Handbook of Pediatric Anesthesia

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HANDBOOK of PEDIATRIC ANESTHESIA

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CONTENTS

Appendix

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PREFACE

The pediatric anesthesiology faculty at Columbia University Medical Center has put together this book as a guide to the practice of clinical anesthesia in neonates, infants, children, and adolescents. The authors are clinicians with considerable experience in the practice of pediatric anesthesiology. They are also teachers of pediatric anesthesiology. Their daily work includes the education and training of residents and fellows in pediatric anesthesiology in a major academic teaching hospital. This book is not "Pediatric Anesthesia for Dummies." Rather, the authors have organized it as a collection of common and important conditions in children. For each condition, the authors outline the pathophysiology, key perioperative considerations, and important management issues. We hope that residents and practicing physicians will find the book useful as they plan to provide anesthesia care for children.

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1 INTRODUCTION

Robert Kazim, MD

This introduction will highlight the key physiological, anatomical, and pharmacological concepts that novices in pediatric anesthesiology will find helpful for understanding current practice in this field.

THE INFANT AIRWAY

Seven anatomical features distinguish the infant airway from the adult.

1. The tongue is large in relation to the oral cavity, predisposing infants to airway obstruction and challenging intubation. Infants are obligate nasal breathers until 3-5 months of life. Obstruction of the anterior and/or posterior nares (secondary to nasal congestion, stenosis, or choanal atresia) may cause asphyxia.
2. The larynx is positioned higher in the neck (C3-C4) than in adults (C5-C6), allowing for simultaneous nasal breathing and swallowing.

   The larynx creates an acute angulation at the base of the tongue, creating the impression of an anterior larynx. Use of a straight laryngoscope blade to lift the base of the tongue and epiglottis, along with external laryngeal pressure, can aid in viewing the larynx during intubation.
3. The epiglottis is Ω-shaped and protrudes posteriorly over the larynx at a 45° angle; it may be difficult to lift during laryngoscopy.
4. The vocal cords attach anteriorly, which is more caudal and predisposes to catching the tip of the endotracheal tube in the anterior commissure during intubation.
5. The cricoid cartilage is conically shaped and is the narrowest portion of the upper airway (true for the first decade of life) (Fig. 1-1).

   Precise endotracheal tube sizing is critical to avoid cricoid edema and postintubation croup. A pressure leak should be no greater than 18-20 cm H_2O. Newer high-volume–low-pressure cuffed endotracheal tubes for infants avoid repeated laryngoscopies to determine the most appropriate endotracheal tube size.

   Given that resistance to airflow is inversely proportional to radius to the fourth power, a 1-mm reduction in airway diameter increases resistance to airflow by 16-fold in the infant airway.
6. The tonsils and adenoids are small in the neonate but reach maximal size in the first 4-5 years of age. Use of continuous positive pressure and/or an oral airway will commonly overcome this obstruction.

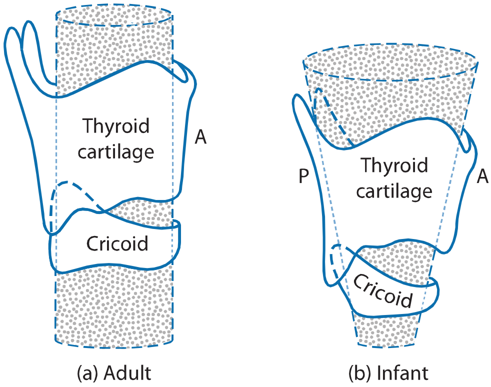

FIGURE 1-1 Schematic of an adult (a) and infant (b) airway. A, Anterior; P, Posterior. [Reprinted from Cote CJ, Todres ID. The pediatric airway. In: Ryan JF, Todres ID, Cote CJ, et al, eds. *A Practice of Anesthesia for Infants and Children*. Philadelphia, PA: WB Saunders; 1986:35-58, with permission from Elsevier.]

7. The occiput is large. When the infant is placed on a flat surface, extreme neck flexion will cause airway obstruction. A small roll placed behind the baby's shoulders will reduce neck flexion and aid in maintaining the airway.

PEDIATRIC RESPIRATORY PHYSIOLOGY

LOWER AIRWAY

The alveolar bed is incompletely developed at birth; mature alveoli are seen at 5 weeks of age, with alveolar multiplication with adult morphology being reached by 8 years of life (Table 1-1). Infant lung compliance is

TABLE 1-1 RESPIRATORY SYSTEM DEVELOPMENT

Age	
24 weeks gestation	Gas exchanging surface forms Surfactant production begins
Newborn	Decreased reserve because of: • Increased oxygen consumption • Decreased FRC
60 weeks postconception	Increased risk of postoperative apnea in premature infants until this age
8 years	Number of alveoli reach adult values
10 years	Fully muscular pulmonary arteries are seen at the alveolar duct level
19 years	Fully muscular pulmonary arteries are seen at the level of the alveoli

extremely high due to the absence of elastic fibers; it resembles the emphysematous lung. It is prone to airway collapse and premature airway closure secondary to low elastic recoil.

The cartilaginous rib cage and poorly developed intercostal muscles result in a highly compliant chest wall, leading to inefficient ventilation. The circular configuration of the rib cage (which is ellipsoid in adults) and the horizontally attached diaphragm (which is oblique in adults) lead to poor respiratory mechanics. The chest wall begins to stiffen at 6 months of age, improving the outward recoil of the chest wall.

The diaphragm has fewer Type I muscle fibers (sustained twitch, highly oxidative, and fatigue resistant) and is susceptible to fatigue. The adult diaphragm contains 55%, the neonate 25%, and the preterm only 10% Type I fibers.

LUNG VOLUMES

Functional residual capacity (FRC) in the spontaneously breathing infant is dynamically maintained at 40% of total lung capacity (similar to adults). See Table 1-2. The following mechanisms play a role in dynamically maintaining FRC in the *awake* infant:

- Termination of the expiratory phase before the lung volume reaches FRC, "auto-PEEP"
- Glottic closure during the expiratory phase (grunting), maintaining lung volumes
- Diaphragmatic braking: diminished diaphragmatic activity extending to the expiratory phase
- Tonic activity of the diaphragmatic and intercostal muscles, stiffening the chest wall and maintaining higher lung volumes

Dynamic control of FRC is abolished in the *anesthetized* child. Under apneic conditions, the FRC has been estimated to be reduced to 10% of total lung capacity. The reduced FRC results in reduced intrapulmonary oxygen reserve and rapid hypoxemia in the infant.

TABLE 1-2 AGE-DEPENDENT RESPIRATORY VALUES

	Neonate	Infant	Child/Adult
Tidal volume (mL/kg)	6-8	6-8	7-8
Respiratory frequency (bpm)	30-50	20-30	12-16
Minute ventilation (mL/kg/min)	200-260	175-185	80-100
Functional residual capacity (mL/kg)	22-25	25-30	30-45
Total lung capacity (mL/kg)	60	70	80
Metabolic rate (mL/kg/min)	6-8		3-4

NEONATAL APNEA

Apnea is defined as cessation of breathing for 10-15 seconds and can be associated with bradycardia and loss of muscle tone. Apnea is common in premature infants (defined as gestational age <38 weeks) and is related to immature respiratory control mechanisms. This phenomenon is rare in full-term infants. Both theophylline and caffeine have effectively reduced apneic episodes in these infants. Exposure to respiratory depressants, such as inhaled agents, opioids, and benzodiazepines, all induce apnea in this population.

Premature infants less than 58-60 weeks postconceptual age have been shown to be at greater risk of postanesthetic apnea. Apneic episodes have been described up to 12 hours postoperatively.

Use of a regional anesthetic technique, ie, spinal anesthesia, has been advocated in this population, although it has not been shown to reduce the incidence of apnea. Therefore, the need for observation in the perioperative period is not dependent on the anesthetic technique.

NEONATAL HYPOXEMIA

Respiratory control is poorly developed in neonates and preterm infants.

- Increased metabolic demand.
- Prone to upper airway obstruction.
- Immature respiratory control and irregular breathing.
- Hypoxia transiently increases then depresses ventilation.
- Hypoxia depresses hypercapneic ventilatory response.
- Anesthetics abolish mechanisms to maintain FRC.

NEONATAL RENAL FUNCTION

Renal components are incompletely developed at birth, although the formation of nephrons is complete at 36 weeks gestation. Rapid maturation occurs during the first month of life, then these components continue to fully mature over the first year of life:

- Reduced glomerular filtration rate (GFR)—25% of adult
- Inadequate tubular function (adult values reached after 2 years of age)

Neonates have difficulty with *both* volume loading and volume depletion. Volume depletion, though, has more serious implications. Sodium balance is directly related to intake. The administration of sodium-free solutions may lead rapidly to hyponatremia.

BODY COMPOSITION

Water constitutes 75% of the weight of a neonate as compared with 65% of that of a 12-month-old infant and 55% of that of an adult. The reduction in total body water is accompanied by a shift in the distribution of

TABLE 1-3 ASSESSMENT OF HYDRATION/EXTENT OF DEHYDRATION

Signs/Symptoms	Dehydration (%)	Fluid Deficit (mL/kg)
Thirsty, restless	5	50
Poor tissue turgor, sunken fontanelle	10	100
Orthostatic, oliguric, comatose	15	150

fluid from extracellular to intracellular. Fat represents 16% of the body weight of a neonate and increases to 23% by 12 months of age.

Increased fluid requirements occur with:

- Increased metabolic rate
- Increased insensible fluid loss
- Increased obligatory fluid loss

See Table 1-3 for a summary of hydration assessment.

INFANT FLUID REPLACEMENT

Typically 50% of the deficit is replaced over the first hour, with the remaining deficit being replaced over the next 2 hours. Maintenance fluids can be calculated using the 4/2/1 rule.

Surgical procedures involving only mild tissue trauma may entail third space losses of 3-4 mL/kg/h. This ranges up to 10 mL/kg/h in very large abdominal procedures.

VITAL SIGNS

Changes in heart rate, respiratory rate, and blood pressure as the child ages are summarized in Table 1-4.

TABLE 1-4 TYPICAL VITAL SIGNS

Age	Heart Rate	Systolic BP	Diastolic BP	Respiratory Rate
Preterm, first day	120	50	35	60
Full term, first day	120	65	45	50
1 month	160	95	55	40
3 months	140	95	60	30
1 year	125	95	60	24
3 years	100	100	65	24
8 years	80	105	70	22
12 years	75	115	75	18