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Seven Myths of Mechanical Ventilation in Paediatric and Neonatal Patients

In this article, we will examine clinical concepts that have persisted over time, despite advancements in our understanding of physiology and technological innovations that have demonstrated their inapplicability in the routine clinical care of paediatric patients requiring respiratory support. These enduring beliefs have effectively transformed into myths.

Myth 1: The use of cuffed endotracheal tubes is not recommended for paediatric patients

Historically, uncuffed endotracheal tubes (ETTs) were preferred for young children because the paediatric airway narrows below the vocal cords, creating an anatomical seal around the distal tube. Concerns about tracheal injury associated with cuff usage, such as fistulas or tracheal stenosis, led to the use of uncuffed ETTs for an extended period. The incidence of tracheal injuries from ETTs decreased with the introduction of low-pressure cuffs in the 1970s (Stoller 1999). Prior to 2010, both cuffed and uncuffed ETTs were deemed acceptable for intubating infants and children. Cuffed devices were recommended in specific clinical scenarios, such as low lung compliance, high airway resistance, or glottic air leaks (Kleinman et al. 2010).

Numerous contemporary studies and systematic reviews now support the safety of cuffed ETTs (De Orange et al. 2017; Chen et al. 2018; Shi et al. 2016). Advantages of using cuffed ETTs include improved capnography accuracy, reduced need for tube changes (which can lead to high-risk reintubations or delayed compressions), potential decrease in aspiration risk, and improved administration (and measurement) of pressure and tidal volume during mechanical ventilation—an essential aspect of preventing ventilator-induced lung injury (Chambers et al. 2018; Schweiger et al. 2013; Weiss et al. 2009). Subglottic stenosis is rare when employing cuffed ETTs in children and following meticulous technique (Black et al. 1990). European and North American paediatric cardiopulmonary resuscitation guidelines advocate for the use of cuffed ETTs in paediatrics (Topjian et al. 2020; Van de Voorde et al. 2021). It is vital to monitor cuff pressure and adhere to each manufacturer’s recommendations (typically <20 to 25 cm H₂O). Cuff pressures are dynamic during transport at altitude (Orsborn et al. 2016) and with increasing airway oedema.

The smallest internal diameter available for Microcuff® ETTs is 3.0 mm, recommended solely for newborns ≥3 kg. No stan-
MECHANICAL VENTILATION

Myth 2: Patients weighing less than 10 kg should be ventilated in pressure-controlled assist-control mode, while those weighing more than 10 kg should be ventilated in volume-controlled assist-control mode

The choice of ventilatory mode in paediatric patients has been historically influenced by a paradigm: using pressure-controlled assist-control ventilation (PC-AC) for patients weighing less than 10 kg and neonates, and volume-controlled assist-control ventilation (VC-AC) for those weighing over 10 kg. This was attributed to the following reasons: 1) the belief that VC-AC mode lacked continuous flow and significant leaks from an uncuffed endotracheal tube would interfere with ventilation; 2) the inability to compensate for compressible volume in the airway; and 3) technical limitations of some ventilators to provide the required low tidal volumes (VT) and flows to prevent volutrauma (Gregory et al. 1971). These largely technical challenges have been addressed with the advent of ventilators and circuits adapted for paediatric and neonatal ventilation. The proximal flow sensor can accurately measure tidal volume and low flows, and these ventilators can deliver tidal volume and low flows while compensating for compressible volume and leaks, providing continuous basal flow.

The advantages of ventilating patients weighing less than 10 kg in VC-AC mode include strict control over tidal volume, potentially avoiding volutrauma, closer monitoring of plateau pressure (Pplateau) and driving pressure (DP), as well as improved alveolar air distribution, resulting in more homogeneous distribution and reduced risk of barotrauma and pneumothorax. The main limitation of VC-AC mode is the lack of consensus on determining the optimal protective tidal volume formula for the paediatric population. An alternative is the use of pressure-regulated volume control mode (PRVC) in premature newborns, which has shown benefits in survival and prevention of volutrauma in bronchopulmonary dysplasia.

A systematic review and meta-analysis in 2017 identified 20 controlled and randomised studies comparing Volume-Controlled Ventilation (VCV) and Pressure-Limited Ventilation (PLV) in neonates and premature neonates (Klingenberg et al. 2017). VCV compared to PLV resulted in:
1. Shorter duration of mechanical ventilation by 1.35 days.
2. Lower incidence of pneumothorax.
3. Lower incidence of bronchopulmonary dysplasia (BPD) at 36 corrected weeks.
4. Lower incidence of periventricular leukomalacia or grade 3 or 4 intraventricular haemorrhage.
5. A non-significant trend towards lower mortality.

Myth 3: Low PEEP levels of 0 to 4 cm H₂O should be programmed for paediatric and neonatal patients.

Lung volume changes occur only when changes in transpulmonary pressure (PTP) magnitude occur. Contrary to intuition, lung volume change is not solely influenced by the value of alveolar pressure (Pals) but rather by the value of PTP. As the lung fills with air, each lung volume corresponds to a specific PTP value (Medina 2015).

The summary of the aforementioned is depicted in Table 1. Regardless of the values of Palv and pleural pressure (Ppl), if PTP is +5 cm H₂O, the lung fills with a volume of air corresponding to functional residual capacity (FRC). If PTP = +30 cm H₂O, the lung volume matches total lung capacity (TLC). If PTP = +3 cm H₂O, the corresponding volume is residual volume (RV).

The penultimate row in the table represents a scenario where the patient has pleural effusion, causing the inapleural pressure to become positive (+5 cm H₂O). Without applying PEEP of +10 cm H₂O for ventilation, their end-expiratory volume wouldn’t reach FRC.

It has been suggested that PEEP ranges of 5-8 cm H₂O are necessary during invasive mechanical ventilation, and higher PEEP levels may be necessary based on the severity of the underlying disease (also in cardiac patients). Adjusting PEEP levels should always be considered, including adding PEEP in obstructive lung disease when air trapping is present. In cases of malacia, PEEP is used to place a stent in the upper airways (Kneyber et al. 2017).

Myth 4: The synchronised intermittent mandatory ventilation (SIMV) mode should be used for weaning off the mechanical ventilator.

MV improves survival in patients with respiratory failure, yet this therapy is not without complications, including ventilator-induced lung injury (VILI), ventilator-associated pneumonia, critical illness-associated weakness, right ventricular dysfunction, and increased costs associated with prolonged MV. Consequently, ventilator withdrawal should occur as soon as the patient is capable of maintaining adequate spontaneous breathing.

Ventilator withdrawal encompasses two scenarios: the gradual reduction of respiratory support (weaning) and the removal of the endotracheal tube (extubation). Extubation failure (EF) refers to a set of conditions leading to reintubation and VM reestablishment within the first 72 hours post-extubation. The decision to initiate weaning depends on the fulfilment of specific clinical criteria, including control of the underlying cause neces-
sitting intubation and MV, effective gas exchange, appropriate neuromuscular condition, sufficient consciousness to protect the airway, and stable haemodynamic status.

The most commonly used weaning method in paediatrics involves the synchronised intermittent mandatory ventilation (SIMV) mode. This mode is often programmed with pressure support to achieve a target tidal volume (Vt) based on patient needs. The theoretical advantage is to alleviate additional respiratory effort imposed by the endotracheal tube and mechanical ventilator circuit. However, in adults, it is evident that this method significantly prolongs MV compared to daily spontaneous breathing trials (SBT) and pressure support ventilation (PSV). Therefore, its use is not recommended.

Commonly employed SBT methods include continuous positive airway pressure (CPAP), tube T trials, and PSV. In paediatrics, method choice largely depends on the treating team’s experience, as there is no conclusive evidence that one method is superior to another. Implementing a ventilator withdrawal protocol that includes SBT allows for early identification of patients ready for weaning and facilitates a safer withdrawal process.

**Myth 5: PSV is ineffective in paediatrics due to children becoming fatigued.**

In 2001, evidence-based guidelines were published for weaning and discontinuing ventilatory support. They classified adult studies on weaning from MV into 1) discontinuation assessment trial (ERT) strategies, 2) controlled trials of gradual reduction in mechanical support, and 3) controlled trials of alternative discontinuation strategies.

A study by Esteban et al. (1997) compared 2-hour spontaneous breathing trials with PS of 7 cmH₂O to tube T trials. A higher number of patients in the PS group tolerated the trial and were extubated at the end of the study compared to the tube T group (86% vs. 78%; relative risk of failure, 0.64; 95% CI, 0.43 to 0.94). There was no difference in reintubation rates. A similar second study by Esteban et al. (1999) also showed no differences in

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<td>High-flow nasal</td>
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<td>Continuous positive airway pressure</td>
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<td>High-frequency oscillatory ventilation</td>
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<td>Liquid ventilation</td>
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<td>Triggering</td>
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<td>Plateau pressure</td>
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<td>Extra-corporeal life support</td>
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**Table 1: Potential clinical implications of the recommendations from the paediatric mechanical ventilation consensus conference (PEMVECC)**
reintubation rates between the groups. However, the shorter tube T trial benefited patients by reducing ICU and hospital stays (2 and 5 days shorter, respectively).

Five randomised clinical trials compared alternative methods to reduce ventilatory support in patients where several days of extubation were thought to be needed. The most informative results came from the two largest studies by Esteban et al. (1997) and Brochard et al. (1994). Both showed that when patients were initially evaluated for extubation using a tube T trial, around 76% could be extubated without weaning. The remaining patients were randomly assigned to be weaned using 2-hour spontaneous breathing trials with various modalities: daily multiple tube T/CPAP breathing, PS mode, and SIMV. The Esteban trial also included a fourth arm, tube T trials once daily. There was no difference in ventilation duration between tube T and PS, and trends were opposite in the two studies: Esteban et al. (1995) favoured tube T weaning, while Brochard et al. (1994) favoured PS. Both studies showed shorter ventilation duration with tube T compared to SIMV. In the PS vs. SIMV comparison, both studies found trends in favour of PS, although the effect in the Brochard study was much larger.

In the paediatric population, there are few studies comparing PS to other weaning methods. Farias et al. (2001) compared spontaneous breathing trials (SBT) using PS of 10 cmH\textsubscript{2}O to a tube T trial. The rationale for using PS was to overcome endotracheal tube resistance. The 257 subjects had to tolerate the 2-hour trial (either PS or tube T) to be considered for extubation. The attending physician could interrupt SBT due to objective (e.g., increased RR or SpO\textsubscript{2} < 90%) or subjective (e.g., sweating or increased respiratory effort) signs of poor tolerance. There were no differences in extubation failure rates within 48 hours (15.1% vs. 12.8%) or SBT failure (20.8% vs. 22.7%). The study concluded that a 10 cmH\textsubscript{2}O PS SBT was as effective as a tube T trial. In 2002, the same authors studied 418 patients intubated for at least 48 hours using a 2-hour SBT with tube T or 10 cmH\textsubscript{2}O PS (<60%). Of the 323 patients (77%) who passed the SBT and were extubated, 14% were re-intubated within 48 hours. Respiratory rate, tidal volume, RSBI, and maximum inspiratory negative pressure (PIm\textsubscript{ax}) were poor predictors of extubation outcome. In both studies, patients underwent an SBT only when deemed ready by the attending physician, possibly not at the earliest point when an SBT could have been performed.

In adults, Esteban et al. (1997) found that two-thirds of patients passed an SBT even before weaning started. If the SBT had been performed earlier in the Farias study, there could have been an increased SBT failure rate in the tube T group compared to the PS group. Willis et al. (2005) quantified respiratory work (measured by a surrogate, the product of pressure rate) in 22 patients. They found no difference between CPAP and 5 cmH\textsubscript{2}O PS. Both provided reduced respiratory work compared to tube T (with or without heliox) or extubated patients. Patients on tube T had less respiratory work than when extubated. Takeuchi et al. (2000) demonstrated that breathing work through an ETT for infants was only marginally higher than after extubation. They also showed that 4 cmH\textsubscript{2}O PS was more than sufficient to compensate for marginal increases in respiratory work through an internal diameter of 3.5 to 4.5 mm ETT and was equivalent to breathing without the ETT. A series of studies involving 634 infants and children (Farias et al. 2001) demonstrated that a safe spontaneous breathing trial lasting up to two hours could be performed using a tube T trial for ERT. While the trend of using PS with PEEP instead of CPAP or tube T breathing to overcome ETT resistance has emerged, evidence shows that the resistance increase is minimal and the additional respiratory work insignificant. If a baby or small child cannot sustain an SBT with CPAP or a tube T for several hours, the likelihood of extubation failure is as probable as with applied PS. Additionally, PS addition likely masks respiratory failure and contributes to a higher extubation failure rate.

**Myth 6:** In the case of cardiopulmonary resuscitation, mechanical ventilation should not be maintained during resuscitation

Advanced cardiopulmonary resuscitation (CPR) often requires a significant number of healthcare personnel. In situations where an emergency department is overwhelmed, there is a shortage of available healthcare staff, or personnel are less trained in manual ventilation, the use of mechanical ventilation provides advantages. This allows airway-focused personnel to concentrate on other tasks during CPR, such as chest compressions, defibrillation, identifying the causes of cardiac arrest, and more (Weiss et al. 2005).

Positive pressure ventilation can be delivered through an advanced airway using a bag-valve mask (BVM) or a mechanical ventilator. It was found that both ventilation methods were equally effective in terms of arterial gas measurements in a prospective intervention study involving 122 patients with cardiac arrest (Johannigman et al. 1995).

In adults, the “six-dial strategy” has been described for mechanical ventilator programming during CPR. This involves setting six parameters: PEEP of 0 cm H\textsubscript{2}O (to favour venous return), using volume-controlled mode with 8 ml/kg of ideal body weight and FiO\textsubscript{2} of 100% (to ensure adequate oxygenation), respiratory rate of 10 breaths per minute (for proper ventilation), inspiratory pressure alarm set at 60 mm H\textsubscript{2}O (to deliver the tidal volume during chest compressions), trigger or sensitivity turned off (to prevent triggering during chest recoil), and an I:E ratio of 1:5 (to achieve an appropriate inspiratory time) (Sahu et al. 2020).

For children already on mechanical ventilation, the 2021 European Resuscitation Council Guidelines for Paediatric Life Support emphasise the need to ensure that the ventilator is in a volume-controlled mode, with triggers and limits deactivated. The ventilation frequency, tidal volume, and FiO\textsubscript{2} should be appropriate for cardiopulmonary resuscitation. There is no evidence to support a specific level of PEEP during CPR. Always bear in mind that ventilator dysfunction itself could be a cause of cardiac arrest (Van de Voorde et al. 2021).

More information regarding mechanical ventilation during CPR
is anticipated. Recently, a porcine model of paediatric asphyxial cardiac arrest was used to demonstrate that pressure-controlled ventilation at a rate of 20 breaths/minute with FiO₂ of 100% provided adequate oxygenation and appropriate normocapnia.

Myth 7. Maintaining a SpO₂ of 100% is safe and appropriate for paediatric and neonatal patients

The critically ill patient presents various nuances in intensive care or emergency settings, where we must recall the oxygenation goals for each specific clinical scenario. Excessive delivery of FiO₂ is linked to an excess of oxygen-free radicals. (Bohnhorst et al. 2000). We will outline the oxygenation goals for different clinical conditions, aiding in the avoidance of elevated FiO₂ levels, as well as high pressures (positive end-expiratory pressure and peak inspiratory pressure) and utilised tidal volumes (Table 2).

Pulse oximeters can serve as a surrogate for arterial blood gas saturation. These devices need to be accurate across a wide range of skin tones and thicknesses and for a broad spectrum of saturations. Generally, pulse oximeters are most accurate at higher saturations, typically above 75% (Bohnhorst et al. 2000; Carter et al. 1998; Fanconi 1988).

Pulse oximetry estimates the percentage of haemoglobin saturation. It is not intended to be a substitute for blood oxygen pressure (PaO₂) measurement, especially at extreme values. The relationship between PaO₂ and oxygen saturation is influenced by multiple factors, including haemoglobin type and the state of the oxyhaemoglobin dissociation curve. The latter is affected by acid-base status, temperature, and 2,3-diphosphoglycerate (DPG) levels. Pulse oximetry is known to be inaccurate during periods of hypoxaemia (saturations, 85%-90%) and generally reads 98% to 100% when PaO₂ exceeds 100 mm Hg. Both external and patient-related factors, including movement, ambient light, and low tissue perfusion, can interfere with its accuracy.

Pulse oximeters are not precisely calibrated for low saturations seen in cyanotic congenital heart diseases. However, there is a blue sensor designed for the saturation range found in patients with these clinical conditions. The PaO₂ values need to meet the metabolic demands of a neonate range from 50 to 80 mmHg due to their high proportion of circulating foetal haemoglobin (HbF). In neonates, SpO₂ levels between 85 and 95% correlate with PaO₂ levels between 45 and 65 mmHg (Quine et al. 2008). However, these measurements are limited in scenarios of significant hypoxaemia or hyperoxaemia. For saturations above 96%, PaO₂ levels continue to increase without a significant change in SpO₂, potentially leading to hyperoxaemia. The high affinity of HbF for oxygen shifts the haemoglobin dissociation curve to the left, resulting in relatively high saturations (85%) for PaO₂ levels below the 45 mmHg threshold, leading to complications associated with hypoxae-

Conflict of Interest
None.

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<thead>
<tr>
<th>Clinical Condition</th>
<th>Target</th>
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<tbody>
<tr>
<td>Acute Respiratory Distress Syndrome with PEEP &lt;10 cm H₂O</td>
<td>SpO₂ 92-97%</td>
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<tr>
<td>Acute Respiratory Distress Syndrome with PEEP &gt;10 cm H₂O</td>
<td>SpO₂ 88%-92%</td>
</tr>
<tr>
<td>Return of Spontaneous Circulation (ROSC) after Cardiopulmonary Resuscitation (CPR)</td>
<td>SpO₂ 94%-98%</td>
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<tr>
<td>Severe Asthma Crisis</td>
<td>SpO₂ ≥92</td>
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<tr>
<td>Severe Traumatic Brain Injury</td>
<td>SpO₂ 94-99%</td>
</tr>
<tr>
<td>Potential Organ Donor</td>
<td>SpO₂ &gt;95% Less percentage of oxygen as possible</td>
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<tr>
<td>Carbon Monoxide Poisoning</td>
<td>SpO₂ 100% (If there is no 6-8 wavelength pulse oximeter)</td>
</tr>
<tr>
<td>Premature Newborn and Bronchopulmonary Dysplasia</td>
<td>SpO₂ 90%-95%</td>
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<td>Acute Chest Syndrome in Sickle Cell Disease</td>
<td>SpO₂ &gt;94%</td>
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<tr>
<td>Drowning</td>
<td>SpO₂ 94%-98%</td>
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Table 2: Oxygenation goals for different clinical conditions
References


