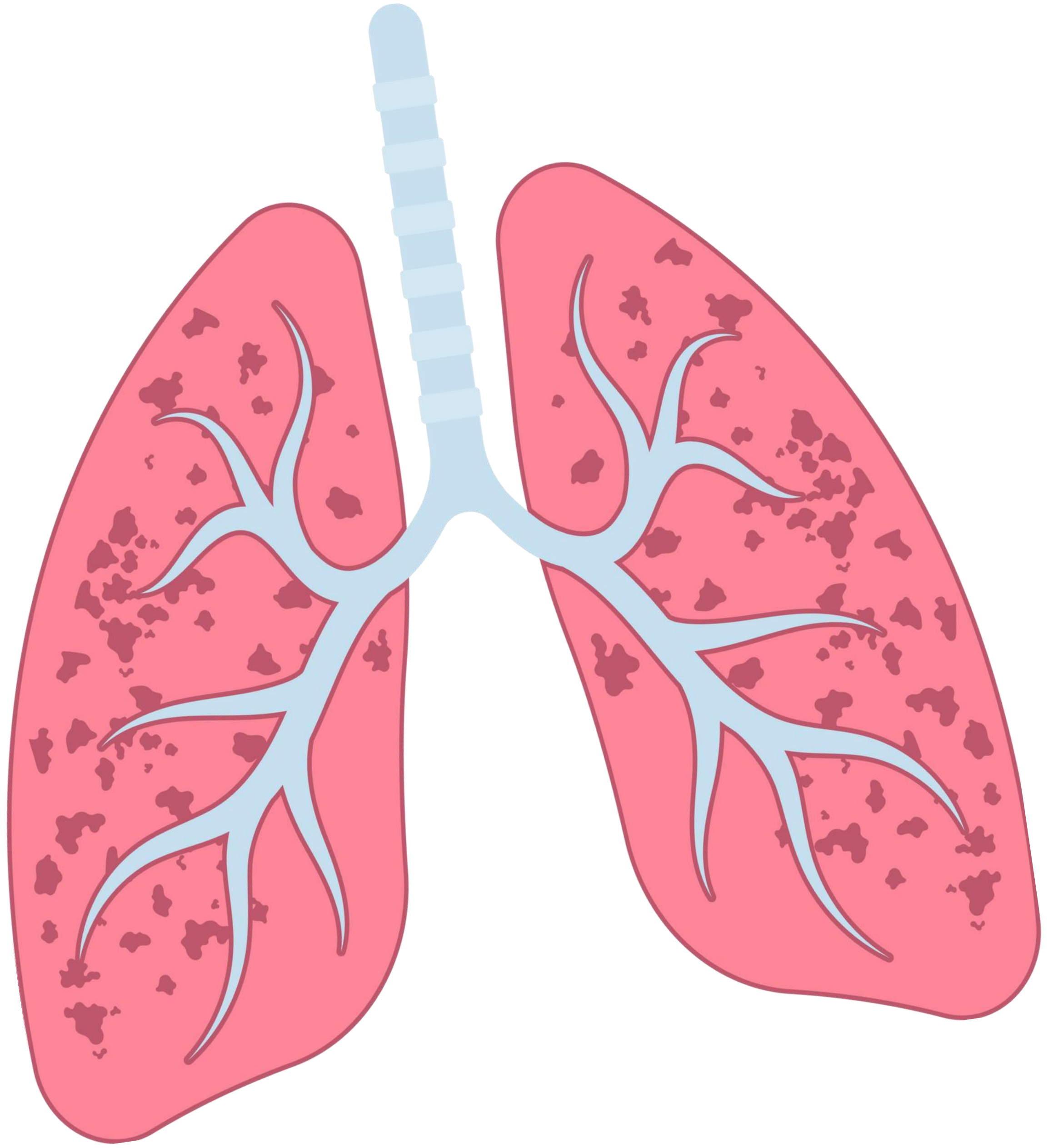
BASIC NEONATAL MECHANICAL VENTILATION



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LEARNING CONTENT

1. Indication and how we ventilate
2. Basic understanding of MV Parameters
3. Understanding different mode of Ventilation
4. Challenges and Troubleshooting
5. Simple Waveform, loops and Pulmonary mechanics

What are we trying to achieve during mechanical ventilation

Oxygenation

What it is:

- Enhancing oxygen delivery to tissues via the lungs and bloodstream.

How to improve oxygenation:

- **Increase FiO_2** (fraction of inspired oxygen).
- **Increase MAP** to recruit alveoli.
- **Use PEEP** to prevent alveolar collapse.
- **Optimize surfactant therapy** and **positioning** (prone or midline).
- **Minimize oxygen toxicity** by titrating FiO_2 to target SpO_2 range.

Monitoring tools:

- **Pulse oximetry** (SpO_2).
- **Blood gases** for PaO_2 and oxygenation index.

Target an Open Lung Strategy

What it is:

- Removal of carbon dioxide (CO_2) from the lungs via exhalation.

Why it matters:

- CO_2 buildup (hypercapnia) can cause acidosis, apnea, and brain injury.
- Too little CO_2 (hypocapnia) can reduce cerebral blood flow and cause IVH or PVL.

How to improve CO_2 elimination:

- **Increase tidal volume** (within safe limits).
- **Increase respiratory rate** (more breaths = more CO_2 cleared).
- **Ensure good lung compliance** (positioning, surfactant, gentle ventilation).
- **Minimize dead space** in circuits.

Why the Neonatal Lung Is So Dynamic

Transition from Fluid to Air

- At birth, lungs shift from fluid-filled to air-filled structures.
- First breaths require high pressure (~30–40 cmH_2O) to recruit alveoli.
- Surfactant production ramps up postnatally, altering compliance dramatically.

Timeframe	Compliance	Resistance
Birth	↓ (stiff lungs)	↑ (fluid-filled, narrow airways)
Day 1–3	↑ (post-surfactant)	↓ (airway clearance begins)
Day 4–7	Variable (depends on disease, ventilation)	May ↑ in BPD, MAS

Rapid Changes in Compliance & Resistance

- These shifts affect tidal volume delivery, gas exchange, and ventilator settings daily.

- **D**: Dead space ↑
- **Y**: Yielding chest wall
- **N**: New surfactant production
- **A**: Apnea-prone control centers
- **M**: Minute-to-minute compliance shifts
- **I**: Immature alveolar structure
- **C**: Constant ventilator reassessment

Neonatal Respiratory Physiology

Compliance

- *Definition:* How easily the lungs expand
- *Category:* Elastic property

Resistance

- *Definition:* How much opposition the airways present to airflow
- *Category:* Resistive property

Time Constant (τ)

- *Definition:* Time needed for lungs to fill/empty ~63%
- *Formula:* **Compliance × Resistance**
- *Category:* Dynamic parameter (influences breath timing)

- **“C-R-T = Choose Right Timing”**
- **C**: Compliance guides **pressure and VT**
- **R**: Resistance affects **flow and Te**
- **T**: Time constant **tailors rate** and **I:E ratio, Ti**

- **Short τ** → fast volume change → **short Ti**, **high rate**
- **Long τ** → slow volume change → **longer Te**, **lower rate**
- Always match **Ti and Te to τ** to avoid **incomplete inspiration or expiration**

Disease	Compliance	Resistance	Time Constant (τ)	Ventilation Strategy
RDS (Respiratory Distress Syndrome)	↓ (stiff lungs)	Normal or ↓	**Short τ**	Use **short Ti**, **higher rate**, **adequate PEEP** for recruitment
MAS (Meconium Aspiration Syndrome)	Variable	↑ (obstructive)	**Long τ**	Use **longer Te**, **lower rate**, avoid air trapping; consider **HFOV**
BPD (Bronchopulmonary Dysplasia)	↓ or variable	↑	**Long τ**	Use **longer Te**, **moderate rate**, **volume-targeted modes** to avoid VILI
CDH (Congenital Diaphragmatic Hernia)	↓ (hypoplastic lungs)	↑	**Long τ**	Use **gentle ventilation**, **low VT**, **longer Te**, consider **HFOV** or **VG**
TTN (Transient Tachypnea of the Newborn)	Normal or ↑	Normal	**Normal τ**	Use **standard Ti/Te**, monitor for spontaneous improvement
Apnea of Prematurity	Normal	Normal	**Normal τ**	Use **PSV or SIMV**, support spontaneous breathing with minimal settings
Pneumothorax / PIE	↓	↑	**Long τ**	Use **minimal pressures**, **long Te**, avoid overdistension; consider **HFOV**

Principles of Neonatal Ventilation

Neonatal Ventilation: Core Principles

Individualized Care
Tailor settings to **gestational age**, lung pathology, and disease progression.

Avoid Hyperoxic Injury

- Titrate FiO_2 to maintain safe SpO_2 targets (90–95%)
- Use blended oxygen and pulse oximetry alarms
- Minimize exposure to high FiO_2, especially in ELBW

Kaltsogianni et al., *Front Pediatr*, 2023 –

Prevent Air Trapping & Desynchrony

- Ensure adequate expiratory time (TE), especially in obstructive dise
- Use synchronized modes (SIMV, PSV, NSIMV) to reduce WOB
- Monitor waveforms for breath stacking or missed triggers

Loyola NICU Guidelines –

Target an Open Lung Strategy

- Use adequate PEEP to maintain functional residual capacity (FRC)
- Recruit alveoli without overdistension
- Monitor chest expansion, oxygenation, and CXR for lung inflation

Dargaville & Keszler, *Pediatric and Neonatal Mechanical Ventilation*, 2013

Prioritize Airway Management

- Secure ETT position and minimize leaks
- Use Cannulaide or nasal masks for non-invasive modes
- Avoid nasal trauma and monitor for obstruction or malposition

Kaltsogianni et al., *Front Pediatr*, 2023

- **"C-R-T = Choose Right Timing"**
- **C**: Compliance guides **pressure and VT**
- **R**: Resistance affects **flow and Te**
- **T**: Time constant **tailors rate** and **I:E ratio, Ti**

Match Mode to Disease & Mechanics

- Select ventilation mode based on compliance, resistance, and pathology
- Use volume-targeted modes for RDS, HFOV for PIE/CDH, SIMV+PS for BPD
- Adjust Ti, rate, and VT to match disease physiology

Chakkarapani et al., *Int J Pediatr Adolesc Med*, 2020

VENTILATOR SETTINGS IN THE NICU: 5 FUNDAMENTAL QUESTIONS

Modality Selection

- *What is the right modality for the pathophysiology?*
- → Choose based on disease type: e.g., HFO for homogeneous disease, VG for variable compliance.

PEEP Optimization

- *What PEEP is appropriate for the lung disease and desired lung volu*
- → Tailor to disease (e.g., RDS vs BPD) and recruitment goals

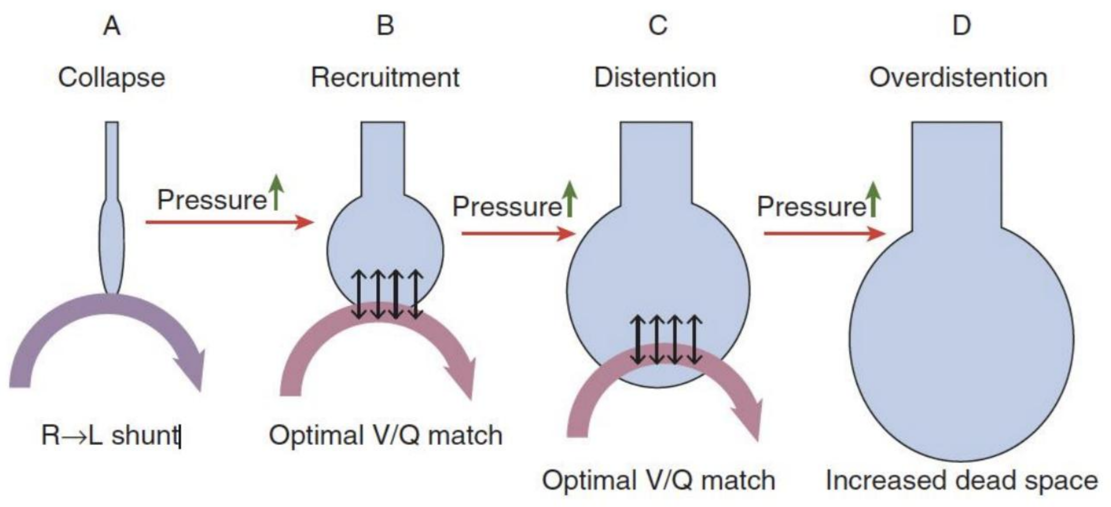
Target an Open Lung Strategy

- *What insp time suits the lung's time constant and baby's pattern?* – compliance/resistance and spontaneous effort.

PIP Targeting

- *What PIP yields ~4–6+ mL/kg tidal volume (initially)?* → Adjust base measured VT; reassess with compliance changes.

Decreased oxygen requirement with good V/Q match



Rate Setting

- *What rate ensures adequate minute ventilation and CO_2 clearance?*
- → Balance rate with VT and dead space; consider permissive hypercapnia if needed.

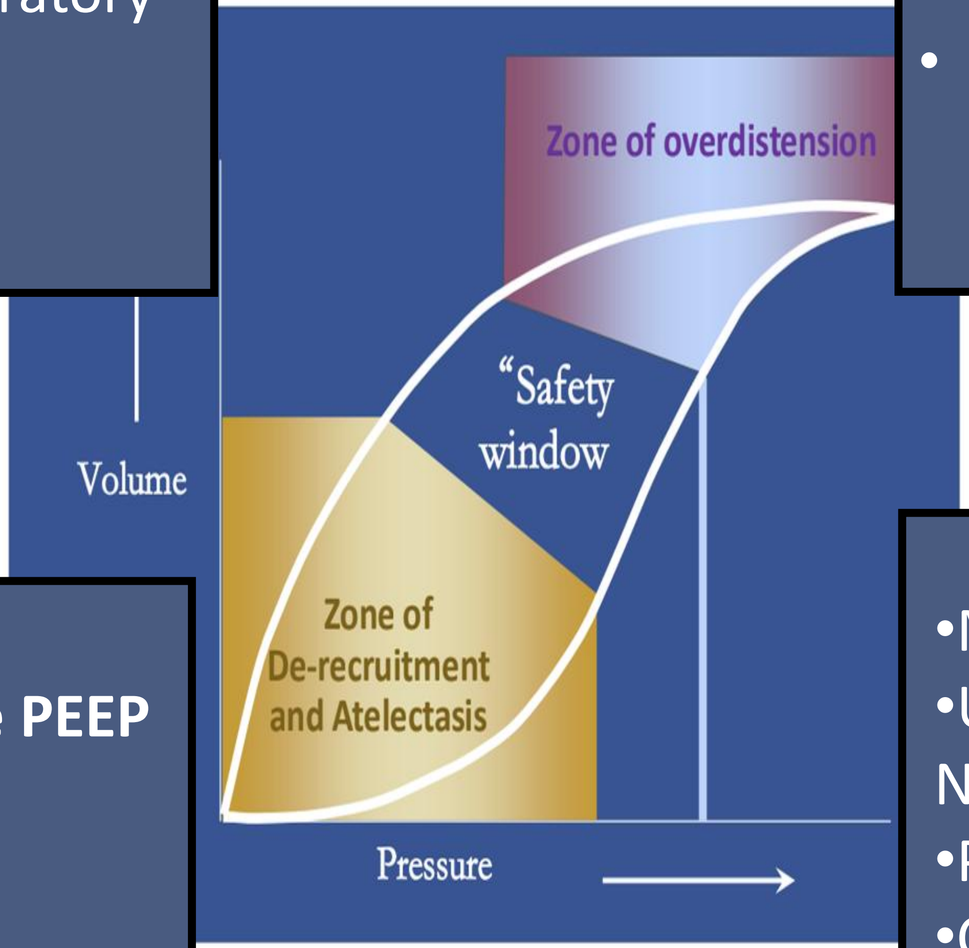
VENTILATOR-INDUCED LUNG INJURY (VILI): MECHANISMS & TRIGGERS

Volutrauma (Overdistension)

- Use **volume-targeted ventilation** (PTV+VG)
- Limit VT to 4–6 mL/kg (preterm)
- Avoid air trapping: ensure adequate expiratory time
- Monitor graphics for overinflation

Barotrauma (Excessive Pressure)

- Avoid unnecessarily high PIP/MAP
- Optimize oxygenation via PEEP and Ti—not just PIP
- Consider **HFOV** for poor compliance or air leak syndromes



Atelectrauma (Collapse-Reopen Injury)

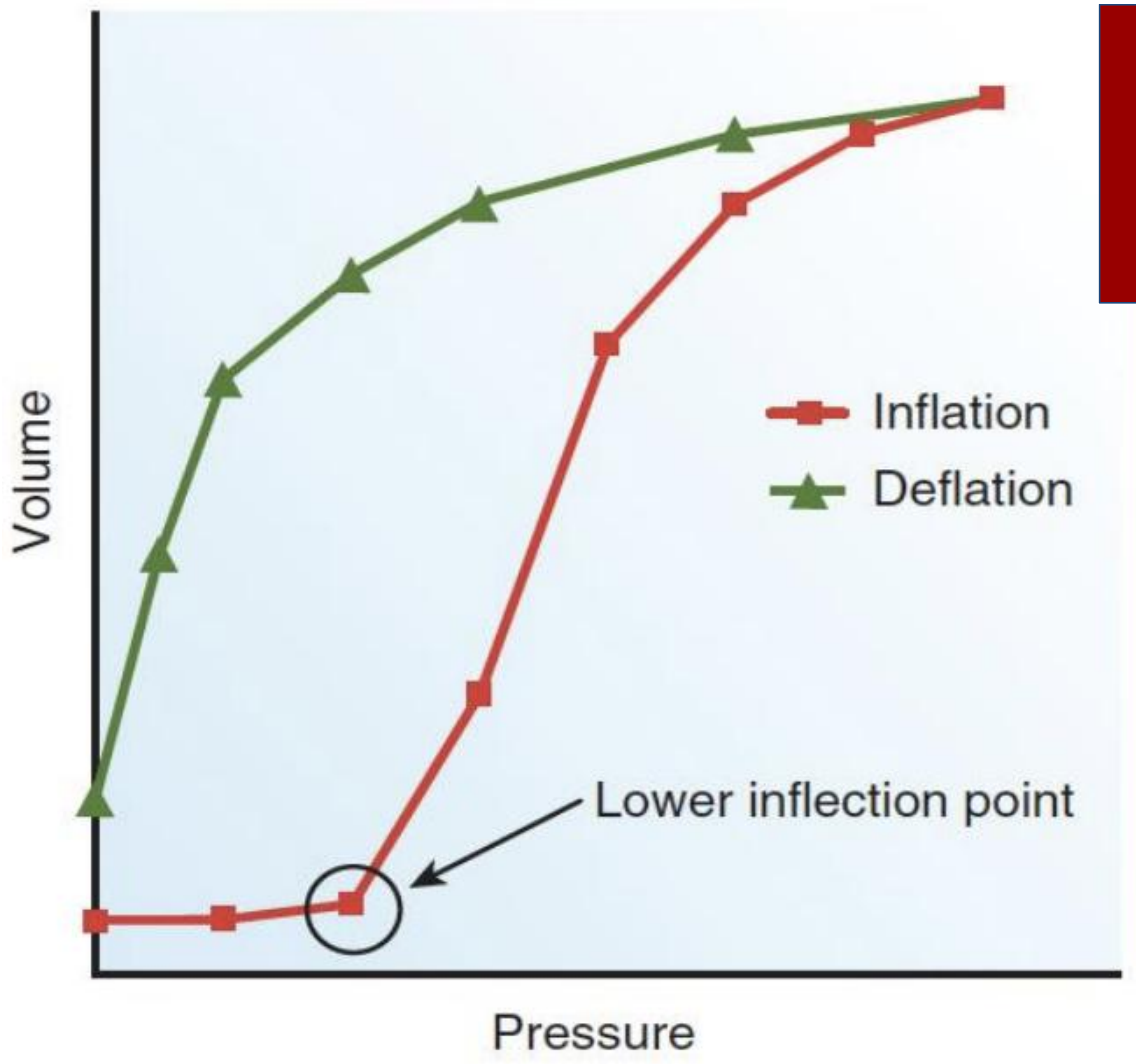
- Maintain alveolar stability with **adequate PEEP**
- Use open lung strategies and gradual recruitment
- Avoid low VT or under-recruitment in surfactant-deficient lung

Biotrauma (Inflammatory Cascade)

•Minimize duration of invasive ventilation
•Use **non-invasive support** when feasible (NCPAP, NIPPV), LISA
•Prevent repetitive collapse/stretch cycles
•Consider steroids in selected high-risk cases (DART protocol)

Target an Open Lung Strategy

Lung recruitment



PIP/Volume	Recruit alveoli
PEEP	Maintain alveoli recruited

Appropriate PIP/volume+ PEEP

↓

Open the collapsed lung & keep it open

↓

Improved compliance

Less lung injury

VENTILATOR MODES

Physiological/Conventional

Non triggered

CMV/Control

We set the volume (or pressure), inspiratory time, PEEP and rate
Not used anymore coz of not synchronized mode
Ideal for:
Sick
Sedated or
Paralysed

Triggered

PTV / AC / PC-AC/ SIPPV

We set the volume (or pressure), inspiratory time, PEEP

Infant decides the rate
Full ventilation cycle every time the patient take a breath

- Ideal for premature babies with low to no sedation

SIMV

We set volume (or pressures), inspiratory time, PEEP and rate

Only the number of breath we set will be supported in a synchronised fashion

- Not suitable for most premature babies (panting)

PSV (can be used with SIMV)

We set a volume or pressures on some ventilators you can deliver lower pressures if they are infant triggered
Infant decides the rate (on SIMV only set number of breaths are supported)

Baby decides the inspiratory time

- Only useful as weaning mode
- Beware of panting

Non Physiological

High-frequency oscillation ventilation

NUH-NICU VENTILATOR MODES

Physiological/Conventional

Triggered

PTV / AC / PC-AC/ SIPPV

We set the volume (or pressure), inspiratory time, PEEP

Infant decides the rate
Full ventilation cycle every time the patient take a breath

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SIMV
SIMV+PSV

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DISEASE-BASED RECOMMENDATIONS

RDS

- Use PC-AC/SIPPV + VG initially.
- Wean to PSV + VG or SIMV + PS + VG.
- HFOV: MAP 10–16 cmH_2O, 10–15 Hz.

CDH

- PC-AC with low PIP (<25 cmH_2O), low VT.
- HFOV: MAP 10–13 cmH_2O, 10 Hz.

PIE

- HFJV preferred; HFOV with low frequency (5–6 Hz).
- Minimize Ti and PIP; lateral positioning or selective intubation.

MAS

- PC-AC/SIPPV + VG → SIMV + VG.
- Lower RR, longer Ti to avoid air trapping.
- HFOV: 6–9 Hz; HFJV: 240–360 bpm

BPD/CLD

- SIMV + PS ± VG.
- VT: 6–12 mL/kg; low RR, long Ti.
- HFOV for exacerbations.

- Volume-targeted ventilation is now standard for lung protection.
- Synchronization improves outcomes; PSV offers physiological support.
- HFV is valuable in specific pathologies but requires careful titration.
- Disease-specific strategies optimize outcomes and minimize harm.

https://www.cochranelibrary.com/cdsr/doi/10.1002/14651858.CD003212.pub4/

Mode of ventilation (ETT)

- **NUH NICU mode of preference**

PTV / PTV+ VG

- Preferred Mode of ventilation for ALL intubated babies <35Weeks

SIMV only

- For term TTNB as an option if severely hypocarbic due respiratory alkalosis

SIMV +PSV

- Weaning or supportive for Term CLD/severe BPD/ growing Peads patient
- Growing babies with Evolving BPD

VENTILATOR MODES

SIMV

•Delivers a set number of synchronized mandatory breaths. Spontaneous breaths are unsupported unless **Pressure Support (PS)** is added.
•Transitional mode for neonates needing **moderate support**.
•**Pathology**: RDS, pneumonia, evolving BPD, post-op recovery.
•**GA**: All gestational ages; common in **VLBW/ELBW**

SIMV+PSV

SIMV + PS (Pressure Support on top of SIMV)
•Gives a set number of synchronized mandatory breaths.
•Adds **pressure support** to spontaneous breaths to help overcome ETT resistance and reduce work of breathing.
•Great for **weaning**, improving synchrony, and prepping for **extubation**.
•**Pathology**:RDS, Sepsis-related lung disease, Early evolving BPD
•**GA**:Used across all gestational ages. Especially usefu for **weaning/extubation prep**.

VENTILATOR MODES

PTV

- Infant-triggered breaths receive full support with **set pressure (all breaths are supported)**
- Includes a **back-up rate** to ensure safety during apnea or weak effort.
- For infants with **intact respiratory drive.**Enhances synchrony and reduces ventilator-patient mismatch.
- **Pathology**: Moderate RDS,Stable infants with good effort, Improves comfort and stability in synchrony-responsive cases
- **GA**: **Preterm >27–28 weeks** and term infants.
- **Less effective in apneic ELBW** unless back-up rate is robust/high.

VOLUME TARGETED/GUARANTEE

PTV+VG

(also called **PC-AC + VG**, or **Volume Guarantee in AC mode**)

Infant-triggered breaths with auto-adjusted **PIP** to deliver set **VT**. Backup rate ensures safety.

Best for: Preterms ≥26–28w GA with consistent effort Stabilized RDS, weaning/extubation prep

Pros:

✅ Excellent synchrony
✅ Limits volutrauma (PIP capped)
✅ ↓ Work of breathing

Evidence: ↓ BPD, IVH, pneumothorax, ventilation time *(Cochrane + RCTs)*

Limits:

Poor fit for apneic ELBW <26w (must increase back up rate)

⚠ VT accuracy ↓ with large ETT leaks

SIMV+VG

•**How it works**: Synchronized mandatory breaths with **volume targeting**
•Spontaneous breaths: **unsupported or PS-assisted**
•Backup rate ensures safety during apnea
•**Advantages**:
• ✅ Guaranteed breaths = safety
• ✅ Volume targeting ↓ volutrauma
• ✅ Synchrony improves comfort & gas exchange
• ✅ Common initial mode in VLBW
•**Limitations**:
•⚠ ↑ Work of breathing if no PS
•⚠ Prolonged weaning if rate not tapered

Early volume guarantee

- **Applied to all types of mode (PTV, SIMV or HFOV)**
- **Volume is being set /controlled (avoiding volutrauma) while Pressures (PIP) varies depending on lung compliance change; PMAX limit is being set accordingly to avoid over shooting of PIP (barotrauma)**

Table 2 Recommended initial tidal volume (VT) and peak inflation pressure (PIP) settings for different clinical situations and patient conditions. Individual patients may need slightly smaller or larger VT. The stated PIP is a reasonable starting point based on underlying physiology and clinical experience, not published literature

Condition	Initial V_T	Initial PIP limit
Term, late preterm, normal lungs	4–4.5 mL/kg	18 cm H_2O
Preterm RDS 1250–2500 g	4–4.5 mL/kg	26 cm H_2O
Preterm RDS 700–1249 g	4.5–5 mL/kg	24 cm H_2O
Preterm RDS <700 g	5.5–6 mL/kg	24 cm H_2O
Preterm evolving BPD, 3 weeks old	5.5–6.5 mL/kg	26 cm H_2O
Term MAS with classic CXR*	5.5–6 mL/kg	28 cm H_2O
Term MAS with white-out CXR	4.5–5 mL/kg	30 cm H_2O
Term CDH	4–4.5 mL/kg	24 cm H_2O
Established severe BPD	7–12 mL/kg	30 cm H_2O

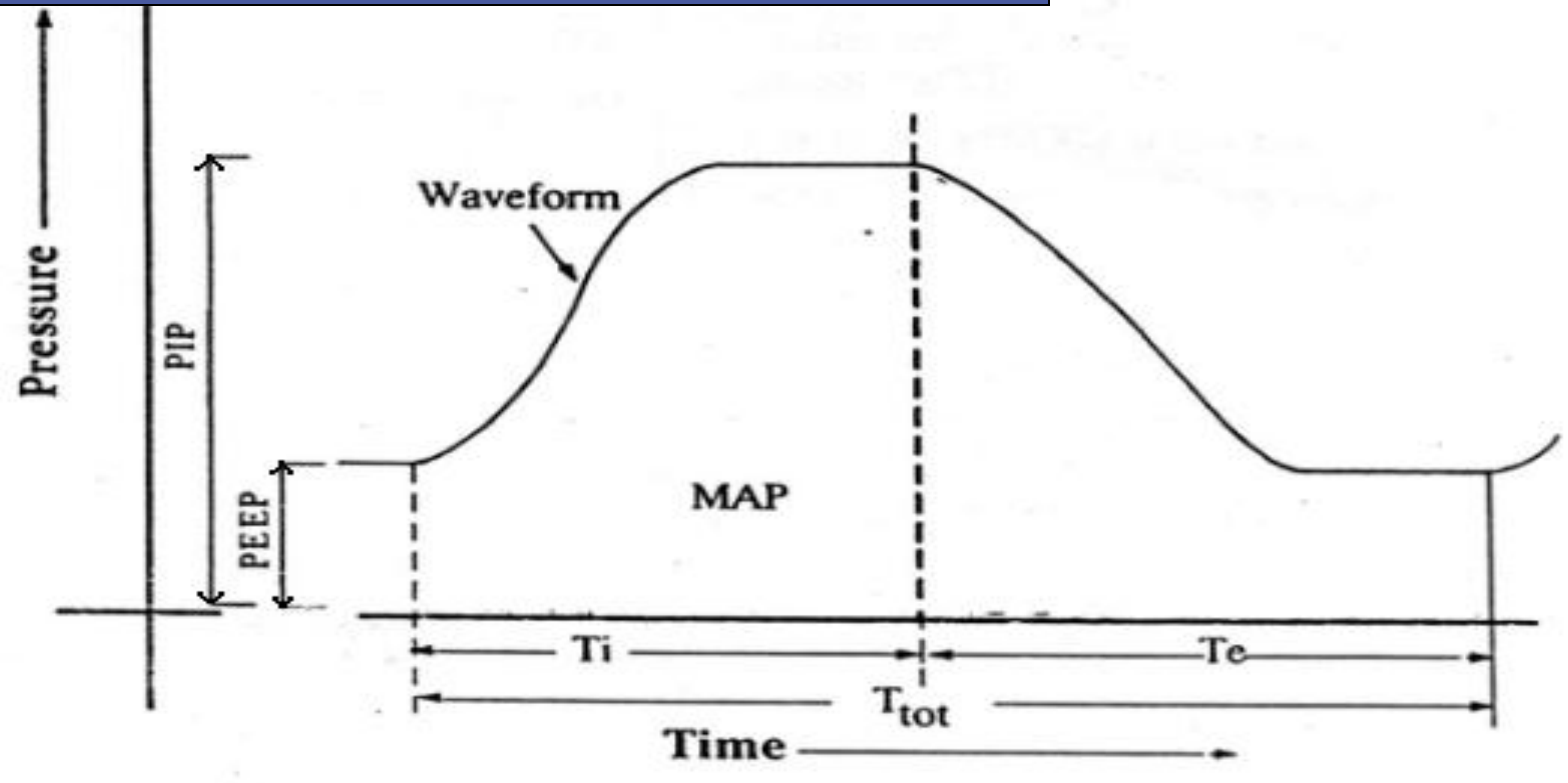
2018 Keszler

Mode	Description	Key Features	Use Case
CMV (Continuous Mandatory Ventilation)	Delivers set breaths regardless of patient effort	Fixed rate and pressure	Rarely used alone; may be backup in apneic neonates
SIMV (Synchronized Intermittent Mandatory Ventilation)	Synchronizes mandatory breaths with spontaneous efforts	Allows spontaneous breathing between mandatory breaths	Useful for weaning
SIPPV / PTV / AC (Assist Control)	Supports every spontaneous breath with a mechanical breath	Backup rate if no spontaneous effort	Common in initial support
PSV (Pressure Support Ventilation)	Supports spontaneous breaths with pressure, no set rate	Infant controls rate and inspiratory time	Often used in weaning
VC / VG (Volume Control / Volume Guarantee)	Delivers target tidal volume with variable pressure	PIP adjusts to achieve set VT	Reduces volutrauma risk

Conventional Ventilator Settings

Settings Parameter	Concept
PEEP	"This is the baseline pressure that stays in the lungs at the end of exhalation. It keeps alveoli open."
PIP	"This is the peak pressure during inspiration. It pushes air into the lungs."
Ti	"This is how long the ventilator holds the breath in. Too short, and you don't fill the lungs. Too long, and you risk air trapping."
Te	"This is the time for the lungs to empty. If it's too short, air gets trapped."
Ttot	"This is the full cycle time—Ti plus Te. It determines the respiratory rate."
MAP	"This is the average pressure over the whole breath. It's key for oxygenation." MAP – net outcome of all parameters except Fio2 and RR; true measure of average pressure; should be maintained between 8-12 cm H20 .

Element	Description
PEEP	Baseline pressure maintained during expiration to prevent alveolar collapse
PIP	Peak pressure during inspiration—drives tidal volume
MAP	Mean Airway Pressure—average pressure over the cycle, key for oxygenation
Ti	Inspiratory Time—duration of pressure rise and hold
Te	Expiratory Time—duration of pressure return to baseline
Ttot	Total Cycle Time = Ti + Te



“This waveform shows how pressure changes over time during each breath the ventilator gives. It helps us understand how much pressure the lungs are exposed to, and for how long.”

Parameter	Definition	Clinical Relevance
Mode	The control strategy used to deliver breaths (e.g., CMV, SIMV, PSV, HFOV)	Determines breath type, trigger, and cycling
FiO_2	Fraction of inspired oxygen (0.21–1.0)	Adjusted to maintain target SpO_2
PEEP	Positive End-Expiratory Pressure	Prevents alveolar collapse, improves oxygenation
PIP	Peak Inspiratory Pressure	Drives tidal volume; excessive PIP risks barotrauma
ΔP	Pressure difference (PIP − PEEP)	Determines delivered VT in pressure modes
VT (Tidal Volume)	Volume of gas delivered per breath (mL/kg)	Targeted in volume modes; adjusted for disease state
Rate (f)	Number of breaths per minute	Affects minute ventilation and $PaCO_2$
Ti (Inspiratory Time)	Duration of inspiration (sec)	Must match lung time constant for full VT delivery
Te (Expiratory Time)	Duration of expiration (sec)	Must be long enough to prevent air trapping
I:E Ratio	Ratio of inspiratory to expiratory time	Typically 1:2; adjusted for resistance/compliance
MAP (Mean Airway Pressure)	Average pressure across the respiratory cycle	Key determinant of oxygenation
Trigger Sensitivity	Effort required to initiate a breath (flow or pressure)	Affects synchrony and WOB
Rise Time	Time taken to reach PIP during inspiration	Impacts comfort and synchrony in pressure modes
Cycle Type	How the ventilator ends inspiration (time, flow, volume)	Defines breath termination logic
Bias Flow	Continuous flow in the circuit (common in HFOV)	Helps maintain circuit pressure and detect triggers
Leak Compensation	Adjusts for volume loss due to leaks	Important in NIV and uncuffed ETTs
Backup Rate	Minimum rate delivered if spontaneous effort fails	Ensures safety incase of apnea

Understanding Vent settings

Peak Inspiratory Pressure (PIP)

Neonate with normal lung requires PIP of about 12 cm H2O for ventilation.

Appropriate to start with PIP of 18-20 cm H2O for mechanical ventilation.

Primary variable determining tidal volume.

High PIP – Barotrauma.

Inspired oxygen concentration

Fraction of O2 in inspired air-oxygen mixture

Regulated by Vent blenders system

Fio2 – kept at a minimum level to maintain PaO2 of 50-80 mm Hg.

Initial Fio2 –Term 21%-Prem 30%

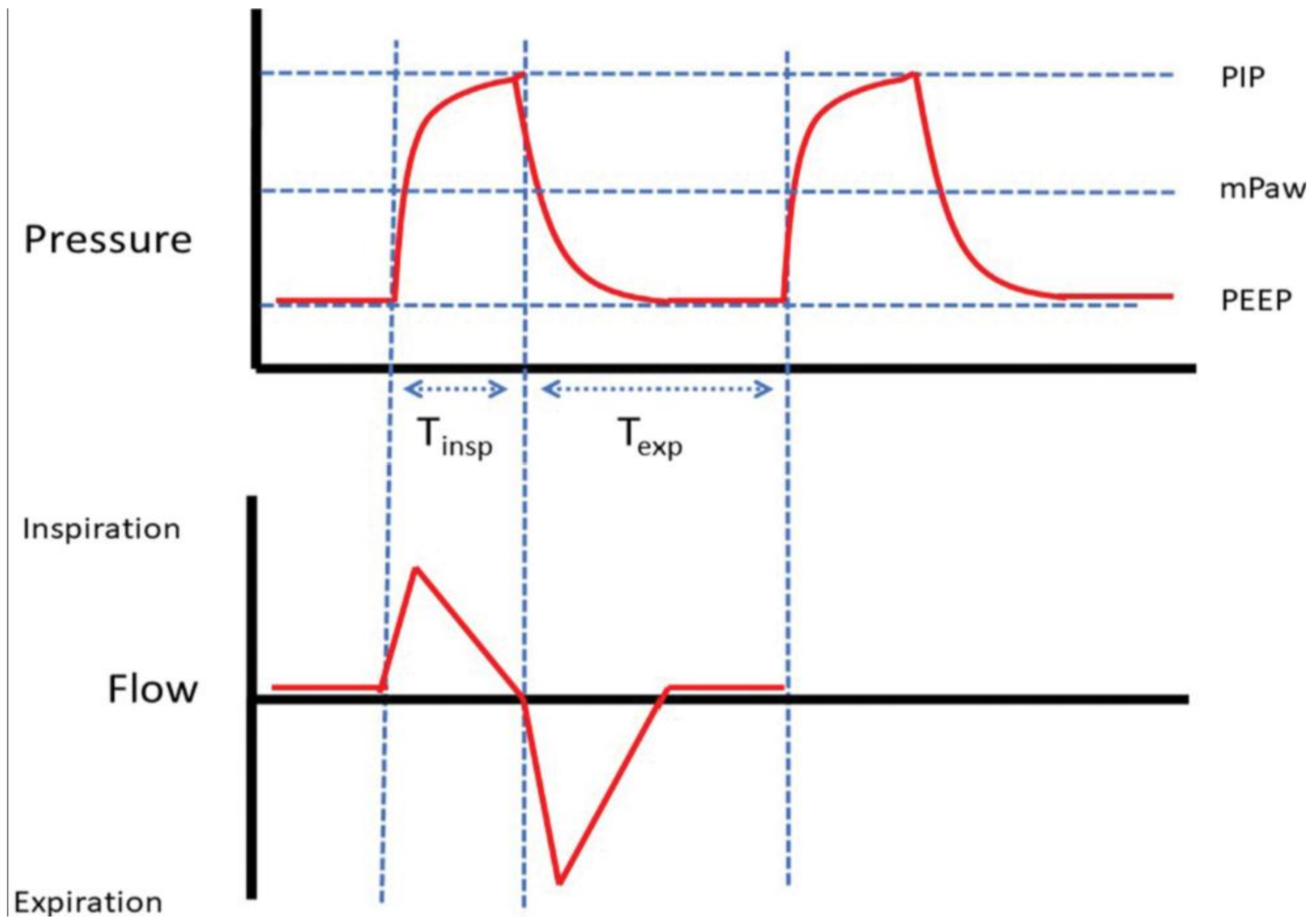
Positive End Expiratory Pressure (PEEP)

Most effective parameter that increases MAP.

Has opposite effects on CO2 elimination.

PEEP range of 4-8 cm H2O is safe and effective.

Excess PEEP decreases compliance, increase pulmonary vascular resistance.



Understanding Vent settings

Respiratory Rate (RR)
Main determinant of minute ventilation.
Rate to be kept within normal range or higher than normal rate, especially at the start of mechanical ventilation.

Inspiratory Time (Ti) is the duration of the inspiratory phase during mechanical ventilation. It determines how long gas is delivered into the lungs during each breath.

Neonate Type	Typical Ti Range	Clinical Notes
Extremely Preterm (<28w)	0.25–0.35 sec	Short time constants; avoid gas trapping; may need longer Ti for stiff lungs
Very Preterm (28–32w)	0.30–0.35 sec	Balance between adequate VT delivery and avoiding breath stacking
Moderate to Late Preterm (32–37w)	0.35–0.40 sec	Often tolerate slightly longer Ti; monitor for asynchrony
Term Neonate (≥37w)	0.40–0.50 sec	Longer Ti may improve oxygenation in stiff lungs (e.g., MAS, pneumonia)
BPD/CLD	0.5-0.8sec	Longer Ti may improve oxygenation in stiff lungs

Ventilator Parameters

Parameter	Typical Range	Clinical Notes
PIP (Peak Inspiratory Pressure)	16–25 cmH_2O	Adjust to achieve adequate chest rise and VT (~4–6 mL/kg)
PEEP (Positive End-Expiratory Pressure)	4–6 cmH_2O	Prevents alveolar collapse; higher in severe RDS
RR (Respiratory Rate)	40–60 bpm	Higher in neonates; adjust based on $PaCO_2$
Ti (Inspiratory Time)	0.3–0.5 sec	Shorter in preterms; avoid air trapping
FiO_2 (Fraction of Inspired Oxygen)	0.21–1.0	Titrate to maintain SpO_2 90–95% (or per unit target)
MAP (Mean Airway Pressure)	8–12 cmH_2O	Key determinant of oxygenation, esp. in HFOV

Ventilation Strategy Comparison: Initial RDS vs Established BPD

Feature / Focus	Initial RDS	Established BPD
Pathophysiology	Surfactant deficiency → ↓ compliance, atelectasis	Heterogeneous lung disease: fibrosis, hyperinflation, ↑ resistance
Primary Goal	Recruit alveoli, optimize oxygenation	Minimize air trapping, support ventilation
Compliance	↓ (uniformly)	↓ and variable (patchy)
Resistance	Normal or mildly ↑	Markedly ↑
Time Constants	Short	Long
Ventilator Mode	SIMV + VG / PC-VG / HFOV	SIMV + VG / PC-VG / NAVA / PSV
VT (Tidal Volume)	4–6 mL/kg	6–10 mL/kg
PEEP	5–6 cm H_2O	6–8 cm H_2O
Rate	40–60 bpm	25–35 bpm
Ti (Inspiratory Time)	0.3–0.4 sec	0.4–0.5 sec
Te (Expiratory Time)	Short (0.4–0.6 sec)	Long (≥0.6–0.8 sec)
FiO_2 Target	SpO_2 90–95%	SpO_2 90–95% (avoid hyperoxia)
Graphics Focus	Lung recruitment, avoiding overdistension	Detecting air trapping, flow limitation
Adjuncts	Early surfactant, HFOV if severe	Steroids (DART), bronchodilators (selective)
Extubation Strategy	CPAP or NIPPV	NIPPV, CPAP, gradual wean

WHEN TO ESCALATE AND VENTILATE

Indications for CPAP from Hoodbox/O2 therapy/RA
•**Low FRC conditions**: RDS, TTN, pulmonary edema, PDA
•**Recurrent apneas**: Especially in preterm infants
•**Weaning**: From mechanical ventilation
•**Airway closure diseases**: BPD, bronchiolitis, tracheomalacia
•**Short trial**: In meconium aspiration syndrome

Failure of CPAP – Indications for Intubation & Mechanical Ventilation
•**PaO_2 < 50 mmHg** on 60–80% FiO_2
•**$PaCO_2$ > 60 mmHg**
•**Severe distress**: Marked retractions, frequent apneas, bradycardia
•**Intractable acidosis**
•**Cardiovascular collapse**
•**Neuromuscular compromise**
•**Deep sedation/paralysis**
Note: In **VLBW infants with RDS**, intubate and administer surfactant if FIO2 >30%

WHEN TO INTUBATE

Intubation & Surfactant Guidelines – Neonatal RDS
GA 23–27 weeks: → Intubate in delivery room → Administer surfactant early (ideally on NICU arrival)
GA >27 weeks with RDS: → Surfactant given when clinical criteria are met → Early rescue surfactant reduces mortality, CLD, and air leaks (ETT MV or LISA NSIMV)
Within first 72 hours of life, surfactant is indicated if:

- Progressive respiratory distress
- FiO_2 > 0.30
- Hypoxia/hypercarbia on blood gases
- Radiologic evidence of moderate/severe RDS

NUH-NICU Standard Initial setting parameters

Preterm ETT

PIP	PEEP	TI	RR	Rise time	Trigger sensitivity
20-25	5-6	0.35	40-60	0.1	0.2-0.4
Titration depending on patient vent requirement (VG might be activated early)					

Term ETT

PIP	PEEP	TI	RR	Rise time	Trigger sensitivity
18-20	5	0.4	40	0.1	0.4-0.6
Titration depending on patient vent requirement (VG might be activated early)					

Extubated Prem and Term (non-invasive modes)

PIP	PEEP	TI	RR	Rise time	Trigger sensitivity
20-25 or higher	6 or higher	0.5 or higher	30 or higher	0.1	100%
Titration depending on patient vent requirement					

NONINVASIVE VENTILATOR MODES

CPAP

- Provides constant distending pressure (PEEP only)
- No breath synchronization or support
- Requires stable spontaneous effort
- Used for mild RDS, apnea of prematurity, post-extubation
- GA: ≥28 weeks with reliable drive
- Simple, low WOB, but ineffective in weak or apneic infants

Nasal SIMV

NSIMV – Nasal Synchronized Intermittent Mandatory Ventilation

Delivers synchronized mandatory breaths via nasal interface

Optional pressure support for spontaneous breaths

Includes backup rate for apnea protection

Used for moderate RDS, variable drive, extubation prep

GA: ≥26 weeks, especially VLBW/ELBW with inconsistent effort

Improves synchrony, reduces WOB, better CO_2 clearance

ADVANCED VENTILATOR MODES

HFOV

What it is: Delivers tiny tidal volumes at high rates (5–15 Hz) with active inspiration and expiration.
How it works: High **MAP** for oxygenation, **amplitude** for CO_2 clearance, **frequency** tuned to disease.
Best used in: Severe RDS, PIE, CDH, air leak syndromes, poor compliance lungs.
Advantages:
✅ Precise oxygen/CO_2 control
✅ Lung-protective (low VT)
✅ Effective in stiff lungs
Limitations:
⚠ Risk of overdistension
⚠ Requires close monitoring (CXR, gases, chest wiggle)
⚠ May impact hemodynamics

Freq selection

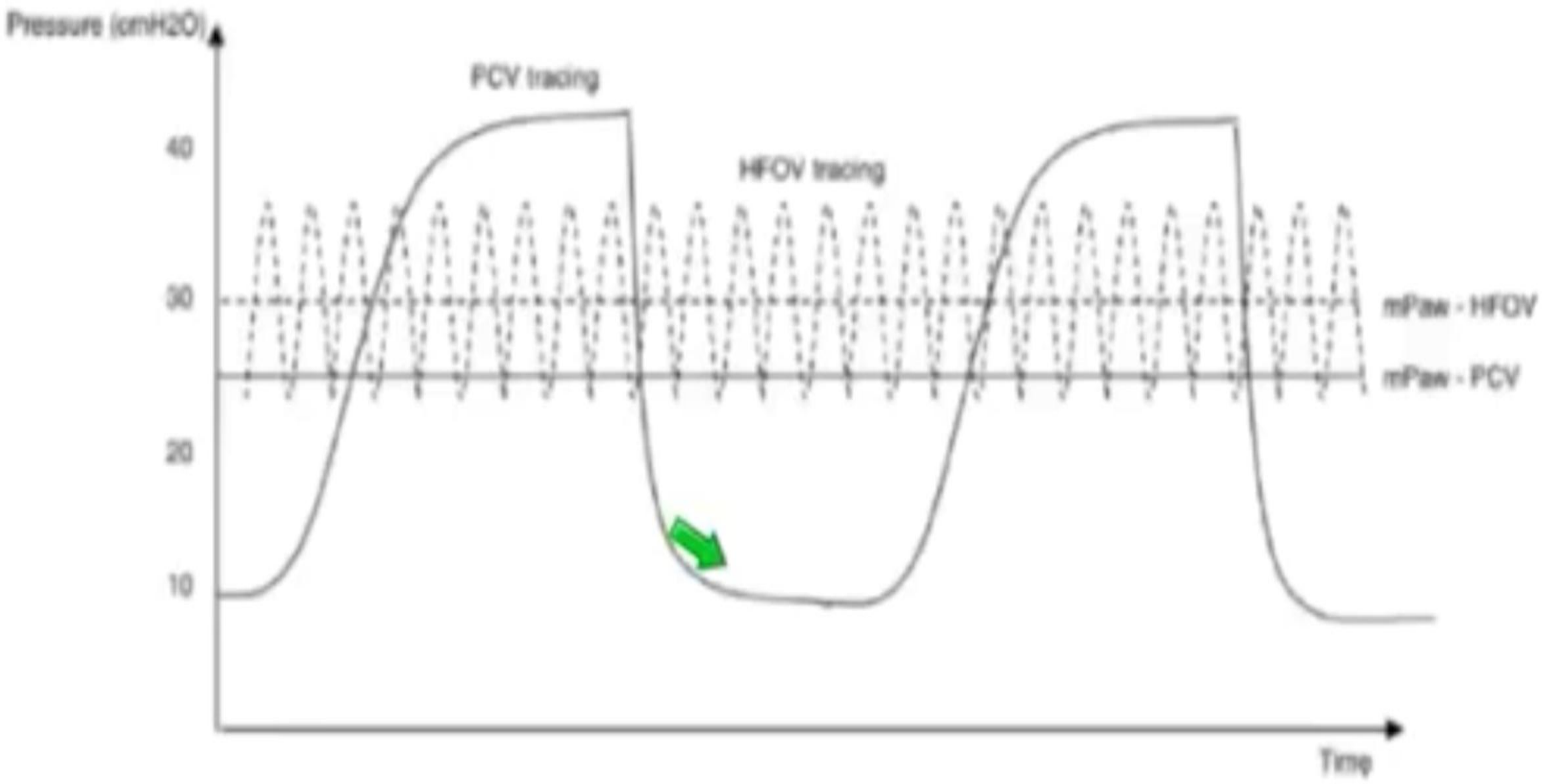
Diffuse Homogeneous Lung Diseases

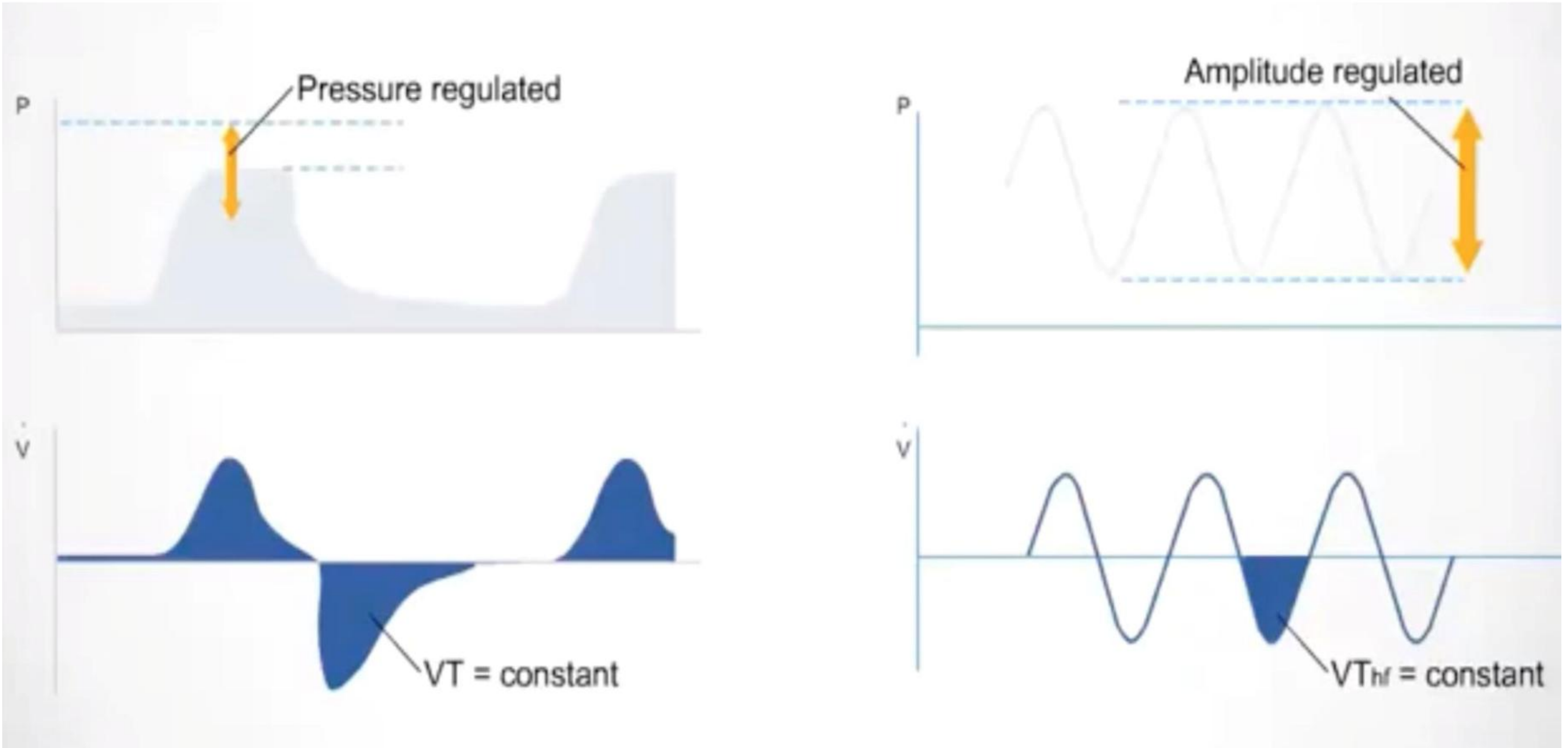
Respiratory distress syndrome, Diffuse pneumonia and Bilateral lung hypoplasia.

HOMOGENEOUS LUNG DISEASES	HFOV FREQUENCY
SEVERE PULMONARY INTERSTITIAL EMPHYSEMA	5-10
MECONIUM ASPIRATION	6-11
TERM LUNG DISEASE	8-12
CONGENITAL DIAPHRAGMATIC HERNIA	10-15
PRETERM HMD (RDS)	12-15
EARLY PIE	12-15

PRACTICAL TIP : Suggested HFOV frequency ranges for common neonatal conditions.

CONVENTIONAL VS HFOV





Neonatal Ventilation Strategy by Clinical Scenario

(Adapted from Dargaville & Keszler, 2013)

Situation	Examples	Pathophysiology	Mode	PEEP	VT (mL/kg)	Key Considerations
Apnoea	Apnoea of prematurity, RSV	Poor drive, episodic desats	SIMV	Low–Medium	4–5	Low rate; lungs often compliant—avoid overdistension
Post-Surgery – General	Painful incision	Sedation, pain-limited excursion	(S)IMV	Medium	5–6	May not trigger if sedated; low VT risks atelectasis
Post-Surgery – Abdominal	NEC, gastroschisis	↑ intra-abdominal pressure	SIMV or AC	Medium–High	5–6	May need HFOV/HFJV if conventional fails
Post-Surgery – Thoracic	PDA ligation, lobectomy	Compliance shifts, air leak risk	SIMV or AC	Medium	4–5	Adjust VT/PEEP intra-op
Diffuse Lung Disease	RDS, pulmonary oedema	Poor compliance	AC or SIMV	High	4–6	PEEP recruitment; short Ti for RDS, longer Ti for oedema
Localized Lung Disease	Pneumonia, MAS	Mixed compliance	SIMV ± PSV	Medium	5–6	Risk of overdistension; MAS needs higher VT
Chronic Lung Disease	BPD	↑ resistance, ↓ compliance	SIMV + PSV or AC	Medium–High	5–7	Longer TE; prevent flow limitation

Neonatal Ventilation Strategy by Clinical Scenario

(Adapted from Dargaville & Keszler, 2013)

Situation	Examples	Pathophysiology	Mode	PEEP	VT (mL/kg)	Key Considerations
Pulmonary Hypoplasia	CDH, prolonged ROM	Small lungs, high PVR	SIMV or AC	Low–Medium	3–5	Avoid high PIP/VT; consider HFOV if PIP >25
Air Leak / Gas Trapping	PIE, pneumothorax	Compression, persistent leak	SIMV or AC	Medium	4–5	HFJV preferred; HFOV if leak persists
Pulmonary Insufficiency	ELBW failing extubation	Immature system	AC or SIMV + PSV	Medium	4–5	Risk of overdistension once compliant
PPHN (with lung disease)	RDS + PPHN	↑ PVR, ↓ oxygenation	SIMV or AC	Medium	4–6	Tailor PEEP/VT to lung disease
PPHN (normal lungs)	Isolated PPHN	↑ PVR only	SIMV or AC	Low	4–5	Avoid hyperventilation
Cardiac – L→R Shunt	PDA, VSD	Pulmonary overcirculation	AC	High	5–6	↑ CO_2 may reduce shunt
Cardiac – Vulnerable Circulation	HLHS, PA	Flow sensitive to pressure	SIMV	Low–Medium	5–7	Avoid overdistension; modulate CO_2 to control flow
Neuromuscular Disease	Myotonic dystrophy	Weak muscles, low VT	AC or SIMV + PSV	Medium	4–6	Support every breath
Airway Obstruction – Supra	Pierre Robin	Hypoventilation, normal lungs	SIMV	Low–Medium	4–6	May need positioning or airway adjuncts
Airway Obstruction – Subglottic	Tracheomalacia, OA	Gas trapping, expiratory delay	SIMV	Variable	4–6	Adjust ETT tip; high PEEP if obstruction persists

Monitoring and Adjustment

- Regularly assess **blood gases**, chest movement, and ventilator graphics.
- Adjust settings based on **lung compliance**, resistance, and clinical response.
- Watch for signs of overdistension or under-ventilation.

ABG

Parameter	**Term Neonate**	**Preterm Neonate**	Notes
pH	7.35–7.45	7.30–7.40	Accept pH ≥ 7.25 in permissive hypercapnia
$PaCO_2$	35–45 mmHg (4.6–6.0 kPa)	40–55 mmHg (5.3–7.3 kPa)	Higher $PaCO_2$ tolerated in BPD, permissive hypercapnia
PaO_2	50–80 mmHg (6.7–10.7 kPa)	45–65 mmHg (6.0–8.7 kPa)	Avoid PaO_2 > 80 mmHg to prevent ROP
HCO_3^-	22–26 mEq/L	20–24 mEq/L	Lower in preterms due to immature renal compensation
Base Excess	−2 to +2 mmol/L	−4 to +2 mmol/L	More negative values may be tolerated early on
Lactate	<2.0 mmol/L	<2.5 mmol/L	Elevated in hypoxia or poor perfusion

Gestational Age	Days of Life	pH	$PaCO_2$ (mmHg)	PaO_2 (mmHg)	HCO_3^- (mEq/L)	Base Excess (mmol/L)
Extremely Preterm(<28 wks)	Day 1–3	7.25–7.35	45–60	40–60	18–22	−4 to 0
	Day 4–7	7.30–7.40	40–55	45–65	20–24	−3 to +1
Very Preterm(28–32 wks)	Day 1–3	7.30–7.40	40–55	45–65	20–24	−3 to +1
	Day 4–7	7.35–7.45	35–50	50–70	22–26	−2 to +2
Moderate Preterm(32–36 wks)	Day 1–3	7.35–7.45	35–50	50–70	22–26	−2 to +2
	Day 4–7	7.35–7.45	35–45	55–75	22–26	−2 to +2
Term Neonate(≥37 wks)	Day 1–3	7.35–7.45	35–45	60–80	22–26	−2 to +2
	Day 4–7	7.35–7.45	35–45	65–85	22–26	−2 to +2

1 www.aap.org 2 respiratory-therapy.com

ABG AND VENT CHANGES

Start

⬇

ABG Interpretation

⬇

Is pH < 7.35?

⬇

No

→ **No**

🔍 Is pH > 7.45?

- ↓ $PaCO_2$ → 🟦 Respiratory Alkalosis → ⚠️ Reduce MV
- ↑ HCO_3^- → 🟧 Metabolic Alkalosis → ❌ No MV change
- Both ↓ $PaCO_2$ & ↑ HCO_3^- → 🟥 Mixed Alkalosis → ⚠️ Reduce MV + assess perfusion

⬇️

🏁 **End**

Yes

→ **Yes**

🔎 Check $PaCO_2$ & HCO_3^-

- ↑ $PaCO_2$ → 🟥 Respiratory Acidosis → ✅ Escalate MV (↑ RR or Vt)
- ↓ HCO_3^- → 🟧 Metabolic Acidosis → Apply Winter's Formula
  - $PaCO_2$ > Expected → 🟥 Mixed Acidosis → ✅ Escalate MV
  - $PaCO_2$ ≈ Expected → 🟩 Pure Metabolic → ✅ Support perfusion
  - $PaCO_2$ < Expected → 🟦 Overcompensation → ⚠️ Reduce MV

HOW TO EXTUBATE

maximizing extubation success in ELBW/VLBW infants, anchored in Cochrane reviews and recent literature.

Optimize Before You Extubate

- **Caffeine**: Ensure therapeutic levels (20 mg/kg loading, 5–10 mg/kg/day maintenance). Reduces apnea & extubation failure.
- **Avoid SBTs**: Neonatal spontaneous breathing trials don't improve outcomes; may destabilize.
- **Readiness Bundle**: Stable vitals, improving lung disease, manageable secretions, acceptable gases/vent settings, no escalating apnea/bradycardia. → Risk factors: lower GA/BW, high O_2/vent needs, acidosis.

Choose the Right Post-Extubation Support

NIPPV > CPAP: Strongest evidence for reducing failure in very preterm infants. (Cochrane review)

Start Immediately: At extubation, with adequate PIP/PEEP or delta-P (PIP-PEEP)

CPAP: Acceptable fallback, but higher failure risk.

HFNC: Gentler interface, but not superior; reserve for step-down.

Emerging Modes: NI-HFV, NIV-NAVA show promise—use in expert

https://www.cochranelibrary.com/cdsr/doi/10.1002/14651858.CD013830.pub2/

Weaning from mechanical ventilation and assessment of extubation readiness – ScienceDirect

Nasal intermittent positive pressure ventilation (NIPPV) versus nasal continuous positive airway pressure (NCPAP) for preterm neonates after extubation - Lemyre, B - 2023 | Cochrane Library

- **Extubation Readiness Criteria**
- **Stable ABG**: pH > 7.25, $PaCO_2$ < 60 mmHg, PaO_2 > 50 mmHg on FiO_2 ≤ 0.3–0.4
- **Ventilator Settings**: PIP ≤ 14–18 cmH_2O, rate ≤ 40 bpm, MAP ≤ 8–10 cmH_2O
- **Clinical Stability**: Minimal apnea/bradycardia, manageable secretions, good spontaneous effort
- **Caffeine**: Ensure therapeutic levels before extubation (standard: citrate 20 mg/kg loading, 5–10 mg/kg/day maintenance)
- **Avoid SBTs**: Spontaneous breathing trials are not routinely recommended in neonates

Support Mode	Starting Settings	Best Use Case	Evidence Summary
NSIMV	PIP 16–20, PEEP 5–6, Rate 30–40, Ti 0.4-0.5sec	ELBW/VLBW post-extubation	↓ Extubation failure vs CPAP
CPAP	6–8 cmH_2O	Mild RDS, apnea, post-extubation support	↓ BPD vs MV; ↑ failure vs NIPPV

Extubation Readiness Estimator for Preterm Neonates

Extubation Success Calculator

Variable	Value	
Gestational Age *GA is in completed weeks. For example GA of 26 0/7 or 26 6/7 weeks should be entered as 26.*		*23 to 33*
Extubation Day of Life		*1 to 59*
Pre-extubation % Oxygen		*21% to 100%*
Highest Respitory Severity Score* in First 6 Hours		*1 to 21*
Weight at Extubation (g)		*460 to 2300*
Pre-extubation pH		*7.1 to 7.6*

Probability of Successful Extubation

Calculate

Clear

0%

HOW TO EXTUBATE

maximizing extubation success in ELBW/VLBW infants, anchored in Cochrane reviews and recent literature.

- ✓ Deliver **precise peak inspiratory pressures (PIP)** and **PEEP**
- ✓ Allow for **synchronization** with the infant's spontaneous breathing (in NSIMV)
- ✓ Maintain **higher pressure capabilities** (often >15–20 cmH_2O)
- ✓ Use **standard neonatal circuits and interfaces**

Evidence Highlights

Short binasal prongs were used in 15 of the 19 trials in the 2023 Cochrane meta-analysis comparing NIPPV vs CPAP
Ventilator-generated NIPPV via short prongs showed the **strongest reduction in extubation failure** (RR 0.49, 95% CI 0.40–0.62).
Synchronization may enhance outcomes, but data are still evolving.

Extubation Bundle (Timing & Action)

Ensure **proper sizing** and secure fixation to avoid leaks.
Use **humidification** to reduce mucosal injury.
Monitor for **nasal trauma** and rotate interface if needed.
For NIPPV/NSIMV: prioritize **ventilator-driven delivery** over bilevel devices when possible.

USE OF RAM VS HUDSON

For **high-risk extubations** (ELBW/VLBW) where every cmH_2O counts, default to **short prongs or mask NSIMV**; consider RAM only if you can **verify delivered pressures** or if prongs/mask are not tolerated

- There is **no Cochrane verdict RAM vs Hudson**. Use Cochrane's interface guidance (mask vs prongs) plus trial/bench data when choosing between **RAM and Hudson**
- If your **primary goal is extubation success in ELBW/VLBW**, most centers still favor **occlusive short binasal prongs (Hudson-type) or a nasal mask** for better, more reliable pressure delivery—especially when you need higher MAP/ΔP.

RAM cannula can be reasonable when:

- You **optimize the seal** (Nasal seal) and
- **Compensate pressures** (expect to set higher CPAP/NIV pressures to achieve equivalent pharyngeal pressures), and
- You're prioritizing **reduced nasal trauma** and easier nursing care.

Troubleshooting

- **Sudden Clinical Deterioration**
- **Common Signs**
- Drop in oxygen saturation
- Hypotension
- Bradycardia
- Cyanosis
- Hypercapnia

Mnemonic: DOPE

- **D**islodgement
- **O**bstruction
- **P**neumothorax
- **E**quipment failure

Immediate Actions

- Check ventilator function and waveform display
- Inspect for disconnected tubing or hoses
- Rule out mechanical issues: displaced, kinked, or blocked ETT
- Assess chest expansion and air entry
- Perform quick ETT suction
- Consider direct laryngoscopy to confirm ETT position
- Exclude pneumothorax via auscultation or transillumination
- Emergency aspiration if tension pneumothorax suspected
- Reintubate if tube is blocked or dislodged

Troubleshooting

Gradual Clinical Deterioration

Typical Trends

- Slow fall in PaO_2
- Gradual rise in $PaCO_2$

Initial Checks

- Rule out displaced/blocked ETT or air leak
- Confirm ventilator settings are appropriate

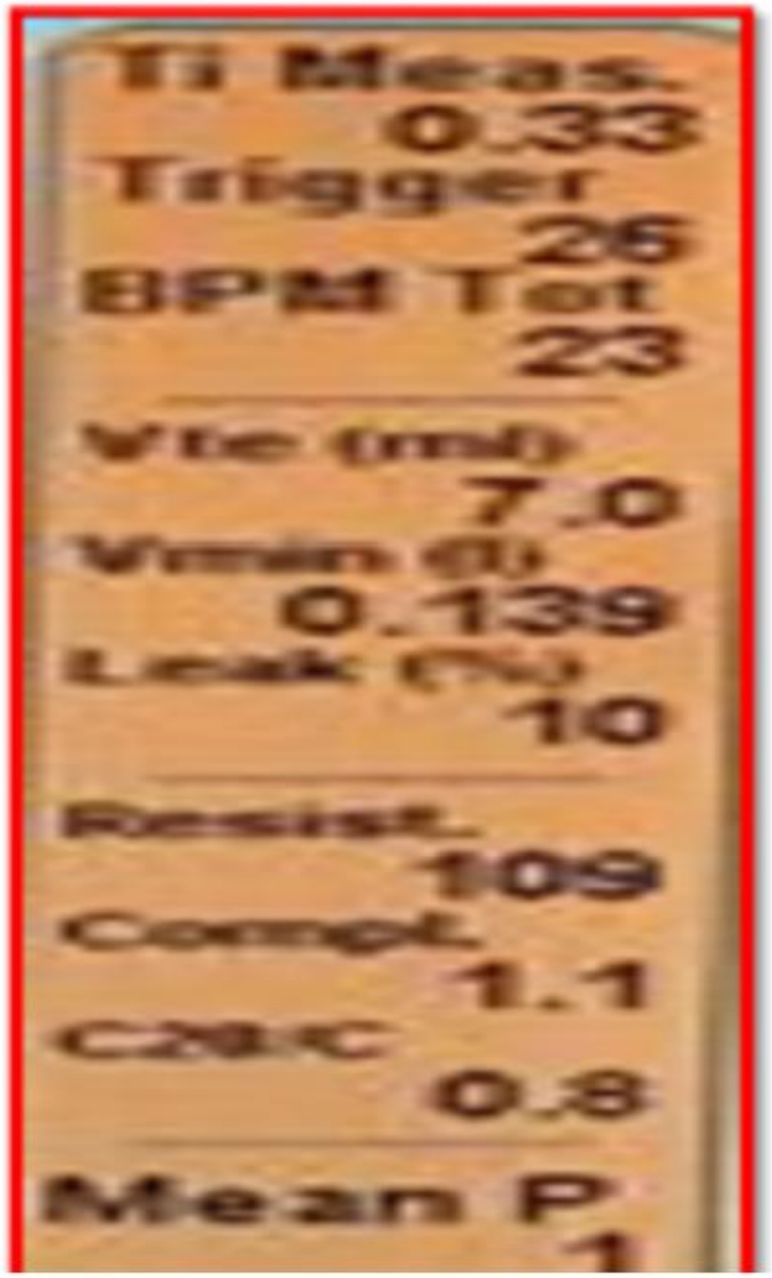
Possible Causes
Inadequate ventilator settings (↑ PIP, rate, FiO_2 may be needed)
Baby fighting ventilator (exclude obstruction before sedation)
Intraventricular hemorrhage (look for pallor, bulging fontanel, seizures, acidosis)
Patent ductus arteriosus
Infection (nosocomial): pallor, poor perfusion, test appropriately
Fluid overload: edema, excessive weight gain
Hypotension: check BP, review fluids, consider NS bolus
Anemia: often iatrogenic (e.g., frequent blood sampling)
Metabolic imbalance: check urea, creatinine, electrolytes
Poor environmental support: avoid excessive handling, maintain thermo-neutrality

Understanding pulmonary mechanics

PULMONARY MECHANICS

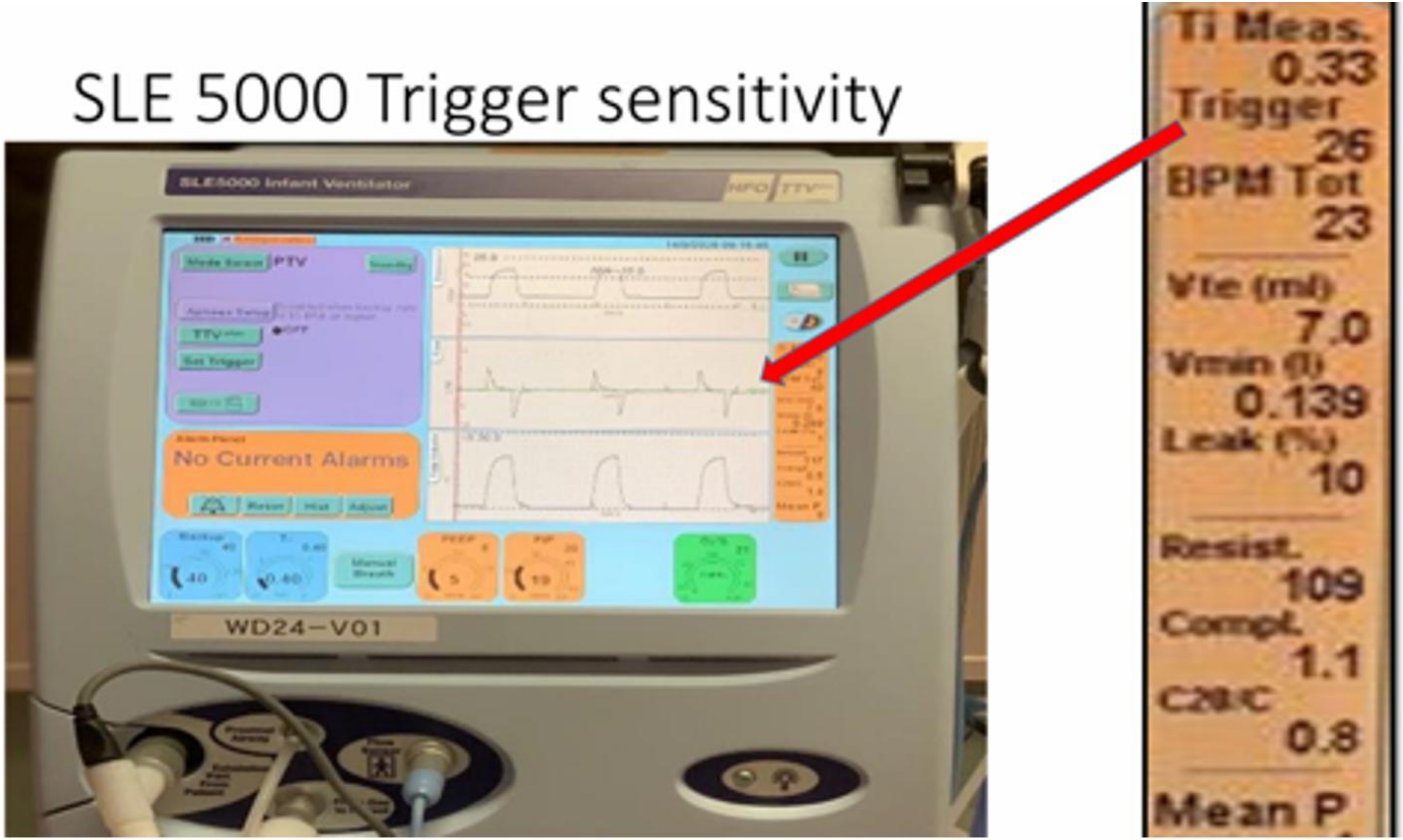
Measured values are now separated from set values and change/rearrange in position

SLE 5000



SLE 6000

SLE 5000 Trigger sensitivity

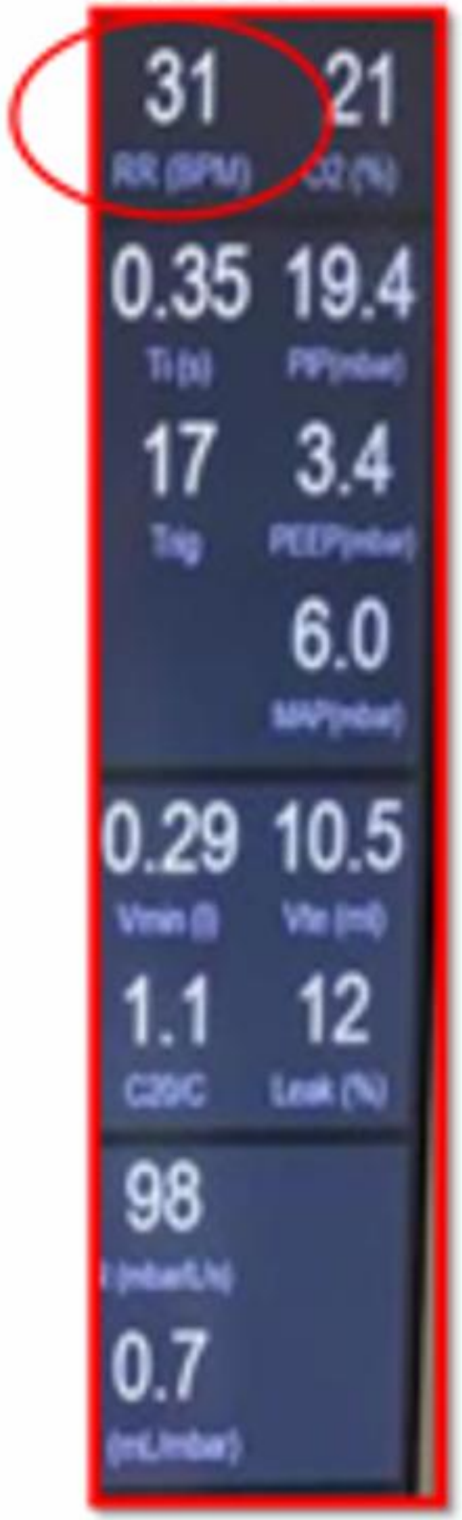


BPM measurement

- The Ventilator Measures BPM In 2 Different ways with or without flow sensors
- With flow sensor : all breaths are counted: triggered spontaneous and mandatory
- Without flow sensor: only triggered and mandatory breaths are counted by the pressure sensor inside the machine. –Pressure triggering

SLE 5000

SLE 6000



Vti vs VTe

Low Tidal Volume
Reset
12:37:39
SIMV
Mode
Alarms
Utilities
Layout
Additional Parameters
Manual Breath
38
15.1
PEEP
5.7
7.3
4.0
15
RR
30
Ti Max
0.40
PEEP
5.0
PIP Max
15
Vte Target
6.0
O2
40

WD24-V31
PTV
55
0.35
20.6
3
6.9
10.7
0.24
4.3
1.9
10
286
0.3
SLE

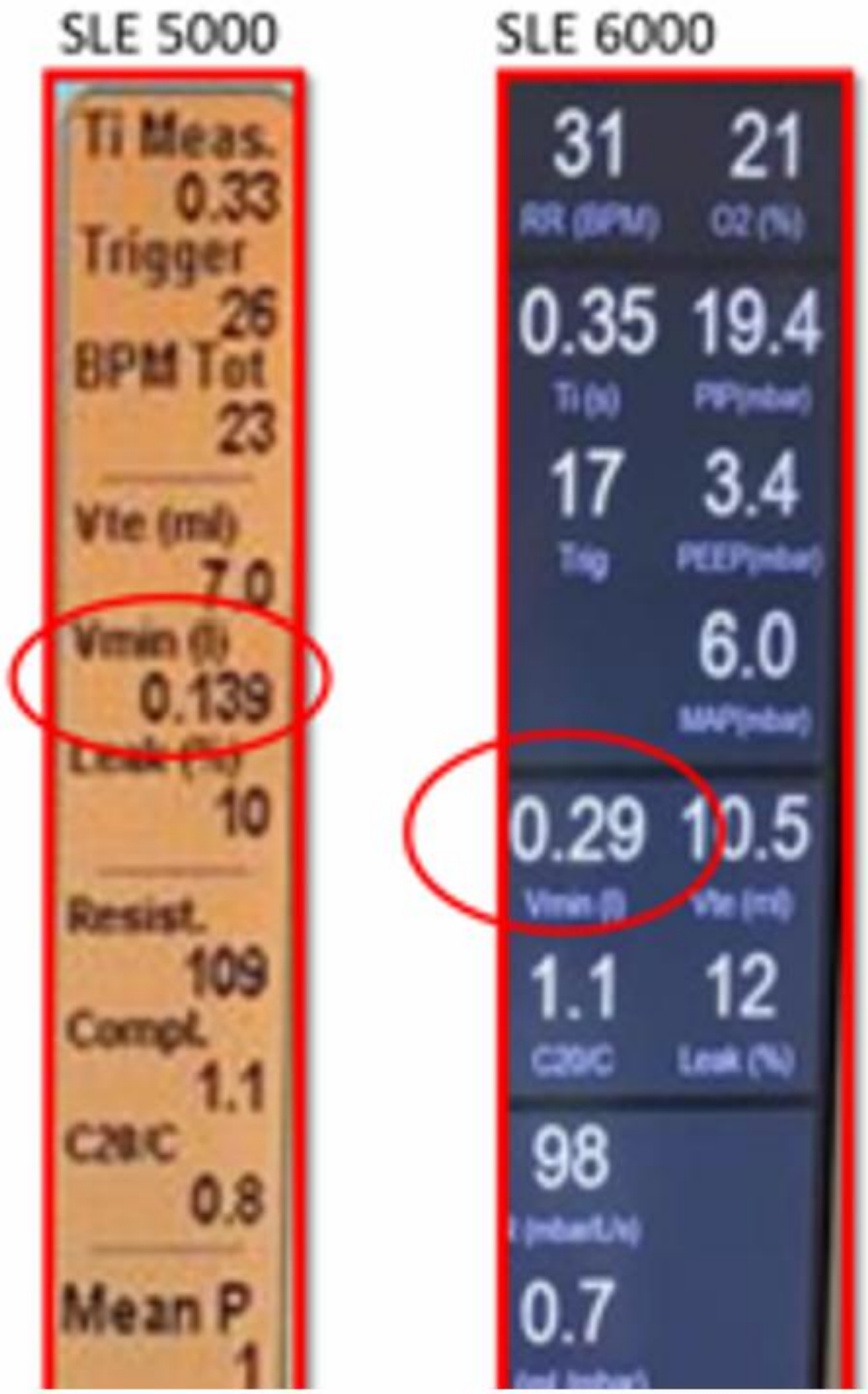
Measured Minute Volume Vmin (L)

Minute Volume in healthy neo

- FT newborn 0.2-0.4L/min/kg
- Preterm 0.2-0.3L/min/kg

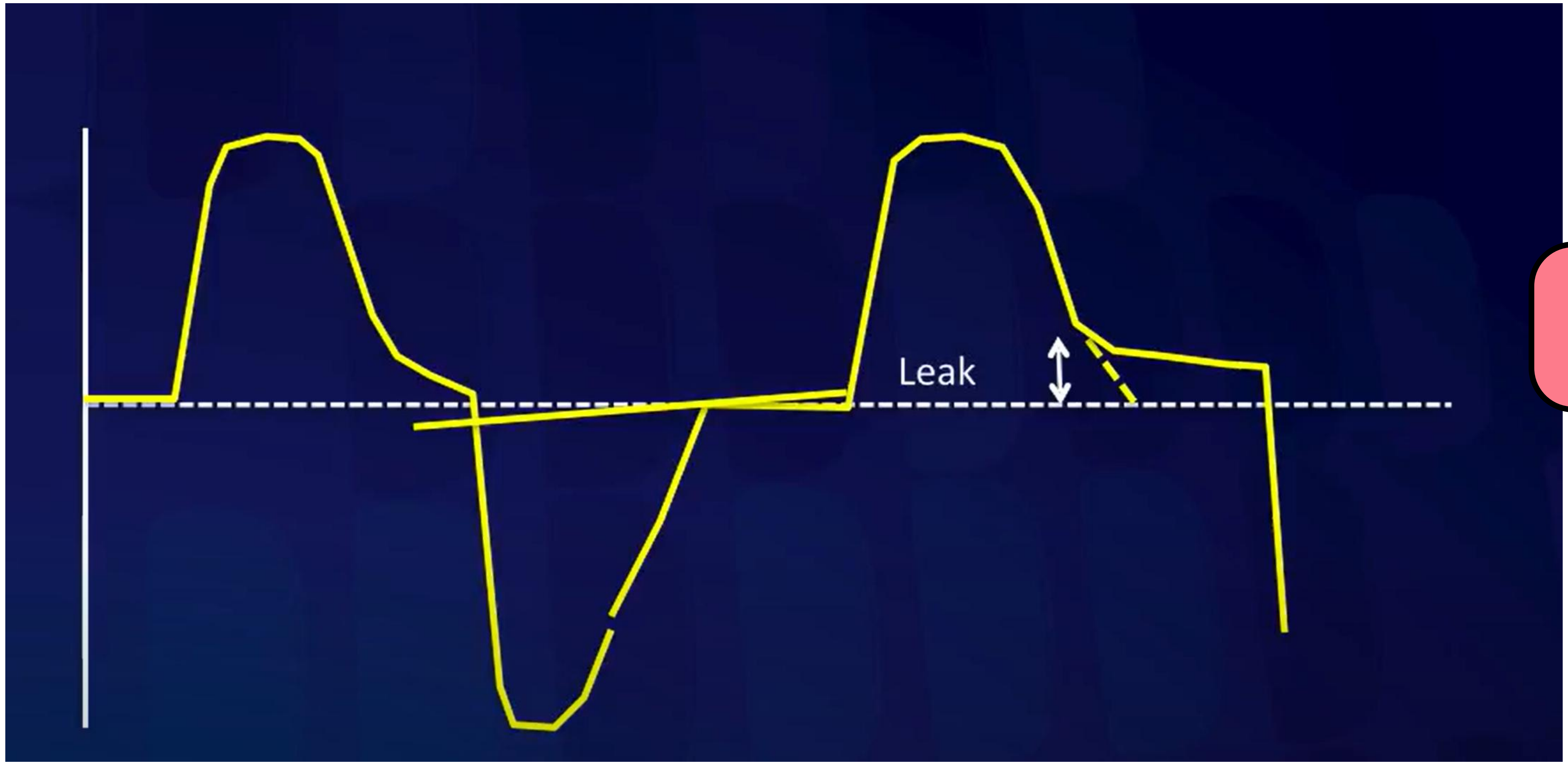
- Useful for guessing over or under ventilation before blood gas is done.

- Alarm limits set 10-20% above and below the limit of ranges above



Leakage

- Refers to the discrepancy between the volume of gas entering the lungs and the volume leaving the lungs during singe breath due to **gas escaping around the uncuffed ETT.**
- Leakage >50%
- Expected alarms
- Breath not detected



High Leakage

Why Leaks Interfere with Time Constant Assessment

1. Volume Loss

•Leaks cause **delivered volume to escape** before reaching the lungs.

•The ventilator measures volume based on what it sends—not what the lungs actually receive.

•This makes **compliance (C_RS)** appear falsely low or variable.

2. Flow Distortion

•Leaks alter the **shape and slope of flow waveforms**, especially during expiration.

•This affects the calculation of **resistance (R_RS)** and the timing of volume change.

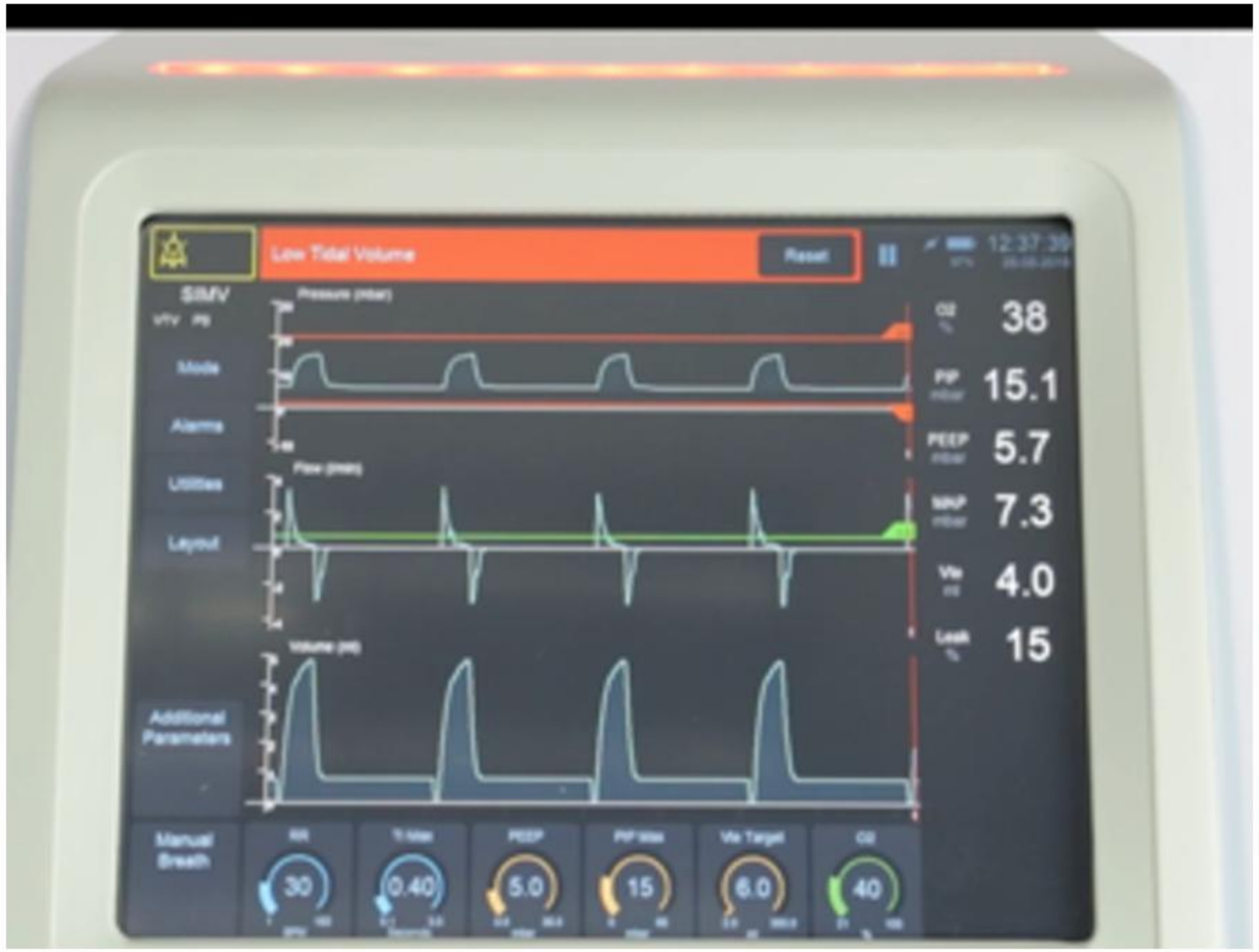
3. Invalid τ Calculation

•Since τ=CRS×RRS\tau = C_{RS} \times R_{RS}, both inputs are corrupted by the leak.

•The resulting τ is **not physiologically meaningful**—it reflects circuit error, not lung mechanics.

"The only true solution in the presence of a larger leak is to assess chest wall movement."

Parameters that will be affected when leakage is HIGH >30%



Measured Values :Resistance (mbar/l/sec)

- Acceptable :
- ETT 2.5 130 to 200
- ETT 3-3.5 50-100

- Very high values (more than 300) can be accepted but should never be neglected

Common reasons

- Kinked or partially blocked ETT
- ETT impinging on carina
- Recent surfactant administration
- Thick secretion
- Severe BPD or MAS
- Very high PIP and rate together in 2.5 ETT (high Turbulence)

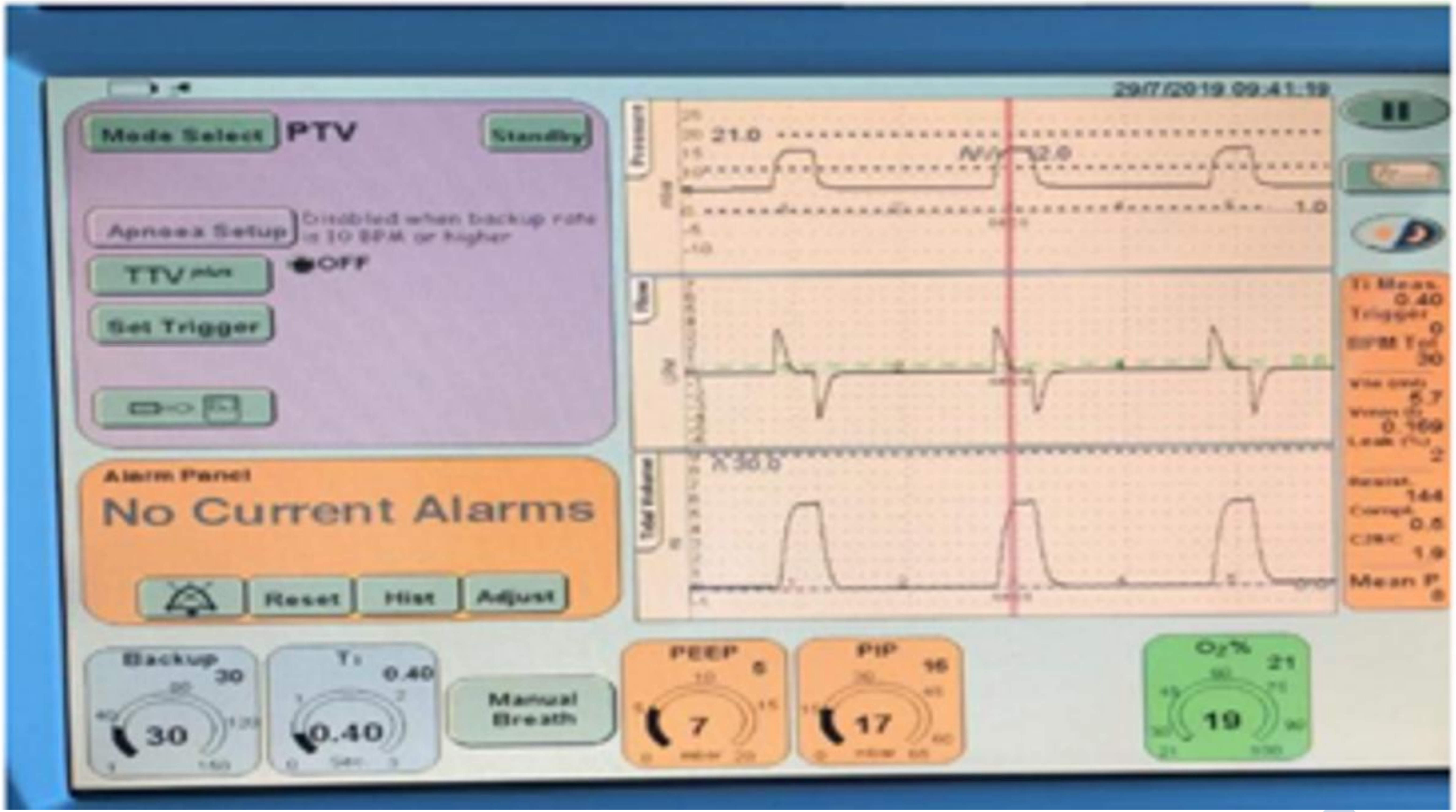
High Resistance

2 hrs post surfactant administration

Resistance >999 post surfactant or on going surfactant

High resistance abutting ETT tip towards carina or tracheal wall

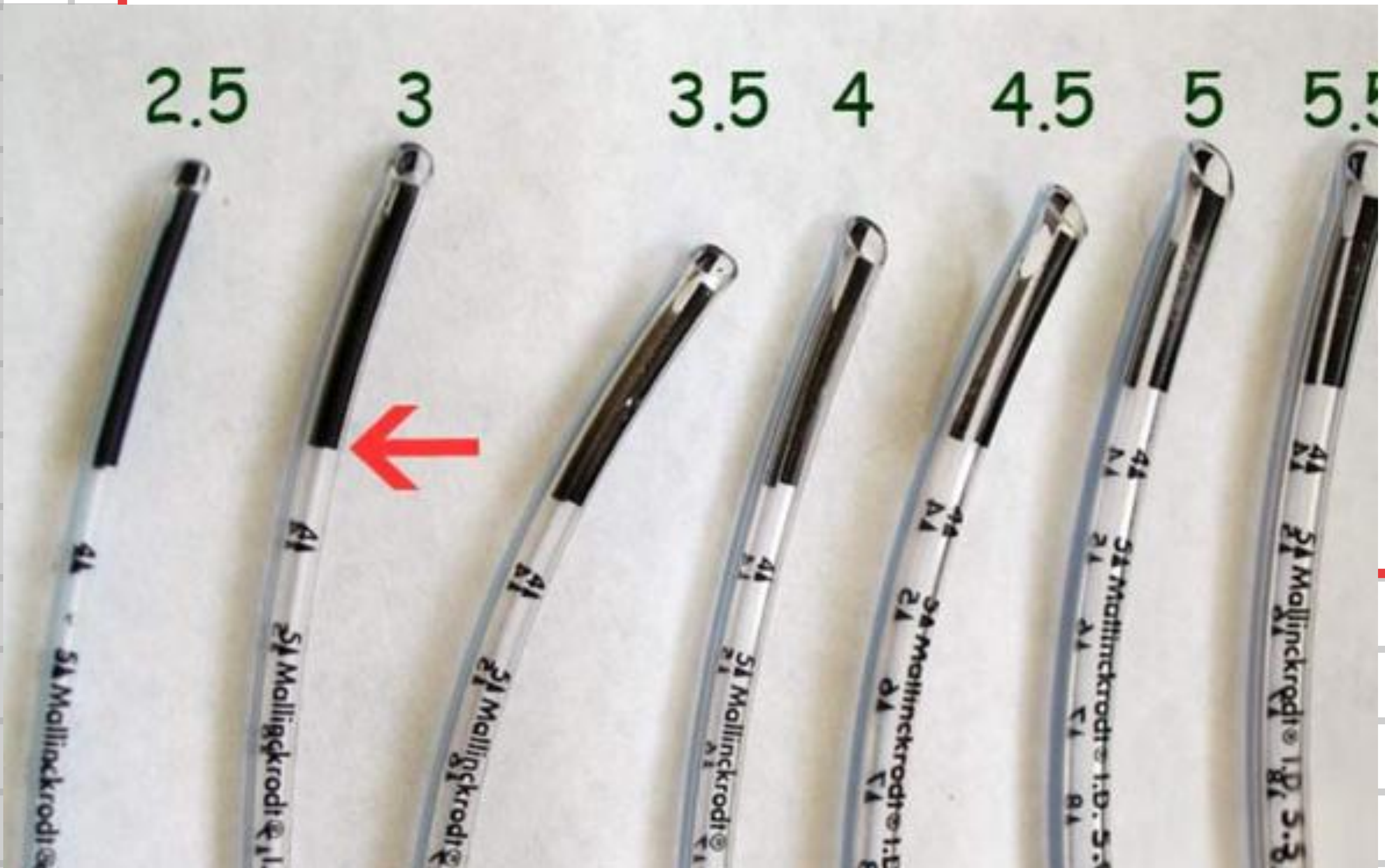
Low Resistance



4 hr post surfactant

- **Smaller tubes = more resistance**
- Tiny ETTs make it harder for air to flow in and out.
- **High flow = higher resistance**
- Fast breathing or crying increases effort.
- **What this means:**
- Baby may need to work harder to breathe
- Can lead to CO_2 buildup and breathing fatigue
- **Tube length has minor effect**
- Shorter tubes help slightly, but don't make a big difference overall.

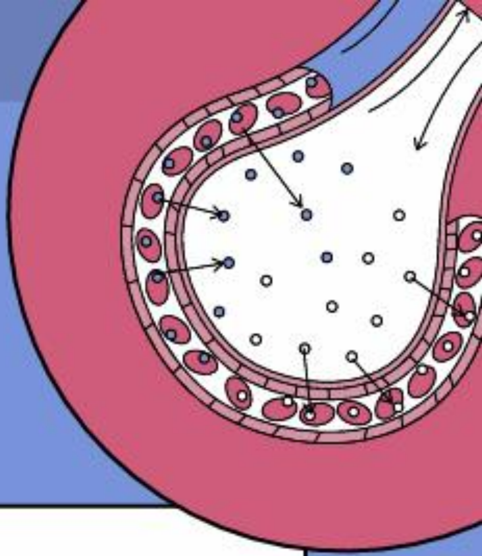
Resistance



- Airway diameter
- Airway length
- Viscosity of gas

Management Strategies:

- **Suctioning** to clear secretions
- **Positioning** to optimize airway patency
- **Humidified oxygen or CPAP** to stent open airways
- Treat underlying causes (e.g., bronchiolitis, MAS, BPD)

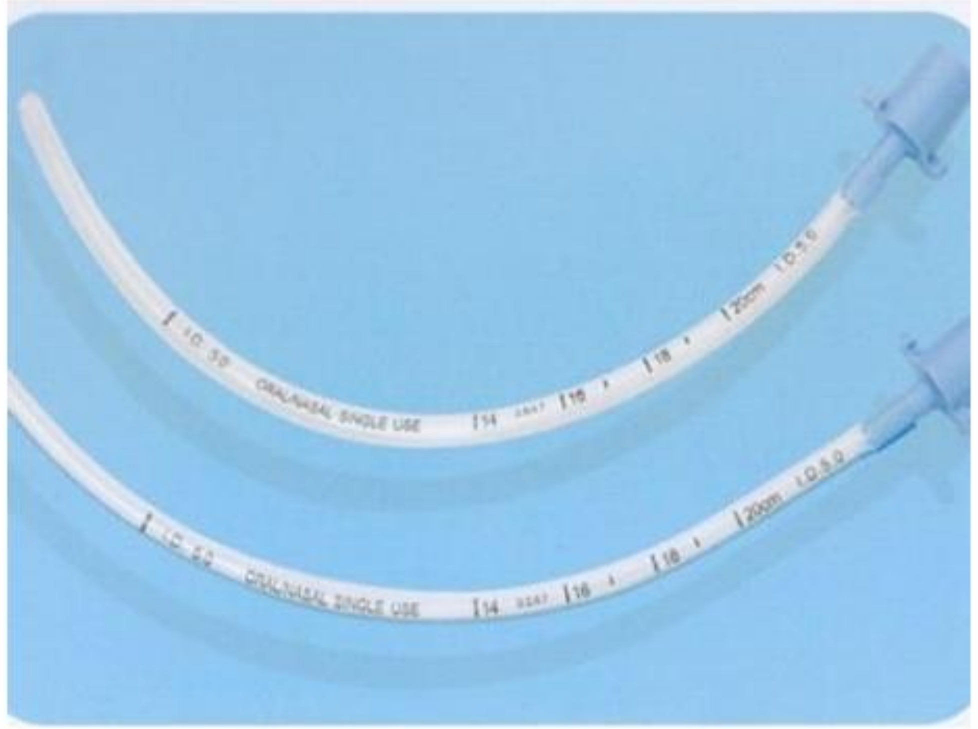


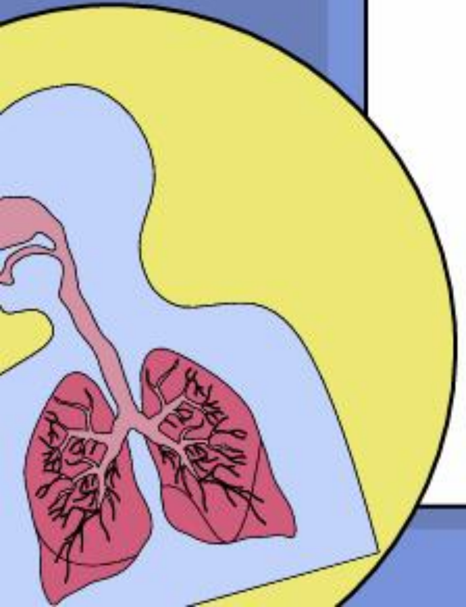
ETT cut By 2CM from Full length

By 2CM from Full length

Can be done early if patient is using MAC Multi access catheter for surfactant administration or later after 72hrs post surfactant as preferred

Size	length	Cut by (-2CM)
ETT 2.5	15>	13cm
ETT 3.0	17>	15cm
ETT 3.5	19>	17CM





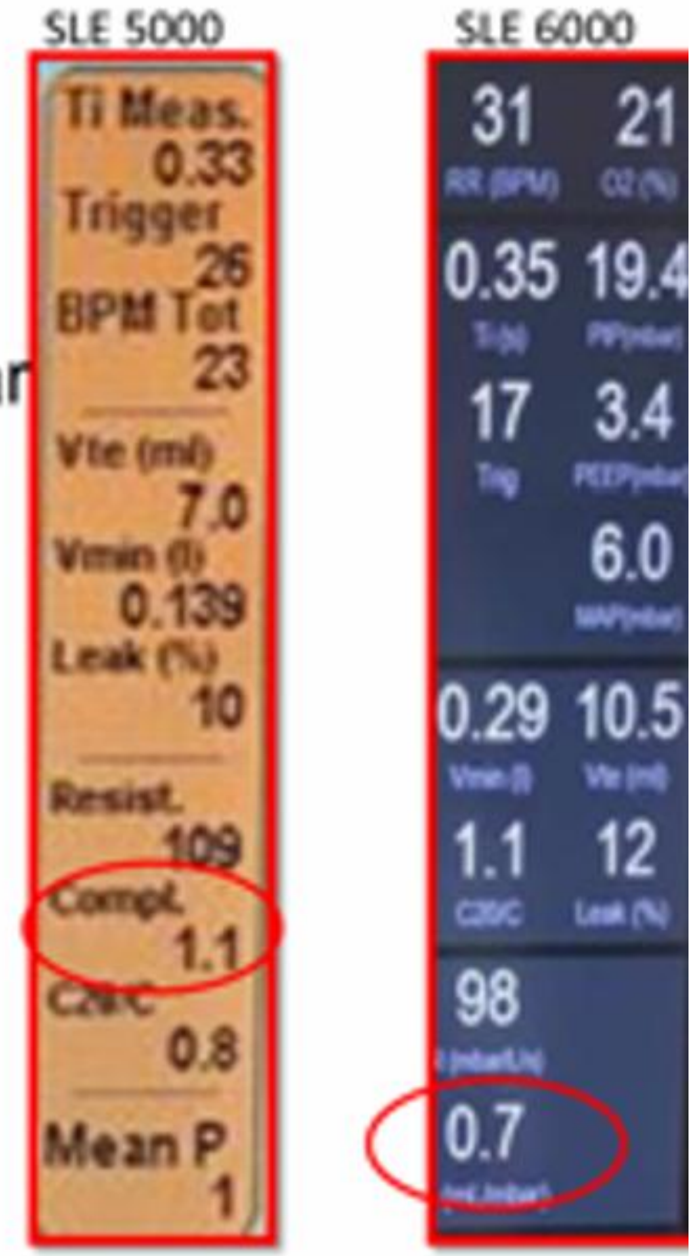
Changing my neck position will solve the problem High Resistance

Lung Compliance

Compliance (ml/mbar)

- Acceptable values:
- Normal Full term not on ventilator 2-2.5ml/mbar
- Good for extubation >1 ml/mbar

- Expected in Preterm/RDS phase 0.1-1ml/mbar

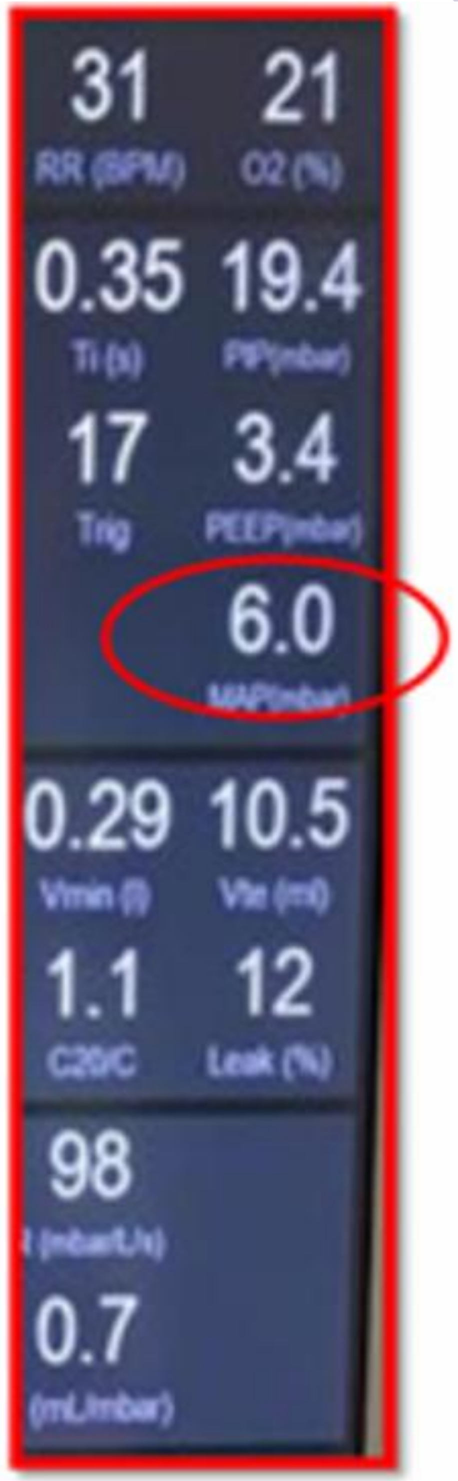


MAP cmh20

- Mean Airway Pressure-
- Average Pressures that you have in the settings over a time

- TI, PIP,PEEP, RR

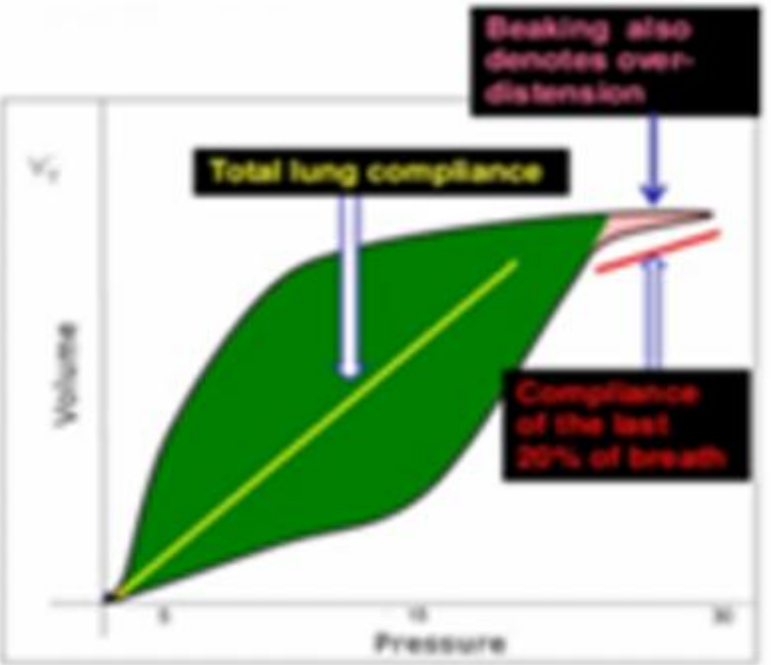
- Most Influential is PEEP

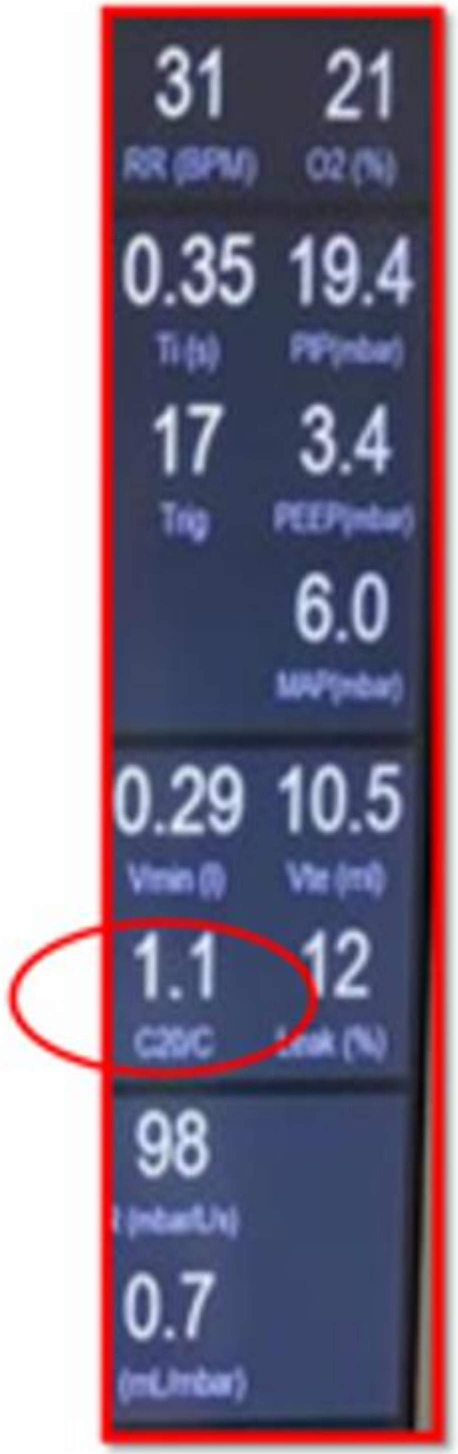


Paw= (inspiratory Time x Frequency) / 60) x (PIP-PEEP) +PEEP

C20/C ratio for over distension

- Ratio of compliance during the last 20% of breath cycle to the total compliance.
- If this calculated value is less than 0.8, the lungs are overinflated therefore PIP should be reduce.





DCO2

Is a relatively new value and can be a marker of alveolar hypoventilation. DCO2 is dependent on the size of the baby (rough target is 40-80 ml2/sec for a 1000g baby)

Value is calculated by VN 500 as

DCO2 (ml2/sec)=. $VThf^2$ x Fhf

Documenting the DCO2 hourly and maintaining this at a stable level can be helpful during ventilation

*Decrease dco2 by 10% means increase in CO2

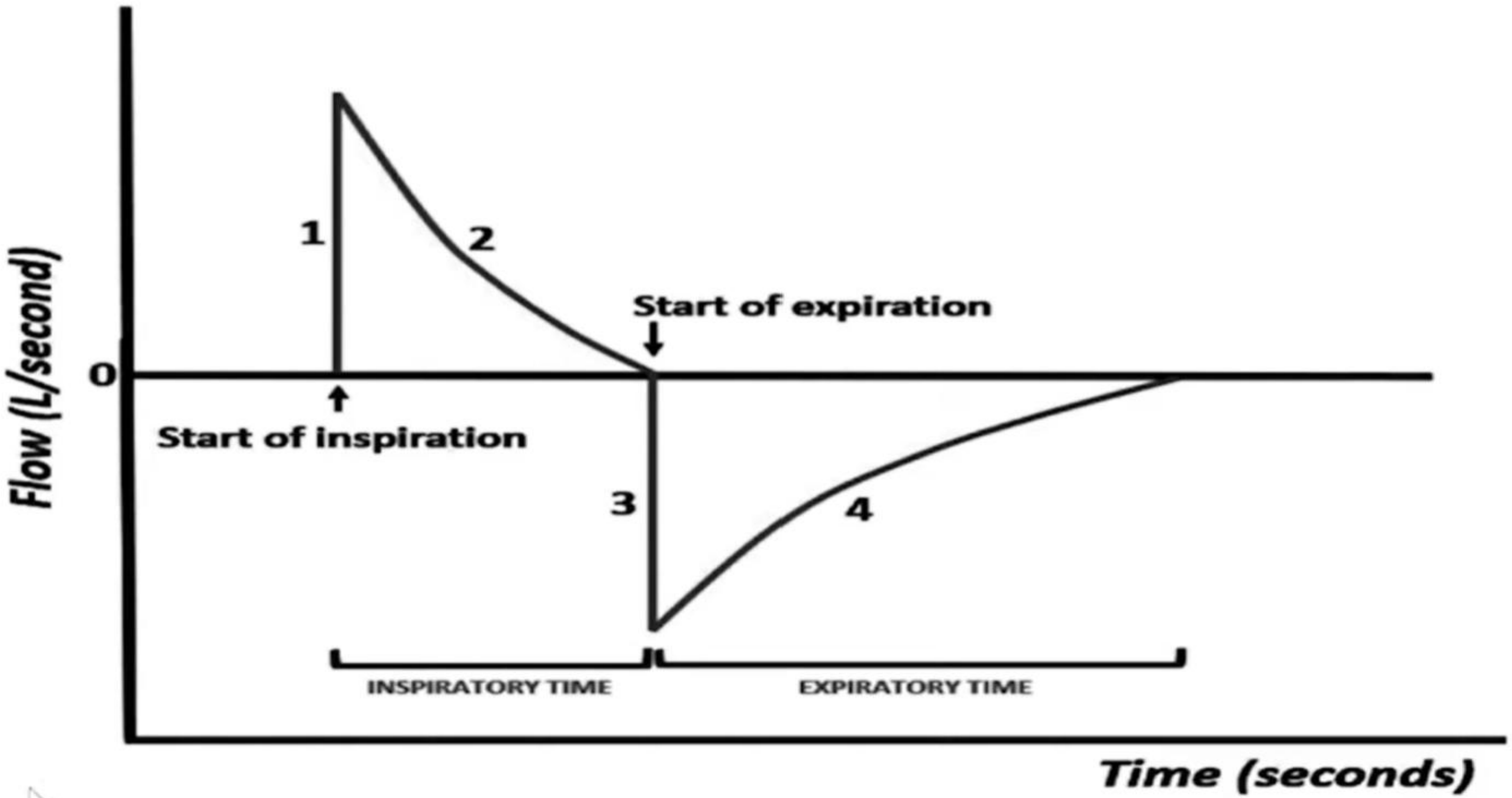
Increasing DCO2 trending means a good elimination of CO2

INITIAL DCO_2 FOR DIFFERENT PATIENT WEIGHTS

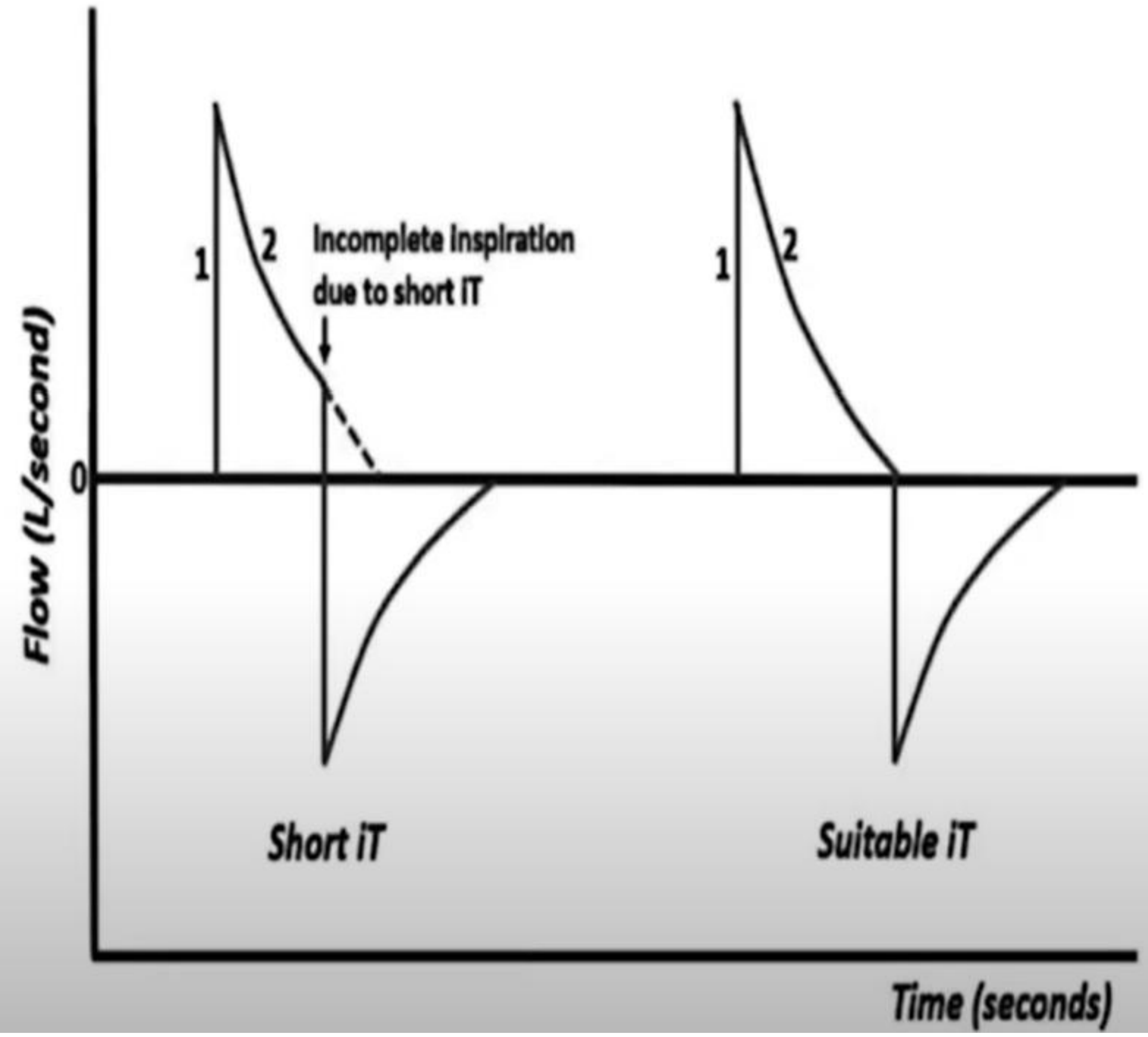
Weight (kg)	5 Hz 3.46 mL/kg	7 Hz 2.93 mL/kg	10 Hz 2.45 mL/kg	15 Hz 2.00 mL/kg
0.5	15	15	15	15
1	60	60	60	60
2	240	240	240	240
3	540	540	540	540
4	960	960	960	960

Table 1: Different combinations of frequency and tidal volume to reach same DCO_2 for permissive hypercapnoea.

Normal Flow - Time scalar

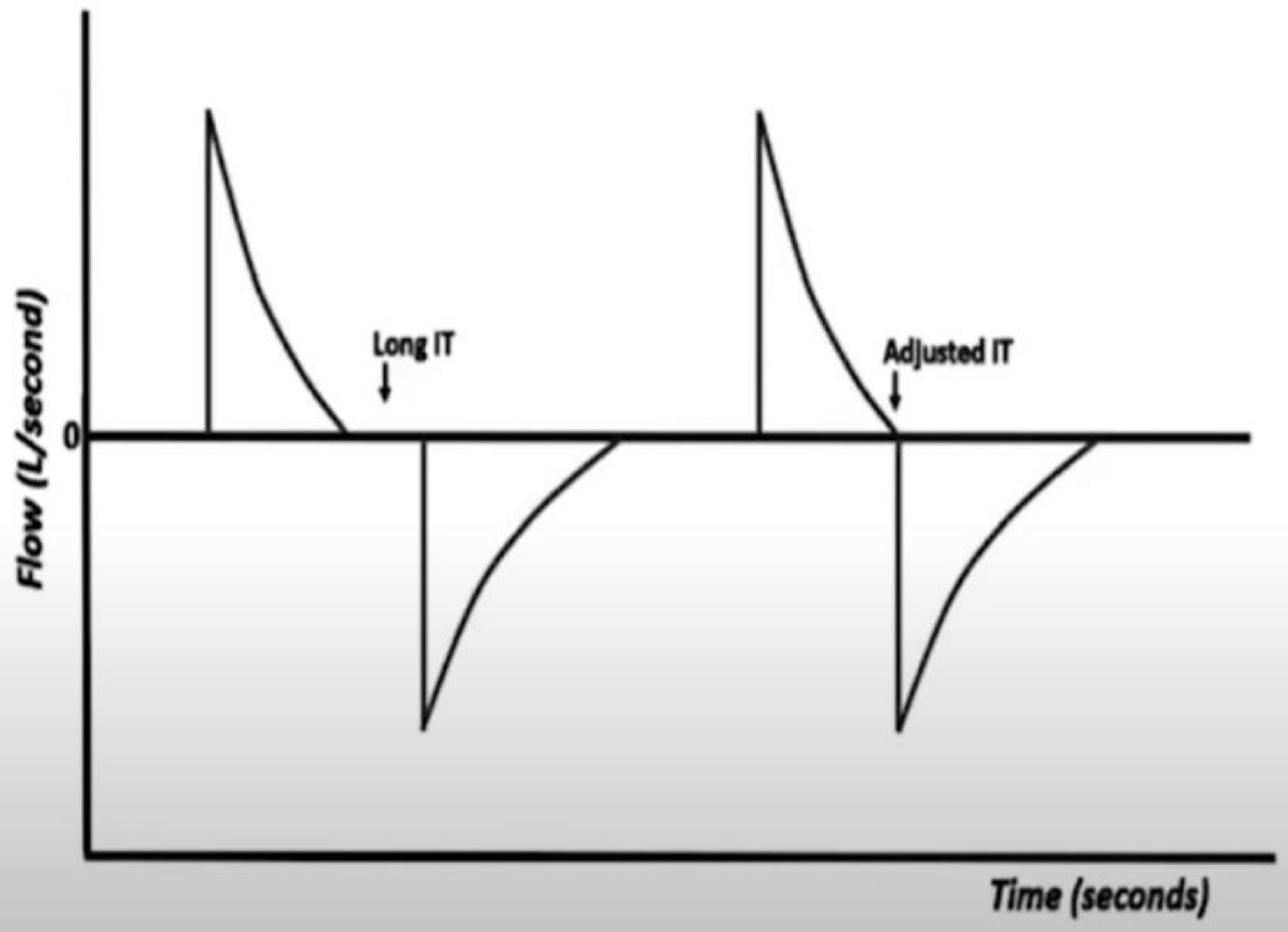


When Ti Set too Short



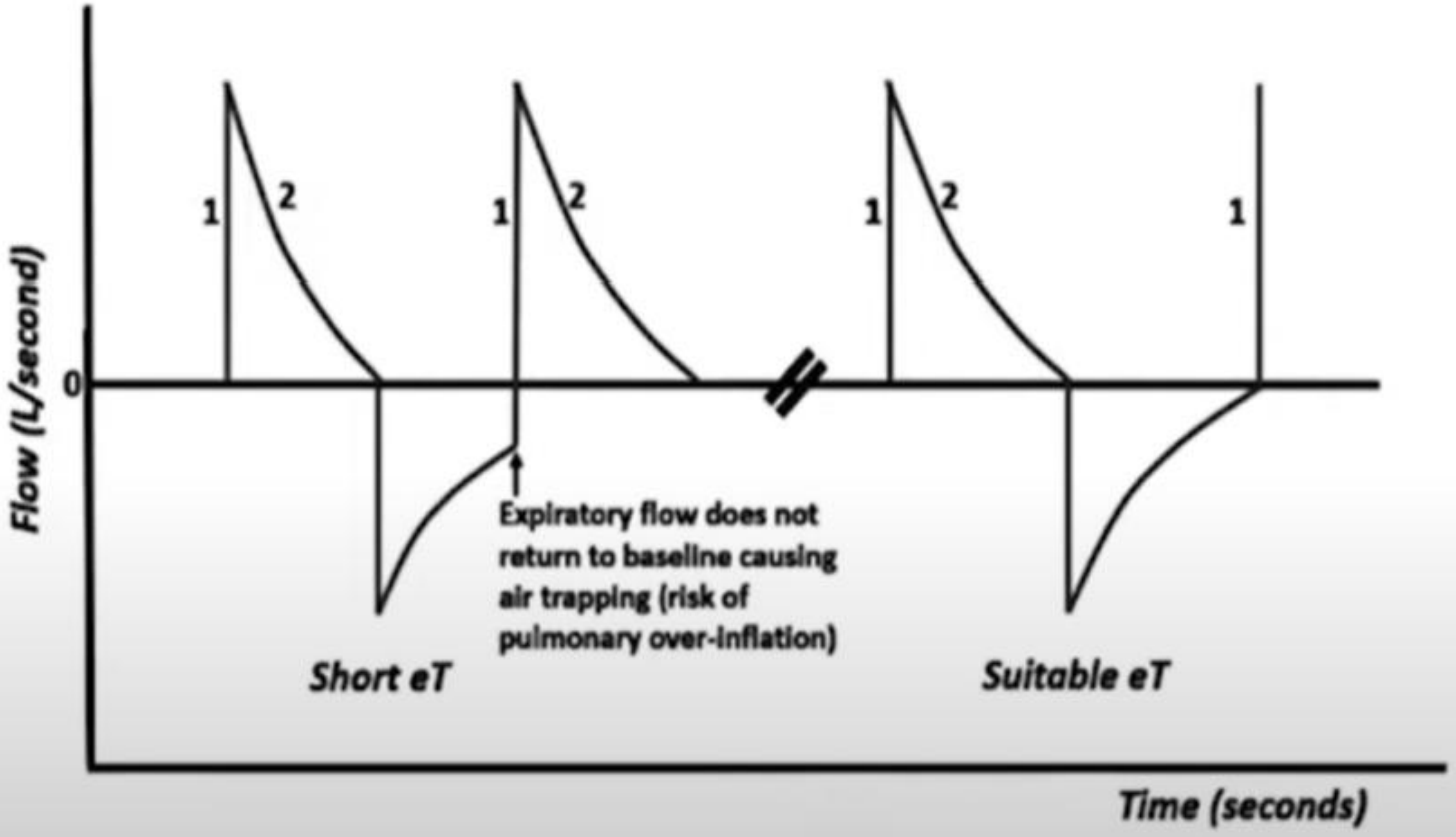
- When T_i is too short, the air flow is not completely delivered to the lungs.
- In this case, increasing the inspiratory time allows for complete inspiration.

When Ti set too long



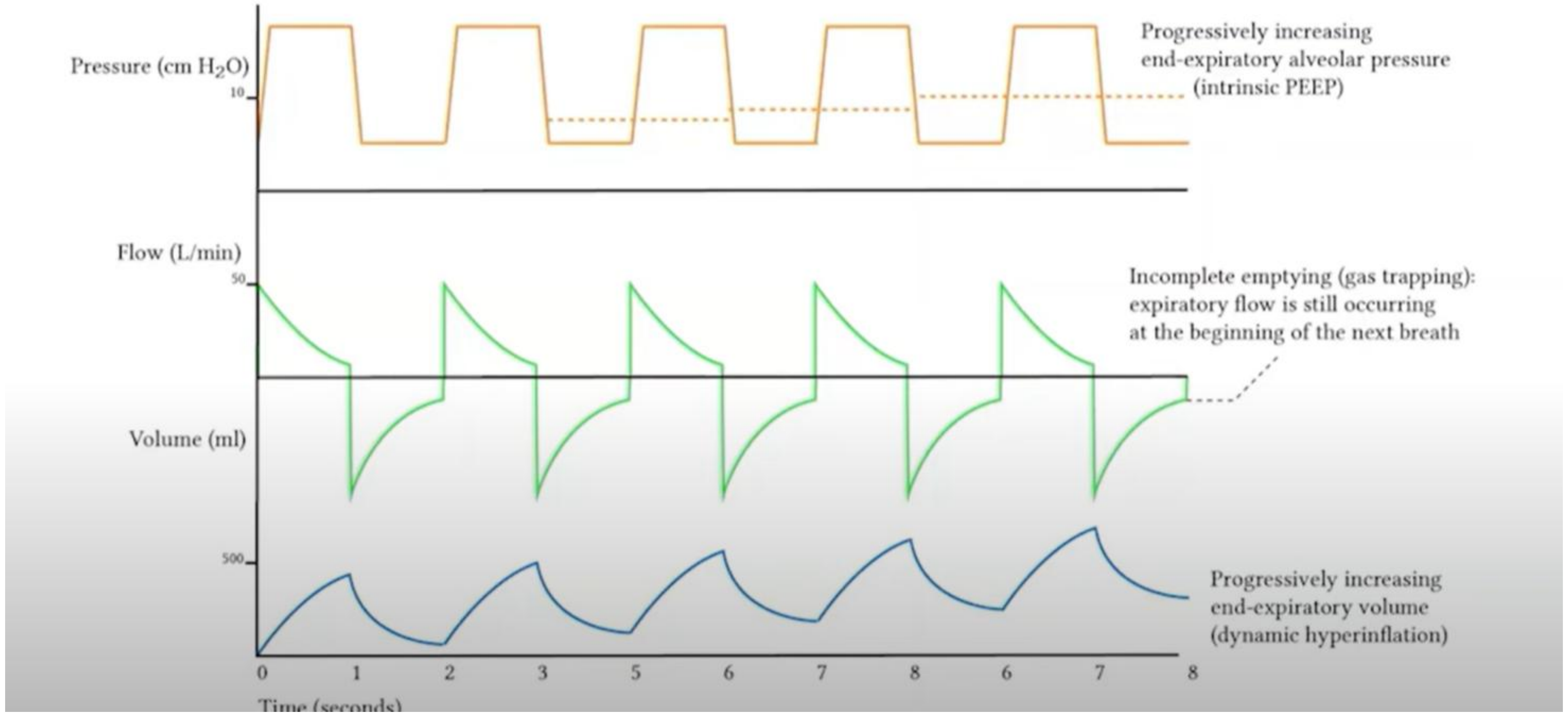
- When the T_i is too long , there is timing in the ventilatory cycle that is not used and that may be necessary to complete the expiration time, especially when using high ventilation frequencies.
- In this case, it is enough to decrease the T_i, so that the expiration starts immediately after the end of the inspiration.

Airtrapping or Auto PEEP

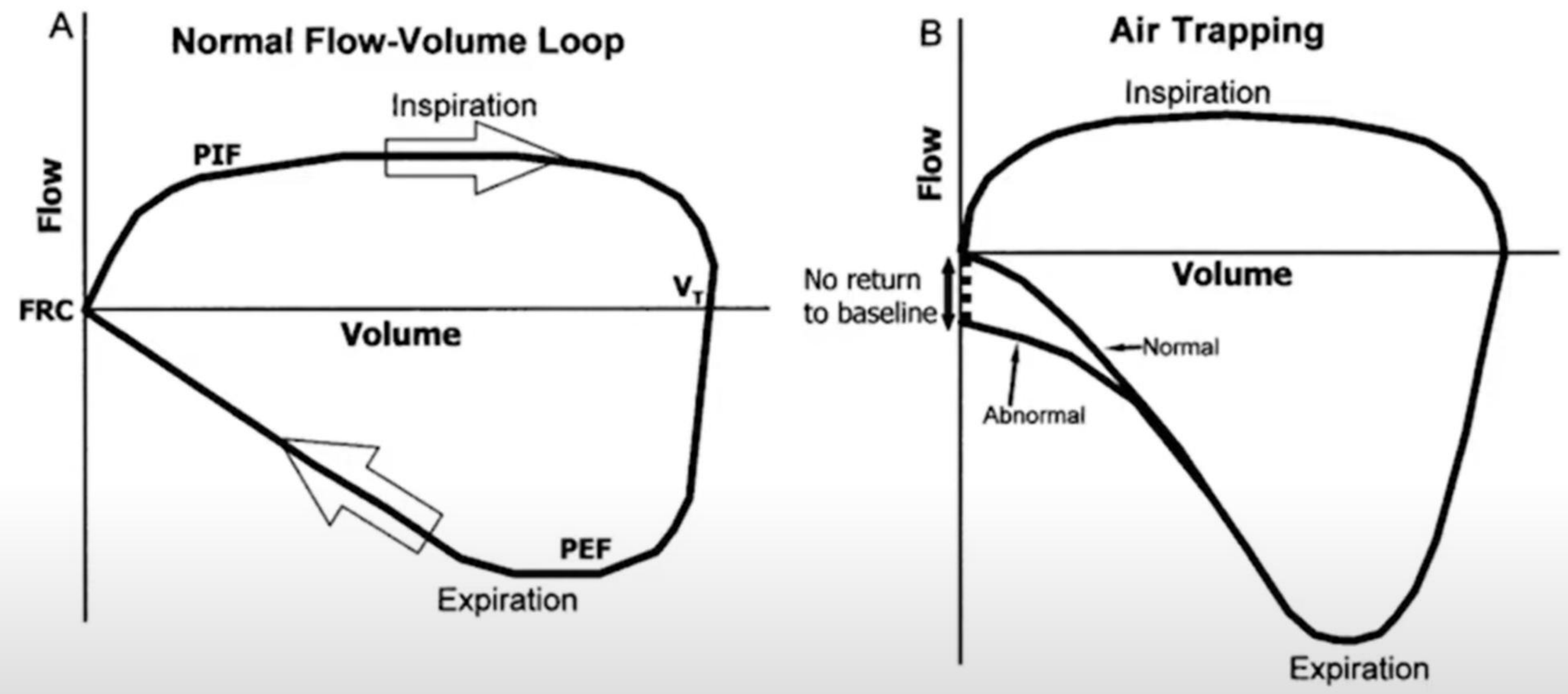


- When the expiratory time (T_e) is too short, the air flow is not completely expelled from the lungs , resulting in air trapping (auto-Peep) with risk of pulmonary over-inflation.
- In this case, increasing the T_e will allow the air flow to completely exit.

Ventialtor Waveforms showing Auto PEEP and its effects



Flow-Volume Loop showing air trapping



Flow - time scalar and flow volume loop are the best ones to look for air trapping in ventilator waveforms.