Effects of Inspiratory Rise Time on Triggering Work Load During Pressure-Support Ventilation: A Lung Model Study

Shinya Murata MSc, Kazuki Yokoyama MSc, Yushi Sakamoto MSc, Ken Yamashita MSc, Jun Oto MD, Hideaki Imanaka MD, and Masaji Nishimura MD

BACKGROUND: The rise in inspiratory flow is important during patient-triggered ventilation. Many ventilators incorporate a function to control the time to reach the targeted airway pressure (inspiratory rise time). However, it has not been clarified how inspiratory rise time affects inspiratory work load under various ventilator settings. In a bench study we investigated the effect of inspiratory rise time on inspiratory work load during pressure-support ventilation (PSV). METHODS: We studied 6 ICU ventilators. We measured flow and pressure at the airway opening (P_{ao}) at PEEP of 5 cm H_2O, pressure-support of 5 cm H_2O and 10 cm H_2O, 4 triggering sensitivities, and inspiratory drives 300 mL, 500 mL, and 700 mL. The inspiratory-rise-time setting was not consistent between the ventilators, and we chose 3 inspiratory-rise-time levels with each ventilator. The inspiratory delay time (DT) was defined as the time between the onset of inspiration and the return of P_{ao} to baseline, and was divided into 2 parts at the point of the lowest P_{ao}: before the lowest P_{ao} (DT_1), and after the lowest P_{ao} (DT_2). As an indicator of inspiratory work load we calculated the pressure-time-product (PTP) of the P_{ao} over the DT. PTP was also divided into PTP_1 and PTP_2, at the point of the lowest P_{ao}. RESULTS: Short inspiratory rise time reduced DT_2, PTP_1, and PTP_2, regardless of the pressure-support level, triggering sensitivity, or inspiratory drive. However, the inspiratory-rise-time setting did not affect DT_1. The PTP_1, PTP_2, and DT_2 values differed significantly among the ventilators. A combination of short inspiratory rise time, high PSV, and sharp triggering sensitivity resulted in the smallest PTP and DT values. CONCLUSIONS: Short inspiratory rise time decreased inspiratory work load, regardless of the pressure-support level, triggering sensitivity, or inspiratory drive. Inspiratory work load can be maximally lowered by a combination of a short inspiratory rise time, a sharp triggering sensitivity, and a high inspiratory pressure-support level for a given patient's inspiratory effort. *Key words: inspiratory rise time; pressure-support ventilation; pressure-time-product; inspiratory delay time.* [Respir Care 2010;55(7):878–884.

Introduction

Patient-ventilator synchrony is important to reduce the patient's inspiratory work load during patient-triggered ventilation.[1] Trigger delay and inspiratory flow are 2 major factors influencing the inspiratory work load.[2] Flow-triggering function improves the inspiratory work load due to the trigger delay. When inspiratory flow does not meet the patient's demand, the ventilator cannot appropriately reduce the patient's inspiratory work load.[3] Many ventilators have a function to regulate initial flow, termed inspiratory rise time, because it also regulates the time to reach the targeted airway pressure. Previous studies dem-

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The authors have disclosed no conflicts of interest.

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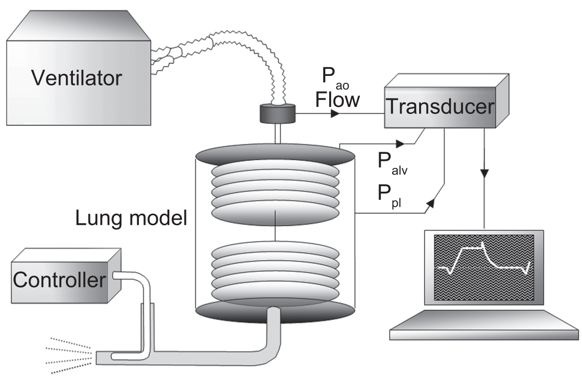

Fig. 1. Experimental setup. P_{ao} = airway opening pressure. P_{alv} = alveolar pressure. P_{pl} = pleural pressure.

onstrated that the inspiratory assistance increased and patient's inspiratory work load decreased under short inspiratory rise time.[4-7] However, the relationship between the inspiratory-rise-time setting and inspiratory work load under various ventilator settings has not been fully clarified.[8] The aim of this bench study was to investigate the effects of combinations of inspiratory rise time and other ventilator settings on inspiratory work load during pressure-support ventilation (PSV), using a lung model that simulated spontaneous breathing. We hypothesized that short inspiratory rise time would reduce inspiratory work load, regardless of the magnitude of inspiratory drive or ventilator settings such as the pressure-support level or triggering sensitivity. We also searched for the optimal combination of inspiratory rise time and other ventilatory settings to decrease inspiratory work load.

Methods

This research was performed at the University of Tokushima Graduate School, Tokushima, Japan.

Lung Model

We used a 2-bellows-in-a-box type lung model, with a compliance of 27.2 mL/H_2O and a resistance 12.0 cm H_2O/L/s (Fig. 1). Details of this lung model were described before.[6,9] Briefly, the lung model consisted of 2 bellows placed in a plastic air-tight box and simulated spontaneous breathing with different inspiratory drives. The upper bellows, lower bellows, and the space between the bellows and box represented the lung, diaphragm, and pleural cavity, respectively. The diaphragm bellows was connected to a T-tube, and jet flow was injected into it to create negative pressure in the bellows. The jet flow was created by wall-gas source, pressure regulator, and proportional solenoid valve, which was regulated by a computer. A movement of the diaphragm bellows inflated the lung bellows. During the expiratory phase the diaphragm bellows was opened to the atmosphere and returned to the original position.

We set the lung model at a respiratory rate of 15 breaths/min and an inspiratory time of 1.0 s. The jet flow was adjusted to create tidal volumes (V_T) of 300 mL, 500 mL, and 700 mL, at which the pressures generated during the first 0.1 s of an airway occlusion were 3.5 cm H_2O, 5.8 cm H_2O, and 10.3 cm H_2O, respectively. The lung model was connected to the ventilator through a standard ventilator circuit (Tyco Healthcare, Mirandola, Italy), an 8-mm inner-diameter endotracheal tube (Portex, Keene, New Hampshire), and a heat-and-moisture exchanger (Hygrobac S, Mallinckrodt Dar, Tyco Healthcare, Mirandola, Italy).

Examined Ventilators

We studied 6 ventilators: e500 (Newport Medical Instruments, Costa Mesa, California); Evita XL (Dräger Medical, Lübeck, Germany); Servo-*i* (Maquet, Solna, Sweden); Servo 300 (Maquet, Solna, Sweden); PB 840 (Puritan-Bennett/Covidien, Carlsbad, California); and G5 (Hamilton Medical, Reno, Nevada).

The scale for inspiratory rise time differed among the ventilators, and it was impossible to establish an identical setting for all the ventilators. Table 1 shows the inspiratory rise times, triggering sensitivities, and termination criteria we examined with each ventilator. We set PEEP at 5 cm H_2O, pressure support at 5 cm H_2O and 10 cm H_2O, and triggering sensitivity at -1 cm H_2O and -2 cm H_2O and 2 L/min and 4 L/min. With the e500 the lowest triggering sensitivity setting was 2 L/min, and we tested it at 1 L/min and 2 L/min. Pressure-triggering was not available on the Evita XL, and a numerical setting for flow-triggering was not available on the Servo 300. The termination criteria for pressure support were chosen so that premature termination did not occur (see Table 1).

Measurements and Calibration

After a stabilization period we measured flow, pressure at the airway opening (P_{ao}, between the endotracheal tube and the heat-and-moisture exchanger), alveolar pressure (P_{alv}), and pleural pressure (P_{pl}) of the lung model (see Fig. 1). The flow was measured with a pneumotachometer (model 3700A, Hans-Rudolph, Shawnee, Kansas) and a differential pressure transducer (TP-602T [$\pm$ 5 cm H_2O], Nihon-Koden, Tokyo, Japan). P_{ao}, P_{alv}, and P_{pl} were measured with differential pressure transducers (TP-603T [$\pm$ 50 cm H_2O], Nihon-Koden, Tokyo, Japan). We calibrated the pressure transducers at 0 cm H_2O and 20 cm H_2O, with a water manometer. All signals were amplified, sent

Table 1. Inspiratory Rise Times, Triggering Sensitivities, and Termination Criteria

Ventilator*	Inspiratory Rise Time			Triggering Sensitivity		Termination Criteria (%)
	Minimum	Medium	Maximum	Pressure (cm H_2O)	Flow (L/min)	
e500	1	10	19	–2	2	10
				–1	1	
Evita XL	300 ms	150 ms	0 ms	ND	4	25
				ND	2	
Servo-*i*	300 ms	150 ms	0 ms	–2	4	15
				–1	2	
Servo 300	300 ms	120 ms	0 ms	–2	Green	5
				–1	Red	
PB 840	1%	60%	100%	–2	4	10
				–1	2	
G5	200 ms	100 ms	25 ms	–2	4	20
				–1	2	

* The e500 has inspiratory rise time as integral numbers from 1 (minimum) to 19 (maximum), and the maximal setting for flow-triggering-sensitivity setting is 2 L/min.
The Evita XL has only flow triggering, so we collected no data (ND) about the triggering sensitivity.
The Servo 300 does not have a digital setting for flow triggering, but has a colored setting.
The PB 840's inspiratory-rise-time scale is from 1% (minimum) to 100% (maximum).

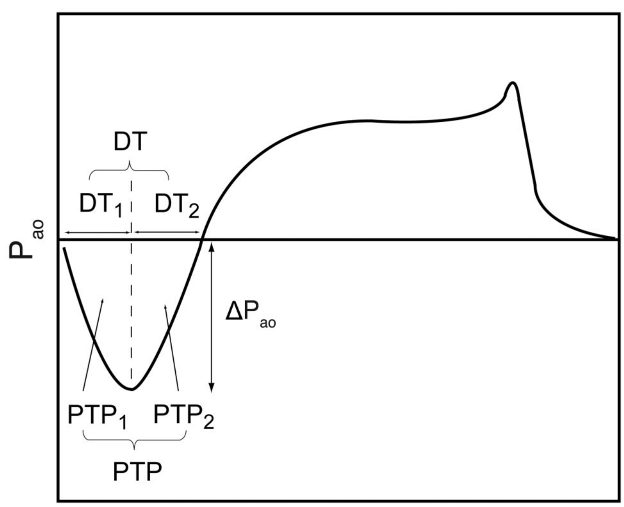

Fig. 2. Definitions of studied variables. DT = inspiratory delay time. DT_1 = the time from the onset of inspiration to the lowest airway opening pressure (P_{ao}). DT_2 = the time from the lowest P_{ao} to the return to baseline. PTP = pressure-time-product from the area of P_{ao}-time curve below baseline during DT. PTP_1 = PTP during DT_1. PTP_2 = PTP during DT_2. ΔP_{ao} inspiratory trigger pressure.

to an analog/digital converter, sampled at 100 Hz, and recorded and analyzed with data-acquisition software (WINDAQ, Dataq Instruments, Akron, Ohio).

Studied variables are illustrated in Figure 2. We determined the start of inspiration when the inspiratory flow started to increase. Inspiratory trigger pressure (ΔP_{ao}) was defined as the difference between the baseline pressure and the lowest P_{ao}. The same value was measured for ΔP_{alv} and ΔP_{pl}. The time from the onset of inspiration to the return of P_{ao} to baseline was defined as the inspiratory delay time (DT). The DT was divided into 2 components: the time from the onset of inspiration to the lowest P_{ao} (DT_1), and the time from the lowest P_{ao} to baseline (DT_2). As an indicator of patient inspiratory work load we calculated the pressure-time-product (PTP) of the P_{ao}-time curve below baseline. PTP was also divided into values during DT_1 (PTP_1) and during DT_2 (PTP_2). Peak inspiratory flow was measured from the flow waveform. V_T was calculated by integrating flow.

Statistical Analysis

Three consecutive breaths were analyzed. Data are expressed as mean ± SD. Comparisons were performed with analysis of variance. When significant differences were observed, post hoc analysis was performed with the Bonferroni test. Differences were considered significant when $P < .01$. All statistical analysis was performed with statistics software (SPSS 11.01, SPSS, Chicago, Illinois).

Results

Figure 3 shows representative P_{ao} waveforms when inspiratory-rise-time setting was the shortest and the longest for each ventilator. DT_2 was shorter and ΔP_{ao} was smaller with the shortest inspiratory rise time than with the longest inspiratory rise time with all ventilators.

As inspiratory rise time became shorter, both PTP_1 and PTP_2 decreased with all ventilators, regardless of inspira-

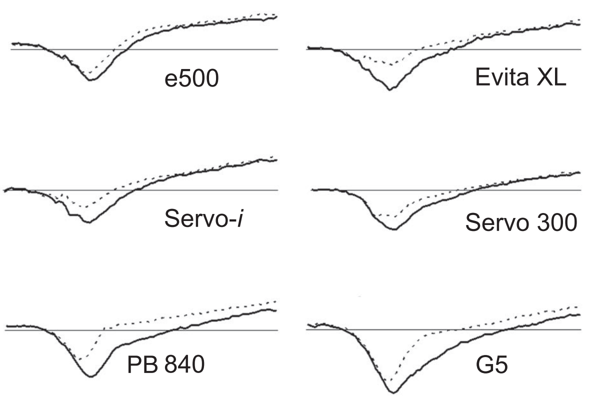

Fig. 3. Representative tracings of airway pressure-time curves. The dotted lines represent the shortest inspiratory-rise-time settings. The solid lines represent the longest inspiratory-rise-time settings. The ventilator settings were zero PEEP, pressure support 5 cm H_2O, and tidal volume 300 mL. The triggering sensitivities were 4 L/min with the Evita XL and −2 cm H_2O with the other ventilators.

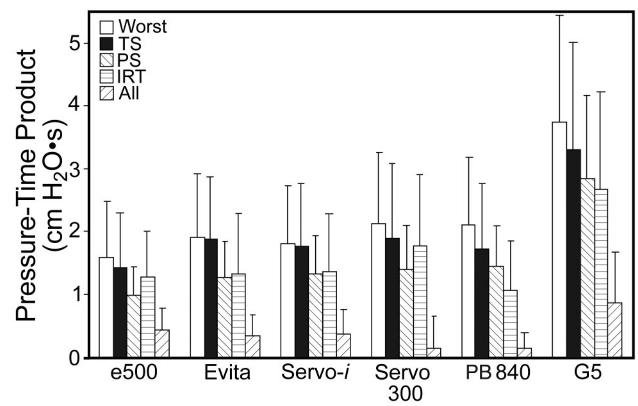

Fig. 5. Combined effects of triggering sensitivity, pressure-support, and inspiratory-rise-time settings on pressure-time product. Worst = the combination of lowest triggering sensitivity, lowest pressure support (5 cm H_2O), and slowest inspiratory rise time. TS = with the maximum triggering sensitivity setting. PS = with the maximum pressure-support setting (10 cm H_2O). IRT = with the fastest inspiratory rise time. All = the combination of the highest triggering sensitivity, highest pressure support (10 cm H_2O), and fastest inspiratory rise time. This figure shows the pooled results from all the inspiratory efforts (300 mL, 500 mL, and 700 mL).

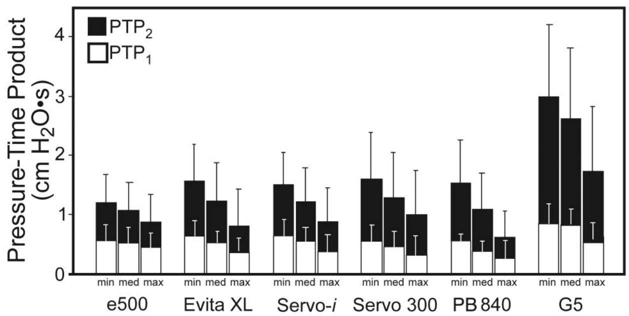

Fig. 4. Effects of inspiratory rise time on pressure-time product (PTP, see text for definitions of PTP_1 and PTP_2), with the minimum, medium, and maximum inspiratory-rise-time settings. The inspiratory-rise-time scales differed among the tested ventilators. This figure shows the pooled results from all the modeled inspiratory efforts (300 mL, 500 mL, and 700 mL) and pressure-support levels of 5 cm H_2O and 10 cm H_2O.

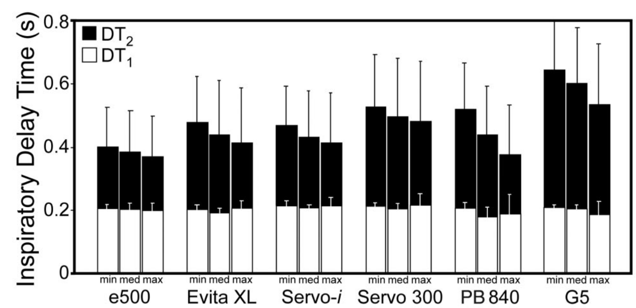

Fig. 6. Effects of inspiratory rise time on inspiratory delay time (DT), with the minimum, medium, and maximum inspiratory rise times. This figure shows the pooled results for all the inspiratory efforts (300 mL, 500 mL, and 700 mL) and pressure-support levels of 5 cm H_2O and 10 cm H_2O.

tory drive, pressure-support level, or triggering sensitivity ($P < .01$) (Fig. 4). The PTP_1 values were smallest with the PB 840 and the Servo 300, and largest with the G5. The PTP_2 values were smallest with the PB 840 and largest with the G5. The effect of inspiratory rise time change on PTP_2 was more apparent than the effect on PTP_1 with most ventilators. The combined effects of adjusting the triggering sensitivity, pressure support, and inspiratory-rise-time setting on PTP are shown in Figure 5. Optimizing each of the triggering sensitivity, pressure support, and inspiratory rise time decreased PTP by 9%, 31%, and 28%, on average, respectively. When optimizing all, PTP decreased by 83%.

DT_1 did not change significantly between the various inspiratory-rise-time settings with any of the ventilators (Fig. 6). In contrast, as inspiratory rise time became shorter, DT_2 decreased with all the ventilators, regardless of inspiratory drive, pressure-support level, or triggering sensitivity ($P < .01$). The effect of inspiratory rise time change on DT_2 differed among the ventilators ($P < .01$). The DT_2 values were smallest with the e500 and largest with the G5. The combined effects of adjusting the triggering sensitivity, pressure support, and inspiratory-rise-time setting on DT are shown in Figure 7. Optimizing each of the triggering sensitivity, pressure support, and inspiratory rise time decreased DT by 2%, 10%, and 30%, on average, respectively. When optimizing all, DT decreased by 47%.

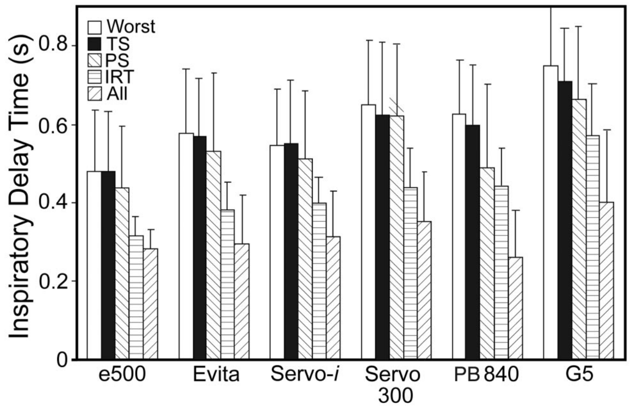

Fig. 7. Combined effects of triggering sensitivity, pressure support and inspiratory rise time on inspiratory delay time (DT). Worst = the combination of lowest triggering sensitivity, lowest pressure support (5 cm H_2O), and slowest inspiratory rise time. TS = with the maximum triggering sensitivity setting. PS = with the maximum pressure-support setting (10 cm H_2O). IRT = with the fastest inspiratory rise time. All = the combination of the highest triggering sensitivity, highest pressure support (10 cm H_2O), and fastest inspiratory rise time. This figure shows the pooled results from all the inspiratory efforts (300 mL, 500 mL, and 700 mL).

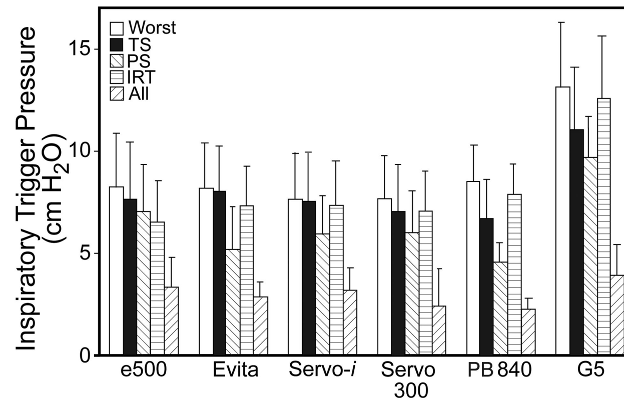

Fig. 9. Combined effects of triggering sensitivity, pressure-support level, and inspiratory rise time on inspiratory trigger pressure. Worst = the combination of lowest triggering sensitivity, lowest pressure support (5 cm H_2O), and slowest inspiratory rise time. TS = with the maximum triggering sensitivity setting. PS = with the maximum pressure-support setting (10 cm H_2O). IRT = with the fastest inspiratory rise time. All = the combination of the highest triggering sensitivity, highest pressure support (10 cm H_2O), and fastest inspiratory rise time. This figure shows the pooled results from all the inspiratory efforts (300 mL, 500 mL, and 700 mL).

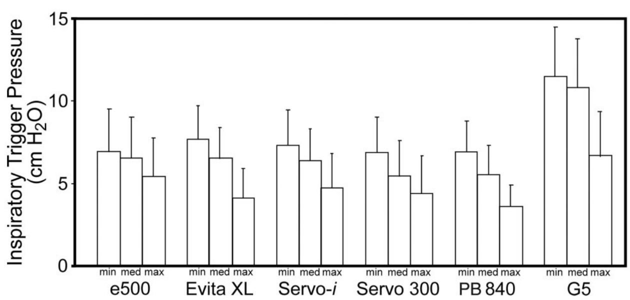

Fig. 8. Effects of inspiratory rise time on inspiratory trigger pressure, with the minimum, medium, and maximum inspiratory rise times. This figure shows the pooled results from all the inspiratory efforts (300 mL, 500 mL, and 700 mL) and pressure-support levels of 5 cm H_2O and 10 cm H_2O.

As inspiratory rise time became shorter, ΔP_{ao} decreased with all the ventilators, regardless of inspiratory drive, pressure-support level, or triggering sensitivity ($P < .01$) (Fig. 8). The ΔP_{ao} values were smallest with the PB 840 and largest with the G5. The combined effects of adjusting the triggering sensitivity, pressure support, and inspiratory-rise-time setting on ΔP_{ao} are shown in Figure 9. Optimizing each of the triggering sensitivity, pressure support, and inspiratory rise time decreased ΔP_{ao} by 9%, 28%, and 9%, on average, respectively. When optimizing all, ΔP_{ao} decreased by 66%.

Table 2 shows the results for DT, DT_1, DT_2, PTP, PTP_1, PTP_2, ΔP_{ao}, ΔP_{alv}, ΔP_{pl}, and peak inspiratory flow, which were pooled for all inspiratory effort and pressure-support levels, for the shortest inspiratory rise time and the most sensitive triggering. PTP and PTP_2 were smallest with the PB 840 and largest with the G5 ($P < .01$).

Discussion

The main findings of this bench study are:

1. Short inspiratory rise time reduced PTP_1, PTP_2, and PTP, regardless of the inspiratory drive, pressure-support level, or triggering sensitivity, with all the ventilators.
2. DT_2 decreased as inspiratory rise time decreased, whereas DT_1 did not.
3. PTP_1, PTP_2, and DT_2 were different among these ventilators.
4. A combination of short inspiratory rise time, high pressure-support, and sharp triggering sensitivity gave the smallest PTP and DT values.

Bonmarchand et al reported that short inspiratory rise time decreased the work of breathing (WOB) in patients with obstructive[4] and restrictive[5] diseases, when the pressure-support level was fixed in each patient. However, they compared very slow inspiratory rise times (1.0 s, 1.25 s, and 1.5 s) to modest inspiratory rise times (0.1 s and 0.25 s). The range of clinically used inspiratory-rise-time setting is not that wide: inspiratory rise time longer than 1.0 s is too slow for most patients. The ventilators we investigated in the present study exhibited better performance, probably because we used a clinically realistic range of inspiratory rise times.

To evaluate the effect of inspiratory rise time on pre-trigger and post-trigger events separately,[2] we divided PTP and DT into 2 components at the lowest P_{ao}. DT_1 did not

Table 2. Results at the Shortest Inspiratory Rise Time and the Most Sensitive Triggering Setting

	e500	Evita XL	Servo-*i*	Servo 300	PB 840	G5
DT (s)*	0.36 ± 0.14	0.41 ± 0.20	0.41 ± 0.18	0.48 ± 0.20	0.37 ± 0.21	0.52 ± 0.22
DT_1 (s)*	0.21 ± 0.02	0.20 ± 0.03	0.22 ± 0.03	0.23 ± 0.01	0.19 ± 0.06	0.21 ± 0.04
DT_2 (s)*	0.16 ± 0.13	0.21 ± 0.18	0.19 ± 0.17	0.25 ± 0.20	0.18 ± 0.17	0.31 ± 0.19
PTP (cm H_2O•s)*	0.80 ± 0.68	0.81 ± 0.85	0.84 ± 0.85	0.78 ± 1.10	0.55 ± 0.73	1.53 ± 1.39
PTP_1 (cm H_2O•s)*	0.43 ± 0.25	0.36 ± 0.24	0.37 ± 0.27	0.17 ± 0.36	0.24 ± 0.27	0.55 ± 0.38
PTP_2 (cm H_2O•s)*	0.37 ± 0.44	0.45 ± 0.63	0.47 ± 0.59	0.61 ± 0.76	0.31 ± 0.47	0.98 ± 1.03
ΔP_{ao} (cm H_2O)*	4.87 ± 2.53	3.98 ± 1.94	4.41 ± 2.24	3.86 ± 2.63	2.97 ± 1.53	5.26 ± 2.68
ΔP_{alv} (cm H_2O)	8.67 ± 3.63	7.73 ± 3.54	7.79 ± 3.77	7.21 ± 3.88	6.56 ± 3.21	8.80 ± 3.72
ΔP_{pl} (cm H_2O)	6.40 ± 2.50	6.05 ± 2.55	5.95 ± 2.55	5.91 ± 2.54	5.32 ± 2.53	6.68 ± 2.72
PIF (L/min)	69.3 ± 11.8	61.3 ± 10.0	63.2 ± 10.4	59.6 ± 11.0	62.7 ± 9.2	58.2 ± 8.9

* = $P < .01$ among ventilators. These are the pooled results for all the inspiratory efforts, at 300 mL, 500 mL, and 700 mL, and both pressure-support levels (5 cm H_2O and 10 cm H_2O).
DT = delay time
DT_1 = pre-trigger DT
DT_2 = post-trigger DT
PTP = pressure-time product
PTP_1 = PTP during DT_1
PTP_2 = PTP during DT_2
ΔP_{ao} = maximum deflection of airway pressure during DT
ΔP_{alv} = maximum deflection of alveolar pressure during DT
ΔP_{pl} = maximum deflection of pleural pressure during DT
PIF = peak inspiratory flow

change significantly among the different inspiratory-rise-time settings (see Fig. 3). DT_1 consisted mainly of the DT from the start of inspiratory effort to triggering of the ventilator, and short inspiratory rise time did not affect this measurement. In contrast, as inspiratory rise time shortened, DT_2 decreased with all the ventilators. Shorter inspiratory rise time decreased the WOB, as evidenced by the decreased DT_2 and PTP_2. Because DT_1 was a pre-trigger event, it was reasonable that DT_1 increased with less sensitive triggering but did not increase with longer inspiratory rise time. However, short inspiratory rise time decreased ΔP_{ao} in all ventilators, whereas DT_1 was not affected by inspiratory rise time. The supplied flow could not exceed the demand immediately after the inspiratory triggering, and the P_{ao} continued to drop more with longer inspiratory rise time. Therefore, as inspiratory rise time shortened, PTP_1 and ΔP_{ao} decreased with no change of DT_1.

In this study, both short inspiratory rise time and high PSV reduced DT_2, ΔP_{ao}, PTP_1, and PTP_2, although they did not reduce DT_1. Although raising the pressure-support level is commonly used to increase ventilatory assistance, it does not always reduce patient's inspiratory work load when inspiratory drive is high. To decrease the patient's inspiratory work load, initial inspiratory flow may be more important than the peak value.[10] Uchiyama et al suggested that increasing initial inspiratory flow was more effective than raising the pressure-support level to preserve inspiratory assistance of PSV in patients with high inspiratory drive.[6] In this study we observed that shortening inspiratory rise time and raising the pressure-support level af-

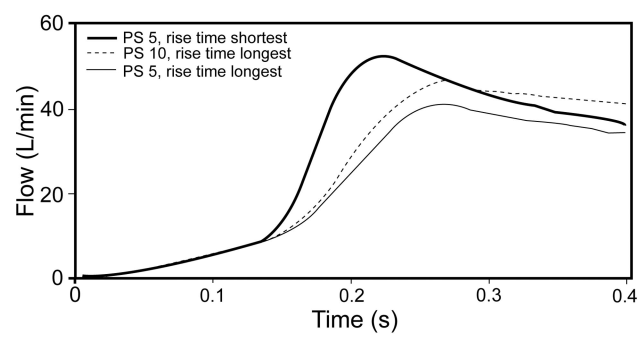

Fig. 10. Representative flow-time curves from the PB 840 with 3 combinations of pressure-support (PS) level and the inspiratory-rise-time setting. The increase in initial inspiratory flow was more remarkable with the shorter inspiratory rise time than with the higher pressure-support level.

fected the initial inspiratory flow differently, although both increased peak inspiratory flow. Figure 10 shows representative flow-time waveforms from the PB 840 with 3 combinations of pressure-support level and inspiratory rise time. The increase in initial inspiratory flow was more remarkable with the shorter inspiratory rise time than with the higher pressure-support level. To effectively reduce the patient's inspiratory work load an appropriate combination of inspiratory rise time and pressure-support level may be necessary.

To our knowledge, this study is the first to demonstrate the combined effects of adjusting inspiratory rise time, triggering sensitivity, and pressure-support level on inspiratory work load. We found that combining all of the best inspiratory rise time, triggering sensitivity, and pressure-support level decreased the inspiratory work load the most (see Figs. 5, 7, and 9). The effects of the combination were greater than the sum of each effect. Uchiyama et al reported that increasing the initial inspiratory flow with maximum inspiratory rise time was more effective than raising the pressure-support level alone in preserving the inspiratory assistance of PSV when inspiratory drive was high.[6] It is reasonable that optimizing triggering sensitivity decreases the inspiratory work load more.

All of our tested ventilators except the G5 showed similar changes in PTP, DT, and inspiratory trigger pressure as we shortened the inspiratory rise time. Richard et al[11] and Thille et al[12] compared the inspiratory assistance of newer-generation and older ventilators, and of turbine-powered versus gas-powered ventilators. With an enormous amount of data they demonstrated that the improvements in ventilator performance were huge, in comparison with the previous ones, but the progress reached a technical ceiling in recent years. They evaluated PTP over the first 0.3 s and 0.5 s of inspiration, using a 2-chamber type test lung. In contrast, we calculated the PTP below the baseline airway pressure to evaluate the inspiratory work load, using a 2-bellows-in-a-box type test lung and simulated pleural space, as did previous studies.[6,9]

There were differences between our data and those of Thille et al concerning DT.[12] While most of the ventilators in their study had DT $\leq$ 0.1 s, the DT in our study was 0.3–0.6 s. Although a definite reason was not specified, we speculated it might be due to the different lung model used (2-bellows-in-a-box type), different design to simulate inspiratory effort (negative pressure created in the pleural space), and insertion of a heat-and-moisture-exchanger into the circuit in our study.

Limitations

Since this was a lung model study, direct application of the data to the clinical settings is limited. The relationship between inspiratory rise time and WOB/PTP is not linear, and impact on WOB/PTP cannot be directly transposed to patients.[7,8] Prinianakis et al showed that fast inspiratory rise time decreased PTP in patients with chronic obstructive pulmonary disease but was accompanied by substantial air leaks and poor tolerance.[8] By using a lung model, however, we could compare a large number of ventilators with each other under multiple simulated clinical situations, which is difficult to do with patients.[13] We examined only a single condition of lung mechanics, which simulated acute respiratory distress syndrome in patients with high resistance. Chatmongkolchart et al found results similar to ours when they used a lung model with normal lung mechanics and one pressure-support level and one PEEP setting.[14]

Conclusions

In this lung model study, shorter inspiratory rise time decreased the inspiratory work load, regardless of the pressure-support level, PEEP setting, triggering sensitivity, or inspiratory drive. To minimize the inspiratory work load, all of the inspiratory rise time, pressure-support level, and triggering sensitivity need to be optimized.

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