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BRIEF REPORT

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Inappropriate ventilator triggering caused by an in-line suction catheter

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Abstract *Objective:* To examine the phenomenon of inappropriate triggering caused by an in-line suction catheter. *Design:* We used a test lung to assess inappropriate triggering in four ventilators with both pressure and flow triggering. *Results:* With pressure triggering, inappropriate triggering occurred only in the presence of PEEP. However, with flow triggering, inappropriate triggering occurred both with and without PEEP. Inappropriate triggering did not occur in a model of severe airflow obstruction. *Conclusion:* In-line suction catheters may lead to inappropriate triggering and potentially dangerous increases in delivered ventilation.

Keywords Mechanical ventilators · Positive end-expiratory pressure · Suction · Triggering · Air leak

Introduction

In patient-triggered modes of ventilation, ventilatory support is delivered in response to the patient's spontaneous inspiratory effort. The ventilator senses the patient's inspiratory effort on the basis of either a pressure or flow signal [1]. An optimal triggering system minimizes the patient's work of breathing without causing inappropriate triggering, i.e., triggering that occurs in the absence of an inspiratory effort by the patient. We recently cared for a sedated and paralyzed patient who was noted to be triggering the ventilator repeatedly. On closer inspection we observed that the in-line suction catheter was pulled back too far, thereby creating an air leak. When the catheter position was advanced slightly, the patient ceased to "trigger" the ventilator. We used a test lung to further characterize the phenomenon of inappropriate triggering associated with in-line suction catheters.

Methods

We tested the four ventilators in use at our institution: Servo 300A (Siemens-Elema, Solna, Sweden), PB7200 and PB840 (Puritan Bennett, Carlsbad, Calif., USA), and Bird 8400STi (Bird Products, Palm Springs, Calif., USA). The ventilators were attached to a Dual Adult Training Test Lung (Model 2600I, Michigan Instruments, Grand Rapids, Mich., USA) with standard low compliance ventilator tubing (Airlife, Allegiance Healthcare, McGaw Park, Ill., USA). We measured flow, pressure, and volume from the analog output of the ventilators. Lung compliance was set at 50 ml/cmH_2O and airway resistance at 2.7 cmH_2O s^{-1} /l^{-1} (at a flow rate of 1 l/s). A 4.6-mm closed tracheal suction system (Trach Care 2210, Ballard Medical Products, Draper, Utah, USA) was interposed between the "Y" in the ventilator circuit and the lung simulator, but no suction was applied to the catheter system. The suction catheter was retracted so as to create an air leak (Fig. 1) which resulted in visible distention of the plastic sheath surrounding the catheter. The ventilators were set in assist-control mode with a rate of 12 breaths/min, tidal volume of 0.7 l, and inspiratory flow rate of 0.6 l/s. The Bird 8400STi allowed only pressure triggering; the remaining ventilators were equipped with both pressure and flow triggering.

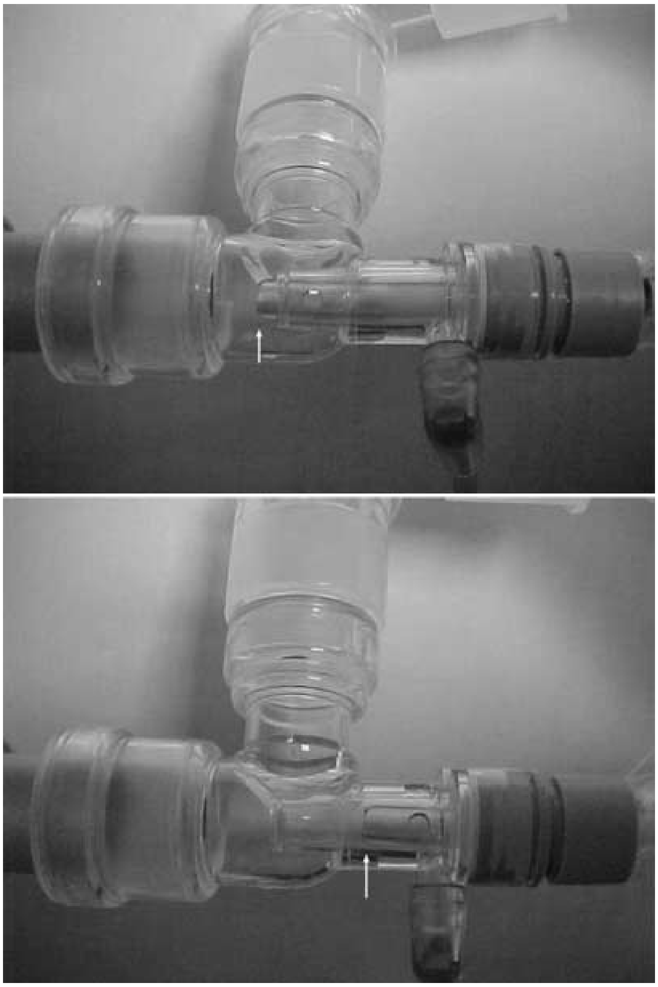

Fig. 1 Photograph of the model. *Upper panel* Catheter in the normal position; *lower panel* the catheter retracted too far, thereby creating an air leak in the catheter system. *Left* Test lung; *top* ventilator; *right* catheter system. *Arrow* Tip of the catheter. Note that the difference between correct and incorrect positioning of the catheter is quite small and could easily go undetected

We tested both pressure and flow triggering over a range of trigger sensitivities. For pressure triggering the sensitivity was changed in increments of 0.5–1.0 cmH_2O; for flow-triggering the sensitivity was changed in increments of 1.0 l/min. We varied the continuous flow rate in increments of 5.0 l/min for the PB7200; for the Servo 300A the continuous flow rate is fixed at 2.0 l/min, and for the PB840 the continuous flow rate is automatically adjusted to a level 1.5 l/min above the flow trigger sensitivity. The sequence was repeated with PEEP set at 0 and 5 cmH_2O. In order to simulate the effect of dynamic hyperinflation in patients with obstructive lung disease we placed a resistor between the test lung and the tracheal suction system. This increased airway resistance to 25.8 $cmH_2O\ s^{-1}\ /l^{-1}$ (at a flow rate of 0.1 l/s); compliance was kept constant. We set ventilator PEEP at 0, but the remainder of the ventilator settings were not changed.

Table 1 Ventilator triggering at different levels of pressure sensitivity with PEEP set at 5 cmH_2O. Inappropriate triggering occurred whenever the trigger sensitivity was set equal to or below the threshold value. The number of inappropriately triggered breaths varied among ventilator models

Ventilator	Threshold trigger sensitivity (cmH_2O)
PB7200	2.0
PB840	1.0
Bird 8400 STi	1.0
Servo 300A	0.5

Results

Pressure triggering

None of the ventilators triggered when PEEP was set to 0. All four ventilators triggered when PEEP was set at 5 cmH_2O, although the trigger sensitivity at which they did so varied from 0.5 cmH_2O with the Servo 300A to 2.0 cmH_2O with the PB7200 (Table 1). An example of inappropriate triggering is shown in Fig. 2.

Flow triggering

Triggering varied as a function of ventilator model, trigger sensitivity, continuous flow rate, and the presence or absence of PEEP (Table 2). In contrast to pressure triggering, the PB7200 and PB840 ventilators both triggered inappropriately in the absence of PEEP, whereas the Servo 300A did not, even when the flow trigger sensitivity was set at “maximum.” When PEEP was set at 5 cmH_2O, the Servo 300A triggered inappropriately over the entire range of flow sensitivity. In the presence of 5 cmH_2O PEEP the PB840 triggered when flow sensitivity was set at ≤6 l/min, whereas in the absence of PEEP triggering occurred only when the flow sensitivity was set at ≤3 l/min. With 5 cmH_2O PEEP the PB7200 triggered inappropriately over a wide range of continuous flow rates whenever the flow sensitivity was 3 l/min.

Effect on ventilation

When inadvertent triggering occurred, the respiratory rate increased to as much as 21 breaths/min; the exact rate varied as a function of method of triggering, trigger sensitivity, and ventilator model (data not shown). We compared inspired and exhaled volumes to determine how much of the set tidal volume was lost through the air leak. With the inspired tidal volume set at (and measured at) 0.7 l, the exhaled tidal volume averaged about 0.62 l, indicating that slightly less than 15% of the tidal volume was lost through the suction catheter system.

Fig. 2 Airway pressure tracing with the ventilator in assist-control mode. *Upper tracing* Recorded with the suction catheter in its proper position, and showing that the set and actual respiratory rates are the same (12 breaths/min). *Middle, lower tracings* The suction catheter has been retracted too far, and the respiratory rate with both pressure triggering (*middle panel*, 16 breaths/min) and flow triggering (*lower panel*, 21 breaths/min) significantly exceeds the set respiratory rate. *Middle tracing* Loss of PEEP associated with pressure triggering; *middle, lower tracings* the drop in peak airway pressure resulting from the air leak through the suction catheter

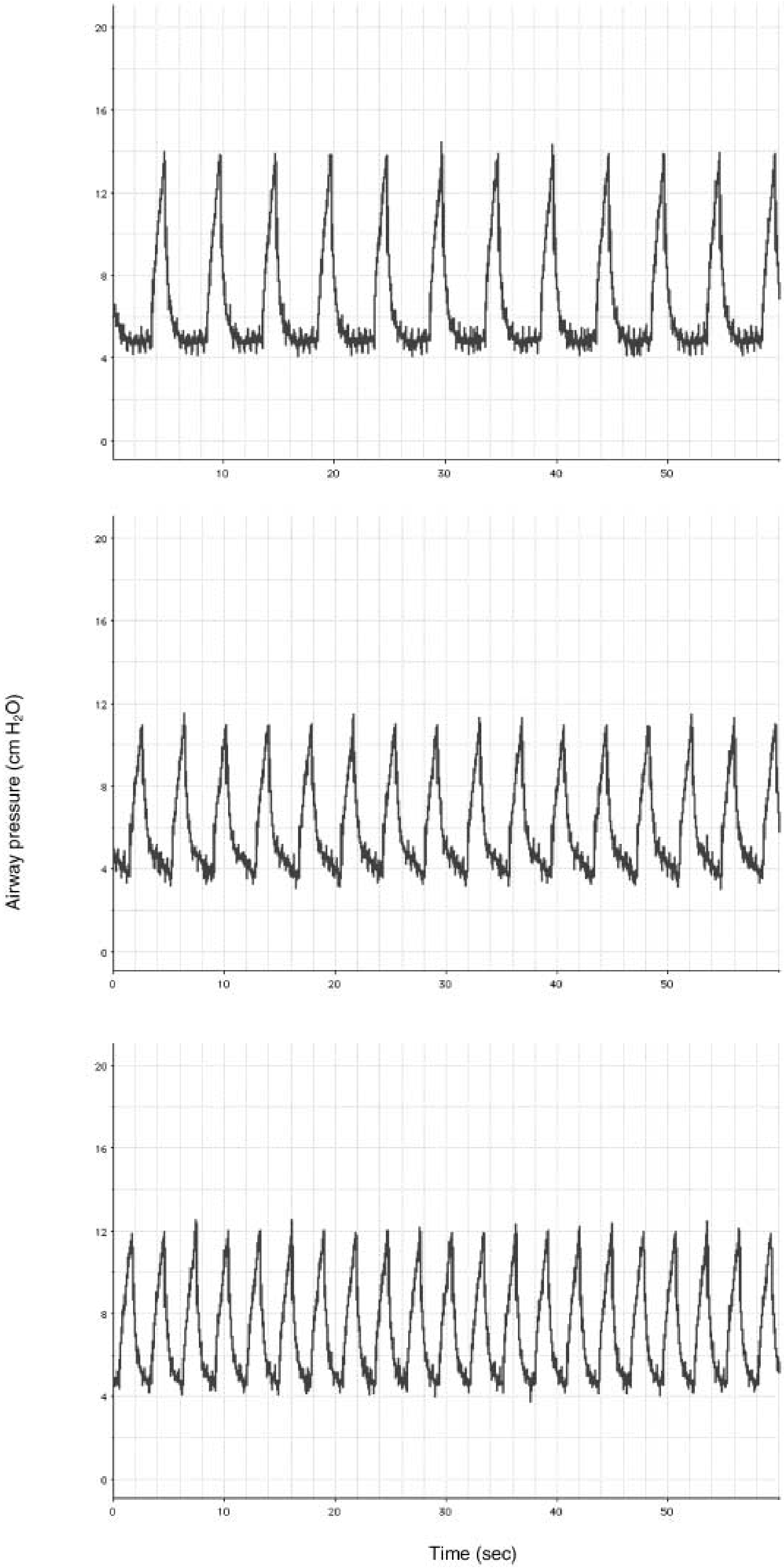

Table 2 Triggering at selected levels of PEEP, continuous flow rate, and flow sensitivity

Ventilator[a]	PEEP (cmH_2O)	Continuous flow rate[b] (l/min)	Threshold trigger sensitivity[c] (l/min)
PB7200	0	5	2.0
	0	10	1.0
	0	15	1.0
	0	20	–[d]
	5	5	3.0
	5	10	3.0
	5	15	3.0
	5	20	3.0
PB840	0	4.5	3.0
	5	7.5	6.0
Servo 300A	0	2.0	–[d]
	5	2.0	Minimum[e]

[a] The Bird 8400STi was not equipped with flow triggering
[b] The PB7200 is the only ventilator which allows adjustment of the continuous flow rate; for the PB840, the continuous flow rate is automatically adjusted 1.5 l/min above the trigger sensitivity, and for the Servo 300A, the trigger sensitivity is fixed at 2.0 l/min
[c] The Servo 300A does not allow one to set the actual flow trigger sensitivity; it allows only qualitative adjustment of the flow sensitivity between "minimum" and "maximum"
[d] Absence of inappropriate triggering
[e] Triggering occurred over the entire range of flow sensitivity

Since the respiratory rate increased to as much as 21 breaths/min, even with the air leak the net effect was usually a significant increase in the delivered minute ventilation.

Effect of hyperinflation

The additional resistance resulted in significant hyperinflation and the development of 7 cmH_2O auto-PEEP. With neither pressure nor flow triggering was there inappropriate triggering even when trigger sensitivity was set at its maximum value.

Discussion

There are previous reports of inadvertent ventilator triggering caused by movement of water in the ventilator circuit tubing [2] and transmission of cardiac pulsations [3, 4], but to our knowledge this is the first report of inadvertent triggering caused by malpositioning of an in-line suction catheter. Our results show that this phenomenon may occur with either flow or pressure triggering, but the mechanism of inappropriate triggering differs somewhat between the two triggering systems.

When the ventilator is set to trigger on the basis of a pressure change, inappropriate triggering depends upon the presence of PEEP. The air leak caused by the malpositioned suction catheter results in dissipation of PEEP, and the resulting drop in airway pressure is "interpreted" as an inspiratory effort, and the ventilator triggers. In the absence of PEEP there is no mechanism by which the air leak can cause inappropriate triggering. As we demonstrated, the trigger sensitivity is also an important variable in determining whether inadvertent triggering occurs. We did not systematically explore the effect of variations in respiratory mechanics or the pattern of ventilation, but these factors undoubtedly play a role by influencing the rate at which the elastic recoil pressure of the respiratory system is dissipated and the time available (i.e., expiratory time) for that dissipation to occur.

With flow triggering, the leak caused by malpositioning of the suction catheter results in loss of some of the continuous flow, which is sensed and interpreted by the ventilator as an inspiratory effort. We found that a greater trigger sensitivity predisposes to inadvertent triggering, and for the PB7200, the only ventilator which we tested that allows independent variation in the continuous flow rate, there was an inverse relationship between the continuous flow rate and the threshold for inappropriate triggering. As with pressure triggering, inadvertent triggering with flow triggering is also influenced by the use of PEEP and must also be affected by respiratory mechanics and the pattern of ventilation as outlined above. In our model inappropriate triggering occurred more readily with flow triggering than with pressure triggering, although depending on the trigger sensitivity and the patient's respiratory mechanics this may not always be the case.

Clinical implications

In our model the in-line suction catheter caused opposing effects on the delivered ventilation. The loss of tidal volume associated with the air leak decreased the tidal volume delivered to the test lung, but this was more than offset by the increase in respiratory rate resulting from inadvertent triggering. For example, at the maximum respiratory rate observed in our model (21 breaths/min) the delivered minute ventilation was approximately 13 l/min, which represents a 55% increase above the set minute ventilation. In a patient undergoing mechanical ventilation such an increase in ventilation could induce a significant respiratory alkalosis.

In patients with severe asthma or chronic obstructive pulmonary disease hyperinflation is the most important determinant of ventilator-associated complications [5], and the phenomenon of inadvertent triggering would be of particular concern in such patients. However, in our model of severe obstructive lung disease we found no evidence of inappropriate triggering with either pressure or flow-triggering over a wide range of trigger sensitivities. With pressure triggering, inappropriate triggering occurs when the air leak through the catheter system results in dissipation of PEEP. However, an increase in airway resistance and the associated increase in the time constant may allow better regulation of PEEP, thus limiting inappropriate triggering caused by a pressure drop. With flow triggering inappropriate triggering requires that some of the continuous flow be lost through the leak in the suction catheter system; however, in the presence of auto-PEEP this is offset by expiratory flow which persists throughout expiration, and therefore the ventilator does not "see" the loss of the continuous flow through the suction catheter system. In order for inadvertent triggering to occur the rate at which air leaks from the suction catheter during expiration must exceed the expiratory flow rate by an amount equal to the flow sensitivity. Although this did not occur under any of the conditions tested in our model, it is possible that there are other conditions under which it could occur. However, auto-PEEP acts to oppose the occurrence of inadvertent triggering, and it is unlikely that auto-triggering associated with an in-line suction catheter would induce severe hyperinflation or cause significant worsening of preexistent hyperinflation. This contrasts with other forms of auto-triggering, such as that due to cardiac oscillations, in which hyperinflation occurs [4].

In summary, any air leak in the ventilator circuit is a potential cause of inadvertent ventilator triggering, and the avoidance of air leaks is therefore of great importance. In-line suction catheters, which have not previously been reported as a cause of air leaks, are increasingly used in the care of critically ill patients. Our results show that when the catheter is pulled back too far, inadvertent triggering occurs over a wide range of ventilator settings. In our lung model the magnitude of the effect was substantial; the number of breaths delivered by the ventilator increased by as much as 9 breaths/min (75% increase). Although the results in patients would undoubtedly vary as a complex function of the patient's breathing pattern and respiratory mechanics, it is likely that malpositioning of the suction catheter could cause some patients to experience significant increases in ventilation, as was the case in the patient who prompted us to explore this phenomenon. Furthermore, the occurrence of inappropriate triggering is not dependent on the application of suction to the catheter system, and thus inappropriate triggering could be a sustained phenomenon. In some settings inappropriate triggering could have serious consequences. Therefore physicians, respiratory care practitioners, and nursing personnel should be aware of the potential for inappropriate triggering with the use of in-line suction catheter systems.

References

1. Kacmarek RM, Hess D (1994) Basic principles of ventilator machinery. In: Tobin MJ (ed) Principles and practice of mechanical ventilation. McGraw-Hill, New York, pp 88–93
2. Sansome AJ (1988) Inappropriate triggering. Anaesthesia 43:1065–1066
3. Willatts SM, Drummond G (2000) Brainstem death and ventilator trigger settings. Anaesthesia 55:676–677
4. Imanaka H, Nishimura M, Takeuchi M, Kimball WR, Yahagi N, Kumon K (2000) Autotriggering caused by cardiogenic oscillation during flow-triggered mechanical ventilation. Crit Care Med 28:402–407
5. Williams TJ, Tuxen DV, Scheinkestel CD, Czarny D, Bowes G (1992) Risk factors for morbidity in mechanically ventilated patients with acute severe asthma. Am Rev Respir Dis 146:607–615