Società di Anestesia e Rianimazione Neonatale e Pediatrica Italiana
S.A.R.N.e P.I.

Paediatric Ventilation

Ins and outs

Anna Camporesi
Anestesia e Rianimazione Pediatrica
Ospedale dei Bambini Vittore Buzzi
Milano

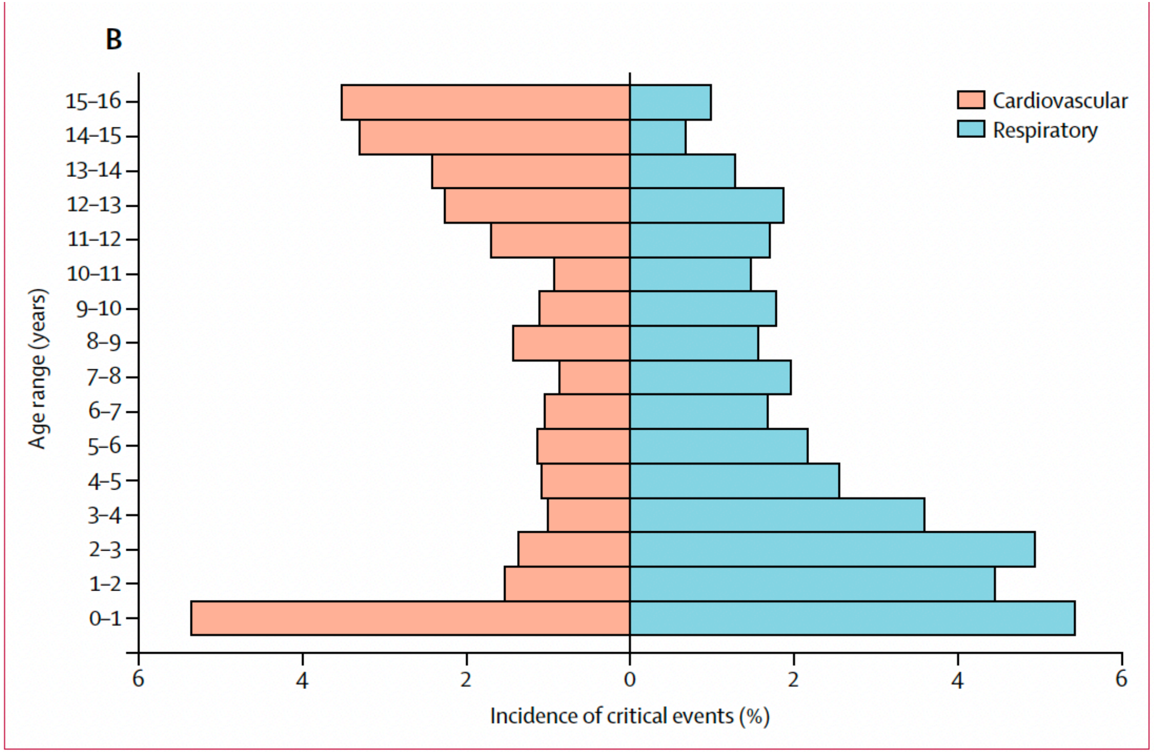
Sistema Socio Sanitario
OSPEDALE DEI BAMBINI Vittore Buzzi
Regione Lombardia
ASST Fatebenefratelli Sacco

Outline

Why are we talking of ped vent?

Developmental aspects of breathing
Developmental physiology
Ventilation during induction
Ventilation during maintenance
OLV

Critical adverse events

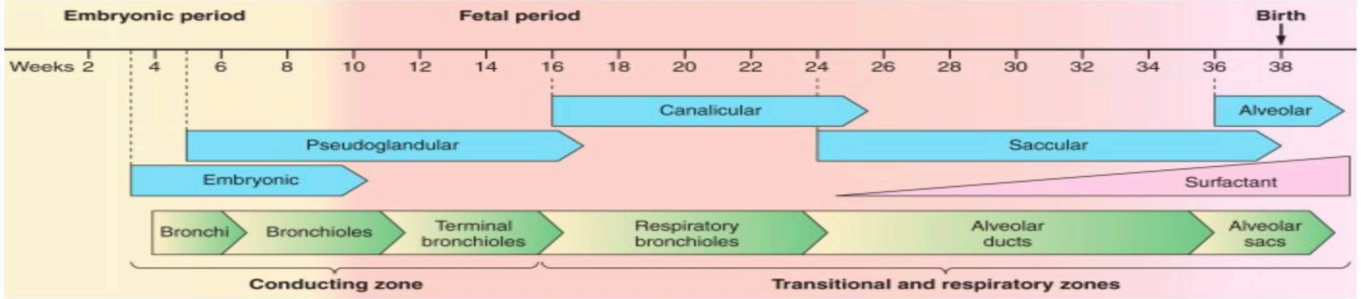


Incidence of severe critical events in paediatric anaesthesia (APRICOT): a prospective multicentre observational study in 261 hospitals in Europe

*Walid Habre, Nicola Disma, Katalin Virag, Karin Becke, Tom G Hansen, Martin Jöhr, Brigitte Leva, Neil S Morton, Petronella M Vermeulen, Marzena Zielinska, Krisztina Boda, Francis Veyckemans, for the APRICOT Group of the European Society of Anaesthesiology Clinical Trial Network**

Developmental aspects of breathing control

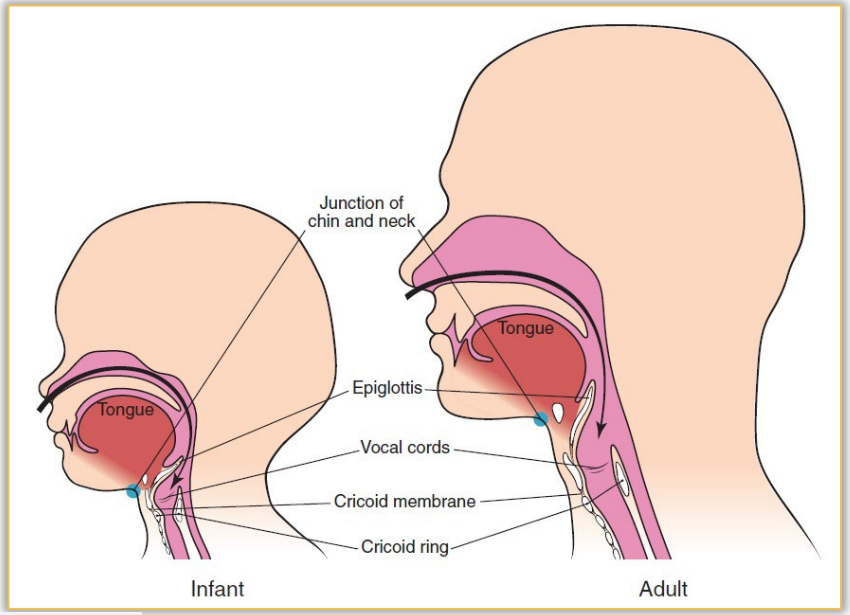
- Breathing starts in utero (end first trimester) and is influenced in utero by pCO2 and pO2
- At birth, minute ventilation at any pCO2 is *higher* in *neonates* and *infants* compared with adults
- Hypoxia leads to ventilatory depression up to 6 months of age
- Immature breathing control manifests as apneas



Developmental respiratory physiology

Daniel Trachsel[1] | Thomas O. Erb[2] | Jürg Hammer[1] | Britta S. von Ungern-Sternberg[3,4,5]

Small airways, big problems



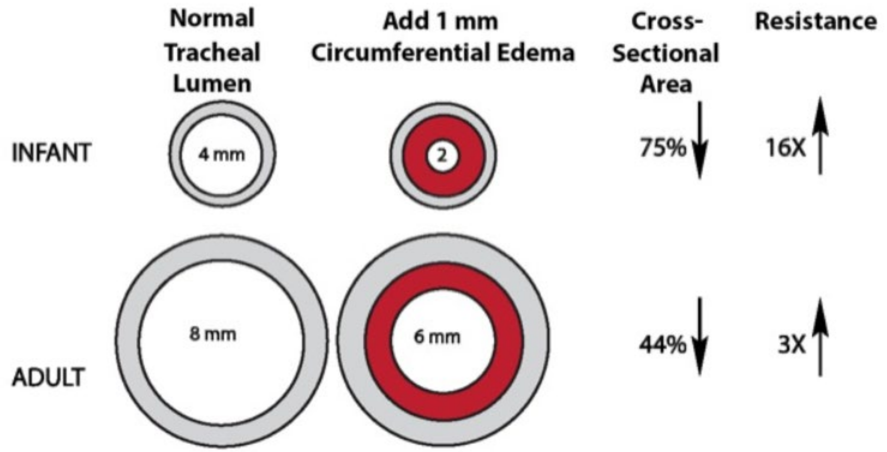
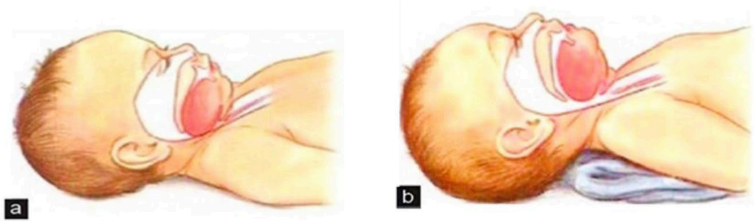


Figure 6.

Comparison of effects of 1-mm circumferential edema on the adult and infant airways.

Developmental physiology of airways

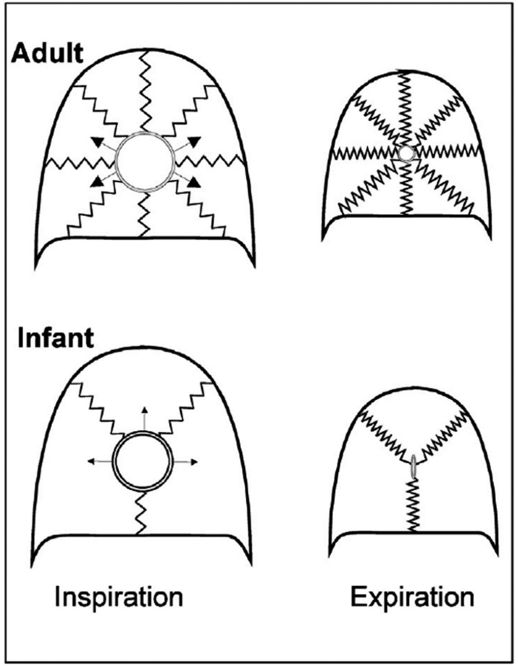
- Supraglottic airway small and soft
- The critical closing pressure of the pharynx during quiet, unimpeded inspiration is smaller both than the upstream, atmospheric pressure and the downstream pressure within the large airways (snoring)
- Obstructive apneas occur as a physiological phenomenon in normal young infants with up to 3 obstructive events/hour

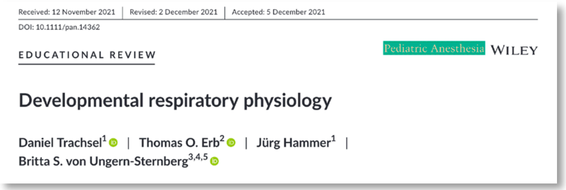


- Pharyngeal walls depend on muscles and head position
- Airways from larynx down are stabilized with cartilagineous scaffold

The fewer alveoli and interstitial septa of immature lungs offer considerably less suspension forces, such that forced expiration and coughing readily lead to peripheral airway collapse in babies.

During early childhood, continued alveolarization by the formation of new alveolar septa increases the fine interstitial network suspending collapsible airways

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EDUCATIONAL REVIEW

Pediatric Anesthesia WILEY

Developmental respiratory physiology

Daniel Trachsel[1] | Thomas O. Erb[2] | Jürg Hammer[1] | Britta S. von Ungern-Sternberg[3,4,5]

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Developmental physiology of chest wall and diaphragm

- Thoracic spine lengthens by 50% during the first 5 years
- Chest volume grows from an original 6% of its final volume at birth to 30% at 5 years and 50% of the final thoracic space at 10 years of age
- Chest wall stiffens in the first 2 years of age (acquisition of standing posture)
- There is a sternal downshift of the more horizontally positioned ribs of the infant into a slanting position in the older child

Developmental changes in Cw may also influence strategies of maintaining end-expiratory lung volume (EELV). In adults, EELV is determined by the balance of outward recoil of the relaxed chest wall and inward recoil of the lung. Young infants, on the other hand, dynamically maintain EELV above that volume determined by the passive mechanical properties of the system by employing laryngeal adductor and diaphragmatic activities to retard expiratory flow (14, 23, 25,

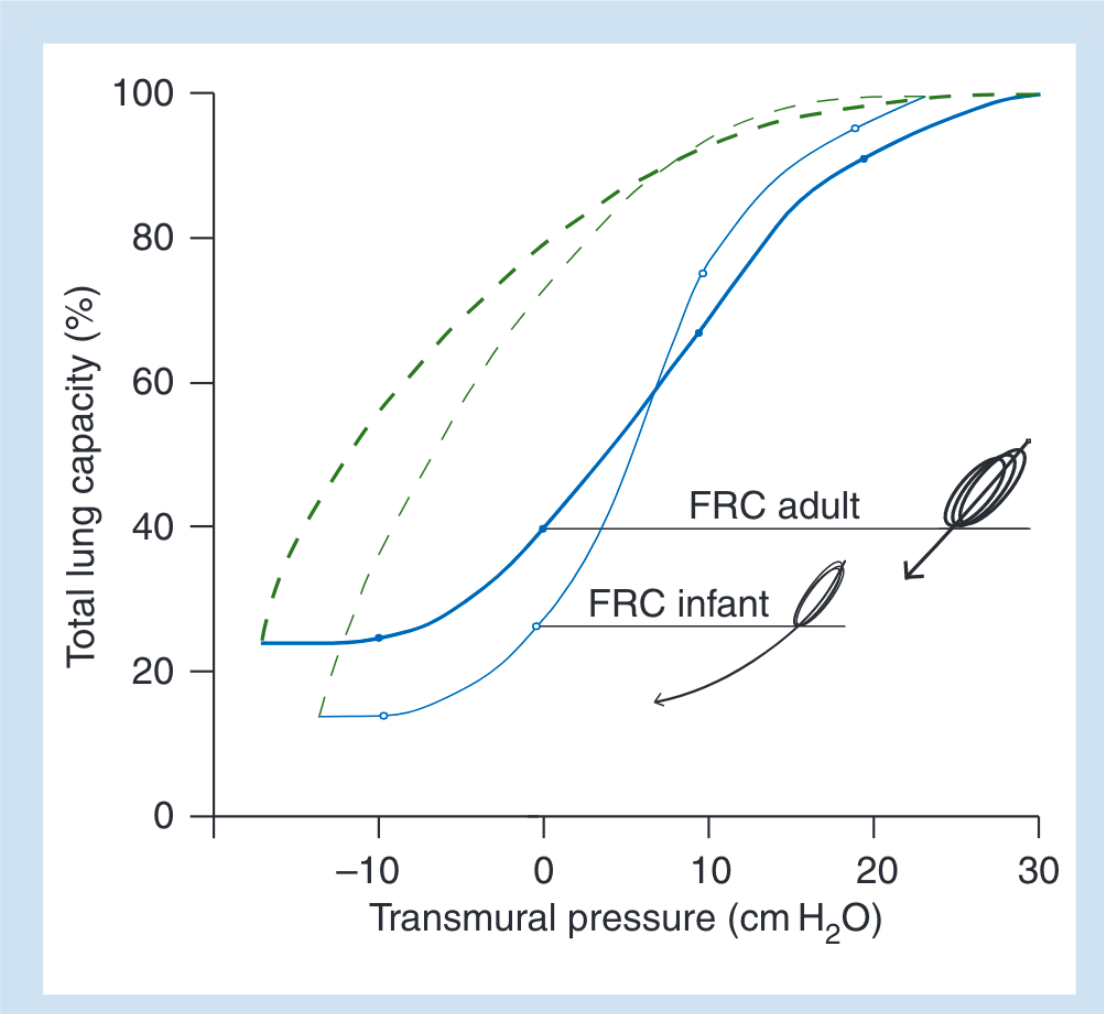
Developmental changes in chest wall compliance in infancy and early childhood

CAITLIN PAPASTAMELOS, HOWARD B. PANITCH, SANDRA E. ENGLAND, AND JULIAN L. ALLEN
St. Christopher's Hospital for Children, Department of Pediatrics, Temple University Medical School, Philadelphia, Pennsylvania 19143; and Department of Pediatrics, Robert Wood Johnson Medical School, New Brunswick, New Jersey 08901

- In the first year of life, **the chest wall is nearly three times as compliant as the lung**
- The compliant chest wall offers less resistance to the lung's inward recoil.
- As this moves the lungs toward or below the closing volume, that is, the volume at which atelectasis ensues, the infant actively defends its FRC, mainly by **sustained tonic diaphragmatic** activity during the entire respiratory cycle.
- This is associated with an **increased work of breathing**.
- Any increase in respiratory frequency will increase dead space/tidal volume ratio

With growt

- Reducti   ght
- Lung co   ng height
- Specific   ted to the
  function   infancy and
  remains   rom up to 5
  years of
- FRC incr   0 mL in adults
- Pressure



Lung volumes

	Infants	Adults
FRC (ml/kg)	27-30	30-34
Residual volume	20	25-30
Tidal volume	6-8	5-7
Dead-space volume	2-2.5	2.2
Alveolar ventilation	100-150	60
V_A/FRC	4-5	1-2

V_A per unit of lung volume is higher than in adults:

→ higher metabolic rate (twice the adult), VO_2

→ smaller lung volume

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Reference values

	Infant	Child	Adult
Compliance	1.5–2.0 mL/cmH_2O/kg	2.5–3.0 mL/cmH_2O/kg	0.1 L/cmH_2O *note different units
Resistance	20–40 cmH_2O/L/s	20–40 cmH_2O/L/s *up to 2 years	1–2 cmH_2O/L/s
Functional residual capacity	20–25 mL/kg	20–25 mL/kg *up to 18 months	1.9–2.4 L *note different units
Tidal volume	4–8 mL/kg *preterm 3–5 mL/kg	4–8 mL/kg	6–8 mL/kg
Respiratory rate	20–60 breaths/min	20–30 breaths/min	12–20 breaths/min
Minute ventilation	240–480 mL/kg/min		5–8 L/min *note different units

GREGORY'S
PEDIATRIC ANESTHESIA
SIXTH EDITION

Mask ventilation

What to consider during induction

1. Upper airway obstruction:

Frequent problem due to child anatomy —> smaller airways, physiological tonsillar and adenoidal hypertrophy

Various head positions and maneuvers help maintain airway patency during induction

Young children are particularly susceptible

Watch out for gastric distension during bag ventilation —> best use APL valve with < 20 cmH2O

Mask ventilation

Table 1 Causes of unexpected face mask ventilation problems

Anatomical airway obstruction	Functional airway obstruction
Inadequate head positioning	Upper airway
Poor face mask technique	Inadequate anaesthesia
Large adenoids, tonsils, obesity	Laryngospasm
Foreign body, gastric content, blood	Opioid-induced glottic closure
	Lower airway
	Opioid-induced muscle rigidity
	Bronchospasm
	Alveolar collapse (apnoea, tracheal suctioning)
	Overinflated stomach

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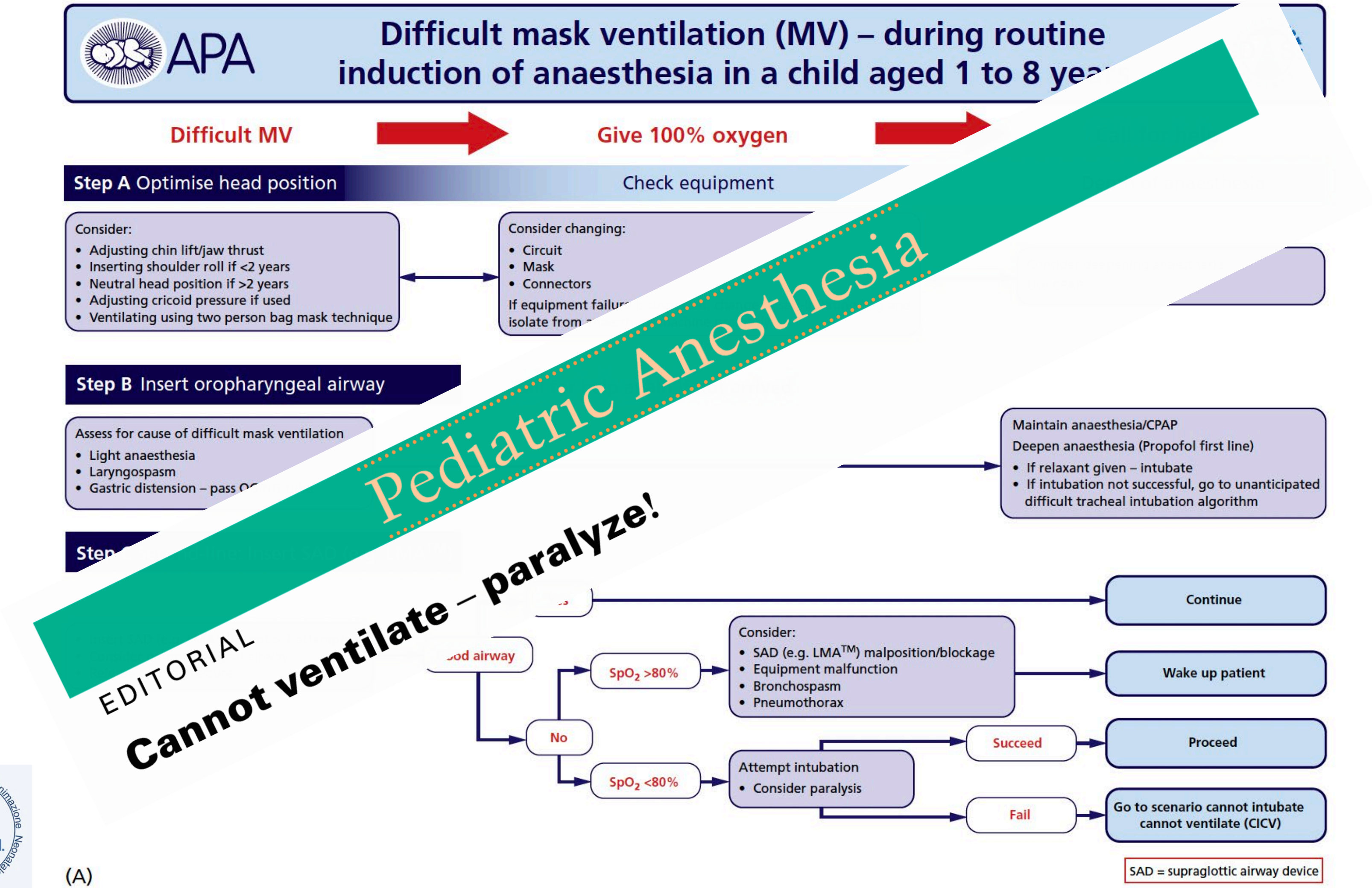

APA
Difficult mask ventilation (MV) – during routine
induction of anaesthesia in a child aged 1 to 8 yea
Difficult MV
Give 100% oxygen
Step A Optimise head position
Check equipment
Consider:
Adjusting chin lift/jaw thrust
Inserting shoulder roll if <2 years
Neutral head position if >2 years
Adjusting cricoid pressure if used
Ventilating using two person bag mask technique
Consider changing:
Circuit
Mask
Connectors
If equipment failur
isolate from
Step B Insert oropharyngeal airway
Assess for cause of difficult mask ventilation
Light anaesthesia
Laryngospasm
Gastric distension – pass OG
Maintain anaesthesia/CPAP
Deepen anaesthesia (Propofol first line)
If relaxant given – intubate
If intubation not successful, go to unanticipated difficult tracheal intubation algorithm
Continue
Consider:
SAD (e.g. LMA™) malposition/blockage
Equipment malfunction
Bronchospasm
Pneumothorax
Wake up patient
No
SpO2 >80%
SpO2 <80%
Attempt intubation
Consider paralysis
Succeed
Proceed
Fail
Go to scenario cannot intubate cannot ventilate (CICV)
SAD = supraglottic airway device
Pediatric Anesthesia
EDITORIAL
Cannot ventilate – paralyze!

(A)

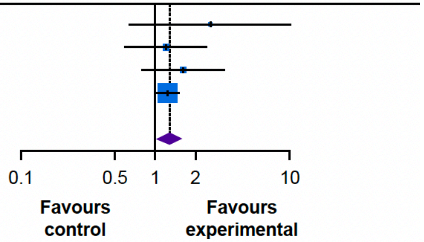
Mask ventilation

Apnoeic oxygenation

First-pass success rate

Study	Experimental Events	Experimental Total	Control Events	Control Total	Weight	Risk ratio MH, random, 95% CI
Bruckner and colleagues (2021)28	4	7	2	9	1.7%	2.6 [0.6–10.2]
Foran and colleagues [Preterm] (2023)30	8	15	8	18	6.7%	1.2 [0.6–2.4]
Foran and colleagues [Term] (2023)30	5	7	8	18	6.8%	1.6 [0.8–3.2]
Hodgson and colleagues (2022)33	85	124	69	124	84.8%	1.2 [1.0–1.5]
Total (95% CI)		**153**		**169**	**100.0%**	**1.3 [1.0–1.6]**

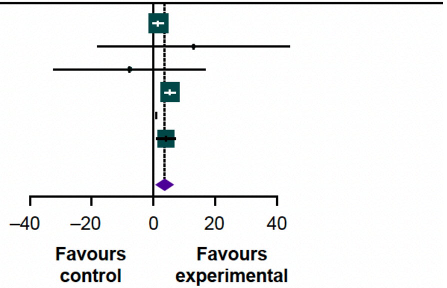
Heterogeneity: $Tau^2=0$; $\chi^2=1.56$, df=3 ($P=.67$); $I^2=0\%$
Test for overall effect: $t_3=3.56$ ($P=.04$)



Lowest Sp02 (%)

Study	Experimental Mean	Experimental SD	Experimental Total	Control Mean	Control SD	Control Total	Weight	Mean difference IV, random, 95% CI
Dias and colleagues (2017)29	97.6	2.9	47	95.9	5.8	48	34.8%	1.6 [–0.2–3.5]
Foran and colleagues [Preterm] (2023)30	57.3	35.6	15	44.3	50.0	15	0.5%	13.0 [–18.1–44.1]
Foran and colleagues [Term] (2023)30	75.3	28.2	7	83.0	20.8	10	0.9%	–7.7 [–32.2–16.9]
Gandhi and colleagues (2021)31	97.8	2.8	40	92.4	3.7	40	37.9%	5.3 [3.9–6.8]
Olayan and colleagues (2018)	100.0	0.0	15	99.0	1.5	15	0.0%	1.0
Hodgson and colleagues (2022)33	90.8	11.4	124	86.8	12.1	124	25.9%	4.0 [1.1–6.9]
Total (95% CI)			**248**			**252**	**100.0%**	**3.6 [0.8–6.4]**

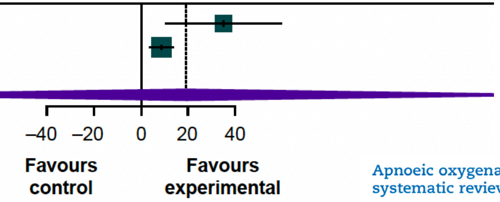
Heterogeneity: $Tau^2=3.1$; $\chi^2=10.87$, df=4 ($P=.03$); $I^2=63\%$
Test for overall effect: $t_4=3.6$ ($P=.02$)



Apnea times during paediatric tracheal intubation (s)

Study	Experimental Mean	Experimental SD	Experimental Total	Control Mean	Control SD	Control Total	Weight	Mean difference IV, random, 95% CI
Windpassinger and colleagues (2016)26	166	47	24	131	39	24	39.1%	35 [11–59]
Hodgson and colleagues (2022)33	44	20	124	36	20	124	60.9%	9 [4–14]
Total (95% CI)			**148**			**148**	**100.0%**	**19 [–143–102]**

Heterogeneity: $Tau^2=262.4$; $\chi^2=4.25$, df=1 ($P=.04$); $I^2=76\%$
Test for overall effect: $t_1=1.49$ ($P=.38$)



Apnoeic oxygenation during paediatric tracheal intubation: a systematic review and meta-analysis

Alexander Fuchs[1,2,*,†], Gabriela Koepp[1,†], Markus Huber[1], Jonas Aebli[1], Arash Afshari[3], Rachele Bonfiglio[2], Robert Greif[4,5], Andrea C. Lusardi[2], Carolina S. Romero[6], Marc von Gernler[7], Nicola Disma[2,‡] and Thomas Riva[1,‡]

Cuffed or uncuffed tubes?

- ✓ Historically, uncuffed tracheal tubes were preferred in children up to the approximate age of 8–10 years.
- ✓ The lack of a cuff allowed for a greater internal diameter, which translated into lower resistance and decreased work of breathing during spontaneous ventilation, and greater ease of suctioning secretions.

- ✓ There was also a concern for increased incidence of subglottic injury for cuffed tubes, that has been disporven with modern low-pressure cuffs

- ✓ The use of cuffed tubes in children is associated with a decreased incidence of postintubation stridor

Rapid sequence induction and intubation

RSII is often more challenging in pediatric patients when compared to adults because infants and small children have relatively higher oxygen consumption rates, reduced functional residual capacity (FRC), and elevated closing volumes, and thus will develop oxyhemoglobin desaturation more quickly during periods of apnea.

Many pediatric anesthesiologists perform a "modified" rapid-sequence induction

Gentle facemask ventilation is performed using low inflation pressures (<10–15 cmH2O) until enough time has elapsed for complete neuromuscular blockade to be established

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What to consider during induction

2. Respiratory drive loss:

Inhalational induction —> volatile anesthetics significantly suppress minute ventilation only at doses around and above 1 MAC

Intravenous induction with propofol —> difficult to predict effect on the respiratory drive even at low doses. At induction doses it invariably determines apnea

Propofol induces skeletal muscle relaxation by central inhibition of motor pathways and by sodium channel blockade in the muscular sarcolemma

What to consider during induction

3. Rapid hypoxemia

All anaesthetics (volatile and intravenous except ketamine) reduce respiratory muscle activity and tone, starting with the glossopharyngeal muscles, involving then the intercostal muscles and finally the diaphragm. This leads to a reduction in FRC and a lower tolerance to apneic periods.

Ventilation during maintenance

Pressure or Volume Controlled Ventilation?

1. VCV
2. PCV

From a historical perspective, pediatric anesthetists prefer pressure controlled ventilation (PCV) for the fear of high peak pressures in VCV

No data on outcomes are available for VCV against PCV

Ventilation during maintenance

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.

VCV can be an advantage in situations when changes in respiratory system compliance (CRS) are expected, for example, in case of capnoperitoneum or re-positioning.

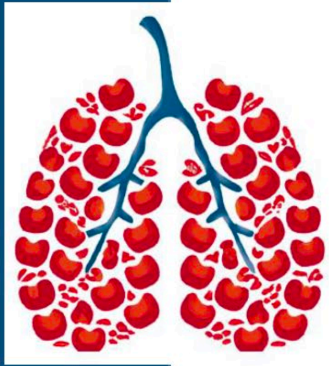
Ventilation during maintenance

- What about adaptive modes of ventilation such as PRVC?
- In theory combines the advantages of each without magnifying their disadvantages.
- Advantages:
  - Square pressure waveform favours early and sustained lung unit recruitment
  - Mean airway pressure is as high as with PCV
  - Pressure is minimised for any given prescribed tidal volume
  - A minute volume is guaranteed, preserving a degree of control over $PaCO_2$
- Disadvantages:
  - A variable patient effort may lead to a highly variable tidal volume

BIG APPLE study

Current Practice of Ventilation Strategies in Children undergoing General Anesthesia and Associations with Postoperative Pulmonary Complications

- a Multicenter Prospective Cohort Study -



Ventilation during maintenance

What ventilation parameters to choose?

1. Vt

No association between Vt and mortality was found when Vt was dichotomized at 7, 8, 10, or 12 mL/kg. A comparison of patients ventilated with Vt <7 mL/kg and >10 mL/kg or >12 mL/kg and Vt <8 mL/kg and >10 mL/kg or >12 mL/kg also showed no association between Vt and mortality.

Tidal Volume and Mortality in Mechanically Ventilated Children: A Systematic Review and Meta-Analysis of Observational Studies*

Pauline de Jager, MD[1]; Johannes G. M. Burgerhof, MSc[2]; Marc van Heerde, MD, PhD[3]; Marcel J. I. J. Albers, MD, PhD[4]; Dick G. Markhorst, MD, PhD[3]; Martin C. J. Kneyber, MD, PhD[1,3,5]

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Ventilation during maintenance

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)

Based on the available pediatric data, it may be argued that targeting a Vt between 6 and 10 mL/kg IBW is justifiable for pediatric ventilation but that Vt > 10 mL/kg should be avoided

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.

DOI: 10.1111/pan.14366

EDUCATIONAL REVIEW

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Understanding pediatric ventilation in the operative setting. Part II: Setting perioperative ventilation

Johannes Spaeth[1,2] | Stefan Schumann[1,2] | Susan Humphreys[3,4]

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Ventilation during maintenance

2.RR

The clinician may be encouraged to adjust RR toward a lower limit as high RRs can increase dead space.

Consideration of the time constant of the respiratory system (Tau = CRS · RRS) may be of help in this regard.

The setting of an appropriate inspiratory to expiratory ratio can be based on the expiratory flow profile.

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Ventilation during maintenance

3.PEEP

The optimal level of PEEP maintains tidal ventilation on the steep slope of the P/V curve and thus preserves FRC and respiratory system compliance without compromising the haemodynamic function

	ZEEP ($n = 30$)		PEEP 5 ($n = 30$)		*P* value
	MEDIAN	P25, P75	MEDIAN	P25, P75	
FiO_2	0.40	0.36, 0.50	0.40	0.36, 0.50	1.000
V_{TE}	6.79	6.18, 7.36	6.53	5.97, 7.20	0.290
RR	24	21, 26	24	21, 26	1.0
PIP	12	11, 14	15.5	14.0, 18.5	< 0.01
P_{PL}	7.9	7.2, 9.18	10.95	9.7, 12.6	< 0.01
Paw	4.1	3.6, 4.9	8.5	7.9, 9.8	< 0.01
Q_I	11	8.1, 13.1	11	8.1, 13.1	0.317
Q_E	13.8	11.8, 13.1	11.7	9.1, 13.5	< 0.01
RawI	25.7	18.6, 34.3	26.4	20.1, 33.1	0.447
RawE	28.9	21.9, 39.4	29.3	22.3, 42.1	0.629
C_{RS}	0.96	0.89, 1.22	1.19	0.94, 1.39	< 0.01
R_{IT}	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

RESEARCH ARTICLE Open Access

CrossMark

Positive end-expiratory pressure improves elastic working pressure in anesthetized children

Pablo Cruces[1,2], Sebastián González-Dambrauskas[3], Federico Cristiani[4], Javier Martínez[3], Ronnie Henderson[4], Benjamin Erranz[5] and Franco Díaz[5,6,7*]

Ventilation during maintenance

4. FiO2

The oxygen consumption of spontaneously breathing children under the age of 3 years depends on body surface area and heart rate: 130 to 190 ml/(min ·m2). In children > 3 years, the oxygen consumption slightly decreases to about 160 ml/(min ·m2) with gender being a significant factor as well.

While increasing FIO2 increases oxygen reserve and tolerance to hypoventilation, it also accelerates pulmonary derecruitment and masks worsening V/Q mismatch.

REVIEW ARTICLE

Effects of anaesthesia on paediatric lung function

D. Trachsel[1], J. Svendsen[2], T. O. Erb[3] and B. S. von Ungern-Sternberg[4,5,*]

DOI: 10.1111/pan.14366

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EDUCATIONAL REVIEW

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Ventilation during maintenance

Flow

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.

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Be careful!

Modern anesthesia machines have the capability to measure airway pressures, volumes, and flows using spirometry combined with pneumotachygraph technology; however, in most cases these parameters are not measured at the patient airway but at some point proximal to all the connections of the circle breathing system. This configuration introduces the potential for significant error in measurement of pressures and tidal volumes, particularly in small patients weighing less than 5–10 kg with tidal volumes <100 mL, because of the compression volume of the circle system. In other words, the average plastic disposable circle system has a compliance volume loss of 1–3 mL per cmH2O of pressure during inspiration; as much as 60 mL tidal volume is delivered not to the patient but rather to the circle system.

Dead Space

$$V_{dphys} = V_{daw} + V_{dalv} + V_{dApp}$$

Dead space, when using a circle anesthesia circuit to provide conventional ventilation, is any portion of the breathing circuit or lungs where there is bidirectional gas flow without gas exchange.
In a healthy, intubated infant ventilated using a circle anesthesia system, total dead space includes the volume in the circuit distal to the Y-piece, the tracheobronchial tree distal to the endotracheal tube, and any alveoli in Zone 1.

The clinical significance of increasing the dead space to tidal volume ratio (Vd/Vt) is an exponential increase in the PaCO2 as Vd/Vt increases, or an exponential increase in minute ventilation required to maintain a normal PaCO2.
Increased dead space also increases the gradient between endtidal and arterial carbon dioxide measurements such that endtidal CO2 monitoring is a less reliable predictor of PaCO2 as dead space increases

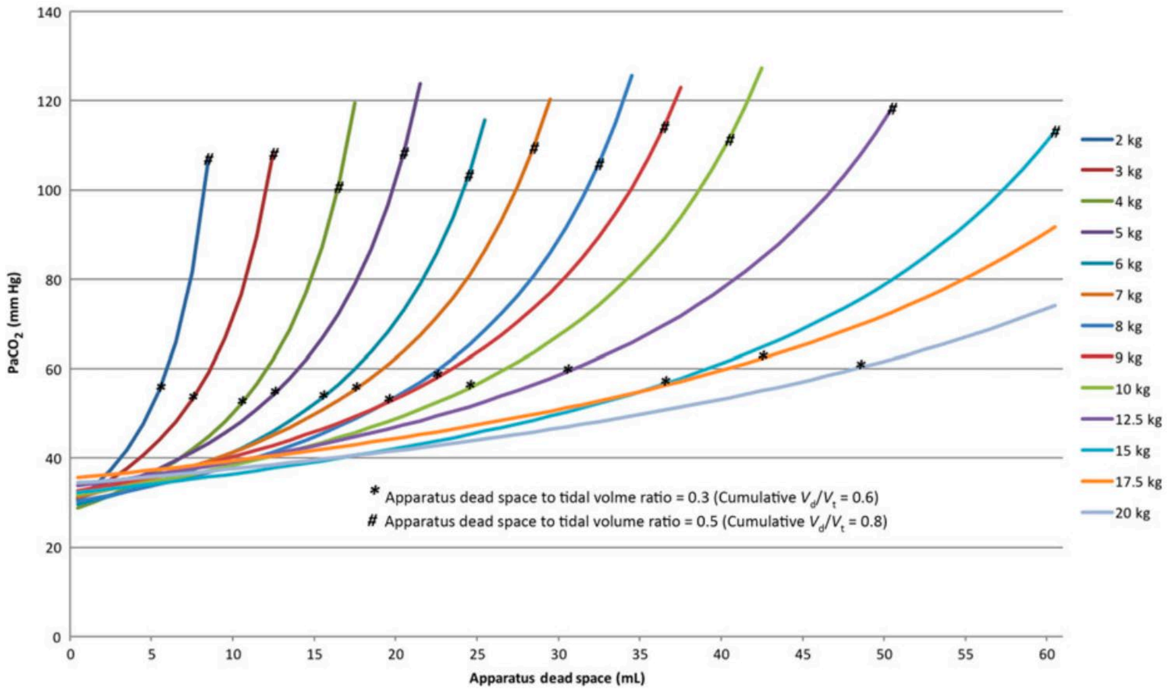
EDUCATIONAL REVIEW

WILEY Pediatric Anesthesia

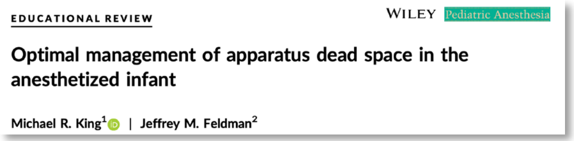
Optimal management of apparatus dead space in the anesthetized infant

Michael R. King[1] | Jeffrey M. Feldman[2]

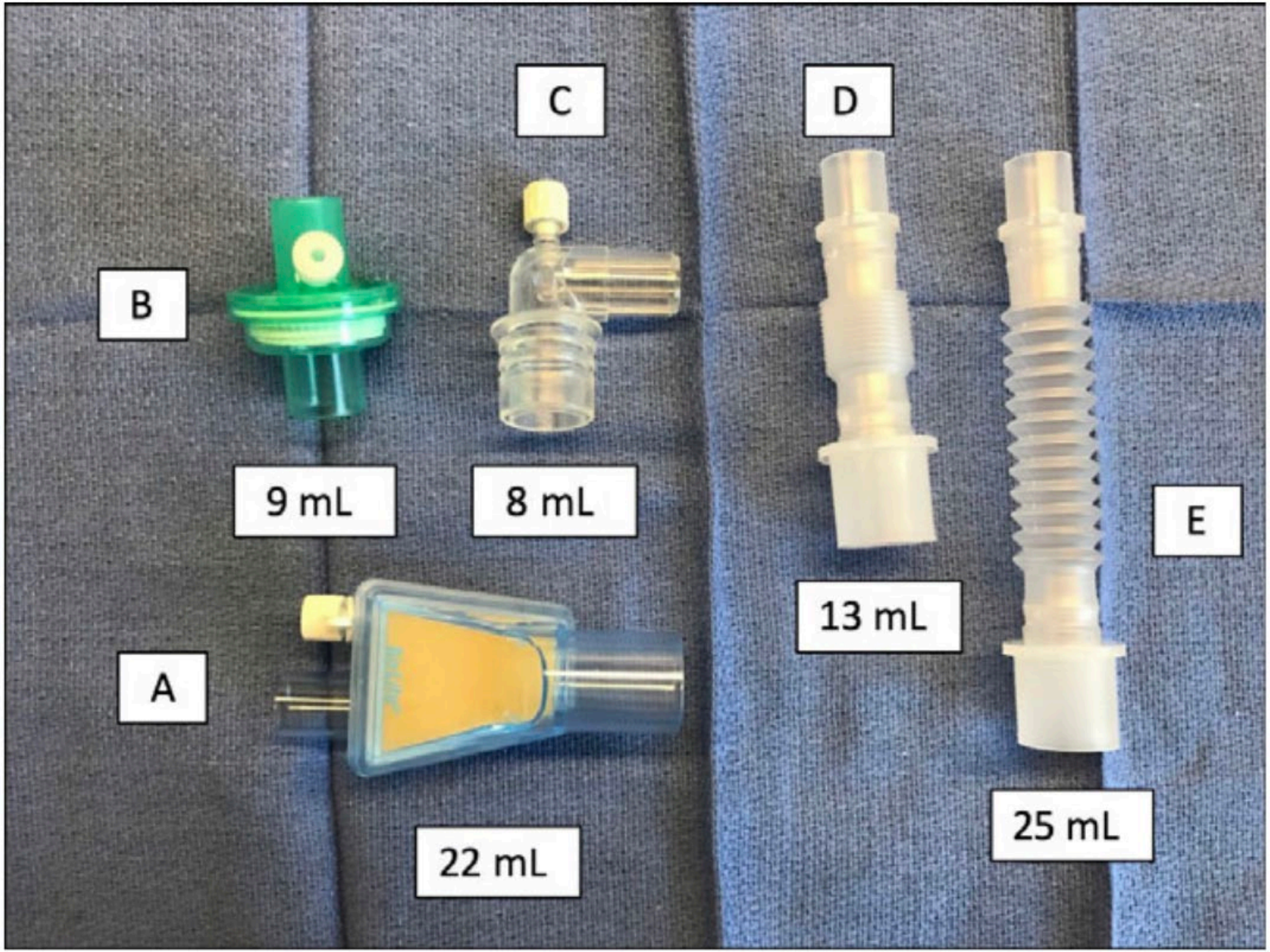
Dead Space



140
120
100
80
60
40
20
0
PaCO2 (mm Hg)
0
5
10
15
20
25
30
35
40
45
50
55
60
Apparatus dead space (mL)
* Apparatus dead space to tidal volme ratio = 0.3 (Cumulative Vd/Vt = 0.6)
# Apparatus dead space to tidal volume ratio = 0.5 (Cumulative Vd/Vt = 0.8)
2 kg
3 kg
4 kg
5 kg
6 kg
7 kg
8 kg
9 kg
10 kg
12.5 kg
15 kg
17.5 kg
20 kg



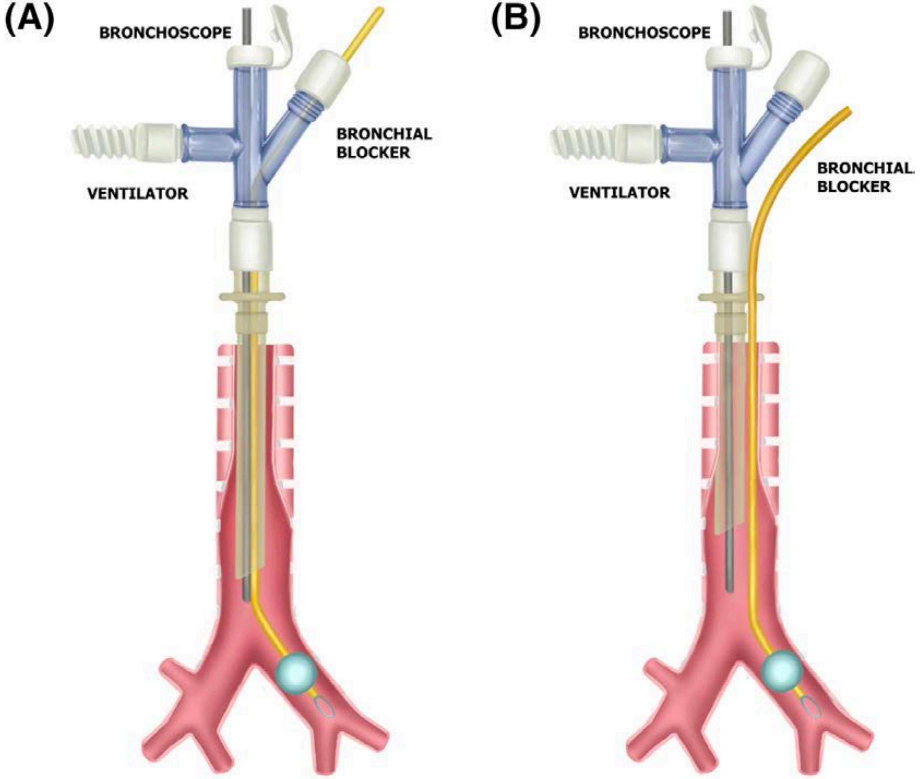
EDUCATIONAL REVIEW
WILEY Pediatric Anesthesia
Optimal management of apparatus dead space in the anesthetized infant
Michael R. King1 | Jeffrey M. Feldman2

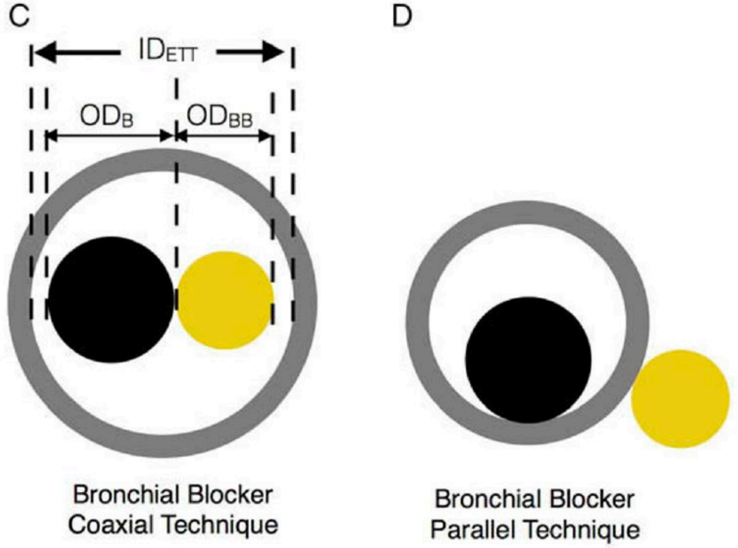

B
C
D
9 mL
8 mL
13 mL
E
A
22 mL
25 mL

Dead Space

- As a rule of thumb, if dead space is more than 1/3 of the TV, CO_2 will rise steeply
- Cutting the ET tube has been used for years but for a 3.5 ET a one-cm reduction avoids only 0.1 ml dead space
- Humidifiers are required

OLV in kids

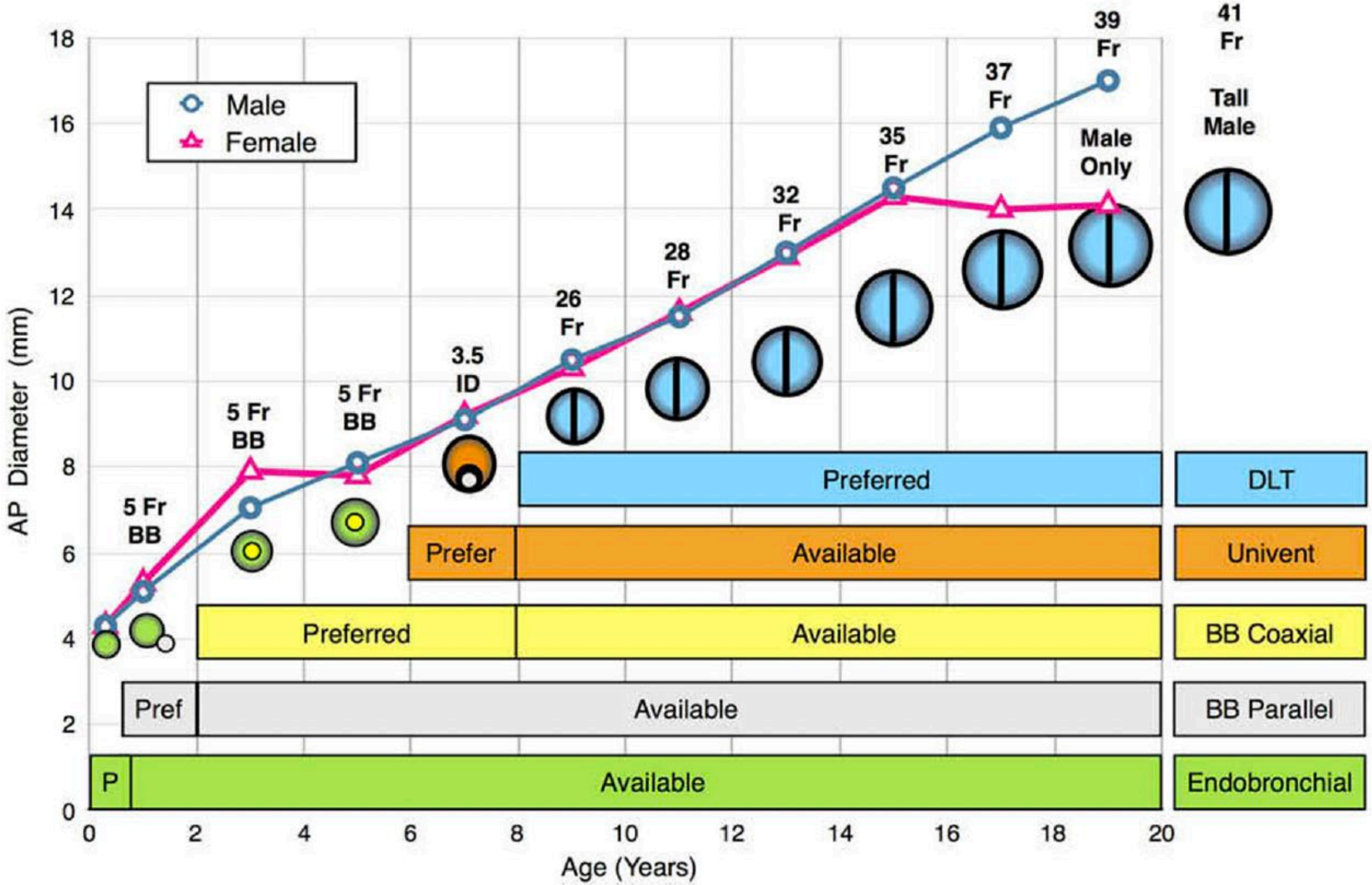




Fibroscope diameter/BB diameter/ET ID

- Fbs → consider OD
- ETT → consider ID

For efficacious pass: $OD_B/ID_{TT} < 0.9$
To have residual ventilation: $OD_B/ID_{TT} < 0.7$



Male
Female
AP Diameter (mm)
Age (Years)
5 Fr BB
5 Fr BB
5 Fr BB
3.5 ID
26 Fr
28 Fr
32 Fr
35 Fr
37 Fr
39 Fr
41 Fr
Male Only
Tall Male
Preferred
DLT
Prefer
Available
Univent
Preferred
Available
BB Coaxial
Pref
Available
BB Parallel
P
Available
Endobronchial

Bibliography

Thank you!