GUIDELINES FOR THE USE OF AIRWAY PRESSURE RELEASE VENTILATION (APRV)

APRV is an unconventional mode of mechanical ventilation, used to treat severe hypoxic/type I respiratory failure.
APRV splints the lungs open using high pressure to allow maximum alveolar recruitment to improve oxygenation, with a short release phase to allow transport of CO_2 out. APRV maintains adequate ventilation and lung protection.
APRV is a modified form of Continuous positive Airway Pressure (CPAP), whereby the lung is held open at a high pressure, and ventilation is achieved by providing a short, time cycled release phase or 'release breaths'. The patient can be fully sedated making no spontaneous respiratory effort or breathing spontaneously on top of the high positive pressure throughout the APRV cycle. [1] (Fig 1.). APRV is complementary to other therapies in ARDS including conservative fluid strategy and prone positioning.
Conventional ARDSnet ventilation strategies should normally have been attempted and optimized before moving to APRV.

Indications

- Patients receiving invasive mechanical ventilation
- Hypoxic +/- hypercapnic respiratory failure where alveolar collapse / consolidation is a predominant feature e.g. ARDS, pneumonia, pulmonary contusion, cardiogenic pulmonary oedema, significant atelectasis (post operative, obesity)
- Inadequate gas exchange on conventional ventilation, or inability to maintain lung protective ventilation

Relative contraindications

- Obstructive airways disease or bronchospasm
- Fixed restrictive lung disease with limited recruitability e.g. pulmonary fibrosis
- Barotrauma or high risk of barotrauma (e.g. pneumothorax, pneumomediastinum, bullous or cystic lung disease, bronchopleural fistula)
- Pulmonary hypertension / right heart failure
- Uncorrected hypovolaemia or severe cardiovascular instability
- Acute TBI/neurosurgical patients

Ventilator

- The Servo U, Drager Evita/XL and Hamilton G5/T1 ventilators are suitable for APRV
- Drager and Hamilton Ventilators: select the mode APRV
- Servo U Ventilator: select the mode BIVENT/APRV
- Use a standard ventilator circuit with HME and closed suction
- The Servo U has Circuit compensation on all of the time; no changes need to be made.
- If using the Hamilton and Drager (PRH) Ventilators, Automatic tube compensation (ATC)(Hamilton) / tube compensation (Drager) must be turned ON at 100%,
- Pressure support should be set to OcmH_2O (zero)
- Ensure P-peak alarms are set appropriately above anticipated P-high. Other alarms may need to be adjusted due to variable 'tidal volumes' (see below)

Before starting APRV

- The decision to use APRV should be made by a Consultant, or senior registrar in Intensive Care. APRV should be set up by a Consultant, Senior Registrar or Senior Nurse (Shift leader level)
- Due consideration should be given to the nursing and junior medical skill mix and familiarity with this unconventional mode of ventilation
- Perform chest imaging to assess lung pathology and to exclude barotrauma prior to high pressure mechanical ventilation. Chest CT is gold standard but may not be an appropriate modality for unstable or isolated patients
- Assess the circulatory status, intravascular volume and right heart performance. Formal measurement / imaging is not essential but consider CO monitoring / ECHO / fluid challenge in unstable patients.
- Complete any manoeuvres that may lead to subsequent derecruitment before initiating APRV e.g. patient transport, chest physiotherapy, ETT change or cutting, ventilator circuit change, insertion of nebuliser circuit
- Ensure all actions have been taken to optimize conventional ventilation
- For patients with severe but potentially reversible respiratory failure, consider early discussion with regional respiratory failure / ECMO centre

APRV SETTINGS

APRV (Drager & Hamilton) / BIVENT/APRV (Servo U) (Figs 1 and 2)

Settings	
FiO_2	**Set at 100%,** with the intention to quickly titrate down as clinical improvement is seen.
P-high (Hamilton, Drager & Servo U)	**Start with setting the P-high at 5cmH_2O more than the *mean* airway pressure was in conventional ventilation.** **Typical Range 20-30 cmH2O** The P-high is a key determinant of the mean airway pressure (MPaw) that will be achieved and hence of recruitment. A starting P-high will be similar to the plateau pressure in a conventional volume-controlled ventilator mode. As a reference P-high should be between 20-30cmH_2O (may be higher in some cases), taking into account severity of hypoxaemia, estimated transmitted trans-alveolar pressure (consider patient body habitus, intra-abdominal pressure, pleural effusion) and circulatory status. When using high pressure ventilation, consider the potential risks of barotrauma and effects on the circulation.
P-low (Hamilton & Drager) **PEEP (Servo U)**	**P-low/PEEP is always set to 0cmH_2O (zero).** Provided the T-low/T-PEEP is set appropriately, the alveolar pressure will not decrease to zero and recruitment will be maintained during the release phase. Setting a P-low/PEEP above zero will reduce the driving pressure and hence flow rate in expiration and will reduce the effectiveness of ventilation.

T-high (Hamilton, Drager & Servo U)	**Start at T-high at 5.0 seconds. Typical range is 4-8 seconds** This would be appropriate for most patients, adjusted as follows: T-high may need to be reduced in cases of hypercapnia, and therefore increasing the frequency of releases in one minute. T-high may need to be reduced where there is haemodynamic instability or no spontaneous ventilation. T-high can be extended when CO_2 and circulation are stable, and when spontaneous ventilation has established.
T-low (Hamilton & Drager) T-PEEP (Servo U)	**Start at T-low/T-PEEP at 0.5s, Typical range is 0.2-0.8 seconds** T-low/T-PEEP should be adjusted to allow sufficient exhalation to clear CO_2 adequately, whilst being sufficiently short to prevent alveolar collapse. To optimize T-low/T-PEEP, the ventilator should cycle back to T-high when expiratory flow reaches 50-75% of peak expiratory flow. (Fig 2). The stiffer the patient's lungs, the faster the recoil will be in expiration (higher elastance) and the shorter the T-low/T-PEEP will need to be. (e.g. ARDS patients). Practical guide on how to optimize T-low/T-PEEP can be found for each ventilator in: Fig 3 (Servo U) Fig 4 (Hamilton) Fig 5 (Drager)

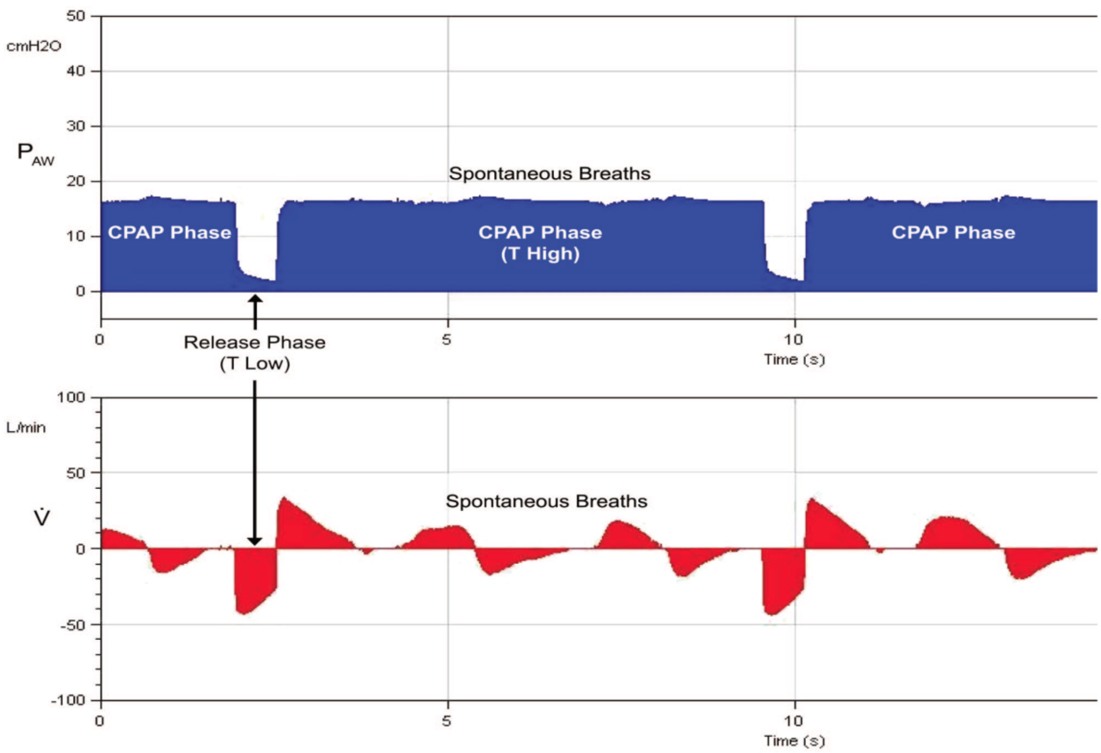


Figure 1 Typical pressure and flow curves in APRV demonstrating the long P-high / T-high phase with short P-low / T-low releases. Spontaneous breathing is occurring here but is not

1. **Sedation and paralysis**
   Stop paralysis when commencing APRV.
   Lighten sedation where possible to promote spontaneous ventilation.
   APRV is more effective, and CO_2 and sputum clearance are enhanced, if the patient can breathe over the release breaths. Many patients being commenced on APRV will have critical oxygenation and may be on "maximized" conventional ventilation, continuous deep sedation and neuromuscular blocker infusion, and may even be in the prone position. APRV can work well in the prone position. Clinical judgement will be required to estimate the best yet safest level of sedation in a proned patient on APRV.

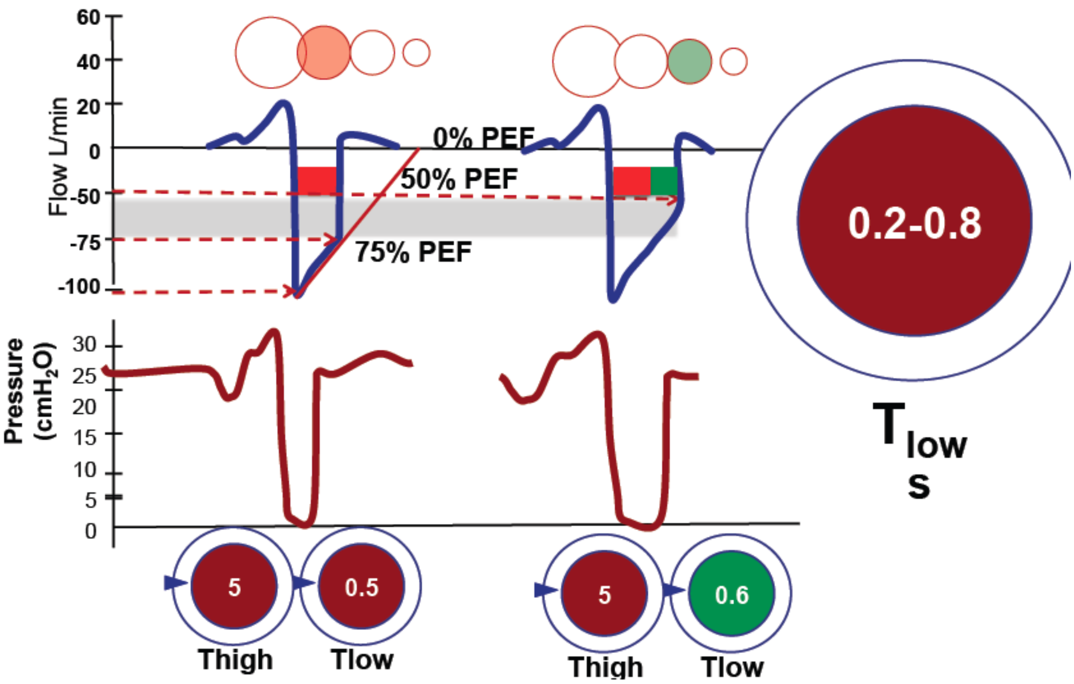
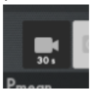


Figure 2 T-low (or T-PEEP) is adjusted in 0.05-0.1s increments so that the ratio of peak expiratory flow (PEF) to end expiratory flow is 50-75%.
Usual settings for T-low (or T-PEEP) are 0.2-0.8s

Figure 3

Optimising the T-PEEP on the Servo U ventilator

1. Select BIVENT/APRV, with starting settings as per table above
2. To reduce PEEP <5 cmH20, double confirm with  sign in bottom left corner
3. Press the RECORD button  (top right corner of screen). This takes a 30 second recording of the waveforms and values.
4. Press  button (top right corner of screen)to view your recording
5. Use the cursor on screen to scroll through the flow waveform
6. Expiratory flow should cut off at 50-75% of *peak* expiratory flow. (see text boxes in the image) This can be adjusted by altering T-PEEP in 0.05-0.1 second increments. (See figure 2)
7. Repeat the process until T-PEEP is optimized

Original: GG (2015). Review: AH/MH (Jan 2022)

Figure 4

Optimising T-low on the Hamilton ventilator

1. Select APRV, with starting settings as per table above
2. Freeze the screen by pressing here
3. Use the rotary knob to move the cursor to scroll through the waveform
4. Expiratory flow should cut off at 50-75% of *peak* expiratory flow. (see text boxes in the image) This can be adjusted by altering T-low in 0.05-0.1 second increments (See figure 2)
5. Repeat the process until T-low is optimized

Figure 5

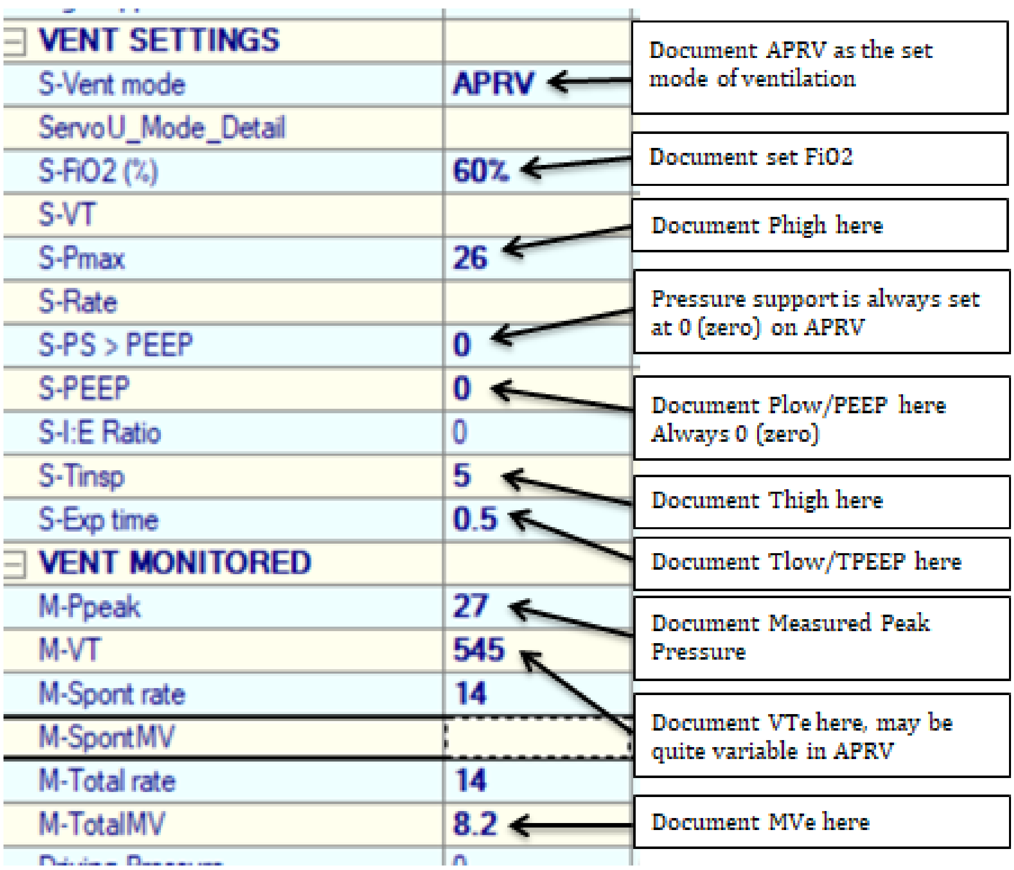
Optimising T-low on the Drager ventilator

1. Select APRV, with starting settings as per table above
2. Freeze the screen by pressing here
3. Use the rotary knob to move the cursor to scroll through the waveform
4. Expiratory flow should cut off at 50-75% of *peak* expiratory flow. This can be adjusted by altering T-low in 0.05-0.1 second increments
5. Repeat the process until T-low is optimized

Original: GG (2015). Review: AH/MH (Jan 2022)

Figure 6

What to Document



Problem solving and Troubleshooting

'Tidal volume' is 'too high'	Once the patient is well recruited, 'release volumes' may be quite high (in excess of 1000ml). This appears concerning when we are used to targeting low tidal volume ventilation (6ml/kg PBW). However, because the lung is well recruited, and is operating at, or close to total lung capacity, the unit change in volume, per recruited alveolus during the 'release' is low. Contrast this to conventional ventilation, where the lung is incompletely recruited and the tidal volume is all coming from only a small portion of the lung. Ensure that the T-low/T-PEEP is not too long (> 50-75% peak exp. flow), which would lead to excessive 'release volume' and alveolar derecruitment. This would usually be accompanied by poor gas exchange. Do not wean the APRV just because the release volume is high, unless there is evidence that the patient is recovering and you

	can reduce P-high anyway, or unless there is evidence that the APRV is harmful (barotrauma or air leak).
Patient looks uncomfortable	APRV does look different to conventional ventilation, especially if focusing on the ventilator waveforms. In particular the 'tidal volume' appears very variable (because there are both 'release volumes' and spontaneous volumes). Most patients find APRV quite comfortable and can be awake +/- spontaneously breathing despite significantly abnormal lung compliance, high MPaw and high oxygen requirements. It is not uncommon for patients to be tachypnoeic, and some degree of tachpnoea accepted. Sedation or opiates may be required.
Patient is hypoxic	The most common reason is insufficient alveolar recruitment (MPaw). i) Ensure that T-low/T-PEEP is set appropriately and that excessive alveolar derecruitment is not occurring during the T-low/T-PEEP (not > 50-75% peak exp. flow). Set this appropriately first, aiming for 75% if oxygenation is poor. T-low may need to be decreased, usually in increments of 0.05-0.1s, but not typically <0.2s ii) P-high may be increased, in increments of 2cmH_2O or more, considering potential risks of barotrauma and effects on the circulation iii) T-high may be increased in increments of 0.5s iv) Ensure that the circulatory status is adequate and consider oxygen consumption
Patient is hyperoxic	If the PaO_2 is above targets, reduce FiO_2 first. Once FiO_2 is down to 40-50%, then consider reducing P-high.
Patient is hypercapnic (beyond an acceptable target of permissive hypercapnia / acidosis)	This not uncommon when initiating APRV, especially before there has been time for adequate recruitment and if there is no spontaneous ventilation. It often improves just with time but other considerations are: i) Ensure adequate expiratory flow / release volume (50-75% rule). Common reasons why expiratory obstruction may occur are ETT ID too small, pulmonary secretions, kinked or otherwise obstructed ETT, saturated HME or bronchospasm. Having considered and addressed these, if expiratory phase is still not adequate, T-low may be increased in increments of 0.05-0.1s, but not typically >0.8s, to ensure end expiratory flow : peak expiratory flow is no more than 75%. If oxygenation is good, this ratio can be extended to 50%. Do not be tempted to increase beyond this, as alveolar derecruitment will occur. ii) Consider increasing 'diffusive ventilation'. The problem may be inadequate surface area / recruitment for gas exchange during the T-high. This may commonly be

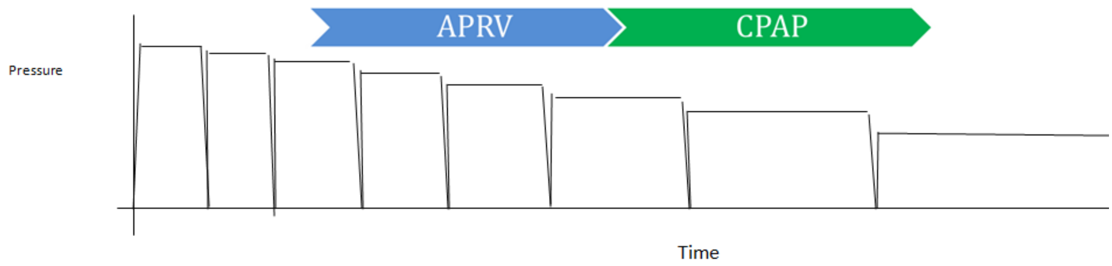
	accompanied by poor oxygenation. Increasing the P-high (+/- T-high) can be an effective method of improving CO_2 clearance. P-high may be increased, in increments of 2cmH_2O or more, considering potential risks of barotrauma and effects on the circulation iii) Consider increasing 'minute ventilation'. Reducing the T-high in increments of 0.5s will increases the number of releases and will increase conventional 'minute ventilation' but should not be achieved at the cost of reducing MPaw and allowing derecruitment. Consider increasing P-high to compensate for decreased T-high. Additionally, try encouraging spontaneous breaths (no pressure support) by reducing sedation. iv) Consider issues of excessive circuit dead space and CO_2 production.
Overdistension	Occasionally deterioration in gas exchange may occur because the high MPaw leads to overdistension of the lung. This is usually accompanied by evidence of significant circulatory disturbance. Look for signs of overdistension on CXR and consider trial of 1. optimizing volume status / Right Heart function 2. reducing P-high.

Patient transport is required:
APRV can be provided on both Hamilton T1 and MR1 ventilators, and the Servo U ventilators have a good battery life (which can be extended by increasing the number of battery packs). When swapping ventilators clamp the ETT to prevent derecruitment (not when spontaneously breathing) and ensure that the transferring team is familiar with APRV as a mode of ventilation.

Patient is no better:
If optimal APRV has been applied for a period of 4-6 hours and there is no improvement in gas exchange, then is unlikely that the patient will benefit from this specific mode.

Weaning

Patients should be weaned in APRV to a safe level before transition back to conventional ventilation. The most common strategy of weaning patients from APRV should be a 'drop and stretch' approach where the patient moves from APRV with high pressure and frequent releases to continuous CPAP, breathing spontaneously as they recover.



However, some patients are weaned from APRV to a conventional mode of ventilation (CPAP/PS or Pressure controlled mode of ventilation). Consider higher PEEP if going from APRV to a conventional mode of ventilation as APRV and high MPaw may 'flatter' some patients and a rapid wean to a lower MPaw / conventional ventilation may lead to a significant deterioration.

- Weaning the Pressures
  Reduce the P-high in 2cmH_2O increments as tolerated, allowing sufficient time between reductions to ensure patient is stable. If gas exchange deteriorates, without another obvious cause, stop weaning and consider returning to previous stable settings.

- Weaning the ventilation (CO_2 clearance)
  Increase the T-high in 0.5 to 1s increments, thereby reducing the number of 'release breaths' per minute. At the same time, spontaneous breaths / minute ventilation should / will need to increase.

Be aware that a simultaneous reduction in P-high and increase in T-high may lead to no significant change in MPaw, and so P-high may be able to weaned more quickly.
This strategy will eventually lead to a patient breathing spontaneously on CPAP with no release breaths.
Alternatively, once the MPaw is <20cmH_2O and the patient is stable you may wish to transition directly to a conventional Pressure Controlled or Pressure Support mode.

1. Habashi, N. Other approaches to open lung ventilation: Airway pressure release ventilation. *Crit Care Med* 2005; **33**: S228-240
2. Swindin, Sampson and Howatson. Airway pressure release ventilation. *BJA Education* 2020; **20 (3)**: 80-88.

Acknowledgements to L Camporota for figures, reproduced with permission.

Original: GG (2015). Review: AH/MH (Jan 2022)