Current Anaesthesia & Critical Care 21 (2010) 262–268

Contents lists available at ScienceDirect

Current Anaesthesia & Critical Care

journal homepage: www.elsevier.com/locate/cacc

FOCUS ON: MECHANICAL VENTILATION IN THE OR

Ventilating the newborn and child

Javier Garcia-Fernandez [a,*], Luis Castro [a], F. Javier Belda [b,c]

[a] Paediatric Anaesthesiology and Postsurgical Critical Care Department, Hospital Universitario La Paz, Madrid, Spain
[b] Anaesthesiology and Critical Care Department, Hospital Clinico Universitario, Valencia, Spain
[c] School of Medicine, University of Valencia, Spain

Keywords:
Mechanical ventilation
Paediatric anaesthesia
Newborn ventilation
Paediatric ventilation
Paediatric critical care

SUMMARY

The mechanical ventilation of neonates and children in operating theatres has always posed a challenge for anaesthesiologists. Firstly, the extreme physiological features of neonatal lungs make them very difficult to ventilate with an anaesthesia ventilator. Gattinoni's "baby lung" concept to describe ARDS lungs in adults comes from the physiological features of neonatal lungs (low dynamic compliance, low pulmonary time constant, low FRC, high closing volume, proneness to atelectasis, high inspiratory airway resistance). Secondly, the performance and technology (peak flow, insufflation power, trigger sensitivity, ventilation modes, etc.) of anaesthesia ventilators is still less advanced than those of critical care ventilators. It is possible to ventilate a normal healthy adult lung with an anaesthesia ventilator, but even today, using circle circuits, ventilating a premature baby, newborn or child in the operating theatre can be a real challenge. Over the last 5 years, great changes have been made to anaesthesia workstations, which now boast better mechanical ventilation performance for children as well as new ventilation modes. However, there is a lack of background knowledge regarding mechanical ventilation in operating theatres, and this limits the advantages that can be derived from this new technology, and thus any potential safety improvements in paediatric surgery.

1. Introduction

Over the last decade, many new developments have been incorporated into anaesthesia ventilators and it is becoming an increasingly important to have ICU ventilator performance in the operating theatre. Precision in terms of tidal volumes and pressure delivery and optimisation of ventilation settings and assisted spontaneous breathing are all important considerations, especially in children, obese patients, patients with ARDS and other patients at risk of pulmonary complications.[1,2]

The healthy lungs of neonates are good physiological models for altered pulmonary states in adults. Neonates have a low functional residual capacity so they are prone to atelectasis during anaesthesia. They are therefore perfect models for recruitment manoeuvres, the prevention of atelectasis and how to set PEEP. The low lung compliance of neonates is a good model for how to ventilate patients with ALI/ARDS, and their high airway resistance provides a good model for the study of bronchospasm. Neonatal lungs are the hardest, most critical test for any anaesthesia ventilator if you wish to know how the ventilator is going to behave when faced with altered pulmonary states in adults. That is why even an adult anaesthetist who is never going to anaesthetise children must know which key points to take into account when using mechanical ventilation with circle circuits in paediatric anaesthesia, because this will give him advance knowledge of how the ventilator will perform with adults.[1–4]

In this paper, we will provide a short review of all the aspects involved in perioperative ventilation in paediatric patients, highlighting only those aspects that are specific to paediatric patients.

2. Applied respiratory physiology

The differences between the respiratory systems of paediatric and adult patients are inversely proportional to the age of the child, with the greatest differences seen in premature babies and newborns. From six years of age, the respiratory system becomes more and more similar to that of adults, both physiologically and physiopathologically. The main differences in the respiratory physiology of adults and children are summarised in Table 1.[1,2,5]

---

* Corresponding author. Hospital La Paz, Po de la Castellana 261, Servicio de Anestesiología y Cuidados Críticos H. Infantil, 28046-Madrid, Spain. Fax: +34 654 130 844.

E-mail address: ventilacionanestesiapediatrica@gmail.com (J. Garcia-Fernandez).

0953-7112/$ – see front matter © 2010 Elsevier Ltd. All rights reserved.
doi:10.1016/j.cacc.2010.07.014

Table 1

Respiratory physiology: main differences between neonates and adults: All of these features are crucial to increased patient safety during neonatal anaesthesia.

Applied physiology of newborn and child

1. Glottis – cephalad and anterior: most neonates present a difficult intubation.
2. High bronchial hyperreactivity during the first-two years: bronchospasm is more frequent.
3. Less functional residual capacity (FRC): proneness to atelectasis and less apneic oxygenation time.
4. High airway respiratory resistances: anaesthesia ventilators have problems ventilating the newborn.
5. Easier barotrauma: because pulmonary compliance is much less than thoracic compliance.
6. More sensitive to volutrauma: always use Vt 6 ml/kg.
7. Respiratory incident more frequent: apnea of prematurity, laryngospasm, etc.

2.1. Anatomical differences in the respiratory system

The main anatomical differences in the respiratory systems of newborns are: relative macrocephaly, macroglossia, anterior glottis, large curled epiglottis, problems with nasal ventilation and subglottic stenosis. These anatomical characteristics make newborns difficult to ventilate and intubate, and we must always be prepared for such difficulties.[1,5,6] Cormack-Lehane laryngoscopy grades of III and IV are to be expected, so we need to use the little finger of the left hand to move the glottis back so that the planes are aligned and we can see the chords.[1,7]

2.2. Mechanics of the respiratory system

Upon birth, neonates have to generate an exceedingly high negative pressure of up to (−) 80 cmH$_2$O to expand their lungs for the first time.[1,5–7] The main characteristic of neonatal lungs is their low functional residual capacity (FRC), which makes them more prone to lung collapse and atelectasis, as well as shorter periods of apneic oxygenation. This decreased FRC is due to the force of pulmonary elasticity that makes the lung collapse during expiration. The cartilaginous rib cage in newborns cannot impede lung collapse as effectively as the bony rib cage of the adult. Newborn FRC is very close to the critical alveolar closing volume; so neonatal lungs will collapse more and faster than adult lungs. Newborns use a physiological mechanism to prevent their lungs from collapsing, closing their vocal cords before the end of expiration, stopping the expiration process using the glottic closure and Hering-Breuer reflex. Furthermore, their high respiratory frequency (twice or thrice that of adults) means that expiratory time is much shorter than in adults.[1,5–8]

The end-expiratory lung volume (EELV) of newborns is higher than their FRC and closing volume, and this leads to auto-PEEP (2–3 cmH$_2$O) that keeps their lungs open during expiration, avoiding atelectasis (Table 2).[1,5–8]

Table 2

Pulmonary volumes: differences between neonates and adults: All values are expressed per kilo except anatomical deadspace because we want to emphasise how important it is to take into account the artificial deadspace that we add in newborn and small children.

Volumes (ml/kg)	Newborn	Adult	Difference
Functional residual capacity (FRC) (anaesthetized)	20–25	45	+80%
Tidal volume	6–7	7–9	+15%
Minute volume (ml/kg/min.)	200–250	100	−65%
Anatomical deadspace (total volume not per kilo)	(6–8 ml)	(120–180 ml)	

2.3. Respiratory time constants

The time that a neonatal lung takes to fill up and empty is determined by the inspiratory and expiratory time constants, which are much shorter in newborns than in adults. Neonatal lungs fill up and empty much more quickly than adult lungs (newborn Ti 0.4 s vs. adult Ti 1.5–1.8 s). Newborns usually have an I:E ratio of 1:1, while adults usually have an I:E ratio of 1:2.[1,6,8]

2.4. Oxygen consumption

Metabolic oxygen consumption in newborns is 2 or 3 times higher than in adults (5–6 ml/kg/min vs. 2–3 ml/kg/min). To cope with this higher demand for oxygen, newborns increase their respiratory minute volume by doubling or tripling respiratory frequency, but maintaining tidal volume constant at 6–7 ml/kg. The increased oxygen consumption results in a much shorter apneic oxygenation time in newborns than in adults (30 s vs. 3–4 min).[1,7]

2.5. Lung and thorax compliance

There are three types of lung compliance or distensibility: specific, static and dynamic. Specific lung compliance measures alveolar distension capacity due to the structure of their wall. This way, refers to the Compliance per unit of lung volume (ratio C/Total lung volume); this way Specific lung compliance remains constant throughout a person's lifetime, and in all mammals. However, during the first few hours of life, newborns have a diminished specific lung compliance, which normalizes when the pulmonary surfactant is properly distributed and all amniotic fluid is cleared from the alveoli.[6]

Static compliance, measured when the inspiratory flow has been interrupted for a certain period of time, describes alveolar distension in the absence of any influence from flow resistance. Static compliance is also diminished in newborns during the first few days of life, until the pulmonary surfactant is well distributed.[7,8]

Dynamic lung compliance (C_{dyn}) is an overall measurement of lung distension. C_{dyn} is very low in newborns ($<$4 ml/cmH$_2$O) in comparison to adults (50–80 ml/cmH$_2$O). C_{dyn} continues to be very low (1 ml/cmH$_2$O per kg of ideal body weight) until between 10 and 12 years of age (Fig. 1).[9]

Chest wall compliance (C_W) is very high in newborns (100 ml/cmH$_2$O), and is always higher than C_{dyn}. This difference between C_{dyn} and C_W means that newborns are very susceptible to direct barotrauma, as the chest wall will never stop lung distension. Another key difference in newborns is that their cartilaginous chest wall will never prevent the lungs from collapsing during the expiratory phase.[1,5]

2.6. Airway resistance

Airway resistance basically depends on the production of turbulent flows and the diameter of the airways through which the air flows. Although the required airflow for paediatric patients is always lower than that for adult patients, neonatal airways are very narrow, leading to turbulent airflow at various points (first three bronchial branches), causing an exponential increase in resistance.[10]

Inspiratory airway resistance is 7–10 times higher in newborns than in adults ($>$75 cmH$_2$O/l/s vs. 10–15 cmH$_2$O/l/s). In premature babies, inspiratory airway resistance can even exceed 150 cmH$_2$O/l/s.[6,9,10]

In a study we carried out on 60 children between 2 months and 14 years of age, inspiratory airway resistance was found to have an inversely exponential relationship with the weight and age of the child. Thus, the children under 2 years of age had an airway resistance of more than 40 cmH$_2$O/l/s in all cases, and the smallest patient in the sample group (2 months, 4 kg) had an airway resistance of 64 cmH$_2$O/l/s. Meanwhile, the children between 2 and 4