CHAPTER 15

MECHANICAL VENTILATION

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Ensuring adequate oxygenation, ventilation, and securing the airway in an emergency may be potentially life-saving. Non-invasive positive pressure ventilation and invasive mechanical ventilation are not curative therapies but can support the body by providing oxygen, ensuring ventilation, and reducing work of breathing. A basic understanding of how to optimize gas exchange will empower the practitioner to improve patient outcomes.

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Abbreviations:

ABG	arterial blood gas
AC	assist control
ARDS	acute respiratory distress syndrome
ASV	adaptive support ventilation
ATLS	Acute Trauma Life Support
BIPAP	bi-level positive airway pressure
CABG	coronary artery bypass graft
CHF	congestive heart failure
CO_2	carbon dioxide
COPD	chronic obstructive pulmonary disease
CPAP	continuous positive airway pressure
CXR	chest x-ray
$EtCO_2$	End-tidal carbon dioxide
DKA	diabetic ketoacidosis
DNI	do not intubate
ENLS	Emergency Neurologic Life Support
ETT	endotracheal tube
FiO_2	fractional inspiration oxygen
FRC	functional residual capacity
IBW	ideal body weight
ICP	intracranial pressure
MV	mechanical ventilation
NCCU	neurocritical care unit
NIPPV	noninvasive positive pressure ventilation
NIF	negative inspiratory force
NIPPV	noninvasive positive pressure ventilation
NMBA	neuromuscular blockade agent
PC	pressure control
PE	pulmonary embolism
PEEP	positive end expiratory pressure
PIP	peak inspiratory pressure
Pplat	plateau pressure
PRVC	pressure regulated volume control
RR	respiratory rate
RSBI	rapid shallow breathing index
RSI	rapid sequence intubation
SIMV	synchronized intermittent mechanical ventilation
SpO_2	oxygen saturation
VALI	ventilator associated lung injury
VC	volume control
V_T	tidal volume

INTRODUCTION

Inadequate oxygenation and/or ventilation are frequently encountered within the NCCU. Urgent airway protection is often needed for the critically ill neuroscience patient due to altered mental status, depressed level of consciousness, and respiratory compromise.

Typical escalations of supplemental oxygen therapy:

Nasal cannula → Simple mask (e.g. Venturi) → Non-rebreather mask → NIPPV → Mechanical ventilation

1 This chapter includes major contributions from prior authors: Benedict Tan, Paul Nyquist & Asma Moheet.

NON-INVASIVE POSITIVE PRESSURE VENTILATION

NIPPV refers to mechanical ventilation without an endotracheal tube. The most common way to administer NIPPV is using a mask interface that conducts gas from a positive-pressure ventilator into the nose and/or mouth.

For a summary of types of acute respiratory failure treated with NIPPV, see Table 1. For contraindications to NIPPV, see Table 2. Common types of NIPPV are reviewed below:

High Flow Nasal Cannula (HFNC)

- Air-oxygen blender that can generate up to 100% FiO_2 with a very high flow rate where FiO_2 and flow can be titrated
- Provides some PEEP which can improve alveolar recruitment and compliance and decrease work of breathing
- Used primarily in hypoxic respiratory failure

Continuous Positive Airway Pressure (CPAP)

- Used with a tight face or nose mask, provides a fixed level of positive pressure continuously. A good seal is important to achieve intended positive pressure
- Start with an initial pressure setting of 10 cm H_2O. Increase or decrease based on patient's comfort level and effectiveness of treatment. FiO_2 delivery should also be titrated based on PaO_2 or pulse oximetry
- May be uncomfortable to some patients, and may cause dryness, nasal congestion, skin breakdown, vomiting (increased risk of aspiration in those unable to remove mask), and eye irritation

Bi-level Positive Airway Pressure (BiPAP or BiLevel)

- Used with a tight face or nose mask, delivers different levels of pressure during inspiration (IPAP) and expiration (EPAP)
- Start with IPAP between 12-15 cm H_2O and EPAP between 4-7 cm H_2O. Increase or decrease based on patient comfort and treatment efficacy. FiO_2 delivery should also be titrated based on PaO_2 or pulse oximetry
- Hypoxia can be addressed by increasing the EPAP or increasing the FiO_2, and hypercapnia can be addressed by increasing the difference between the IPAP and EPAP
- May be uncomfortable to some patients, and can cause dryness, nasal congestion, skin breakdown, vomiting, and eye irritation
- Best NIPPV option for hypercapnic respiratory failure

INDICATIONS FOR INTUBATION

In any acutely ill patient, it is important to ensure a patent and secure airway. The decision whether to escalate to intubation and initiate MV is crucial. Various indications for intubation include:

- Inadequate gas exchange
- Hypoxic respiratory failure/ARDS
- Hypercapnic respiratory failure

- Impending respiratory distress
- Inspiratory muscle weakness and impending respiratory muscle fatigue
- Airway protection
- Toxic overdose
- Acute CNS disease
- Blunted, diminished or weakened airway reflexes (i.e. at risk for aspiration)
- Contraindications to NIPPV

Patient specific disease-state and anatomic factors should be evaluated for potential difficulty airway. These patients may need a plan in place for advanced airway management before any sedatives or paralytics are administered and the patient's own respiratory drive is suppressed.

- Risk factors for difficult airway: suspicion of cervical spine injury, s/p recent transsphenoidal surgery, facial or airway trauma, restricted mouth opening, and anatomical features such as neck size and thyromental distance

Skilled bag-mask ventilation is the most important and valuable bridge to intubation, and ensuring adequate clearance of airway obstruction

- Techniques: jaw thrust, head tilt/chin lift (avoid if possible cervical spine injury), nasopharyngeal airway device (avoid if possible facial/skull base fracture) or oropharyngeal airway device, appropriate hand positioning for mask seal (occasionally two hand technique required)

For more details on indications for converting from NIPPV to intubation, see Table 3.

RAPID SEQUENCE INTUBATION (RSI)

RSI is the preferred method to achieve urgent tracheal intubation. This technique utilizes sedation and a NMBA. Many of the induction agents can cause hypotension. Having a vasopressor at bedside is essential. For a pre-intubation checklist, see Table 4.

Hypnotics/Sedatives

- Propofol 0.5-2 mg/kg IV - may cause hypotension
- Midazolam 0.01-0.05 mg/kg IV - slower onset than propofol, minimal hemodynamic effects
- Fentanyl 2-3 mcg/kg IV - may cause hypotension and bradycardia. Good for analgesia, does not provide amnestic properties
- Etomidate 0.3 mg/kg IV - minimal hemodynamic effects, risk of adrenal suppression, particularly with repeated use
- Ketamine 1.5-2 mg/kg IV - may cause slight hypertension, tachycardia, increased ICP

NMBAs

- Rocuronium 1 mg/kg IV - no hemodynamic change or significant contraindications. Onset effect about 1 min. Prolonged duration of action but reversal agent, sugammadex available
- Succinylcholine 1.5-2 mg/kg IV - contraindicated with prolonged bedrest, hyperkalemia, myopathy, burns, spinal cord injury, renal failure, and malignant hyperthermia. May cause bradycardia and increased ICP.

POST-INTUBATION MANAGEMENT

The ETT must be confirmed and secured, and post-intubation sedation addressed. Optimizing oxygenation and ventilation through appropriate ventilator settings is key.

The following checklists are considered important in the immediate post-intubation period:

- Confirmation of ETT placement
  - Immediate confirmation:
    - Direct visualization of ETT passing through vocal cords
    - Condensation within the ETT
    - Colorimetric CO_2 detector or waveform capnography (Caveats: first few positive ventilations may yield CO_2 despite being in esophagus and CO_2 may not be detectable in cardiac arrest despite proper positioning)
    - Auscultation for symmetric breath sounds and observation for symmetric chest rise
- If there is ANY concern for esophageal placement, the ETT should be removed immediately, the patient bagged, and intubation strategy revisited.
- Securing the ETT following immediate confirmation using tape or a tube holder, noting the tube position at the lip, teeth, or gums.
  - Delayed confirmation:
    - ETT position on CXR. The tip of the ETT should be ~4 cm above the carina. The tip may travel 2-3 cm downward with neck flexion or 2-3 cm upward with neck extension.
- Sedation: Should always be used while the patient is paralyzed. Utilize for patient comfort, ventilator synchrony, and optimal gas exchange. Choice of agent will depend on the patient's underlying clinical condition and hemodynamic stability. (See Chapter 14 High-Yield Medications)
- Assessment of hemodynamics: Hypotension may occur after intubation due to medication effect or reduced venous return in the setting of increased intrathoracic pressure from MV. Start IVF prior to intubation process and have vasopressors available
- Assessment of gas exchange: SpO_2, $EtCO_2$, and ABG can be used. In cases where adequate analgesia and sedation are not enough to ensure optimal oxygenation and ventilation, paralysis may also be used. (See Chapter 14 High-Yield Medications)

BASIC VENTILATOR SETTINGS

Tidal Volume (V_T)

- Typically 6-8 mL/kg initially. See lung protective ventilation protocol below. Should be modified in the context of $PaCO_2$ goals.

Respiratory Rate (RR)

- Typically rate of 10-14 bpm, but pre-intubation respiratory rate/minute ventilation should be considered.
- Consider short-term hyperventilation for cerebral edema or impending herniation. Should be modified in the context of $PaCO_2$ goals.

Inspired O_2 concentration (FiO_2)

- Initially set at 60-100% immediately after intubation then wean based on SpO_2 and PaO_2 goals.
- Hypoxia is a validated cause of secondary brain injury and must be avoided, but at the same time, hyperoxia leads to reperfusion injury and is associated with worse outcome.

Positive end-expiratory pressure (PEEP)

- Initial PEEP of 5 cm H_2O to prevent alveolar collapse during end-expiration is reasonable.
  - Higher PEEP may be appropriate for severe hypoxia or patient anatomic considerations (e.g. morbid obesity)
- High PEEP can worsen hypotension, increase intra-abdominal pressures, and lead to auto-

PEEP.

- ◻ PEEP > 10 cm H_2O can also raise ICP

Peak inspiratory pressure (PIP)

- ■ Airway pressure at the end of each lung inflation which is a measure of airway resistance and lung/chest wall compliance
  - ◻ Normal PIP are typically < 25 cm H_2O
- ■ ↑ PIP with no change in Pplat suggests ↑ airway resistance (e.g., bronchospasm, mucus plugging)
- ■ ↑ PIP with ↑ Pplat suggests decreased lung compliance and has a much broader differential (e.g., tension pneumothorax, right main-stem intubation, atelectasis, pulmonary edema, pneumonia, etc.)
- ■ ↓ PIP suggests ↓ airway resistance or air leak.

Plateau pressure (Pplat)

- ■ Peak pressure in the alveoli at the end of inspiration when there is <u>no flow</u>

Interpreting chest wall/lung compliance:

- ■ ↑ Pplat suggests ↓ lung or chest wall compliance (pneumothorax, pneumonia, pulmonary edema, atelectasis, auto-PEEP)
- ■ Maintain Pplat < 30 cm H_2O to minimize barotrauma

<u>Highlights of ARDSnet protocol* for lung protective ventilation</u>

- ■ V_T = 6-8 mL/kg (predicted body weight)
- ■ Pplat < 30 cm H_2O
- ■ pH = 7.30-7.45
- ■ Oxygenation goal: PaO_2 55-80 mmHg or SpO_2 88-95%

*Please refer to the webpage of ARDSnet (http://www.ardsnet.org) for the full protocol

Remember, this approach is often modified in NCCU patients to avoid hypoxia or excessive hypercapnia.

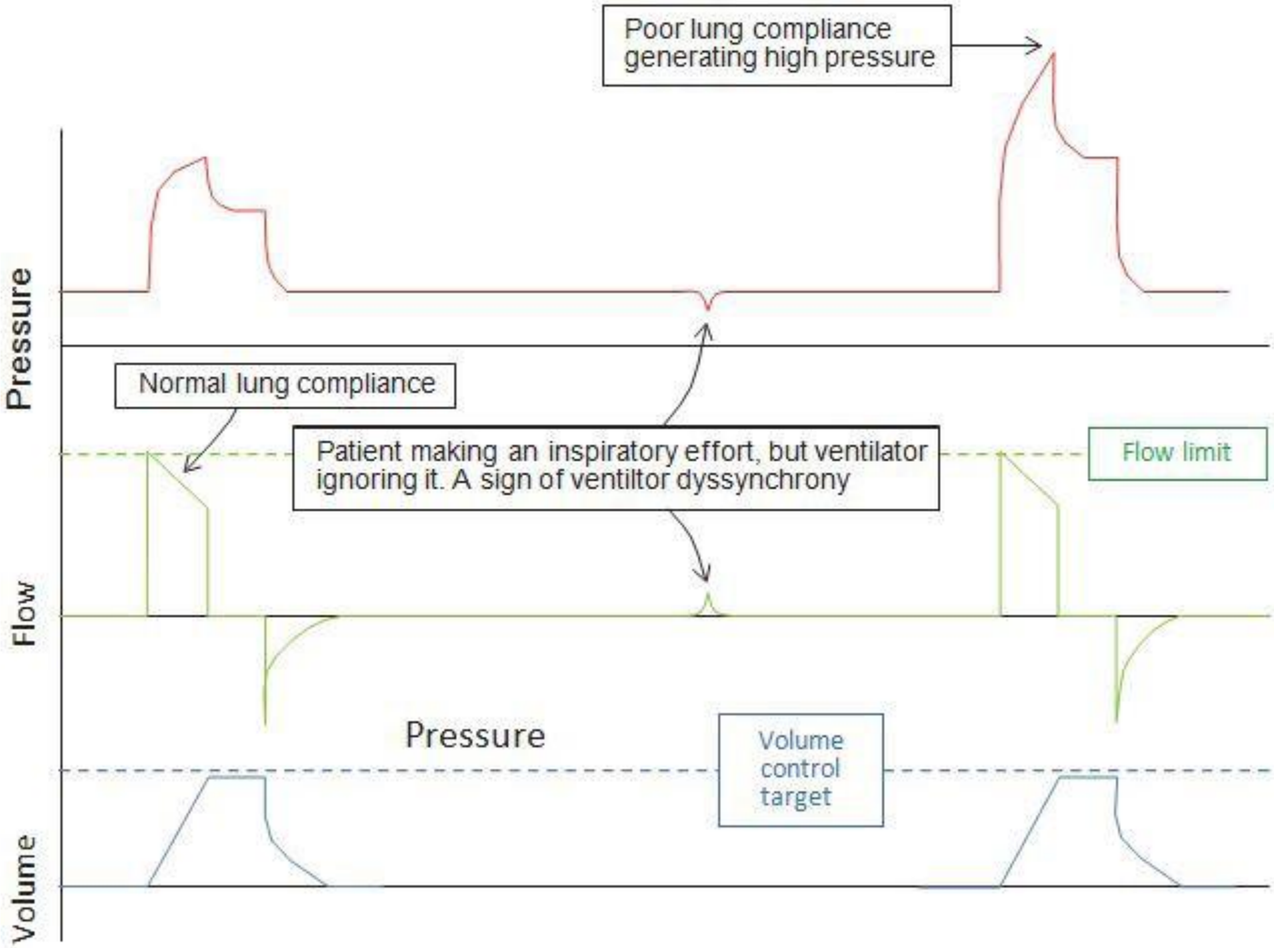
BASIC MECHANICAL VENTILATION PHYSIOLOGY

The initiation and delivery of a breath can be controlled by the patient or the ventilator. The positive pressures of lung inflation can either be volume-controlled (VC – where inflation volume is constant) or pressure-controlled (PC – where inflation pressure is constant). Most physicians select the mode with which they are most comfortable. Sometimes the choice is limited by the capability of the ventilator. For comparisons, see Tables 5 and 6.

CONTINUOUS MANDATORY VENTILATION OR ASSIST-CONTROL VENTILATION

Breaths are assisted or controlled, but all breaths are the same and can be either volume-controlled (AC/VC) or pressure-controlled ventilation (AC/PC). Sets a minimum minute ventilation = RR x $V_{T,}$ but the patient can trigger additional breaths which are "assisted" to receive the set V_T. See Figure 1.

Figure 1. AC/VC mode



Advantages:

- Initial mode right after intubation is AC/VC to allow more control, however if higher airway pressures AC/PC may be appropriate
- Permits respiratory muscle rest
- During passive ventilation, V_T, PEEP, Pplat, and peak airway pressure are measured easily, allowing the calculation of resistance, compliance and time constant of the respiratory system
- No known absolute contraindications

Disadvantages:

- Can be uncomfortable for the patient and require significant sedation
- Spontaneous breaths receive full V_T. Tachypnea may result in respiratory alkalosis, breath stacking, and auto-PEEP

SYNCHRONIZED INTERMITTENT MECHANICAL VENTILATION

SIMV delivers a minimum number of fully assisted breaths per minute which synchronize with the patient's spontaneous respiratory rate. Breaths taken between the time/volume-cycled breaths are unassisted and reflect patient pulmonary mechanics, strength, and effort. If the patient does not trigger spontaneous breaths, it is identical to AC modes.

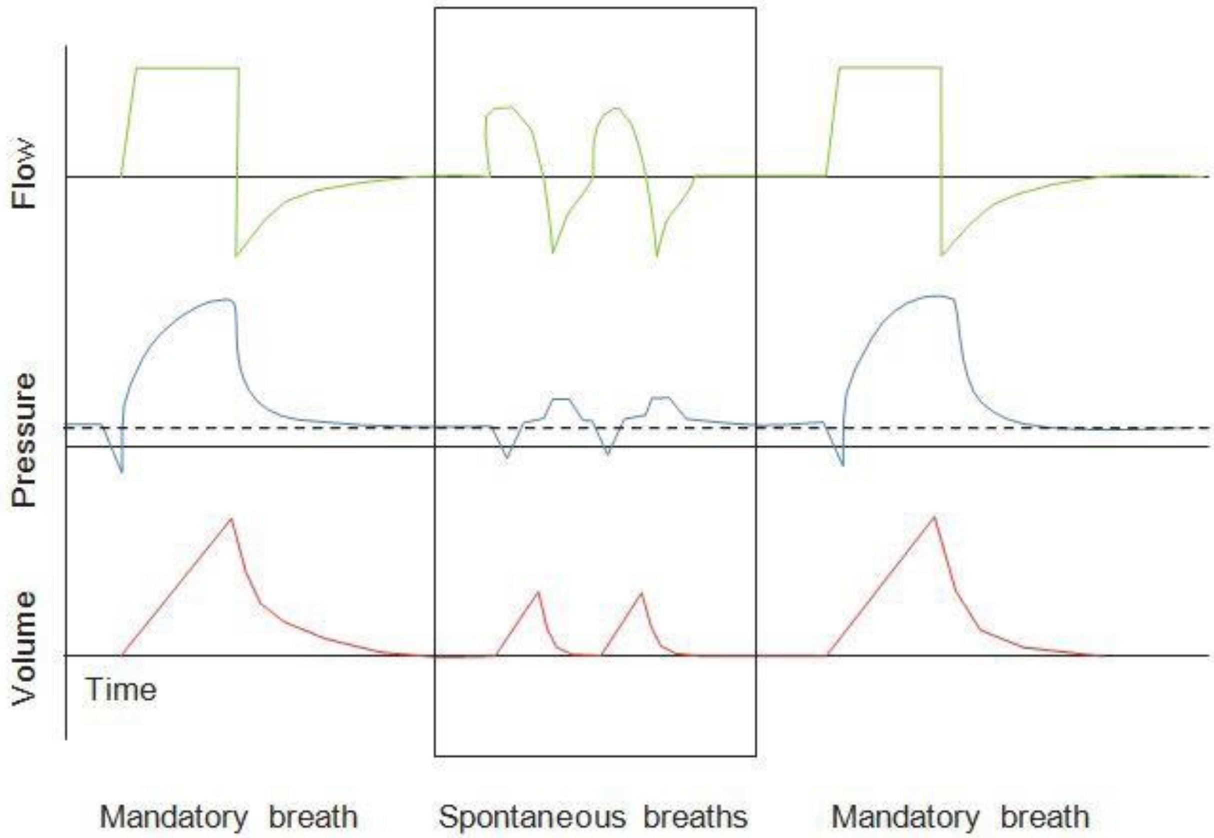
Advantages:

- Permits spontaneous breathing which can be more comfortable
- Results in lower mean airway pressure than AC modes

Disadvantages:

- May increase the work of breathing for patients due to unassisted breaths
- May lower cardiac output in patients with left ventricular dysfunction

Figure 2. SIMV mode



PRESSURE-REGULATED VOLUME CONTROL

PRVC is a pressure-controlled mode with a volume target.

Advantages:

- Allows a set V_T. As patient compliance or effort improves, will wean from pressure limits

Disadvantages:

- V_T is not controlled as precisely as in AC/VC
- As patient effort increases, the ventilator reduces support, this may not be ideal if the patient is not yet ready

ADAPTIVE SUPPORT VENTILATION

A mode that is increasingly gaining acceptance. ASV automatically selects the appropriate V_T and frequency for mandatory breaths and the appropriate V_T for spontaneous breaths based on the mechanics of the respiratory system and the target minute alveolar ventilation.

Advantages:

- Can be used from initial support to weaning

Disadvantages:

- Precise control of $PaCO_2$ levels may be more difficult to achieve. This can be problematic in

NCCU patients who may have tight goals for $PaCO_2$

- Inability to recognize dead space ventilation or shunts and adjust ventilation

PRESSURE SUPPORT VENTILATION

PSV is spontaneous mode that delivers an inspiratory pressure at a set amount when the patient initiates spontaneous breaths. The amount of this support can be set to overcome the resistance of the ventilator tubing (generally PS of 5-10 cm H_2O) and PEEP to prevent alveolar collapse. Volume and respiratory rate are patient determined based on effort and lung mechanics.

Advantages:

- More comfortable for the patient
- Useful to assess readiness for extubation

Disadvantages:

- Does not provide full or near-full ventilatory support
- Central apnea may occur if respiratory drive is suppressed
- Adequate minute ventilation cannot be guaranteed
- Associated with poorer sleep than AC
- Suboptimal for patients with increased airway resistance

ADJUSTING VENTILATOR SETTINGS

- To improve oxygenation (pO_2)
  - ↑ FiO_2 and/or ↑ PEEP
  - Improved oxygenation with ↑ PEEP and stable Pplat suggests recruitable lung and can up titrate to a maximum of Pplat 30 cm H_2O
  - No change in oxygenation suggests nonrecruitable lung so reasonable to ↓ PEEP to minimize shunt and dead space from overdistended lung
- To improve ventilation (pCO_2)
  - ↑ V_T and/or ↑ RR

RESPONDING TO VENTILATOR CRISES

Changes in clinical condition may occur over the course of MV. We will focus on practical approach to ventilator deterioration in relation to PIP.

Increased PIP (> 40 cm H_20)

- With normal Pplat = increased airway resistance (e.g., bronchospasm, secretions, aspiration, ventilator tubing kinked or obstructed)
- With increased Pplat = decreased lung/chest wall compliance (e.g., asynchronous breathing, auto- PEEP, pneumothorax, mainstem intubation, atelectasis, pneumonia, PE, pulmonary edema)

Reduced Oxygen Saturation

- Worsening lung disease (e.g., edema, pneumonia, atelectasis, pneumothorax, PE, ARDS, etc.)
- Worsening ventilation/perfusion mismatch (e.g., change in body position, increasing shunt)
- ETT malposition or presence of a cuff leak
- Ventilator malfunction (may need to disconnect and hand-bag ventilate the patient)
- Increased oxygen consumption

- Intra-cardiac shunt (right-to-left)
- Acute blood loss

Rising $PaCO_2$

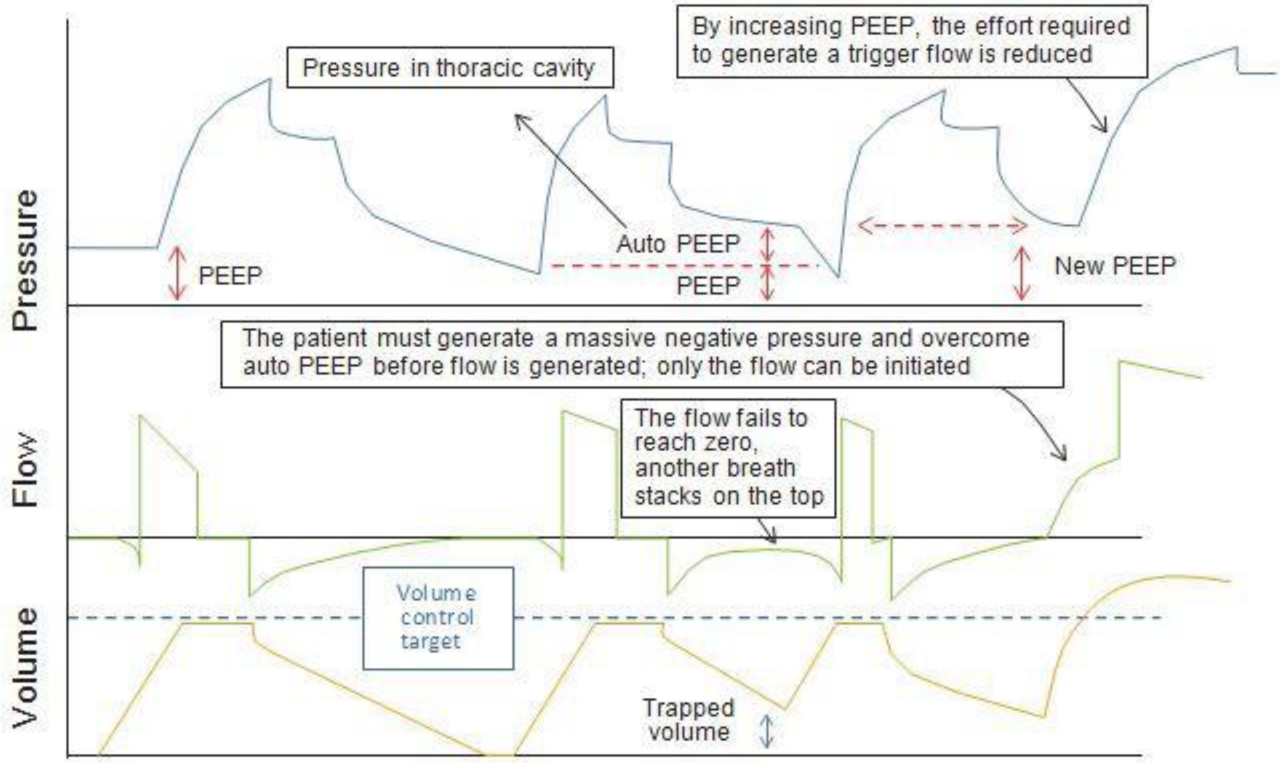
- Increased CO_2 production due to underlying disease
- Increased CO_2 retention due to increased sedation or paralysis, bronchospasm
- Increased dead space
- Possible ventilator malfunction

COMPLICATIONS OF MECHANICAL VENTILATION

AUTO-PEEP (INTRINSIC PEEP)

- Incomplete expiration prior to initiation of the next breath leads to progressive air trapping and subsequent increased intrathoracic pressure.
- Three main causes:
  - High minute ventilation (large V_T or high RR) leading to insufficient time for lungs to return to FRC
  - Expiratory flow limitation (e.g., bronchospasm, COPD, mucus plug, exhalation valve malfunction)
  - High expiratory resistance (e.g., kinked ETT, secretions, ventilator asynchrony)
- Complications:
  - Accumulation of air leads to ↑ alveolar pressure at the end of expiration causing ↑ intrathoracic pressure leading to ↓ venous return, ↓ cardiac output, and potential hypotension
  - The increase in pressure also causes alveolar over-distention, increasing the likelihood of pulmonary barotrauma and ventilator-associated lung injury (VALI)
  - Alveolar over-distention may also cause hypoxemia due to compression of adjacent pulmonary blood vessels leading to V/Q mismatch
  - Increases the work required for a patient to trigger a ventilator breath when pressure-triggering is being used
- Ways to check for auto-PEEP:
  - Perform an end-expiratory pause for 3-5 sec. This allows alveolar pressure to equilibrate with airway pressure (auto-PEEP = end-expiratory alveolar pressure – applied PEEP)
  - See Figure 4 for example of recognizing auto-PEEP on ventilator tracings
- Management:
  - Identify underlying cause and treat
  - ↓ inspiratory time/↑ expiratory time if either can be tolerated

Figure 4. Example of auto-PEEP



VENTILATOR DYSSYNCHRONY

Patient-ventilator dyssynchrony is delivery of a breath from the mechanical ventilator that is not matched to the patient effort, and is a common problem in the NCCU. This can result in inadequate oxygenation and/or ventilation, patient discomfort, and increased intrathoracic, intra-abdominal, and intracranial pressures.

The most common causes are:

- Patient factors: increased respiratory drive, timing of the respiratory rhythm, hiccups, coughing, cardiac oscillations, shivering, neuromuscular weakness, seizures, agitation, inadequate sedation
- Ventilator factors: inconsistent delivery mechanism (flow, volume or pressure), inappropriate mode for patient, droplet condensation in the circuit, triggering sensitivity too low, inappropriate I:E ratio, high auto-PEEP

Management:

- Correction of the underlying cause

VENTILATOR WEANING AND EXTUBATION

Defining specific extubation criteria for patients in NCCU has proved to be problematic due to the wide range of indications for MV (e.g., airway protection, hypoxia, weak respiratory muscles, etc.). Successful extubation requires both improvement of the underlying disease process (pulmonary or neurologic) and the ability to maintain airway patency. More than half of the patients can be successfully liberated from mechanical ventilation after a brief SBT.

SPONTANEOUS BREATHING TRIAL (SBT)

- PS, CPAP, and T-piece trials are the most common methods used for SBT. No strong evidence supports one over the other.

- The first SBT should last about 30 min. A longer trial has not been found to predict extubation failure more accurately.
- Failure: Respiratory distress or increased work of breathing (agitation, diaphoresis, rapid breathing, paradoxical abdominal movement, use of accessory muscles, impaired gas exchange (ABGs, $PaO_2/FiO_2 < 200$),
  - In the setting of a failed initial SBT, intensivists may choose to repeat and sometimes extend SBTs (up to 2 hours). If the patient does well, extubation is considered.
- Despite a successful SBT, reintubation is necessary ~15% of the time.

<u>Minimum criteria for SBT</u>

- PaO_2/FiO_2 > 150-200 mm Hg with $FiO_2 < 50\%$
- PEEP ≤ 8 cm H_2O
- pH > 7.25
- Patient can initiate an inspiratory effort
- Institutions may have specifc SBT or liberation protocols

<u>Other criteria that should be considered during SBT</u>

- Resolution/improvement of the initial condition requiring mechanical ventilation support
- Medical appropriateness to undergo an SBT: normal ICP, hemodynamically stable (e.g., off vasopressors, no active arrhythmias), no concern for sepsis
- Level of alertness
- Ability to manage secretions
- Presence of cuff leak may be considered (not a robust predictor and may be absent due to ETT size and patient anatomy)
- $PaCO_2$ is normal or at baseline

WEANING PREDICTORS

RSBI = ratio respiratory frequency to tidal volume (f/V_T)

- Rapid breathing without increased tidal volume (hyperventilation) suggests anxiety rather than ventilatory failure
- Weaning failure increased with RSBI $\geq$ 105
  - Better at identifying potential extubation failures than successes

Negative inspiratory force (NIF) is a measurement of inspiratory muscle strength. Patient is instructed to maximally inhale against a closed valve and the force/pressure that is generated at the mouth is recorded.

- NIF weaker than -20 cm H_2O is associated with weaning failure
- Useful in neuromuscular respiratory failure as is seen with GBS or MG

EXTUBATION RISK ASSESSMENT

Post-extubation stridor/laryngeal edema is a major cause of reintubation.

- Risk factors: self-extubation within the last week, intubation more than once within 5 days, difficult intubation, and agitation

For high risk patients, consider pre-extubation treatment and precautions:

- Administer steroids prior to extubation
- Consider using an airway exchange catheter
- Administer nebulized budesonide 1 mg prior to extubation

Treatment of post-extubation stridor:

- Administer racemic epinephrine 1 mg via nebulizer
- Administer steroids x 24-48 hours

DISEASE SPECIFIC CONSIDERATIONS

Facial trauma or post-transsphenoidal surgery

- Consider early intubation due if there is edema, blood in the airway, or direct trauma to the trachea or larynx.
- Nasotracheal intubation should be avoided in nasal or skull base fractures or after skull base surgery.
- NIPPV is contraindicated due to danger of causing tension pneumocephalus related to dural tears of lack of dural integrity after surgery.

Impending herniation and increased ICP (ENLS recommendations)

- Hyperventilation can be a temporizing intervention to acutely ↓ ICP and can be considered with concomitant hyperosmolar therapy while awaiting definitive therapy.
- Maximal cerebral vasoconstriction can be achieved at $PaCO_2$ of 20 mmHg, but the risk of ischemia with ↓ CBF versus lowering ICP must be weighed.
  - In addition to having a short duration of effect, rebound ↑ in ICP can be seen.
  - Therefore, as a temporizing measure for ↑ ICP a goal $PaCO_2$ of 30-35 mmHg is recommended for ideally < 30 min and no more than 6 hours.

Cervical injury (ATLS & ENLS recommendations)

- Cervical spine stabilization principles as outlined in ATLS should be applied.
- Cricoid pressure should not be implemented as it may cause posterior displacement of the cervical spine.

Neuromuscular weakness (ENLS recommendations)

- Because of potential for exacerbating weakness and prolonged medication effect, the administration of NMBAs, corticosteroids, and muscle relaxants is not recommended.
- Some NMBA (succinylcholine) may cause severe hyperkalemia and should not be used.

Pneumothorax

- A tension pneumothorax is life-threatening and requires immediate placement of a chest tube (+/- preceding needle decompression).
- If mechanical ventilation is needed, the ventilator setting should support fistula closure. Limit inflation pressure. Early spontaneous breathing may support fistula closure.

Acute respiratory distress syndrome (ARDSnet protocols)

- The ARDSnet trial showed improved mortality when a tidal volume of 6 mL/kg compared to the traditional 12 mL/kg was utilized.
  - Please refer to the webpage of ARDSnet (http://www.ardsnet.org) for the full protocol, and please refer to the 2012 ARDS Task Force for the Berlin Definition of ARDS.
- Low V_T ventilation was the primary independent variable associated with reduced mortality and plateau pressure < 30 cm H_2O was the secondary goal.
- Low V_T often results in some degree of relative hypoxia and permissive hypercapnia, and for this reason ARDS ventilation strategies are often modified in patients with intracranial pathologies

that cannot tolerate hypoxia and hypercapnia due to potential for secondary brain injury.

Table 1. Types of acute respiratory failure treated with NIPPV*

Types of acute respiratory failure treated with NIPPV (graded)
Strong evidence - **Recommended** COPD exacerbation Acute cardiogenic pulmonary edema Immunocompromised (hematologic malignancy, bone marrow or solid organ transplantation, AIDS) Facilitation of weaning/extubation in patients with COPD
Intermediate evidence Asthma Community acquired pneumonia in COPD Extubation failure in COPD Hypoxemic respiratory failure DNI patients (COPD and CHF exacerbations) Post-operative respiratory failure (lung resection, bariatric, CABG)
Weaker evidence ARDS with single organ involvement Community acquired pneumonia in non-COPD Cystic fibrosis Facilitation of weaning/extubation in non-COPD patients Neuromuscular disease/chest wall deformity OSA/obesity hypoventilation Trauma Upper airway obstruction
Not recommended Severe ARDS with multiple organ failure Postoperative upper airway or esophageal surgery Acute deterioration in end-stage interstitial pulmonary fibrosis Upper airway obstruction with high risk occlusion Additional contraindication: Patients with a defect in skull base/sphenoid sinus either due to surgery or trauma. They are at risk for tension pneumocephalus with positive pressure ventilation.

*Modified from Principles and Practice of Mechanical Ventilation, 3rd Edition, Martin Tobin MD, Chapter 18 Noninvasive Methods of Ventilator Support, Table 18-1. Page 452

Table 2. Contraindications to NIPPV

Contraindications to NIPPV
▪ Inability to protect airway or clear secretions ▪ Impaired consciousness (severely agitated, very uncooperative patients) ▪ Cardiac arrest ▪ Respiratory arrest ▪ Hemodynamic instability ▪ Facial surgery ▪ Trauma or deformity of the face or head ▪ Recent transsphenoidal surgery (may lead to tension pneumocephalus) ▪ Pneumothorax ▪ Upper airway obstruction ▪ Complicated multi-organ failure ▪ Recent esophageal anastomosis

Table 3. Converting from NIPPV to intubation

Indications for converting from NIPPV to intubation
▪ Inability to tolerate NIPPV ▪ Large leak or poor mask fit for anatomical reasons ▪ Progressive hypercapnia with adequate support (usually > 1 hour) ▪ High total PEEP (> 25 cm H_2O) ▪ Hypoxemia despite adequate PEEP and FiO_2 ▪ Worsening mental status and declining ability to protect airway ▪ Evolving respiratory muscle fatigue or impending respiratory arrest
Indications for endotracheal intubation

▪ Airway protection (e.g., altered mental status, TBI, stroke, cervical SCI, neuromuscular bulbar weakness, SE)
▪ Obstruction (angioedema, neck hematoma, anaphylaxis, tumor)
▪ Pulmonary diseases
  ▫ Hypoxemia (pneumonia, pulmonary edema, pulmonary embolism, interstitial lung diseases, etc.)
  ▫ Hypercapnia (COPD, hypoventilation, etc.)
  ▫ ARDS
▪ Failed trial of extubation
▪ Foreseeable protracted course of respiratory failure
▪ Cardiac arrest or severe shock (sepsis, hypovolemic, neurogenic)
▪ Severe metabolic derangements (DKA, metabolic acidosis)

Table 4. Pre-intubation checklist

Preparation of equipment	Preparation of team
▪ Cardiac monitor, pulse oximetry ▪ IV access ▪ Bag-valve mask with 100% oxygen ▪ RSI/ACLS drugs ▪ End-tidal CO_2 detector ▪ Laryngoscope/intubation kit ▪ Suction with Yankauer tip ▪ ETT with stylet, 10 mL syringe ▪ Airway adjuncts ▪ Emergency airway plan	▪ Optimal patient positioning ▪ Pre-oxygenation ▪ Prepare plan for difficult airway ▪ Oxygenation plan in event of failed intubation ▪ Confirm roles: pre-oxygenation, intubation, drug administration, cricoid pressure, in-line stabilization

Table 5. Volume-controlled versus pressure-controlled ventilation

Volume-controlled	Pressure-controlled
Volume is **set** to be delivered over a set time.	Volume **fluctuates** depending on flow.
Pressure **fluctuates** depending on lung resistance, as flow (volume over time) remains the same.	Pressure is **set** to be delivered over a set time.
Flow **remains constant** until the volume is delivered.	Flow **starts high** to achieve the desired pressure and **decreases** gradually on a slope, depending on compliance. If lung compliance is high, less flow is required to maintain the same pressure and vice versa.

Table 6. Comparison of different modes of ventilation

	CMV/ACV	SIMV	ASV	APRV	PSV	PRVC
Type of breath	Assisted & mandatory	Assisted, mandatory, & spontaneous	Assisted & spontaneous	Spontaneous	Spontaneous	Assisted, mandatory, & spontaneous
Trigger	Ventilator/ patient	Ventilator/ patient	Ventilator/ patient	Ventilator/ patient	Patient	Ventilator/ patient
Weaning	No	Intermediate	Yes	Yes	Yes	No
pH & PaCO2 control	Yes	Yes	Difficult	Difficult	No	Yes
NM diseases	Yes/Yes	No*	No data	No	Yes	Yes

*Not recommended

Mechanical Ventilation Pearls & Pitfalls:

- Two main components of mechanical ventilation are oxygenation and ventilation. In hypoxia, increase PEEP and/or FiO_2. In hypercapnia, increase RR or V_T.
- ACV, CMV, and SIMV are identical modes in a patient who is not spontaneously breathing, such as those heavily-sedated or paralyzed.
- The ARDSnet protocol was originally designed as a lung protective strategy for ARDS patients. Its use may be modified in acutely-ill NCCU patients when it is crucial to avoid hypoxia or hypercapnia.
- Abnormal neuro exams are very frequently encountered in the NCCU. Extubation may still be considered if the patient meets other criteria on an individualized basis.
- Neither weak cough, lack of gag reflexes, or absence of a cuff leak necessarily prevents extubation but will need special precautions for aspiration and low threshold for reintubation.

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