Mechanical Ventilation: How to interpret the pressures?

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Mechanical Ventilators

- Ventilators need a high pressure source and deliver gas under pressure
- The pressure source is usually the wall pressure or a pressurized tank of compressed gas.
- Small portable vents utilize their own turbines to generate pressure.
Mechanical Ventilators monitor the pressure of the Volume they deliver.
Why pressure is needed for ventilating the chest?

• Pressure is force
• Two main forces oppose the entry of gas in the chest.
  • To counteract these forces, pressure is needed
• One force is the resistance of the tubings and the airways to airflow
• The other force is the elastic recoil of the lung
What makes pressure becoming elevated?

• The quantity of volume which is delivered

• The resistance of the tubings and airway (eg asthma, obstructive airway, secretions)

• The elasticity of the lung (eg atelectasis, pneumothorax, fibrosis) and its size (the smaller the lung the higher the pressure for a given volume)
Respiratory Mechanics:

• Resistance $\rightarrow$ Resistive Pressure
• Elastic Recoil (Compliance, Elastance) $\rightarrow$ Elastic Pressure
Mechanical Ventilation

• The ventilator can deliver a fixed volume, set by the clinician. The mode is called *volume-controlled ventilation*
Mechanical Ventilation

• The ventilator can deliver a fixed pressure set by the clinician. The mode is called pressure-controlled ventilation
Mechanical Ventilation

• The ventilator can deliver a fixed volume, set by the clinician. The mode is called volume-controlled ventilation

• The pressure resulting from the insufflation of this volume depends on
  – The volume
  – The resistance
  – The elasticity
Volume controlled Ventilation = Waveforms

In a passive patient, this is displayed and monitored on the screen at every breath.
Volume controlled Ventilation (square flow)

Pressure

Flow

Peak pressure

Plateau pressure

End Inspiratory Pause: 0.2sec

INSP
Flow is ‘positive’

EXP
Flow is ‘negative’

In a passive patient, this is displayed and monitored on the screen at every breath
How can we explain the positive pressure?

• Pressure means force
• Force opposing entrance of gas in the lungs
• One force is called resistance and is related to the friction of molecules against tubes and airways (it exists only in dynamic condition, i.e. with flow)
• One force is called elastance and is due to the elastic recoil of the system (better measured in static conditions, i.e. without flow)
The plateau pressure is obtained by the pause and allow to measure respiratory mechanics. It acts as a Pulmonary Function Test.
Volume or Flow controlled

Pressure

Flow

Presistive
Peelastic
Volume or Flow controlled

High resistance
($\gg 10 \text{ cm H}_2\text{O}$)
Volume or Flow controlled

High elastance
(= low compliance)
(>>15 cmH2O)
Volume or Flow controlled

Pressure

Flow

High driving pressure (>>15 cmH2O)

ARDS
Driving pressure $> 15$ cmH2O is at risk of injury and trauma for the lung.
The pause allows to measure the alveolar pressure (= plateau)
The plateau pressure is the maximum alveolar pressure. P$_{\text{vent}}$ = P$_{\text{alv}}$ = P$_{\text{plateau}}$. 

**Diagram:**
- **Pressure**
- **Flow**
Max Alveolar pressure > 30 cmH2O is at risk of injury and trauma for the lung

Plateau = Palv > 30

ARDS
The alveolar pressure is also influenced by the chest wall and the pleural pressure. Usually the chest wall plays a small part. When it increases the plateau pressure, this does not distend the lungs.

To measure pleural pressure an esophageal catheter is needed.

High pleural pressure may be present in obesity, abdominal compartment and ARDS.
Resistance

• Resistive force corresponds to a pressure dissipation = this pressure never reaches the lung
• The resistive pressure does not expose the patient to any risk
Volume or Flow controlled

Pressure

Flow

High resistance
($>>10$ cm H$_2$O)
What makes pressure become elevated?

- The quantity of volume which is delivered
- The resistance of the tubings and airway (e.g., asthma, obstructive airway, secretions)
- The elasticity of the lung (e.g., atelectasis, pneumothorax, fibrosis) and its size (the smaller the lung the higher the pressure for a given volume)
VT = 500 ml

VT 500 ml (ZEEP)

Pplat = 10 cmH2O

Compliance = 500 ml / 10 cmH2O
= 50 ml/cmH2O
Pplat = 20 cmH2O

VT 500 ml (ZEEP)
Selective intubation

New compliance = 500 ml/20 cmH2O
= 25 ml/cmH2O
ARDS: “baby lung”

- Low compliance in ARDS: small lung not stiff lung

Gattinoni L and Pesenti A. The concept of « baby lung » ICM 2005
What about expiration?

Expiration is passive
The lung needs a certain time to exhale
Time constant for expiration

\[ V = V_0 e^{-t/\tau} \]

\[ \tau = R \times C \]

Exponential decay

\[ 4\tau = 98\% \ V_0 \]
Auto-PEEP is detected by an expiratory flow which does not have time to return to zero.

![Graphs showing flow, volume, and pressure changes with different PEEP levels.](image-url)
Auto-PEEP is measured by an end-expiratory hold, available on all ventilators. In this example it was 15 cmH2O and was totally hidden.
Auto-PEEP

• Is more frequent in COPD, emphysema, asthma
• Has the same hemodynamic consequences than external PEEP or risk of barotrauma
• Is dependent on the amount of tidal volume and minute ventilation
• Reducing Vt and VE always reduce auto-PEEP
• It may also be reduced by longer expiratory time
Conclusion (I)

• The only pressure at risk for the patient is the elastic pressure
• The higher the elastic pressure (plateau and driving pressure) the smaller is the open or ventilated lung
Conclusion (II)

• Plateau pressure higher than 30 cmH2O or driving pressure higher than 15 cmH2O exposes the lungs to high risk of injury and impose strain on the right ventricle.

• Lower pressures may be safer (no safe threshold).

• These high pressures may impose to reduce Vt and/or PEEP.
Conclusion (III)

• The difference between peak and plateau is the resistance (resistive pressure = tube, secretions)
• increased elastance and elastic pressure = atelectasis, ARDS, pneumothorax
• During volume control, set a plateau of 0.2 to 0.3 sec
• High elastic pressure may impose to reduce VT (driving and plateau) and/or PEEP (plateau)
Conclusion (IV)

- Auto-PEEP is not measured by the ventilator
- It is detected on the expiratory flow curve
- It is measured by an end-expiratory hold maneuver on the ventilator
- It has the same effects than set PEEP