



Chapter 2 – Mechanical Ventilation and Noninvasive Ventilatory Support

NOTE: CONTENT CONTAINED IN THIS DOCUMENT IS TAKEN FROM ROSEN'S EMERGENCY MEDICINE 9th Ed.

Italicized text is quoted directly from Rosen's.

Key Concepts:

- 1. There have been no demonstrated outcomes differences between BiPAP and CPAP. After appropriate patient selections, begin NIPPV with an inspiratory pressure for 10 cm of water and expiratory pressure of 5 cm of water and evaluate frequently for tolerance and need to titrate up or down.*
- 2. Pressure controlled (PC) ventilation delivers breaths at a predetermined pressure, which might result in low volume delivery, while volume controlled (VC) delivers a predetermined inspiratory volume, which might lead to excessive pressures. Continuous mandatory ventilation (CMV) delivers a required number of volume of breaths per minute while synchronized intermittent-mandatory ventilation (SIMV) synchronizes mandatory breaths with spontaneous breaths.*
- 3. Noninvasive ventilatory support is often adequate for reversal of impending respiratory failure and should be considered as the first-line therapy for patients with exacerbations of chronic obstructive pulmonary disease and acute cardiogenic pulmonary edema in whom immediate intubation is not required. When non-invasive ventilation is attempted for patients with pneumonia, it should be abandoned in favor of intubation with mechanical positive-pressure ventilation unless the patient is clearly improving. Prolonged use of non-invasive ventilation that ultimately fails is associated with worse outcomes for patients than when intubation is undertaken earlier.*
- 4. Invasive mechanical ventilation is not without consequence and requires dynamic, ongoing management. After intubation, blood gas analysis should be performed to confirm appropriate ventilation and provide correlation with noninvasive monitoring of oxyhemoglobin saturation and end-tidal carbon dioxide. In addition, positive pressure can have adverse hemodynamic consequences. Elevated lung pressures can be deleterious and plateau pressure should be maintained below 30 cm water whenever possible, but adjusting ventilator settings. Progressive elevation in ventilation pressures prompts consideration of ventilator circuit obstruction, obstruction at any point of the airway, increased bronchospasm, mainstem intubation, tension pneumothorax or hemothorax, increased chest wall resistance (from a constricting device or intrinsic chest wall) or rigidity (as from high doses of fentanyl). Suddenly reduced ventilation pressures are often accompanied by increasing hypoxemia and indicate ventilator circuit leak or faulty connection, endotracheal tube cuff leak, accidental intubation, or esophageal intubation.*



5. *The Richmond Agitation Sedation Score (RASS) or a similar scoring system should be used to manage sedation and analgesia of the mechanically ventilated patient to avoid unnecessary use of prolonged neuromuscular blockade. When RASS is used, a target score of -2 to 0 avoids both over and under sedation.*

Core Questions:

1. What are the physiologic changes that occur with a transition from negative to positive pressure ventilation?
2. Differentiate between pressure-controlled ventilation (PCV) and volume-controlled ventilation strategies (see Table 2.1), and describe when to use each mode.
3. Describe the following ventilator strategies:
 - Continuous Mechanical Ventilation (CMV)
 - i. Assist-control
 - Intermittent Mandatory Ventilation (IMV)
 - i. Synchronized intermittent mandatory ventilation (SIMV)
 - Continuous Spontaneous Ventilation (CSV)
 - i. Pressure-support ventilation (PSV)
 - ii. Continuous positive airway pressure (CPAP)
 - iii. Bi-level positive airway pressure (BL-PAP)
4. Describe options for non-invasive ventilation (NIV) and an approach to initial settings for CPAP and BL-PAP.
5. What is the Richmond Agitation-Sedation Scale (RASS) and what is it used for?
6. What analgesics and sedatives are commonly used for post-intubation management?
7. How do you troubleshoot a ventilator?
8. Outline your approach to ventilator settings in the following situations:
 - Healthy Intubated Adult
 - Acute exacerbation of Chronic Obstructive Pulmonary Disease (AECOPD)
 - Status Asthmaticus
 - Acute Respiratory Distress Syndrome (ARDS)

Wisecracks:

1. What conditions benefit from non-invasive ventilation?
2. What is high-flow nasal cannula (HFNC) and when should it be used?
3. What are some strategies to prevent ventilator-acquired pneumonia (VAP)?
4. What should you target your RASS scores to when sedating patients post-intubation?
5. What is auto-peep?



Rosen's in Perspective

Complex yet undoubtedly necessary topics presented here today, listeners. Knowing how to manage patients requiring invasive and non-invasive ventilation is becoming exceedingly important in the setting of the Emergency Department. Now, perhaps more than ever, emergency physicians are expected to know a tremendous amount about specific ventilatory strategies, ventilatory, BiPAP, and CPAP machine settings, and sedation and analgesic protocols.

This podcast will serve to provide you a jumping off point to explore the finer points of mechanical ventilation and non-invasive ventilatory support. If you have any other questions, we will be providing some additional links in the show notes that should help you find out more about ventilators and ventilator accessories. (Owen, I know you love the King of the Hill reference).

Core Questions:

[1] What are the physiologic changes that occur with a transition from negative to positive pressure ventilation?

Normal Breathing = Negative Intrathoracic Pressure Generation

- Accomplished by the diaphragm and intercostal mm. Contraction increases intrathoracic **volume** which in turn decreases intrathoracic **pressure**.
- Chest Recoil and diaphragm relaxation reverses those changes.
- Normally, Cardiac output is transiently increased by negative intrathoracic pressure, due to increased pressure gradient between LV and aorta.

Positive Pressure

- Causes changes in cardiovascular and pulmonary physiology.
- Venous return diminished by positive intrathoracic pressure. Cardiac output falls, decreased pressure gradient between LV and aorta.
- Manifestation = relative hypotension.

Resuscitate before you intubate.

This is why.



[2] Differentiate between pressure-controlled ventilation (PCV) and volume-controlled ventilation strategies (see Table 2.1), and describe when to use each mode.

- Mechanical ventilation - main consideration is **how each breath should be delivered**.
 - Volume, duration, frequency of the breath, as well as the degree of interaction the patient has with the ventilator.
- Control variable = how a ventilator defines a breath.
- PCV and VCV are both under the umbrella of **continuous mechanical ventilation and classified as assist-control modes of ventilation**. More on the nomenclature in the next question.
 - PCV = pressure control ventilation. The ventilator delivers a set pressure with each breath.
 - **Useful to prevent barotrauma.**
 - **Additionally, because inspiratory flow is not fixed, improved ventilator synchrony in patients with high respiratory drive.**
 - Set parameters: Pressure target, inspiratory time, Resp Rate, PEEP.
 - Variables: Tidal volume, inspiratory flow rate.
 - Clinical Implications: controls airway pressure but **tidal volume becomes a function of lung compliance and can vary.**
 - Clinical application: asthma, COPD, salicylate toxicity.
 - VCV = volume controlled ventilation. The ventilator delivers a set volume with each breath. Pressure varies.
 - **Advantage: useful in conditions like ARDS where strict control of tidal volume has been shown to prevent mortality.**
 - **Useful in patients with obesity or other cause of decreased chest wall compliance (eg burn) to ensure adequate TV delivered.**
 - Set parameters: Tidal volume, Resp rate, inspiratory flow rate, inspiratory time.
 - Variables: Peak Inspiratory Pressure, End expiratory alveolar Pressure.
 - Clinical Implications: guaranteed tidal volume - but may cause high lung pressures. Must measure plateau pressure as end inspiratory alveolar pressure cannot be measured.
 - Clinical application - ARDS, obesity, severe burns.



[3] Describe the different ventilator strategies:

Continuous Mechanical Ventilation (CMV)

- **Assist-control - see previous question.** Intended to provide full ventilatory support. If a patient generates a breath, ventilator will assist, otherwise runs on set resp rate. **Patient receives minimum preset number of breaths but can generate additional breaths.** Used in deeply sedated ± paralyzed patient.
- Disadvantage - patient initiated breaths are not proportional to patient effort. A minimal inspiratory effort may result in a full breath being delivered. Effects include hyperventilation, air trapping, poor synchrony, hypotension.
 1. **Pressure Control** - outlined in Q2
 2. **Volume Control** - outlined in Q2

Intermittent Mandatory Ventilation (IMV)

- **Synchronized intermittent mandatory ventilation (SIMV)**
 - i. Used in patient with respiratory effort is regular, but poor.
 - ii. Delivers both **mandatory** and **spontaneous** breaths.
 - iii. **Mandatory breath** given at preset rate. But the vent synchronizes with spontaneous patient breaths as much as possible.
 - iv. If patient breathing below set rate - essentially similar to A/C. If patient breathing above rate, patient-generated breaths will be at a volume determined by their resp effort.
 - v. **Clinical application:** patients who are sedated but have weak resp effort.
- attenuates air trapping and promotes synchrony.
- **Continuous Spontaneous Ventilation (CSV)** = breath ONLY delivered on a patient initiated trigger.
 - i. **Pressure-support ventilation (PSV)**
 1. Supports patients intrinsic respiratory effort by delivering set pressure to airway when a breath is triggered.
 2. Occurs only during inspiratory flow to allow spontaneous exhalation.
 3. Pressure support is the only set parameter on the vent. Inspiratory flow, inspiratory time, TV all determined by patient's resp effort.
 4. **Clinical application:** awake and interactive patients who have been intubated for temporary airway protection.
 - ii. **Continuous positive airway pressure (CPAP)**
 1. Non-invasive - delivery via mask as opposed to endotracheal tube.
 2. Constant positive pressure throughout the respiratory cycle
 - iii. **Bi-level positive airway pressure (BL-PAP)**
 1. Non-invasive technique
 2. Note that BIPAP is a trade name
 3. Alternates between higher pressure during inspiration (termed IPAP) and lower pressure with expiration (EPAP)



[4] Describe an approach to NPPV (non-invasive positive pressure ventilation) and initial settings for CPAP and BL-PAP.

- Remember, deciding to intubate a patient should not be taken lightly. As was described earlier in the podcast, there are numerous physiologic consequences associated with the intubation process, so if we can obviate the need to tube, we should!
- Non-invasive positive pressure ventilation (NPPV) is an option that you can consider in several clinical circumstances. Simply put, NPPV is a means of providing ventilatory support to patients without having to intubate them. This is accomplished by providing delivering CSV using a sealed mask.
- There are two types of NPPV that are traditionally used in hospital. These are:
 - CPAP - continuous positive airway pressure
 - Provides continuous non-varying positive pressure during the entire respiratory cycle
 - BL-PAP (BiPAP) - bilevel positive airway pressure
 - Provides continuous varying positive airway pressure throughout the inspiratory and expiratory phases of the respiratory cycle
 - The detection of inspiration triggers the ventilator to increase the amount of positive pressure delivered, assisting the patient with respiration
 - Once inspiration is complete, the ventilator delivers a lower positive pressure that provides the patient with ventilatory support during the expiratory phase
- Conditions that typically respond well to NPPV:
 - AECOPD
 - CHF Exacerbation
- When considering NPPV, you need to consider the relative contraindications:
 - Altered or diminished LOC
 - Lack of respiratory drive
 - Increased secretions
 - Hemodynamic instability
 - Facial trauma
 - Impending respiratory failure despite trial of NPPV (must reassess frequently)
- Treatment failure of NPPV in AECOPD is defined as:
 - GCS < 11
 - Sustained arterial pH < 7.25
 - Tachypnea >35 BrPM
- As per Rosen's, no specific predictors of failure of NPPV have been identified in the patient with CHF exacerbation
- Initial settings of for NPPV
 - Remember, the selection of the equipment and machine settings is based on a number of clinical factors, including but not limited to:
 - Cooperativeness of the patient
 - Degree of patient comfort
 - Degree of patient dyspnea



- Need for patient to communicate
 - Need for patient to perform adequate pulmonary toileting
- NPPV can be provided through nasal masks or face masks
 - Rosen’s suggests greater complications with nasal masks, and specifically recommends full face masks
- Choosing BL-PAP or CPAP is also a more complex process. Rosen’s suggests there seems to be no clear benefit of one over the other. However, some evidence exists that notes greater benefits of NPPV through BL-PAP rather than CPAP in the patient with CHF.
- Initial settings for the degree of positive pressure support are:
 - Inspiratory support (IPAP) initiated at 10 cmH₂O
 - Expiratory support (EPAP) initiated at 5 cmH₂O
- Titration of machine settings takes into account multiple factors:
 - Patient’s tolerance
 - RR
 - Oxyhemoglobin saturation
- If the patient is not responding well enough to therapy, consider adjusting EPAP and IPAP by 1-2 cmH₂O at a time.
- The maximum IPAP recommended in Rosen’s is 20 cmH₂O, as the risk for gastric insufflation is high at this level of support

[5] What is the Richmond Agitation-Sedation Scale (RASS) and what is it used for?

Richmond Agitation and Sedation Scale (RASS)		
+4	Combative	Violent, immediate danger to staff
+3	Very Agitated	Pulls or removes Tube(s) or catheter(s); aggressive
+2	Agitated	Frequent non-purposeful movement, fights ventilator
+1	Restless	Anxious, apprehensive but movements not aggressive or vigorous
0	Alert and Calm	
-1	Drowsy	Note fully alert, but has sustained awakening to <i>voice</i> (eye opening & contact ≥10sec)
-2	Light Sedation	Briefly awakens to <i>voice</i> (eye opening & contact <10sec)
-3	Moderate Sedation	Movement or eye-opening to <i>voice</i> (but no eye contact)
-4	Deep Sedation	No response to <i>voice</i> , but movement or eye opening to <i>physical</i> stimulation
-5	Unarousable	No response to <i>voice</i> or <i>physical</i> simulation

10 Point scale - range from +4 to -5.

- +4 = Combative
- 0 = Alert and Calm
- -5 = unrousable to voice or physical stim



[6] What analgesics and sedatives are commonly used for post-intubation management?

- As we have said before in other podcasts, sedation and analgesia post-intubation is exceedingly important. Being intubated is not exactly the most comfortable state to be in, so be cognizant of your patient's needs post-intubation
- The primary goal of sedation and analgesia post-intubation is to:
 - Maximize patient comfort
 - Promote patient-ventilator synchrony
- The degree of sedation provided will likely be determined by the clinical goals and the patient's tolerance of the tube.
 - Lighter sedation may be useful if, for example, the clinical situation made necessary recurrent neurological examinations
 - Deep sedation may be useful if the patient is paralyzed
- Remember the Richmond Agitation-Sedation Scale (RASS). It will give you valuable guidance regarding how to best optimize your patient's analgesic and sedative requirements.
 - Should be maintained at the lowest RASS score possible (0 to -2)
 - Needs to be reassessed ROUTINELY
- In most cases, the patient only needs a good combination of analgesia and sedation
 - NMBA's are generally not required.
 - Remember, only use paralytics continuously after intubation if there is poor ventilator synchrony that is interfering with ventilation sedation and analgesia
- Analgesia can be achieved with doses of opioid medications (commonly fentanyl or morphine).
 - Remember to assess renal function (if renal impairment, fentanyl > morphine)
- Sedation can be achieved using multiple pharmacologic therapies
 - Benzodiazepines (lorazepam or midazolam)
 - Typically use intermittent bolus administration before continuous administration is considered, given metabolic/pharmacodynamic changes in the critically-ill patient
 - Propofol
 - Benefit of limited pharmacokinetic changes in the critically ill patient
 - Some evidence to suggest benefit over benzodiazepines in mechanically-ventilated patients
 - Others:
 - Dexmedetomidine
 - Haloperidol
 - Cannot be used as a single agent for sedation



[7] How do you troubleshoot a ventilator?

Crashing Patient?

“Disconnect the vent and bag with 100% O₂”

DOPE

Displacement of ETT into right mainstem, dislodged, or esophagus?

Obstruction of Tube - mucous plugs or kinks in tubing

Pneumothorax (tension) - through that probe on!

Equipment failure or circuit issues.

See table 2.4 in Rosen's 9th Edition Chapter in Mechanical Ventilation and Non-invasive Ventilatory Support

- With hemodynamic compromise: immediately discontinue mechanical ventilation
 - Increased intrinsic positive end-expiratory pressure (iPEEP)
 - Tension pneumothorax
 - Massive pulmonary embolus
- Without hemodynamic compromise: search for underlying cause
 - Mechanical
 - Endotracheal tube migration into bronchus
 - Endotracheal tube obstruction
 - Endotracheal tube cuff leak
 - Inadvertent extubation
 - Discontinuity in ventilator circuit
 - Physiologic
 - Worsening lung compliance
 - Worsening airway obstruction
 - Abdominal distension
 - Pulmonary embolus
 - Pain or inadequate sedation



[8] Outline your approach to ventilator settings in the following situations:

- **Healthy intubated adult**
- **Acute exacerbation of Chronic Obstructive Pulmonary Disease (AECOPD)**
- **Status Asthmaticus**
- **Acute Respiratory Distress Syndrome (ARDS)**

General approach to settings. (<https://emcrit.org/wp-content/uploads/vent-handout.pdf>)

- Tidal Volume (usually 6-8cc/kg predicted body weight) = **protection**
- Flow rate - **comfort**.
- Resp rate - ~12-18 breaths/min and titrate (in most situations) = **ventilation**
- FIO₂ and PEEP = **oxygenation**
 - FIO₂ 100% and PEEP 0 - 5, wait 5 min and draw an ABG. Then set FiO₂ to 30% and start titrating based on chart, go up q5-10min.
 - Oxygenation goal PaO₂ of 55-80mmHg or SpO₂ 88-95%.

Specific Clinical Situations:

- **Healthy intubated adult.**
 - i. **Assist control** - useful modality for most ED patients who are sedated and paralyzed for intubation
 - ii. TV 8cc/kg
 - iii. RR ~12-14
 - iv. PEEP 5cmH₂O
 - v. FIO₂ 100% then titrate down to PaO₂ of 55-80mmHg or SpO₂ 88-95%

The next 3 scenarios illustrate a key dichotomy in ventilation - obstructed lungs vs. injured lungs.

Obstructed Lungs

- **Acute exacerbation of Chronic Obstructive Pulmonary Disease (AECOPD)**
 - i. Obstructive Lung pathology
 - ii. Goal is to minimize auto PEEP
 - iii. Mode - AC, either PCV or VCV
 - iv. VT 6-8cc/kg
 - v. Low RR ~10
 - vi. I:E ratio (inspiratory to expiratory time) of 1:4 or 1:5 to allow for expiration
 - vii. Permissive hypercapnia - aim for pH >7.1
 - viii. PEEP of 5cmH₂O according to Rosen's
 - ix. Deep sedation!
- **Status Asthmaticus**
 - i. Similar to COPD with key differences
 1. Airway obstruction located in larger airways
 2. Decreased lung compliance due to diffuse inflammation.



- ii. Similar to above, but PEEP = 0, and use VCV (decreased lung compliance and increased potential for iPEEP may result in inadequate tidal volumes).

Injured Lungs

- **Acute Respiratory Distress Syndrome (ARDS)** - “spectrum of inflammatory lung disease characterized by heterogenous noncardiogenic pulmonary edema, hypoxia, diffuse consolidation. Severity = mild, moderate, severe. Defined by ratio of arterial O₂ concentration to FIO₂ - PaO₂ / FIO₂.
- Our goal is to avoid **ventilator induced lung injury (VILI)**
 - i. Mode - AC
 - ii. 6-7cc/kg and PPlat < 31cmH₂O mortality benefit (ARDSnet trial and other data)
 - iii. FIO₂ - start at 100% and titrate down
 - iv. PEEP - active area of research. Can use 5.

Special Situations:

- **Salicylate OD**
 - Want to match the minute ventilation (determined by VT and Resp rate) pre-intubation .. to avoid hypercapnia and arrest..
 - Pressure control strategy - does not limit inspiratory flow and is beneficial in patients with high respiratory drive.

Wisecracks:

[1] What conditions benefit from non-invasive ventilation?

- Spaced repetition here. Remember, the following two conditions have solid evidence to suggest benefit:
 - Acute exacerbation of COPD
 - Acute exacerbation or decompensation with CHF
- Note: just because these two have robust evidence does not mean you cannot use NPPV in other scenarios. Continue to watch as more and more research is done in this field to guide your practice in the future.

[2] What is high-flow nasal cannula and when should it be used?

HFNC is a method to deliver NIV through nasal cannula rather than facemask.

Delivers **humidified oxygen** at high flow rates to achieve high O₂ concentrations.

Multiple theories as to how this affects pulmonary physiology - dead space washout, small level of positive airway pressure or some other mechanism - incompletely understood.

Useful for **hypoxic respiratory failure** either of unclear diagnosis, or due to parenchymal lung disease (Pneumonia, ARDS, ILD).



[3] What are some strategies to prevent ventilator-acquired pneumonia (VAP)

- Strategies to prevent VAP:
 - Management of secretions with regular endotracheal suctioning
 - Placement of an NG or OR tube for gastrointestinal decompression
 - Elevating the head of the bed, placing the patient in a semi-recumbent position
 - Continuous aspiration of supraglottic secretions

[4] What should you target your RASS scores to when sedating patients post-intubation?

- Remember, we already spoke to this multiple times. If you forget, check out the key points at the beginning of the shownotes document:
- *“The Richmond Agitation Sedation Score (RASS) or a similar scoring system should be used to manage sedation and analgesia of the mechanically ventilated patient to avoid unnecessary use of prolonged neuromuscular blockade. When RASS is used, a target score of -2 to 0 avoids both over and under sedation.”*

[5] What is auto-PEEP

- The term “auto-PEEP” or “iPEEP” refers to a physiologic and intrinsic positive-end expiratory pressure. Largely results from the accumulation of end-expiratory volume when the patient cannot completely exhale.
- iPEEP is accomplished by reducing the expiratory time by increasing the RR, inspiratory volume, or tidal volume
- Commonly seen in acute asthma exacerbation and AECOPD
 - This is commonly referred to as “breath stacking”
- It is important to note that auto-PEEP may actually result in improper ventilation when sufficient time to completely exhale is not given. You need to watch these patients closely and intervene early to ensure they are best cared for.
- Can result in
 - Increased PIP’s
 - Hypotension
 - Circulatory collapse
- Addressed by:
 - Reducing the RR
 - Increased expiratory time