Review Article

Ventilator triggering

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Abstract. Allowing spontaneous respiration during mechanical ventilation requires that the ventilator system can interpret a trigger signal from the patient and then deliver a synchronous breath. The majority of current ventilators are triggered by preset changes in pressure or flow detected in the system as a patient is initiating a breath. However, other triggers such as chest wall motion, waveform alteration, and diaphragmatic electromyograms have also been utilized. The time between initiation of a breath by a patient and delivery of a breath by the ventilator is known as trigger delay. Most trigger delay is inherent in the mechanics of the patient-ventilator interaction. However, recent advances in technology have captured a neural signal from the diaphragm to trigger the ventilator to deliver a breath, reducing trigger delay. Understanding trigger delay is important as it may lead to increased work of breathing and patient-ventilator asynchrony. Types of asynchrony related to the triggering phase are ineffective triggering, double triggering, and autotriggering. The presence of asynchrony has been shown to have deleterious effects on patients, including duration of mechanical ventilation and increased length of hospital stay. Recognizing asynchrony and understanding how to manipulate the trigger variable will reduce adverse effects on patients.

Keywords: Mechanical ventilation, triggering

1. Introduction

Patient-ventilator interactions require a trigger variable that signals the ventilator to deliver a breath. When controlled ventilation is used, the trigger variable is time, which is independent of patient effort [1,2]. The focus of this review, however, is the trigger and the triggering phase during assisted mechanical ventilation for spontaneously breathing patients. Patient-triggered ventilation offers significant advantages for patients over controlled ventilation including reduced diaphragmatic dysfunction [3], improved hemodynamics [4], reduction in air leaks, and decreased duration of ventilation [5].

The triggering phase is defined as the beginning of patient inspiratory effort to the start of flow delivery by the ventilator [6], and the trigger is the “variable that is manipulated to deliver inspiratory flow” [7] (Fig. 1). Triggering is a very small portion of the inspiratory cycle; however, inappropriate management or settings can increase work of breathing [7,8], require increased sedation, and lead to patient-ventilator dyssynchrony [9].

2. Types of triggers

A patient-initiated breath requires the ventilator to interpret a pneumatic signal, either pressure, volume, or flow, from the patient's airway. Pressure and flow triggers are the most common; volume triggers are rarely utilized [2]. With a pneumatic trigger, a patient initiates a breath by altering the pressure or flow within the system to a preset value, which will then open a demand

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Fig. 1. Flow, pressure and volume waveform showing trigger phase and trigger delay.

valve on the ventilator [7,9,10]. Inspiratory muscles contract isotonically to change flow and isometrically to change pressure [11,12]. The ideal place to detect pressure or flow changes in the airway is the trachea [13]; however, all current ventilators trigger from signals captured from inside the ventilator circuit [7]. With pressure triggering, the ventilator must detect a pressure drop in the system that is created with inspiratory effort from the patient [1]. Flow triggering requires continuous bias inspiratory air flow with simultaneous continuous measurement of expiratory flow by the ventilator [7,9,10]. When the difference between inspiratory and expiratory flow achieve a certain set trigger value, the ventilator will then deliver a breath [1].

Flow triggering occurs without the creation of negative inspiratory pressure. In fact, it was actually created to eliminate the required pressure drop for a pressure-triggered breath [1]. Many studies have suggested that flow triggering reduces work of breathing when compared to pressure triggering [9,14–18]. Early studies of flow triggering were performed using continuous positive airway pressure, and all of these studies demonstrated that inspiratory work of breathing was lower during flow triggering than during pressure triggering [14,17,18]. However, in a study by Branson et al. [9], if the total work was separated into the trigger and

post-trigger segments, the majority of the reduction in work of breathing seen with flow triggering occurred during the post-trigger phase. Subsequent and more recent studies have actually shown no clinically relevant difference between flow and pressure triggering [19,20]. It has been suggested that the differences in work of breathing demonstrated in the past studies are unrelated to the actual type of trigger used, but instead are dependent on how the ventilator support settings are programmed with each trigger. For example, the addition of pressure support to a pressure triggering system will counteract the work difference between flow and pressure triggering [10].

While controversy remains regarding flow triggering and decreased work of breathing, certain populations of patients can benefit from flow triggering. For example, patients with chronic obstructive pulmonary disease have a high incidence of intrinsic positive end expiratory pressure (PEEP) due to dynamic hyperinflation. These patients have a reduction in work of breathing with flow triggering systems [9,21] because they do not have to overcome both their own intrinsic PEEP in addition to the pressure in the ventilator circuit in order to trigger the ventilator. Additionally, the continuous bias flow provided in the circuit with flow triggering results in a small amount of PEEP in the circuit, which

will lessen the required drop in pressure needed to trigger the ventilator and decrease work of breathing [1]. Flow triggered systems have reduced trigger delay and less asynchrony than pressure triggered systems in mechanically ventilated very immature infants [15]. Flow triggering may also decrease work of breathing in children with decreased lung compliance [19].

There are several additional signals that can initiate triggering, including abdominal and chest wall motion, waveform triggering, transdiaphragmatic pressure, and diaphragm electromyography [22]. Abdominal and chest wall motion sensors have predominantly been used in premature neonates, and both are problematic [23,24]. Chest wall signals can have significant trigger delay and are prone to motion and cardiac artifact as well as autotriggering [24]. Abdominal wall sensors also are susceptible to autotriggering, especially with patient movement [24]. Traditional pressure triggers were found to be better at detecting respiratory effort in neonates [25], except perhaps in the extremely premature [26].

Shape-signal triggering, also referred to as waveform triggering, occurs when inspiratory effort alters the expiratory flow waveform [27]. This type of triggering is initiated when the ventilator creates a new shape-signal flow by offsetting the signal from the actual flow by 0.25 L/sec and delaying it for 300 ms [12]. This delay makes the flow shape signal lag slightly behind the patient's actual flow rate. A rapid decrease in expiratory flow, which is caused by inspiratory effort intersecting the shape signal, and thus triggers the ventilator [12]. Shape-signal triggering may be beneficial because it results in fewer wasted efforts than flow triggering; however, autotriggering is more common. Currently, this type of trigger is only used in one brand of ventilator in combination with volume signaling [27].

3. Trigger delay

Trigger delay is the time from the start of triggering effort by the patient to the start of flow delivery by the ventilator [6]. Some amount of trigger delay is unavoidable, since it is inherent in ventilator mechanics and design. Older generation ventilators can have trigger delays greater than 400 ms [28], but with improvements in technology, the majority of ventilators released after 2000 have a trigger delay of less than 60 ms [29].

Minimizing trigger delay is important because 10–30% of a patient's total breathing effort occurs during the trigger phase of inspiration [30]. Therefore,

a reduction in trigger delay should also reduce work of breathing. Trigger delay is also directly related to a patient's respiratory drive. The more time that it takes for triggering to occur, the more inspiratory effort is needed by the patient to trigger a breath [30]. Trigger delay can also lead to patient-ventilator asynchrony.

If technology could capture neural output directly from the respiratory center in the brain and coordinate it with the ventilator, patient-ventilator interactions would be perfectly in sync without trigger delay [31]. Neurally adjusted ventilatory assist (NAVA) is a more recently developed ventilatory mode where triggering is independent of a pneumatic signal from the patient's airway. Alternatively, NAVA interprets a neural signal from the diaphragm to trigger a supported breath [32]. This technology provides the patient with the means not only to control when the ventilator delivers a breath, but also how much support they receive [31]. Several studies have shown that trigger delay is reduced with neural triggering, both in animal models [33–36], children [35], and adults [34] with respiratory failure. With this reduction in trigger delay, NAVA may also reduce patient-ventilator asynchrony [36,37].

4. Patient-ventilator asynchrony

Patient-ventilator asynchrony is a common but often unrecognized and undertreated problem [30] that may occur in up to 25% of ventilated patients [38]. Asynchrony is both poor timing between a patient's inspiratory effort and the delivery of a ventilator breath, as well as inadequate breath delivery in relation to a patient's needs [31]. Deleterious effects of patient-ventilator asynchrony include increased sedation needs, ventilation-perfusion mismatch, increased work of breathing, respiratory muscle injury, prolonged ventilator weaning, increased length of hospital stay, and higher costs [39]. Asynchrony may also result in excessive ventilatory support [38] and cause sleep disruption [40].

Trigger asynchrony, also referred to as ineffective triggering, is a common subtype of asynchrony that occurs when a patient's inspiratory effort fails to initiate breath delivery from the ventilator [41] (Fig. 2). Any disparity between a patient's desire for a breath and the ventilator settings chosen by the clinician can lead to ineffective triggering [38]. It occurs in all modes of mechanical ventilation [42]. Ineffective triggering is the most frequent type of asynchrony seen in chronic obstructive pulmonary disease patients [43], but is also

Fig. 2. Flow, pressure and volume waveform showing ineffective triggering.

frequently found in mixed intensive care unit populations [38,44]. In a study by Thille et al. [38], more than 80% of asynchronous breaths were due to ineffective triggering in patients ventilated more than 24 h. In these patients, ineffective triggering was directly associated with high levels of pressure support, high tidal volumes, and alkalosis, which suggests that patients with ineffective efforts may be receiving too much ventilatory support. Switching the patients from pressure to flow triggering had no effect on reducing the rate of ineffective triggering [38]. Ineffective triggering can also occur immediately after intubation. In another study of adults with respiratory failure, 25% of patients had ineffective trigger efforts in up to 10% of breaths during the first 24 h of ventilation [43].

Many factors contribute to the presence of ineffective triggering and include both patient factors and ventilator factors. Intrinsic patient factors include dynamic hyperinflation, decreased respiratory drive, decreased respiratory muscle strength [45,46] and flail chest [1]. However, it should be emphasized that

decreased patient effort is not a cause for ineffective triggering [42]. In a study by Leung et al. [42], patient effort was actually significantly higher for ineffective triggers than during the trigger phase of successful attempts.

Patient factors may be unavoidable, however, ventilator factors can often be manipulated by the clinician to minimize or eliminate ineffective triggering. Insensitive trigger settings, excessive set minute ventilation, high-pressure support level [43], high bias flow, high circuit resistance, and circuit leaks [1] will all increase the incidence of ineffective efforts. Nebulizer treatments that increase flow in the circuit can also cause ineffective triggering, but may be avoided if the trigger is changed from flow to pressure [39].

Recognizing ineffective triggering is essential. Respiratory muscle fatigue or injury may result from the increased work of breathing seen with ineffective triggering [45]. The presence of ineffective triggering may worsen patient outcomes because it is associated with increased duration of mechanical ventilation [41],

a reduction in the rates of successful weaning [38], an increased rate of tracheostomy placement [41], and longer length of hospital stay [43]. However, while there is an association with worse outcomes, no studies demonstrate that ineffective triggering alone is the cause of prolonged ventilation [45].

Double triggering is another type of asynchrony that occurs during the triggering phase. It is two breath cycles that are separated by a short expiratory time [47] (Fig. 3). The first cycle of the double triggering event is initiated by the patient [38]. The double trigger results from premature termination of a mechanical breath with persistent inspiratory effort that subsequently reduces expiratory flow to zero and begins a new breath [48]. In a clinical setting, double triggering occurs when patient inspiratory effort surpasses the flow- or volume-delivery settings on the ventilator either because the settings were insufficient for the patient's demands or because the patient has an abrupt increase in demand (sigh breaths or coughing) [39]. There is little data on the clinical significance of double triggering. In Thille's study previously mentioned, patients who

exhibited double triggering had more hypoxemia with higher PEEP and peak inspiratory pressures, so these patients may have more severe lung injury [38].

Autotriggering, also referred to as autocycling, is another subset of asynchrony associated with the trigger phase where the ventilator delivers a triggered breath without patient effort [1]. Autotriggering may occur more often in patients with low respiratory drive and low respiratory rate who also do not have evidence of intrinsic PEEP. This scenario allows for a short period of zero flow in the system after expiration and prior to inspiration that renders the circuit vulnerable to triggering from factors other than inspiratory effort [49]. It can commonly result from circuit leaks, water in the circuit, random circuit noise [1], and even cardiogenic oscillations [50]. The clinician should have a high index of suspicion for autotriggering in a patient with sudden onset of persistent tachypnea unrelated to a change in sedation or clinical condition. If no leaks or water are present in the circuit, decreasing the trigger threshold setting on the ventilator (making it more difficult for a patient to trigger) may stop the autotriggering [51].

Fig. 3. Flow, pressure and volume waveform showing double trigger. The ventilator signal and edi (diaphragm electrical activity) tracing are also shown.

Autotriggering can have serious medical ramifications if not recognized. It can cause respiratory alkalosis and lung hyperinflation [50]. Case reports describe the presence of autotriggering from either cardiogenic oscillations or endotracheal tube leaks in brain dead patients that have delayed declaration of death and organ donation [52–54]. Other clinical examples of autotriggering include patients with bronchopleural fistulas [55], patients after surgery for artificial heart placement [51], and in-line suction catheters that have been pulled back too far [56].

5. Summary

Patient-ventilator interactions depend on the ability of the ventilator system to interpret a trigger signal from the patient. Triggers are typically changes in pressure or flow detected in the system as the patient's chest wall muscles contract to initiate a breath. NAVA is a novel mode of ventilation in which a neural trigger is used to signal the ventilator to deliver a breath. Trigger delay is the time between initiation of a breath by a patient and delivery of a breath by the ventilator. Trigger delay leads to increased work of breathing and patient-ventilator asynchrony. Ineffective triggering, double triggering, and autotriggering are types of asynchrony related to the triggering phase. The presence of asynchrony can have deleterious effects on patients.

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