CLINICAL GUIDELINE	
Ventilation: Conventional	
Scope (Staff):	Nursing and Medical Staff
Scope (Area):	NICU KEMH, NICU PCH, NETS WA

This document should be read in conjunction with this DISCLAIMER

Contents

Modes of Conventional Ventilation

Keszler provided an approach to defining the different modes of conventional ventilation.

The three important questions are:

1. How is the breath initiated (ventilator or patient triggered)?
2. How gas flow is moderated (pressure limited, volume limited)?
3. How the breath is terminated (volume, time and/or flow cycled)?

Conventional ventilation is the primary mode of ventilation for most newborn infants. There are several modes of conventional ventilation that support the infant’s spontaneous respiratory efforts in different ways. All modalities used at KEMH/PCH and on transports are synchronized to the infant’s spontaneous breathing.

In addition, volume guarantee is an important function on most current ventilators that assists in reducing ventilator induced lung injury.

The **main indications** for putting an infant on mechanical ventilation are:

1. Oxygenation problem (hypoxia).
2. Ventilation (gas exchange) problem (e.g., hypercarbia).
3. Apnoea.

The **goals** of mechanical ventilation are:

1. Assist infant to maintain “normal”/acceptable physiological parameters.
2. Minimize iatrogenic lung injury.

The ventilators currently in use are the Draeger VN500 (PCH) and the Fabian (KEMH). There are some differences between the two ventilators, so it is important to understand the different modes and functions of both ventilators.

Mode	Information	Advantages/Disadvantages
Assist control/SIPPV/ (+VG) **PC-AC** Time cycled, pressure limited (+volume target)	**Use:** Infants that require full ventilator support, or who require all breaths to be supported, those with minimal spontaneous breathing (e.g., sepsis), and those infants with high imposed work of breathing through small tracheal tubes (for whom SIMV is inappropriate). Ventilator and patient triggered breaths. All ventilator/patient triggered breaths are supported to set PIP (or to a PIP at which set VG achieved). Patient determines rate (if above backup rate). Fixed IT useful to recruit the atelectatic lung, and to limit breath duration in presence of large leak.	**Advantages** May reduce work of breathing. Control all aspects of ventilation (IT, rate, PIP, PEEP and tidal volume). Ventilator will cut-in during apnoea (dependent on IT and ET) to the set (backup) ventilator rate. **Disadvantages** If IT is inappropriately long may lead to dysynchrony with ventilator increased risk of air-trapping and gas leak syndrome (active inspiration against closed expiratory valve. Inability to sigh. Risk of hypocarbia if auto-triggering. Potential for hypercarbia if low back up rate and infant has no respiratory drive. No inclusion of diaphragmatic training as all breaths are supported to the same pressure/volume level.
PSV (+VG) **PC-PSV** Flow cycled, pressure limited (+Volume target)	**Use:** Used as an initial or weaning mode of ventilation. Allows for ventilator and patient triggered breaths. Inspiration is flow-cycled: inspiration terminates once inspiratory flow has decreased to 15 % of peak inspiratory flow. If there is an ETT leak the flow may not fall below 15% and thus inspiration terminates at the set (backup) IT.	**Advantages** Improved patient ventilator synchrony. If backup IT set appropriately, infant can sigh on ventilator and dictate their own IT dynamically based on ventilator settings (e.g., flows), their lung resistance and compliance, and inspiratory drive. **Disadvantages** Persistent high leak around ETT may result in infant receiving prolonged backup inspiratory time over an

		extended period, increasing risk of air leak and ventilator dysynchrony. Potential for hypercarbia if low back up rate and infant has no respiratory drive. Risk of hypocarbia if auto-triggering. No inclusion of diaphragmatic training as all breaths are supported to the same pressure/volume level.
SIMV+PS (+VG) **PC-SIMV** Time cycled, pressure limited mandatory breaths Flow cycled, pressure support of patient triggered breaths (+volume targeting)	**Use:** May be used infants that develop hypocarbia on A/C, SIPPV, PTV mode; useful as full support ventilation or as a weaning mode of ventilation. Ventilator and patient triggered breaths. Mandatory breaths are supported to set PIP/volume target; patient triggered breaths are supported to either the PS level (Fabian), or to PS + PEEP (VN500). Ventilation is weaned by weaning PS or mandatory rate, as appropriate - See weaning guide	**Advantages** Useful mode for across the spectrum of respiratory disease. Separate level of pressure support for patient triggered breaths contributes to diaphragmatic training. Mandatory rate supports ventilation during apnoea. Addition 2 min apnoea ventilation is an available option on the VN500. **Disadvantages** If PS for patient triggered breaths is too low, may result in atelectasis or increase work of breathing (usually evident as tachypnoea), increased oxygen requirements and fatigue.
MMV (mandatory minute ventilation) **PC-MMV**	**Use:** Extension of SIMV+PS+VG, providing seamless transition from full ventilatory support to infant-driven, supported spontaneous respiratory ventilatory rhythms. Useful across range of ventilatory needs in patients with at least some respiratory drive. Mandatory breaths only given if patient triggered breaths do not meet a minimum minute volume (MV). Desired MV is set using rate and VG. The ventilator ensures the patient will receive the set MV. As the infant increases their spontaneous breathing the ventilator will provide fewer mandatory breaths to	**Advantages** Allows infant to increase spontaneous respiratory whilst keeping minute ventilation stable. May be a useful weaning modality and promote respiratory and diaphragm muscle development. Observing the percentage of spontaneous breaths may help identify infants that will tolerate extubation. All mandatory breaths are volume targeted. **Disadvantages**

	achieve the set minute volume. Once the infant's spontaneous breathing is sufficient to achieve the set MV, then no further mandatory breaths are provided unless the infant's MV falls below the set MV.	Not appropriate when a large (> 60 %) ETT leak is present. No additional advantage in infants without a respiratory drive. If PS for spontaneous breaths is set too low it may lead to gradual atelectasis, increase work of breathing (usually evident as tachypnoea), increased oxygen requirements and fatigue. If PS for spontaneous breaths is set too high, it may result in excessive ventilator support during triggered breaths and hypocarbia/volutrauma, and reduce benefit for diaphragm.
Volume control (VG)	**Use:** Reduce risk of volutrauma Relevant breaths are supported to the PIP required to achieve a set tidal volume (volume guarantee). Different algorithms define the amount of PIP provided for mandatory (set rate) and additional spontaneous breaths. Volume target varies between ventilators (e.g., Fabian and VN500). Desired VG needs to consider if leak compensation is being used or if VG is determined by expired tidal volume.	**Advantages** Reduce risk of volutrauma during periods of sudden changes in compliance/resistance (e.g, post surfactant, volume-recruitment, secretions etc) Reduces need for constant changes to ventilator settings by clinical staff – "autoweaning" of PIP. **Disadvantages:** Reduced effectiveness in presence of high leak around tracheal tube.

Ventilator Settings

SETTINGS	DESCRIPTION
PEEP	PEEP is the continuous baseline distending pressure that increases FRC and helps improve lung expansion. Higher levels of PEEP raise the MAP and thus improve oxygenation and may be beneficial for short periods to overcome severe atelectasis. PEEP may also support airway patency in patients with compliant airways (e.g., tracheomalacia). Older infants with chronic lung disease may tolerate higher levels of PEEP with improvement in oxygenation. Excessive PEEP may promote over-distension with resultant gas trapping, reduced lung compliance, and decreased pulmonary perfusion due to increased pulmonary vascular resistance.
PIP	PIP is the peak pressure during inspiration. DeltaP (PIP-PEEP) is the driving pressure determining flow to the lungs at any given level of resistance and compliance. Delta P is important in altering the V_T and MV. Increases in PIP at a constant PEEP will increase MAP and may improve oxygenation (unless the lung is over-distended). Use of a high PIP with associated high tidal volume may increase the risk of barotrauma and volutrauma with resultant air leaks and bronchopulmonary dysplasia or chronic lung disease (CLD). The level of PIP needed is determined by the required tidal volume and the lung compliance and airway resistance. Set PIP is reviewed through assessment of gas exchange and chest movements. Required tidal volume is dependent on infant maturity, lung disease, and ventilator, including whether leak compensation is in use of not.
Rate IT (insp time) ET (exp time) IT:ET ratio	Rate is influenced by IT and ET: Rate = 60/ (IT+ET). Setting an appropriate IT is important to ensure delivery of the required tidal volume at the minimum required pressure. The IT is best determined by observing the flow-time graph. The time constant (Tau, τ) is the product of compliance and resistance. In mechanical ventilation, the inspiratory time constant measures the time it takes to deliver 63 % of the tidal volume to the lung, whilst the expiratory time constant is the time taken to remove 63 % of the volume previously inspired. For example in RDS, compliance is very low so τ is short, thus a shorter IT is required. In CLD or acute meconium aspiration the resistance is high so τ is long thus the infant requires a longer IT. 5 time constants estimates 99 % inflation of the lungs (ie K=0.06;

	thus IT should at least 0.3). Assuming there is no ETT leak; the IT should be set so that the ventilator flow reaches 0 on the flow-time graph. In A/C, or SIMV, a short end-inspiratory pause reduces risk of atelectasis due to absence of sigh allowance. IT:ET ratio should be less than 1. If the IT is too long, it may result in insufficient expiratory time for lung deflation and thus air trapping. The absolute inspiratory time required varies from infant to infant depending on the lung mechanics, the driving pressure (delta P) and the bias flow.
Flow Insp Flow and exp flow (Fabian) Slope (VN500)	Bias flow provided by the ventilator to support inspiration and expiration. The Fabian allows manipulation of both inspiratory and expiratory flows. The VN500 ("slope") allows manipulation of inspiratory flows. Adequate inspiratory flow is needed to generate the expected pressure. If the flow is too low, the PIP may not be reached. If the flow is too high then the tidal volume may be delivered too rapidly, which will increase shear force trauma to the lungs (alveoli being rapidly opened due to high instantaneous flows). Review of the pressure-time and flow-time graphs will guide flow required. Smaller infants require lower flows than large infants.
Oxygen (FiO2)	Oxygen is the most commonly used "drug" in neonates. As with all "drugs" it offers both benefits and harm. It is important to try and reduce the FiO_2 when able to reduce the risk of oxygen radical formation. Formation of oxygen radicals promotes inflammation within organs and may result in CLD and retinopathy of prematurity.
VG	Volume targeted ventilation. The ventilator algorithm continuously adjusts PIP to achieve a desired (set) tidal volume (VG). VG is very useful when expecting changing compliance such as after surfactant therapy. Target tidal volume needs to be adjusted with consideration for infant maturity, physiological respiratory rate, disease condition and severity, specific ventilator, and software options (e.g., leak compensation).

Respiratory Physiology

Oxygenation

Lung expansion, perfusion, F_IO_2 and driving pressure influence oxygenation.

Adequate lung expansion, particularly optimising the functional residual capacity (FRC), is important to optimise oxygenation. Over distension or atelectasis will impair both oxygenation and ventilation so it is important to ventilate in the optimal area of the compliance curve. In the atelectatic lung, increases in MAP will improve FRC and thus oxygenation. In the over distended lung, a decrease in MAP will improve oxygenation, by reducing lung over distension. MAP is the area under the pressure x time curve so is influenced by PEEP, PIP, IT, ET, rate and flow. Of these, increasing PEEP will generally have the biggest impact on MAP.

Ventilation

Minute ventilation is a product of rate (frequency) and tidal volume. Increases in either the rate or tidal volume will increase minute ventilation.

The tidal volume is influenced by the delta P (PIP-PEEP) and lung mechanics. Adequate lung expansion will allow ventilation to occur in the optimal part of the compliance curve using the lowest pressures to achieve desired tidal volume.

The rate is dependent on the IT and ET. It is important to monitor the IT:ET ratio because if this is increased too much it will impede full exhalation: the infant will develop auto-peep and air trapping, which will worsen ventilation.

Compliance Curve

Compliance = delta V/ delta P and hence is reported as mL/cmH_2O.

Dynamic compliance is the slope of the pressure volume curve. Dynamic lung compliance changes throughout inspiration and expiration limbs.

Ventilation is ideally achieved on the deflation limb of the static pressure –volume relation of the lung. The point of optimal curvature on the deflation limb is the optimal position for ventilation, avoiding both atelectasis and over distension, whilst allowing ventilation at the lowest mean distending pressure. Optimal lung volume is generally achieved by altering the mean airway pressure. For some babies, a PEEP higher than 5 cmH_20 is required to achieve optimal lung volume (CLD, post-operative neonates, older neonates, or neonates with acute atelectasis). If there are concerns about over-distension or atelectasis please discuss with the on-service senior registrar or consultant.

Waveforms

The waveforms provide important information about setting appropriate flows and IT. It is important to note that the following requires that there is a leak of < 20%.

Setting an appropriate IT will assist in better synchronisation and more comfortable breathing. To optimise the IT we look at the flow-time waveform. The optimal IT is one that allows for full inspiration with the flow-curve reaching zero. Given that IT is dynamic and infants occasionally take a sigh breath it is important to accommodate this when setting the IT. In the presence of leak, the end of inspiration is the point at which the "shoulder" on the inspiratory flow waveform develops (ie parallel to the zero flow line).

The next important waveform to review is the Pressure-time waveform. The pressure time-waveform will help guide the flow that is required. In general a "square" waveform should be avoided as this will lead to more shear stress damage by opening up atelectatic alveoli quickly. A more gentle rise to reach PIP will lead to less shear stress damage.

Waveforms that achieve the PIP by about 2/3 of the set inspiratory time (allowing tidal volume to just plateau) will provide a more gentle breath than one in which tidal volume is delivered very rapidly.

Making Changes to the Ventilator

Before making changes to the ventilator it is important to:

1. Observe the patient.
2. Keep a memory of the current ventilator settings and the current patient information (SaO_2, RR, $TcCO_2$, $ETCO_2$).
3. Review the blood gas.
4. Review ventilator trends.
5. Discuss with nurse at the bedside (patient behaviour trend over time, recent interventions such as suctioning, cares, recent nebulisation etc.).
    - For example: recent suctioning or nebulisation may have led to de-recruitment of the lungs and will only require transient changes.
    - A more gradual trend over time may require an increase in ventilation requirements.

Changes to Ventilator Guide

SCENARIO	**SUGGESTED CHANGES**
Hypoxia	Increase FiO_2 – usually this step is a transient step until the cause of the hypoxia is identified and adequately treated. Identify cause of hypoxia: If hypoxia is secondary to atelectasis or over distension, optimize lung expansion - Overall goal is to adjust MAP to achieve optimum lung distension. This goal is achieved by adjusting one or more of PEEP, PIP, IT or rate. - In the absence of disturbed ventilation (CO_2 removal), it is important to ensure that the combination of changes do not alter MV. If hypoxia is due to gross air leak, consider evacuation of air (discuss with senior clinician). If hypoxia is due to cardiac disease, refer to consultant.
Hyperoxia	Reduce FiO_2 first. Once $FiO_2 < 0.5$ consider gently weaning MAP by reducing PEEP if lungs are well expanded. Continue to wean FiO_2. Wean MAP further once $FiO_2 < 0.3$.
Hypocarbia	Decrease minute volume • Reduce rate to an acceptable back up rate, if infant not breathing above set ventilator rate. • Reduce V_T (if not on VG then reduce PIP) – but do not decrease V_T below 4 mL/kg • If on SIMV+PS or MMV and predominantly breathing spontaneously, progressively decrease pressure support

	providing respiratory rate remains physiologically appropriate (i.e., not tachypnoeic).
Hypercarbia	Optimize lung expansion. Increase minute volume • Increase set respiratory rate if no spontaneous/triggered breathing. • Increase V_T o if not on VG then increase PIP and/or decrease PEEP, ensuring MAP change does not affect oxygenation. o If on SIMV+PS or MMV and breathing spontaneously, and/or tachypnoeic, consider increasing pressure support to achieve more effective ventilation from pressure supported breaths.

Weaning from Ventilator

Ventilation strategies should consider the needs of the infant for extubation, including a strong, consistent respiratory drive and an effective respiratory muscular pump. Consequently, ventilation strategies that reduce and preferably eliminate the need for sedation to encourage respiratory drive, and which facilitate support and endurance training of the diaphragm are highly desirable. This is especially important for infants at high risk of prolonged mechanical ventilation.

- Morning caffeine administration combined with the lowest safe back-up rate for each individual infant that will avoid significant over or under ventilation, will promote respiratory drive.
- Avoidance of excessive IT and hence avoidance of negative feedback resulting from the Hering-Breuer reflex will also support spontaneous respiratory rhythm.

SIMV+PS (+VG) and MMV are especially useful weaning modalities for promotion of diaphragm endurance. These are combined ventilator modalities that include differential levels of pressure support for mandatory inflations and spontaneous breaths. Consequently, both modalities may promote training of the diaphragm via gradual reduction of pressure support for spontaneous breaths.

- It is desirable that the infant has some intrinsic respiratory drive to derive optimal benefit from SIMV+PS (+VG) or MMV.
- In the absence of strong respiratory drive, SIMV+PS (+VG) and MMV need to be used in a way that makes them no different from full support A/C or SIMV (i.e. rate needs to be increased for mandatory ventilator breaths to account for absent contribution of spontaneous breaths to ventilation).

MMV offers the most seamless transition from mandatory ventilation to a spontaneous breathing rhythm, whilst ensuring the clinician retains some control over the level of ventilation.

It is important to review ventilation regularly in all modalities and always have a goal and a plan for weaning and early extubation.

Fabian Specifics

The Fabian has a default variable inspiratory (I-flow) and expiratory (E-flow/ base flow) flows. The inspiratory is set at 8 L/min and the expiratory at 6-7 L/min. The E-flow is usually 2/3rd of I-flow and maintains PEEP between mechanical breaths. The E-flow is set on the default screen.

Select flow sensor calibration (by blocking both sides of the sensor with a gloved hand). If new flow sensor is connected, calibrate it before connecting ventilator to baby.

- Volume guarantee (VG) to be set at 4.5- 6 mL/kg, VG maintains a stable tidal volume with changing lung compliance.
- **Trigger** to be set at 3 (equivalent to Draeger trigger of 1).
- **Frequency:** back up ventilator rate to achieve appropriate minute volume (200-300 mL/kg/min).

If using a sidestream CO_2 sensor, flow calibration needs to include the CO_2 sensor to ensure accurate recording of the VT delivered to the infant.

Modes of ventilation screen (Fabian)

VN500 Specifics

Depending on the configuration of the VN500, the user has the option to adjust inspiratory bias flow or to adjust the slope (rise time of the pressure waveform).

Tidal volume settings on the VN500 will differ according to ventilator configuration. If leak compensation is not enabled, the reported tidal volume (and the tidal volume used for volume guarantee) is the expired tidal volume. Thus tidal volume settings in the VN500 when used without leak compensation are no different to the tidal volume settings for the BL8000+.

However, when leak compensation is enabled in the software, the tidal volume used for VG settings is the calculated actual V_T – which is higher than the expired tidal volume. Therefore, tidal volume settings need to be higher (~ 1 mL/kg) in the VN500 when leak compensation is enabled.

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