Basic respiratory mechanics relevant for mechanical ventilation

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**Basics of respiratory mechanics important to mechanical ventilation**

- Pressure Difference
- Gas Flow
- Time
- Volume Change

**Compliance**

\[ C = \frac{\Delta V}{\Delta P} \]

**Airway Resistance**

Resistance is the amount of pressure required to deliver a given flow of gas and is expressed in terms of a change in pressure divided by flow.

\[ R = \frac{\Delta P}{\text{Flow}} \]

**Mechanical response to positive pressure application**

Active inspiration

\[ \text{Compliance: } C = \frac{V}{P} \quad (\text{L/cmH2O}) \]

Resistance: pressure - volume

\[ R = \frac{\Delta P}{V} \quad (\text{cmH2O/L/s}) \]

Equation of motion: \[ P = \frac{1}{C_{rs}} V + R_{rs} \dot{V} \]

Passive exhalation
Pressure – Flow – Time - Volume

\[ P = \left( \frac{1}{\text{Crs}} \right) \times V + \text{Rrs} \times V \]

\[ \Delta \text{Vol}_{\text{max}} = \Delta P \times \text{Crs} \]

Volume change requires time to take place. When a step change in pressure is applied, the instantaneous change in volume follows an exponential curve, which means that, formerly faster, it slows down progressively while it approaches the new equilibrium.

**Time constant: \( T = \text{Crs} \times \text{Rrs} \)**

Will pressure equilibrium be reached in the lungs?

- A: \( \text{Crs} = 1, \text{R} = 1 \)
- B: \( \text{Crs} = 2 (T = \text{R} \times 2\text{C}) \)
- C: \( \text{Crs} = 0.5 (T = \text{R} \times \frac{1}{2}\text{C}) \) (reduced inspiratory capacity to 0.5)
- D: \( \text{R} = 0.5 (T = \frac{1}{2}\text{R} \times \text{C}) \)
- E: \( \text{R} = 2 (T = 2\text{R} \times \text{C}) \)

Effect of varying time constants on the change in lung volume over time (with constant inflating pressure at the airway opening)

<table>
<thead>
<tr>
<th>Time constant</th>
<th>Description</th>
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<tbody>
<tr>
<td>( \text{Crs} = 1, \text{R} = 1 )</td>
<td>( T = \text{R} \times 2\text{C} )</td>
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Ventilators deliver gas to the lungs using positive pressure at a certain rate. The amount of gas delivered can be limited by time, pressure or volume. The duration can be cycled by time, pressure or flow.

Expiration flow waveform: normal vs pathologic

Premature flow termination during expiration = “gas trapping” = deadspace (\( V_d/V_t \)) will increase
Flow termination and auto-PEEP detection

Analysing time settings of the respiratory cycle
1) Too short Te → intrinsic PEEP
2) Unnecessary long Ti
1) Correct Te
2) Too short Ti

Optimizing tidal volume delivery at set Δ-pressure

Correction for Auto-PEEP
- Bronchodilator

Appropriate inspiratory time
Progressive increase in inspiratory time

Too short Ti will reduce delivered Vt

- unnecessary high
- PIP will be applied
- unnecessary high intrathoracic pressures

Too short Te will not allow to deliver max. possible Vt at given P

- will induce PEEPi
- increases the risk for hemodynamic instability

CAVE: you have to set Frequency and Ti (Control) or Ti and Te (TCPL)

Lucangelo U, Bernabe F, and Blanch L. Respir Care 2005; 50(1):55–65
**Proximal Airway Pressure**

**Alveolar Pressure**

*Look at the flow – time curve!*

**Cave!**

**Ti settings in presence of an endotracheal tube leak**

*The only solution in presence of an important leak: Look how the thorax moves*

**Who’s Watching the Patient?**

*Pierson, IN: Tobin, Principles and Practice of Critical Care Monitoring*

**Compliance ↓**

**Compliance ↑**

*Pressure Ventilation*

- Decreased Tidal Volume
- Increased Pressure

*Volume Ventilation*

- Increased Tidal Volume
- Decreased Pressure

*and do not forget, the time constant (T = Crs x Rrs) will change too!*

**Compliance decrease**

*Lucangeli U, Bernabe F, and Blanch L. Respir Care 2005;50(1):55– 65*

**Change in compliance after surfactant = change in time constant after surfactant**

*Kelly E Pediat Pulmonol 1993;15:225-30*
**Volume Guarantee: New Approaches in Volume Controlled Ventilation for Neonates.**


**To measure compliance and resistance - is it in the clinical setting important?**

\[ \text{Time constant: } T = \frac{C_{rs} \times R_{rs}}{\text{inflow}} \]

Use the flow curve for decision making about the settings for respiratory rate and duty cycle in the mechanical ventilator.

The saying “we ventilate at 40/min” or “with a Ti of 0.3” is a testimony of no understanding!

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**Pressure Control versus Pressure Support**

**Inspiratory time or cycle off criteria**

- Pressure Control
- Pressure Support

Flow
- Peak Flow
- Ti set
- Ti given by cycle off criteria

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**Pressure-Support and flow termination criteria**

The non synchronized patient during Pressure-Support (inappropriate end-inspiratory flow termination criteria)


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**Pressure-Support and flow termination criteria**

**Termination Sensitivity = Cycle-off Criteria**

- Peak Flow (100%)
- Ti set (max)
- Ti set (eff.)
- Leak
- Increase in RR, reduction in VT, increase in WOB

Nilsetuen J, Respir Care 2005.
What do airway pressures mean?

\[ P_{\text{alv}} = P_{\text{pl}} + P_{\text{tp}} \]

Where \( P_{\text{tp}} \) is transpulmonary pressure, \( P_{\text{alv}} \) is alveolar pressure, and \( P_{\text{pl}} \) is pleural pressure.

\[ P_{\text{tp}} = P_{\text{alv}} - P_{\text{pl}} \]

When airway resistance is nil (static condition):

\[ P_{\text{alv}} = P_{\text{pl}} + P_{\text{tp}} \]

\[ P_{\text{tp}} = P_{\text{aw}} \times \left[ \frac{E_L}{E_L + E_{cw}} \right] \]

\[ P_{\text{pl}} = P_{\text{aw}} \times \left[ \frac{E_{cw}}{E_L + E_{cw}} \right] \]
$P_{aw} = P_{pi} + P_{tp}$

when airway resistance is nil (static condition)

$P_{tp} = P_{aw} \times [E_{L} / (E_{L} + E_{cw})]$  
$P_{pi} = P_{aw} \times [E_{cw} / (E_{L} + E_{cw})]$  

In normal condition:  
$E_{L} \approx E_{cw}$  
$E_{cw}/E_{tot} = 0.5$  
$E_{L}/E_{tot} = 0.5$  
$P_{tp} \approx 50\%$ of $P_{aw}$ applied

In ARDS:  
$P_{tp} \approx 20$ to $80\%$ of $P_{aw}$ applied

In primary ARDS:  
Stiff lung, soft thorax  
$E_{L} > E_{cw}$ ($E_{L}/E_{tot} > 0.5$)  
$P_{tp} > 50\%$ of $P_{aw}$ applied

In secondary ARDS:  
Soft lung, stiff thorax  
$E_{L} < E_{cw}$ ($E_{L}/E_{tot} < 0.5$)  
$P_{tp} < 50\%$ of $P_{aw}$ applied

Elastic properties, compliance and FRC in neonates

Neonate chest wall compliance, $C_{W} = 3-6 \times C_{L}$, lung compliance tending to decrease FRC, functional residual capacity

By 9-12 months $C_{W} = C_{L}$

In infant RDS (HMD):  
Stiff lung, very soft thorax  
$E_{L} \gg E_{cw}$ ($E_{L}/E_{tot} \gg 0.5$)  
$P_{tp} \gg 50\%$ of $P_{aw}$ applied

Elastic properties, compliance and FRC in neonates

Neonate chest wall compliance, $C_{W} = 3-6 \times C_{L}$, lung compliance tending to decrease FRC, functional residual capacity

By 9-12 months $C_{W} = C_{L}$

Dynamic FRC in awake, spontaneously ventilating infants is maintained near values seen in older children and adults because of:
1. continued diaphragmatic activity in early expiratory phase
2. intrinsic PEEP (relative tachypnea with start of inspiration before end of preceding expiration)
3. sustained tonic activity of inspiratory muscles (incl. diaphragma) (probably most important)

By 1 year of age, relaxed end-expiratory volume predominates

Pplat = P_{plv};  
P_{plv} = Transpulmonary Pressure +15 cm H_{2}O

Stiff chest wall

transpulmonary pressure = 15 cm H_{2}O

P_{plv} 30 cm H_{2}O

+15 cm H_{2}O

Stiff chest wall
Pplat = Ppalv; Pplat = Transpulmonary Pressure?

transpulmonary pressure = 45 cm H₂O

PCV 20 cm H₂O
PEEP 10 cm H₂O; Pplat 30 cm H₂O

Active inspiratory effort

Risk of VILI may be different with the same Pplat

Pressure – Flow – Time – Volume

The ventilator display can help us....

but we still have to decide about respiratory rate, tidal volumes, pressure settings …

… that have to be adapted to the patients respiratory mechanics

Avoid ventilation out of control!