Airway Pressure Release Ventilation (APRV) Mode

- What is APRV
- Advantages of using APRV
- When to use APRV
- How to adjust parameter based on oxygenation, ventilation, and patient effort
- When and how to wean off APRV

What is APRV mode?

It is a time and pressure controlled inverse ratio mode with a prolonged inspiratory time and a short release phase.

- During the inspiratory time maintains a high pressure for a prolonged time which maximizes lung recruitment, the 'open-lung' approach, and allows the exchange of O2 and CO2 by convection and diffusion, even if the patient is not breathing.
- It has an open valve during the inspiratory time that allows for spontaneous breathing.
- For physiologic reasons, the ability to breath spontaneously is encouraged but APRV can also be used in non-spontaneously breathing patients under deep sedation and muscle paralysis.

There are 4 unique parameters to set with APRV (see figs 1 and 2):

- **Pressure high (P-high):** is the highest level of pressure applied to the respiratory system. It is set to maintain lung inflation.
- **Time high (T-high**): is the inspiratory time and indicates the time in seconds spent at P-high.
    - Together, the P-high and the T-high deliver an almost continuous positive pressure (CPAP) to maintain adequate lung volume and alveolar recruitment.
- **Pressure low (P-low):** is the lowest pressure applied by the ventilator to the respiratory system. It is set to facilitate the release phase.
- **Time low (T-low):** is the expiratory time and indicates the time in seconds spent at P-low.
    - Together, the P-low and T-low create the release phase where most of CO2 removal and clearance of airway secretions occur.

There are 3 additional parameters to be set, obviously, the **FiO2, the release frequency** that is calculated as 60 divided by the sum of T-high and T-low, and the **automatic tube compensation (ATC)** that should always be on when the patient is breathing spontaneously.

Another more sophisticated feature of APRV is the analysis of the **expiratory flow deceleration angle** (see Fig 3). The flow deceleration angle in a normal lung is ~45 degrees.

- Low angle ("steep" flow curve) may reflect de-recruitment or decrease compliance (e.g., ARDS, abdominal compartment syndrome).
- High angle ("flat" flow curve) may reflect over-distension or obstruction (e.g., bronchospasm or secretions in large airways).

Advantages of using APRV

- Effective safe alternative for difficult-to-oxygenate patients with acute lung injury/ acute respiratory distress syndrome (ALI/ARDS).

- APRV main appealing feature is minimizing ventilator-induced lung injury (VILI) using lung protective strategies. During APRV, lung units are kept open more consistently. This reduces the cyclical opening and collapse of atelectatic but recruitable units, thereby minimizing lung injury.
- Spontaneous breathing plays a very important role in APRV, allowing the patient to control his/ her respiratory frequency without being confined to an arbitrary preset I:E ratio, thus improving patient comfort and patient-ventilator synchrony with reduction of the amount of sedation necessary.
- Diaphragmatic activity promotes recruitment and ventilation of the lung bases.

- Active breathing may improve venous return and cardiac output.
- APRV is better tolerated than conventional low tidal-volume ventilation, decreasing the need for deep sedation and paralytics.
- APRV is compatible with early-mobility initiatives. Patients can walk on APRV mode.

In summary:

- Better V/Q mismatch while breathing spontaneously and maintaining higher mean airway pressure: **Improves oxygenation**
- Increases venous return and pre-load and consequently increases cardiac output: **Improves hemodynamic**
- Lung units are kept open more consistently: **Reduces VILI**
- Decreases need for sedation-analgesia: **Decrease length of mechanical ventilation and ICU length of stay**

When to use APRV

Indications

It can be used in any patient with respiratory failure requiring invasive mechanical ventilation as an initial or as a rescue strategy.

It is particularly useful in patients difficult-to-oxygenate with ALI/ARDS and those in whom:

- Prone positioning is contraindicated or those who have not responded to a trial of prone positioning.
- A trial of low tidal volume ventilation has failed.

The earlier APRV is used, the more effective it is in recruiting the lung and the more likely it is to be tolerated; therefore, it should be used preferably as a front-line strategy rather than a rescue modality.

- It works best when patients are relatively awake and not paralyzed.
- It is more lung-protective than conventional ventilation.

Relative Contraindications

- Patients with COPD or asthma with severe bronchospasm
- Hypercapnic respiratory failure
- Because of the lower levels of sedation used to allow spontaneous breathing, APRV should not be used in patients who require deep sedation for management of their underlying disease (e.g., cerebral edema with increased intracranial pressure or status epilepticus)
- Profound cardiovascular instability (particularly if secondary to untreated hypovolemia). If BP falls after initiating APRV, give 250 to 500 ML of IVF
- Recent pulmonary resection with staple lines or anastomosis (i.e., postoperative lobectomy and pneumonectomy)
- Pulmonary hypertension with right ventricular decompensation
- Bronchopleural fistula
- Untreated pneumothorax

If gas exchange does not improve within the first 6 - 12 h of initiating APRV or patient does not look comfortable despite optimal APRV settings and sedation/analgesia, the patient will probably not benefit and another mode should be used.

How to use APRV:

There are numerous protocols recommending different approaches. Each patient is different, so ventilator settings will need to be titrated to the individual patient. Not infrequently different settings may need to be trialed to determine which works the best.

Initial setting

- FiO2 100%. This can usually be reduced rapidly
- P-high between 20 and 30, usually 30 and up to 35 in obese pts and those with decreased chest compliance (ascites, increased intra-abdominal pressure)
- P-low is normally set at 0 cmH2O, but the short T-low ensures that the lungs never fully empty generating a time-controlled 'auto-PEEP' thus preventing lung collapse during expiration
- T-high (inspiratory time) between 3 and 8 seconds, usually 5 seconds
- T-low (expiratory time) between 0.3 and 0.8 seconds, usually 0.5 second
- Release frequency: 60/T high - T low. Usually 10–14 frequency/min
- Automatic tube compensation (ATC) should be on if spontaneously breathing

Transition from conventional ventilation

- Transitioning from volume-cycled ventilation: set P-high equal to plateau pressure.
- Transitioning from pressure-cycled ventilation: set P-high equal to peak pressure.

Adjusting T Low

There are two ways to adjust the T-low

- Based on the ratio of the expiratory flow and the peak expiratory flow rate. This is done by examining the flow/time graphical display on the ventilator, as shown in Fig 2.
    - Adjust the T-low to cut off the expiratory flow during a release at about 50% (25-75%) of peek expiratory flow rate (PEFR). Generally, the T-low can be as short as 0.3 seconds (closer to 75% of PEFR in restrictive disease and as long as 1.5 seconds (closer to 25% of the PEFR) in obstructive states.
    - Never allow the termination of expiratory flow to go <25% of PEFR. This intentional "auto PEEP" allows P-low to be set at 0 cmH2O without causing derecruitment.

However, others, the Habashi approach, recommend that the expiratory flow should always terminate at 75% of peak expiratory flow as shown in fig 4. If the expiratory flow terminates at <75% of peak expiratory flow as shown in fig 5 is incorrect and we have to shorten T-low by steps of 0.1 s until the flow terminates at 75%.

- Alternatively, some recommend that rather adjusting T-low based on peak expiratory flow rate, it would be simpler to adjust T-low to target a tidal volume of 6-8 ml/kg.
    - The expiratory time should be short enough to prevent derecruitment and long enough to obtain a suitable tidal volume. If the tidal volume is inadequate, the expiratory time is lengthened; if it is too high (>8ml/kg) the expiratory time is shortened.

How to adjust parameter based on oxygenation, ventilation, and patient effort during APRV

The goals are the same as for any ventilation mode: minimize VILI using a lung protective strategy

- Maintain adequate oxygenation and ventilation.
- Prevent overt lung distention during P-high.
- Avoid lung derecruitment and or too much intrinsic PEEP during P-low.

Changes in expiratory flow deceleration angle can be useful for clinical assessment. For example, sudden increase in angle ("flat" flow curve) could signal acute airway obstruction and sudden decrease ("steep" flow curve) could signal decrease in compliance or de-recruitment.

Maneuvers to correct hyperoxemia

- Reduce FIO2 first. Once the FIO2 is at 40-50%, start to reduce P-high

Maneuvers to correct hypoxemia

- Increase mean airway pressure
- Increase either P-high or T-high or both in increments of 2 cmH20 or 0.5 sec respectively

- Increase P-low is not recommended. Adding a P low >0 cmH2O can reduced tidal volume and increase PCO2 and has a negative effect on secretion removal
- Decrease T-low to be closer to 75% PEFR
- Simultaneous use of other maneuvers
  - Increase FiO2
  - Recruitment
  - Neuromuscular blockade
  - Prone position

Maneuvers to correct hypercapnia

- Tolerate permissive hypercapnia if pH >7.25. Sometimes lower if no contraindication and patient hemodynamically stable.
- Decrease sedation if tolerated to increase the patient's contribution to minute ventilation.
- To increase minute ventilation while keeping stable mean airway pressure, increase P-high in increments of 2 cmH20 up to 30 cmH2O and 35 cmH2O in obese patients.
  - If patient is not breathing spontaneously increase the rate of releases by decreasing T-high in decrements of 0.5s down to 3s.
  - If patient is breathing spontaneously increase T-high in increments of 0.5 sec up to 8s.
- Last resort: to allow more time for alveolar emptying, increase T-low by 0.05-0.1s if end-expiratory flow rate is >50% of the PEFR. However, this is generally undesirable because it may cause derecruitment.

If unable to manage the acidosis with APRV, the mode should be changed to pressure or volume controlled ventilation.

Maneuvers to correct hypocapnia (it may be an indication that the patient is ready for weaning)

- Decrease P-high if oxygenation is adequate or excessive.
- Increase T-high by 0.2 s to decrease the rate of releases if patient is not breathing spontaneously and decrease T-high if patient is breathing spontaneously.
- May decrease T-low.

Maneuvers to manipulate tidal volume (Vt)

- If Vt is less than desired, increase T-low (expiratory time) by 0.05-0.1 s increments
- If Vt does not improve by increasing T-low, assure adequate sedation/analgesia with consideration for muscle paralysis and increase minute ventilation by decreasing the T-high (i.e., increasing rate).
- If Vt is too high, decrease T low (expiratory time) by 0.05-0.1 s decrements

Maneuvers to improve increased respiratory efforts (see Fig 6)

- Elevate mean airway pressure and encourage recruitment.
  - Increase P-high.
  - Decrease T-low only if we can maintain the flow during the release phase <75% of PEFR and the PaCO2 and pH are acceptable (adequate Vt).

Maneuvers to improve forceful expirations (see Fig 7).

If the patient seems to be exhaling forcefully, over-inflation may be present.

- Decrease the P-high in 1-2 cmH2O decrements and increase T-high to maintain the same P mean).
- Increase the T-low allowing more time to exhale only if we can maintain the flow during the release phase >25% of PEFR.

Readiness for weaning

- Patient should be spontaneously breathing at a reasonable rate (e.g., 10-25 breaths/minute) with RASS 0 to -1). This may be facilitated by:
- Anxiolysis: consider adding dexmedetomidine while weaning down Propofol.

- Pain control: consider adding ketamine infusion to allow weaning down Fentanyl.
- T-high is fairly long >6 seconds.
- FiO2 50% or lower.
- Not significantly hypercapnic.
- Ready to assume more of the work of breathing (e.g., not in severe shock).

APRV weaning and liberation from the ventilator: "drop and stretch"
When FiO2 is titrated below 50% and the patient is breathing spontaneously, a continuous gradual wean can begin. P-high must be adjusted very slowly to avoid de-recruitment. T-high is the main driver of the release frequency. As patients wean off ventilator support, T-high will be increased and the release frequency will decrease.

- Start decreasing P-high and increasing T-high which is referred as "Drop and stretch". It should be done every two hours or more as tolerated with continuous monitoring for desaturation and increased work of breathing.
  - Decrease P-high in decrements of 2 cmH20 every two hours or more as tolerated. If this causes hypoxemia, increase P high by 4 cmH2O and wean more slowly.
  - Once P-high is 20 cmH20, increase T-high by increments of 0.5-1 seconds each time P-high is decreased ("Drop and stretch"). Continuing this will wean the patient to CPAP to 10 to 15 cm H2O with minimal releases.
- Once P-high is 10 to 15 cmH2O and T-high reaches 12-20s, the patient is doing nearly all the work of breathing, essentially is in CPAP mode:
  - The patient can be switched to a conventional pressure supported mode, setting PEEP at 10 cmH2O and pressure support 7 to 10 cmH2O and wean conventionally from there.
  - Alternatively, the patient may be extubated directly. Since the patient is spontaneously breathing throughout this process, it is not necessary to do spontaneous breathing trials.
- Extubate to BiPAP or HFNC to maintain ongoing support.
  - Do not transition to standard nasal cannula for 24 hours.

Time Controlled Adaptive Ventilation (TCAV) - The Habashi Approach

TCAV is an APRV mode approach proposed by Dr. Habashi who is a leading APRV investigator at the University of Maryland. What is unique about TCAV is as follows:

- The expiratory flow should terminate at 75% of PEFR (see figs 6), anything else is incorrect. According to Habashi, If the expiratory flow terminates at <75% of PEFR as demonstrated in fig 5, the T-low has to be shorten by steps of 0.1 s until the flow terminates at 75%. Whereas others accept a range between 25 and 75%.
- It uses higher release frequency driven by using shorter T-high compared to others approaches.
  - The release phase is protocolized to maintain the expiratory flow at 75% of PEFR. However, the time to achieve 75% is personalized to each patient based on the severity of the ALI (see fig 8).
  - When the slope angle becomes more acute, a time increase in T-low is necessary to maintain the expiratory flow at 75% of PEFR.
- Optimizing recruitment with TCAV allows the lung to accommodate increased tidal volumes, without increases in driving pressure, due to a concomitant increase in compliance.
- Vt can only increase if compliance increases, which personalizes the Vt to the pathophysiology of the patient's lung in real-time

Initial settings based on severity of ALI when using APRV as rescue initial mode and when transition from another mode are illustrated in tables 1 and 2 taken from Habashi's publications.

These settings are when using TCAV as the initial rescue mode and differ from early or preemptive TCAV as in post-operative atelectasis or airway protection for normal lungs were using a T-high of 4-6 seconds is adequate. In general, the T-low is set to 0.5s for normal lungs, 0.4s for moderate ALI and 0.3s for severe ALI.

When using APRV-TCAV as a rescue strategy:

- It may be necessary to control the patient's ventilation until mechanical and gas exchange parameters improve to avoid excessive air hunger and breathing effort.
- Sedation should be continued and consideration of neuromuscular blocking agents to control respiratory drive if necessary.
- In addition, the time dependent nature of increase in surface area for diffusive CO2 clearance may not occur for 12-24 hours. Therefore, when using as a rescue strategy a briefer T-high is required to provide more bulk ventilation until the lung has recruited and stabilized.
- TCAV used as rescue on patients with decreased compliance typically results in Vt less than 6 mL/kg resulting in a lower minute ventilation (MVe). If this occurs, increase Mve by decreasing the T-high i.e. (increasing rate) to achieve or exceed previous Mve.
- As the lung recruits compliance improves, Mve requirements decrease allowing the T-high to be increased. According to Habashi, DO NOT increase Mve by increasing T-low unless the expiratory flow is >75% of the PEFR as this will decrease alveolar stability.

FIGURES

Figure 1: pressure-time and flow-time plots – Taken from reference 3

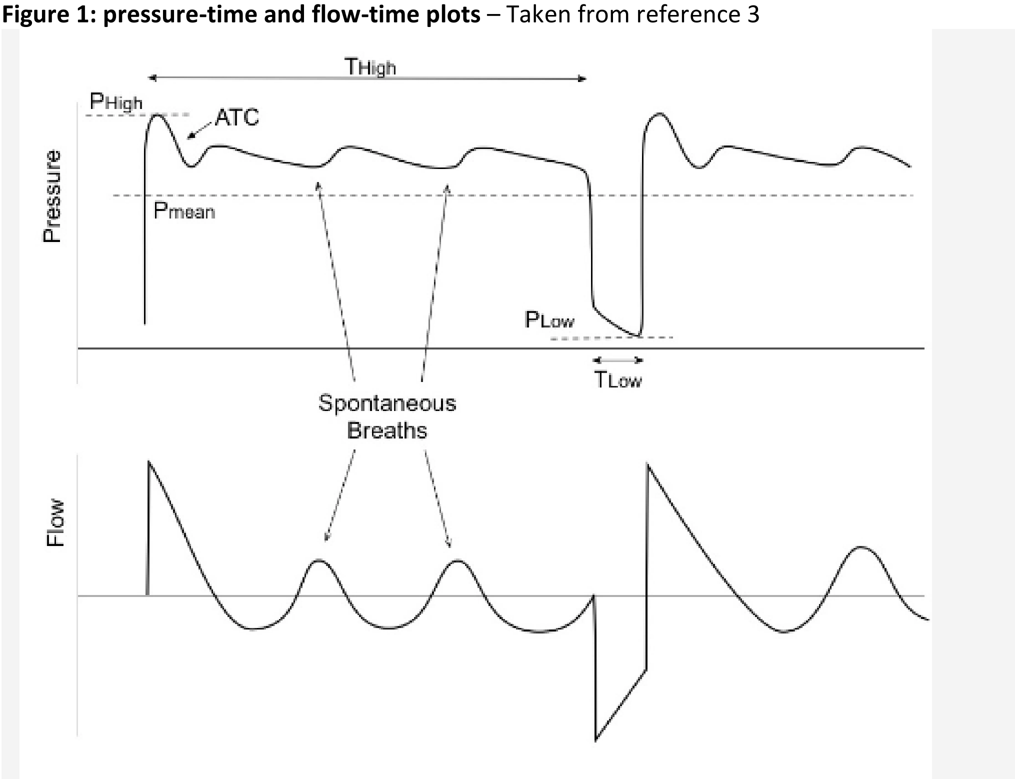


Figure 2: flow-time plot – Taken from reference 3

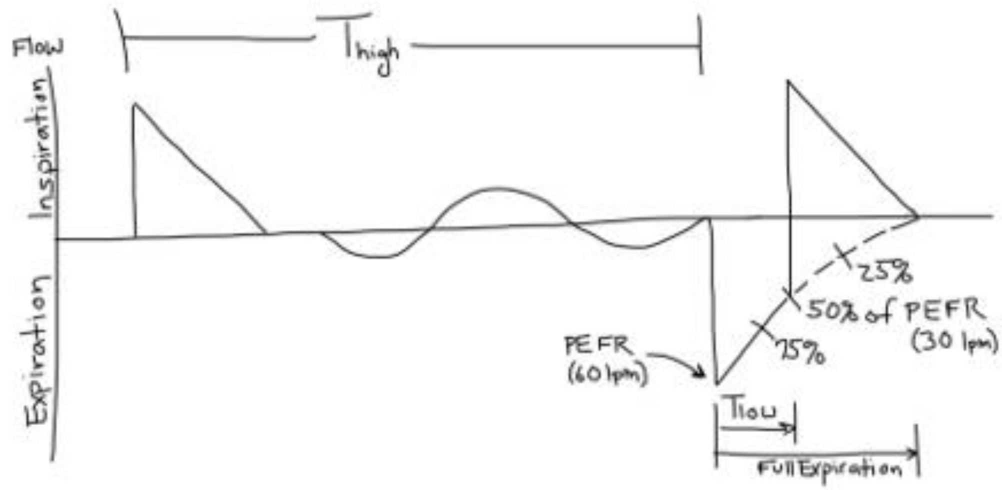


Figure 3: Expiratory flow deceleration angle – Taken from reference 1

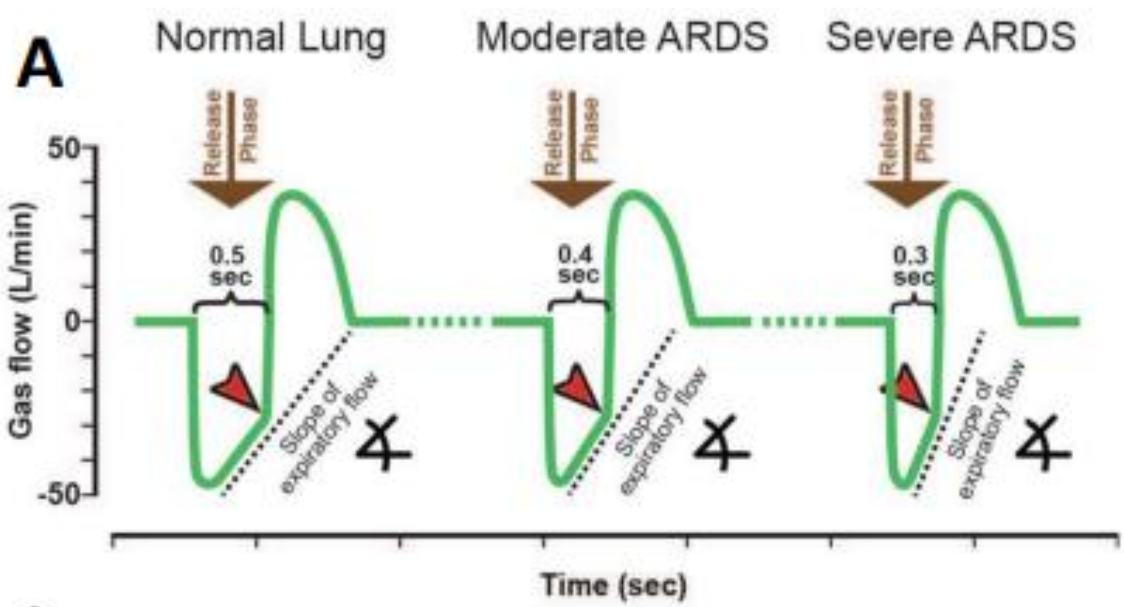


Figure 4: Correct T-low according to Habashi Approach – Taken from reference 2

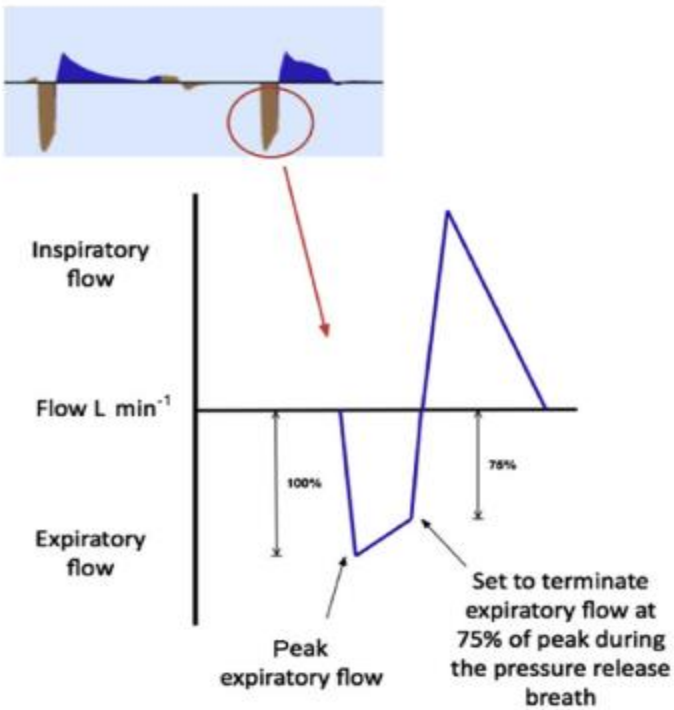


Figure 5: Incorrect T-low according to Habashi Approach – Taken from reference 2

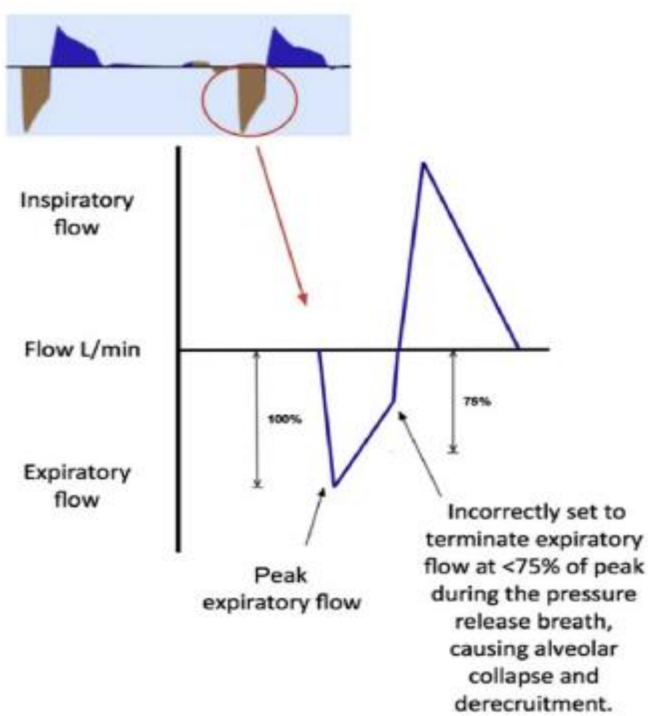


Figure 6: Increased Respiratory Effort – Taken from reference 3

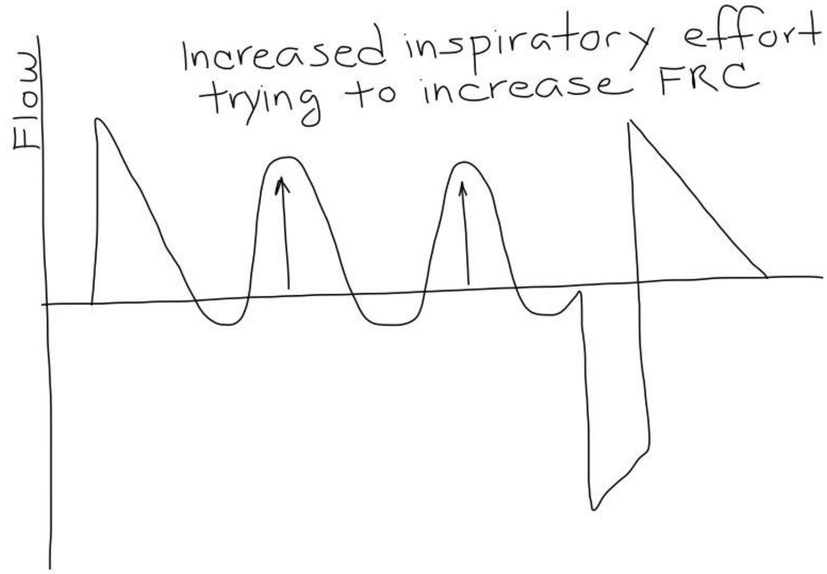
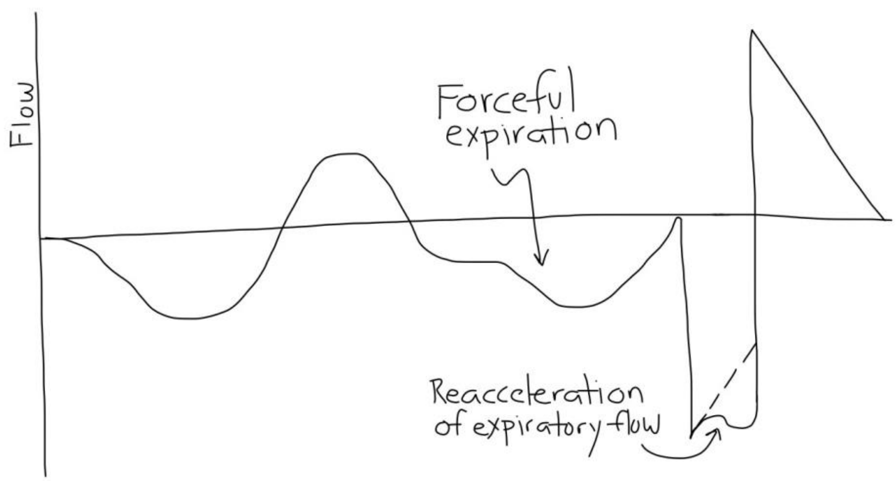


Figure 7: Forceful expiration – Taken from reference 3



TABLES – Taken from reference 1

Table 1: Initial Settings Based on Severity of ALI

Initial Settings – adjustment to settings are based on analysis of MVe, slope angle and blood gases	**Mild**	**Moderate**	**Severe**
P_{High} (cmH_2O) based on Berlin criteria	20-24	25-29	26-30*
P_{Low} (cmH_2O)	0	0	0
T_{High} (seconds) Consider rate required based on respiratory/metabolic acidosis. NOTE: Use these ranges as a starting point and adjust based on blood gas.	2-4	2-3	1-3
T_{Low} (seconds)* set to E_{FT}/E_{FP} of 75%. **NOTE**: These ranges are a ***starting point*** and may require adjustment to achieve E_{FT}/E_{FP} of 75%.	0.4-0.6	0.3-0.5	0.2-0.4

Table 2: Initial Settings When Transitioning From Another Mode

Initial Settings – adjustment to settings are based on analysis of MVe, slope angle and blood gases	**From Volume Control Mode**	**From Pressure Control Mode**	**From Dual Targeted Mode**	**From HFOV**
P_{High} (cmH_2O)*	Equal to plateau pressure	Equal to peak pressure	Equal to peak pressure	Mean airway pressure plus 2-4 cmH_2O
P_{Low} (cmH_2O)	0	0	0	0
T_{High} (seconds)	Set to match rate on mode transitioning from using the formula: (60/current rate) – T_{Low} (i.e. rate 26; (60/26) = 2.3 If T Low is 0.5, then T High would be set to 1.8 seconds			
T_{Low} (seconds)* set to E_{FT}/E_{FP} of 75%. **NOTE**: These ranges are a ***starting point*** and may require adjustment to achieve E_{FT}/E_{FP} of 75%.	0.4-0.6	0.4-0.6	0.4-0.6	0.4-0.6

References

1. Nieman GF et al. Prevention and treatment of acute lung injury with time-controlled adaptive ventilation: physiologically informed modification of airway pressure release ventilation. *Ann Intensive Care* 2020; 10: 1-16.
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4. APRV network by Nader Habashi