From Alarm to Calm: Basic ventilator troubleshooting

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INTRODUCTION

This article aims to provide real-world examples of how to tackle common ventilator pitfalls, specifically focusing on alarm management. In this article, modes of ventilation are not discussed in detail, and specific ventilation strategies are only briefly addressed.

Initial Assessment of Acute Desaturation

Let's first recap the key actions to take in sudden desaturation or hypoxemia in the mechanically ventilated patient:

Immediate action: If the patient is unstable, disconnect the ventilator and perform manual bagging (BVM) with high-flow O2 to differentiate ventilator and connection failure from patient-side issues.

Tube verification: By monitoring capnography waveform (or end-tidal CO2 display), checking endotracheal tube (ETT) depth, and auscultating bilateral breath sounds. We may pass a suction catheter along ETT depth to detect or eliminate any mechanical obstruction.

The DOPES Mnemonic

DOPES mnemonic helps us systematically assess issues starting from the patient, then the circuit, and finally the machine. At this juncture at least we can be sure that the ETT is patent, appropriately placed and secured.

DOPES Mnemonic in Acute Respiratory Deterioration
Dislodged, displaced ETT (including incidental endobronchial intubation) or cuff leak **O**bstructed ETT (commonly kinking, biting, mucous plug or blood clot) **P**neumothorax **E**quipment failure (oxygen source, ventilator power, setting and connection tubing) **S**tacking of breaths (inadequate expiration or auto-PEEP in Asthma or COPD) or gastric insufflation

Table 1: The DOPES Mnemonic

However, there are times we need to go beyond DOPES to troubleshoot ventilator issues. The most common scenarios involve ventilator alarms. We should not simply silence alarms without investigation. The following cases illustrate how we tackle pressure alarms coming up with difficult ventilations. The ventilator used for demonstration below is the Dräger Oxylog® 3000 portable mechanical ventilator.

Understanding High Pressure Alarms

The first two scenarios address difficult ventilation with high pressure alarms where the peak inspiratory pressure (PIP) exceeds the set limit. High inspiratory pressure indicates resistance or decreased lung compliance.

The systematic approach involves:

Step1: Apply the DOPES mnemonic and assess the patient for desynchrony, biting, coughing, bronchospasm, secretions, endobronchial intubation, or pneumothorax. Treat any reversible cause.

Step 2: Evaluate the pressure-time curve.

Step 3: Perform an inspiratory hold maneuver to obtain plateau pressure (Pplat), which helps differentiate between increased resistance and decreased compliance.

<u>Plateau Pressure: A Key Indicator</u>

The plateau pressure (Pplat) is a critical indicator of respiratory system (lung and chest wall) compliance.[1] It measures pressure at the alveoli immediately before expiration. Normally Pplat is below 30cmH_2O. Increased PIP with normal Pplat reflects increased **airway resistance**. The difference between PIP- Pplat can be denoted by ΔP. Conversely, high Pplat above 30cmH2O signifies **decreased lung compliance.** Pplat should be kept <30 cm H2O to prevent ventilator-induced lung injury.[2] The Pressure Time Curve is as shown in Fig.1 and calculation of ΔP and Driving Pressure has been shown in Fig.2. Troubleshooting elevated PIP has been shown in Fig.3.

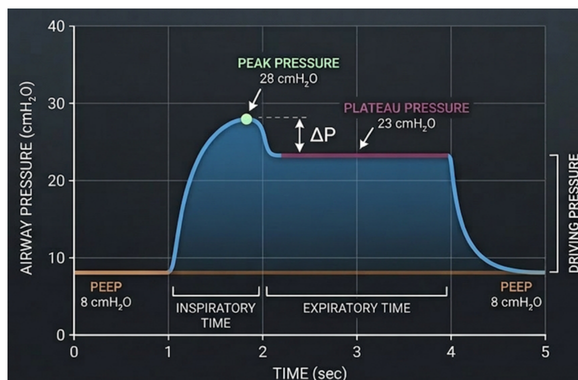

Fig 1. Pressure Time Curve showing PIP, Pplat & calculation of ΔP

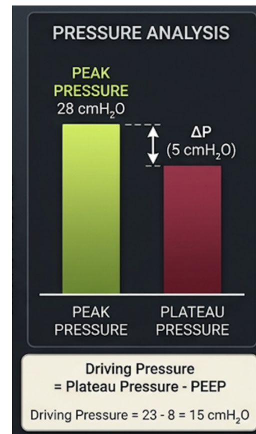

Fig 2. Calculation of ΔP & Driving Pressure

Fig 3. Troubleshooting high PIP

SCENARIOS

Case 1: Acute Severe Asthma with High Airway Resistance

You have intubated a 73-year-old man for acute hypercapnic respiratory failure secondary to status asthmaticus. Before intubation, ABG showed pCO2 8.3kPa (62mmHg) and SaO2 83% despite high flow oxygen devices and inhaled bronchodilator use. You performed Rapid Sequence Intubation (RSI) with Propofol 100mg and Rocuronium 50mg. You initiated mechanical ventilation using continuous mandatory ventilation- volume control (CMV-VC) mode. The patient is hemodynamically stable and shows SpO2 ≥90% with FiO2 0.4. Despite aggressive bronchodilator therapy and adequate sedation with paralysis, the high-

pressure alarm (displayed as 'Paw high') continues to activate, accompanied by low minute-ventilation (MVe). The ventilator setting and tracing are as shown in Fig 4a.

Fig.4a Pressure-time curve tracing of the asthmatic patient

Upon evaluating the pressure-time curve, you observe that it does not reach its peak. The ventilator terminates the breath and alarms immediately when peak pressure exceeds the pressure limit (typically defaulting to 40 cm H2O). The set tidal volume thus cannot be completely delivered to the patient. PEEP remains at its set value. This confirms an elevation in PIP.

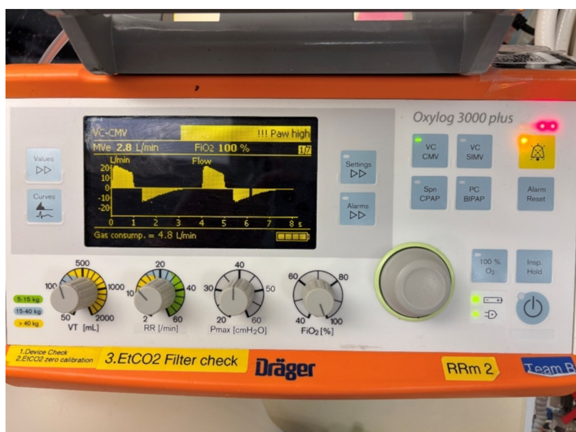

Fig.4b Flow-time curve tracing of the asthmatic patient

The flow-time curve is useful for checking any air-trapping. In Fig.4b, the flow-time curve demonstrates that expiratory flow successfully returns to baseline, indicating no evidence of incomplete exhalation or auto-PEEP.

Fig.4c Performing inspiratory hold to check plateau pressure (Pplat)

After identifying an isolated rise in PIP and evaluating the pressure-time curve, you pressed the inspiratory hold button for 2-3 seconds to allow pressure equilibration between airway and alveoli (Fig.4c). This maneuver yields Pplat <30cmH2O. You can conclude that the increase in PIP is due to increase in airway resistance, which is consistent with the clinical picture of unresolved bronchospasm. While continuing efforts to relieve bronchospasm, you can also adjust the ventilator setting to maintain effective ventilation:

1. Increase pressure limit to 60 cmH_2O to allow tidal volume delivery (Fig.4d)
2. Apply permissive hypercapnia strategy:
    - Reduce respiratory rate (RR) and tidal volume (VT)
    - Reduce PEEP (or eliminate if auto-PEEP present)
    - Increase inspiratory to expiratory (I:E) ratio to prolong expiratory time
    - Accept lower minute ventilation
    - Maintain pH ≥7.15-7.20 (permissive hypercapnia limits)[3]
    - Keep VT ≥4 mL/kg predicted body weight (PBW)
3. Reassess flow-time curve - may cautiously increase RR if no air-trapping evident

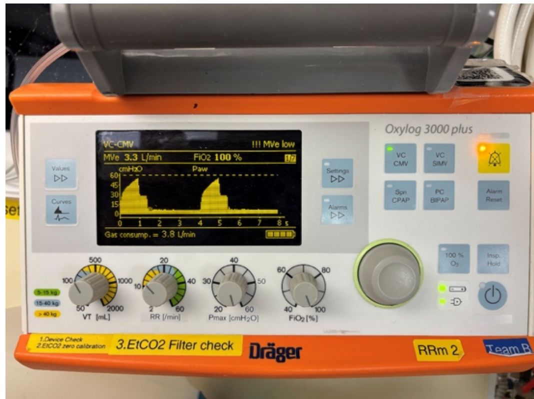

Fig.4d Increasing pressure limit to allow tidal volume delivery

Case 1: Summary of Action Items
Initial DOPES assessment • Disconnect ventilator, manual bag ventilation with FiO_2 1.0 • Assess ETT: capnography waveform, size, position, patency (pass suction catheter) • Assess patient: level of consciousness, muscle tone, biting; bilateral air entry; bronchospasm • Optimize sedation, paralysis, and bronchodilator therapy • Reassess oxygenation
Ventilator reconnection and assessment • Reconnect ventilator, set FiO_2 1.0 • Assess pressure-time curve to confirm elevated PIP
Plateau pressure measurement • Obtain Pplat by inspiratory hold (2-3 seconds) • If Pplat $\leq$30 cmH_2O $\rightarrow$ airway resistance is the cause • Increase pressure limit until adequate tidal volume delivered • Reassess Pplat after adjustment
Ongoing management • Monitor ABG for pH, pCO_2, and oxygenation • Continue aggressive bronchodilator therapy • Ensure adequate sedation and paralysis • Serial reassessment of ventilator waveforms

Case 2: Severe Pneumonia with Decreased Lung Compliance

An 86-year-old man suffering from pneumonia was intubated for respiratory failure with SpO2 60% on non-rebreathing mask and 80% on manual bag ventilation. Lungs were stiff on manual bagging. Post intubation SpO2 was 83-84%. The Chest X-ray is as shown in Fig.5.

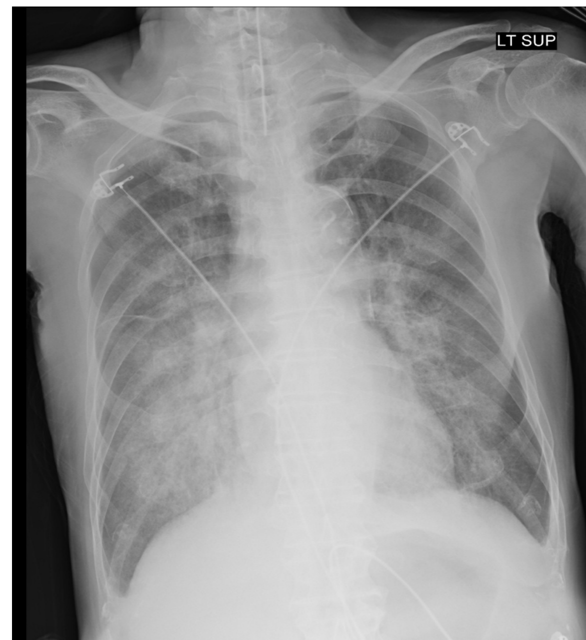

Fig. 5. CXR of the patient with pneumonia

You initiated volume control mode of mechanical ventilation with lung protective strategy:

- VT: 380ml (approximately 6 mL/kg predicted body weight for estimated height 165 cm, weight 63 kg)
- RR: 16 breaths/min
- FiO2: 1.0
- PEEP titration for oxygenation:
    - PEEP 10 cmH_2O $\rightarrow$ SpO_2 85%
    - PEEP 12 cmH_2O $\rightarrow$ SpO_2 88%
    - PEEP 14 cmH_2O $\rightarrow$ SpO_2 $\geq$92%

High pressure alarm was activated. Plateau pressure measured was about 30cmH2O, signifying a decrease in compliance. You then adjusted the set pressure limit at 45cmH2O. The

settings are as shown in Fig 6a.

Fig 6a. Initial ventilator settings

Alveolar recruitment continued over time. Oxygenation and compliance gradually improved with Pplat decreasing to 18cmH2O. ABG at 5min showed pO2 30kPa, SaO2 100%. You then titrated FiO2/ PEEP according to ARDSNet protocol, starting with FiO2 0.4/PEEP 8cmH_2O, aiming at SpO2 approximately 90%. Finally, the patient tolerated well at FiO2 0.6/PEEP 10cmH_2O with SpO2 96%. The settings are as shown in Fig 6b.

Fig. 6b. Adjusted ventilator settings after alveolar recruitment

<u>Acute Respiratory Distress Syndrome (ARDS)</u>

ARDS was first described by Ashbaugh and Petty in 1967 in a case series of 12 ICU patients who shared common features: persistent tachypnea, hypoxemia, bilateral opacities on chest radiographs, and poor lung compliance despite different underlying etiologies.[4] The ARDSNet ARMA study is one of the pivotal clinical trials in critical care that established the current standard of care for mechanical ventilation.[5] This landmark study established the lung-protective ventilation approach, which has since been extended to non-ARDS patients, with the exception of obstructive lung disease (e.g. Asthma/ COPD). The ARDSNet Table provides a sliding scale approach to increase oxygenation by optimizing FiO2 in conjunction with PEEP.

The ARDSNet ventilation strategy applies to any ventilator mode and consists of:

- VT: 6mL/kg is based on predicted body weight (PBW)
  - PBW Formulas:
  - Adult male: PBW (Kg) = 50 + 0.91 (Height cm −152.4)
  - Adult female: PBW (Kg) = 45.5 + 0.91 (Height cm −152.4)
- Set RR to maintain optimal minute ventilation
- Target SpO_2 88-95%
- Increase PEEP and FiO_2 according to the ARDSNet Table (Table 2)
- Maintain Pplat <30 cmH_2O

If necessary, reduce VT stepwise by 1 mL/kg PBW to minimum of 4 mL/kg PBW to keep Pplat<30 cmH_2O.

FiO2	PEEP (cmH_2O)
0.3	5
0.4	5
0.4	8
0.5	8
0.5	10
0.6	10
0.7	10
0.7	12
0.7	14
0.8	14
0.9	14
0.9	16
0.9	18
1.0	18
1.0	20
1.0	22
1.0	24

Table 2. The ARDSNet Table

Recent evidence suggests that driving pressure (ΔP = Pplat - PEEP) may be a better predictor of outcomes than Pplat alone.[6] Aim to maintain driving pressure ≤15 cmH_2O when possible, through PEEP optimization.

Differential Diagnosis: Endobronchial Intubation

During ventilator manipulation, the ETT may migrate deeper, resulting in right mainstem intubation (as shown in Fig.7). An otherwise stable patient would not develop acute pulmonary edema or atelectasis rapidly. Therefore, in addition to pneumothorax, consider endobronchial tube positioning if you encounter a sudden decrease in compliance manifested by elevated PIP and Pplat.

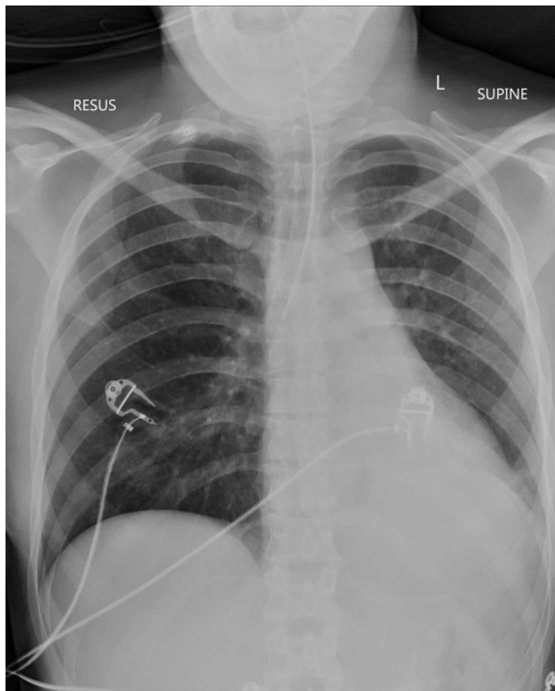

Fig.7 CXR showing right mainstem intubation
(Adapted from Smith D, Endotracheal tube in right main bronchus. Case study, Radiopaedia.org, rID:57358)

The following actions can be taken:

- Verify ETT depth (should be 21-23 cm at teeth for average adult)
- Check for decreased breath sounds on left
- Confirm ETT depth with chest radiograph
- Look for bifid capnography waveform (early sign)

The bifid waveform in capnography, as shown in Fig.8, represents differential ventilation of the two lungs - an early clue to endobronchial intubation. However, if the left lung is completely isolated (total occlusion with inflated cuff), this waveform may not appear.

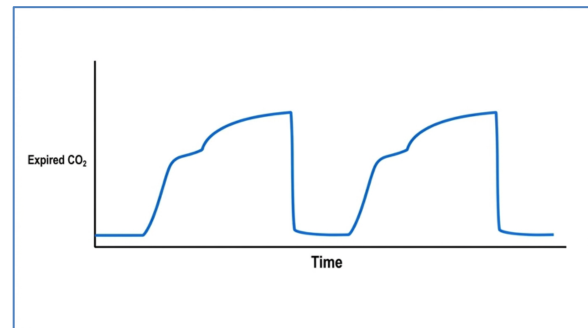

Fig. 8 Bifid waveform in capnography

Case 3: Circuit Leak

A 6-year-old girl (17kg) presented with status epilepticus and was put on propofol as a third-line agent. She was intubated for airway protection. A 5.0 mm internal diameter (ID) uncuffed tube was placed. The patient was paralyzed and put on the ventilator. However, the capnography waveform was inconsistent and intermittently absent, although the patient maintained adequate oxygenation (as shown in Fig. 9).

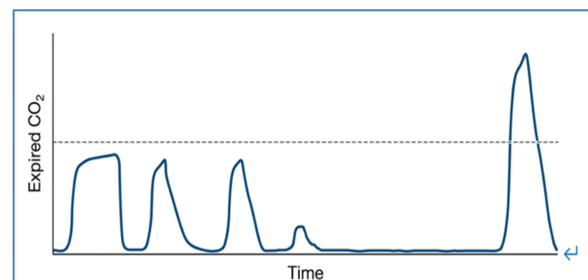

Fig.9 Inconsistent capnography tracing of the patient

You verified tube position again by direct visualization and auscultated bilateral breath sounds. At the same time, the low minute ventilation alarm was triggering.

You obtained a consistent capnography waveform during manual ventilation with BVM (without PEEP valve), but once you put the patient back to the ventilator, the capnography tracing disappeared.

From the pressure-time curve in Fig 10a, you noticed a drop in the PEEP level immediately in the expiratory phase,

Fig.10a Pressure-time curve of the ventilator

From the flow-time curve in Fig.10b, you noticed that the area under the inspiratory curve was significantly larger than the area under the expiratory curve.

Fig.10b Flow-time curve of the ventilator

A colleague suggested using the pressure control mode in which you achieved better minute ventilation and apparently a more normal looking pressure-time curve, as shown in Fig. 10c.

Fig. 10c Pressure-time curve after switching to pressure control mode

However, the leak persisted, as shown in the volume time curve in Fig 10d.

Fig.10d Volume time curve after switching to pressure control mode

<u>Understanding Circuit and Cuff Leaks</u>

A leaking ventilator circuit or cuff is identified on waveforms by an inspiratory volume that is larger than the expiratory volume as well as:

- Reduced PIP
- Low exhaled tidal volumes
- Decreased minute ventilation
- Inconsistent or absent capnography waveform

The underlying causes can be classified into circuit issues or airway issues:

Circuit issues: Loose connections, broken tubing, humidifier malfunction, disconnected

bacterial-viral filter

Airway issues: Deflated or damaged ETT cuff, uncuffed tube, cuff positioned above vocal cords

If air leak is suspected, follow the following steps for troubleshooting:

1. Disconnect ventilator, commence manual bag ventilation with FiO_2 1.0
2. Assess ETT and capnography waveform: size, position (including cuff position), cuff pressure
3. Verify cuff pressure with manometer at pilot balloon (target 20-30 cmH_2O)
4. Check bacterial-viral filter (cap of capnography port easily loosens or detaches) (See Fig.11)
5. Assess patient: consciousness level, muscle tone, biting; bilateral air entry; audible air leaks around mouth or neck
6. Consider inflating cuff with additional air (5-10 mL increments) with pressure reassessment (maintain 20-30 cmH_2O)
7. Reconnect ventilator, set FiO_2 1.0, recheck pressure waveform
8. Titrate FiO_2 downward once leak resolved

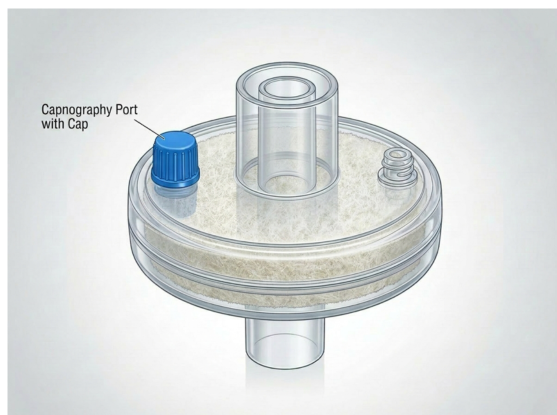

Fig.11 Capnography port on a bacterial-viral filter

Pediatric Considerations: Uncuffed or Cuffed Tubes

Traditionally, uncuffed ETTs were preferred for pediatric patients under 8-10 years of age due to concerns about tracheal injury at the cricoid ring.[7] The primary challenged with uncuffed tubes is air leakage around uncuffed tubes throughout the respiratory cycle, which can cause:

- Reduced minute ventilation
- Unstable, diminished, or absent capnography waveform
- Difficulty assessing respiratory mechanics
- Risk of undetected tube displacement

It is especially challenging if patient transfer is required, as continuous capnography monitoring is essential. Currently, it is recommended that both cuffed and uncuffed tubes are acceptable for infants and children, and cuffed tubes with modern high-volume, low-pressure cuffs minimize mucosal injury risk.[8]

If an uncuffed tube is used, air leak can be minimized by:

- Reducing or removing PEEP
- Reducing VT (volume-control mode) or Pinsp (pressure control mode)
- Considering replacement with a cuffed tube
- Consider a larger uncuffed tube (if cuffed tube unavailable)

In the above case, PEEP was removed, and the patient tolerated ventilation well with improved capnography waveform and minute ventilation.

CONCLUSION

Systematic troubleshooting of mechanical ventilators in the emergency department requires integration of clinical assessment, waveform interpretation, and physiological principles.

The DOPES mnemonic provides an essential starting framework for acute deterioration, but successful management often requires deeper understanding of ventilator alarms and pressure dynamics.

Key principles for emergency physicians:

1. Always start with patient assessment and DOPES algorithm
2. Utilize pressure-time and flow-time waveforms to guide diagnosis
3. Differentiate airway resistance (high PIP, normal Pplat) from decreased compliance (high PIP and Pplat)
4. Apply lung-protective ventilation principles when possible
5. Recognize and manage circuit leaks, particularly in pediatric patients
6. Maintain vigilant monitoring during emergency department stays and transport

Understanding these fundamental troubleshooting approaches enhances emergency physician capability to manage critically ill mechanically ventilated patients safely and effectively.

References

1. A Amato MB, Meade MO, Slutsky AS, Brochard L, Costa EL, Schoenfeld DA, et al. Driving pressure and survival in the acute respiratory distress syndrome. N Engl J Med. 2015;372(8):747-755.

2. Chan MC, Tseng JS, Chiu JT, Hsu KH, Shih SJ, Yi CY, et al. Prognostic value of plateau pressure below 30 cm H2O in septic subjects with acute respiratory failure. Respir Care. 2015 Jan;60(1):12-20.

3. Darioli R, Perret C. Mechanical controlled hypoventilation in status asthmaticus. Am Rev Respir Dis. 1984 Mar;129(3):385-7.

4. Ashbaugh DG, Bigelow DB, Petty TL, Levine BE. Acute respiratory distress in adults. Lancet. 1967;2(7511):319-323.

5. Acute Respiratory Distress Syndrome Network. Ventilation with lower tidal volumes as compared with traditional tidal volumes for acute lung injury and the acute respiratory distress syndrome. N Engl J Med. 2000;342(18):1301-1308.

6. Amato MBP, Meade MO, Slutsky AS, et al. Driving pressure and survival in the acute respiratory distress syndrome. N Engl J Med. 2015;372(8):747-755.

7. Weiss M, Dullenkopf A, Fischer JE, Keller C, Gerber AC; European Paediatric Endotracheal Intubation Study Group. Prospective randomized controlled multi-centre trial of cuffed or uncuffed endotracheal tubes in small children. Br J Anaesth. 2009 Dec;103(6):867-73.

8. De Orange FA, Andrade RG, Lemos A, Borges PS, Figueiroa JN, Kovatsis PG. Cuffed versus uncuffed endotracheal tubes for general anaesthesia in children aged eight years and under. Cochrane Database Syst Rev. 2017 Nov 17;11(11):CD011954.