SMART Trigger versus Flow and Pressure trigger performance during auto-PEEP

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Abstract:

Background
Intrinsic positive end-expiratory pressure (auto-PEEP) is a common problem in mechanically ventilated patients, which can lead to adverse effects on patients comfort, hemodynamics, lung mechanics and gas exchange. Triggering systems play a crucial role in the delivery of mechanical ventilation, and advancements in smart triggering technology aim to optimize patient-ventilator synchrony. This bench study aims to compare the performance of the novel SMART Trigger to traditional pressure and flow triggers in the context of auto-PEEP.

Methods
A lung model simulating severe obstructive pattern with high compliance (80 ml/cmH_2O) and high resistance 30 cmH_2O/L/s was connected to the Panther 5 ventilator (Origin Medical, California, USA). The mode was set at Volume Controlled with a tidal volume of 700 ml and mandatory breath per min (BPM) of 10/min and Inspiratory time of 2 seconds to intentionally create auto-PEEP. Simulated spontaneous breaths set at 20 BPM with increasing muscle pressure (Pmus) from -1 to maximum of -25 or till full trigger of all breaths. Three different triggering systems were evaluated: SMART Trigger (ST sensitivity 1 to 7), pressure trigger (-1 cmH_2O), and flow trigger (1 l/min). The range of auto-PEEP levels induced increased incrementally with the increase in the respiratory rate ranging from 3 cmH_2O for 10 BPM, 8 for 15 BPM, to 13 for 20 BPM. The following parameters were assessed for each triggering system: trigger sensitivity (defined as the number of breaths triggered above the mandatory breaths), and the trigger response time (time it takes from the beginning of muscle effort to the initiation of the breath.

Results
100% of the breaths were triggered at Pmus (cmH_2O) of -15 in the pressure trigger, -25 in flow trigger, -3 for ST1, -9 for ST2, -10 for ST3, -10 for ST4, -12 for ST5, -18 for ST 6, and -22 for ST 7.
Trigger time (msec) for flow was 0.135 ± 0.02, for pressure 0.141 ± 0.04, for ST 1-4: 0.076 ± 0.03, for ST 5-7: 0.104 ± 0.04. Multivariate analysis of variance test showed significant difference between the time to trigger P <0.001.

Conclusion
This bench study highlights the potential advantages of SMART Trigger technology over conventional pressure and flow triggers during auto-PEEP. The SMART Trigger enhanced sensitivity and rapid response might contribute to improved patient-ventilator synchrony. Further research and clinical studies are warranted to validate these findings and explore the impact of smart trigger technology on patient outcomes in real-world scenarios.

Keywords: SMART Trigger, Auto-PEEP, Trigger time

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Introduction

Auto-PEEP or intrinsic-PEEP is a phenomenon where the lungs experience unintentional positive end expiratory pressure at the end of exhalation and is calculated as the difference between total PEEP and applied or extrinsic peep. [1] In these scenarios, imbalance of inspiration and expiration leads to gas retention and generation of positive pressure in the alveoli. Commonly, this is seen in patients receiving high tidal volumes, high respiratory rates or those who have obstructive physiology such as in COPD or asthma. A study by Natalini and colleagues [2] found that up to 47% of patients experience auto-PEEP of 1-6 cmH_2O. Even in patients ventilated without a history of obstructive physiology such as ARDS, and sepsis, auto-PEEP of up to 4.1 cmH_2O was found to occur in up to 35% of patients. Auto-PEEP also comes at significant consequences to the patient including increased patient-ventilator asynchronies, missed triggers, increased work of breathing, impaired pulmonary gas exchange barotrauma and cardiovascular collapse [3] due to high intrathoracic pressures.

In the presence of auto-PEEP it becomes increasingly difficult for a patient to successfully trigger a breath from the ventilator. Currently there are multiple methods ventilators may use to determine when the patient is attempting to breathe and when to deliver a breath: time, flow, pressure, volume and shape. [4] Time triggering gives a breath after a preset time and does not require any work on the patient's part in initiating said breath. Flow and pressure triggers use the change in either flow or pressure generated by the patient's inspiratory effort to notify the ventilator when to provide a breath. [5] One study comparing the two found that in patients demonstrating a restrictive pattern and higher severity respiratory distress, flow trigger ventilation led to decreased duration of ventilation and time in the ICU compared to pressure trigger. [6] Volume triggering detects change in volume to trigger a breath, however, as volume is often calculated by changes in flow rather than measured directly this method is rarely ever used. Shape triggering uses an algorithm to detect changes in the expiratory flow waveform that represent a patient's effort and gives a breath accordingly. Because of this, the specifics of shape triggering may vary widely between manufacturers. Finally, neurally adjusted ventilatory assist (NAVA) is a newer method of triggering that relies on real time EMG (Edi) reading of the diaphragm through a nasogastric tube to determine when the patient has an inspiratory effort. [7] Of these methods, time, pressure and flow are the most commonly used. However, one issue with these methods is that patients with auto-PEEP must generate larger inspiratory efforts to overcome their auto-PEEP and cause a change in pressure or flow that can be detected by the ventilator and successfully trigger breath. This results in higher patient-ventilator asynchronies like delayed and missed triggers.

SMART Trigger is a new software incorporated into the Panther 5 ventilator (Origin Medical, California, USA) that claims to perform better than flow or pressure triggers. As a form of shape triggering, SMART Trigger assesses for patient effort through changes in the flow/pressure waveform rather than their absolute values. Because of this, the postulation that using the SMART Trigger function results in improved trigger response times and decreased missed breaths. The goal of our study was to compare the level of missed and delayed trigger between flow, pressure and SMART Trigger in simulated patients with an obstructive pattern and the presence of auto-PEEP.

Methods

A single compartment lung model using ASL 5000 breathing simulator (IngMar Medical, Pennsylvania, USA) simulating a severe obstructive pattern with high compliance (80 ml/cmH_2O) and high resistance 30 cmH_2O/L/s was connected to the Panther 5 ventilator (Origin Medical, California, USA). The ventilator mode was set to Volume Control with a tidal volume of 700 ml, PEEP of 5 cmH_2O, descending flow pattern and mandatory breath rate of 10 per min (BPM) and Inspiratory time of 2 seconds, to intentionally create auto-PEEP. We did not place any humidification or filters between the ventilator and the lung simulator.

Simulated spontaneous breaths set at 20 BPM (sinusoidal pattern) with increasing inspiratory muscle pressure (Pmus) from -1 to maximum of -25 cmH_2O or till full trigger of all 20 simulated breaths. Three different triggering systems were evaluated: SMART Trigger (ST) with sensitivity 1 (most sensitive) to 7 (least sensitive), pressure trigger (-1 cmH_2O), and flow trigger (1 l/min). The range of induced auto-PEEP levels (cmH_2O) increased incrementally, with increasing respiratory rate, ranging from 3 for 10 BPM, 8 for 15 BPM, to 13 for 20 BPM (Table 1). Each Pmus was examined for 3 min and the average of the last 2 minutes were recorded. The following parameters were assessed for each triggering system: trigger sensitivity (percentage of breaths triggered by the patient above the mandatory rate, e.g. 12 = 20%, 20 = 100%), trigger response time (time from the drop of the Pmus to the time that flow crosses the zero line).

We also measured the time to trigger (Trigger delay) in absence of auto-PEEP during normal respiratory mechanics (compliance 70 ml/cmH_2O and Resistance 5 cmH_2O) using Pressure Support mode, with 5 cmH_2O pressure, and PEEP of 5 cmH_2O with a Pmus of - 5 cmH_2O to compare the delayed trigger with and without auto-PEEP.

Results

Results are summarized in Table 2 and Figure 1.

One hundred percent of the breaths were triggered at Pmus (cmH_2O) of -15 in the pressure trigger, -25 in flow trigger, -3 for ST1, -9 for ST2, -10 for ST3, -10 for ST4, -12 for ST5, -18 for ST 6, and -22 for ST 7.

Trigger time (s) for flow was 0.135 ± 0.02, for pressure 0.141 ± 0.04, for ST 1-4: 0.074 ± 0.03, and for ST 5-7: 0.104 ± 0.04. Multivariate analysis of variance test (MANOVA) showed significant difference between the times to trigger $P < 0.001$.

Trigger time (s) with no auto-PEEP was 0.039 for flow of 1, 0.048 for pressure -1, 0.032 for ST 1, 0.041 for ST 2, 0.05 for ST 3, 0.057 for ST 4, 0.061 for ST 5, and 0.069 for ST 6 and 7 ± 0.02 for all.

Table 1: Respiratory rate (BPM) and the corresponding auto-PEEP (cmH_2O)

Respiratory rate	10	11	12	13	14	15	16	17	18	19	20
Auto-PEEP	2.25	3	3.25	3.5	4.7	5.6	6.5	8.1	9.4	11.5	13.8

Table 2: Percent breaths triggered at different muscle pressures (Pmus) for flow trigger of 1l/min, pressure trigger 1 cmH_2O, and SMART Trigger (ST) with sensitivities of 1-7

Pmus	Flow	Pressure	ST1	ST 2	ST 3	ST4	ST5	ST 6	ST 7
-1	0	0	30	0	0	0	0	0	0
-2	0	0	80	20	0	0	0	0	0
-3	0	0	100	40	10	0	0	0	0
-4	0	0		60	20	0	0	0	0
-5	0	0		70	60	0	0	0	0
-6	0	0		70	70	0	0	0	0
-7	0	0		80	80	30	0	0	0
-8	0	20		90	80	80	0	0	0
-9	0	30		100	90	90	20	0	0
-10	0	40			100	100	30	0	0
-11	20	50					80	0	0
-12	20	60					100	0	0
-13	40	60						10	0
-14	40	80						10	0
-15	40	100						30	20
-16	50							50	20
-17	50							60	30
-18	50							100	40
-19	60								50
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-24	80								
-25	100								

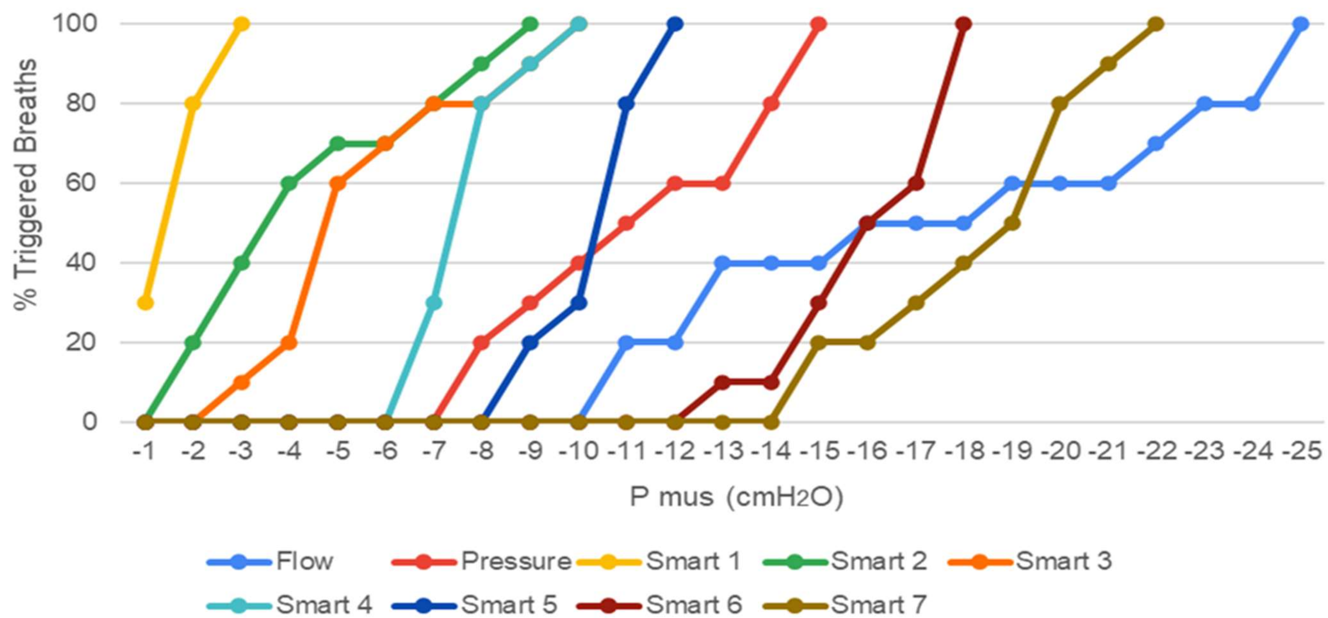

Figure 1: Percent breaths triggered at different muscle pressures (Pmus) in cmH_2O for flow trigger of 1l/min, pressure trigger 1 cmH_2O, and SMART Trigger (ST) with sensitivities of 1-7

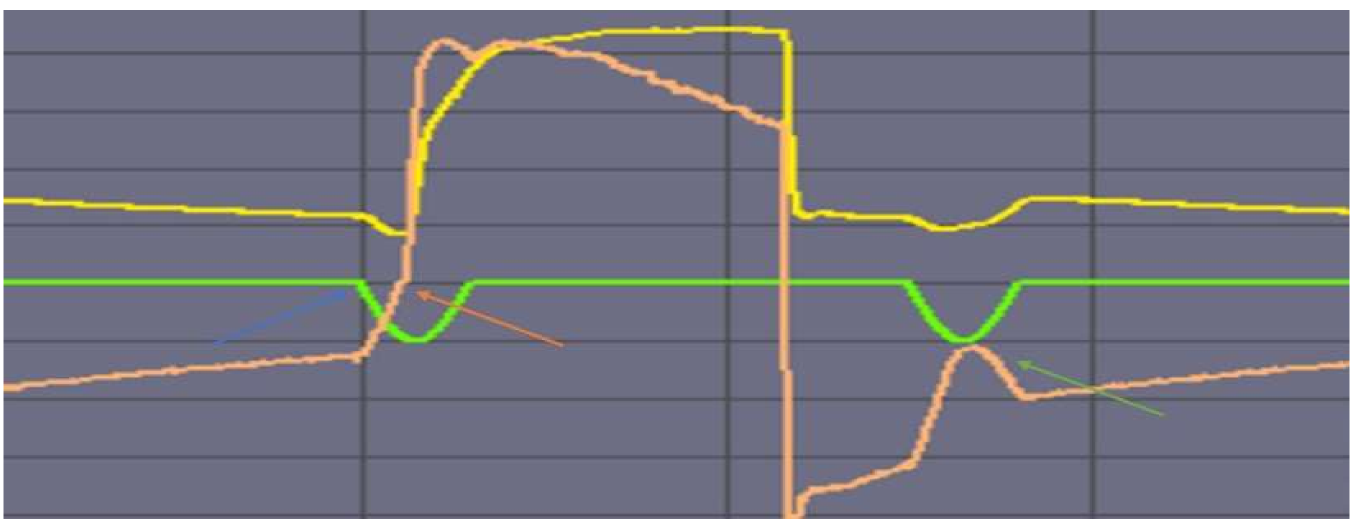

Figure 2: Flow lpm (orange), airway pressure: cmH_2O (yellow), Pmus: cmH_2O (green) versus time. Blue arrow: beginning of Pmus, orange arrow: beginning of ventilator delivered breath, green arrow showing a missed triggered effort.

Table 3: Trigger delay in msec during auto-PEEP of 13.8 cmH_2O flow trigger of 1l/min, pressure trigger 1 cmH_2O, and SMART Trigger (ST) with sensitivities of 1-7

	Flow (1 lpm)	Pressure (1 cmH_2O)	ST 1-4	ST 5-7	P value
Auto-PEEP (13.8)	0.135 ± 0.02	0.141 ± 0.04	0.074 ± 0.03	0.104 ± 0.04	< 0.001

Discussion

Our study design tests multiple levels for auto-PEEP, which was dependent on the respiratory rate triggered. The higher the respiratory rate, the higher the resultant auto-PEEP (table 1). There is not a fixed level. It goes without saying, that in a real clinical scenario, efforts should be undertaken to eliminate or reduce auto-PEEP to avoid its adverse events even if the patients are able to trigger the breaths. Such interventions may include bronchodilators, larger bore endotracheal tubes, decreasing minute ventilation (tidal volume and respiratory rate), through pain, agitation, fever control, adequate sedation, or lengthening expiratory time. [8]

Our results confirmed that the new SMART Trigger from sensitivity 1-5 outperformed low flow (1 l/min) and pressure (-1 cmH_2O) sensitivity triggers with regard to the muscle pressure required to trigger 100% of the spontaneous breaths. Pressure trigger outperformed the lower sensitivity SMART Trigger 6-7. Flow Trigger came in last place.

Additionally, trigger delay was significantly shorter in SMART Trigger 1-4 followed by from 5-7, followed by flow trigger of 1 l/min and pressure trigger of -1 cmH_2O. Of note, there are many factors that affect time to trigger other than auto-PEEP, including the position of the flow and pressure sensors, [9] humidification devices, filters, and the bias flow of the ventilator used. We used the same ventilator with no humidification or filter devices to avoid this interference. [5]

Our results confirm that the presence of auto-PEEP increases the trigger delay of the breaths which has been previously identified as a cause of increased work of breathing and asynchrony. [10] The trigger delay with no auto-PEEP using the flow, pressure, SMART Trigger 1-7 fell within the acceptable range (42-88 msec) studied before by Thille and colleagues. [11] In the presence of auto-PEEP, SMART Trigger with sensitivity of 1-4 still fell within that range, but not from 5-7, or flow of 1 l/min and pressure -1 cmH_2O.

Current data reports that around 25% of patients on mechanical ventilation experience significant levels of patient-ventilator asynchronies, which has also been associated with increased length of stay, longer intubation times and higher mortality. [12] The results of this study suggest that in patients with measurable levels of auto-PEEP, utilization of the SMART trigger function in tandem with measures directed at reducing levels of auto-PEEP may be a viable way to increase patient-ventilator synchrony and improve outcomes. [13]

It is important for the clinician to choose a sensitivity level that best suits the patient's condition that reduces the effort to trigger and the amount of missed and delayed triggers. Conversely, sensitivity should be decreased in scenarios where breaths are being auto triggered in the absence of inspiratory effort. Perhaps with the advancement of artificial intelligence and recognition of different asynchronies, the sensitivity level could be adjusted automatically. [14]

Our results found that -1 cmH_2O pressure triggering outperformed flow triggering of 1 l/min with 100% of breaths triggered at lower Pmus. Also, time to trigger was slightly lower with flow versus pressure triggers 0.135 ± 0.02 vs. 0.141 ± 0.04 respectively. [15,16] This is contrary to conventional teaching that flow triggering is generally superior to pressure triggering, [6] and especially in COPD. However, other studies [17] have found no difference in the inspiratory work of breathing between flow and pressure triggering.

Future areas of interest might include how SMART Trigger fares in circuits with some degree of air leak, especially during non-invasive ventilation. Manufacturers claim that the algorithm developed is also able to detect and function in the presence of varying or large air leaks, however, the efficacy in such scenarios has yet to be studied. This is important for patients requiring non-invasive ventilation where leaks are more abundant and may act as an additional source of patient-ventilator asynchronies.

Measurement and estimation of Pmus is possible using an esophageal balloon or other surrogates like occlusion pressure at 100 msec (P0.1). [18] However, this is rarely done in clinical practice that may add complexity to the real time assessment of missed and delayed triggers and consequent adjustments. Delayed and missed triggers may still be detected through waveform discrepancies, [4] but would likely be more difficult than the methods used in this study.

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