Newborn Critical Care Center (NCCC) Clinical Guidelines

Conventional Mechanical Ventilation (CMV)

BACKGROUND

Mechanical ventilation is not a cure for underlying illness, but it can be a lifesaving therapy that supports infants with respiratory failure while the underlying disease process resolves. Conventional mechanical ventilation and high-frequency ventilation (HFV) are invasive therapies available for managing respiratory failure, while continuous positive airway pressure (CPAP), high-flow and low-flow nasal cannula, and oxyhood are examples of noninvasive therapies available for managing respiratory distress.

Clinicians should provide infants with the appropriate level of respiratory support to ensure optimal oxygenation and ventilation while simultaneously minimizing injury. Inadequate respiratory support may result in morbidity due to hypoxemia, hypercarbia, and/or atelectotrauma, while extraneous respiratory support may result in morbidity due to hyperoxia, hypocarbia, barotrauma, and/or volutrauma.

INDICATIONS

- Respiratory failure secondary to severe respiratory acidosis, hypoxemia, or apnea
- Anticipated respiratory failure, such as immediately before a surgical procedure or with significant cardiovascular compromise
- Severe metabolic acidosis with concern for impending respiratory failure

PHYSIOLOGY

- Ventilation (CO_2):
    - Minute ventilation is the product of respiratory rate (RR) and tidal volume (Vt)

$$\dot{V} = RR\ x\ V_T$$

    - Ventilation is, therefore, increased by increasing the RR or Vt.
- Oxygenation (O_2):
    - Is dependent on the fraction of inspired oxygen (FiO_2) and the recruitment of lung tissue to participate in gas exchange, which is dependent on mean airway pressure (MAP)
    - Oxygenation is increased by increasing the MAP within limits imposed by lung mechanics and by increasing the FiO_2. The MAP is most effectively increased by increasing PEEP, but may also be increased by increasing the inspiratory time (Ti) and peak inspiratory pressure (PIP), if in a pressure mode.

VENTILATION AND LUNG PROTECTIVE STRATEGIES

Providing excessive or insufficient respiratory support can result in lung injury. The absolute tidal volumes and pressures at which the phenomena below occur are determined by the mechanical properties of the lung, which are dependent on the underlying disease process. Strategies should aim to maintain adequate respiratory physiology in the least injurious manner. The following goals should guide the development of a strategy for ventilation:

	What it is?	How do we prevent it?	Using flow-volume loop
Atelectotrauma	Repeated alveoli deflation and decreased lung volumes	Maintain an end-expiratory lung volume (EELV) equal to or greater than predicted normal FRC (above the P_{inf}) • PEEP • Surfactant	Looking at inflation portion of flow-volume loop, assure that the slope starts increasing almost immediately upon a breath. If the slope is flat, the patient may benefit from increased PEEP (Note Figure 2 below)
Volutrauma	Inflation of the lungs to a volume that approaches the total lung capacity (TLC)	Ventilate with tidal volumes that avoid lung over-distention and utilize the minimum peak inspiratory pressures necessary to achieve targeted tidal volumes • Tidal volumes of 4.5-7 mL/kg • Volume guarantee ventilation	On flow-volume loops and best demonstrated below in Figure 1, the area of high volume lung injury is to be avoided. If this "bird-beaking" is excessive, the patient may benefit from less tidal volume if pCO2 is adequate.
Barotrauma	Overinflation and shearing stresses due to high PIPs, theorized not to occur without accompanying volutrauma		
Synchronization	Synchronize ventilated breaths with spontaneous breaths	Utilization of synchronized modes of ventilation (SIMV, AC, PSV)	N/A

Figure 1 below (shaded areas) depicts areas of atelectotrauma and volutrauma in both a normal newborn and a newborn with RDS. The goal of mechanical ventilation is to ventilate using pressures that achieve lung volumes outside of the zones of lung injury and on the steepest portion of the pressure-volume curve (shaded areas in Figure 2)

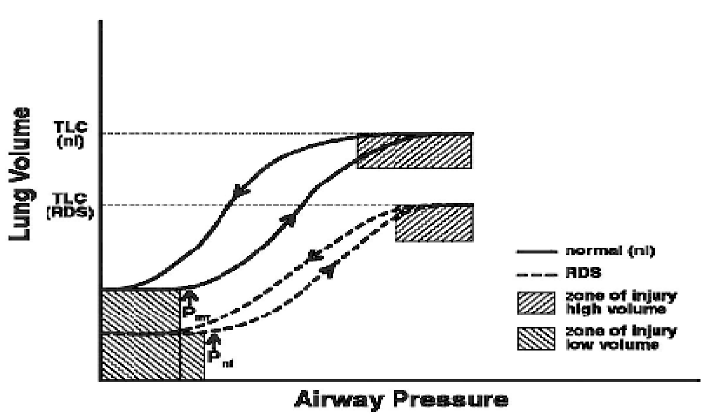

Figure 1. Static pressure-volume curves for infants with normal lungs and infants with RDS. The figure depicts the effects of disease on total lung capacity (TLC) and point of inflection of the inspiratory curve (P_{inf}). Hypothesized zones of lung injury are indicated in the shaded areas.

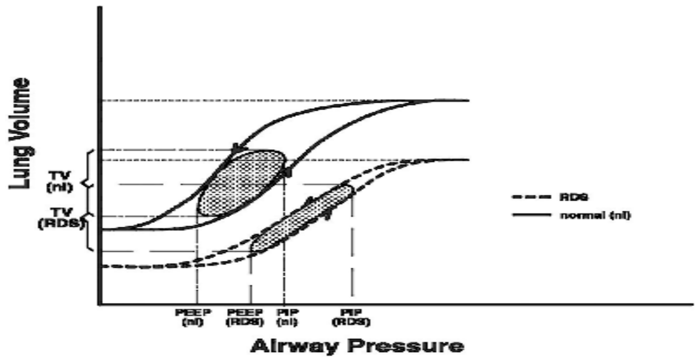

Figure 2. The shaded areas indicate the ideal zones of ventilation.

VENTILATOR MODES

This guideline will focus on the most frequent modes of ventilation, including:

- AC – assist control
- SIMV – synchronized intermittent mandatory ventilation
- NAVA – neurally adjusted ventilatory assist (via Maquet SERVO-i ventilator only)

All three modes are pressure ventilation modes. However, AC and SIMV modes can be used with Volume Guarantee (VG). With VG, the ventilator automatically adjusts the PIP to target a designated tidal volume (Vt).

SETTINGS

The following table summarizes ventilator modes and settings, which providers must set (Operational), and safety feature settings (Alarm/Pop-off), which the respiratory therapist sets unless specified by providers.

Mode	How it works	Operational (Provider Sets)	Alarm/Pop-off
AC + VG*	Every breath is "assisted" or supported to designated tidal volume with a set Ti and set backup rate.	Vt (total volume), PEEP, Ti, back-up rate, FiO_2	PIP limit
AC	Every breath is "assisted" or supported to designated pressure, with a set Ti and set backup rate.	PIP, PEEP, Ti, back-up rate, FiO_2	None
SIMV ± VG	Spontaneous breaths above the back-up respiratory rate are supported via a set pressure support (PS). Breaths below the back up respiratory rate sees the designated tidal volume (if in VG mode) or designated pressure.	Vt (total volume) or PIP, PEEP, Ti, rate, FiO_2, PS	PIP limit in VG Otherwise none
NAVA**	Assists each breath by providing support in proportion to and in synchrony with the infant's own respiratory efforts	*Primary settings:* NAVA level, PEEP, FiO_2 *Back-up settings:* PC above PEEP, Respiratory Rate, Ti, Apnea Time	Number of times in backup mode is tracked (Trends)

**** AC + VG is the initial ventilator mode of choice for most infants.***

Typical starting settings include:

Vt	For infants <= 750g: 5.5 mL/kg For infants > 750g: 5 mL/kg
PEEP	5-6 cm H_20
Ti	Dependent on gestational age and properties of the lung (i.e. 0.25 for 25 weeks, 0.40 for term infant)
Rate	40 breaths per minute (back-up rate)
FiO_2	Titrated to maintain target SpO_2

*****NAVA (neurally adjusted ventilatory assist)***

This mode of ventilation assists each breath by providing support proportionate to and in synchrony with the infant's respiratory efforts. Respiratory efforts are determined by assessing the diaphragm's electrical activity, as assessed via a catheter placed in the esophagus and reflected as an **Edi** value, measured in microvolts (µV). When the infant is apneic, the ventilator provides back-up breaths until spontaneous breaths are again detected. NAVA is a mode of mechanical ventilation that can be provided invasively via an endotracheal tube or non-invasively.

BACKGROUND

NAVA may be considered in the setting of infants who have failed extubation due to apnea or as an escalation mode from NCPAP for apnea. However, multiple meta-analyses have demonstrated no significant differences in death, rates of BPD, need for reintubation, pneumothorax, or length of stay in preterm infants receiving non-invasive (NIV)-NAVA (primary mode or secondary mode-bridge after extubation) compared to other non-invasive modalities, such as nasal CPAP.[1,2]

SETTINGS

Adjustable settings include the NAVA level (cm H_2O/µV, a factor by which the Edi signal is multiplied to adjust the amount of assist delivered to the infant), PEEP, and FiO_2. Edi trigger (minimum value to trigger the ventilator to assist the infant) is an adjustable setting commonly set by the respiratory therapist. Adjustable back-up mode settings for when the infant is not breathing spontaneously include: the apnea time (time before the back-up mode contributes), back-up respiratory rate, pressure control above PEEP, and inspiratory time (Ti).

The Edi peak reflects the electrical activity of the diaphragm during inhalation. Goal Edi peak levels are 10-15 µV. A higher NAVA level reduces Edi peak levels. The Edi min is the electrical activity of the diaphragm during exhalation (in order to maintain auto-PEEP). Goal Edi min levels are 2-5 µV (lower goal Edi min levels in smaller infants). A higher PEEP setting will reduce the Edi min.

Of note, peak inspiratory pressures provided during each spontaneous breath can be calculated by:

$$PIP = [(Edi\ peak - Edi\ min)\ x\ NAVA\ level] + PEEP$$

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NAVA / NIV-NAVA Ventilation Management

Edi Peaks Out of Goal Range * (Goal = 10-15)

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Catheter Misplaced
1. Patient % in backup high even though patient is tachypneic
2. Assess Edi waveforms

YES → Reposition Catheter

NO ←

Edi Peak > 15
Acidotic
Tachypneic
Increased WOB
Increased FiO2

- Mostly in NAVA → Increase NAVA level by 0.2 every 3-5 minutes until the PIP no longer increases and the Edi peak decreases with further NAVA level increases
- Mostly in Backup A/B/D episodes → Increase backup rate; Increase backup PIP; Decrease Apnea time by 1 sec (min 3 sec) → If NIV-NAVA consider intubating; If NAVA consider switching back to conventional mode of ventilation

NO →

Edi Peak < 10
Acceptable pH, pCO2, and FiO2

- Mostly in NAVA → Decrease NAVA level by 0.2; Increase apnea time; If intubated consider extubating to NIV-NAVA; If on NIV-NAVA consider transitioning to BCPAP
- Mostly in Backup → Decrease sedation; Decrease backup rate; Decrease backup PIP; Increase apnea time

Troubleshooting Tips

1. Backup pressure lower than infant's spontaneous PIP = increase Backup Pressure
2. Pressure limit exceeds Alarm = Increase Pressure Limit to acceptable range for GA and disease process
3. Patient spontaneously breathing without ventilator sensing effort = decrease pneumatic trigger with the minimum being 0
4. % of time in backup high and number of switches to backup low = patient not ready to wean
5. % of time in backup low = patient may be ready to wean by lengthening out the apnea time
6. Upper airway obstruction or decreased lung compliance = intubate and place on NAVA if on NIV-NAVA or switch to conventional mode of ventilation

Notes:
[1] Assess patient during periods of non-agitation for accurate Edi values

Consider NIV-NAVA or BCPAP if ALL of the following criteria are met:

- Hemodynamically stable
- NAVA Level < 2
- PEEP < 7 cm H20
- FiO2 < 0.3
- pH ≥ 7.25
- pCO2 ≤ 55 mmHg
- Apnea Time 5-8 sec

NAVA / NIV-NAVA Oxygenation Management

Edi Min (Optimum: 2-5)

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- Edi Min < 2; FiO2 < 0.3 or < baseline FiO2 → Decrease PEEP by 1 cm H2O (min 5 cm H2O)
- Edi Min 2 - 5; FiO2 ≤ 0.3 or ≤ baseline FiO2; Clinically stable → No Change
- Edi Min > 5; FiO2 > 0.3 or > baseline FiO2 → Increase PEEP by 1cm H2O (max 8 cm H2O)

References:

1. Bhader M, Al-Hindi M, Ghaddaf A, Alamoudi A, Abualola A, Kalantan R, AlKhulifi N, Halawani I, Al-Qurashi M. Noninvasive Neurally Adjusted Ventilation versus Nasal Continuous or Intermittent Positive Airway Pressure for Preterm Infants: A Systematic Review and Meta-Analysis. Children (Basel). 2023 Dec 18;10(12):1935.
2. Tomé MR, Orlandin EAS, Zinher MT, Dias SO, Gonçalves-Ferri WA, De Luca D, Iwashita-Lages T. NIV-NAVA versus non-invasive respiratory support in preterm neonates: a meta-analysis of randomized controlled trials. J Perinatol. 2024 Sep;44(9):1276-1284.

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