

CHAPTER 3. Patient Ventilator Dyssynchrony: Types, Frequency and Patterns in Critically Ill Adults

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Patient ventilator dyssynchrony (PVD) is a mismatch between patient and ventilator assisted breaths and the ventilator's inability to meet the patient's flow demand.¹ From observation and anecdote, dyssynchrony is common in the Intensive Care Unit (ICU) but only a few studies have documented its incidence, and only for short periods of time.^{2,3,4} Thille et al.² documented that up to 25% of ventilated patients exhibit dyssynchronous ventilator interaction. PVD can result in adverse clinical outcomes including hypoxemia,⁵ cardiovascular compromise,⁵ patient discomfort,^{6, 7,8, 9,10} anxiety/fear,⁵ impairment of sleep quality,¹¹ prolonged mechanical ventilation,^{2,3} and possible diaphragmatic injury.^{1,12} Dyssynchrony, therefore is perceptible and may lead to complications, however very little is documented regarding the types, frequency and patterns of PVD that occur over longer periods of time exceeding 30 minutes.

Nurses may rely upon patient behaviors (e.g. accessory muscle use, forced exhalation) that are believed to demonstrate dyssynchrony between the patient and ventilator, instead of using more objective graphic measures to identify PVD based on waveform morphology (pressure/time and flow/ time waveform graphics).¹³ Recent sedation assessment tools have attempted to include an evaluation of ventilator dyssynchrony, using indicators of the patient-ventilator interaction,^{14,15,16} but these are not as objective as waveform analysis. Waveform analysis has been measured by visual representation of morphological changes and mathematical measures of inspiratory and expiratory times.^{2,4,17,18,19} The gold standard PVD measure, esophageal pressure (closely correlated with pleural pressure), is obtained from an esophageal balloon catheter;²⁰ however, these are infrequently or rarely, used for monitoring in ICU. Currently, waveform analysis is the most available and least invasive measure for PVD interpretation at the bedside.

While pressure/time and flow/ time waveform morphologic analysis has been cited as a clinically available and useful measure for PVD interpretation, nurses have not generally adopted its use into daily practice. Burns¹³ noted that nurses may not accurately interpret PVD or make clinical applications from their use and may find the waveforms confusing. Indeed, accurate assessment of PVD is difficult and generally nurses are not trained to evaluate airway pressure and flow waveform morphology, a key component of PVD evaluation. As a result, PVD evaluation in the ICU by nurses is based on non-empirical or non-systematic approaches that may lead to inadequate recognition and therefore inappropriate intervention.

Sedation is used to improve patient-ventilator interaction and reduce ventilator dyssynchrony.^{10,21,22} However, inappropriately high levels of sedation are associated with the development of PVD (e.g. ineffective trigger),⁴ have been shown to prolong the duration of mechanical ventilation (MV),^{23,24,25} as well as length of hospital and ICU stay,^{23,24,25} and increase the need for diagnostic testing to determine responsiveness.²⁵ Nurses use standing orders to titrate sedation to manage PVD, however sedation assessment tools do not include the most objective measures of PVD (pressure/time and flow/ time waveform analysis) and these factors may thereby lead to inappropriate and increased use of sedation.

Little information is available about the types, frequency and patterns of PVD identified or evaluated beyond the 30 minute time frame. In addition, there are some types of PVD that have a linked association and have been shown to be followed by other types of PVD.^{26,27,28} Therefore, the specific aim of this study was to identify the type, frequency and pattern of PVD in critically ill adults over time. A secondary aim was to determine the effect of sedation level on PVD. This study is intended to assist clinicians

to identify dyssynchronous breaths and their characteristic traits and patterns so that effective and timely interventions can be developed and executed to improve patient comfort and optimize sedation while reducing the complications of mechanical ventilation (MV).

Methods

Design and Sample

This non-experimental, prospective descriptive study was conducted at the Virginia Commonwealth University Health Systems (VCUHS) in Richmond, Virginia, a 983 bed medical center. Intubated and mechanically ventilated adults from all ethnic and racial backgrounds were recruited from the Surgical Trauma ICU (STICU), Cardiac Surgery ICU (CSICU) and Medical Respiratory ICU (MRICU). Exclusion criteria were: (a) presence of a tracheostomy (rather than endotracheal intubation [ETT]) since an acutely ill mechanically ventilated subject was the focus of this study; (b) administration of neuromuscular blocking agents or presence of chronic, persistent neuro-muscular disorders (such as cerebral palsy and Parkinson's disease) since these may affect the PVD phenomenon; and (c) presence of head trauma or stroke as these may affect respiratory dynamics and influence PVD. Additional ventilator setting exclusion criteria include use of (a) the augmented pressure ventilation mode, (b) increased pressure during inspiration (e.g. Bi-level), and (c) tube compensation since these features were found to increase the complexity of dyssynchrony interpretation in a pilot study prior to study implementation²⁹ and may decrease the incidence of dyssynchrony for evaluation in the study.^{30,31,32,33}

Subjects were enrolled for up to a 1.5 hour observation period, at any time of the day based on the primary investigator's (PI) schedule. Informed written consent was obtained from the patient or if unable to provide consent, from their legally authorized

representative (LAR). After data collection, provision for the subject to consent was offered within 1 week of enrollment if the subject gained recovery of cognition as evidenced by being alert, oriented, receiving no sedation and able to communicate his opinion regarding consent by signing the consent form.

Measurement of Key Variables

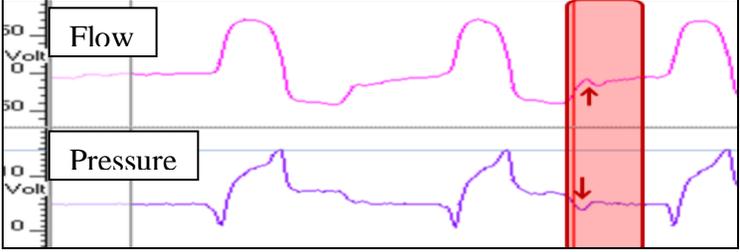
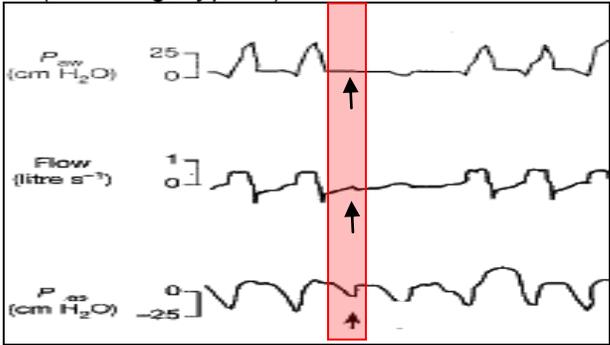
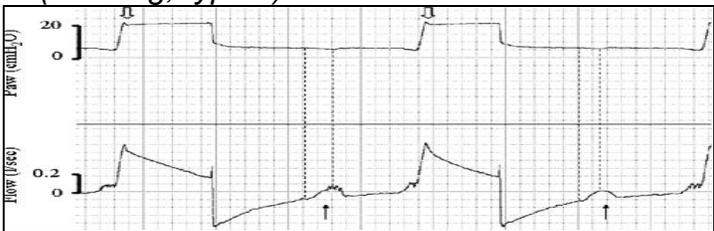
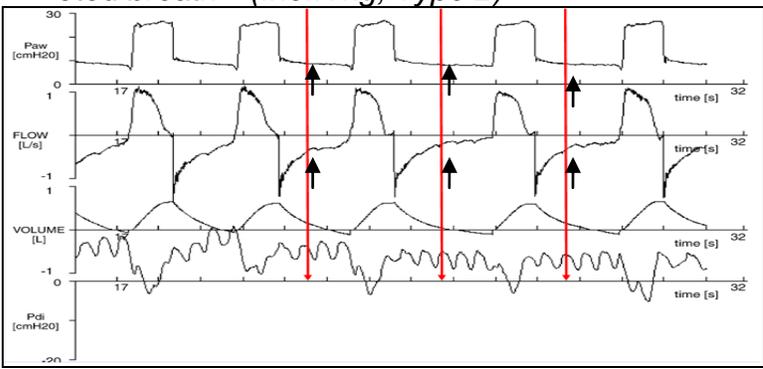
Patient ventilator dyssynchrony. PVD is a mismatch between patient initiated and ventilator assisted breaths and the ventilator's inability to meet the patient's flow demand.¹ To identify PVD types, frequency and patterns, airway pressure-time and flow-time waveform analysis was conducted. The pressure and flow waveforms were obtained using the Non-Invasive Cardiac Output (NICO) Cardiopulmonary Management system (Respironics®, Model 7300, Wallingford, CT) that integrates a non-invasive flow and pressure sensor (a fixed orifice differential pneumotachometer) between the end of the ETT and connection of the ventilator circuit. Gases that pass the pneumotachometer in the ventilator circuit create a decrease in pressure across tubes connected to the sensor. This drop in pressure is transmitted to the NICO where it is correlated with a predetermined stored calibration. The pressure and flow signals collected from the NICO were sent to a data acquisition system (MP 150 Data Acquisition System®, Biopac Systems Inc, Goleta, CA). The MP 150 sampled, synchronized, amplified, time stamped and stored data until downloaded for later analysis.

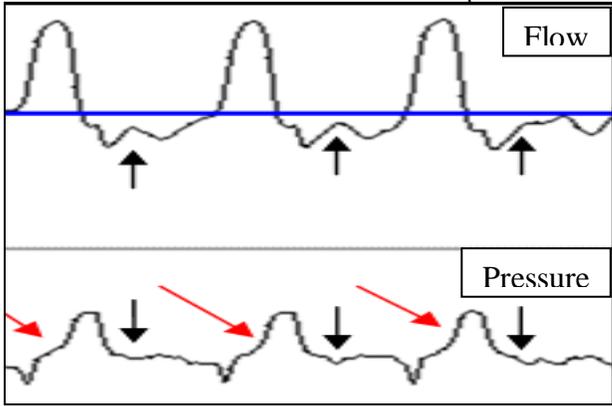
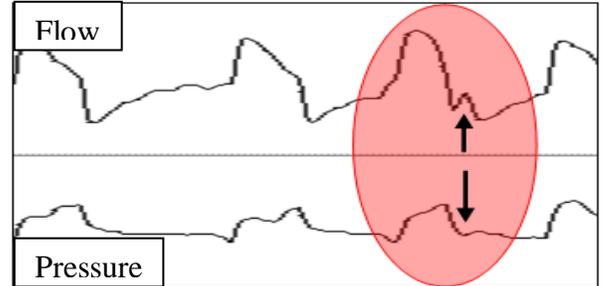
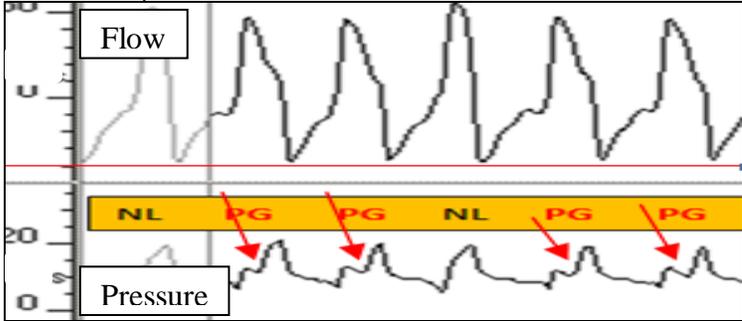
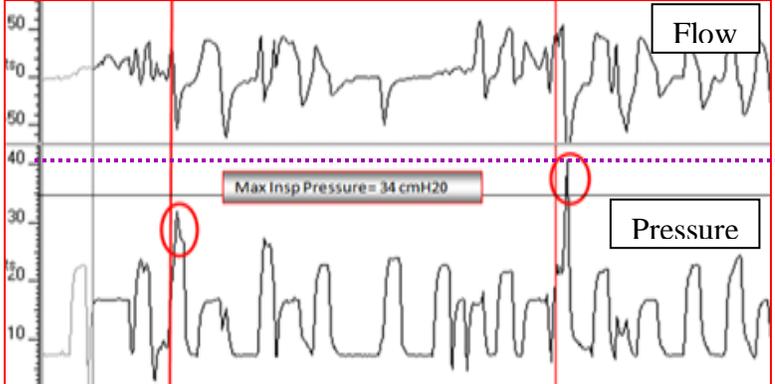
PVD types. Detection, identification and classification of airway pressure and flow over time was based on expert classification of airway dyssynchrony by Nilsestuen and Hargett, 2005.¹⁹ A coding scheme was developed with operational definitions and criteria for evaluation based on ventilator modes. A software package, The Observer XT 8.0® (Noldus, Inc), that integrates coding, analysis and presentation of video and physiological

data, was used to code and document each breath as normal or dyssynchronous (specifically by type). A breath by breath interpretation was completed during each subject's observed time period by the PI (KGM). These breaths were then independently validated with expert consultation. As new dyssynchronous breath types emerged from the data, they were given a descriptive indicator, operational definition and added to the coding scheme for complete and thorough coding and documentation longitudinally.

There were 5 types of dyssynchrony defined in the a priori coding scheme (Ineffective Trigger (Type 1 and Type 2), Double Trigger, Flow, Premature Termination and Delayed Termination).³⁴ However, at the time of data analysis, all types of PVD were reviewed and the coding categories and PVD types were altered to more accurately represent the data (Figure 1). One more breath category (Unknown) and two more PVD types (Premature Termination-Flow and Undocumented) were added. A breath was categorized as Unknown if neither the PI or expert consultants could identify whether the breath represented dyssynchrony or not. One a priori PVD type, Double Trigger (DbITrig), was renamed to the more expansive term, Multiple Trigger since we found more than two breaths may occur in rapid succession with incomplete exhalation between breaths. This modification resulted in 3 overall breath categories (Normal, Dyssynchronous and Unknown) and 7 PVD types for analysis (Ineffective Trigger [IneffTrig], Premature Termination-Flow [PreTerm-Flow], Premature Termination [PreTerm], Undocumented, Multiple Trigger [MultTrig], Flow and Delayed Termination [DelTerm]). Several PVD types also had subtype breaths, Ineffective Trigger (2 subtypes), Undocumented (8 subtypes) and Multiple Trigger (4 subtypes). The final adjusted coding schemes for PVD types including operational definitions are described in Figure 1.

Figure 1 Waveform Categories used for Coding and Data Analysis

Category of Dyssynchrony <i>Type of Dyssynchrony</i> <i>(Operational definitions based on mode)</i>	Picture of Dyssynchrony
<p>Ineffective Trigger (IneffTrig)</p> <p>1. Ineffective Trigger, Type 1 (IneffTrig, Type 1) <i>(Same in all modes)</i></p> <p>Flow: Positive inflection not followed (f/b) by mechanically ventilated (MV) breath AND Paw: Negative deflection, not f/b MV breath.</p> <p>2. Ineffective Trigger, Type 2 (IneffTrig, Type 2) <i>(Same in all modes)</i></p> <p>Flow: Positive inflection, not f/b MV breath AND ASSOCIATED with, Paw: No negative deflection or unnoticeable change.</p>	<p>1. Ineffective Trigger, Type 1 (IneffTrig, Type 1)</p>  <p>2. Ineffective Trigger, Type 2 in a Volume breath¹⁹ (IneffTrig, Type 2)</p>  <p>2. Ineffective Trigger, Type 2 in a PSV breath¹⁸ (IneffTrig, Type 2)</p>  <p>2. Ineffective Trigger, Type 2 in a Pressure targeted breath³⁵ (IneffTrig, Type 2)</p> 

<p>Premature Termination-Flow (PreTerm-Flow) (Seen in AC-Pressure Targeted)</p> <p>Flow: PreTerm is positive inflection at end of expiration *black arrows, AND, Paw: PreTerm is negative deflection directly associated with bump in pressure *black arrow. Flow PVD is “scooped out” on inhalation.*red arrows</p>	<p>Premature Termination - Flow (PreTerm-Flow)</p> 
<p>Premature Termination (PreTerm) (Same in all modes)</p> <p>Flow: Negative deflection directly associated with bump in pressure, AND, Paw: Positive inflection at the end of expiration.</p>	<p>Premature Termination (PreTerm)</p> 
<p>Undocumented PVD (8 types)</p> <p>1. Patient Gasp PVD (Seen in SIMV- Volume Targeted mode)</p> <p>Paw: Initial Paw begins to ramp up at normal rate, but quickly dishes out, then returns to normal pressure pattern.</p> <p>2. PVD Variant (3 subtypes)</p> <p>A. Resisting Ventilation (Seen in SIMV-Pressure Targeted mode)</p> <p>Paw: Paw spikes upward past maximum pressure expected *straight gray line for patient with a possible pressure “pop-off” *purple dotted line.</p>	<p>1. Patient Gasp- PVD (PG=Patient Gasp PVD; NL = Normal)</p>  <p>2. PVD Variant</p> <p>A. Resisting Ventilation</p> 

2. PVD Variant (cont'd)

B. Variable Inspiratory Effort

(Seen in SIMV-Pressure Targeted and Spontaneous modes)

Flow: Flow reveals variable patient effort during inhalation in proportion to Paw response.

C. Variant Flow Effort

(Seen in SIMV-Pressure Targeted mode)

Flow: Flow negative or unproportional to Paw response.

3. Active Double Trigger – Premature Termination

(ActDbITrigg-PreTerm)

(Seen in AC- Pressure Targeted mode)

Flow: Active DbITrig breath has flow between 2 breaths that barely dips below “0”. PreTerm breath shows a positive inflection after last exhaled Active DbITrig breath, AND,

Paw: Active DbITrig breath with more negative Paw than triggered breaths *black arrow. PreTerm breath has negative dip after exhalation *red arrow.

4. Double Trigger–Flow

(DbITrig–Flow)

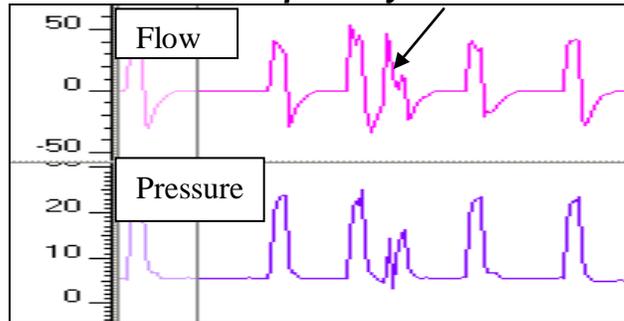
(Seen in AC- Pressure Targeted mode)

Flow: 2 positive inflections without full exhalation, *red arrows AND,

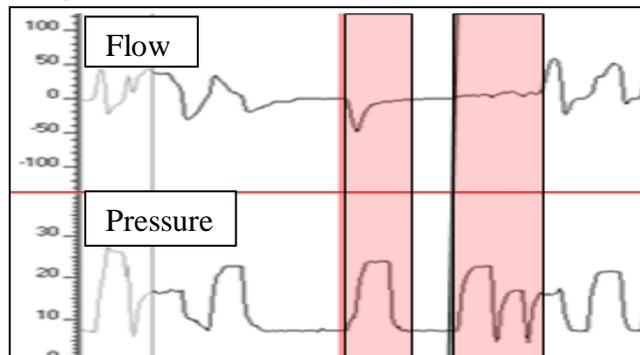
Paw: Same as DbITrig *red arrow, & Flow PVD *black arrow

2. PVD Variant (cont'd)

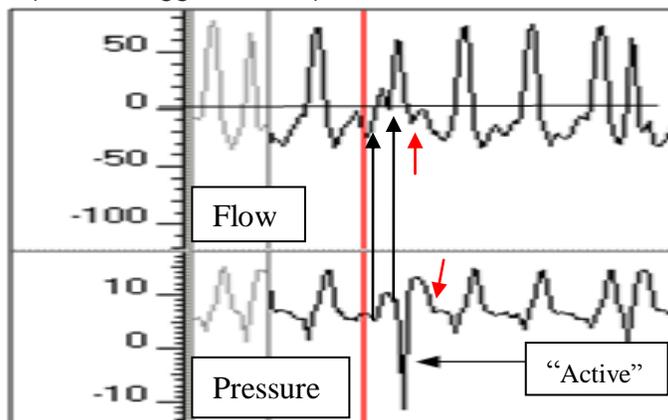
B. Variable Inspiratory Effort



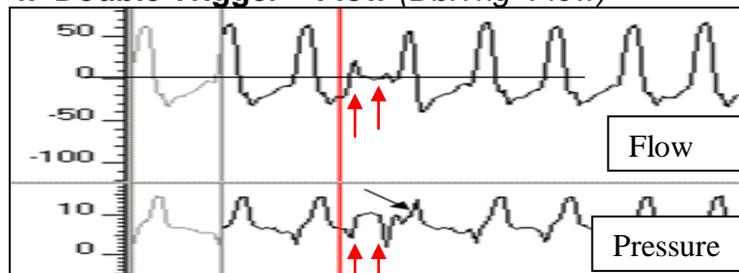
C. Variant Flow Effort



3. Active Double Trigger–Premature Termination (ActDbITrigg-PreTerm)



4. Double Trigger – Flow (DbITrig–Flow)



5. Double Trigger–Premature Termination

(DbITrig-PreTerm)
(Seen in AC-PressureTargeted and Spontaneous mode)

Flow: Same as DbITrig *black arrows, and PreTerm*red arrow,
AND,
Paw: Same as DT and PreTerm*red arrow.

6. Active Multiple Trigger–Premature Termination

(ActMultTrig-PreTerm)
(Seen in AC-PressureTargeted mode)

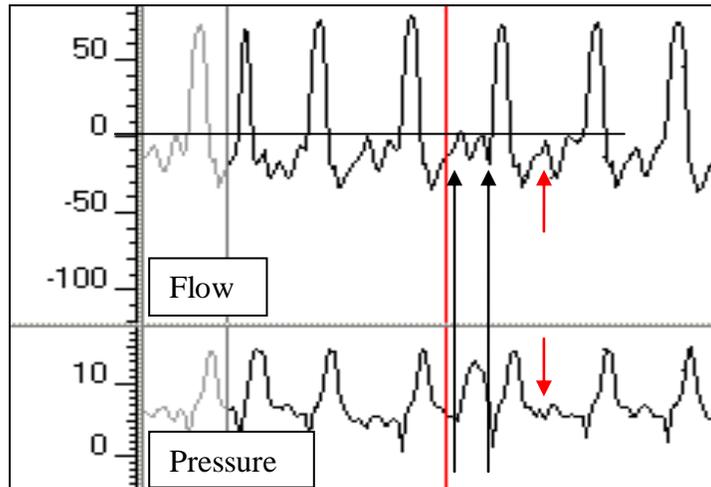
Flow: Active MultTrig, no exhaledFlow between breaths *blackarrow. PreTerm as described *red arrow,
AND,
Paw: Same as Active DbITrig-PreTerm, except more than 2 breaths triggered.

7. MultipleTrigger–Premature Termination

(MultTrig-PreTerm)
(Seen in AC-Pressure Targeted mode)

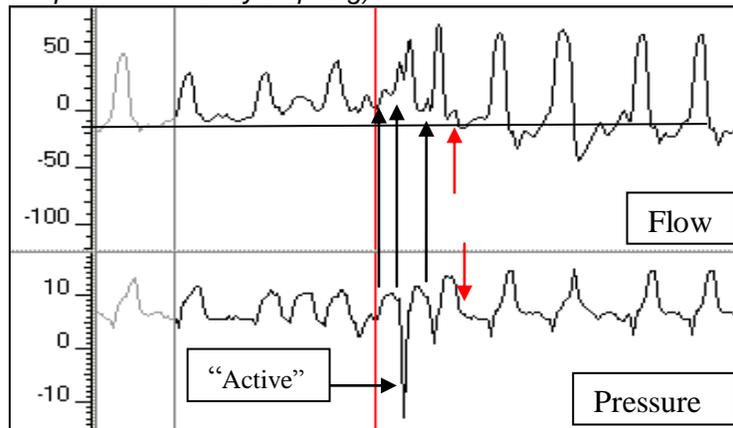
Flow: Same as MultTrig *black arrows. Same as PreTerm *red arrow.
AND,
Paw: Same as MultTrig *black arrow, Same as PreTerm * red arrow.

5. Double Trigger-Premature Termination (DbITrig-PreTerm)

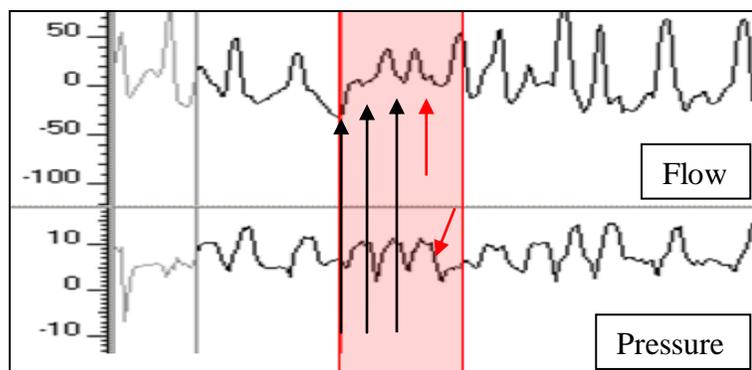


6. Active Multiple Trigger–Premature Termination (ActMultTrig-PreTerm)

(3 Triggers, breaths never reach target pressure because patient is actively inspiring)



7. Multiple Trigger–Premature Termination (MultTrig-PreTerm)



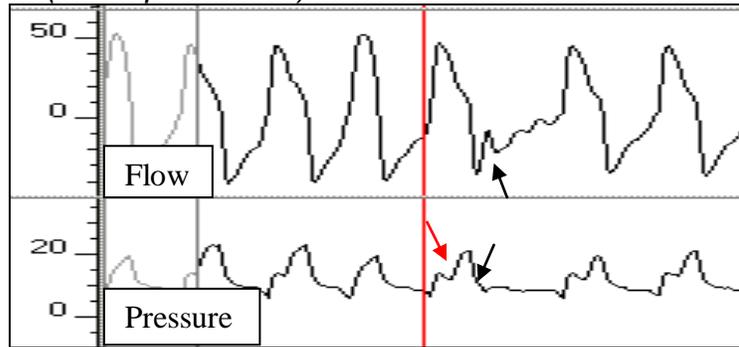
8. Patient Gasp PVD – Premature Termination

(Seen in SIMV- Volume Targeted mode)

Flow: PreTerm breath has a positive inflection after exhalation, *black arrow, AND,

Paw: PreTerm breath has a negative dip after exhalation *black arrow. Patient GaspPVD described above.

8. Patient Gasp PVD – Premature Termination (PtGasp-PreTerm)



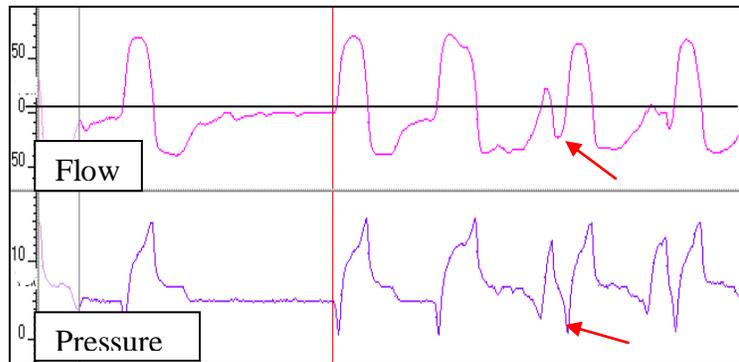
Multiple Trigger

1. Double Trigger (DbITrig)
(Same in all modes)

Flow: Initial triggered breath f/b 2nd increased flow in same breath cycle. No significant drop in expiratory flow after first triggered breath (barely exhales below “0” *red arrow), AND,

Paw: Drops to trigger threshold after first triggered MV breath causing 2nd positive inflection.

1. Double Trigger (4th and 5th breaths are DbITrigs)



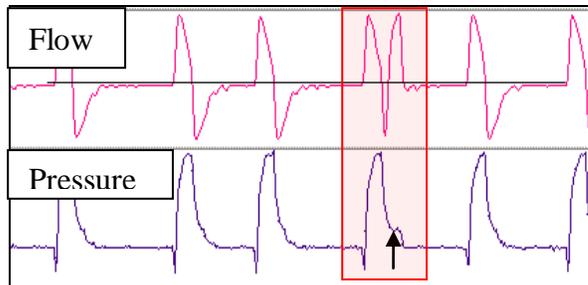
2. Unusual DT

(Seen in Spontaneous mode)

Flow: Same as in DbITrig, except flow goes deeper than usual, AND,

Paw: second breath in cycle exhibits a small positive Paw *black arrow.

2. Unusual DT

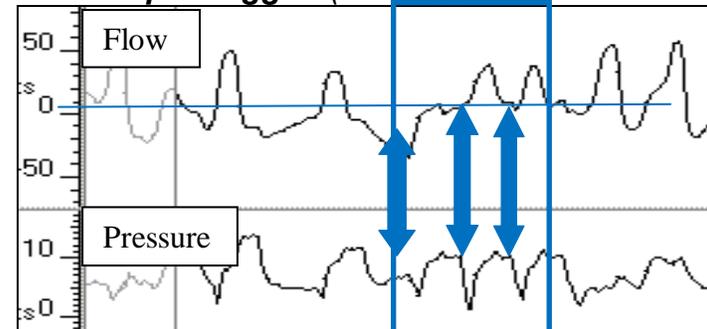


3. Multiple Trigger (MultTrig)
(Same in all modes)

Paw: Same as in DbITrig, but now may have more than 2 triggers AND,

Flow: Same as in DbITrig, but more than 2 flow inflections.

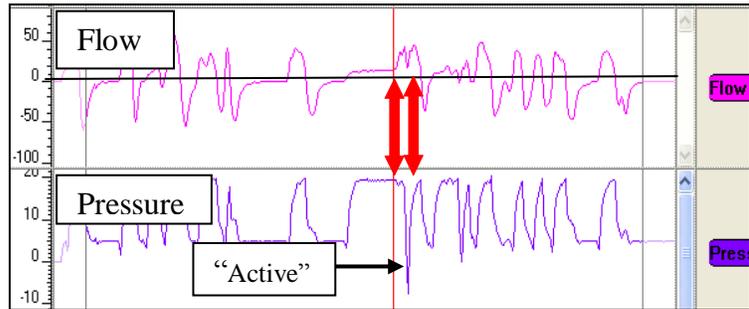
3. Multiple Trigger (MultTrig)



4. Active Double Trigger
(ActDbITrig)
(Same in all modes)

Flow: Same as in DbITrig *red arrows.
AND,
Paw: Same as in DbITrig, except that one pressure dip is much more negative than subject's other Paw trigger pressures. *black arrow

4. Active DT in Spontaneous mode (ActDbITrig)

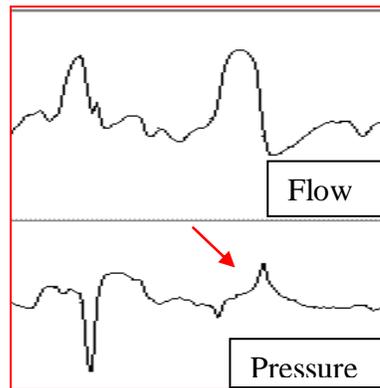


Some subjects, although not common, used excessive negative pressure to generate Double and Multiple Triggers. The phrase "Active" was used because of the obvious effort the subject was using during active triggered breaths, the Paw had a much larger negative pressure compared to the subject's other initiated breaths.

Flow Dyssynchrony (Flow)
(Same in all modes)

Flow: Normal wave,
AND,
Paw: Concave Dip (-), "scooped out" on the accelerating wave.

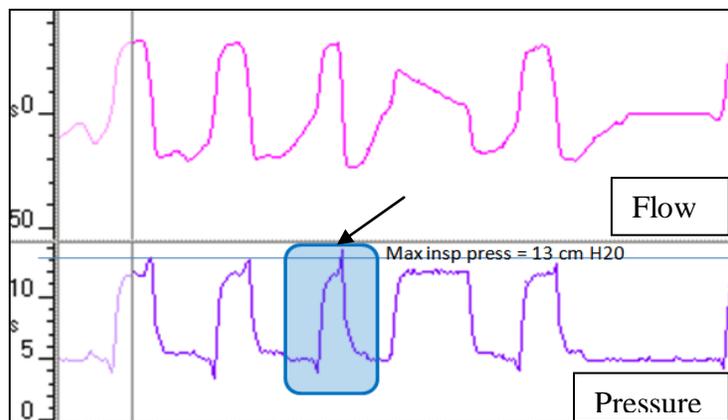
Flow Dyssynchrony (Flow)



Delayed Termination (DelTerm)
(Same in all modes)

Flow: Normal wave,
AND,
Paw: Pressure spike just Before exhalation. Spike goes higher than expected maximum inspiratory pressure. *black arrow.

Delayed Termination (DelTerm)



Paw= Airway Pressure waveform, PSV= Pressure Support Ventilation, AC= Assist Control mode, SIMV= Synchronized Intermittent Mandatory Ventilation mode, cmH2O= centimeters water pressure.

The Undocumented PVD type was added because new dyssynchrony was found that has not been previously identified in the literature and combinations of dyssynchronous breaths were observed during the same breath cycle (e.g. PreTerm and DbITrig occur simultaneously). The PVD type of PreTerm-Flow, although not documented in the literature, was frequent and therefore listed separately. This classification system enabled a mutually exclusive representation of the data for analysis.

PVD frequency. PVD frequency was expressed by comparing the number of PVD occurrences relative to the total number of breaths taken (including those triggered or not, or of wasted effort) in the observed time.² A dyssynchrony index (DI), expressed in percentage, was calculated by dividing the number of dyssynchronous breaths by the sum of total breaths, then multiplied by 100 in the entire sample.² The DI accounted for all patient breaths. A high incidence of PVD was defined as a DI greater than 10%, based on the previous work of Thille et al, 2006² and Vitacca et al., 2004.³⁶ An index (PVD type) was also calculated for each PVD type. The PVD type index⁴ was calculated by dividing the number of each PVD type by the total number of breaths for each subject (Normal, Dyssynchronous and Unknown breaths), then multiplying by 100.

PVD patterns. Some types of PVD are associated with other types of PVD types due to respiratory dynamics, patient and ventilator factors.^{10,19} The first association is the development of MultTrig following the occurrence of a PreTerm breath. Tokioka et al.²⁶ found that as breath termination criteria was adjusted so that breath termination occurred sooner (inspiratory termination criteria set at 35% and 45% of peak flow), the frequency of double trigger increased. In this study, 8 subjects having acute respiratory distress syndrome on pressure support ventilation (PSV) experienced DbITrig.²⁶ This occurs because patients continue to inhale when the ventilator is set to stop gas delivery thereby

working inspiratory muscles into and throughout the expiratory phase.¹⁰ van de Graaff and colleagues^{37,page 1088} noted that this can cause a “retriggering and a stuttering pattern of ventilatory activation” for patients on PSV.

A second association is the development of IneffTrig after DelTerm.^{19,38} The occurrence of Delayed Termination in patients with chronic obstructive pulmonary disease (COPD), can cause a high lung volume resulting in ineffective triggering of the following inspiratory effort.^{28,27} Nava et al.²⁷ found a significant correlation between ineffective triggering and the increased duration of diaphragmatic contraction (Pdi) in COPD subjects on PSV.²⁷ Parthasarathy et al.²⁸ simulated delayed termination (airflow limitation) experimentally with a Starling resistor and found that healthy subjects breathing with a mouthpiece on the ventilator had ineffective efforts. They attributed this to an increase in elastic recoil during expiration while the ventilator was not finished delivering volume.²⁸ In a more recent study, DelTerm and IneffTrig were the only two associated asynchronies likely to be grouped in subjects on non-invasive MV ($p= 0.0003$).³⁹ Although these findings are not with intubated subjects, they do suggest associations between DelTerm and IneffTrig. PVD patterns have not been systematically evaluated on critically ill subjects using large data sets, and it is unknown how often these patterns may occur over time.

The aforementioned software, Observer XT 8.0 ® (Noldus, Inc) was used to measure and detect patterns that occur between two different dyssynchronous types within a certain lag or time period. Two types of lag patterns were explored (state lag and time lag). State lag frequency between the two specified PVD associations (PreTerm to MultTrig, and DelTerm to IneffTrig) was calculated over a specified period for the sample. State lag frequency measures how often a “response” dyssynchronous breath (e.g.

DbITrig) occurs within the subject's breath order (e.g. next breath, second breath, third breath) after a specified "predictor" PVD breath (e.g. PreTerm). Time lag analysis explores a specified window of time when transitions from a predictor PVD lead to a response PVD type. Specifically, time lag frequency detects how often a response dyssynchrony occurred during a time window after a predictor PVD breath. In this exploratory analysis where patterns are being initially investigated it is unclear what the time effect may be, therefore multiple time frames were selected and were based on reasonable periods when response PVD breaths may be expected clinically. Time lag frequency analysis was used to explore the association between PreTerm and MultTrigs (all subtypes) as well as DelTerm and IneffTriggs (Type 1 and 2).

Level of sedation. Because sedation level may directly affect PVD,⁴ the subject's level of sedation was documented using the Richmond Agitation Sedation Scale (RASS).¹⁶ The RASS evaluates level of consciousness and responsiveness using a 10-point scale, ranging from -5 (unarousable) to 0 (calm and alert) to +4 (combative), based on observation of specific patient behaviors. It has been validated against a visual analogue scale of sedation and agitation and tested for inter-rater reliability in 5 adult ICUs, validated against other published sedation scales and tested for reliability by comparing bedside nurses to trained instructors.¹⁶ The RASS was used to describe the sample and their level of sedation in relation to dyssynchrony exhibited.

Subject descriptive data. Subject demographic data (age, gender, ethnicity, race, admission diagnosis, reason for intubation, duration of MV, hospital and ICU stay) were collected, along with ventilator information (ventilator settings, presence of fluid in the ventilator circuit and presence of jet nebulizer treatment during data collection), subject medical history (COPD history was gathered by history/physical/progress notes), and

severity of illness. Severity of illness was determined using scores on the Acute Physiology and Chronic Health Evaluation (APACHE) III.⁴⁰ The APACHE scoring system has demonstrated validity in the ICU setting.⁴¹

Procedure

The study was reviewed and approved by the Virginia Commonwealth University's institutional review board. Informed consent was obtained from the subject or LAR if the subject was unable to consent. Once the subject was enrolled, demographics and ICU admission information were obtained. Information for the APACHE III was recorded for the 24 hours prior to study enrollment.

Data Collection Procedure.

Subjects were enrolled for up to a 1.5 hour observation period. Prior to the actual start of the electronic data collection, the NICO was time synchronized and time stamped with respect to the computer's real-time clock. The NICO carbon dioxide sensor was zeroed and calibrated, the airway circuit was assessed for excessive humidification and all fluid removed from the circuit to avoid measurement error in PVD interpretation. In addition, the patient's breath sounds were assessed and the need for suctioning determined. If suctioning was required, it occurred before data collection since this may cause measurement error in PVD interpretation.⁴² The respiratory therapist working with the patient or the PI connected the NICO sensor to the ventilator circuit to ensure a stable connection. RASS data was collected by the PI every 20 minutes.

Data Analysis

Descriptive statistics were used to summarize the characteristics of the sample, counts and proportion for discrete variables and mean, range, standard deviation and

median, IQR for continuous variables through JMP 8.0 (SAS Institute, Inc.) statistical software.

Waveform analysis was conducted by using an a priori coding scheme based on ventilator mode algorithm that was developed with an expert consultant. Waveform coding was completed by the PI in consultation with two clinical experts. To avoid waveform interpretation and measurement bias two methods were used, (a) subject selection for waveform coding was randomized using a random number table, and (b) an assistant blinded the PI from the subject's identification number on the waveform file before waveform coding ensued. Dyssynchrony Index and PVD type indices were calculated for each individual subject and these data were used to evaluate the entire sample using medians and ranges.

PVD patterns were evaluated as described by lag sequential analysis through Observer XT 8.0® (Noldus, Inc.) software. Since PVD patterns have not been reported extensively, short intervals were selected to determine when the response PVD types occurred. Breath order for state lag frequency was calculated up to the seventh consecutive breath. Time lag windows of observation were specified at 3, 5, 10, 15, 20, 25, 30, 35, 40, 45, 60 second intervals from the occurrence of the predictor PVD type.

ANOVA was used to test the relationships among demographic variables. Wilcoxon rank score was used to test, ventilator modes, level of sedation and DI. The nonparametric Kruskal Wallis test was used to identify whether ventilator mode affected PVD type. The most common RASS value of the six documented scores was used to determine an overall sedation level (awake or deeply sedated) for each subject.

Results

Characteristics of the Sample

Forty-nine patients were approached for consent. Of these, 30 were consented and enrolled (LAR refused = 17; ventilator setting changed after enrollment = 2), with 27 subjects available for data analysis (2 had equipment synchronization errors and 1 did not have waveform recording available). The 27 patients in this sample (mean age 55 years, 56% men) were primarily intubated for hypoxemic respiratory failure (Table 1). The sample was almost equally distributed among medical and surgical ICU's and was primarily in a spontaneous (PSV) mode of ventilation. The mean APACHE III score was 75 (range 30-173), which represents moderate illness severity. Although one subject (APACHE III score 173, severely ill) was significantly out of this range.⁴⁰ The total observation time for the sample was 2,221 minutes (35 hours) with a mean of 79 minutes (range 53 – 92) per subject. During this time, 43,758 individual breaths occurred.

Table 1 Characteristics of sample and major variables (n= 27)

Variable	Frequency	%		
Gender				
Male	15	56		
Female	12	44		
Ethnicity				
White, Non Hispanic	15	56		
Black, Non Hispanic	11	41		
Pacific Islander, Non Hispanic	1	3		
ICU Type				
Medical Respiratory ICU	14	52		
Surgical Trauma ICU	10	37		
Cardiac Surgical ICU	3	11		
Admitting Diagnosis				
Sepsis	8	30		
Surgery	7	25		
Pneumonia	3	11		
Cardiac Surgery	3	11		
Trauma	3	11		
GI Bleed	1	4		
Liver Failure	1	4		
Metastatic Cancer	1	4		
History of COPD	9	33		
Reason for Intubation				
Hypoxemic respiratory failure	12	44		
Airway control	7	26		
Both hypoxemic and ventilatory failure	4	15		
Respiratory distress	4	15		
Ventilatory failure	0	0		
Mechanical Ventilation Mode				
Spontaneous- PSV	15	55		
Assist Control- Pressure Targeted	2	7		
Assist Control- Volume Targeted	0	0		
SIMV- Pressure Targeted- PSV	5	19		
SIMV- Volume Targeted- PSV	5	19		
Variable	Mean	Range	SD	
Age (years)	55	32- 83	13.3	
APACHE III	75	30- 173	31.6	
PSV (cm H20)	11	0- 18	3.9	
Positive End Expiratory Pressure (cm H20)	6	5- 10	1.6	
MV duration (days)	13	2- 56	10.6	
ICU length of stay (days)	19	3- 72	16.5	
Hospital length of stay (days)	31	5- 86	19.8	
Observation time (minutes)	79	53- 92	13.0	

Gastrointestinal (GI), Chronic Obstructive Pulmonary Disease (COPD), Standard Deviation (SD) Pressure Support Ventilation (PSV), Synchronized Intermittent Mandatory Ventilation (SIMV), Positive End Expiratory Pressure (PEEP), Acute Physiology and Chronic Health Evaluation Physiological (APACHE III)

Patient Ventilator Dyssynchrony

Patient ventilator dyssynchrony was found in both medical and surgical subjects and during each of the MV modes (Spontaneous, SIMV, Assist Control, Pressure Control) included in this study.

PVD types. Seventy-six percent of the sample's breaths were normal during the observed time period (Table 2). The most common occurring PVD type in the sample was IneffTrigg (63% of all dyssynchronous breaths), with Type 2 being more prominent than Type 1. The second most common PVD type was PreTerm-Flow, although this type was experienced by one subject. However, PreTerm, the third most common type of PVD, was observed in 19 subjects (70% of sample). Surprisingly, Undocumented PVD (not previously described in the literature) was almost as frequent as PreTerm, but was mostly comprised by the PVD type, Patient Gasp PVD (n = 898, 96% of all Undocumented type). Similar to PreTerm-Flow, Patient Gasp PVD was also observed in only one subject. The least common category and type of PVD in descending order was MultTrigg, Flow and DelTerm.

Variability in PVD types. Twenty-one of the 27 subjects (77%) experienced more than one category of PVD. Two subjects had no PVD, four had 1 PVD type, seven had 2 PVD types, seven had 3 PVD types, six had 4 PVD types, and one had 6 PVD types. (Figure 2) IneffTrigg was present in 20 (74%) patients, PreTerm in 19 (70%), MultTrigg in 17 (63%), Undocumented in 6 (22%), DelTerm in 6 (22%), Flow in 2 (7%) and PreTerm-Flow in 1(4%).

Table 2 Breath types (Total ventilated breaths of sample, n= 43,758)

Breath Category	Frequency	% of total breaths	% of PVD
Normal	33,403	76.34	---
Dyssynchrony	10,195	23.30	---
Ineffective Trigger (IneffTrig)	6,411	14.65	62.88
IneffTrig, Type 2	4,035	9.22	39.58
IneffTrig, Type 1	2,376	5.43	23.30
Premature Termination-Flow (PreTerm-Flow)	1,712	3.91	16.79
Premature Termination (PreTerm)	937	2.14	9.19
Undocumented	935	2.14	9.17
Patient Gasp PVD	898	2.05	8.81
PVD Variant	22	0.05	0.22
Active Double Trigger-Premature Termination (ActDbITrig-PreTerm)	7	0.02	0.06
Double Trigger-Flow (DbITrig-Flow)	2	0.01	0.02
Double Trigger-Premature Termination (DbITrig-PreTerm)	2	0.01	0.02
Active Multiple Trigger-Premature Termination (ActMultTrig-PreTerm)	1	<0.01	< 0.01
Multiple Trigger-Premature Termination (MultTrig-PreTerm)	1	<0.01	<0.01
Patient Gasp PVD–Premature Termination	1	<0.01	<0.01
Multiple Trigger	102	0.24	1.00
Double Trigger (DbITrig)	75	0.17	0.74
Unusual Double Trigger	24	0.06	0.24
Multiple Trigger (MultTrig)	3	<0.01	0.03
Active Double Trigger (ActDbITrig)	1	<0.01	<0.01
Flow	89	0.20	0.87
Delayed Termination (DeITerm)	9	0.02	0.09
Unknown	160	0.37	---

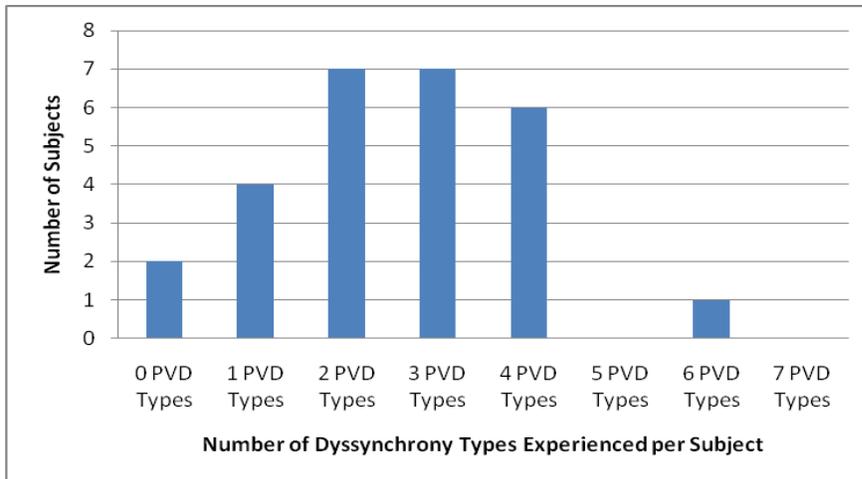


Figure 2 Number of Dyssynchrony Types per Subject.

Unexpected PVD types. There were a variety of unexpected PVD types detected during waveform analysis. These were defined as Undocumented PVD types. (Figure 1 and Table 2). Patient Gasp PVD, the most frequent in this PVD type, occurred in only one subject with COPD who also experienced 1 combined breath of Patient Gasp PVD-PreTerm. This subject was on SIMV-Volume targeted, PSV/PEEP and experienced three other PVD types (IneffTrig, PreTerm, Flow). Patient Gasp PVD occurs when the subject starts to breathe, then gasps once the ventilator begins inspiratory gas flow. In Figure 1, notice that the initial pressure begins to increase at a normal rate, but then indents or “scoops” out because the patient suddenly changes their inspiratory effort. The patient is not relaxed and tries to breathe ahead of the ventilator, but the ventilator cannot synchronize to this gasping pattern.

The second most common type of Undocumented PVD, PVD Variant, occurred in 4 subjects. The 22 breaths of this type were varied with the most frequent subtype of, Resisting Ventilation occurring in 73% (16 breaths) of all PVD Variant. While both DelTerm and Resisting Ventilation breath types have a spike at the end of the breath, the Resisting Ventilation pattern has a sharp spike that frequently resulted in the ventilator

reaching the peak pressure limit or "pop off", while the DelTerm had a smaller spike that more closely followed the 2 cmH₂O pressure above target pressure rule for Pressure Support termination.

In total, there were only 14 breaths in the sample that were combined types of PVD (Table 2- Undocumented types). Although a very small portion of the PVD experienced in this sample, combined phase dyssynchronies are nevertheless an important finding that has not been discussed in the literature. The most common combination was Active DbITrig-PreTerm, which all occurred in the same subject with six of the seven occurrences happening over an 8 minute period. Five of the six combination PVD types involve PreTerm combined with either, DbITrig, Active DbITrig, MultTrig and Active MultTrig in order of occurrence.

The last unexpected finding was a MultTrig type that we termed, Unusual DbITrig with a unique defining criterion. These breaths have two positive flow inflections but no associated second rise in pressure for the second breath. There is a spike in the expiratory flow trace that occurs after the first breath in the DbITrig cycle, but it is unusual that there is no second increase in the pressure waveform associated with the second breath. Only one subject had Unusual DbITrig where it occurred over an 11 minute time period.

PVD frequency. Twenty-five subjects (93% of sample) experienced dyssynchrony (at least one occurrence of PVD during their observation period). One of these subjects had all normal breaths except for one incident of Multiple Trigger. For the 27 subjects, the median DI (IQR) for the sample was 4% (1% - 9%). There were 6 subjects (22%) who experienced a clinically significant level of PVD (DI \geq 10%), in this group the median DI (IQR) was 61% (42% - 85%). Table 3 displays the median index, range and IQR for each

breath category and PVD type. IneffTrig was the most common PVD type index, followed by PreTerm index.

Table 3 PVD Breath Categories (% for n= 27 subjects)

Breath Category	Median	Range	IQR
Normal	95.23	0.32 - 99.46	88.23 - 97.91
Dyssynchrony	4.19	0.00 - 99.30	0.97 - 9.27
Ineffective Trigger	1.78	0.00 - 71.14	0.00 - 4.86
Premature Termination-Flow	0.00	0.00 - 45.85	0.00 - 0.00
Premature Termination	0.25	0.00 - 80.35	0.00 - 1.45
Undocumented	0.00	0.00 - 44.31	0.00 - 0.00
Multiple Trigger	0.06	0.00 - 3.00	0.00 - 0.24
Flow	0.00	0.00 - 2.22	0.00 - 0.00
Delayed termination	0.00	0.00 - 0.17	0.00 - 0.00
Unknown	0.21	0.00 - 3.61	0.00 - 0.35

There was no significant difference in DI between subjects with medical or surgical diagnoses using Wilcoxon 2 sample test ($Z = -0.56$, $p = 0.58$). Although the median DI between the two groups was not statistically significant, the DI IQR for medical versus surgical subjects appear strikingly different (medical= [0.5- 57%], surgical= [2-9%]), suggesting a skewed sample in the medical group. In addition, subjects with COPD had a trend for higher median DI (IQR) 6% (2-61%) than those without COPD 4% (0.8-6%), but these were not statistically significant ($Z = 1.23$, $p = 0.22$). Ventilator mode setting did not influence DI in the sample ($\chi^2 (2) = 5.41$ $p = 0.07$).

PVD patterns. The relationships between associated PVD breaths were evaluated with lag sequential analysis. The two major breath associations examined were the presence of (a) Premature Termination followed by Multiple Triggers (any type) and, (b) Delayed Termination followed by Ineffective Triggers (Type 1 or 2). Figure 3 shows figures of these associated PVD patterns. Table 4 notes the state lag frequency for the occurrence of response breaths as the very next breath up to the seventh breath after a

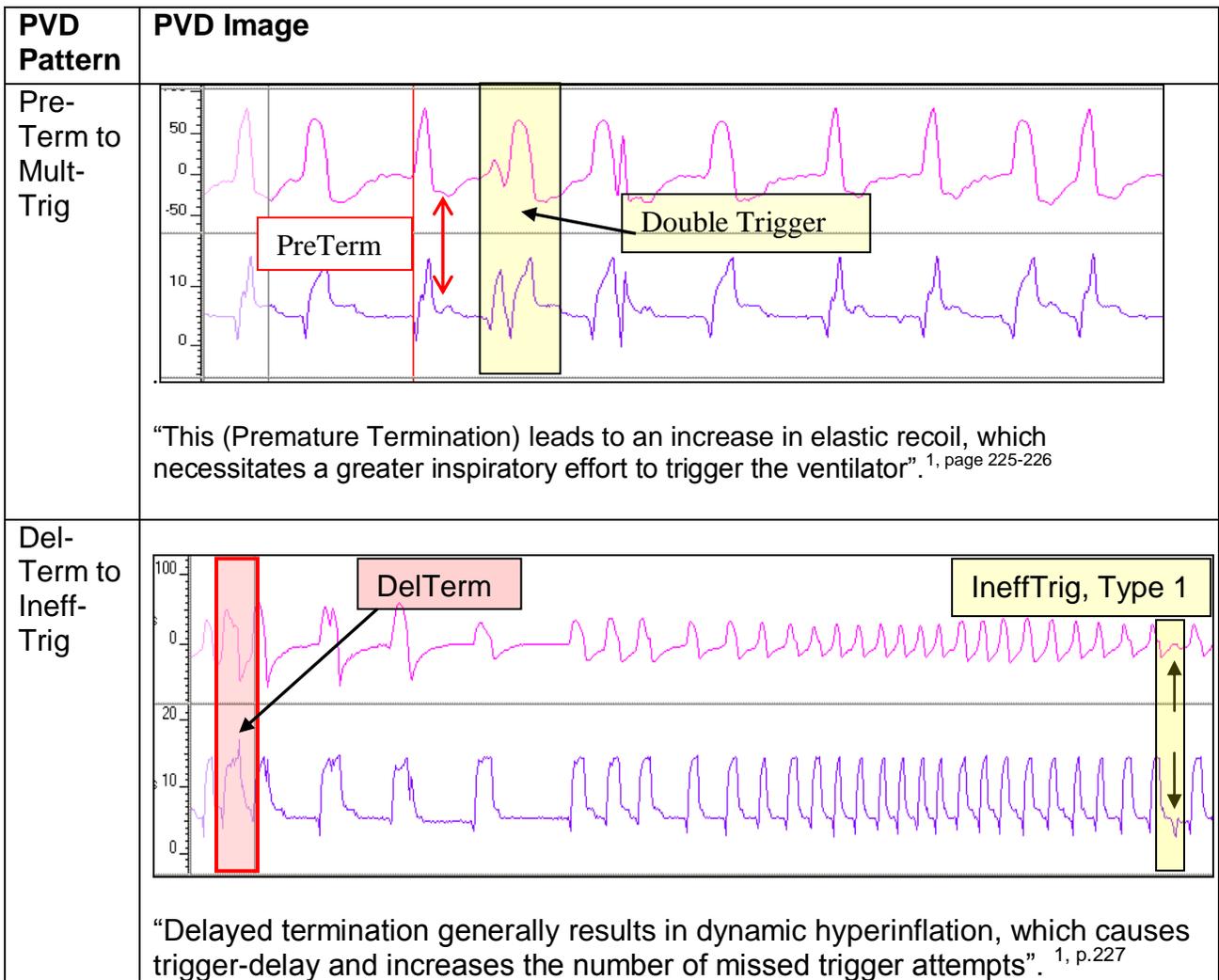


Figure 3 Patterns of PVD Associations

predictor breath.

The most frequent next breath after a (a) PremTerm breath was the response PVD subtype Double Trigger with 3 occurring as the very next breath in the sample, whereas after (b) DelTerm, there was no incidence of Ineffective Trigger type 1 or type 2 that occurred as a next breath or any other breath thereafter.

The time lag association between Premature Termination and Multiple Triggers

Table 4 State Lag Analysis, Frequency for Premature Termination and Delayed Termination

Breath Order →	Next Breath	2 nd Breath	3rd Breath	4 th Breath	5 th Breath	6 th Breath	7 th Breath
Premature Termination to Multiple Triggers (all types)							
DbITrig	2	4	1	4	2	2	0
DbITrig-Flow	0	0	0	0	0	0	0
DbITrig-PreTerm	0	0	0	0	0	0	0
Unusual DbITrig	0	0	0	1	0	0	0
ActDbITrig-PreTerm	0	0	0	0	0	0	0
MltTrig	0	0	0	0	0	0	0
MltTrig - PreTerm	1	0	0	0	0	0	0
ActMultTrig-PreTerm	0	0	0	0	0	0	0
Delayed Termination to Ineffective Triggers (Type 1 and 2)							
IneffTrig, Type 1	0	0	0	0	0	0	0
IneffTrig, Type 2	0	0	0	0	0	0	0

n = Frequency of the response PVD occurring as the very next breath after the predictor PVD

was initially seen with Double Triggers and a MultTrig-PreTerm breath appearing 3 seconds after the predictor PVD type PreTerm breath. (Table 5) The PVD type associations between PreTerm and MultTrigs (subtype) occurred between 5 seconds and up to 1 minute. (Table 5) Concerning the time lag association between Delayed Termination and Ineffective Trigger, no response PVD was seen until 30 seconds after the predictor PVD type. (Table 5) The only IneffTrig subtype to appear was Type 1, which occurred at 30 seconds, then again once more at 35 seconds. IneffTrig, Type 2 did not appear until 8

Table 5 Time lag- Frequency Matrix for Premature Termination to Multiple Triggers and Delayed Termination to Ineffective Triggers

Time →	3s	5s	10s	15s	20s	25s	30 s	35s	40s	45s	60s
	n	n	n	n	n	n	n	n	n	n	n
PVD Response =	PVD Predictor= Premature Termination										
DbI Trig	3	5	10	12	11	13	14	17	16	16	17
DbI Trig-Flow	0	0	0	0	0	0	0	0	0	0	0
DbI Trig-PreTerm	0	0	0	0	0	0	0	0	0	0	0
DbI Trig-DelTerm	0	0	0	0	0	0	0	0	0	0	0
Unusual DbI Trig	0	0	0	0	1	1	1	2	3	4	6
ActDbI Trig-PreTerm	0	0	0	0	0	0	0	1	1	1	1
MultTrig	0	0	1	1	1	1	1	2	2	2	2
MultTrig-PreTerm	1	1	1	1	1	1	1	1	1	1	1
ActMult Trig-PreTerm	0	0	0	0	0	1	1	1	1	1	1
PVD response =	PVD predictor= Delayed Termination										
Ineffective Trigger, Type 1	0	0	0	0	0	0	1	2	2	2	2
Ineffective Trigger, Type 2	0	0	0	0	0	0	0	0	0	0	0

n= Frequency of the response PVD occurring within “x” time after a predictor PVD;

s= seconds; m= minutes

8 minutes after the occurrence of Delayed Termination. In general, there were 19 subjects who experienced PreTerm, and thirteen of these subjects (68%) also experienced some type of MultTrigs. There were 9 subjects who experienced DelTerm, and 7(78%) also experienced IneffTrigs.

Level of Sedation

Level of sedation ranged from unarousable (RASS = -5) to agitated (RASS= +2). Fifty percent of the RASS values were at the sedated levels (-3, -4, -5). Only one evaluation of the total RASS scores for 27 subjects was at the agitated level. Since the data were skewed to greater levels of sedation, a binomial categorization by subject was created based on the (RASS = -3 to -5; 56% of subjects) or awake (RASS= -2 to +2; 44% of subjects). Based on this broad sedation categorization, level of sedation did not affect the DI ($F(1, 25) = 1.33, p = 0.26$). In addition, there was no significant relationship between level of sedation (awake or deep sedation) and PVD type index (Ineffective Trigger Index) using ANOVA ($F(1, 25) = 0.005, p = 0.94$).

Discussion

PVD is a common event for mechanically ventilated patients in the ICU, however it is not frequently recognized by all clinicians. PVD can lead to unstable physiological states, patient discomfort, poor sleep quality and is associated with prolonged MV.^{2,3,5,6,7,8,9,11} There are few studies that have documented the types and frequency of PVD over time. Nurses need to be able to recognize PVD, such that interventions can be initiated. Therefore, the purpose of this study was to identify the types, frequency and patterns of PVD over time. A secondary purpose was to determine the effect of sedation level on PVD.

Subjects/Sample

Although the subjects were representative of the ICU population, this sample may differ from those in the general ICU population because specific ventilator modes were not studied (augmented pressure, increased pressure during inspiration and tube compensation) and only subjects with an ETT were enrolled. These modes may result in PVD as well, but its frequency remains unknown.

PVD Types

Patient ventilator dyssynchrony occurs frequently in critically ill, mechanically ventilated adults. This study found PVD types similar to those in published reports (IneffTrigg, DbITrig, Flow, PreTerm and DelTerm). However, the operational definitions for PreTerm and DelTerm differ between our study and others in that we use morphological definitions that are not bound by mathematical measures for Double Trigger, Premature and Delayed Termination. In addition, we evaluated for literature-supported variation of IneffTrigg, specifically Type 2,¹⁸ which other studies have not recently evaluated. However, this may complicate comparisons with other published work.

The scope of dyssynchrony types in this study vary from other cited works^{2,3,4,39} since this was an evaluation of all breaths during a longer study period than has been previously reported and a function of our coding scheme. Similar to other reports that looked at more than one type of PVD,^{2,4} IneffTrigg was the most common dyssynchrony in this study. We included a second, ‘non-classic’ type of IneffTrigg (Type 2)¹⁸ that has been less studied, but we found that it was more frequent in this sample than Type 1.

We found that Premature Termination was the second most common type of PVD. It appeared in two breath categories (a) PreTerm-Flow, and alone as (b) PreTerm. However, PreTerm (or short cycling) has not been common in prior studies. This may be due to shorter duration of observation in those works, our definition or, more likely from

the individually pre-set ventilator termination criteria on our subjects. In addition, previous studies have not described a combination of phase dyssynchrony types, such as Premature Termination and Flow Dyssynchrony occurring in the same breath cycle. However, the combination of two dyssynchronies occurring within the same breath cycle is theoretically possible. In the case of a PreTerm-Flow dyssynchronous breath, two phases of a mechanically ventilated breath are influenced: gas flow and cycling off.

Furthermore, PreTerm occurred with the phenomenon of Patient Gasp PVD during gas delivery. This combination may occur in a patient whose flow demand is greater than what is pre-set on the ventilator flow setting. He/she may be experiencing anxiety trying to adjust to the ventilator's gas flow causing a gasp during the inspiratory phase, thereby causing a longer neural inspiratory time to which the ventilator does not respond because of its predetermined cycle-off criteria. Additionally, PreTerm PVD was also combined with active multiple triggers in the same patient who experienced almost every breath as PreTerm-Flow. Theoretically, it is possible that more patient effort was generated to trigger a breath (reflected by the active trigger- a deeper Paw trace), and this caused neural inspiratory time to be longer, thereby influencing the development of PreTerm after the active trigger. Although double trigger has been identified in other studies as a common type of PVD,^{2,4,39} we identified a broader category (Multiple Trigger) to include double trigger as well three additional subtypes.

While multiple triggers were not prominent in this study, they were complicated with a variety of features. First, MultTrigs were combined with other underlying problems such as PreTerm-Flow dyssynchrony. It is probable that an increased respiratory drive is the common feature involved in MultTrigs, PreTerm and Flow PVD and this is why they are combined. This has not been documented in the literature to our knowledge. Unusual

Double Trigger had some traits of double trigger, but not the characteristic increase in the pressure trace associated with the second breath. This may have been related to a ventilator malfunction or a problem with the flow sensor, since the same subject had high flows that did not return to zero during exhalation at times. In addition, a new phenomenon to appreciate is the active MultTrig where a deeper negative pull on the Paw trace may indicate air hunger, an aggressive manifestation of increased patient demand, changing clinical status or discomfort. The underlying cause of the active triggered breath may be the presence of intrinsic PEEP from dynamic hyperinflation, influencing the patient to work harder to inhale. Perhaps early identification of this MultTrig morphology could alert clinicians to perform a focused assessment of the patient ventilator interaction. Last, we observed more than two breaths in succession without full exhalation after inhalation, such as three or four breaths in a row. Patients who manifest this type of MultTrig may be at risk for physiological consequences, (e.g. significant over-inflation, pressure induced lung injury, pneumothorax, interference with hemodynamics) and clinicians should monitor subjects closely for respiratory dynamics, patient factors that could promote stress and result in more PVD.

PVD Frequency

PVD occurs in the vast majority of mechanically ventilated patients, in addition 77% of our subjects experienced more than one type of PVD. The presence of multiple dyssynchronies occurred at a high percentage in our subjects in comparison to what has been reported in prior studies. Vignaux et al.³⁹ found that 22% of their sample had more than one type of PVD. The differences here may be explained by our longer study period and differences in sample characteristics and ventilation, Vignaux et al.³⁹ studied those on noninvasive MV with 55% of the sample being hypercapnic.

PVD was not associated w/ COPD. Similar to our study, de Wit et al.⁴ did not find that having COPD correlated with Ineffective Trigger. However, higher incidence of Ineffective Trigger has been found in patients with COPD in other studies.^{2,3,27} In comparing our study with others, one reason for the possible difference in PVD is that we had a smaller sample of COPD subjects (33%) than those who found an association (COPD= 44%³, 80%²⁷). Patients with COPD experience more dynamic hyperinflation, which may result in higher levels of PVD.

Although other studies have focused primarily on the medical ICU population,^{2,4} and a regional weaning center³ this study documented PVD in both medical and surgical subjects. Although the median DI between medical and surgical groups was not statistically significant, the amount of variation as exhibited by the median IQR for both groups was strikingly different. There were several subjects who had multiple categories of PVD and very high frequencies of PVD which may account for this wide dispersion of DI among medical and surgical subjects.

PVD Patterns

The suspected theoretical patterns of associated PVD types have been cited, but few studies have documented their presence for the predictor type Premature Termination and response type Multiple Triggers.²⁶ The predictor PVD type, Premature Termination, was followed by Multiple Triggers in this study, however only at a low occurrence rate. This could be attributed to the overall small number of MultTrigs found in our sample versus other studies who have found frequent Multiple Triggers. Also, the study by van de Graaff et al.³⁷ enrolled only surgical subjects, which differs from our mixture of medical and surgical subjects.

Our study has findings similar to those of other data-based studies in which the association of the predictor, Delayed Termination, with Ineffective Trigger was examined. While our study had very few samples of Delayed Termination breaths, there were no DelTerm breaths followed by an IneffTrig as the very next breath or up to the seventh next breath. The associations between DelTerm and IneffTrigs occurred at different time points, time 30 seconds (Type 1) and at time 2 minutes (Type 2). As time moves further away from the predictor PVD (Delayed Termination), it is more difficult to see how it could physiologically effect the generation of an Ineffective Trigger. This type of analysis may be the only one of its kind to demonstrate this and further research is needed to explore this association.

Level of Sedation and PVD

Deeper levels of sedation may lead to PVD as sedated patients may lose their respiratory drive and be unable to trigger the ventilator appropriately. This has been documented particularly during IneffTrigg.⁴ Although half of the subjects were deeply sedated and IneffTrigg was the most common type of PVD, we did not find similar results. This may be related to use of two broad categories (awake, deeply sedated), which may mask the effect of specific levels of sedation on PVD. Shorter time periods for analysis may be beneficial in further evaluation of this relationship.

Limitations

This is the first study that we are aware of that comprehensively identifies types of PVD in a cross section of subjects for up to a 90 minute time period. Hence, the results of PVD types, frequency and PVD patterns are unique to this study condition. The study duration may be a limitation to the study results, because not all factors could be controlled in the subject's environment that may have contributed to PVD or waveform

morphology changes, such as need for suctioning or alterations in the ventilator circuit. Notes were taken during the observation period and events that could influence waveform morphology were coded during waveform analysis. However these conditions may have resulted in a greater incidence of Unknown breaths in the form of artifact or other morphologies.

A second limitation is the use of three operational definitions (Double Trigger, PreTerm and DelTerm) in our coding scheme, that are somewhat different than those published in two other studies at this time.^{2,4} Careful comparison of these 3 PVD types in this study with those published in other reports should be considered. While authors^{2,4} have used mathematical definitions averaging over 30 breaths and calculating mean inspiratory and expiratory times to define PreTerm and DelTerm, the advantage of using a morphological coding scheme as done in our study is that it may be more clinically realistic for bedside assessment and onsite intervention.

While PI blinding was generally effective, some subjects were difficult to blind since their respiratory behaviors were dramatic and unique, potentially adding to coder bias. Finally, the use of a convenience sample may reduce generalizability to other ICU populations.

Conclusions

This study contributes new knowledge about the phenomena of PVD. This comprehensive study of PVD may assist clinicians to monitor patients for such conditions so that interventions can be made to improve the patient experience on the ventilator and reduce risk from ventilator complications. While physicians and respiratory therapists may be more adept at recognizing PVDs, nurses typically spend many more hours at the bedside with the opportunity to detect PVDs. In addition, this study documented that PVD

is present in medical and surgical ICU adult patients, and that PVD can be complex in its presentation (i.e. combined types of PVD in one breath cycle, possible associated patterns of PVD). As a result, clinicians should be familiar with alterations during each phase of a ventilated breath, so that interventions to correct triggering, flow delivery, cycling off or expiratory timing can be corrected. It is also important for clinicians to recognize that preset termination criteria needs to be uniquely determined for the individual and adjusted based on the graphic capabilities of the ventilator.

Pressure/time and flow/ time waveform analysis can detect PVD, yet requires a trained eye. Since the frequency of PVD is common, varied and complex, clinicians need to be knowledgeable regarding waveform analysis to detect ineffective patient ventilator interaction during different ventilator modes. This requires multifaceted knowledge of ventilator algorithms, respiratory physiology, PVD taxonomy and morphological changes on waveforms, as well as patient factors. Nurse educators and clinical experts should collaborate with respiratory therapists and pulmonary physicians to educate bedside nurses about waveform analysis for use in clinical care.

Future technology may provide continuous monitoring of PVD at the bedside, however, until sedation, PVD-related discomfort and PVD-related mechanical ventilation is optimized, complications will continue. Examples of future directions for nursing research include examining the patterns of PVD and their relationships to patient behaviors, investigating the use of waveform analysis to improve the use of sedative therapy, determining how nurses interpret and use ventilator graphics, and application of a continuous computerized PVD monitor to improve patient ventilator interaction.

ACKNOWLEDGMENTS

This research was supported by grants from the National Institute of Nursing Research (F31 NR009623 to KGM)

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