A Practical Guide for Adaptive Pressure Ventilation (APV) in Preterm Infants<32 weeks’ GA using Volume Targeting

Table of abbreviations and definition of terms

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<td>PEEP</td>
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<td>Peak Inspiratory Pressure</td>
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<td>Target tidal volume set on the ventilator, ml</td>
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Introduction

The rationale for volume targeting

The major disadvantage of pressure-limited ventilation is the variance in tidal volume (VT) with changes in lung compliance. Rapid changes in lung compliance often occur in the immediate postnatal period as a result of clearing of lung fluid, recruitment of lung volume and surfactant replacement therapy. Rapid improvement in lung compliance while on pressure-limited ventilation can lead to delivery of excessively large VT causing lung injury (volutrama) and inadvertent hyperventilation leading to hypocapnia and transient reduction in cerebral blood flow [1]. Experimental animal studies clearly show that excessive VT, not pressure by itself, is primarily responsible for lung injury [2, 3]. In addition, insufficient VT can
lead to atelectasis (atelectotrauma), increased work of breathing, increased oxygen requirements, or inefficient gas exchange due to increased dead space to $V_T$ ratio \[4\]. This leads to hypercapnea, loss of cerebral blood flow autoregulation and increased cerebral blood flow. Insufficient $V_T$ at any pressure can develop because of decrease in lung compliance, increase in airway resistance, air trapping or decrease in spontaneous respiratory effort. Thus a ventilator mode that decreases the amount of variation in tidal volume has the potential to decrease ventilator induced lung injury.

Various ventilator devices provide similar modes of volume-targeted ventilation but carry different proprietary nomenclature dependent on the manufacturer. The terms and abbreviations in these guidelines will be specific to the Hamilton G5 ventilator which is the primary ventilator used in the Riley NICU. However, Bird ventilators are still being used in the Riley NICU but only in conjunction with the jet ventilator because they are both able to run off a single blender. With every mode of ventilation in the Hamilton G5 ventilator, unlimited flow is available to the baby. Therefore, in actively breathing patients, flow starvation is minimized as flow may be increased with increased patient demand.

**Adaptive Pressure Ventilation modes (APV)**

APV mode is an automatic feedback loop mode of ventilation that adjusts inspiratory pressure to maintain a target expiratory tidal volume. A similar feedback loop mode of ventilation is referred to in the literature as “volume guarantee” ventilation and is the most thoroughly studied mode of volume-targeted ventilation\[5\]. Continuous reassessment of the patient’s dynamic lung status is designed to guarantee a set tidal volume while preventing atelectotrauma or volutrauma as the patient’s lung compliance changes. However, if the whole lung is not recruited, the open, most compliant portions of the lung can become over-distended while the atelectatic portions remain collapsed. It is especially important to maintain lung recruitment with APV to avoid over-distension of the more compliant portions of the lung with the full desired tidal volume \[5, 6\].

In APV the operator sets the target $V_T$, rate, PEEP, and the high pressure alarm limit. The parameters needed for APV are measured breath by breath. The adaptive controller in the ventilator compares the exhaled $V_T$ to the target $V_T$ and adjusts the PIP to the lowest level possible to achieve the target $V_T$. If the patient’s actual tidal volume is equal to the target $V_T$, APV maintains the PIP. If the monitored tidal volume is higher or lower than the target volume, PIP is gradually titrated as much as 2 cmH2O per breath to attain the target level. The range of PIP needed to achieve the target volume will vary from the minimal pressure delivered which is 3 cmH2O above PEEP to the high pressure alarm limit minus 10 cmH2O.

There is a constant pressure during inspiration with variable flow. The actual breath delivered is similar to a conventional pressure control breath except that the exhaled tidal volume is targeted rather than the pressure. Exhaled tidal volumes are targeted because they more accurately reflect the volume going into the patient’s lung compared to inspiratory volumes which can be quite large depending on the % leak around the endotracheal tube\[7, 8\].

The ventilator should wean the PIP as the baby’s compliance improves. However, if the baby becomes agitated and temporarily has increased respiratory effort without an improvement in lung compliance,
the ventilator will think that it does not need to deliver as much PIP to maintain the exhaled tidal volume and will under support the baby. In this case the infant will become more tachypneic and increase the work of breathing even further.

1. In APVcmv mode, all breaths triggered by the patient will be a full volume targeted breath. Controlled mandatory ventilation (CMV) is the same method of ventilation as the assist control mode in the Avea ventilator. The rate is simply a backup rate in case the patient is apneic. There is no pressure support in CMV mode. All machine breaths are time cycled, meaning each breath ends when the set inspiratory time has elapsed. The inability of the patient to flow-cycle and terminate their breaths can lead to breath-stacking in a tachypneic baby due to the set inspiratory time not allowing enough time for exhalation. Patients can be fully supported in this mode. A benefit of this mode is that the ventilator automatically adjusts and gives less support as the patient improves clinically. This feature has been referred to as “self weaning.” See weaning and trouble-shooting section for more detail.

2. In APVsimv mode, synchronized machine breaths are given at a set rate and are volume targeted. If the baby is breathing over the set rate, those additional breaths are pressure supported. These spontaneous pressure support breaths allow the infant to sigh, or obtain a larger breath than the machine breath delivers. The pressure supported breaths are flow cycled by the patient, meaning the patient may terminate the breath before the set time limit (both inspiration and exhalation are synchronized to the infant’s effort). All machine breaths are time cycled, meaning those breaths end when the set inspiratory time has elapsed.

Advantages of APV mode

1. Through the automatic regulation of the inspiratory pressure and flow, the set target volume is achieved with the lowest pressure possible.

2. The ventilator titrates peak inspiratory pressure between each breath to maintain a consistent exhaled tidal volume.

3. PIP automatically decreases as lung function improves while maintaining a target tidal volume (self-wean).

Disadvantages/Considerations of APV mode

1. For effective ventilation, the ventilator must measure accurate exhaled tidal volumes. Exhaled tidal volumes are not reliable with an air leak of more than 40%.

2. The ventilator may not adequately support a baby with increased work of breathing or tachypnea.
Algorithm for APV ventilation – A Practical Guide

1. APVcmv mode: The operator sets:

   Initial settings:

PEEP: Must be sufficient to distribute the tidal volume evenly into an optimally aerated lung. The range is generally 5-10 cm H$_2$O. Optimal peep should be tailored to the lung disease and should be at a level above derecruitment but below over expansion (depicted as “B” in the graph below). To determine the optimal PEEP, the patient needs to be physically assessed and the following should be monitored:

- Work of breathing
- Oxygen requirement
- Chest x-ray, especially if the FiO2 remains high or weans to less than 30%
- Pressure-volume loops

The patient should also be reassessed frequently once support is initiated and as compliance improves.

![Figure 1: Tidal volume target](image)

**Tidal volume target:** The suggested initial tidal volume settings are listed in the table below. The smallest infants need larger tidal volume to compensate for the dead space of the flow sensor.

<table>
<thead>
<tr>
<th>Clinical Situation</th>
<th>Tidal Volume</th>
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<tbody>
<tr>
<td>Preterm infant with RDS, &gt;2000 grams</td>
<td>4 ml/kg</td>
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<tr>
<td>Preterm infant with RDS, 700-1500 grams</td>
<td>4-5 ml/kg</td>
</tr>
<tr>
<td>Preterm infant with RDS, &lt;700 grams</td>
<td>5-6 ml/kg</td>
</tr>
<tr>
<td>Preterm infant with BPD</td>
<td>5-7 ml/kg</td>
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Table adapted from Sant’Anna, et al. Developing a neonatal unit ventilation protocol for the preterm baby. [9]
**Rate (f):** Initial rate of 30-40 to provide an effective back up rate.

**I-time:** 0.3-0.35, titrate based on respiratory rate, and disease process. Avoid I:E ratios of greater than 1:2

**PIP:** This is not a set value in this mode but should be monitored. The PIP will change as the patient’s lung compliance and respiratory status changes.

- The operator sets the high pressure alarm limit. This should be set at least 10 cmH2O above the pressure needed to obtain the desired tidal volume. This value is generally set by the RT and should not be changed unless done in consultation with faculty and/or respiratory clinical specialist.

**PS:** Not used in the CMV mode

**Extubation from APVcmv**

Patients may be successfully extubated from the APVcmv mode. Because the ventilator automatically decreases the amount of PIP delivered as the patient improves, it is not necessary to change the set parameters before extubation in all patients.

A trial of extubation may be considered when the patient is consistently over breathing the set ventilator rate without increased work of breathing and both the MAP and FiO2 have dropped to acceptable levels (see table 2).

| Table 2: Summary of Extubation Criteria\(^1\) (based on current weight) |
|-----------------------------|-----------------------------|
| MAP | <1000 g | 1000-2000 g |
| FiO2\(^2\) | 8-10 | 9-10 |
| FiO2 ≤ 0.35 | FiO2 ≤ 0.35 |

\(^1\) Adapted from criteria used in the SUPPORT trial [10]

\(^2\) Extubation from higher FiO2 may be necessary for infant with established lung disease.

If weaning of set parameters is desired, the following should be kept in mind:

Rate: In CMV, the set rate is only a backup. If the patient is over breathing the rate, decreasing this setting will not affect minute ventilation.

PEEP- In APVcmv, if the PIP is very low, the PEEP is the main contributor to MAP. Therefore, if the MAP is already 8 or less, weaning the PEEP may cause increased work of breathing due to the need to overcome the restriction of airflow caused by small diameter ETTs. If the MAP is in the range of extubation criteria in Table 2, extubation may be considered without further weaning of the PEEP.

Tidal volume target: Once a tidal volume is found that provides adequate minute ventilation without increased work of breathing, it is not necessary to wean the tidal volume. The patient will increase their contribution to the work of breathing as their clinical status and lung compliance improve.
2. **APVsimv mode.** The operator sets:

**Initial settings:**

Set Tidal Volume Target, I-time, PEEP and high pressure alarm limit as above.

Pressure Support (PS): This is an additive pressure above PEEP level. This should be set at a pressure that allows the patient to get the desired tidal volume without increased work of breathing. Generally when starting ventilation this will be in the range of 8-12. This should be titrated as patient status and compliance improve.

Rate: should be initiated at that patient’s physiologic respiratory rate based on gestational age, which will generally be 40-60 bpm.

**Extubation from APVsimv**

Weaning in APVsimv is similar to weaning in cmv with the following differences:

Rate: Weaning the rate decreases the number of mandatory volume-targeted breaths but does not affect the pressure support breaths initiated by the patient. Therefore the effect of weaning the mandatory rate on minute ventilation depends on the tidal volumes generated with the pressure support breaths. Weaning the mandatory rate allows the clinician to assess the patient’s respiratory effort prior to extubation. However, low mandatory rates in this mode will lead to more tidal volume variation because the pressure support breaths are not volume-targeted.

Pressure support: weaning the PS shifts more of the work of breathing to the patient. Caution is advised as this pressure is necessary to help the patient overcome the resistance in the small diameter ETT, and weaning too low will significantly increase the patient’s work of breathing.

Tidal volume target: Once a tidal volume is found that provides adequate minute ventilation without increased work of breathing, it is not necessary to wean the tidal volume. The patient will increase their contribution to the work of breathing as their clinical status and lung compliance improve.

A Trial of extubation may be considered when the patient meets the criteria in table 3.

<table>
<thead>
<tr>
<th>Table 3: Summary of Extubation Criteria</th>
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<tr>
<td>MAP</td>
<td>8-10</td>
</tr>
<tr>
<td>FiO2²</td>
<td>FiO2 ≤ 0.35</td>
</tr>
<tr>
<td>Rate</td>
<td>20-30</td>
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1 Adapted from criteria used in the SUPPORT trial [10]
2 Extubation from higher FiO2 may be necessary for infant with established lung disease.
Trouble-shooting APV Mode

1. Large or variable problematic air leak
   a. Per the manufacturers recommendation from Hamilton, leaks over 40-60% are too high
      for the APV mode to be effective.
   b. If the ventilator alarms continuously for maximum leak compensation, then the leak is
      too large to maintain goal exhaled tidal volume.
   c. Use the trend screen to view leaks and tidal volumes to determine the prevalence of the
      leak.
   d. When the leak is > 40-60%, mechanical ventilation maybe ineffective. In these cases, a
      trail of extubation is warranted. If the baby fails extubation, consider re-intubating with
      a larger ETT or a cuffed ETT of the same size.
   e. In the face of a large leak (consistently greater than 40%), APV mode will increase
      pressure to achieve goal VT and may deliver excessive inhaled tidal volumes. If the team
      does not feel comfortable re-intubating with a cuffed or larger ETT, the patient can be
      switched to Pressure Control ventilation. On Pressure Control ventilation, the baby
      should be clinically assessed for chest wall excursion and work of breathing rather than
      exhaled tidal volume to determine the optimal PIP. Blood gases and chest x-ray can be
      used to evaluate the ventilator settings.

2. When the patient is receiving minimal PIPs to achieve the set tidal volume, but looks in distress.
   a. Use ventilator graphics to determine appropriate settings (Figure 2).
   b. Some patients may be reaching higher than target tidal volumes with no assistance from
      the ventilator due to the desire for a larger tidal volume than ordered. Decreasing PIPs
      are expected when the patient is improving during the weaning period but if the PIPs
      are lower than expected and the patient has increased WOB, this may be a sign that
      they need a larger tidal volume than ordered. Consider increasing the targeted tidal
      volume and rate to better support the patient’s minute ventilation [11].
   c. If MAP is low, consider increasing the PEEP.
   d. If the MAP is within one cmH2O of, or equal to, the PEEP, the patient is essentially in
      CPAP mode. There is almost no assistance on inspiration. If the patient is comfortable,
      then extubate. If the patient has increased WOB, then increase ventilatory support by
      increasing the ordered tidal volume.
   e. If the above steps do not help, another option is to adjust the Inspiratory Time and/or
      Rise Time for patient synchrony and comfort. This requires consultation with the RT
      charge or a clinical specialist.
   f. If problem persists, consider switching to Pressure Control ventilation.
3. When you have a “Check high Pressure Limit alarm”, then the ventilator is hitting the high pressure limit that is set.
   a. This indicates that the patient’s clinical condition has changed since the initial ventilator settings were ordered and should prompt evaluation of the patient.
   b. If after evaluation of the patient the high pressure limit alarm continues, consider increasing the PIP alarm setting if the PIPs are appropriate. PIP will limit 10cmH2O below the alarm setting.
   c. Consider decreasing set tidal volume if the patient’s flow/volume loops are over-distended.
4. In CMV mode on the Hamilton G5, the inspiratory time is clinician set and not flow-cycled by the patient.
   a. If the patient has a particularly variable respiratory rate, the patient’s inspiratory times may need to vary by switching to SIMV mode and adding pressure support
   b. If staying in CMV mode and the baby has periodic breathing, the patient may need to be placed on a higher respiratory rate to create stable minute ventilation.

Figure 2: Pressure volume loop reflects large volume movement (28 ml) with little to no positive pressure as the majority of work of is being done by the patient (negative pressure ventilation) near PEEP level. PEEP set to 5.0, MAP = 4.9, PIP = 5.5. There are also points during the respiratory cycle where the pressure is actually at 0cmH2O. Vtarget is set at 8.6ml, but patient is achieving 28ml, therefore machine is decreasing pressure to the point of near CPAP.
References


