Neonatal tidal volume targeted ventilation

Colin Morley

Retired Professor of Neonatal Medicine,
Royal Women's Hospital, Melbourne, Australia.
Honorary Visiting Fellow, Dept Obstetrics and Gynaecology,
University of Cambridge

Why we used pressure limited ventilation for years?

- Early ventilators did not measure tidal volume entering the ETT.
- The ETT was uncuffed and some tidal volume leaked.

- Neonatologists became very familiar with pressure limited tidal volume.
- They believe it work well.
- It was simple.
- However, they had no measurements or display to show what was really happening to the delivered gas.

- Now ventilators accurately measure:
  - inspired tidal volume,
  - expired tidal volume,
  - endotracheal tube leak,
  - inflation, inspiration, expiration times and pressures.
- Should we change to controlling tidal volume or is pressure limited ventilation good enough?
- A set peak inflating pressure cannot not deliver a set tidal volume because baby breathes, cries, obstructs, is apnoeic, and compliance changes.

- Volume- targeted ventilation (VTV) strategies aim to deliver a consistent tidal volume (VT).
- Different ventilators have different modes of VTV.
- Depending on ventilator and mode selected it adjusts one or more of PIP, inflation time, and inflation flow.
- The clinician sets a target VT.
- Different ventilators set either VT_i, VT_e, or both, to control VT delivery.
- Expired VT is less affected by ETT leaks
- Measuring VT_i and VT_e enables ETT leak to be quantified.

Simple respiratory physiology

How to control oxygenation

- Gas does not need to move in and out of the lung so it is not controlled by tidal volume.
- Just need:
  - oxygen in the lung
  - enough surface for oxygen to diffuse into blood
  - blood flowing through the alveolar capillaries
- If baby is hypoxic:
  - increase FiO_2
  - open the lung - PEEP or CPAP or mean airway pressure
  - improve blood flow in lungs – volume, BP, NO

How to control CO_2

- Move gas in and out of the lung to remove CO_2
- This is controlled by:
  - Tidal volume
  - Ventilator rate / spontaneous rate
  - Assisting baby's breathing
- Treatment of hypercarbia or hypocarbia:
  - Alter tidal volume
  - Alter ventilator rate

It is primarily the tidal volumes that injure the neonatal lung

Volutrauma not barotrauma

Dreyfuss et al. Am Rev Resp Dis 1988;137:1159

Mature rats ventilated at high PIP = 45 cm H_2O

Half had the chest and abdomen strapped to limit the tidal volume.

No strapping:

- High PIP & high V_T produced oedema & damage

With strapping:

- High PIP & low V_T no oedema or damage

6 large tidal volumes compromise lung function at birth

Bjorklund et al. Acta Anaesthesiol Scand 1995;39:153

- Five sets of twin lambs delivered at 127-128 days.
- One of each pair had 6 inflations of 35-40 mL/kg at birth before ventilation.
- Both had surfactant at 30 min.

➢ Bagged lambs had one third of the inspiratory capacity & maximum compliance at 4 hrs

RDS is acute lung damage

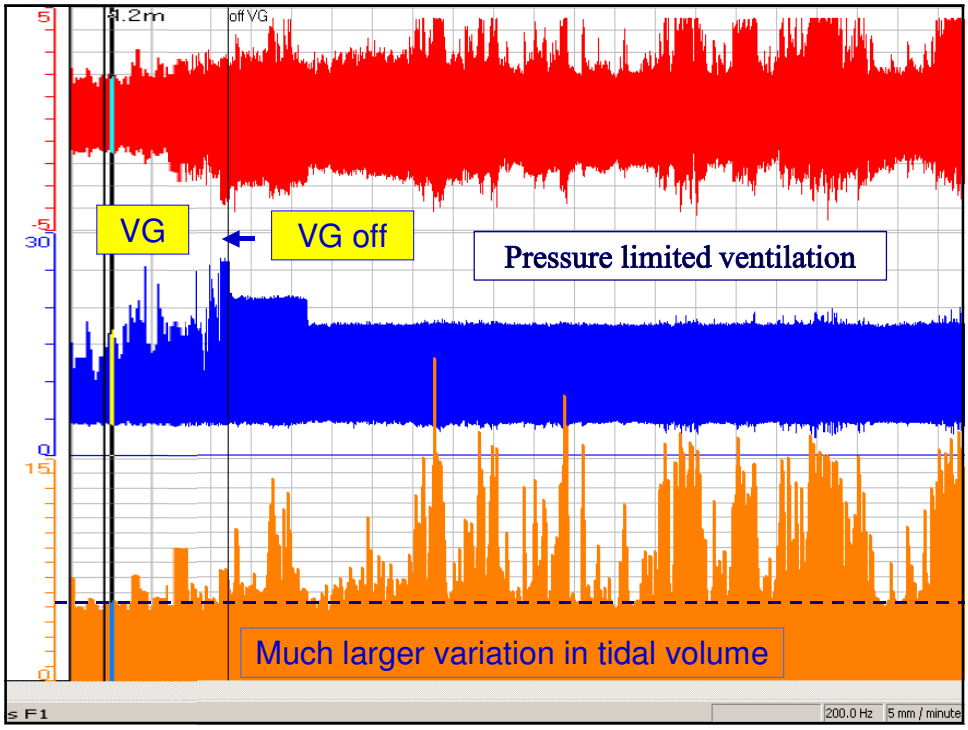
- Over-distension damages the immature lung. - volutrauma
- Repeated ventilation of an atelectatic lung causes damage. - atelectotrauma
- Proteins leak and coagulate to hyaline membranes.
- Inflammatory mediators are higher in babies who get BPD.

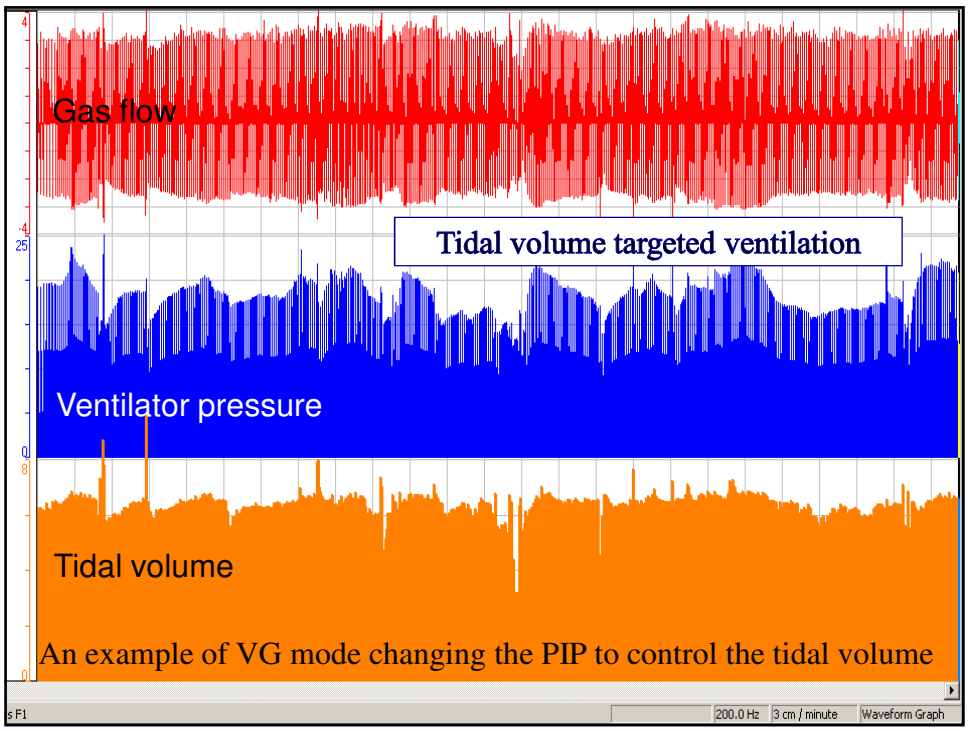
To avoid tidal volume damage, ventilator must adapt rapidly to changing respiratory parameters:

- Baby breathing in synchrony or out of synchrony with inflations
- Baby crying
- Baby splinting abdomen or diaphragm to obstruct inflations
- Apnoea
- Compliance and resistance
- Surfactant treatment
- ETT leak

If you use pressure limited ventilation what peak pressure will you use with a new admission?

- Pick a pressure, "watch chest move, adjust peak pressure and do blood gases"
- BUT with a set peak pressure tidal volume is always changing.
- A set peak pressure cannot deliver a set tidal volume because tidal volume is always changing.
- Modern neonatal ventilation needs to target the expired tidal volume not the PIP.
- Some of the inflation tidal volume is lost with ETT leak





Think – volumes not pressure

- Expired tidal volume
  - With an ETT leak some inflation tidal volume (V_{ti}) does not enter lungs.
  - Watch expired tidal volume (V_{Te}) rather than V_{Ti}
  - approx 4 – 6 mL/kg
  - Don't forget baby can contribute a lot of the V_T
- Minute volume
  - ~250 – 350 mL/min/kg

Volume-targeted versus pressure-limited ventilation in the neonate

Cochrane Database of Systematic Reviews 2010, Issue 11. Art. No.: CD003666.

Wheeler K, Klingenberg C, McCallion N, Morley C, Davis P.

Objectives

- To determine effect of volume-targeted ventilation vs. pressure-limited ventilation on mortality and morbidity.
- And whether there was a difference in: air leak, IVH and PVL and neurodevelopment.

Selection criteria

- All randomised and quasi-randomised trials comparing VTV vs. PLV in infants of <28 days.

RCTs

- 9 RCTs with different ventilators: 4 Babylog 8000, 3 Bird VIP, 2 Servo 300
- Different ways of giving VTV and PLV
- 630 babies enrolled

Volume targeted ventilation reduced:

Death or BPD 32% v 43%

RR 0.73 95% CI 0.57 to 0.93, NNT 8

Pneumothorax 4% v 10%

RR 0.46 95% CI 0.25 to 0.84, NNT 17

Hypocarbia ($PaCO_2$ < 35 mmHg / 4.7 kPa)

RR 0.56 95%CI 0.33 to 0.96, NNT 4

PVL or grade 3-4 IVH 8% v 16%

RR 0.48 95% CI 0.28 to 0.84, NNT 11

Days of ventilation

-2.36 95% CI -3.9 to -0.8

VTV modes were not associated with increased adverse outcomes

Studies have also shown Volume Guarantee with the Babylog 8000+ has:

- Less variation in tidal volume.
- Less lung inflammation.
- A more stable $PaCO_2$.
- Less variation in cerebral blood flow.

Volume Guarantee with Drager Babylog 8000+

- PIP changes for each inflation to "ensure" a set expired tidal volume.
- Uses expired rather than inspired tidal volume because of variable ETT leaks.
- Compensates for leaks to ~ 50% by ↑ PIP
- If tidal volume >130% set V_{Te} inflation stops.
- Separate control of triggered & untriggered inflations.

Accuracy of volume guarantee
expired tidal volumes as % set expired volume

Analysed from 6693 inflations

Triggered inflations

Mean (SD) V_{Te} =102% (29%), range 0–378%

Non triggered inflations

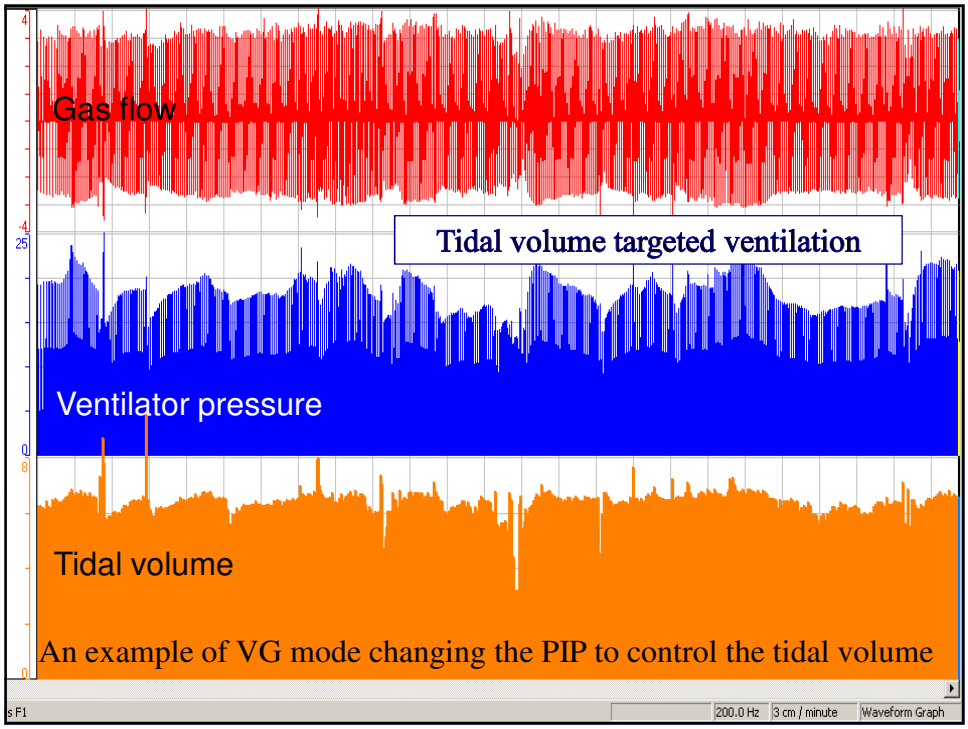
Mean (SD) V_{Te} = 97% (31%), range 0-322%

Large variation due to:

"crying" and "splinting"

What maximum pressure should be set?

- PIP changes for each inflation to try and deliver the set V_{Te}.
- In VG the set PIP is the maximum pressure the ventilator can use without alarming.
- If set PIP is too low the target V_{Te} will not be achieved and it will alarm “low tidal volume”.
- The PIP will vary a lot for each baby.
- I suggest you choose 30 or 35 cm H_2O.
- Some people advise ~5 cm H_2O above average PIP being used by VG. The problem is there is no average PIP.



What tidal volume should be set?

- Anatomical dead space is about 2 to 2.5 ml/kg
- A V_{Te} about 2x this gives adequate ventilation.
- Preterm infants with RDS have an FRC about 11 ml/kg and a TLC of about 19 ml/kg.
- A V_{Te} of about 4 to 6 ml/kg is appropriate for infants with RDS.
- A V_{Te}>8 ml/kg may cause volutrauma or at least over-ventilation.

Selecting the back-up rate in A/C VG ventilation: A randomised crossover trial Kevin Wheeler - submitted

Back up rate	30/min	40/min	50/min
Delivered inflations	56(6)	58(9)	62(8)
% triggered	85 (11)%	75 (19)%	61 (25)%

Cardio-respiratory parameters were stable at all rates.

Conclusion:

During A/C VG ventilation, most triggering with a BUR ventilator rate of 30/min.

Pressure differences between triggered & untriggered inflations

- 6540 inflations assessed, 62% were triggered.
- Triggered inflations have a 4 cm H_2O lower PIP than non-triggered : 12.9 v 16.7 cm H_2O ($p<0.001$)
- When PIP <3 cm H_2O above PEEP, SpO_2, heart rate and $TcCO_2$ were better than with higher PIP.

What happens when the PIP is reduced to PEEP?

- When PIP < 3 cm H_2O above PEEP, the SpO_2, heart rate and $TcCO_2$ were better than with higher PIP.
- This is because the baby must be breathing well if the PIP is so low in VG.

Good times to use volume guarantee:

- on admission

-surfactant administration

-baby breathing

-Before extubation

All the time !!

Advantages of A/C VG ventilation

- ✓ Works with the baby
- ✓ More stable tidal volumes
- ✓ Auto-weaning of pressures
- ✓ More stable $PaCO_2$
- ✓ Automatically compensates for:
  - ✓ changing ETT leak
  - ✓ changing compliance
- ✓ Automatic PIP adjustment if PEEP changed.
- ✓ Less lung injury

Journal of Perinatology (2011), 1–11

www.nature.com/jp

STATE-OF-THE-ART

A practical guide to neonatal volume guarantee ventilation

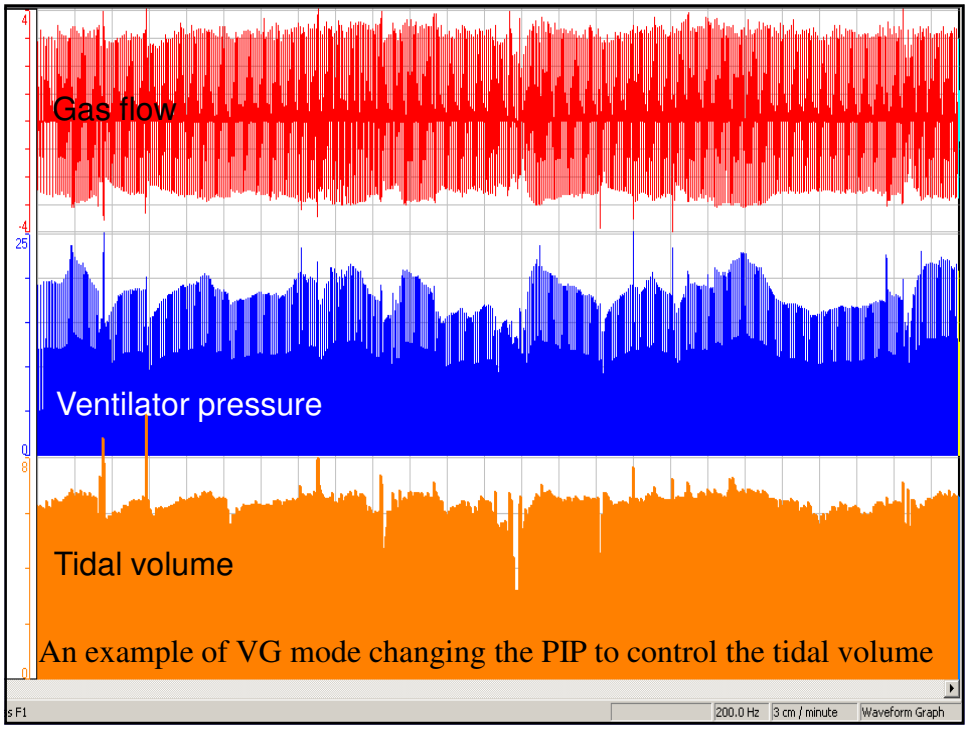
C Klingenberg[1,2,3], KI Wheeler[2,4,5], PG Davis[2,4,6] and CJ Morley[2,4,6]

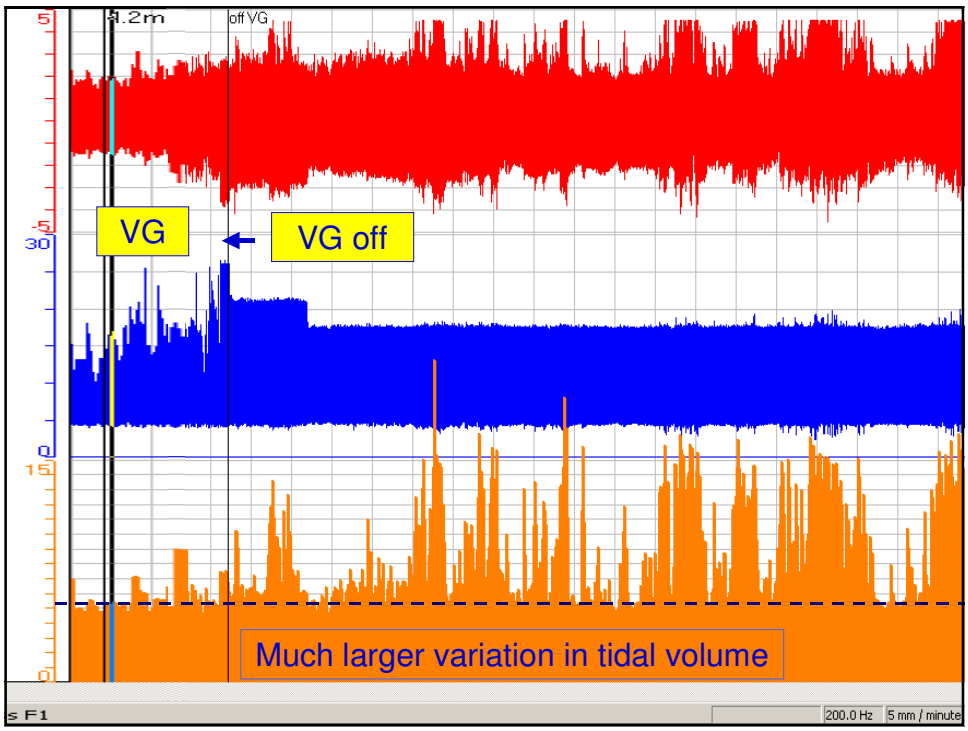
BUT…..

- VTV is designed to deliver a tidal volume.
- However this is calculated for the whole lung.
- Regional distribution of VT will vary depending on lung disease.
- In non-homogenous lung disease, using VTV does not eliminate the regional risk of lung injury from local volutrauma or shear stress.
- Opening the lung with PEEP and increased mean airway pressure is the best way to help this.

Turning off VTV and going back to PLV will not help this


Thank you for listening


Gas flow
Ventilator pressure
Tidal volume
An example of VG mode changing the PIP to control the tidal volume
200.0 Hz
3 cm / minute
Waveform Graph


4.2m
off VG
5
-5
30
0
15
0
VG
VG off
Much larger variation in tidal volume
s F1
200.0 Hz
5 mm / minute