Conventional Ventilation in Newborn Infants - Neonatal Clinical Guideline – Joint Derby and Burton

Reference no.: NIC RC 04/Jan 21/v005

1. Introduction

Invasive ventilation, or the administration of respiratory support via an endotracheal tube or tracheostomy, using a mechanical ventilator [1] is an key component of neonatal intensive care and must be optimised to prevent or minimise respiratory morbidity.

This document is a general guideline covering some basic principles of invasive ventilation. Invasive mechanical ventilation must be tailored to individual infant's needs and changing clinical condition. Always consult a senior colleague when in doubt.

2. Aim and Purpose

To ensure a standardised approach to the management of infants requiring invasive ventilation

To improve understanding of use of mechanical ventilation in newborn infants

To improve the understanding of neonatal ventilation, blood gas analysis and optimal ventilatory support

3. Definitions, Keywords

Abbreviations

CPAP	Continuous positive airway pressure
CMV	Continuous mandatory ventilation
ECMO	Extra-corporeal membrane oxygenation
ETT	Endo-tracheal tube
FiO_2	Fractional inspired oxygen
HFOV	High Frequency Oscillatory Ventilation
MAP	Mean airway pressure
SIMV	Synchronised intermittent mandatory ventilation
PEEP	Positive End Expiratory Pressure
PIP	Peak Inspiratory Pressure
Ti	Inspiratory Time
TV	Tidal volume
VTV	Volume-targeted Ventilation

4. Main body of Guidelines

1.1 Indications for use

- **Lung disease** such as respiratory distress syndrome (RDS), meconium aspiration syndrome, persistent pulmonary hypertension of the newborn, pneumonia, congenital malformations such as congenital diaphragmatic hernia
- **Poor respiratory drive** or effort such as in apnoea of prematurity, systemic illness such as sepsis, cardiovascular compromise needing inotropic support, hypoxic ischaemic encephalopathy (HIE), neuromuscular disease
- **Maintenance of a safe airway** such as in airway disease, undergoing surgery or imaging procedures requiring sedation

1.2 Ventilator settings

1.2.1 Ventilator parameters

Positive end expiratory pressure (PEEP) is the continuous distending pressure applied to the infants' airways throughout the respiratory cycle. This prevents alveolar collapse during expiration, maintains functional residual capacity and reduces the work of breathing. PEEP of 4-6 cm of H_2O is often the starting point with PEEP of 8-10 cm of H_2O used for short period to improve lung recruitment or in specific cases.

Tidal volume (TV) is the volume of air that is exchanged with each breath. It is 4-6ml/kg at all gestational ages. In volume-targeted ventilation, set the TV at 4-6 ml/kg and allow adequate Pmax to allow the ventilator to deliver the volume. In pressure-targeted ventilation, the ventilator determines the target volume.

Peak Inspiratory pressure (PIP) is the positive pressure applied during the inspiratory phase of the respiratory cycle to enable gas flow into the lungs. In pressure-targeted ventilation, starting PIP is determined by the infant's gestational age and clinical condition and may range from 18-28 cm of H_2O. In volume-targeted ventilation, **maximum allowed PIP (Pmax)** is set to allow the ventilator to vary PIP with each breath in order to deliver the targeted tidal volume.

Rate is the number of breaths delivered by the ventilator per minute. Starting settings should be 40-60 per minute with higher end of the range used for preterm infants.

Inspiratory time (Ti) is the time for which the PIP is maintained. Ti is typically set at 0.3 to 0.4 seconds. The expiratory time is decided by the ventilator by taking the rate and Ti in to account. This means that when the rate is increased, infant will have shorter periods for expiration in each breath. Long Ti with high respiratory rates can reverse the inspiratory:expiratory (I:E) ration causing air trapping.

Flow is the rate at which the air/oxygen mixture is delivered to the infant. Flow is rarely manipulated. **Do not change this** without consulting a senior colleague. Flow determines the slope of the inspiratory phase of the respiratory cycle and higher flows mean that the PIP will be achieved faster. This will show as a square wave on the pressure-time curve on the ventilator display.

Please see the appendix (Section 2) for how to set the above parameters on the SLE5000 used on the Royal Derby Hospitals site and appendix (Section 3) for ventilator settings on the Queen's Hospital, Burton site.

1.2.2 Modes of mechanical ventilation

1.2.2.1 Pressure-targeted vs. Volume-targeted ventilation

Ventilators can be set to deliver a set PIP per breath (pressure-targeted) or a set tidal volume (volume-targeted). In pressure-targeted ventilation, the operator sets a PIP, the ventilator delivers this in each breath while the tidal volume varies breath-by-breath depending on lung compliance and airway resistance. In volume-targeted ventilation, the operator sets a targeted tidal volume, the ventilator delivers this in each breath and to achieve it varies the peak inspiratory pressure breath-by-breath depending on lung compliance and airway resistance. To safeguard against an inadvertently delivered excessive pressure, inspiratory pressure in volume-targeted ventilation is limited to a set Pmax. Flow rate, PEEP, Ti, and rate are set similarly in both modes.

1.2.2.2 Continuous mandatory vs. Synchronised ventilation

This choice refers to the ventilator working with or independent of the infant's spontaneous efforts. In **Continuous Mandatory Ventilation (CMV**) the ventilator works independently and delivers breaths at the set rate, with equal intervals between the breaths. In infants with spontaneous breathing efforts, this causes asynchronicity with the ventilator and may cause discomfort and air leaks. It is only used in infants without any breathing activity such as those who are sedated, and muscle relaxed. However, even in completely apnoeic or muscle relaxed infants, this is rarely used now a days. Setting the ventilator to an appropriate synchronised mode with adequate back-up settings works as CMV when the infant makes no breathing efforts.

In all infants with any breathing effort, even when minimal, synchronised modes are preferred. **Synchronised Intermittent Mandatory Ventilation (SIMV)** works by delivering ventilator breaths when the infant starts taking a breath thus "synchronising" the ventilator with the infant's breathing. There are various options in SIMV: in conventional SIMV, the ventilator support only as many of the infant's breaths as set as the rate. If the infant is breathing at a respiratory rate higher than the set rate, other breaths are unsupported. In SIMV with **Pressure Support Ventilation (PSV**), a lower level of inspiratory pressure can be set for the extra breaths so that each spontaneous breath is "pressure supported". PSV is a flow cycled mode i.e., while the mandated breaths have a set volume or peak pressure, the "pressure-supported" breaths are cut short when the inspiratory flow reaches a set fraction of the peak inspiratory flow. A **Timax** may be set to protect against excessively long inspirations. Some ventilators offer an **Assist Control (AC)** or **Patient Triggered Ventilation (PTV)** which provide synchronised pressure or volume support whenever the infant takes a breath. The rate is, therefore, determined by the infant's respiratory rate. A back up rate is set up to ensure continued ventilation during periods of apnoea. "Trigger sensitivity" is set to determine the limit at which the flow of air generated by the infant's breath will be picked up by the ventilator to generate additional pressure or volume support. Setting the trigger low means more breathing efforts will be picked up and supported.

In all synchronised modes, the ventilator delivers the set rate of ventilator breaths if the infant is apnoeic or their respiratory efforts are too slow or too weak to be sensed by the ventilator.

Clinical recommendation (NICE Quality Standard [1]): *Preterm babies having invasive ventilation are given volume-targeted ventilation (VTV) in combination with synchronised ventilation.*

This guidance states that "volume-targeted ventilation in combination with synchronised ventilation has a lower mortality rate before discharge in preterm babies compared with other invasive ventilation techniques. It also reduces the risk of bronchopulmonary dysplasia (BPD) and pneumothorax (collapsed lung), and the number of days on invasive ventilation."

1.2.3 Setting the ventilator and weaning in frequently used modes

1.2.3.1 Volume-targeted Synchronised Intermittent Mandatory Ventilation

See the ventilator specific instructions given in the Appendices 2.1 (for Derby).

Set the volume target mode on the ventilator and choose the appropriate

- targeted tidal volume (4-6ml/kg)
- maximum allowed PIP
- rate, Ti, PEEP, and FiO_2

On-going adjustments and weaning from SIMV with TTV

TV and rate can be increased **to improve ventilation** (CO_2 clearance) and reduced to wean. If PEEP is high and causing alveolar overdistention, reducing it improves ventilation. Check on X-ray and do not reduce PEEP to <4 cm of H_2O

To improve oxygenation, FiO_2 can be increased. Increasing the TV will also improve oxygenation. However, TV should remain in the range of 4-6l/min and not increased further. Ensure Pmax is set adequately high to ensure delivery of the higher TV. Other ways to optimised oxygenation include increasing the Ti and increasing the PEEP (improves alveolar recruitment).

Monitor blood gas and as the pCO_2 improves, reduce TV by 0.5ml/kg or rate by 5-10 per minute. Both will reduce the ventilation and wean ventilatory support.

Watch the PIP and MAP generated for each breath, if the ventilator is consistently giving low MAP (<8 cm of H_2O), and the infants has adequate spontaneous respiratory drive, consider extubation.

1.2.3.2 Synchronised Intermittent Mandatory Ventilation (SIMV)

See the ventilator specific instructions given in the Appendices 2.2 (for Derby).

Set the SIMV mode with volume targeting "off" on the ventilator and choose the appropriate

- PIP

- rate, Ti, PEEP, and FiO_2

On-going adjustments and weaning from SIMV

PIP and rate can be increased **to improve ventilation** (CO_2 clearance) and reduced to wean. If PEEP is high and causing alveolar overdistention, reducing it improves ventilation. Check on X-ray and do not reduce PEEP to <4 cm of H_2O

To improve oxygenation, FiO_2 can be increased. Increasing the PIP will also improve oxygenation. Other ways to optimised oxygenation include increasing the Ti, and increasing the PEEP (improves alveolar recruitment).

Monitor blood gas and as the pCO_2 improves, reduce PIP by 1-2 cm of H_2O or rate by 5-10 per minute. Both will wean ventilatory support.

Watch the MAP generated, if the ventilator is shows low MAP (<8 cm of H_2O), and the infants has adequate spontaneous respiratory drive, consider extubation.

1.2.3.3 Patient triggered ventilation (PTV) or Synchronised Intermittent Positive Pressure ventilation (SIPPV)

This can be used as an alternative to SIMV and is considered a good mode for smaller infants who may require support with each breath. As each of the infant's breath is supported by the ventilator, there is a risk of overventilation if the infant's respiratory rate is high. However, note that smaller infants have "smaller" spontaneous breaths which may not be sensed by the ventilator. It is important to use this mode with experienced advice.

PTV can we used with or without volume-targeting.

See the ventilator specific instructions given in the Appendices 2.3 (for Derby).

- Ensure mode is selected to have both patient triggered and volume target "on"
- Set the tidal volume, PEEP, maximum allowed PIP, and Ti
- Set a back-up rate
- Adjust trigger sensitivity to such that sufficient breaths are picked up by the ventilator
- To do the same without volume targeting, ensure volume target if set to "off" and select appropriate PIP instead of tidal volume and maximum allowed PIP.

On-going adjustments and weaning from PTV with TTV

Adjustments and weaning are similar to that in SIMV with TTV except changing the rate makes no difference. **Do not reduce the rate to wean when on PTV.** When the PIP is low, change to SIMV and gradually wean the rate until ready to extubate. You can extubate from PTV if the rate is low (20-30/min).

On-going adjustments and weaning from PTV without TTV

Adjustments and weaning are similar to that in SIMV except changing the rate makes no difference. **Do not reduce the rate to wean. Do not reduce the rate to wean when on**

PTV. When the PIP is low, change to SIMV and gradually wean the rate until ready to extubate.

1.3 Monitoring the mechanically ventilated infant

Oxygenation is determined by FiO_2 and the MAP. Depending on the mode of ventilation selected, MAP can be increased by increasing the TV or PIP. Increasing the PEEP also increases the MAP but this is not usually used for improving oxygenation unless poor alveolar recruitment is thought to cause poor oxygenation (see below). Increasing the rate also increases the MAP.

Ventilation or CO_2 elimination is determined by **minute ventilation** which is the product of rate and tidal volume. CO_2 elimination is therefore improved by increasing the rate. In volume-targeted ventilation, CO_2 elimination will improve if the TV is increased. In pressure-targeted ventilation, increase in TV can be attained by increasing the PIP.

If PEEP is high and causing overdistention of the lungs, decreasing the PEEP can improve gas exchange although more frequently low PEEP leading to poor alveolar recruitment may underlie poor gas exchange and paradoxically a period of increased PEEP (with increased PIP) improves both oxygenation and CO_2 elimination.

1.3.1 Oxygen saturation monitoring

Peripheral oxygen saturation (SaO2) is continuously monitored in all ventilated infants. Aim to maintain SaO_2 levels appropriate for gestational age.

1.3.2 Blood gas monitoring

Infants on mechanical ventilation should have regular blood gas monitoring. Usually any changes in ventilation settings (apart from FiO_2) should be followed by a blood gas measurement within 1 hour of the change. There are no rules for regular blood gas monitoring frequency in other situations. Infants clinical condition and trends in blood gas results should be used to determine the frequency of blood gas monitoring.

Some infants on the neonatal unit will have arterial access to allow for arterial blood gas (ABG) analysis. More frequently, capillary blood gas monitoring (CBG) is used to monitor ventilation in infants. Oxygenation cannot be assessed on CBG results.

Acceptable ranges for ABG samples are:

- pH: 7.25 to 7.45
- PaO_2: 6.5 – 10 kPa
- $PaCO_2$: 4.5 to 6.5 kPa

However, all blood gas results must be interpreted in the context of the infant's clinical history e.g., infants with chronic lung disease may have high $PaCO_2$ with normal pH. Trying to reduce the $PaCO_2$ would be detrimental in such instances.

1.4 Troubleshooting

1.4.1 Acute clinical deterioration

Sudden hypoxemia, hypercarbia, or peripheral circulatory failure can occur in ventilated infants. Consider:

- **D**isplacement of ETT**-** Check the chest movements and the air entry on both lung fields. Look for gastric distension.
- **O**bstruction of ETT- Watch chest movements, listen for air entry
- **P**neumothorax- Transilluminate the chest
- **E**quipment- Consider ventilator failure- disconnect from the ventilator and ventilate with self-inflating bag or T- piece

If in doubt replace ETT

1.4.2 Slow clinical deterioration

Consider:

- Check blood gas parameters: is this deterioration respiratory? Metabolic acidosis (such as in NEC, severe sepsis) and deteriorations due to cardiovascular collapse should not be corrected by ventilatory adjustments. Treat the cause underlying the disease causing the deterioration. The purpose of mechanical ventilation in these situations is to provide support and maintain adequate gas exchange and support tissue oxygenation.
- Are the infant's breaths synchronised with the ventilator? Consider a synchronised mode (PTV or SIMV) or increase sedation. Routine sedation is not recommended as the aim, particularly in preterm infants ventilated for RDS, is a brief period of mechanical ventilation with extubation to non-invasive support as soon as possible. However, some infant may require longer periods of ventilation or may be difficult to ventilate and will require sedation. Where indicated, especially in larger infants with conditions such as PPHN or MAS, consider muscle relaxation.
- Is the respiratory disease getting worse or is it such that conventional mechanical ventilation is inadequate to provide the required support?
- What is the oxygenation index (OI)*?
- Consider High Frequency Oscillation
- Discuss with Consultant who may take advice from Tertiary NICUs and consider nitric oxide (NO) and/or extra-corporeal membrane oxygenation (ECMO)

*__Oxygenation Index (OI):__ this is a measure of the respiratory support required to attain adequate oxygenation in an infant at any moment. Calculation of OI requires an arterial partial pressure of oxygen (PaO_2) measurement.

OI is measured in arbitrary units. To apply the calculation below please ensure FiO_2 is entered rather than the percentage of oxygen delivered (i.e. 0.21 and not 21 for air) and that the PaO_2 is entered as on the blood gas results i.e. in kPa. The mean airway pressure (MAP) can be obtained from the right-hand side of the display panel on SLE ventilators.

$$OI = \frac{MAP \times FiO_2 \times 100}{PaO_2 \text{ (in kPa)} \times 7.5}$$

1.4.3 Escalating care beyond conventional ventilation

The steps outlined below require direct involvement of the on-call Consultant. Please speak to them before taking any of the following actions.

1.4.3.1 High frequency oscillatory ventilation (HFOV)

Used for

- Severe respiratory disease where conventional ventilation is inadequate such as PPHN, MAS, severe CLD
- To reduce barotrauma when high pressure is required on conventional ventilation
- In conditions with air leaks such as pulmonary interstitial emphysema (PIE) or pneumothorax

1.4.3.2 Nitric oxide therapy

Usually used for infant >34 weeks' gestation who are unable to oxygenate adequately despite optimum conventional ventilation and HFOV support. High OI (>15) is an excellent indicator for this situation. Clinical conditions where such a situation is likely to include:

- Clinical or ECHO confirmed PPHN
- Meconium aspiration syndrome (MAS)
- Pulmonary hypoplasia (including Congenital Diaphragmatic Hernia)
- Severe respiratory disease such as in congenital pneumonia

1.4.3.3 Extracorporeal membrane oxygenation (ECMO)

Usually for infants' >35 weeks' gestation, weight > 2 kg who have reversible lung disease. Infants with major intracranial haemorrhage, major congenital or chromosomal anomalies, severe encephalopathy, or those who have already received prolonged mechanical ventilation (>10-12 days) may be excluded from receiving this support. Full criteria are available on the ECMO centre websites.

Referral centre for UHDB is the Glenfield Hospital (https://www.leicestershospitals.nhs.uk/aboutus/departments-services/heart-services/ecmo/ecmo-treatment-criteria/).

All cases where ECMO may be indicated require to be discussed with the Tertiary Centre (Nottingham) and ECMO referral centre with adequate arrangement made for transport via the CenTre transport team or ECMO retrieval team.

1.5 Extubation

The readiness for extubation and its exact timing must be individualised for each infant and their specific need for respiratory support.
In general, the infant should

- Have adequate respiratory drive and be off sedation
- Premature infants (<34 weeks' gestation) should have received caffeine
- Stable on minimal ventilatory support

Decide and arrange and required post-extubation respiratory support. Many preterm infants would need CPAP for successful extubation. Infants <28 weeks' gestation should be put on CPAP or BiPAP immediately after extubation.

Clear airway secretions, ensure stomach is emptied with in situ naso-gastric tube, and help is available to support respiration if extubation does not work before removing the ETT.

Closely monitor all vital signs, work of breathing, and blood gases in the post-extubation period. Re-intubation decision should be taken in consultation with the senior medical and nusing team.

5. References (including any links to NICE Guidance etc.)

1 National Institute for Health and Care Excellence (Great Britain), National Guideline Centre (Great Britain). *Specialist neonatal respiratory care for babies born preterm*. 2019. https://www.ncbi.nlm.nih.gov/books/NBK542121/ (accessed 6 Jul 2020).

6. Documentation Controls

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2 Appendix: Setting the ventilator on the Derby site (SLE 5000)

2.1 Synchronised Intermittent Mandatory Ventilation (SIMV) with Targeted-tidal volume (TTV)

1. Press “Mode Select”. Select SIMV
2. Press “TTV mode” to “ON”
3. Set tidal volume “V_T” to 4-6 ml/kg – start with middle of the range volume and then adjust as per blood gas results.
4. Set Pmax – select a pressure that is at least 5 cm of H_2O above the current PIP to ensure targeted volume is adequately delivered.
5. Set Rate 40-60 per min
6. Set Ti 0.3-0.4 sec
7. PEEP 4-8 cm of H_2O
8. Set FiO_2 titrated to the infant’s oxygen saturation levels targeted as per guidelines
9. Press “Confirm”

2.2 Synchronised Intermittent Mandatory Ventilation (SIMV)

1. Press “Mode Select”. Select SIMV
2. Press “TTV mode” to “OFF” – this is the default on SLE 5000
3. Set PIP – select a pressure between 18-24 cm of H_2O and adjust according to chest rise and subsequent blood gases.
4. Set Rate 40-60 per min
5. Set Ti 0.3-0.4 sec
6. PEEP 4-8 cm of H_2O
7. Set FiO_2 titrated to the infant’s oxygen saturation levels targeted as per guidelines
8. Press “Confirm”

2.3 Patient triggered ventilation (PTV) or Synchronised Intermittent Positive Pressure ventilation (SIPPV)

Setting PTV with TTV

1. Select “PTV” on “mode select”
2. Press “TTV mode” to “ON”
3. Set V_T, PEEP, FiO_2, Pmax, and T_i as for SIMV with TTV

4. Set back up rate at 30-40 per min
5. Adjust trigger sensitivity to 0.2. You many need to lower this to ensure adequate number of breaths are “picked-up” by the ventilator.

Setting for PTV without TTV

1. Select “PTV” on “mode select”
2. Press “TTV mode” to “OFF” – this is the default on SLE 5000
3. Set PIP, PEEP, FiO_2, and T_i as for SIMV
4. Set back up rate at 30-40 per min
5. Adjust trigger sensitivity to 0.2. You many need to lower this to ensure adequate number of breaths are “picked-up” by the ventilator.

3 Appendix 3: Setting the ventilator on the Burton site (GE Engstrom Carestation)

3.1 Synchronised Intermittent Mandatory Ventilation (SIMV)

1. Press “Vent Setup”
2. Rotate ComWheel to Select SIMV-PC – Push ComWheel to confirm

For other Settings below:

Press the Quick key below the parameter

Rotate the ComWheel to set the desired value

Push ComWheel to confirm setting

3. Set PEEP 4-8 cm of H_2O
4. Set PIP* - Select a pressure between 18-24 cm of H_2O and adjust according to chest rise and subsequent blood gases.

***Please note that the desired PIP includes the PEEP value e.g if PEEP is set at 5cm, then the PIP value should be set at 15cm to give a desired PIP of 20cm of H_2O**.

5. Set Rate 40-60 per min
6. Set Ti 0.3-0.4 sec
7. Set FiO_2 titrated to the infant’s oxygen saturation levels targeted as per guidelines