Pressure vs Flow Triggering During Pressure Support Ventilation*

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Background: Adult mechanical ventilators have traditionally been pressure- or time-triggered. More recently, flow triggering has become available and some adult ventilators allow the choice between pressure or flow triggering. Prior studies have supported the superiority of flow triggering during continuous positive airway pressure, but few have compared pressure and flow triggering during pressure support ventilation (PSV). The purpose of this study was to compare pressure and flow triggering during PSV in adult mechanically ventilated patients.

Methods: The study population consisted of 10 adult patients ventilated with a mechanical ventilator (Nellcor-Puritan-Bennett 7200ae) in the PSV mode. In random order, we compared pressure triggering of −0.5 H2O, pressure triggering −1 cm H2O, flow triggering 5/2 L/min, and flow triggering 10/3 L/min. Pressure was measured for 5 min at the proximal endotracheal tube using a data acquisition rate of 100 Hz. From the airway pressure signal, trigger pressure (ΔP) was defined as the difference between positive end-expiratory pressure (PEEP) and the maximum negative deflection prior to onset of the triggered breath. Pressure-time product (PTP) was defined as the area produced by the pressure waveform below PEEP during onset of the triggered breath. Trigger time (ΔT) was defined as the time interval between PEE and onset of the triggered breath.

Results: A pressure trigger of −0.5 cm H2O was significantly more sensitive than the other trigger methods for ΔP, PTP, and ΔT (p<0.001). There was also a significant difference between patients for ΔP, ΔT, and PTP for each trigger method (p<0.001).

Conclusions: For this group of patients, flow triggering was not superior to pressure triggering at −0.5 cm H2O during PSV. (CHEST 1997; 111:1649-53)

Key words: flow trigger; mechanical ventilation; pressure support ventilation; pressure trigger

Abbreviations: ANOVA=analysis of variance; CPAP=continuous positive airway pressure; ΔP=trigger pressure; PEEP=positive end-expiratory pressure; PSV=pressure support ventilation; PTP=pressure-time product; SIMV=synchronous intermittent mandatory ventilation; ΔT=trigger time

During mechanical ventilation, inspiration is initiated when a trigger variable reaches a preset value. With full ventilator support (controlled ventilation), the trigger variable is time. When patient efforts initiate the breath delivery, the trigger can be either pressure or flow. Traditionally, patient-initiated breaths have been pressure triggered. For a pressure-triggered breath, the ventilator senses the patient’s effort as a drop in baseline pressure. The drop in pressure required to trigger the ventilator is clinician determined. In the late 1980s, flow triggering became available and is now provided on most current-generation ventilators. For a flow-triggered breath, the ventilator senses patient effort through changes in inspiratory flow created by the patient. Specifically, a base flow and a flow sensitivity are set by the clinician. For one ventilator (Nellcor-Puritan-Bennett 7200ae; Carlsbad, Calif), the base flow can be set between 5 and 20 L/min, and the flow sensitivity can be set as low as 1 L/min to a maximum of half of the base flow. The base flow passes through the circuit during the expiratory phase. When the flow sensed at the expiratory valve decreases by the amount of the flow sensitivity, the ventilator triggers to the inspiratory phase.

There have been many evaluations of flow-triggered ventilation during spontaneous breathing with continuous positive airway pressure (CPAP). Most, but not all, have reported superiority of...
flow-triggering during CPAP. However, there have been relatively few comparisons of flow triggering with pressure triggering during assisted modes such as synchronous intermittent mandatory ventilation (SIMV) or pressure support ventilation (PSV). Giuliani et al.\(^5\) found that flow triggering reduced inspiratory effort during both mandatory and spontaneous SIMV breaths. This is in contrast to Sassoon et al.,\(^6\) who found that the method of triggering affected inspiratory muscle work during spontaneous breaths, but had no significant effect on the inspiratory work of mandatory breaths. Owing to the high initial flow delivery during PSV, Sassoon and Gruer\(^7\) suggested that there may be minimal differences between pressure triggering and flow triggering with this mode. Sassoon et al.\(^8\) have shown that 5 cm H\(_2\)O PSV is comparable to CPAP with flow triggering. In rabbits intubated with a 4-mm endotracheal tube, Nishimura et al.\(^9\) reported no differences between flow triggering and pressure triggering during PSV.

We conducted this study to evaluate triggering during PSV using a specific ventilator (Puritan-Bennett 7200ae). We compared pressure triggering and flow triggering in a series of patients in stable condition recovering from acute respiratory failure.

**Materials and Methods**

**Patient Population and Ventilator System**

We studied 10 patients recovering from acute respiratory failure: median age, 66 years (range, 27 to 83 years); six men and four women; median PSV, 10 cm H\(_2\)O (range, 8 to 25 cm H\(_2\)O); and median positive end-expiratory pressure (PEEP), 5 cm H\(_2\)O (range, 3 to 7.5 cm H\(_2\)O). All were in hemodynamically stable condition and breathing comfortably on PSV with a ventilator (Puritan-Bennett 7200ae). All ventilators were from the clinical fleet of the respiratory care department; no ventilator was replaced or specifically chosen for purposes of this study. All ventilators were maintained in accordance with manufacturer's specifications. Disposable ventilator circuits (5-foot length) were used with heated cascade humidifiers. Water condensate was evacuated from the circuit before the study protocol was initiated.

**Study Protocol**

The study was approved by the Human Studies Committee and informed consent was waived owing to the minimal risk and noninvasive nature of the protocol. All patients were comfortably positioned either supine or sitting at 30 to 45° throughout the study. There was no change in position during the study. Other than trigger sensitivity, no ventilator changes were made for purposes of the study. Four trigger settings were randomly applied: pressure –0.5 cm H\(_2\)O; pressure –1.0 cm H\(_2\)O; base flow 5 L/min with flow sensitivity of 2 L/min; and base flow 10 L/min with flow sensitivity 3 L/min. At least 5 min were allowed on each trigger setting before the initiation of data collection. Five minutes of data were collected for each trigger setting.

**Measurements and Analysis**

Pressure and flow were measured at the proximal airway using a calibrated respiratory monitoring system (VenTrak Respiratory Monitoring System; Novametrix; Wallingford, Conn.). Pressure calibration was performed at 0 and 10 cm H\(_2\)O using a water column. Data were sampled at 100 Hz, then exported to a spreadsheet (Microsoft Excel; Redmond, Wash.) for analysis. Ten breaths free of artifact were chosen midway through each sample period for analysis. The following were calculated from each airway pressure trace (Fig 1): trigger pressure (ΔP)—the maximum negative pressure (cm H\(_2\)O) deflection from baseline; pressure-time product (PTP)—the total area (cm H\(_2\)O · s) below baseline during onset of the pressure-supported breath, which was further subdivided: PTP1—the area (cm H\(_2\)O · s) below baseline pressure from initial negative deflection to maximum negative deflection; PTP2—the area (cm H\(_2\)O · s) below baseline pressure from maximum negative deflection to the point of pressure return to baseline; trigger time (ΔT)—the time associated with the total area below PEEP at the onset of the breath, which was further subdivided: ΔT1—the time (s) between the initial negative pressure deflection from baseline to the maximum pressure deflection from baseline; ΔT2—the time (s) between the maximum pressure deflection from baseline and the return of pressure to baseline.

**Statistical Analysis**

Data are presented as mean ± SD. Two-way analysis of variance (ANOVA) was performed with trigger type (four levels) as a repeated measure (within groups) variable and patients (10 levels) as a between groups variable. Differences between trigger type were further evaluated using post hoc Scheffé analysis. p<0.05 was considered significant. All statistical analysis was performed using commercially available software (SPSS; Chicago).

**Results**

Summary data are provided in Table 1. For each dependent variable (ΔP, PTP, PTP1, PTP2, ΔT, ΔT1, ΔT2), there was a significant difference between trigger types (p<0.001 by ANOVA). Pressure trigger of –0.5 cm H\(_2\)O was consistently more sensitive than the other three trigger methods (p<0.05 by Scheffé analysis). For each trigger type,
there was a significant difference between patients (p<0.001 by ANOVA) for each dependent variable.

**Discussion**

During PSV with the type of ventilator used in this study, a pressure trigger of −0.5 cm H2O was more sensitive to patient effort than the other trigger types that we evaluated. Despite the statistically significant differences between trigger types, the absolute differences were small (Table 1) and may not be clinically important.

The ventilator used in this study performs differently for pressure-triggered and flow-triggered breaths during CPAP. During pressure-triggered CPAP, the ventilator attempts to maintain a pressure limit at the baseline pressure (ie, PEEP) minus the sensitivity. During flow-triggered CPAP, the ventilator attempts to maintain a pressure limit 0.5 cm H2O above the baseline pressure. In other words, flow triggering produces a small level of PSV. It is reasonable that patient effort should be less during flow-triggered CPAP than pressure-triggered CPAP, as has been shown in several studies. In contrast to CPAP, during PSV, a flow up to 180 L/min is provided until the PSV setting is reached. Unlike CPAP, the pressure limit during PSV is identical during pressure and flow triggering—the PSV level. These differences explain why patient effort might be similar for pressure-triggered and flow-triggered breaths during PSV. Sassoon et al14 compared flow-triggered CPAP (flow trigger setting of 10 L/min) and pressure-triggered CPAP (pressure trigger of −1 cm H2O), and pressure-triggered PSV (pressure trigger −1 cm H2O, PSV 5 cm H2O) in nine patients recovering from acute respiratory failure. Consistent with our findings, the inspiratory work of breathing with pressure-triggered PSV was comparable to flow-triggered CPAP. However, they did not compare pressure-triggered PSV with flow-triggered PSV. Nishimura et al15 compared pressure-triggered PSV with flow-triggered PSV in rabbits intubated with a 4-mm endotracheal tube and found no difference between the two trigger types.

Most other studies of triggering have evaluated flow vs pressure triggering, but few have compared trigger sensitivities. In some of those studies, the trigger sensitivity was not reported.6,11 In one study, Sassoon et al8 compared flow trigger levels of 5/2 and 20/2 during CPAP, and reported no difference between the two base flow levels. We found that a flow trigger of 5/2 L/min was slightly more sensitive than 10/3 L/min (Table 1), but the clinical importance of this difference is unknown. One potential effect of a higher base flow is a slight increase in PEEP,4,15 which might explain the superiority of flow triggering when auto-PEEP is present.13

The slope to the airway pressure deflection below baseline during the trigger phase is determined by patient inspiratory muscle strength and respiratory drive.3 This may explain why ΔP was greater than the trigger pressure sensitivity set on the ventilator (Table 1) and why there was a significant ΔP even for flow-triggered breaths. It is interesting to note that the ΔP for flow-triggered breaths exceeded that for pressure-triggered sensitivity of −0.5 cm H2O. Although it has been suggested that the base flow during flow triggering may be useful to meet patient demand during the trigger phase,13 it is unlikely that a flow of 5 to 10 L/min will be sufficient to meet the flow requirement of a patient with a moderate-to-high ventilatory drive.

We did not evaluate PSV in combination with SIMV. Although Giuliani et al13 found that flow triggering reduced inspiratory effort during both mandatory and spontaneous SIMV breaths, Sassoon et al10 found that the method of triggering affected

<table>
<thead>
<tr>
<th>Trigger Type</th>
<th>ΔP, cm</th>
<th>PTP1, cm</th>
<th>PTP2, cm</th>
<th>PTP, cm</th>
<th>ΔT1, s</th>
<th>ΔT2, s</th>
<th>ΔT, s</th>
</tr>
</thead>
<tbody>
<tr>
<td>H2O</td>
<td></td>
<td>H2O</td>
<td>H2O</td>
<td>H2O</td>
<td></td>
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<td></td>
</tr>
<tr>
<td>0.5 cm</td>
<td>1.06±0.40</td>
<td>0.088±0.039</td>
<td>0.012±0.007</td>
<td>0.100±0.044</td>
<td>0.173±0.060</td>
<td>0.021±0.007</td>
<td>0.193±0.064</td>
</tr>
<tr>
<td>1.0 cm</td>
<td>1.62±0.47</td>
<td>0.142±0.042</td>
<td>0.021±0.009</td>
<td>0.161±0.045</td>
<td>0.197±0.060</td>
<td>0.025±0.006</td>
<td>0.222±0.051</td>
</tr>
<tr>
<td>5/2 L/min</td>
<td>1.34±0.67</td>
<td>0.119±0.054</td>
<td>0.017±0.013</td>
<td>0.136±0.064</td>
<td>0.181±0.042</td>
<td>0.026±0.013</td>
<td>0.207±0.047</td>
</tr>
<tr>
<td>10/3 L/min</td>
<td>1.42±0.71</td>
<td>0.136±0.073</td>
<td>0.024±0.022</td>
<td>0.161±0.086</td>
<td>0.187±0.051</td>
<td>0.033±0.023</td>
<td>0.210±0.054</td>
</tr>
</tbody>
</table>

*There was a significant difference between trigger types (p<0.001 by ANOVA), and pressure trigger of −0.5 cm H2O was more sensitive to patient effort than the other three trigger methods (p<0.05 by Scheffe analysis).
inspiratory muscle work only during spontaneous breaths. Because Sassoon et al\textsuperscript{10} used peak inspiratory flows 15 to 50\% greater than Giuliani et al\textsuperscript{13} these differing results may be explained on the basis of the postrigger phase. Thus, the results of Giuliani et al\textsuperscript{13} may be consistent with Marini, et al\textsuperscript{16} who have shown that patient effort increases with lower peak inspiratory flows. Our results and those of Sassoon et al\textsuperscript{7} suggest that the results of Giuliani et al\textsuperscript{13} may have been different with SIMV and a low level of PSV.

We did not measure esophageal pressure and therefore could not calculate patient inspiratory work of breathing or patient PTP. Our study is similar in that regard to the study of Saito et al\textsuperscript{5} who also did not measure esophageal pressure. Because we analyzed the airway pressure waveform, our study evaluated the responsiveness of the ventilator.\textsuperscript{17} Evaluation of the esophageal pressure includes not only the effects of ventilator responsiveness, but respiratory system impedance and respiratory drive as well. Prior studies that have measured esophageal pressure have not reported the imposed ventilator contribution to patient effort, which can be assessed only by evaluating the proximal airway pressure waveform.

Recently, the concept of tracheal triggering has been introduced. Tracheal pressure triggering has been shown to substantially reduce the work of breathing in lung models simulating spontaneous breathing with CPAP.\textsuperscript{18,19} Because pressure changes move at nearly the speed of sound, moving the pressure sensor to the carinal end of the endotracheal tube is unlikely to greatly affect trigger sensitivity.\textsuperscript{20,21} Like flow triggering, it is likely that the benefit of tracheal triggering occurs in the postrigger phase. As recently shown by Bhatt et al,\textsuperscript{22} the decrease in imposed work of breathing with tracheal triggering during CPAP is not due to an improvement in triggering per se, but rather because a small amount of pressure support is produced at the proximal endotracheal tube. We speculate that tracheal triggering, like flow triggering, will have little effect on trigger sensitivity when PSV is used with adult patients. Targeting pressure in the trachea rather than the proximal airway may be of benefit during the postrigger interval of PSV because a square wave of pressure will be produced in the trachea (rather than the proximal airway), which may better satisfy active patient flow demands.\textsuperscript{20} Tracheal triggering may also be of benefit when small endotracheal tubes are used (eg, neonatal ventilation).\textsuperscript{12}

No study of triggering to date (and to our knowledge) has assessed outcome. Most studies, like ours, have been short-term evaluations of physiologic response to various forms of triggering. It is unknown whether one approach to triggering is superior to others with respect to duration of mechanical ventilation or other indexes of morbidity. Because flow triggering increases the cost and complexity of triggering, it would be of interest to know whether the type of triggering affects outcome. Our data suggest that pressure triggering at $-0.5$ cm H\textsubscript{2}O—available on most commercially available ventilators—is more sensitive than flow triggering at the levels we evaluated during PSV.

There are several limitations of this study. We evaluated only one ventilator system, and different results may occur with other commercially available ventilators capable of flow triggering. We evaluated only four trigger settings, which were chosen because they are commonly used in our clinical practice. We did not evaluate PSV in combination with SIMV, and we did not evaluate pressure vs flow triggering with other modes like assist/control or volume vs pressure limited breaths. Finally, because we evaluated a small and relatively homogeneous group of patients, it was not possible to determine whether flow triggering during PSV may be superior to pressure triggering in some patient populations.

**CONCLUSIONS**

For this group of patients, flow triggering was not superior to pressure triggering during PSV, and pressure triggering at $-0.5$ cm H\textsubscript{2}O was the most sensitive of the trigger levels that we evaluated. We also found significant differences among patients, suggesting that respiratory drive may have an important effect on triggering.

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