Wales Neonatal Network Ventilation Guideline

Version 3 (September 2013)

This guideline should be read in conjunction with Network Guidelines:

06 Neonatal Ventilation: Ventilation Modes

07 Neonatal Ventilation: How to do it?
# Index

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Scope and general principles

Scope: This guideline provides some basic strategies for neonatal ventilation and is not intended to be adhered rigidly or supersede local preferences. While reading this guideline one must be aware that in the majority of clinical scenarios, there is lack of high quality randomised trial data to support superiority of one mode of ventilation over another. Not surprisingly therefore, practices vary not only between different neonatal units but also amongst paediatricians/neonatologists within the same unit.

With advances in technology there are many modalities available for conventional ventilation in neonates. Most modern neonatal ventilators provide pressure limited ventilation with additional facilities to target/guarantee pre-set tidal volumes. Most of these ventilators use a highly sensitive flow sensor inserted in the circuit to measure flow of gas in and out of the airways, calculate volume and allow rapid response synchronisation with patient effort. This guideline is not equipment specific and one will need to adapt the guiding principles to the available local equipment.

The common indication for ventilation in neonates is either one or a combination of the following -
1. Parenchymal lung disease or VQ mismatch (e.g. RDS, Meconium aspiration, pneumonia, PPHN etc.)
2. Poor respiratory drive (e.g. apnoea of prematurity, hypoxic–ischemic encephalopathy, sepsis etc.)
3. Lung malformations (e.g. diaphragmatic hernia, CCAM)
4. Mechanical (e.g. abdominal distension, airway obstruction)

The aim of neonatal ventilation is to provide
1. Adequate oxygenation
2. Adequate ventilation i.e. removal of CO$_2$
3. Minimise ventilation associated lung injury
4. Maximise patient comfort

General Principles of Conventional Ventilation: (skip this section if you are familiar with basic concepts)
- In neonates, uncuffed ET tube is used and therefore for any ventilation to be effective an appropriate sized ET tube should be inserted to an optimum length aiming to minimise leak while at the same time balance the risk of pressure necrosis. The table in Appendix 1 provides a guide that is commonly followed across the network.
- Ventilation is most effective when the lung is ventilated around the Functional Residual Capacity (FRC) i.e. the volume of lung where the inward recoil of the lung matches the outward recoil of the chest wall thereby reducing work of breathing and facilitating gas exchange through open alveoli and pulmonary vasculature. This usually equates to lung expansion of 8-9$^{th}$ posterior ribs on Chest X-ray and results in normal blood gases if perfusion is adequate.
- An infant on adequate ventilation should be comfortable, with no chest recession, acceptable bilateral chest movements, Tidal Volume(TV) of 4-8mls/Kg and a Minute Volume (MV) of 200-300 mls/kg
- Modern ventilators through the use of sensitive flow sensors provide accurate measurement of TV MV. These should be used, where available along with clinical observations, for initial set up and further adjustments to ventilation. This requires a change in mindset. However, through careful clinical observations, one must be on guard to identify technical failure to ensure patient safety.
- For all mechanically ventilated babies less than 30 weeks gestation, load with Caffeine on Day 0 followed by maintenance doses.
- Delay or avoid routine opiates if infant likely to be extubated soon.
- Weaning from ventilation and extubation should be achieved at the earliest opportunity (See Appendix 2 for a suggested scheme)
- There are important ventilation circulation interactions and concomitant attention to maintain adequate pulmonary and systemic circulation is important to facilitate the ultimate goal of adequate tissue oxygenation
Determinants of gas exchange and adjustments to ventilation

A. Oxygenation:
This is directly related to Mean Airway Pressure (MAP) and FiO₂

MAP is affected by –
- Peak Inspiratory pressure (PIP) – Higher the PIP, higher the MAP and better oxygenation
- Positive End Expiratory Pressure (PEEP) – This has a slightly variable effect. Increasing PEEP will improve oxygenation by recruiting more alveoli provided there is no hyperinflation.
- Inspiratory time (T₁) – Longer the T₁, higher the MAP and better oxygenation, provided it does not cause hyperinflation.
- Flow –
  - Higher flow improves MAP and oxygenation by reaching PIP quicker. Inappropriately high flow can cause lung injury and increased airway resistance.
  - Inadequate flow may not allow adequate PIP to be achieved within the set inspiratory time and increases patient discomfort through flow hunger.

The lung volume generated by MAP is in turn dependant on -

Lung compliance (a measure of stiffness to expansion) - affected by the disease pathology and in RDS improved following surfactant therapy

Lung resistance (a measure of obstruction to airflow) - affected by size and length of ETT, secretions and calibre and spasm of small airways. Ventilate using the biggest size ETT tube that will not cause trauma or pressure necrosis. Minimise dead space by shortening the length of extra-oral segment of ETT.

Therefore all these parameters may need to be considered or altered to improve oxygenation

Alveolar oxygenation is proportionate to tissue oxygenation provided there is adequate pulmonary and systemic circulation

B. CO₂ elimination:
- This is determined by minute ventilation (MV) = Tidal volume × Respiratory rate
- Delta P i.e. (PIP-PEEP) in conjunction with inspiratory time (T₁), compliance (measures lung stiffness) and resistance (measures obstruction to airflow) determines Tidal Volume (TV).

Adjusting ventilation to achieve best gas exchange:
Always consider an overview of the clinical situation. With the availability of volume information on modern ventilators, in addition to clinical evaluation we should make it a habit (a change in mindset) to note TV / MV and MAP measurements to guide adjustments to ventilator settings.

Target values:

<table>
<thead>
<tr>
<th>Target values</th>
<th>Oxygen saturations</th>
<th>pH</th>
<th>pCO₂  (kpa)</th>
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</thead>
<tbody>
<tr>
<td>Preterm infant, week 1</td>
<td>91-95%</td>
<td>&gt;7.22</td>
<td>4.5-8</td>
</tr>
<tr>
<td>Preterm infant after week 1</td>
<td>91-95%</td>
<td>&gt;7.2</td>
<td>&gt;4.5, allow compensated permissive hypercapnia - no upper limit defined</td>
</tr>
<tr>
<td>Term infant at risk of PPHN</td>
<td>&gt;95%</td>
<td>7.3-7.4</td>
<td>4.5-6</td>
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Target TV – Normally 4-6 mls/Kg for a small baby and up to 8mls/Kg for bigger term/near term babies.
Target MV – 200-300mls/Kg
Where this information is not available or is judged unreliable by the clinician (often due to big leak 25-40%), clinical evaluation and best informed adjustments are necessary. Usual magnitude of change is as follows -

- PIP – 2 cm
- PEEP – 1 cm
- I-time (T₁) – 0.05 seconds
- Rate – 5-10/minute

Bigger changes can be undertaken by experienced clinicians and is better guided by volume measurements.

In order for a better understanding of the principles, the suggested changes are mainly based on Continuous Mandatory Ventilation (CMV) and could be applied to Synchronised Intermittent Mandatory Ventilation (SIMV), where patient control is minimum. For other modes of ventilation, where the patient has greater control over certain parameters for e.g. rate in SIPPV, alternative parameters may preferentially need to be adjusted.

**If blood gases are outside desired targets, first check the following:**

**Reliability of blood gas:**
- Is the blood gas result reliable?
- Has there been a sudden unexpected change from previous blood gas values?
- Did sample contain an air bubble?
- Was it obtained from a poorly perfused site?

**Baby's status:**
- Is baby's chest moving adequately?
- How is the air entry?

**Ventilator and tubing**
- Is there an air leak (consider transillumination to exclude it)?
- What is the TV?
- Are the measured ventilatory values markedly differently to the set ones?
- Is there a large (>40%) endotracheal tube (ETT) leak?

**For causes of acute deterioration on a ventilator - Remember DOPE!**
- Displacement
- Obstruction,
- Pneumothorax
- Equipment failure

**Common Scenarios:**

**Low oxygenation and High CO₂** – (Inadequate lung volume is most likely - Low MAP, TV and MV)
- Clinically evaluate to rule out conditions such as pneumothorax and tube block/displacement.
- In some cases such as early RDS – improving lung compliance by giving surfactant may be the most appropriate solution. Pressure –volume loops or CxR appearance may be helpful.
- Consider changes that affect both MAP and TV
  - First choice may be to increase PIP to improve MAP and Delta P. If TV measurements available adjust pressure settings manually to achieve a TV of at least 4mls/Kg and if already achieved consider increasing up to 6 mls/Kg. **You may be able to achieve this using VG mode if available (see later)**
  - If lungs show signs of atelectasis or consolidation, increasing PEEP is appropriate but ensure that Delta P i.e. (PIP-PEEP) is not reduced. Consult with seniors if PEEP exceeds 6 cm
- You may also need to increase FiO2 and rate as appropriate (enough to achieve target MV) after ensuring that adequate lung expansion and TV is achieved
- Consider HFOV if poor response or settings considered too aggressive
Low oxygenation and Low/Normal pCO\textsubscript{2} – (Normal MV, possibly normal TV, VQ mismatch – poor diffusion across lung)

- Increase FiO\textsubscript{2} but investigate cause? Pneumonia / PPHN /worsening RDS. Note TV
- If increments of FiO\textsubscript{2} big, consider increasing MAP without significantly altering TV -
  - 1\textsuperscript{st} choice - Increase both PIP and PEEP to keep Delta P same — will not work if bigger increments required i.e. >1-2 cm - caution not to overinflate. You can achieve the same as above point by using VG at current TV but increasing set PEEP
  - 2\textsuperscript{nd} choice - Increase I time (T\textsubscript{I}) but ensure that I:E ratio is not inverse as this will cause air trapping
- Adjust rate to modify MV
- If settings too aggressive or poor response consider HFOV / Nitric oxide as appropriate

Normal /High oxygenation and Low pCO\textsubscript{2} – (Over ventilated - Likely high MAP, TV and MV)

- Reduce Pressures – PIP as first choice. Try not to reduce PIP to levels that gives a TV < less than 4 mls/Kg. Use VG mode if available with TV@4mls/Kg if high tidal volume noted
- You may need to consider reducing PEEP if lungs are overinflated
- Reduce FiO\textsubscript{2} as appropriate
- You may need to consider reducing rate if MV still remains high or if such information not available and pCO\textsubscript{2} still low. This will not work in SIPPV/PSV if breathing above back up rate – consider autocyling!

Normal /High oxygenation but High pCO\textsubscript{2} – (Likely low MV but normal MAP and TV)

- Rule out partial tube block / secretions – See resistance indices or flow –volume loops if available
- If possible increase rate to achieve desired MV. However, beware that increasing rate too much (usually when >60/min and T\textsubscript{I} ~0.4sec) may reverse I:E ratio and cause CO\textsubscript{2} retention. Therefore in this scenario, you may consider reducing I\textsubscript{T} simultaneously if > 0.3 seconds
- Consider reducing PEEP if lungs well inflated (this will reduce MAP but improve Delta P). Do not go below 3 cm as it may cause atelectasis

Minimise ventilation induced lung injury:

Avoid both high and suboptimal lung volumes. Always wean the most harmful parameter first

Maximising Comfort:

- This is generally achieved by improving synchronisation of mechanical ventilator breaths with patient effort.
- While inspiratory synchronisation is provided by modes such as SIMV /SIPPV, a greater control can be given to patients with additional expiratory synchronisation in PSV mode or throughout the cycle (proportional assist mode).
- In some neonates consideration may need to be given for appropriate sedation and comfort boundaries i.e. nesting
Classification of Conventional Ventilation:

Abbreviations commonly used to describe modes of ventilation:
CMV - Continuous Mandatory Ventilation
SIPPV - Synchronised Intermittent Positive Pressure Ventilation
AC – Assist Control (same as SIPPV)
PTV – Patient triggered ventilation (same as SIPPV)
PSV - Pressure Support Ventilation
VG – Volume Guarantee Ventilation

All modalities of conventional ventilation could be classified by the following basic principles -

Initiation or Trigger –
- Time – Here breath is initiated by a preset time determined by set frequency completely unrelated to patient effort – classic example – CMV
- Flow – This is the most common and sensitive type of trigger in modern ventilators– the ventilator detects a flow towards patient initiated by patient’s inspiratory effort and synchronises the breath e.g. SIMV /SIPPV or AC or PTV/PSV
- Volume – a ventilator breadth is triggered when a preset volume of gas flow is detected towards patient (derived from flow over time)
- Pressure- ventilator breath is triggered by negative pressure generated by spontaneous patient effort – less sensitive – can be used for synchronised ventilation if a flow sensor is not available – SIMV/SIPPV

Limit – Pressure / volume – The ventilator will stop increments when either a set pressure or volume limit is reached

Cycling or termination – defines how inspiration is terminated?
- Time – inspiration terminated at the end of a set inspiratory time (SIMV/SIPPV)
- Flow – Inspiration terminated when the inspiratory flow decays (this can take variable time due to the balancing effect of the inward flow rate of the ventilator and the patient's desire to breathe out on that breath) to a set proportion of the peak inspiratory flow rate – usually 5-15%. Therefore the patient controls the inspiratory time which is variable breath to breath. Classic example PSV

Commonly used ventilation modalities:

Continuous Mandatory Ventilation (CMV) – Time triggered, pressure limited, time cycled ventilation with no relation to the patient’s respiratory effort – should not be used as a primary mode of ventilation. Although increasingly rare, this mode is primarily used by some neonatal transport teams due to technical limitation of the transport ventilators

Synchronised modes in paralysed or deeply sedated apnoeic patients is equivalent to CMV but has the added advantage of spontaneous synchronisation when they wake up or improve. Therefore such infants should not be converted to CMV mode on the neonatal unit. Synchronised modes of ventilation have been proven to reduce the length of time ventilated, therefore this mode cannot be recommended in routine practice. (6)

Synchronised Intermittent Mandatory Ventilation (SIMV) – Flow /volume/pressure triggered, pressure limited, time cycled ventilation. A set number of breaths are supported as determined by the back-up rate. The ventilator divides a minute into set windows based on the back up rate. If no spontaneous breath suitable for triggering is generated within that window, a mandatory breath is delivered. Any additional spontaneous patient breaths are unsupported

Synchronised Intermittent Positive Pressure Ventilation (SIPPV)/Assist Control (AC)/ Patient Triggered Ventilation (PTV) - Flow /volume/pressure triggered, pressure limited, time cycled ventilation. All spontaneous patient breaths are supported should they satisfy set trigger threshold. Back up mandatory breaths kick in if the patient’s spontaneous breaths are lower than the set back up rate.
Pressure Support Ventilation (PSV) – Flow /volume triggered, pressure limited, flow cycled ventilation. Variable inspiratory time and rate. Back up breaths kick in if patient's spontaneous breaths are lower than set back up rate.

SIMV + Pressure support – Often used during weaning to a low rate. Spontaneously triggered breaths are augmented by additional airway pressure by the ventilator up to a pre-set proportion of the PIP and are flow terminated. Periods of inactivity/ apnoea is supported by a pressure limited time-cycled breath up to the set PIP and back up rate

Volume guarantee (VG) – Best used in situations where there is rapidly changing lung compliance. Volume limited by set tidal volume but the volume guarantee is overridden if maximum pressure setting is reached ( It is volume limited for some breaths and pressure limited for some – hybrid mode! Can be used in combination with SIMV, SIPPV/AC or PSV)

Practical Guide to Conventional ventilation Modes

Choice of Ventilation Mode:

This varies significantly from one unit to another. There are theoretical advantages of one mode over another in a specific group of patient but it is important and far more beneficial to ventilate in the mode that one is most familiar with.

Most units would prefer to use SIPPV in small ELBW babies to maximise support for every breath for such babies. A greater vigilance of leak and water in the circuit is required to prevent autocycling. Appropriate setting modification is required in rapidly breathing babies to avoid hyperinflation and hypocarbia. Triggered or synchronised ventilation have been shown to reduce duration of ventilation as compared to CMV.

PSV is an excellent mode in babies with good respiratory drive, relatively mild lung disease and during weaning. It does not always work so well in babies with stiff lungs such as bad chronic lung disease. Experience and close bedside observation required to set appropriate flow.

SIMV is a very popular ventilation mode more suitable for bigger babies and often used in stable phase and weaning. There is less risk of hyperinflation and hyperventilation from autocycling but greater risk of lung atelectasis and work of breathing at lower rates.

Recent Cochrane review has suggested that use of volume guarantee ventilation reduces the combined outcome of death or chronic lung disease. It also reduces the risk of hypocarbia, pneumothorax, days on ventilation and a combined outcome of PVL or severe intraventricular haemorrhage on brain ultrasound scan. Volume guarantee should be considered when lung compliance is changing rapidly or there is increased risk of atelectasis due to stiff lungs and increased airway resistance. It can be used in conjunction with other modalities of synchronised ventilation.

High Frequency Oscillation Ventilation is widely used in the UK as a rescue mode for both preterm and term infants with respiratory failure. Its use as elective mode of ventilation is less common. Despite widespread acceptance and use in tertiary units, the evidence for its usefulness is inconsistent from RCTs and recently updated Cochrane review has failed to provide evidence for its benefit for either elective or rescue use in respiratory failure in neonates. Correct choice of patient, pathology and operator competence may be important factors in success.

Practical set up, adjustments, troubleshooting and weaning in a preterm infant with RDS: This is described in detail for SIPPV mode and any additional modifications are described for other modes.
Synchronised Intermittent Positive Pressure Ventilation (SIPPV)
Also Known as Assist Control (AC) or Patient Triggered Ventilation (PTV)

- Flow triggered – pressure limited – time cycled ventilation
- All spontaneous breaths over and up to the set trigger threshold is supported
- Set frequency will provide back up during periods of apnoea
- Can be used with Volume Guarantee

Common set up: The following parameters need to be set up

Flow – 5-8 litres is sufficient for most preterm infants (Higher flow may be required to maintain MAP in settings with very short inspiratory time, high PIP and fast rate) Very high flow can damage preterm lungs and increase airway resistance. Some ventilators have preset flows and do not need this to be set

Set Trigger threshold – For smaller babies keep trigger threshold close to the lowest setting to allow most breaths to be triggered. The most sensitive trigger threshold should be avoided as it increases the risk of auto cycling from water, leak and movement of circuit tubing. If you have pulmonary graphics display, set the trigger threshold just below the flow generated during spontaneous patient breaths.

PEEP – Usual starting point 4-5 cm. Higher PEEP may be useful in very stiff lungs, turgid lungs with large PDA and significant abdominal distension. Lower PEEP may be useful in air leak syndromes but be aware of atelectasis. Lung inflation on X-ray may provide a good guide to adjust PEEP. When PEEP >6 cm is necessary, take senior advice

PIP – Usual starting point is 18cm. Adjust according to TV readings of 4-4.5 mls /Kg. Usual increments is by 2cm. Usual range 14-26cm. If PIP higher than 26 cm is required, consider senior input and HFOV.

I time- Usually set at 0.3-0.4 sec. Higher I time may be useful for babies with CLD and stiff lungs but be aware of air trapping in infants with higher spontaneous breath rates.

Back up rate – This is usually set at 40-50/min to allow back up during periods of tiredness and apnoeas. It must not be set too high as it reduces the window of triggering for the baby

If using with Volume Guarantee mode – Set PIP is the ‘Maximum pressure’ allowed to deliver desired tidal volume.

Set alarm limits as appropriate for your ventilator and your patient. They should be set in such a manner that a balance is struck between early warnings of deviation and alarm nuisance. MV will vary a lot depending on patient’s respiratory effort and therefore an initial wide MV alarm limit (±30%) may be required. Set a more narrow limit when infant has settled in a rhythm.

Adjustments: see section 2. Remember adjusting or weaning the respiratory rate is unlikely to affect gas exchange as this is a patient controlled parameter, unless the patient is apnoeic or breathing slower than the back up rate.

Troubleshooting:

Infant not triggering –
- sedated or unwell infant with poor central drive
- overventilated infant with low PCO₂
- back up rate set too high leaving no window for spontaneous breathing – reduce back up rate and maintain minute volume by adjusting parameters that increase TV

Very high ventilator rate
- Low tidal volume - Ensure optimal TV of at least 4mls/Kg
- Autocycling – ventilator senses artefacts as trigger for initiating ventilator breaths
o Check for water in the circuit
o Check for big leaks
o If still persists after sorting above consider increasing trigger threshold or light sedation

Infant fighting the ventilator
- **Asynchrony** – check if ETT patent, inspiratory time too long, water in circuit, inappropriate back up rate

**Weaning:**
- Normally weaned by reducing PIP by 1-2 cm (and / or PEEP) and not by rate unless the child has slower spontaneous respiratory effort than back up rate when weaning is questionable.
- Extubate when infant is triggering steadily at PIP of 16 cm
- Do not wean pressure to low in babies with significant Chronic lung disease as it promotes atelectasis and extubation failure
Synchronised Intermittent Mandatory Ventilation (SIMV):

- Flow triggered – pressure limited – time cycled ventilation
- Only pre-set number of spontaneous breaths up to the set trigger threshold is supported. Any additional spontaneous breaths are unsupported by the ventilator. For e.g. if the rate is set at 60, and the infant is breathing at 70, 10 breaths a minute will be unsupported.
- Set frequency will provide back up during periods of apnoea
- Can be used with Volume Guarantee
- Avoid in extremely small babies with narrow ETT

Parameters that need setting in SIMV

**Flow** – Similar to SIPPV

**Trigger** – Similar to SIPPV

**PIP and PEEP** – Similar to SIPPV

**I Time** ($T_i$) – 0.3-0.4 sec – less likely to develop air trapping due to fast spontaneous rates

**Rate**: Usually started @ 60/min to achieve better synchronisation. Thereafter adjusted as required to attain target minute volume. Only the set number of breaths will be supported.

**Alarms** – Same principle except that limits much easier to set as expected MV is easier to calculate (set rate × TV generated)

If using with Volume Guarantee mode set PIP is the maximum PIP

**Adjustments:**
Similar to SIPPV except that rate adjustment could be used to regulate MV and pCO$_2$

Additional pressure support mode is available in some ventilators to avoid lung atelectasis on slow back up rates. This ensures pre-set additional pressure support for every synchronised spontaneous patient effort (usually a few cm above PEEP but lower than the set PIP for mechanised breath). The amount of pressure support is then gradually reduced as patient gets ready for extubation.

**Troubleshooting:**
Similar to SIPPV except autocycling is unlikely a problem and risk of hyperinflation is reduced.

**Infant not triggering** –
- sedated or unwell infant with poor central drive
- overventilated infant with low PCO$_2$
- back up rate set too high leaving no window for spontaneous breathing – reduce back up rate and maintain minute volume by adjusting parameters that increase TV
- Infant too tired due to increased work of breathing against a small tube secondary to inadequate back up rate

**Infant fighting the ventilator**
- Asynchrony – check if ETT patent, inspiratory time too long, water in circuit, inappropriate back up rate

**Weaning:**
- Both pressures (affecting TV) and rate can be reduced during weaning but most prefer to wean pressure first
- Do not wean to very low rates i.e. <30/minute. Lower rates should be used for the minimum duration possible. Lower ventilator rates for prolonged period forces the infant with higher spontaneous breathing rate to struggle to breathe against a narrow ETT thereby tiring the infant and promoting atelectasis and subsequent extubation failure.
- Consider additional pressure support over and above CPAP when slower rate is being used
Pressure Support Ventilation (PSV)

- Flow triggered – pressure limited – flow cycled ventilation
- Both inspiratory and expiratory synchronisation
- Variable inspiratory time and rate controlled by patient
- All spontaneous breaths over and up to the set trigger threshold is supported
- Set frequency will provide back up during periods of apnoea and can be used in conjunction with volume guarantee mode

**How does it work?**

- The ventilator monitors flow across the flow sensor on endotracheal tube in real time
  - maximal inspiratory flow is recorded
  - when the actual flow into the patient reaches 5% of maximal inspiratory flow recorded in the same breath, inspiratory support is terminated and pressure is dropped to expiratory pressure
  - the patient is allowed to exhale immediately after the tidal volume was delivered
  - if the actual flow still exceeds 5% of maximal inspiratory flow, breath is cycled by time (pressure is dropped to expiratory pressure when inspiratory time is completed)
- Set Ti determines only the upper limit for inspiratory time
  - the real inspiratory time depends on patient’s spontaneous effort, lung mechanics, and maximum inspiratory flow
  - inspiratory flow becomes a crucial parameter in controlling of duration of inspiratory pressure and inspiratory pattern

**Advantages:**
- customised patient controlled inspiratory time avoids inspiratory plateau and reduces over-distension
- provides greater comfort
- works best for mild lung disease and during weaning

**Disadvantages:**
- Adjusting appropriate flow is a crucial element that requires meticulous clinical observation and experience. Avoid if not used to the principles
- May not work in practice for very stiff, pressure /volume dependant lungs with significant V/Q mismatch and increased airway resistance i.e. significant CLD

**Set up:**
- Set PIP, PEEP, Trigger threshold, back up rate and FiO₂ in the usual way
- **Set Ti is the maximum inspiratory time allowed. Set Ti to 0.4 second**
- Once PSV mode is on – observe patient for work of breathing and comfort
- Adjust inspiratory flow to minimise work of breathing
- Check spontaneous inspiratory times generated Ti spo. Ti spo should be between 0.20 and 0.35 s.
- Re-evaluate work of breathing and set inspiratory flow if Ti spo outside this range
- When used in conjunction with VG – Set desired TV. Set PIP as the maximum allowed pressure

PSV+VG allow the infant to control almost all aspect of ventilation and allows auto-weaning

However, adjustments during PSV in practice require experience in clinical observation and a good understanding of changing lung mechanics in disease. Consult a more senior colleague early.

(Adapted from Royal Gwent Guidelines 2011 & Dräger Teaching Files)
Volume Guarantee Ventilation (VG)

- Flow triggered, volume guided (although actually pressure limited), flow or time cycled depending on modalities it is used with
- Can be used with any modality – SIPPV, PSV, SIMV

How does it work?
Instead of prescribing a set PIP to be achieved for each breath, set tidal volume (TV) can be prescribed on the ventilator. The ventilator will try to deliver this prescribed TV with the lowest possible pressure. This can be achieved on a breath-to-breath basis, by analysing how much volume was delivered with the previous breath and adjusting the PIP up or down to increase or decrease the TV accordingly for the next breath. Some ventilators can achieve this alteration only over the next few breaths.

Contraindication:
- Leak of >40% - as TV measurements are unreliable
- Use with caution in leaks 25-40%

Advantages:
- Provides uniform lung volumes with changing lung compliance – RDS following surfactant
- If properly set - avoids barotrauma, volutrauma and atelectotrauma

Limitations:
- Does not work with big leaks
- Awareness of the minimum volume that your ventilator can deliver reliably may be useful in extremely small babies.
- Be vigilant in small babies for hyperinflation as initial TV volume prescription is still a guesstimate and may need to be tailored to individual baby.

Set up:
- Set Flow, Trigger threshold, PEEP, Ti, FiO2 as appropriate (see SIPPV/SIMV/PSV guideline)
- Select an initial PIP that will give you the desired TV on the conventional pressure limited mode (see below)
- Select VG
- Set TV 4-6 mls/kg. It is common to start with 4.5 mls/kg for RDS and higher volumes of 5-6 mls /Kg in established CLD
- **On VG, ‘Set PIP’ in essence is the maximum PIP allowed to deliver the desired TV. This is essentially an alarm limit.** Once VG is activated reset the PIP 20% higher (usually 4-6 mbar) higher than currently required to deliver the desired TV. If you set it too close to current setting you may not achieve desired TV for every breath (affected by movement, splinting, secretions) or if the lung mechanics deteriorates (atelectasis, worsening RDS, pneumonia) and you will have frequent alarms. In contrast, if you set it too high, you will deliver the volume but will not be alerted to a deterioration in pulmonary status and an imperceptible rise in delivered PIP that may require further action (for e.g. clinical assessment, chest x-ray, treatment for sepsis etc.).
- However be prepared to allow higher pressures to achieve TV if your clinical assessment matches information provided by the ventilator
- Set rate/Back up rate as appropriate to provide an estimated MV of 200-300 mls/Kg
- Set MV alarm limit to ±30% of this value to prevent frequent alarms (common cause of inappropriate discontinuation of VG)

Monitoring:
- Monitor as normal with frequent observations of saturations, HR, perfusion, BP and blood gases. Check for appropriate lung inflation on CxR
- Chart not only ‘set PIP’ but also ‘measured PIP’. Awareness that technology is not always full proof particularly in small babies may be useful. There is no substitute to a thorough clinical assessment
Adjustments and Weaning:
- The PIP limit needs to be adjusted from time to time in response to changes in lung mechanics. Maintain the PIP limit sufficiently close to actual PIP, yet avoiding frequent alarms.
- If you need to increase the amount of guaranteed TV, you may need to increase the PIP so that the ventilator can deliver the set TV.
- Persistent O₂ requirement – If set TV thought to be adequate, increase PEEP.
  - If the infant is persistently tachypnoeic (RR>80)
    - normal pH and pCO₂ – consider increasing the volume target as it suggests increased work of breathing.
    - Low pCO₂ - consider sedation.
- Weaning should be on the basis of volume. If the baby is over-ventilated, reduce the prescribed volume by an appropriate amount. Usual change is 0.5mls/Kg. Avoid going below 4mls/Kg.
- There is no point reducing the rate if the baby is breathing above the ventilator on PSV or SIPPV as each spontaneous breath is assisted. On SIMV, reducing the rate will reduce the number of assisted breaths but this may increase the work of breathing as it will increase the time spent receiving ET CPAP.
- There is no point reducing the pressures without reducing the set TV - all you will do is make the ventilator alarm because it is less likely to be able to deliver the volume prescribed with the pressures set.
- Extricate when VT maintained at set levels
  - PIP 14-18
  - FiO₂ <0.35
  - Good spontaneous respiratory effort

Troubleshooting:

Frequent low TV alarms!
- Check for leak – is it too high?
- Is ETT blocked?
- Check for set TV – is it still what it was supposed to be?
- Check the maximum set PIP – is it still the same as set?
- Confirm adequate Ti and flow rate – may need to increase either or both
- Check the alarm delay limit and adjust if too short.

If all ok – increase PIP limit and investigate cause of change in lung mechanics e.g. atelectasis, pneumothorax, pulmonary oedema.

If pressure limit needs substantial or repeated increase verify TV measurements are accurate!
(assess chest rise, obtain a blood gas and if required get a Chest X-ray)

Frequent MV alarms:
Set limits to ±30% of desired TV. If you use the automatic alarm limit reset, do not do this when your minute volume is too low or too high (e.g. just before or after suction or during a splinting episode as it will alarm again when the problem is resolved).
High Frequency Oscillation Ventilation (HFOV)

High frequency oscillatory ventilation is a type of mechanical ventilation that
• uses a constant distending pressure (MAP) to keep the lungs open throughout the cycle
• generates small pressure swings or ‘oscillations’ around the MAP (Delta P) to produce tidal volumes smaller than the dead space
• these oscillations are applied at very high rates (up to 900 cycles per minute)

How does it work?

The above measures improve recruitment of alveoli and uniform gas distribution reducing V/Q mismatch, improves molecular gas diffusion in proximal airways and creates a continuous two-way traffic for inward and outward gas flow (as opposed to bulk convection in conventional ventilation where inspired gas replaces expired gas).

The result is more efficient oxygenation and CO₂ elimination. It is also regarded as less aggressive due to minimal pressure/volume swings. On principle it reduces atlectotrauma along with baro and volutrauma

Indications:
• ‘Rescue’ in infants with refractory respiratory failure on Conventional ventilation
• Lung protection in ‘air leak syndromes’ (PIE changes, Pneumothorax)
• Conditions where assured uniform lung inflation may be beneficial (PPHN, severe RDS). It is thought to work better in homogenous lung disease

This modality of ventilation is very powerful and requires judgment and expertise to use properly. Please seek senior guidance if not familiar with its use.

Strategies
• High volume strategy (optimal lung inflation) – 1st Choice and most commonly used for homogenous lung disease
• Low volume strategy only reserved for air leak syndromes and possibly in pulmonary hypoplasia to minimise further lung injury

Controls and adjustments:

Mean Airway Pressure (MAP or Paw) – This primarily determines lung inflation and oxygenation. Higher MAP improves oxygenation provided it has not caused hyperinflation! Usual magnitude of change 1-2 cm / step

Delta P or Amplitude or Power – This is a measure of pressure swing around MAP and creates the small TV. This primarily determines CO₂ elimination. Higher the amplitude greater the CO₂ elimination. It is most effective when there is optimum lung inflation or MAP.

However, what is set on the machine is largely attenuated (by small ET tube, compliant circuit etc.) and is not the same when delivered at patient level. Therefore the right setting on the machine is the one that provides adequate chest oscillation rather than the actual numbers. Start at twice the set MAP as guide and then adjust according to chest oscillation and pCO₂. Usual magnitude of change 4-6 / step

Frequency – This determines the frequency of the pressure swings and usually varies from 7-15 Hz (1 Hz = 60 cycles/min) in neonatal practice. Ventilation is most efficient if the frequency matches the natural resonant frequency of the diseased lungs. It is a very powerful tool for CO₂ elimination and should only be altered after careful consideration and discussion with senior experienced personnel. Usual magnitude of change 1 Hz / step

Lower the frequency greater the CO₂ elimination (Remember it is exactly opposite that of Conventional Ventilation!!)

This is because a higher frequency reduces TV and has a greater cumulative effect on final MV or DCO₂ as per equation below
**DCO₂ = Frequency × TV²**

**Inspiratory time** (often expressed as a percentage of time there is forward oscillation or as an I/E ratio). Usual setting is 33% (1:2) with a maximum of 50% (1:1). The latter has a greater risk of gas trapping. In some ventilators this is preset and cannot be altered.

**Bias flow:** This is the rate of replacement fresh gas flow used while maintaining MAP. Usually set at 12 litres/min. This is preset in some ventilators.

**Preparation before starting HFOV:**
- Ensure appropriate ETT size and position
- Suction airways. Insert a close suction mechanism
- Apply and calibrate Transcutaneous oxygen and CO₂ monitoring
- Ensure appropriate sedation (paralysis not always required)
- Review existing lung inflation, if available on a recent chest X-ray
- Baseline record of heart rate, invasive blood pressure, blood gases including lactate and urine output

**Initial Set Up (High volume strategy):**
- Bias flow – 12 litres/min on Sensormedics, not set in other ventilators
- I time - 33% sensor medics, other ventilators where option available set I/E ratio as 1:2 or 1:1
- Fio₂ as required to maintain saturations – usually high by this time e.g. 0.7-1.0
- Frequency – 12-15 Hz for babies less than 1000 grams, 10Hz for others including near term and term babies
- MAP/ PaW – Start 2 cm above that on conventional ventilation
- Delta P / Amplitude – Initially set as twice the MAP and adjust up and down according to chest wobble. The chest wobble should be assessed by bending down at the level of patient’s chest. The wobble should extend up to the umbilicus but not beyond. Adjust the provisionally set delta P to achieve this

**Adjustments and further monitoring:**
- Increase MAP by 1 cm every 5 minutes until you see a response - a rise in oxygen saturations and a fall in FiO₂
- Observe trends on TcCO₂ and fine tune Delta P
- Blood gas at 20-30 minutes. Continue to monitor TcCO₂ (if reliable) or pCO₂ on gases frequently and adjust Delta P accordingly until you have seen the nadir of pCO₂. This practice is very important to avoid hypocarbia!!
- Obtain a chest X-ray within 30-60 minutes to assess lung inflation – optimum – 8-9th posterior ribs. Adjust MAP to ensure optimum inflation if not already achieved
- Adjust delta P by 2-4 units to obtain desired co₂. ↑dP = ↑ co₂ elimination
- Do not wean MAP until Fio₂ 0.3-0.4 in homogenous lung disease such as RDS. This may not be achieved in CLD where a significant reduction in FiO₂ or levels below 0.6 may be acceptable
- Once the above goal is achieved wean MAP to the minimum tolerated i.e. where you see the saturations dropping again! Reset MAP 1 cm higher than this.

**This step is very important to avoid hyperinflation! You can maintain an open lung with lower pressures than you required to open it in the first place!!**

- If unable to eliminate CO₂ retention despite a very high setting of delta P
  - Reassess that chest is still wobbling
  - Rule out pneumothorax (Cold light / Chest X-ray)
  - Ensure optimum lung inflation – Do you need to adjust MAP –If in doubt get a chest X-ray
  - If the above optimum – Reduce frequency after discussing with consultant
- Avoid routine suctioning. If this is necessary re-recruit lungs by resetting MAP 1-2 cm above current setting for 10 minutes and then reduce back to baseline.
• At all times monitor for cardiovascular compromise related to hyperinflation
  o Drop in systemic blood pressure and rise in HR
  o Rise in FiO₂ and pCO₂ after initial improvement
  o Reduced urine output and rising lactate
  o If in doubt see clinical response by dropping MAP by 2 cm or confirm on chest X-ray

Chest X-ray in hyperinflation - lung inflation >9th posterior ribs, narrow cardiac silhouette, flat diaphragm, bulging intercostal spaces

Troubleshooting:
• Acute rise in TcCO₂/pCO₂
  o Loss of wobble - commonest (blocked or kinked tube)
  o Pneumothorax – chest drain will be required
• Gradual rise in FiO₂ and pCO₂
  o Hyperinflation – reduce MAP
  o De-recruitment following suction – manage as described above
  o Worsening of lung disease – escalate settings
  o Associated unresolved PPHN
  o Alternative diagnosis (e.g. cardiac)

Recognised complications and prevention:
• Hypocarbia – TcCO₂ monitoring and fine tuning of delta P
• Hyperinflation – Early chest X-ray and reduction to minimum MAP tolerated after initial improvement. Awareness of features of hyperinflation
• End organ manifestation of poor cardiac output
  o Hypotension
  o Poor urine output / renal failure
  o Rising lactate
  o Rarely intraventricular haemorrhage

These complications are not usually seen if care taken to avoid cardiovascular compromise

Low volume strategy: Used in air leak syndrome and pulmonary hypoplasia as lung protective strategy

• Start with MAP = that on conventional ventilation
• Consider starting on higher frequency 12-15 Hz
• Accept higher pCO₂ and perhaps lower oxygen saturations
• Rib count of 9th rib for lung inflation unrealistic and unreliable in pulmonary hypoplasia – aim lower
References and further reading:

- De Paoli AG, Clark RH, Bhuta T, Henderson-Smart DJ. High frequency oscillatory ventilation versus conventional ventilation for infants with severe pulmonary dysfunction born at or near term. Cochrane Database of Systematic Reviews 2009, Issue 3. Art. No.: CD002974. DOI: 10.1002/14651858.CD002974.pub2

Acknowledgements:

Respiratory guidelines – ABMU Neonatal Guidelines 2011
SIPPV/PSV guidelines – Royal Gwent Hospital 2011
Guidelines on conventional ventilation – Auckland District Heath Board, New Zealand
Ventilation: North Trent Neonatal Network Clinical Guideline 2011
Golden Hour: Yorkshire Neonatal Network Guideline
Appendix 1: Guide to approximate oral ETT size and length

<table>
<thead>
<tr>
<th>WEIGHT (GMS)</th>
<th>GESTATION (approx.)</th>
<th>ETT size (mm)</th>
<th>LIP MARK (cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>450 – 850</td>
<td>23 – 25+6</td>
<td>2.5</td>
<td>6.0</td>
</tr>
<tr>
<td>850 – 1000</td>
<td>26 – 27+6</td>
<td></td>
<td>6.5</td>
</tr>
<tr>
<td>1000 – 1400</td>
<td>28 – 29+6</td>
<td>2.5 or 3.0</td>
<td>7.0</td>
</tr>
<tr>
<td>1400 – 1900</td>
<td>30 – 32+6</td>
<td>3.0</td>
<td>7.5</td>
</tr>
<tr>
<td>1900 – 2000</td>
<td>33 – 34+6</td>
<td></td>
<td>8.0</td>
</tr>
<tr>
<td>2200 – 2600</td>
<td>35 – 36+6</td>
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<td>9.5</td>
</tr>
<tr>
<td>3400 – 3700</td>
<td>40</td>
<td>3.5</td>
<td>10.0</td>
</tr>
<tr>
<td>&gt;3700</td>
<td>40+</td>
<td></td>
<td>&gt;10.0</td>
</tr>
</tbody>
</table>

Please note that the weight is the most accurate guide, the gestation is only an approximate guide if weight is not known.
Appendix 2: Suggested scheme of initial ventilator management in NICU

Infants < 28th gestation who need ventilation at birth
- Plastic bag
- Early high dose surfactant
- Low pressure ventilation with PEEP 4-5cm
- Start in Air – optimise FiO2 as per oxygen saturations

Admit to NICU (Prime time)
- Conventional trigger ventilation (Short I, Ideally VG with TV 4-6 mls/Kg)
- Blood gas
- BP monitoring
- Delay opiates
- Load with caffeine
- Consider Central Lines

< 30% O2 &/or OI < 5
- 23-25 weeks
- No opiates
- Continue gentle ventilation until ready for extubation

30 - 50% O2 &/or OI 5-10
- 26-27 weeks
- No opiates
- Elective extubation CPAP/BIPAP/NIPPV
- Do not extubate if for transfer out

> 50% O2 &/or OI > 10
- ETT position
- Severe RDS
- Pneumothorax
- Pneumonia
- Pulmonary hypoplasia
- PPHN

Consider cause:
- Ensure optimal pressures
- Continue CV + VG
- Monitor TV
- Consider Opiates

Consider early 2nd dose surfactant if FiO2 >0.4 and or MAP >8cm