Recognizing Patient-Ventilator dyssynchrony

Using the ventilator screen (flow, volume, airway pressure)

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\[ \text{Pmus}_1 = \Delta V \times \text{Ers} + V' \times \text{Rrs} \]

\[ \text{Pel} = \Delta V_2 \times \text{Ers} \]

\[ \text{Pres} = V' \times \text{Rrs} \]

\[ \text{Paw} = \text{Pel} + \text{Pmus}_1 + \text{Paw} \]

\[ \text{Pres} = -V'_E \times \text{R} \]

\[ \text{Paw} = -\Delta V_2 \times \text{Ers} \]

\[ \text{Pel} = \text{Pmus}_1 - \text{Pmus}_E \]
Think the applied pressures as well as their directions and observe Paw, flow and volume.

\[
Paw + Pmus_I = ΔV \times Ers + V' \times Rrs
\]

**Positive values**
Pmus\(_I\), Pel above FRC, Pres (V'\(_I\))

**Negative values**
Pmus\(_E\), Pel below FRC, Pres (V'\(_E\))
Equation of motion with common modes of assisted mechanical ventilation

• Assist volume control
  (AVC, $V_T$ constant)

• Pressure support or pressure control
  (PS, PC, Pressure constant)
Equation of motion
Mechanical ventilation
Volume control

\[ P_{\text{ventilator}} + P_{\text{mus}} = V'xRs + VxErs \]

Dependent variable
Independent variables
Volume control
Inspiratory phase

To identify non-synchrony phenomena observe Paw
Equation of motion
Mechanical ventilation

Pressure control

\[ P_{\text{ventilator}} + P_{\text{mus}} = V'xRs + VxErs \]

Independent variable

Dependent variables
Pressure control/support
Inspiratory phase

To identify non-synchrony phenomena
observe flow (mainly)
and volume

Independent variable

Dependent variable

Dependent variable

Active Passive
During expiratory phase, independent of the mode, observe expiratory flow (not Paw) for dyssynchrony identification.

\[ \Delta P_{\text{aw}} \text{ during expiration} = \Delta V'_E \times R_{rs_{\text{circuit}}} \]

R_{rs_{\text{circuit}}} \approx 0

\[ \Delta V'_E \text{ mainly depends on } \Delta P_{\text{alv}} \]

Better signal in flow waveform
Patient-ventilator dyssynchrony

- Cycling of the ventilator is not in phase with patient’s effort
- The patient instantaneous ventilatory demands are not met by the gas delivered by the ventilator
- The ventilator assist is such that predisposes to apnea or periodic breathing (PB)

- Triggering delay
  - Ineffective efforts
  - Autotriggering
  - Entrainment (Reverse triggering)
  - Expiratory asynchrony

References:
Gilstrap and MacIntyre Am Rev Respir Crit Care Med 2013
Akoumianaki et al. Chest 2013
Do we need Pes?

- Flow (l/sec)
- Paw (cmH\textsubscript{2}O)
- Pes (cmH\textsubscript{2}O)

- Vent. rate = 12 b/min
- Fr = 33 b/min

Time (sec)

5 sec
Ventilator pressure

↑ driving pressure for $V'_I$

↓ driving pressure for $V'_E$

$P_{mus_I}$

$Pel$

Rapid decrease in $V'_E$

Rapid decrease in $V'_E$

Flow (l/sec)

Pes (cmH$_2$O)

Time (sec)

5 sec
During expiration:
Better signal in flow waveform

Flow (l/sec)

Paw (cmH\textsubscript{2}O)

Ineffective efforts

Ineffective efforts

Time

1 sec
Be careful!
These are not ineffective efforts.
Patient-ventilator dyssynchrony

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- Triggering delay
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Gilstrap and MacIntyre Am Rev Respir Crit Care Med 2013
Akoumianaki et al. Chest 2013
Absence of Paw/flow distortion before triggering

No dynamic hyperinflation

Alveolar pressure distortion
↑Triggering sensitivity
Patient-ventilator dyssynchrony

Cycling of the ventilator is not in phase with patient’s effort

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The ventilator assist is such that predisposes to apnea or periodic breathing (PB)

Triggers delay

Ineffective efforts

Autotriggering

Expiratory asynchrony

Entrainment

Gilstrap and MacIntyre Am Rev Respir Crit Care Med 2013
Akoumianaki et al. Chest 2013
Expiratory asynchrony is the inability of the ventilator to synchronize the end of mechanical inflation with the end of neural inspiration.
Expiratory asynchrony

Premature opening

Be careful!!
These are not ineffective efforts

\[ \text{Pel}(t) = \Delta \text{V}(t) \times \text{Ers} \]

Flow (l/sec)

Paw (cmH}_2\text{O})

Pmus (cmH}_2\text{O})

Valve opens

Risk of double triggering (during the delay time Pmus may trigger the ventilator again)

Expiratory time (sec)
Volume control: Double triggering (breath stacking)
Expiratory asynchrony

Delayed opening

Ineffective efforts may indicate expiratory asynchrony of delayed opening type

Risks:
- Triggering delay
- Ineffective efforts (since mechanical inflation extents into neural expiration)

In PS mode a sudden increase in Paw during inspiration is usually due to relaxation of inspiratory muscles (end of neural inspiration) and indicates expiratory asynchrony of delayed opening of the valve


\[ Pel(t) = \Delta V(t) \times E \]
In PS mode a sudden increase in Paw during inspiration is usually due to relaxation of inspiratory muscles (end of neural inspiration) and indicates expiratory asynchrony of delayed opening of the valve.

\[ \text{Pel}(t) = \Delta V(t) \times E \]

\[ \text{Pmus}_I(t) \]

_Prinianakis et al. Intensive Care Med 2008_
Volume control
Inspiratory phase

To identify non-synchrony phenomena observe Paw

<table>
<thead>
<tr>
<th>Independent variable</th>
<th>Dependent variable</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pmus (cmH$_2$O)</td>
<td>Paw (cmH$_2$O)</td>
</tr>
<tr>
<td>Flow (l/sec)</td>
<td>Time (sec)</td>
</tr>
</tbody>
</table>

**Inspiratory phase**

- **Volume control**
- **Passive**
- **Active**
Patient-ventilator dyssynchrony

Cycling of the ventilator is not in phase with patient’s effort

The patient instantaneous ventilatory demands are not met by the gas delivered by the ventilator

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- Triggering delay
- Ineffective efforts

- Expiratory asynchrony

- Autotriggering

- Entrainment (Reverse triggering)

Gilstrap and MacIntyre Am Rev Respir Crit Care Med 2013
Akoumianaki et al. Chest 2013
The ventilator breath triggers inspiratory effort (vagal feedback – cortical influence)

Entrainment (Reverse triggering) implies a resetting of the respiratory rhythm such that a fixed temporal relationship exists between the onset of inspiratory activity and the onset of a mechanical breath.

Simon et al. Am J Respir Crit Care Med 1999
Signs of inspiratory muscles contraction in the absence of patient triggered breaths with a fixed temporal relationship with the onset of mechanical breath.

Cycling of the ventilator is not in phase with patient’s effort

The patient instantaneous ventilatory demands are not met by the gas delivered by the ventilator

The ventilator assist is such that predisposes to apnea or periodic breathing (PB)

Triggering delay
Ineffective efforts

Expiratory asynchrony

Autotriggering
Entrainment

Gilstrap and MacIntyre Am Rev Respir Crit Care Med 2013
Akoumianaki et al. Chest 2013
Volume control

Negative relationship between Paw and Pmus

\[ P_{\text{ventilator}} + P_{\text{mus}} = V' \times R_s + V \times E_r \]

Patient’s effort

Nilsestuen and Hargett Respir Care 2005
Premature opening (Expiratory asynchrony)

Assist volume

Large drop in Pes (strong effort)

Demands are not met

Premature opening (Expiratory asynchrony)

PEEP
Demands are met

Demands may or may not be met

Look for clinical Signs of high drive
Expiratory muscle activity toward the end of expiration may indicate unmet demands.

Be careful! These are not ineffective efforts.
Breath stacking may also indicate unmet demands


Patient-ventilator dyssynchrony

Cycling of the ventilator is not in phase with patient’s effort

The patient instantaneous ventilatory demands are not met by the gas delivered by the ventilator

The ventilator assist is such that predisposes to apnea or periodic breathing (PB)

It is very common and underestimated PB increases morbidity (poor sleep)

Parthasarathy and Tobin Am J Respir Crit Care Med 2000;166:1423
Delisle, S. et al. Respir Care 2013;58:745-753
Alexopoulou et al. Intensive Care Med 2007;33:1139

Gilstrap and MacIntyre Am Rev Respir Crit Care Med 2013
Akoumianaki et al. Chest 2013
Stable

Paw ——— 0

Message:
Periodic breathing is produced by excessive assist (lowers PaCO₂ below apneic threshold)

Sleep quality is poor characterized by severe sleep fragmentation and low levels of deep sleep (REM and N3)
Think the applied pressures as well as their directions and observe Paw, flow and volume.

\[ P_{\text{mus}, 1} = \Delta V \times Ers + V' \times Rrs \]

\[ Pel = \Delta V_2 \times Ers \]

\[ Pel = \Delta V_1 \times Ers \]

\[ Paw = \text{Paw (Ventilator pressure)} \]

\[ Pres = V' \times Rrs \text{ (Resistive pressure)} \]

\[ Pres = -V'_E \times R \]

\[ Pel = -\Delta V \times Ers \]

\[ Paw + -P_{\text{mus}, E} \]

\[ \Delta V_1 \]

\[ \Delta V_2 \]
Which is the commonest cause of patient-ventilator dyssynchrony?
Dyssynchrony between patient and ventilator
With volume-control observe Paw for ineffective efforts during inflation

Assist volume control (constant flow)

Passive: Black
Active: Red

Flow (l/sec)

Paw (cmH$_2$O)

Pmus (cmH$_2$O)

Independent variable

Ineffective effort

Dependent variable

Ineffective effort

Data from Mitrouskka et al. Eur Respir J 1999;13:873
Be careful!
These are not ineffective efforts!

\[ P_{mus_E} \uparrow \]
\[ \uparrow \text{driving pressure for } V'_E \]
1. Consecutive inspiratory cycles
2. Expiratory time < 1s between cycles
3. Expiratory volume < 2 ml/kg of inspiratory volume of 1st cycle
4. Inspiratory time (Pressure modes) >120% set time
5. Final Volume >2 ml/kg PBW of set $V_T$

Independent of the mode, observe expiratory flow (not Paw) for ineffective efforts during expiration.

Paw during expiration is mainly affected by resistance of the circuit ($\approx 0$).
Autotriggering is the commonest cause of asynchrony during NIMV (most probably due to leaks)

Use of Ventilator with efficient leak compensation system
Abrupt increase in Paw toward the end of mechanical inflation indicates the end of neural inspiration.
Message:
Periodic breathing is produced by excessive assist (lowers PaCO₂ > apneic threshold)