Initiation and Management of Airway Pressure Release Ventilation (APRV)

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All three of these techniques increase the mean airway pressure and provide for alveolar stability.

- **↑ pressure**
- **↑ inspiratory time**
- **↓ expiratory time**
• With increased mean airway pressure and improved alveolar stability there is improvement in ventilation and perfusion matching
  • Improved gas exchange
  • Reduced deadspace ventilation
    – More efficient ventilation with lower $V_T / V_E$
• With increased mean airway pressure and improved alveolar stability there is a presumed or theoretical decrease in the incidence of VILI
4. Alveoli can also be recruited by allowing the patient to spontaneously breathe
   - Ventilation of a patient with a relaxed diaphragm is preferentially delivered to the anterior portions of the lung
     • This produces regional extremes in V/Q matching with some lung units exhibiting deadspace ventilation and some units exhibiting shunting
4. Alveoli can also be recruited by allowing the patient to spontaneously breath
   – During diaphragmatic contraction, volume is more uniformly delivered throughout the lung and especially to the dorsal lung regions
   – In addition, pleural pressure will decrease, thereby reducing the forces that an inspiratory volume will have to overcome in order to recruit an alveoli
<table>
<thead>
<tr>
<th>mode</th>
<th>volume A/C</th>
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<tbody>
<tr>
<td>FiO₂</td>
<td>1.0</td>
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<tr>
<td>Flow</td>
<td>90</td>
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<tr>
<td>PIP</td>
<td>38</td>
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<tr>
<td>RR</td>
<td>35</td>
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<tr>
<td>PP</td>
<td>32</td>
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<tr>
<td>Vₜ</td>
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<td>MAP</td>
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<tr>
<td>Vₑ</td>
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<td>PEEP</td>
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<td>pH</td>
<td>7.18</td>
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<tr>
<td>O₂</td>
<td>51</td>
</tr>
<tr>
<td>CO₂</td>
<td>72</td>
</tr>
<tr>
<td>SaO₂</td>
<td>84%</td>
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</table>
• If APRV is used as a “rescue” mode of ventilation or a “last resort” there will be a delay in the alveolar recruitment seen with this mode of ventilation

• Two things occur because of difficulty in recruiting collapsed and flooded alveoli
  
  1. CO$_2$ elimination will diminish and the PaCO$_2$ will increase
     
     – The minute ventilation will be dramatically decreased at the initial switch from volume ventilation to APRV

  2. The expected decrease in FiO$_2$ or pressure may not be realized
     
     – Once the collapsed alveoli are re-recruited the blood gases should normalize

• As a result APRV should be initiated early in the course of acute lung injury
  
  – Within 4-8 hours of LPS failure
**P_{HIGH}**

**P_{LOW}**

**T_{HIGH}**

**T_{LOW}**

**ventilation**

**mode** | **volume A/C**
---|---
FiO$_2$ | 1.0
Flow | 90
PIP | 38
RR | 35
PP | 32
V$_T$ | 420
MAP | 23
V$_E$ | 14.7
PEEP | 15
pH | 7.08
O$_2$ | 51
CO$_2$ | 82
SaO$_2$ | 84%
### Table: Ventilation Parameters

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
<th>Unit</th>
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**Oxygenation**

- **P<sub>HIGH</sub>**
- **P<sub>LOW</sub>**
- **T<sub>HIGH</sub>**
- **T<sub>LOW</sub>**
• The principles of VILI (FiO₂ toxicity, volutrauma & atelectrauma) have NOT changed and are still applicable despite the change in mode.
• \( \text{FiO}_2 \leq 0.60 \)
• \( V_T \leq 6 \text{ ml/kg IBW} \)
• Prevent RACE injury with appropriate air trapping

**Oxygenation**

**Ventilation**
- **P** _HIGH_:
- **P** _LOW_:
- **T** _HIGH_:
- **T** _LOW_:

**ventilation**

**oxygenation**

- FiO$_2$ ≤ 0.60
- $V_T$ ≤ 6 ml/kg IBW
- Prevent RACE injury with appropriate air trapping
  - +
  - If hypoxic, generate a mPaw ≥ 5cmH$_2$O than mPaw on LPS
- Generate a $V_E$ sufficient to maintain adequate ventilation
• The $P_{\text{HIGH}}$ should be set at 30–35 cmH₂O initially
  – Promotes alveolar recruitment by generating a sufficient mPaw
  – Promotes an adequate change in pressure ($\Delta P$) to generate a release volume

• An attempt to titrate the $P_{H}$ to $\leq 30$ cmH₂O should be made as soon as compliance improves ($\uparrow$ release volume)
• The $T_{\text{HIGH}}$ should be set at 3.0-3.5 sec initially
  – Promotes alveolar recruitment by generating a sufficient $m\text{Paw}$
  – Promotes alveolar recruitment by generating a sufficient inspiratory time constant
    • Average inspiratory time constant for ARDS is 0.7 sec
    • To achieve 100% aeration/recruitment requires 5 time constants
  – Promotes an adequate RR to generate a sufficient minute volume
• The $T_{\text{HIGH}}$ should be set at 3.0-3.5 sec initially
  – A $T_{H}$ of 3.0-3.5 sec will mean a release rate of 14-16 will be the initial setting
  
  – An attempt to titrate the $T_{H}$ to a higher value should be made as soon as deadspace improves ($\downarrow \text{CO}_2$)
• The $P_{LOW}$ should be set at 0-5 cmH$_2$O initially
  – $P_L$ is usually set at or near ambient pressure (0 cmH$_2$O) to generate an adequate $\Delta P$
• The magnitude of the $\Delta P$ will determine the release volume
• The magnitude of the $\Delta P$ will also determine the expiratory flow
  – A higher $\Delta P$ will accelerate expiratory flow
• The $P_{LOW}$ should be set at 0-5 cmH$_2$O initially
  
  – The $P_L$ may be set > 0 cmH$_2$O if it is felt that compliance is such that additional FRC is needed to recruit alveoli
  
  – If the $T_{LOW}$, as explained on subsequent slides, requires a parameter setting < 0.7 sec, the expiratory time constant and compliance are such that the $P_L$ greater than 0 cmH$_2$O may be required
Variable expiratory flow and time constants

- The expiratory flow exits from portions of the lung at different flow rates or time constants.

- A diseased, or non-compliant, lung unit has a relatively strong recoil on exhalation.

- The flow exiting this non-compliant lung unit will thus be relatively fast and have a short time constant.
• Variable expiratory flow and time constants
  – The expiratory flow exits from portions of the lung at different flow rates or time constants

• A healthy, or compliant, lung unit has a normal elastic recoil

• The flow exiting the compliant lung unit will be comparatively slower and have a longer time constant
• Variable expiratory flow and time constants
  – The time frame, or $T_{\text{LOW}}$, required to trap an appropriate amount of flow in a healthy lung is therefore different than the $T_{\text{LOW}}$ required to trap the appropriate amount of flow in a diseased lung
  
• In the example to the right, the $T_{\text{LOW}}$ is set to trap the appropriate expiratory flow from a healthy lung unit
Variable expiratory flow and time constants

- The time frame, or $T_{LOW}$, required to trap an appropriate amount of flow in a healthy lung is therefore different than the $T_{LOW}$ required to trap the appropriate amount of flow in a diseased lung.

- If the $T_{LOW}$ is set to trap flow exiting from the healthy lung unit, then the diseased lung unit will completely empty.
• Variable expiratory flow and time constants
  – If gas exchange is not improving as expected and the $T_L$ is required to be $< 0.7 \text{ sec}$, then the use of $P_L > 5 \text{ cmH}_2\text{O}$ may be warranted to maintain alveolar recruitment.
• The $T_{\text{LOW}}$ should be set at 0.8 sec initially

• However, the $T_{L}$ is more precisely set to prevent complete emptying of the lung at end-expiration
  – Requires analysis of the end-expiratory flow and subsequent precision of the ventilator setting
• The $T_L$ is more precisely set to prevent complete emptying of the lung at end-expiration
  – Identify the peak expiratory flow rate (in this case 80 LPM)
  – Set the $T_L$ so that the expiration terminates at a flow approximately 25-50% of the peak expiratory flow rate (in this case between 20-40 LPM)
• The $T_L$ is more precisely set to prevent complete emptying of the lung at end-expiration
  – Upon release and opening of the exhalation valve, the compressible volume flows rapidly out of the system
• The $T_L$ is more precisely set to prevent complete emptying of the lung at end-expiration
  – The point at which the expiratory flow separates should be identified as the peak expiratory flow
Careful observation of the $T_H$ and $T_L$ is warranted when the patient is spontaneously breathing

- Some ventilators will alter the set times to synchronize the pressure changes with the patient spontaneous respiratory efforts
- The implication is a changing $T_L$ that may become inappropriate if the patient were to cease spontaneous efforts
• Correction of ABG abnormalities
  – It is important to understand that when managing cyclic ventilation, those parameters that correct for ventilation and those parameters that correct for oxygenation are typically decoupled and do not effect each other
  – However, the parameters that correct for ventilation and oxygenation in APRV are NOT decoupled and DO effect each other, often in a competing way
• Correction of PaCO₂
  – The fundamentals of correcting PaCO₂ in APRV is no different than in any other mode…..you need to adjust minute ventilation OR increase/decrease Vₜ or increase/decrease RR

  **If CO₂ is high**

  ![Diagram showing adjustments for high CO₂](Diagram showing adjustments for high CO₂)

  - **↑PHIGH**
  - **↓PLOW**
  - **↓T_HIGH**
  - **↑T_LOW**

  **Unintended consequence**

  - **↑mPaw**
  - **↑O₂**
  - **↓mPaw**
  - **↓O₂**
  - **↓mPaw**
  - **↓O₂**
  - **↓mPaw**
  - **↓O₂**
• Correction of PaO\textsubscript{2}
  – The fundamentals of correcting PaO\textsubscript{2} in APRV is no different than in any other mode.....you need to increase or decrease the MAP

- If O\textsubscript{2} is low
  - \( P_{HIGH} \)
  - \( P_{LOW} \)
  - \( T_{HIGH} \)
  - \( T_{LOW} \)

Unintended consequence

- \( \uparrow \) volume
- \( \downarrow \) CO\textsubscript{2}
- \( \downarrow \) volume
- \( \uparrow \) CO\textsubscript{2}
- \( \uparrow \) RR
- \( \uparrow \) CO\textsubscript{2}
- \( \downarrow \) volume
- \( \uparrow \) CO\textsubscript{2}
The clinician should be observant for any changes in compliance that may require a coinciding change to the $P_H$.

In addition, the clinician must also be observant for changes in either the compliance or the $P_H$ that would result in a change to the lung volume:

- When there is a change in lung volume there may be a consequential change to the expiratory time constant.
- This change in the expiratory time constant may require a different $T_L$ to assure the termination of expiratory flow.
• Pressure support
  – Pressure support may be added in support and augmentation of spontaneous tidal volumes

• However, the total pressure during a spontaneous breath is mathematically calculated by adding the PS to the $P_L$
  – This is done even if the spontaneous breath occurs during the $P_H$
  – The actual PS applied can be calculated in this fashion

$PS \text{ applied} = (PS + P_L) - P_H$

$PS \text{ applied} = 15 \text{ cmH}_2\text{O}$
• High **LUNG** volume
  – Excessive lung volume leads to alveolar overdistension and is the result of
    • $P_H$ is too high $\rightarrow$ decrease $P_H$
    • $P_L$ is too high $\rightarrow$ decrease $P_L$
    • $T_L$ is too short $\rightarrow$ increase $T_L$
• High **LUNG** volume
  – Excessive lung volume leads to alveolar overdistension resulting in a number of clinical manifestations
    • Increased RV afterload
    • Increased PVR
    • Decreased CO/BP

• A decrease in release volume as the lung volume approaches total lung capacity

• Unexplained deterioration in gas exchange
  – Increased deadspace ventilation

• The patient will exhibit abdominal accessory muscle use during spontaneous ventilation in an attempt to decrease lung volume during exhalation
• Low **LUNG** volume

– A low lung volume will result in alveoli that remain derecruited and at risk for atelectrauma

– Alveolar derecruitment will result in a number of clinical manifestations
  • Deterioration (or lack of improvement) in gas exchange
  • Decrease (or lack of improvement) in release volume
  • Use of the inspiratory accessory muscles in an attempt to recruit alveoli upon spontaneous inspiration
• Low LUNG volume
  – A low lung volume will result in alveoli that remain derecruited and at risk for atelectrauma
  • \( P_H \text{ is too low } \rightarrow \text{ increase } P_H \)
  • \( P_L \text{ is too low } \rightarrow \text{ increase } P_L \)
  • \( T_H \text{ is too short } \rightarrow \text{ increase } T_H \text{ (decrease RR)} \)
  • \( T_L \text{ is too long } \rightarrow \text{ decrease } T_L \)
• As the patient improves the clinician will see a gradual rise in $V_T$
  – Lower the $P_H$ in a gradual fashion
  – As the $P_H$ is decreased the $T_H$ should be extended
    • Extending the $T_H$ maintains the mean airway pressure and alveolar recruitment
    • It also allows for more spontaneous respirations
    • This is called “drop and stretch”

• This progression can evolve towards traditional CPAP where the $P_H$ is decreased to 8-5 cmH$_2$O and the $T_H$ is stretched to allow only a very few releases
• For any decrease in $P_H$ it is not necessary to increase the $T_H$
  – The patient must be able to support the minute ventilation necessary for gas exchange
  – In patients for whom the $P_H$ is adjusted solely for $CO_2$ management it is not necessary to adjust the $T_H$ coincidingly
- Patients with obstructive disease may require extremely long release times, or $T_L$

- Additional applied air trapping may be detrimental to the patient
- To minimize this risk the $T_L$ should still be set at 25-50% of the PEFR but will have to be extended to do so
- As the $T_L$ is extended the trend is more towards cyclic ventilation
• Patient populations for which an elevated mPaw may be detrimental, this mode may not be tolerated
  – Neurosurgical patients for whom limitation of intracranial pressure is of central importance
  – Patients with an active air leak will not tolerate this mode because the increased mPaw and increased $T_H$ will exacerbate the air leak

• Patients with the inability to tolerate permissive hypercapnea should not be managed with APRV