INTRODUCTION

Clinical evidence regarding ventilation strategies for children with healthy lungs during surgery is still scarce. The pediatric anesthetist needs to make individual decisions regarding the patient’s treatment, taking into account the wide range of physiological characteristics of the respiratory system, changing from birth through adolescence, including information obtained from the anesthesia workstation (AWS). The primary goal of mechanical ventilation settings is to optimize gas exchange within a physiological range. Configuring ventilation settings in order to achieve this goal requires understanding and skills that go far beyond using automatic presets.

From a physical perspective, ventilation aims at transferring pneumatic energy from the ventilator to the patient’s respiratory system. Concerning potential ventilation-related lung injury, setting mechanical ventilation will always be a trade-off between adequate lung ventilation and applying the lowest possible energy transfer. Critically evaluating the following questions in the light of the patient’s characteristics and circumstances may help to determine ventilator settings on a rational basis:

1. Is the ventilation mode the most effective?
2. Is the minute ventilation just as low as required?
3. Is the lung open and not overdistended?
4. Is the composition of the breathing gas adjusted to the actual need?

In the following chapters, we aim to address how the information provided by the AWS may be used to answer these questions.
From a historical perspective, pediatric anesthetists prefer pressure-controlled ventilation (PCV). From the evidence available, volume-controlled ventilation (VCV) has been avoided for the reason of mistrusting the precision of tidal volume application and the fear of high airway pressures. As illustrated before, manufacturers made promising efforts to address shortcomings in regard to the precision of tidal volume application. Fresh gas decoupling and compliance compensation are among the most important (see Part I). In regard to airway pressures, it is important to recall that with identical end-inspiratory alveolar pressure, VCV shows a clearly higher peak airway pressure compared with PCV. This is, however, solely due to the flow-dependent resistive pressure gradient across the airways distal to the Y-piece and therefore does not strain the lungs (see Part I, Figure 4). The uncertainty regarding the “true” inspiratory pressure, however, will continue unless manufacturers of AWS imply tracheal (or alveolar) pressure calculation, for example, based on algorithms as discussed.

To date, there is not enough outcome-related evidence favoring decelerating flow waveform during inspiration (ie, PCV) over squared flow waveform (ie, VCV) in the perioperative setting. Nevertheless, selection should target specific circumstances.

PCV appears the preferred ventilation mode if relevant airway leakage is potentially present, for example, during ventilation via an uncuffed endotracheal tube or a laryngeal mask or during lung separation. In the presence of leakage, the inspiratory flow delivery, up to the limit of the ventilator, ensures the pressure amplitude required for insufflation of the targeted tidal volume. For this reason, the mechanical principle of PCV is also the basis for most assisted ventilation and noninvasive ventilation modes. Furthermore, PCV is preferable when there is a risk of dynamic hyperinflation. The retained volume (and increased end-expiratory pressure) diminishes driving pressure of the subsequent breath. Peak inspiratory pressure remains constant; thus, an excessive pressure increase, as it would develop incrementally during VCV, is avoided.

VCV can be an advantage in situations when changes in respiratory system compliance (\(C_{RS}\)) are expected, for example, in case of capnoperitoneum or re-positioning. Tidal volume is constant at varying peak inspiratory pressures, avoiding hypoventilation and extensive tidal volumes (which may be associated with volutrauma). Moreover, albeit less obvious, the constant flow during inspiration provides (almost) linear conditions, thus facilitating the analysis of respiratory mechanics.\(^1\)

Newer modes of ventilation are available, combining the strengths of both techniques. These modes provide the benefits of a decelerating flow pattern with a warranted tidal volume. Therefore, peak inspiratory pressure is automatically adjusted to deliver a set tidal volume, in certain ranges. With changes in compliance being continuously determined, alveolar ventilation can be ensured at the lowest possible inspiratory pressure. To date, these modes appear to be the most effective for long-term ventilation of preterm and term neonates. The Volume Guarantee mode (most extensively studied; Dräger Medical, Germany) can significantly reduce death and bronchopulmonary dysplasia, pneumothoraces, hypocarbic, and periventricular leukomalacia as well as severe intraventricular hemorrhage compared with PCV.\(^2\) Modes of comparable functionality are also available for peroperative ventilation with modern AWS. Whereas evidence in regard to improved respiratory mechanics is quite convincing in adults undergoing elective surgery,\(^3\) the evidence is less good developed for ventilation during pediatric anesthesia.

From a biomechanical point of view, patients benefit from assisted spontaneous breathing using pressure support ventilation (PSV). During PSV, inspiratory pressure should at least compensate for the resistive pressure gradient of the artificial airways. As resistance depends nonlinearly on flow, the required compensation varies considerably between specific situations and even within a single breath. For example, in an infant, peak inspiratory flow can be as high as 300 mL/s. In this situation, an endotracheal tube of 4.5 mm inner diameter causes about 5 cmH\(_2\)O (Figure 1), the breathing system including connectors about 2 cmH\(_2\)O, and the breathing system filter about 0.5 cmH\(_2\)O of resistive pressure gradient.\(^4,5\)

Accordingly, an inspiratory pressure support of about 3–4 cmH\(_2\)O could compensate for about 50% of the resistance of the artificial airways in this example. Caution is required in regard to trigger sensitivity. Artificial airway resistance counteracts the patient’s efforts to trigger the ventilator. The trigger threshold should therefore be set to achieve sufficient patient-ventilator synchrony (typically about 1 L/min). In case of severe patient-ventilator asynchrony (eg, coughing just before extubation), continuous positive airway pressure may be better suited than PSV to maintain positive airway pressure.

**FIGURE 1** Flow-dependent inspiratory pressure gradient across pediatric endotracheal tubes with an inner diameter (ID) from 2.0 to 6.0 mm. Please note that in the knowledge of the current flow rate (eg, 300 mL/s), the corresponding pressure gradient can be roughly estimated from the ordinate.
Achievement of sufficient alveolar minute ventilation (MV) is the key challenge when setting ventilator variables for pediatric patients. What sounds as simple as just combining two basic variables, VT and respiratory rate, turns out to be difficult in daily practice. The smaller the children, the higher the proportional need for alveolar ventilation. High oxygen consumption, low oxygen diffusion capacity, and low functional residual capacity cause a disproportionally high demand on MV. The need for alveolar ventilation is opposed by the high resistance of the respiratory system, limiting volume exchange with an increased turnover (ie, flow). Postnatally, lungs grow faster than the airways, which accounts for the disproportional high resistance of the respiratory system (Rrs). Above that, the ratio of dead space to VT further complicates sufficient gas exchange. Fortunately, the weight-adjusted amount of anatomical dead space remains relatively stable with growing up.

In the past decades, evidence accumulated in regard to low tidal volume diminishing the risk of ventilator-induced lung injury in adults. The observed benefits in outcome encouraged clinicians and researchers to apply these concepts to perioperatively ventilated lung healthy patients as well. Today, it is widely accepted that tidal volume between 6 and 8 ml per kg ideal body weight (IBW) can reduce the risk of postoperative pulmonary complications (PPCs), as part of a bundle of measures referring to so-called lung-protective ventilation. In this context, it has turned out that the risk for PPCs depends on several factors referring to patients’ characteristics, co-morbidities and type of surgery, for example.

Such evidence is scarce in pediatric patients. Kneyber et al. analyzing evidence in this regard in 2015 is worth reading. The authors conclude that settings of pediatric ventilation are hardly supported by any scientific evidence, and therefore, VT should be close to the physiological range (5–8 ml/kg IBW). Nevertheless, in 2017, the Paediatric Mechanical Ventilation Consensus Conference (PEMVECC) published recommendations for mechanical ventilation of critically ill children, in which it is stated that VT should set below 10 ml/kg IBW. This value should also be reflected in the light of potential sources or error. First, volume measurement in the AWS includes a certain tolerance which may lead to a relevant error, particularly at very small VT; second, between-subject variability of functional characteristics of the respiratory system can be of considerable extent in children. In a 5-year-old child, forced vital capacity (FVC) is considered “normal” within a range of 70%–130% of the predicted value. This range decreases until the age of 15 year, but then still amounts to 80%–120%; third, calculation of IBW in children lacks evidence, if clinically performed at all. The given VT landmarks assume calibration to the patient’s individual

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**Figure 2** Computer-generated simulation of pressure-controlled ventilation curves at constant respiratory rate and inspiratory pressure but different inspiratory to expiratory (I:E) ratios. Airway pressure curve (orange) is superimposed by tracheal pressure curve (blue; upper panel). Please note, that tracheal pressure does not reach airway pressure (set at the ventilator) closely at the end of inspiration at an I:E ratio of 1:2 (middle row). Consecutively, the inspired tidal volume is lower than that at an I:E ratio of 1:1 (left row), at respective inspiratory airway pressures. On the contrary, at an I:E ratio of 2:1 (right row), tracheal pressure does not reach airway pressure at the end of expiration. Consecutively, the expired volume is lower than the inspired volume, indicating dynamic hyperinflation of the lungs and followed by a lower tidal volume with the subsequent breaths.
total lung capacity. Height, and therefore IBW, is accepted as a rough surrogate for TLC. Studies comparing methods of calculating IBW, however, suggest that actual body weight and IBW can differ considerably in children. Calculation of IBW should therefore be limited to children above the age of 2 years. Although there is no gold standard equation for calculating IBW in children, Ward et al. found the McLaren-Read method fits, in children with PARDS between the age of 2 and 10 years, and particularly in children above the age of 10 years, where discrepancies between different calculation methods were most distinct. The authors conclude that the McLaren-Read method is relatively easy to calculate using readily available growth charts that compare weight and height in relation to a child’s age. The modern AWS may be suited to calculate such complex algorithms and display age-adjusted IBW, in order to increase precision.

Setting appropriate VT in preterm and term neonates requires special attention due to the vulnerability for respiratory distress syndrome. In healthy neonates, the average tidal volume is 4–6 ml/kg with a minute ventilation aiming at 0.2–0.3 L/min/kg

When considering opening of the lung, one has to distinguish between two phenomena, intratidal recruitment/derecruitment, and atelectasis. While the first describes the repetitive opening and closing of alveolar tissue, the second refers to more or less consolidated alveolar collapse and thus shunt region, not contributing to gas exchange.

By far, most children develop atelectasis during induction of anesthesia. Lung recruitment maneuvers are supposed to reverse the alveolar collapse. However, due to the usually high intrathoracic pressure recruitment, maneuvers may impair hemodynamics. In adults, peak inspiratory pressure about 40 cmH$_2$O (and about 50 cmH$_2$O in obese) is considered effective, whereas the inspiratory airway pressures applied in children can be lower. Reasoned by the high elasticity of the pediatric thorax, intrapulmonary pressure is distributed in a higher fraction to transpulmonary pressure and a smaller one to transthoracic pressure, compared with adults.

In children aged 6 months to 7 years, increasing PEEP to reach an inspiratory pressure of 30 cmH$_2$O during PCV (Figure 3) effectively prevented atelectasis in the majority of patients during laparoscopic surgery. In the 47 patients enrolled, no relevant hemodynamic events were observed. Even a peak inspiratory pressure of 22 cmH$_2$O (10 cmH$_2$O PEEP + 12 cmH$_2$O driving pressure) was effective, when applied in opposing lateral body positions (90 seconds each side).

 Successful lung recruitment may be detected from imaging, analysis of respiratory system mechanics, or from reduction in anatomical

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**FIGURE 3** Schematic illustration of the course of airway pressure during a lung recruitment maneuver as applied in the study of Acosta and colleagues in 42 lung healthy children aged 6 months to 7 years, before capnoperitoneum. During pressure-controlled ventilation, driving pressure was increased to 15 cmH$_2$O, and then, PEEP was increased to 10 cmH$_2$O and consecutively 15 cmH$_2$O, each condition applied for 3 consecutive breaths. At PEEP 15 cmH$_2$O and driving pressure 15 cmH$_2$O, 10 breaths were applied with the effectiveness of the maneuver controlled via lung ultrasound.
Configure the breathing circuit including all elements (hoses, sensors, HME, filter).

- perform system test of the AWS
- determine IBW (e.g., from growth chart)
- set appropriate alarm limits

**Is spontaneous breathing possible?**

- No
- Yes

### Ventilation mode

- Leak expected?
- One-lung ventilation?
- Dynamic hyperinflation?

(following if available)

**Volume-targeted Ventilation**

- PCV
- VCV
- PSV

### Minute ventilation

- set $P_{\text{insp}}$
- set $V_t$, 6-9 ml/kg IBW$^6, 7$
- set respiratory rate to achieve target etCO$_2$$^5$
- set I:E ratio according to the expiratory time required

### Lung recruitment

- perform lung recruitment manoeuvre (Figure 3)$^1$
- set PEEP (5-9 cmH$_2$O)$^4$
- re-evaluate $V_t$ (≤ 9 ml/kg IBW) and etCO$_2$

- adjust $P_{\text{insp}}$
- adjust $V_t$
- adjust support

### Breathing gas

- adjust FiO$_2$ to achieve SpO$_2$ 95-99% (neonates 85-95%)$^6, 27$

- if SpO$_2$ 100%, decrease FiO$_2$ intermittently to avoid hyperoxia

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**FIGURE 4** Flowchart to setting up the ventilator for pediatric ventilation in the operative setting. Please consider that the suggested task sequence depends on the clinical circumstances and may have to be adapted. Particularly during controlled ventilation, derecruitment of the lungs will take place time-dependently and after loss of positive airway pressure in the breathing circuit (e.g., disconnection). Therefore, lung recruitment procedures need to be repeated and ventilator settings should be adjusted thereafter. *During pressure support ventilation (PSV), inspiratory pressure support should be adjusted to compensate for the resistance of the artificial airways; †Optimal end-tidal CO$_2$ may be within physiological ranges (35-45 mmHg)$^27$ with permissive hypercapnia being accepted in preterms and neonates (45-55 mmHg)$^13$; ‡Caution is required in regard to hemodynamic stability during lung recruitment maneuvers; ‡Positive end-expiratory pressure (PEEP) can be set empirically or guided on respiratory mechanics as described; IBW: ideal body weight; PCV: pressure-controlled ventilation; VCV: volume-controlled ventilation; $P_{\text{insp}}$: inspiratory airway pressure; $V_t$: tidal volume; I:E: inspiratory to expiratory ratio; FiO$_2$: fraction of inspired oxygen; SpO$_2$: oxygen saturation
dead space. $C_{RS}$ increases, and with a valid capnography in place, the Bohr equation allows an approximation of the dead space reduction, correlating to an improved lung aeration (Equation 1).

$$VD = VT \times \frac{PaCO_{2} - PendexpCO_{2}}{PaCO_{2}} \quad (1)$$

Lung recruitment maneuvers appear to be effective for resolving acute atelectasis, for example, due to anesthesia induction or after disconnection of the breathing system. However, during ongoing mechanical ventilation, a study from our group found no persistent effects of recruitment maneuvers on compliance or the recruitment status of the lung. In order to make the effects of a recruitment maneuver more sustainable, an appropriate level of PEEP should be applied thereafter.

While the use of low tidal volumes is widely accepted, the problem of setting optimal PEEP is still unsolved, particularly in pediatric patients. PEEP is supposed to splint the airways and thus to prevent collapse and reopening of the alveoli. When considering the physiological basis of PEEP setting, it has to be considered that closing volume in infants is higher than functional residual capacity.

In our studies, we found that intratidal recruitment/derecruitment was more often present in younger compared with older children and that recruitment maneuvers did not show any persisting effects in one of our studies. Particularly, moderately increased levels of PEEP up to 7 cmH$_2$O did not significantly resolve intratidal recruitment/derecruitment, in contrast to adult patients. This points to a physiological nonrecruitability as a characteristic of the developing lung and may therefore not necessarily be detrimental. This is supported by an early study which suggests that occurrence of terminal airway closure occurs during normal breathing in younger children.

In the absence of outcome-related evidence for PEEP strategies, it appears reasonable to make the adjustment of PEEP based on physiological considerations. Since imaging techniques and complex analyses of respiratory system mechanics are not available in a regular clinical setting, PEEP variation maneuvers may be used to find optimal PEEP. Minimizing driving pressure is currently discussed as target for guiding ventilation setting, though this measure itself is not accessible as control variable of mechanical ventilation. Driving pressure results from the division of tidal volume by compliance. Consequently, PEEP may be set with the intention to improve compliance. A method proved valid in this regard is setting PEEP following a decremental PEEP trial. For this, a maximum PEEP is set and reduced stepwise. If compliance decreases significantly with a certain PEEP step, PEEP is set back to the preceding value. This way, the highest compliance is achieved. As a consequence, during VCV, the lowest driving pressure would result in a certain tidal volume, and during PCV, the highest tidal volume would result in a certain pressure amplitude, which may then allow for reducing peak inspiratory pressure.

## 5 | COMPOSING THE BREATHING GAS TO THE ACTUAL NEED

Setting situation appropriate fraction of inspired oxygen (FiO$_2$) is a challenging task. It requires careful consideration of the patient’s actual need, a safety reserve for what is to come, and possible side effects of oxygen. The oxygen consumption of spontaneously breathing children under the age of 3 years depends on body surface area and heart rate, thereby increasing from about 130 to 190 ml/(min · m$^2$) with age. In children aged 3 years and older, the oxygen consumption again slightly decreases to about 160 ml/(min · m$^2$) with gender being a significant factor as well.

It is well known that due to the high demand but relatively low FRC, the pulmonary oxygen reservoir lasts only a few seconds at sufficient pulmonary perfusion. However, high oxygen concentrations are potentially harmful in patients of all ages, causing negative effects such as lung capillary damage, myocardial infarction, and oxidative stress. Above that, it should be remembered that oxygen tension in the lungs directly affects pulmonary vascular resistance, which may be of relevance in patients with congenital heart disease. Particularly in preterm and term neonates, high oxygen concentrations can worsen retinopathy (due to its potential for neovascularization) and bronchopulmonary dysplasia.

During induction of anesthesia, high oxygen concentrations are generally considered in order to gain time in case of difficult airway management. The optimal FiO$_2$ is not known; however, high oxygen concentration (FiO$_2$ > 0.8) during induction and maintenance of anesthesia can decrease postoperative lung volume and promote ventilation inhomogeneity. If a child tolerates preoxygenation via spontaneous breathing through the breathing circuit, oxygenation can be considered sufficient if the end-expiratory fraction of oxygen is above 0.7 (with FiO$_2$ set at 0.8) or 0.9 (with FiO$_2$ set at 1.0), with the regular presentation of the capnography indicating reliable gas measurement. At oxygen concentration in that range, it is likely that resorption atelectasis will take place, which can, however, be effectively reversed by applying a lung recruitment maneuver and ventilation with PEEP thereafter.

As soon as the airway is secured, FiO$_2$ should be lowered to the minimal level required. Rather than recommending a global value, which is universally applicable, oxygen delivery should be monitored to guide titration of FiO$_2$. If available, arterial oxygen concentration (PaO$_2$) < 60 mmHg constitutes a landmark to increase oxygen concentration in the inspired gas (among other measures). More routinely, oxygen saturation (SpO$_2$) is available as a noninvasively measured surrogate parameter for oxygen concentration in the blood. SpO$_2$ values as low as 95% (approximately corresponding to a PaO$_2$ of 60–80 mmHg at normal pH, temperature, and carbon dioxide) can be accepted in the absence of lung disease. In the healthy neonate, prevultricular values for SpO$_2$ are generally accepted in the range of 85%–95%. In regard to the monitoring of high oxygen levels, however, SpO$_2$ measurement has its limitations as it cannot mirror alveolar oxygen delivery exceeding the need of fully saturated hemoglobin. It is therefore recommended to periodically reduce FiO$_2$ to evaluate the inspired oxygen concentration which is required to just reach sufficient oxygen saturation.
In order to maximize the benefits of the rebreathing system of the AWS, the fresh gas flow should be as low as possible. Minimal-flow anesthesia (<0.5 L/min) mainly bears the advantages of an economic and ecological use of volatile agents. The meaning in regard to climatization (heating (>28°C) and humidification (17 and 30 mg H2O/L)) of the circulating air has declined with the introduction of heat and moisture exchangers. At minimal-flow anesthesia with a FiO2 titrated to the minimal oxygen delivery required, caution of heat and moisture exchangers. At minimal-flow anesthesia

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REFERENCES

1. Terragni PP, Rosboch GL, Lisi A, Viale AG, Ranieri VM. How respiratory system mechanics may help in minimising ventilator-induced lung injury in ARDS patients. Eur Respir J Suppl. 2003;42:15s-21s.

2. Wheeler KI, Klingenbeck C, Morley CJ, Davis PG. Volume-targeted versus pressure-limited ventilation for preterm infants: a systematic review and meta-analysis. Neonatology. 2011;100(3):219-227. 10.1159/000326080

3. Schick V, Dusse F, Eckardt R, et al. Comparison of volume-guaranteed or-targeted, pressure-controlled ventilation with volume-controlled ventilation during elective surgery: a systematic review and meta-analysis. J Clin Med. 2021;10(6):1276. 10.3390/jcm10061276

4. Spaeth J, Steinmann D, Kaltofen H, Guttmann J, Schumann S. The pressure drop across the endotracheal tube in mechanically ventilated pediatric patients. Paediatr Anaesth. 2015;25(4):413-420. 10.1111/pan.12595

5. Wenzel C, Schumann S, Spaeth J. Pressure-flow characteristics of breathing systems and their components for pediatric and adult patients. Paediatr Anaesth. 2018;28(1):37-45. 10.1111/pan.13284

6. Kneyer MC. Intraoperative mechanical ventilation for the pediatric patient. Best Pract Res Clin Anaesthesiol. 2015;29(3):371-379. 10.1016/j.bpa.2015.10.001

7. Kneyer MCJ, de Luca D, Calderini E, et al. Recommendations for mechanical ventilation of critically ill children from the paediatric mechanical ventilation consensus conference (PEMVECC). Intensive Care Med. 2017;43(12):1764-1780. 10.1007/s00134-017-4920-z

8. Smallwood CD, Davis MD. Year in review 2018: pediatric mechanical ventilation. Respir Care. 2019;64(7):855-863. 10.4187/respcare.07029

9. Bilharz JR, Wheeler CR, Walsh BK, Smallwood CD. A comparative analysis of ideal body weight methods for pediatric mechanical ventilation. Respir Care. 2018;63(9):1079-1084. 10.4187/respcare.06021

10. Ward SL, Quinn CM, Steurer MA, Liu KD, Flori HR, Matthay MA. Variability in pediatric ideal body weight calculation: implications for lung-protective mechanical ventilation strategies in pediatric acute respiratory distress syndrome. Pediatr Crit Care Med. 2018;19(12):e643-e652. 10.1097/PCC.0000000000001740

11. Chakkarapani AA, Adappa R, Mohammad Ali SK, et al. “Current concepts of mechanical ventilation in neonates” - part 1: basics. Int J Pediatr Adolesc Med. 2020;7(1):13-18. 10.1016/j.ijpam.2020.03.003

12. Feldman JM. Optimal ventilation of the anesthetized pediatric patient. Anesth Analg. 2015;120(1):165-175. 10.1213/ANE.000000000000472

13. Neumann RP, von Ungern-Sternberg BS. The neonatal lung physiology and ventilation. Paediatr Anaesth. 2014;24(1):10-21. 10.1111/pan.12280

14. Gattinoni L, Tonetti T, Cressoni M, et al. Ventilator-related causes of lung injury: the mechanical factor. Intensive Care Med. 2016;42(10):1567-1575. 10.1007/s00134-016-4505-2

15. Acosta CM, Sara T, Carpinella M, et al. Lung recruitment prevents collapse during laparoscopy in children. Eur J Anaesthesiol. 2018;35(8):573-580. 10.1097/EJA.0000000000000761

16. Acosta CM, Volpicelli G, Rudzik N, et al. Feasibility of postural lung recruitment maneuver in children: a randomized, controlled study. Ultrasounds. 2020;12(1):34. 10.1186/s13089-020-00181-8

17. Wirth S, Artner L, Broß T, Lozano-Zahnenero S, Spaeth J, Schumann S. Intratidal recruitment/derecruitment persists at low and moderate positive end-expiratory pressure in paediatric patients. Respir Physiol Neurobiol. 2016;127(3-4):9-13. 10.1016/j.resp.2016.08.008

18. Schumann S, Feth A, Borgmann S, Wirth S. Dependency of respiratory system mechanics on positive end-expiratory pressure and recruitment maneuvers in lung healthy pediatric patients-A randomized crossover study. Paediatr Anaesth. 2020;30(8):905-911. 10.1111/pan.13927
19. Mansell A, Bryan C, Levison H. Airway closure in children. J Appl Physiol. 1972;33(6):711-714. 10.1152/jappl.1972.33.6.711
20. Neto AS, Hemmes SN, Barbas CS, et al. Association between driving pressure and development of postoperative pulmonary complications in patients undergoing mechanical ventilation for general anaesthesia: a meta-analysis of individual patient data. Lancet Respir Med. 2016;4(4):272-280. 10.1016/S2213-2600(16)00057-6
21. Amato MB, 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. 10.1056/NEJMsa1410639
22. Ferrando C, Suarez-Sipmann F, Tusman G, et al. Open lung approach versus standard protective strategies: effects on driving pressure and ventilatory efficiency during anesthesia - A pilot, randomized controlled trial. PLoS One. 2017;12(5):e0177399. 10.1371/journal.pone.0177399
23. Lundell BP, Casas ML, Wallgren CG. Oxygen consumption in infants and children during heart catheterization. Pediatr Cardiol. 1996;17(4):207-213. 10.1007/BF02524795
24. Walsh BK, Smallwood CD. Pediatric oxygen therapy: a review and update. Respir Care. 2017;62(6):645-661. 10.4187/respcare.05245
25. Grandville B, Petak F, Albu G, Bayat S, Pichon I, Habre W. High inspired oxygen fraction impairs lung volume and ventilation heterogeneity in healthy children: a double-blind randomised controlled trial. Br J Anaesth. 2019;122(5):682-691. 10.1016/j.bja.2019.01.036
26. von Ungern-Sternberg BS, Regli A, Schibler A, Hammer J, Frei FJ, Erb TO. The impact of positive end-expiratory pressure on functional residual capacity and ventilation homogeneity impairment in anesthetized children exposed to high levels of inspired oxygen. Anesth Analg. 2007;104(6):1364-1368, table of contents. 10.1213/01.ane.0000261503.29619.9c
27. Keszler M. Mechanical ventilation strategies. Semin Fetal Neonatal Med. 2017;22(4):267-274. 10.1016/j.siny.2017.06.003
28. Nunn GB. Low-flow anaesthesia. continuing education in anaesthesia, critical care & pain. Br J Anaesth. 2008;8(1):1-4. 10.1093/bjaceaccp/mkm052
29. Humphreys S, Schibler A, von Ungern-Sternberg BS. Carbon dioxide monitoring in children-A narrative review of physiology, value, and pitfalls in clinical practice. Paediatr Anaesth. 2021;31(8):839-845. 10.1111/pan.14208

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