for longer periods at reduced risk for barotrauma and associated complications (2).

The purpose of this study was to measure the trigger delay time in some currently used infant ventilators. The trigger delay was measured at different modes of assisted ventilation in healthy young cats. A preliminary report has been presented previously (7). We have measured the trigger delay as the time from the start of the phrenic nerve signal to the onset of the intratracheal pressure rise resulting from an insufflation given by the ventilator, thereby avoiding the difficulties in measuring changes in oesophageal pressure and in the inspiratory drop in airway pressure.

MATERIAL AND METHODS

Animals, anaesthesia and preparation

In five cats, weighing between 3.1 and 3.9 kg, general anaesthesia was induced with chloroform and maintained with intermittent infusions of chloralose (0.07 mg/kg, E.Merck AG, Darmstadt, Germany). An endotracheal tube was inserted orally until its tip lay about 1 cm above the carina. A ligature was tied around the trachea and endotracheal tube to prevent air leakage. A catheter was inserted through the femoral artery into the thoracic part of the aorta for measurement of arterial blood pressure and blood sampling. Another catheter was introduced through the femoral vein until its tip was placed at the level of the right atrium. A mixture of glucose and sodium

bicarbonate (two-thirds 5.5% glucose solution and one-third 0.6 M sodium bicarbonate) was given intravenously throughout the experiment at a rate of 2 ml/kg/h. Body temperature was maintained in the range of 37.5-38°C with use of a heating pad and a radiant warmer.

Through a medial frontal incision in the pre-tracheal region the left phrenic nerve was exposed and dissected free from connective tissues. The nerve was placed on two platinum hook electrodes and then immersed in mineral oil to prevent drying of the nerve and for electrical insulation.

Measurements

Arterial PO_2, PCO_2, pH, base excess (BE), HCO_3- and oxygen saturation were determined with an automatic acid base analyzer (ABL 300, Radiometer, Copenhagen, Denmark).

Arterial blood pressure and airway pressure (at the proximal part of the endotracheal tube) were measured with identical transducers (Druck AG, Germany). The signals were amplified with an 8-channelled medical amplifier system (Hellige AG, Germany) and fed to a recorder (Recorder 330-P, Hellige AG, Germany). The phrenic nerve activity signals were amplified, filtered and rectified with a Neurolog system (Digitimer Ltd, U.K.) and recorded with a recorder (Recorder 330-P, Hellige AG, Germany).

Ventilators and modes of ventilation

Three commercially available time cycled pressure limited ventilators with patient-triggered ventilation devices were used in the experiments: Infant star Neonatal Ventilator (Infrasonics, San Diego, CA, USA), V.I.P. Bird Infant-Pediatric Ventilator (Bird Products Corporation, Palm Springs, CA, USA), and Babylog 8000 Intensive Care Ventilator for Newborns (Dräger, Lübeck, Germany).

For the triggering of mechanical insufflations the Infant star ventilator is provided with a Star sync Patient Triggered Interface. This device is connected to an air-filled capsule (Graseby) which delivers signals by sensing intra-abdominal movements during inspiration. During the experiment the capsule was placed on the cat's abdomen at the anterior midline xiphisternum position so that every spontaneous breath of the cat was registered on the Star sync spontaneous breath monitor.

In V.I.P. Bird and Babylog 8000 ventilators triggering of mechanical inflations is based on detection of a small change in flow rate by a sensor placed between the endotracheal tube adapter and the ventilator circuit Y-piece.

For patient-triggered ventilation the V.I.P. Bird ventilator is connected with a fibreoptic link with the Partner Volume Monitor. "Assist Sensitivity" is calibrated in litres per minute and adjustable from 0.2 to 5.0 L/min. The flow signal from the sensor is subsequently conveyed from the Partner monitor to the V.I.P. Bird via the fibreoptic link. When the information is received the V.I.P. Bird microprocessor compares the flow information from the sensor against the selected "Assist Sensitivity". If the flow signal meets or exceeds the setting the ventilator will initiate a time cycled pressure limited breath.

A Babylog 8000 ventilator employs a hot wire flowmeter (anemometer) integrated into the Y-piece adapter. The trigger level (sensitivity) is adjustable from 1 to 10 and corresponds to approximately 0.02 to 3 ml. In the most sensitive setting the Babylog 8000 is flow-triggered and will trigger upon detection of a minimal flow rate of 0.25 L/min at the Y-piece. At less sensitive settings the Babylog 8000 is more volume - than flow-triggered, i.e. it is triggered upon detection of a particular volume of gas passing the sensor.

In this study Assist/Control (A/C) and synchronised intermittent mandatory ventilatory (SIMV) modes of ventilation with continuous/demand flow (Infant star) and continuous flow (V.I.P. Bird, Babylog 8000) were used. In the A/C mode of ventilation every inspiratory effort of the cat triggered the mechanical insufflation of the ventilator. In the SIMV mode the cat was allowed to breathe spontaneously from the continuous (demand) flow system and the ventilator delivered the set number of synchronised mechanical breaths (4-6 b.p.m.). In this mode a frequency of mechanical insufflations lower than the cat's spontaneous breathing rate (6-12 b.p.m.) was set.

Experimental procedure

Before any measurements were made, the arterial acid-base status was analysed to ensure that BE was above -5 mmol/l and the arterial pH, PO_2 and PCO_2 within normal ranges. The different

ventilators were studied in random order, starting with the maximal sensitivity (V.I.P. Bird and Babylog 8000) and with the A/C mode. The same ventilator settings were studied with all ventilators (Table 1).

Table 1. Ventilator settings: Flow, peak inspiratory pressure (PIP), inspiratory time (T_I). positive end-expiratory pressure (PEEP) and ventilation frequency (F)

Ventilator	Settings				
	FLOW (l/min)	PIP (cm H2O)	T_i (sec)	PEEP (cm H2O)	F (b.p.m.)
INFANT STAR	10 continuous	12-16	0.5	3	4-6
	10 demand	12-16	0.5	3	4-6
V.I.P. BIRD	10 continuous	12-16	0.5	3	4-6
BABYLOG 8000	10 continuous	12-16	0.5	3	4-6

A 10-minute adaptation period was allowed before any measurements were made. With Infant Star the continuous and demand-flow options were used for patient-triggered ventilation. Different levels (between maximal and minimal) of assist sensitivity were selected for the V.I.P. Bird (from 0.2 to 1.5) and the Babylog 8000 (from 1 to 10) ventilators. Eight to ten ventilatory cycles for each series were recorded both in the A/C and in the SIMV mode.

Treatment of data

Trigger delay time was measured as the time from the start of the phrenic nerve activity to the onset of the pressure increase in the trachea due to the mechanical insufflation. Only recordings where the insufflations from the ventilator had started after the appearance of the phrenic nerve activity were used. Differences in trigger-delay time were assessed for statistical significance using Student's t-test and ANOVA, and were considered significant at $p<0.05$.

When trigger delay times in different modes and different sensitivities were compared, the statistical significance of differences was evaluated between the different modes or sensitivities

in each individual cat, thereby eliminating differences in delay possibly related to the size and therefore distance between the recording site and effect of organ in the different cats. Also, when different ventilators were compared the comparison was made between settings in each individual cat.

RESULTS

Comparisons between A/C and SIMV: The Infant Star ventilator, which is triggered by the abdominal capsule, had longer trigger delay than the ventilators that were triggered by detection of changes in flow. The average trigger delay with the Infant Star ranged between 0.94 - 1.24 seconds. The average trigger delay of the other ventilators (V.I.P. Bird; Babylog 8000) ranged between 0.13 and 0.76 seconds (Table 2).

Table 2. Trigger delay time in different infant ventilators

Ventilators	Trigger delay time (seconds)	
INFANT STAR	**Assist/Control**	**SIMV**
Continuous flow	1.24 ± 0.41	0.94 ± 0.54
Demand flow	1.20 ± 0.38	0.96 ± 0.29
V.I.P. BIRD	**Assist/Control**	**SIMV**
trigger sensitivity 0.2	0.23 ± 0.06	0.13 ± 0.04
trigger sensitivity 0.5	0.32 ± 0.04	0.26 ± 0.05
trigger sensitivity 1.2	0.62 ± 0.03	0.44 ± 0.13
trigger sensitivity 1.5	0.76 ± 0.30	0.74 ± 0.21
BABYLOG 8000	**Assist/Control**	**SIMV**
trigger sensitivity 1	0.16 ± 0.03	0.13 ± 0.04
trigger sensitivity 2.5	0.22 ± 0.00	0.30 ± 0.11
trigger sensitivity 5	0.32 ● 0.04	0.28 ± 0.03
trigger sensitivity 7.6	0.43 ± 0.04	0.36 ± 0.05
trigger sensitivity 10	0.51 ± 0.08	0.42 ± 0.04

The trigger delay of the Infant Star ventilator was shorter in the SIMV than in the A/C mode. This difference was statistically significant in three out of five comparisons ($p < 0.01$ or $p < 0.02$).

When A/C and SIMV modes were compared using V.I.P. Bird, SIMV gave a shorter delay in four out of five comparisons ($p < 0.001$). At lower sensitivities (0.5-1.5), the trigger delay was again shorter in SIMV mode than in the A/C mode in more than 50% of the comparisons.

With the Babylog 8000, the trigger delay recorded with use of A/C did not differ greatly from that with SIMV. Only in six out of 14 comparisons at different levels of sensitivity was a significant difference found between the trigger delay using A/C and that using SIMV. With the highest sensitivities (1 and 2.5), there were very small differences between A/C and SIMV.

Trigger delay using different trigger sensitivities: The trigger delay with the V.I.P. Bird and Babylog 8000 was related to the set level of sensitivity.

When the V.I.P. Bird was used in A/C mode, there was a statistically significant difference between the trigger delay at a sensitivity of 0.2 and that of 1.2 in all comparisons ($p < 0.001$). There was no difference between the trigger delay at a sensitivity of 1.2 and that at 1.5.

When the V.I.P. Bird was used in the SIMV mode, there was a statistically significant difference in trigger delay between sensitivity levels of 0.2 and 0.5 in all comparisons and also in trigger delay between sensitivity levels of 1.2 and 1.5 in all comparisons ($p < 0.001$).

With use of the Babylog 8000, the trigger delay was greater at the lowest sensitivity. When comparisons were made for each step of change in sensitivity using the A/C mode, the difference in delay at each step was statistically significant in five out of eight comparisons. Using the SIMV mode all comparisons between trigger sensitivity 1 and trigger sensitivity 2.5 the delay differed significantly in the few comparisons that were made.

A decreased sensitivity could increase trigger delay three to five-fold using the V.I.P. Bird and the Babylog 8000.

Trigger delay with different ventilators: When the three ventilators were compared in the A/C

mode, we found that at the highest sensitivity the trigger delay was shortest with Babylog 8000, where it differed only very slightly from that with V.I.P. Bird. The Infant Star ventilator had a much longer delay than the Babylog 8000 and the V.I.P. Bird (statistically significant; $p < 0.05$ ANOVA). In the A/C mode the two latter ventilators gave a shorter trigger delay at all sensitivities and all settings than the Infant Star did in this mode.

When the SIMV mode was used the Babylog 8000 and V.I.P. Bird gave trigger delay times of equal length at the highest sensitivity. There were very small differences between these two ventilators even when the trigger sensitivity was lower. Both the Babylog 8000 and the V.I.P. Bird gave shorter trigger delays than the Infant Star ventilator in this mode (ANOVA; $p < 0.05$).

With ventilators that were triggered by detection of changes in flow, the trigger delay was usually significantly shorter in the SIMV than in the A/C mode ($p<0.001$-0.05); the trigger delay times are presented in Table 2. The trigger delay of the V.I.P. Bird and Babylog 8000 ventilators was related to changes in trigger sensitivity. A decrease in set sensitivity increased the delay time. With the V.I.P. Bird, there was a seven-fold increase at the lowest sensitivity compared with the highest and with the Bablylog 8000 a five-fold increase.

DISCUSSION

In this study we found that the trigger delay time of the investigated ventilators somewhat exceeded that found in some clinical studies (1, 4, 5, 8), and also exceeded the trigger delay given in the manuals of the ventilators. The trigger delay was greater when the abdominal sensor (Graseby capsule) was used to trigger ventilation than with use of airflow sensors. In addition, the trigger delay was greater when the ventilators were used in the A/C mode than in the SIMV mode. Our method of measuring the delay as the time between the start of the phrenic burst and the start of the subsequent ventilatory support has not been used earlier in evaluation of trigger delay in infant ventilators. This method may be advantageous, since the start of inspiration is better defined, and may explain the longer trigger delay found in this study (1, 4, 5, 8).

Hird and Greenough (5) measured the trigger delay time in ventilated infants as the time lag

between the pressure change in the oesophagus and the subsequent increase in airway pressure. Bernstein et al (1) measured the response time from the start of spontaneous inspiratory flow to the onset of triggered positive pressure. These methods for determining trigger delay have been more oriented towards measuring the trigger delay in the ventilator system, whereas our method will add the time for impulse transmission and diaphragm activation. The former ways of measuring trigger delay could sometimes be difficult, particularly in the clinical setting, as oesophageal pressure changes can be related to other events than those related to breathing. Changes in oesophageal pressure are also related to the pressure changes in the pleural space, but these changes occur with some delay in relation to those in the airway, because of the inertia of the surrounding tissue. Another way of determing trigger delay is to measure it from the start of the phrenic burst to the start of ventilatory support, in which case the delay includes the whole electro-mechanical event. We believe that our method is more exact and eliminates confounding factors.

If the trigger delay is close to one second the ventilator cannot support every breath in an infant breathing at a rate exceeding 60/min - a rate that is common among newborn infants, and thus abdominal sensors will not be useful in infants with high respiratory rates. The ventilators triggered by flow sensors had a shorter trigger delay, i.e. 25-50% of the delay with use of abdominal sensors. The flow sensor-triggered ventilators may therefore allow for respiratory rates of up to 180 breaths/min.

The trigger delay is shorter with SIMV than with A/C with the Infant Star and the V.I.P. Bird. Such differences were not observed when using the Babylog. This is probably related to the algorithms used, resulting in longer or shorter trigger delays. A long delay obviously increases the risk for a phase shift between the spontaneous breath of the infant and the supporting breath given by the ventilator. Thus inadvertently high pressures may occur. Ventilators triggered by flow sensors will thus reduce the risk for such high pressures.

Although a ventilatory system without a trigger and with continuous support of both inspiration and expiration (9, 10, 11, 12) is not yet clinically available, ventilators with short trigger delay

times can be useful in the weaning process in infants undergoing positive pressure ventilation.

ACKNOWLEDGEMENTS

The authors thank B. Kjällström for skilled laboratory assistance, G. Nilsson, E. Ekström and SG Norberg for special technical assistance, and S.Thorell and S. Albinsson for typing assistance. The study was supported by the Swedish Medical Research Council (19X-04998, 19X-7544) and by the Swedish Institute (fellowship for Arunas Liubsys). We also thank Drägerwerk AG, Lübek, Germany, Bird Corporation, Palm Springs, Ca, USA (through RIUM AB, Sollentuna Sweden) for kindly providing us with the ventilators. The Infant Star ventilator used was a property of the Uppsala University Hospital.

REFERENCES:

1. Bernstein, G., Cleary, J.P., Heldt, G.P., Rosas, J.F., Schellenberg, L.D. & Mannino, F.L.: Response time and reliability of three neonatal patient triggered ventilators. Am Rev Respir Dis 148:358-64, 1993.

2. Greenough, A., Wood, S., Morley, C.J. & Davies, J.A.: Pancuronium prevents pneumothoraces in ventilated premature babies who actively expire against positive pressure inflation. Lancet :1(8367) 1-3,1984..

3. Greenough, A. & Greenall, F.: Patient triggered ventilation in premature neonates. Arch Dis Child 63: 77-78, 1988.

4. Hird, M.F. & Greenough, A.: Gestational age: an important influence on the success of patient triggered ventilation. Clin Phys Physiol Meas 11:307-312, 1990.

5. Hird, M.F. & Greenough, A.: Comparison of triggering systems for neonatal patient triggered ventilation. Arch Dis Child 66:426-428, 1991.

6. Hird, M.F. & Greenough, A.: Patient triggered ventilation using a flow triggered system. Arch Dis Child 66:1140-1142, 1991.

7. Liubsys, A., Norsted, T., Jonzon, A. & Sedin, G.: Trigger delay in infant ventilators. Pediat Res 36:24A (abstr 131), 1994.

8. Nishimura, M., Hess, D. & Kacmarek, R.M.: The response of flow-triggered infant ventilators. Am J Respir Crit Care Med 152:1901-1909, 1995.

9. Schaller, P. & Schulze, A.: A ventilator generating a positive or negative internal compliance. Ups J Med Sci 96:219-234, 1991.

10. Schulze, A., Schaller, P., Gehrhardt, B., Mädler, H.J. & Gmyrek, D.: An infant ventilator technique for resistive unloading during spontaneous breathing.

Results in a rabbit model of airway obstruction. Pediatr Res 28:79-82, 1990.

11. Schulze, A., Schaller, P., Jonzon, A. & Sedin, G.: Assisted mechanical ventilation using elastic unloading: A study in cats with normal and injured lungs. Pediat Res 34:600-605, 1993.

12. Schulze, A., Schaller, P., Jonzon, A. & Sedin, G.: Effect of ventilator resistance and compliance on phrenic nerve activity in spontaneously breathing cats. Am J Resp Crit Care Med 153:671-676, 1996.

Correspondence to:
Gunnar Sedin
Department of Pediatrics
University Children's Hospital
S-751 85 Uppsala
SWEDEN
Tel: 46-18-665886
Fax: 46-18-554079