Ventilator Graphics: Analysis and Interpretation

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Approaches to Invasive Ventilation

1. Know the ventilator and disease pathology
2. Develop a specific strategy for the pathophysiology in each individual patient
3. Change the ventilatory strategy as the pathophysiology changes
4. Always strive to wean the patient off of ventilatory assistance
Listen to your patient!

Photo Courtesy of Sherry Courtney and Kaye Webber RRT
The Respiratory Equation of Motion

\[ \Delta \text{Pressure} = \text{Raw} \times \text{Flow} + \frac{\text{CL}}{\text{Volume}} \]

Airways \quad ET \text{ tube} \quad Lung \quad Chest Wall
What is Measured?

• Real-time waveforms of
  – Proximal Airway Pressure
  – Insp. / Expiratory Flow Rate
  – Insp. / Expiratory Tidal Volume

• Loops
  – Pressure / Volume
  – Flow / Volume
Primary Goals

• Early identification of processes in respiratory pathophysiology and changes in patient’s condition
• Optimize ventilator performance and fine-tuning the ventilator settings
• Determine the effectiveness of ventilation support
• Early detection of possible adverse effects of mechanical ventilation
• Minimizing the risk of ventilator-induced complications or ventilator malfunctioning
Scalar Waveforms
Loops
Phase Variables

A. Trigger: START
   Patient (assisted)- Flow, pressure, EaDi
   Machine (controlled)

B. Limit: TARGET
   Volume
   Pressure
   EaDi

C. Cycle: STOP
   Time
   Flow
   EaDi
Target variables

**Volume Ventilation**

**Pressure Ventilation**
Phase Variables- Flow

Pressure Control

Pressure Support

Inspiratory Time  0.8 s  
Flow Cycle 10%
MODES
Assist/Control (Controlled)
Assist Control (Assisted)
Synchronized Intermittent Ventilation (SIMV)

SIMV: Mandatory (patient or machine initiated Spontaneous Breaths)
SIMV with Spontaneous Pressure Supported Breaths
Patient-triggered ventilation was associated with a shorter duration of ventilation in patients than machine-triggered modes (p=0.0134; Greenough et al.)
Pressure Support Ventilation

CPAP / PSV

15 cmH2O Ppeak
0.0 mL Mand Vte
0.0 mL/kg Mand Vte/kg
6.7 mL/kg Spon Vte/kg
37 bpm Rate

Paw (cmH2O)
Flow (L/min)
Vt (mL)

-10 cmH2O PSV
-5 cmH2O PEEP
0.5 L/min Flow Trig
21 % FiO2
Pressure adjusted to maintain VT in the face of changing compliance.
Neurally Adjusted Ventilatory Assist

O₂ conc.: 37%
PEEP: 5 cmH₂O
NAVA level: 1.5 cmH₂O/μV

Additional settings:
- VTI: 22 ml
- VTe: 6.2 ml
- Leakage (%): 49
- Edi peak (μV): 12
- Edi min (μV): 2.8

Status:
- Admit patient
- NIV NAVA
- 11-30 12:02
- Ppeak (cmH₂O): 22
- PEEP (cmH₂O): 5
- RR (b/min): 50
- O₂ (%): 37
- Ti/Tot: 0.58
- MVe (l/min): 0.9
- Additional values:
  - ...
Airway Pressure Release Ventilation
Abnormalities

• Detection of air-leak
• Over-distension - Gas trapping
• Increased expiratory resistance
• Inspiratory time adjustment
• Airway obstruction
• Patient-ventilator dysynchrony
• Inadequate trigger sensitivity
• Inadequate PSV
• Poor Compliance
Air leak - Related to ET tubes or circuit
Air leak- Related to ET tubes or Circuit
Excessive Inspiratory Time

Inspiratory Time = 0.5 secs
Excessive Inspiratory Time

- Presence of inspiratory plateau
- Created when Inspiratory time exceeds the time constants of the lung or when active exhalation occurs
- May increase WOB and “Fighting” of the ventilator
- May increase intra-thoracic pressure compromising cardiovascular status
- May result in an insufficient expiratory time and gas trapping
- May cause hypercarbia
Excessive Inspiratory Time
Flow Synchronized Ventilation

- Aka “flow cycle” - allows patient to determine their own inspiration time by terminating the breath once a certain percentage of the peak inspiratory flow is met
- May improve preload and eliminate V/Q mismatching
- Improves patient/ventilator dys-synchrony
- May tremendously improve oxygenation and ventilation in spontaneously breathing patients
Flow Synchronized Ventilation
Before and After Flow Cycle Added
Figure 1  This illustrates the way the $V_T$ resets to zero when the flow crosses the zero line if the tidal volume is not at zero. The expired $V_T$ can then appear to become negative. This is because every time the flow crosses zero the tidal volume recording falsely resets to zero. This figure shows three parts. Part A shows a normal inspiratory and expiratory flow above and below the zero line with the tidal volume increasing and then decreasing. Part B shows a normal inspiratory flow pattern with normal inspiratory $V_T$. The expiratory flow starts and then stops after only a small $V_{Te}$. A small inspiratory flow then occurs and as the flow crosses zero the $V_T$ resets to zero. The vertical line marked X is not a true change in volume, it is just a resetting of the recording position. The remainder of the $V_{Te}$ then appears to be negative. It is enclosed in a box with a dotted outline. Part C shows exactly the same part of a recording as B, but here the $V_{Te}$ in the box has been moved and joined at the reset point to show that the $V_{Te}$ which appeared to be below the line was actually a normal expiratory volume curve.
Trigger Sensitivity- Appropriate Flow Trigger

**Pressure SIMV**

- **Peak Pressure (Ppeak):** 11 cmH2O
- **Mand Vte:** 23.6 mL
- **Mand Vte/kg:** 7.9 mL/kg
- **Spon Vte/kg:** 6.0 mL/kg
- **FiO2:** 21%

**Graphs:**
- **Paw (cmH2O):**
- **Flow (L/min):**
- **Vt (mL):**

**Additional Settings:**
- **Rate:** 20 bpm
- **Insp Pres:** 15 cmH2O
- **Insp Time:** 0.40 sec
- **PSV:** 8 cmH2O
- **PEEP:** 4 cmH2O
- **Flow Trig:** 0.5 L/min
- **FiO2:** 21%
Selecting the proper PSV level
Rise Time

• May improve laminar flow of delivered breath
• Assists in reducing pressure overshoot in pressure controlled and supported breaths
  – Increase (less aggressive flow) when:
    • Flow spikes are observed in initial peak flow
    • ETT “chatter” occurs
  – Decrease (more aggressive flow) when:
    • Compensating for leaks
    • Increased patient flow demand
    • Patient has gas trapping
Rise Time - Slow
Increased Expiratory Resistance

• Prolonged expiratory flow indicates an obstruction to exhalation and may be caused by obstruction of a large airway, bronchospasm, or secretions
Increased Expiratory Resistance

Normal Resistance

Elevated Resistance
Insufficient Expiratory Time

- Expiratory flow is unable to return to baseline prior to the initiation of the next mechanical breath
- Incomplete exhalation causes gas trapping, dynamic hyper-expansion and the development of intrinsic PEEP
- Can be fixed by decreasing I-time
Gas Trapping with Inappropriate Inspiratory Time

- Inspiratory Time 0.8 s
- Inspiratory Time 0.4 s
Forced Expiratory Flow
Airway Obstruction - Secretions

BEFORE SX
Airway Obstruction - Secretions

AFTER SX
Airway Obstruction-Secretions in Sensor
Stuff on Flow sensor
Bronchoconstriction
Bronchopulmonary Dysplasia

- Former 25 wk Preemie
- Ventilator dependent
- Severe respiratory distress with anxiety and following bronchodilators
- Bradycardia, cyanosis, hypoxia
- Requiring sedation and paralytics
Airway Obstruction- Tracheal Malacia
Newborn Infant with a viral infection
Vascular Compression

Normal heart:
- Esophagus
- Trachea
- Aorta

Double aortic arch:
- Esophagus
- Trachea
- Aorta

MRI image with an arrow pointing to the aortic arch.
Pressure Volume Curve
27 Wk Preemie; 850 grams

Compliance 0.3 mL/cm H2O
SIMV/PC  FiO2 0.80  RR 60  PIP 26  PEEP 6 Ti 0.3 sec
Tidal Volume: 6 mL/kg
ABG: 7.20 / 65 / 65 / 14
Case Progression
12 hrs post-surfactant

Compliance 1 mL/cm H2O
SIMV/PC  FiO2 0.50  RR 50  PIP 24  PEEP 6  Ti 0.3 sec
Tidal Volume: 20 mL/kg
ABG: 7.49 / 25 / 65 / 18
Volume Guarantee: Theory of Operation

- Once placed into VG modes, a pressure breath is delivered (PEEP+5cmH₂O).
- Compliance is calculated and the pressure for the next breath is determined.
- The next breath is delivered at 75% of the calculated pressure of the previous mandatory breath.
- Each subsequent mandatory VG breath will adjust pressure (~3cmH₂O) to deliver the preset Vₜ target.
- The Vₜ target is a “minimum” value, so patients can breath above this value.

During periods of crying, breathing hard or gasping, the spontaneous $V_T$ may exceed the set $V_T$. VG permits patients to take large breaths but does not augment pressure due to inbuilt safety features.

Volume Guarantee: Limitations
Limitations of volume ventilation
$V_T$ and Auto-PEEP Effects Related to Pause Time and Double-Cycling

DiBlasi et al, AARC Open Forum, AARC, 2012
Esophageal Pressure Monitoring
<table>
<thead>
<tr>
<th>Date/Time</th>
<th>CRS</th>
<th>CLung</th>
<th>CCW</th>
<th>Paw Plat</th>
<th>PTPPL at</th>
<th>PTP PEEP</th>
<th>PEEP</th>
<th>VT</th>
<th>FiO2</th>
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<tr>
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<td>22</td>
<td>89</td>
<td>42</td>
<td>18</td>
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<td>20</td>
<td>90</td>
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<td>20</td>
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<td>19</td>
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<td>0.8</td>
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<tr>
<td>2 (2 hour)</td>
<td>21</td>
<td>29</td>
<td>92</td>
<td>39</td>
<td>16</td>
<td>1</td>
<td>19</td>
<td>600</td>
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<tr>
<td>3 (24)</td>
<td>32</td>
<td>42</td>
<td>108-118</td>
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<td>2</td>
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<tr>
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