Effects of different triggering systems and external PEEP on trigger capability of the ventilator

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Abstract Objective: The triggering capability of both the pressure and flow triggering systems of the Servo 300 ventilator (Siemens-Elema, Sweden) was compared at various levels of positive end-expiratory pressure (PEEP), airway resistance ($R_{aw}$), inspiratory effort and air leak, using a mechanical lung model.

Design: The ventilator was connected to a two bellows-in-series-type lung model with various mechanical properties. Lung complianc and chest wall compliance were 0.03 and 0.12 l/cmH$_2$O, respectively. $R_{aw}$ was 5, 20 and 50 cmH$_2$O/l/s. Respiratory rate was 15 breaths/min. To compare the triggering capability of both systems, the sensitivity of pressure and flow triggered pressure support ventilation (PSV) was adjusted to be equal by observing the triggering time at 0 cmH$_2$O PEEP and 16 cmH$_2$O of pressure support (PS) with no air leak. No auto-PEEP was developed. In the measurement of trigger delay, the PS level ranged from 16 to 22 cmH$_2$O to attain a set tidal volume ($V_T$) of 470 ml at a $R_{aw}$ of 5, 20 and 50 cmH$_2$O/l/s. The PEEP level was then changed from 0, 5 and 10 cmH$_2$O at a PS level of 17 cmH$_2$O and $R_{aw}$ of 5 and 20 cmH$_2$O/l/s, and the trigger delay was determined. The effect of various levels of air leak and inspiratory effort on triggering capability was also evaluated. Inspiratory effort during triggering delay was estimated by measurements of pressure differentials of airway pressure ($P_{aw}$) and driving pressure in the diaphragm bellows ($P_{driv}$) in both systems.

Measurements and results: There were no significant differences in trigger delay between the two triggering systems at the various PEEP and $R_{aw}$ levels. At the matched sensitivity level, air leak decreased trigger delay in both systems, and additional PEEP caused auto-cycling. A low inspiratory drive increased trigger delay in the pressure sensing system, while trigger delay was not affected in the flow sensing system. The $P_{aw}$ and $P_{driv}$ differentials were lower in flow triggering than in pressure triggering.

Conclusions: With respect to triggering delay, the triggering capabilities of the pressure and flow sensing systems were comparable with and without PEEP and/or high airway resistance at the same sensitivity level, unless low inspiratory drive and air leak were present. In terms of pressure differentials, the flow triggering system may require less inspiratory effort to trigger the ventilator than that of the pressure triggering system with a comparable triggering time. However, this difference may be extremely small.

Key words Work of breathing · Pressure support ventilation · Lung model · Artificial ventilation · Ventilators · Trigger delay
Introduction

Both flow and pressure triggering systems are incorporated in most modern ventilators run by microprocessors [1, 2]. The triggering capability of these sensing systems and their responsiveness to patient effort were evaluated in terms of trigger delay [3, 4]. The factors that affected trigger delay were the trigger mechanism and sensitivity, the magnitude of patient inspiratory effort, auto-PEEP (positive end-expiratory pressure), and externally applied PEEP [5]. According to Sassoon and other investigators [5–9], the flow-triggering system is more sensitive than the pressure-triggering system. However, although the highest sensitivity that did no cause auto-cycling was taken in both systems, the direct comparison of the triggering capability of both sensing mechanisms had a significant problem; the set sensitivity of both systems may be different, which would lead to a significant error in comparison.

The purpose of this study was to compare the triggering capability of both pressure and flow triggering during pressure support ventilation (PSV) on the basis that equal sensitivity in terms of trigger time was preset for both systems. Under these conditions, the triggering capability of both systems was examined at different levels of external PEEP, airway resistance, inspiratory drive and air leak. Our lung model was designed to simulate spontaneous breathing with various mechanical properties. It allowed us to measure accurately trigger delay, which was defined as the interval from the onset of spontaneous ventilatory activity to the initiation of fresh gas delivery into the lung.

Materials and methods

A mechanical lung model was used in our study. Details on the model have already been described by Takahashi et al. [10]. The model consisted of two bellows in series suspended by springs (Fig. 1). As an analog of the lung, one bellows was attached in sequence to the ventilator. Analogous to the diaphragm, the remaining bellows was attached to a jet flow generator providing the spontaneous inspiratory effort. Both bellows were surrounded by air space regarded as the pleural space in which the pressure was subatmospheric. Lung compliance (L) was set as 0.03 l/cmH2O, and chest wall compliance was 0.12 l/cmH2O. Airway resistance (Raw) of either 5, 20 or 50 cmH2O/l/s was added by placing resistors of various diameters between the lung and ventilator. A Venturi mechanism of jet flow was used to provide negative pressure inside the diaphragm bellows. The jet flow generator can be driven at a set respiratory rate (RR), driving pressure and inspiratory: expiratory ratio. A waveform of negative pressure in the diaphragm bellows (PdRV), thought to be equivalent to respiratory muscle pressure (Pmus), was applied inside the diaphragm bellows. The waveform of PdRV was adjusted to become exponential by interposing capacitance and resistance between the jet flow generator and diaphragm bellows. The magnitude of PdRV was adjusted by regulating the driving pressure of the jet flow generator. The pressure profile, peak flow rate (0.23 l/s) and magnitude of PdRV were maintained in each setting. Inspiratory effort was transmitted through the pleural space to the lung bellows, allowing the lung bellows to expand, which resulted in gas entering the lung. During exhalation, jet flow was interrupted and the diaphragm bellows was opened to the atmosphere. At the end of expiration, the diaphragm bellows returned passively to the initial level, which was equal to a functional residual capacity of approximately 2000 ml in our model.

Flow was measured with a hot-wire flow manometer (Minato ATD 105, Osaka, Japan) calibrated with a 21 syringe. The flow signal was used for volume measurements. Pleural pressure (Ppl), PdRV, pre- and postresistor pressure, which were considered as airway opening pressure (Paw) and alveolar pressure (Paw), respectively, were measured with separate pressure transducers. Auto-PEEP was determined as end-expiratory Pp, exceeding the externally applied PEEP. All variables were monitored and recorded on a multichannel strip-chart recorder (Omniconder, Sanei, Tokyo, Japan). Trigger delay was determined as an interval from the onset of inspiratory effort indicated by onset of negative deflection on the Paw curve to the onset of flow delivery into the lung (Fig. 2). High-speed tracings were used to analyze trigger delay. The Servo 300 ventila tor (Siemens-Elema, Sweden) was examined with both pressure and flow sensing mechanisms. A standard ventilator circuit without a humidifier was used in all the experiments.

Protocol

PSV was delivered by the Servo 300 ventilator connected to the lung model. The triggering capability of the ventilator was evaluated in the absence of auto-PEEP. To avoid the development of auto-PEEP, a low RR of 15 breaths/min and an inspiratory: expiratory ratio of 1:3 were used in all the experimental settings. At each setting, PdRV was adjusted to obtain a tidal volume (Vt) of 190 ml during T-piece breathing at a Raw of 5 cmH2O. The magnitude of PdRV was not changed during any settings except one with varied inspiratory effort. At a PEEP level of 0 cmH2O, Raw of 5 cmH2O and a pressure support (PS) level of 16 cmH2O, the triggering sensitivity of both pressure and flow were adjusted to be equal. To accomplish this, sensitivity of flow-triggered PSV was adjusted to obtain the trigger delay equal to that in pressure-triggered PSV at a sensitivity of -0.3 cmH2O. At this fixed sensitivity level, trigger delay was compared between flow and pressure triggered PSV under the following experimental conditions. First, the PS level was arbi-