Pediatric Anatomy & physiology

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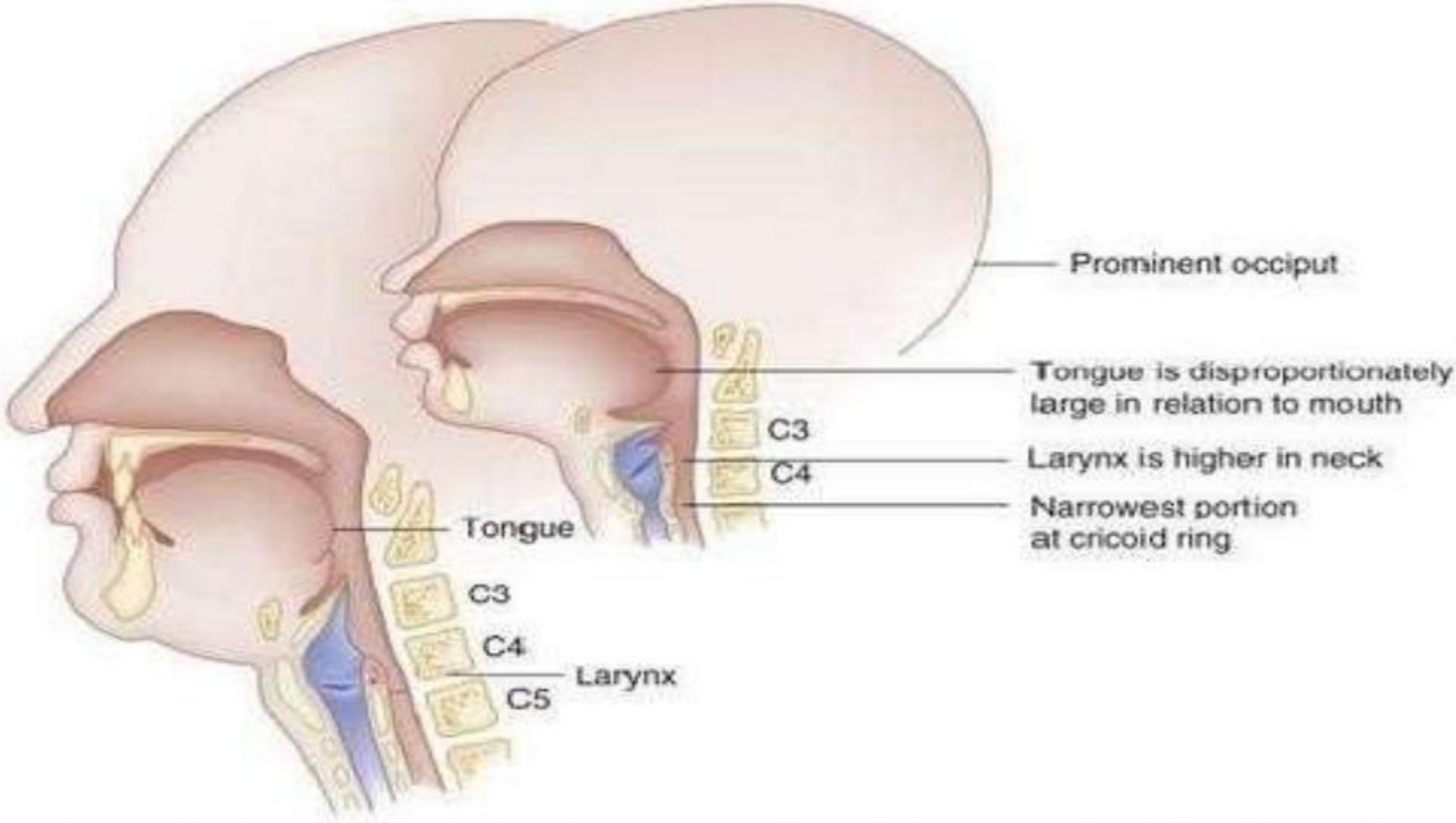
Moderator:- Dr. Pawan Puspa Baral

Objectives:

- To understand the anatomic variations in pediatric group
- To understand the physiologic differences between pediatric and adult group
- Anesthetic implications of the anatomic and physiologic variations

- Preterm infants (born before 37 weeks gestation)
- Post mature infants (born after 42 weeks gestation)
- Neonates (0-1 months)
- Infants (1-12 months)
- Toddlers (1-3 years)
- Small children (4 – 12 years)

Respiratory System
Pediatric airway



Comparison of adult and pediatric airways. *(From Finucane BT: Principles of Airway Management. Philadelphia, FA Davis, 1988.)*

Adult Vs Pediatric airway

Structure	Features
Tongue	Larger in proportion to the oral cavity than in adult.
Epiglottis	Narrower, U- shaped, flops posteriorly
Larynx	High and anterior. Level of C3-C4. (C5-C6 in adults)
Cricoid	More conical shaped in infants, narrower at cricoid cartilage whereas in adults it is at level of vocal cords
Trachea	Shorter (4-5cm), deviated posteriorly and downwards Become anatomically similar to adult between 8-10 years

Pediatric airway

- Obligate nose breathers until 5 months of age.
- Mouth breathing occurs only during crying
- Obligate nose breathing is vital for respiration during feeding

pharynx

- Completely soft tissue
- Easily collapsed by posterior displacement of the mandible, or external compression of the hyoid.
- Pharyngeal lumen may collapse with negative pressure generated through inspiratory effort.

Larynx

- Funnel shaped
- Glottis more cephalad (premature C3, Term C4 and adults C5-6)
- Cricoid ring is complete, and is the narrowest point of the pediatric airway

Larynx

- Anterior and slanting vocal cords
- Epiglottis is omega or tubular shaped
- stubby base and thick and bulky aryepiglottic fold, tip lies at C1 in close apposition with soft palate

ADULT

INFANT

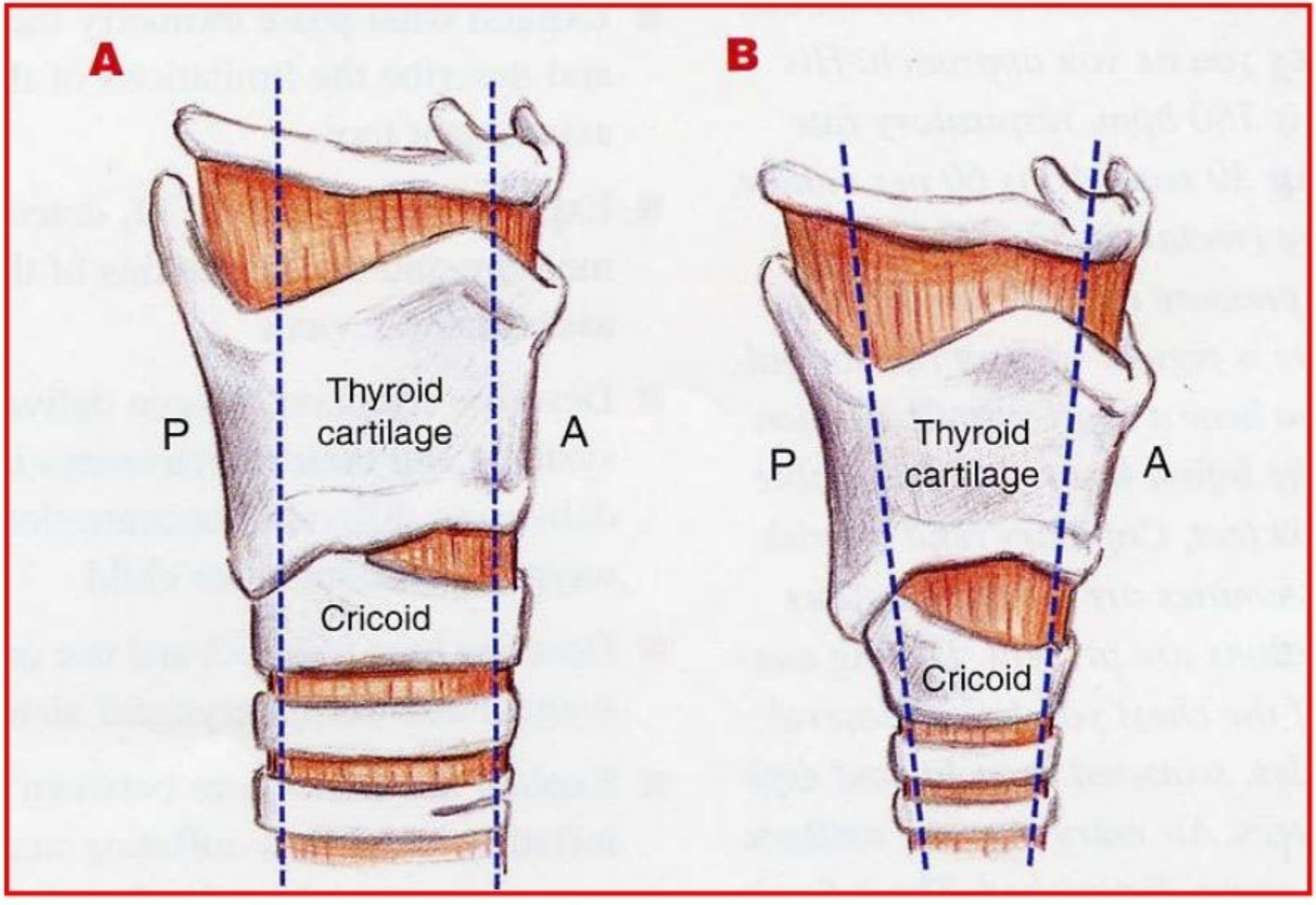


Figure: adult and pediatric larynx

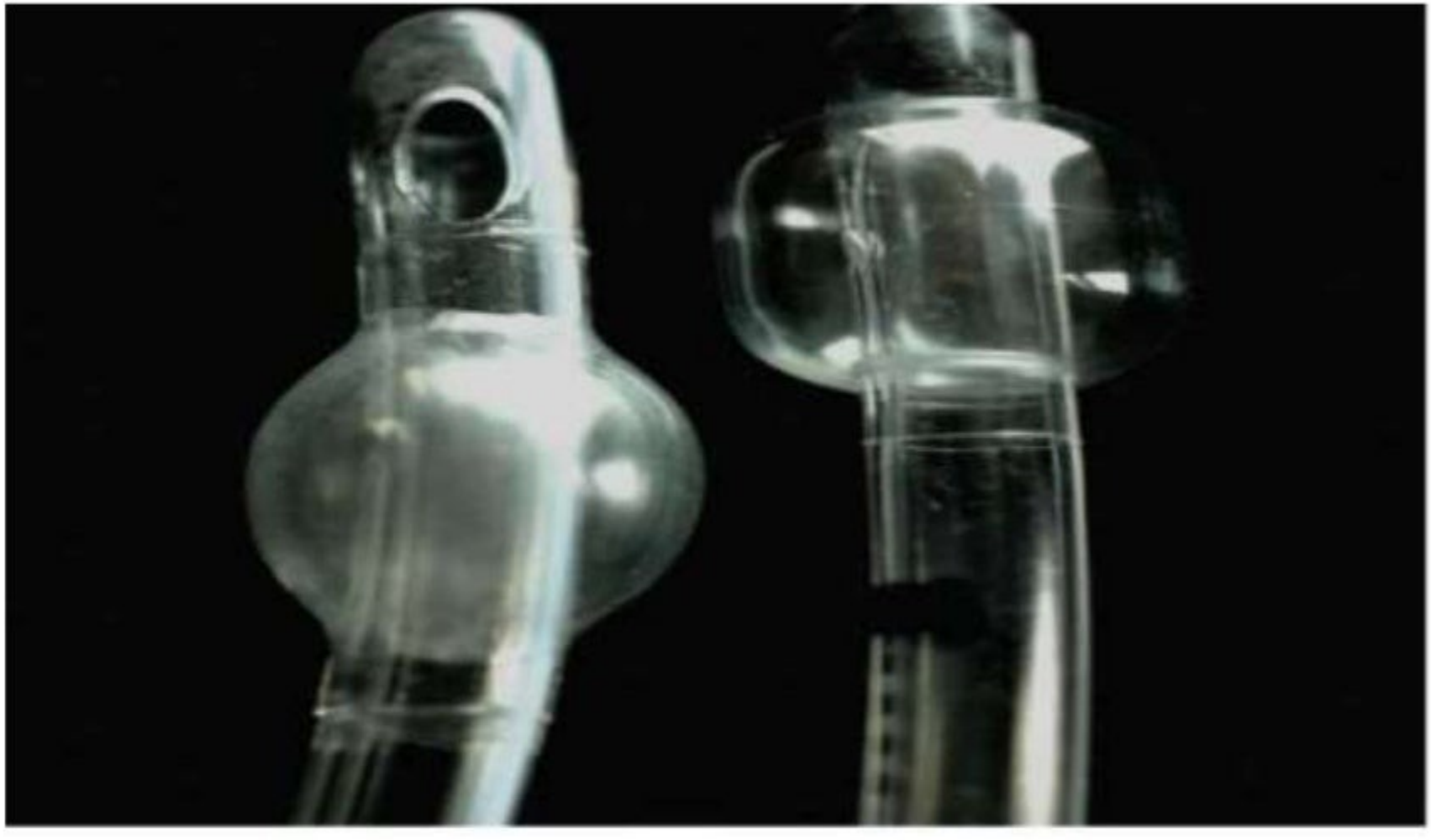


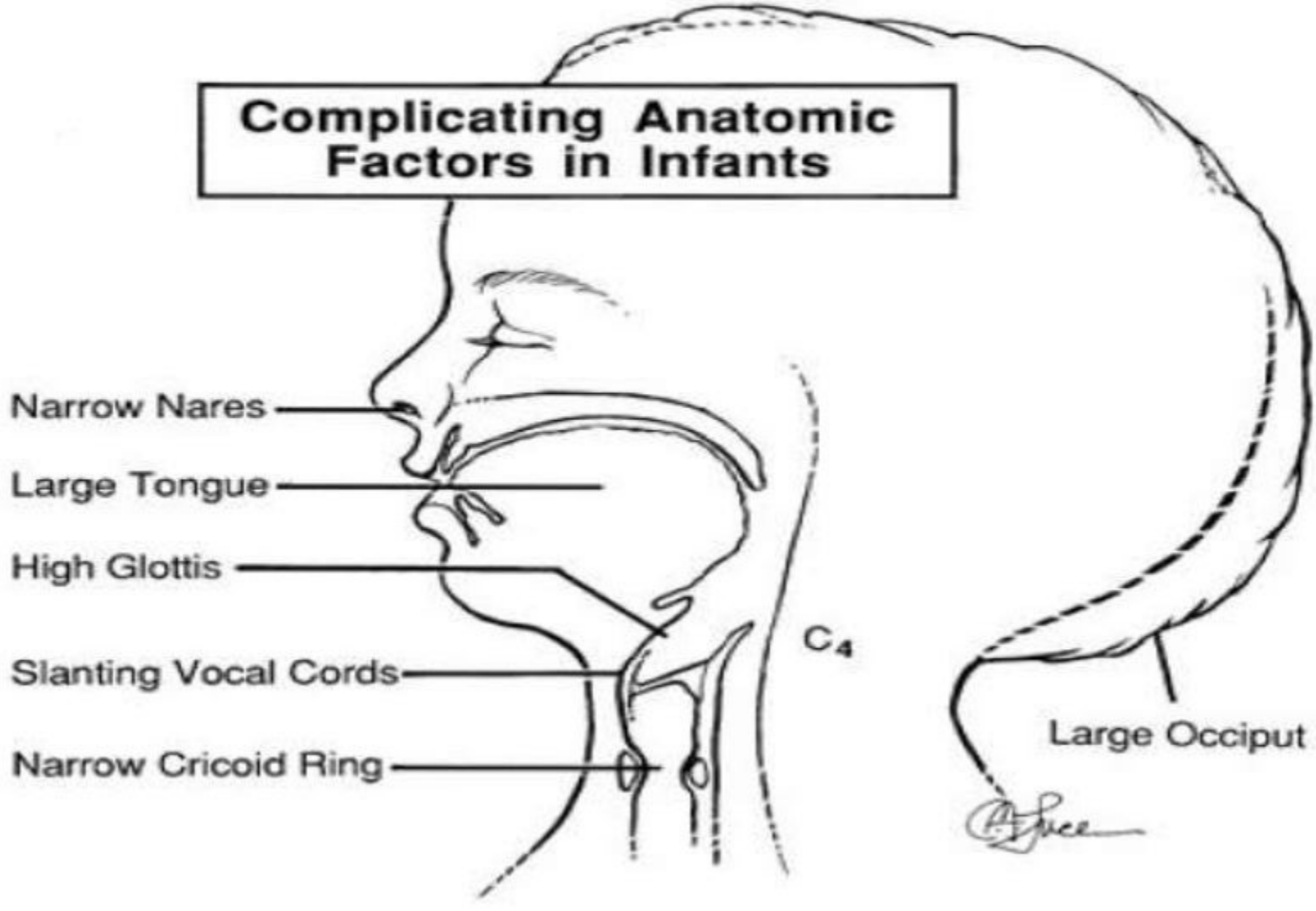
Figure: standard tracheal tube and microcuff tracheal tube

RESPIRATORY SYSTEM

Change at birth:

- 90ml of plasma ultra-filtrate in lungs squeezed out during delivery
- Catecholamine during labor : augment release of surfactant from type II pneumatocytes,
- Lung expansion : increases alveolar and arterial oxygen tension; decreases pulmonary vascular resistance

Pediatric airway



RESPIRATORY SYSTEM

Lungs

- Maturation does not complete until 8 years.
- Alveoli grow and increase in number.
- Surfactant production begins at 20 weeks, but increases between 30-34 weeks

RESPIRATORY SYSTEM

Anatomical differences in the thorax

- compliant chest wall
- Ribs are cartilaginous, horizontally located, limiting an increase in tidal volume.
- Ventilation is primarily diaphragmatic.
- Diaphragm is deficient in type 1 muscle fibers reaches adult level by 2 yrs

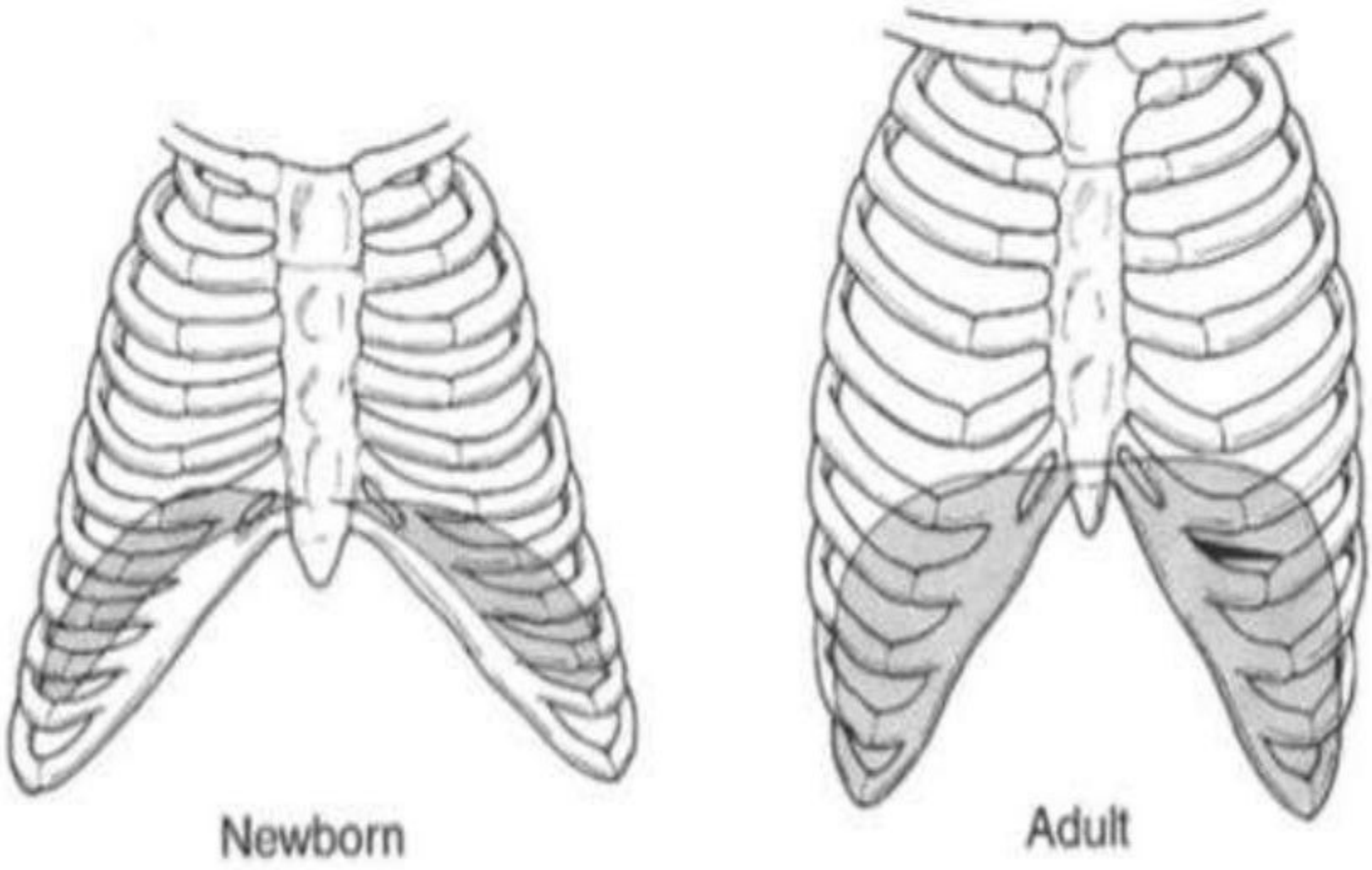


Figure: newborn and adult ribs type

RESPIRATORY SYSTEM

TABLE 1–2. Mean Values for Normal Pulmonary Parameters in Normal Neonates and Adults

	Newborn	Adult
Body weight (kg)	3	70
Tidal volume (ml/kg)	6	6
Respiratory rate (bpm)	35	15
Alveolar ventilation (ml/kg/min)	130	60
Oxygen consumption (ml/kg/min)	6.4	3.5
Total lung capacity (ml/kg)	63	86
Functional residual capacity (ml/kg)	30	34
Vital capacity (ml/kg)	35	70
Residual volume (ml/kg)	23	16
Closing capacity (ml/kg)	35	23
Arterial pH	7.38–7.41	7.35–7.45
$Paco_2$	30–35	35–45
Pao_2	60–90	90–100
Sao_2 (%)	95–100	95–100

From Dobbins, P., & Hall, S.M. (1997). Pediatric anesthesia. In Nagelhout, J., & Zaglaniczny, K.L. *Nurse anesthesia* (p. 336). Philadelphia: W.B. Saunders.

$Paco_2$, Partial pressure of arterial carbon dioxide; *Pao_2*, partial pressure of arterial oxygen; *Sao_2*, oxygen saturation.

RESPIRATORY SYSTEM

- Central apnea- self limited in newborns, approximately 5 seconds
- Apnea of prematurity – 20 seconds or associated with desaturation episodes and bradycardia
- Resolves at 50- 55 weeks gestational age.

RESPIRATORY SYSTEM

- Pediatric airway
  - Infants increase their respiratory rate in the presence of hypercarbia
    - Not as much as adults because chemoreceptors are immature
  - Hypoxia-brief hyperventilation followed by hypoventilation
  - Periodic breathing occurs in 78% of infants, usually during quiet sleep

Anesthetic consideration

- Difficult airway management
- Rapid desaturation
- MAC values
  - premature ↓ 20-30%, after 6mth ↑ 50%, term to 6mths= adult level
  - immature CNS,
  - maternal progesterone and endorphins and
  - immature BBB

- Volatile anesthetic fast onset and recovery
  - alveolar ventilation/FRC 5:1(adults 1.5:1)
  - high cardiac output goes to vessel rich organs
  - low blood gas partition coefficient for volatile anesthetics

CARDIOVASCULAR SYSTEM

Fetal circulation

- high pulmonary vascular resistance, low systemic resistance (placenta) and right to left shunt via PFO and DA.
- Aeration of the lungs – decrease pulmonary vascular resistance(3-4 days), mediated by NO,
- Systemic vascular resistance doubles after first breath by placenta removal

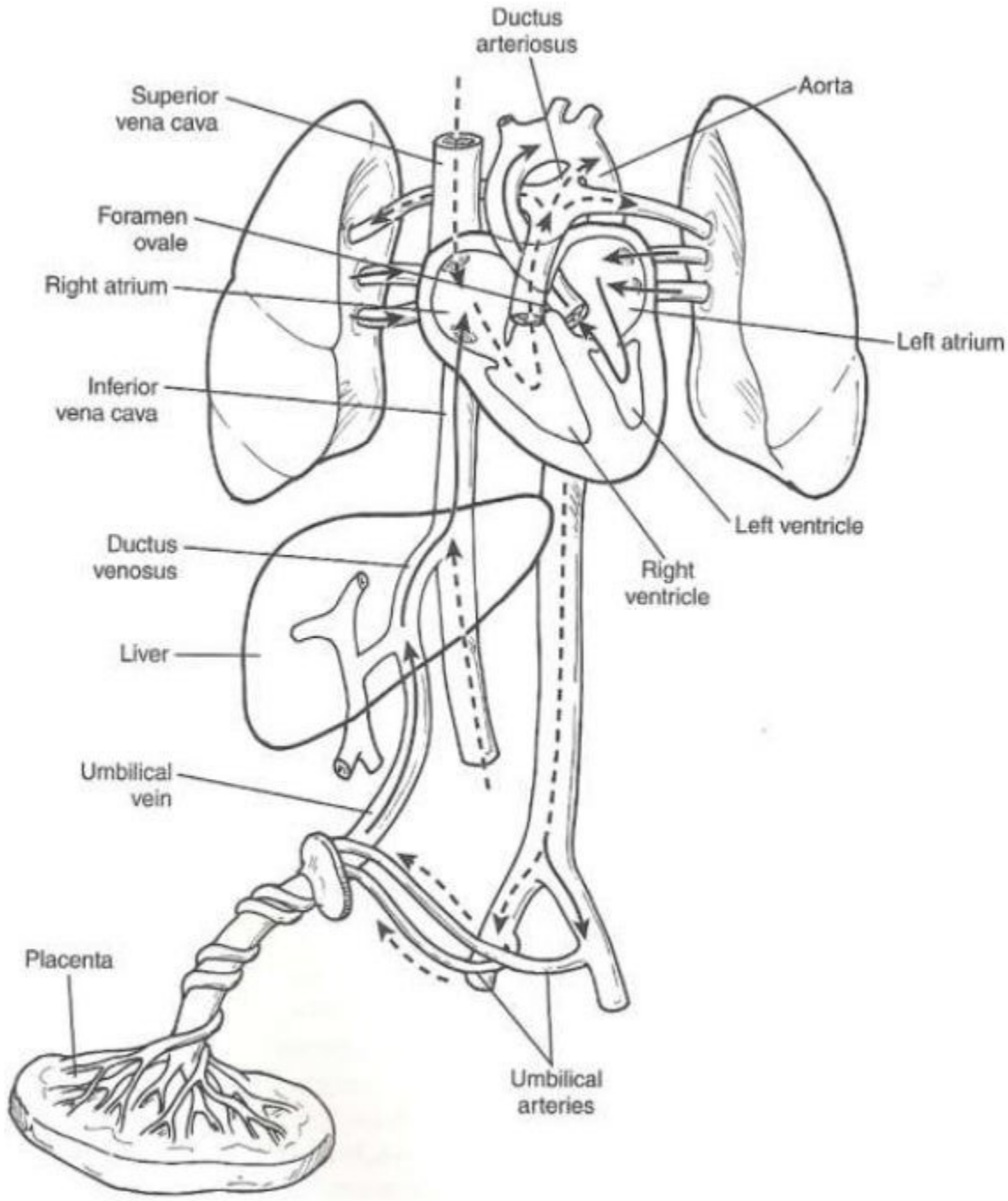


Figure 1-1 Anatomy of the fetal circulation. (Redrawn with permission from Bell C, Kain ZN, Hughes C: *The Pediatric Anesthesia Handbook*, 2nd edn, Mosby, Philadelphia, 1997.)

Figure: Fetal Circulation

At birth

- Placenta removal from circulation- portal blood pressure falls- **ductus venosus closure**

- Exposure of ductus arteriosus to ↑ O2 concentration- **ductus arteriosus closure**

- ↓ PVR- ↑ left side pressure – **foramen ovale closure**

Closure of ductus arteriosus: functional closure 10-15 hrs. after birth, anatomic closure 2-3 wks. after (ligamentous arteriosus)

Closure of foramen ovale: functional closure at birth, anatomic closure at 6 wks.

Closure of ductus venosus: functional closure 3-7 days after birth, anatomic closure – 2-3 months of age (ligamentous venosum)

CARDIOVASCULAR SYSTEM

- Neonatal myocardium contains immature contractile elements (undeveloped SR) and is less compliant
- Stroke volume is relatively fixed
- CO rate dependent
- Neonatal myocardium have high glycogen store

CARDIOVASCULAR SYSTEM

- CO is twice that of the adult.
- CO
  - 300-400ml/kg/min in newborns,
  - 200ml/kg/min at 2 months of age
- Adrenergic receptors mature at birth but incomplete sympathetic innervation.
- Impaired baroreceptor reflex activity.

CARDIOVASCULAR SYSTEM

TABLE 1-1. Circulatory Variables in Infants and Children

Age	Heart Rate (bpm)	Systolic Blood Pressure (mm Hg)	Diastolic Blood Pressure (mm Hg)	Cardiac Index ($L/min/m^2$)	Oxygen Consumption (ml/kg/min)
Preterm	150 ± 20	50 ± 3	30 ± 3		8 ± 1.4
Term	133 ± 18	73 ± 8	50 ± 8	2.5 ± 0.6	6 ± 1.0
6 mo	120 ± 20	89 ± 29	60 ± 10	2.0 ± 0.5	5 ± 0.9
1 yr	120 ± 20	96 ± 30	66 ± 25	2.5 ± 0.6	5.2 ± 0.1
2 yr	105 ± 25	99 ± 25	64 ± 25	3.1 ± 0.7	6.4 ± 1.2
5 yr	90 ± 10	94 ± 14	55 ± 9	3.7 ± 0.9	6.0 ± 1.1
12 yr	70 ± 17	109 ± 16	58 ± 9	4.3 ± 1.1	3.3 ± 0.6
Young adult	75 ± 5	122 ± 30	75 ± 20	3.7 ± 0.3	3.4 ± 0.6

From Katz, J., & Steward, D.J. (1993). *Anesthesia and uncommon pediatric diseases* (2nd ed., p. 5). Philadelphia: W.B. Saunders.

Age	Heart Rate (beats/min)	Blood Pressure (mmHg)
0–3 mos	100–150	65–85/45–55
3–6 mos	90–120	70–90/50–65
6–12 mos	80–120	80–100/55–65
1–3 yrs	70–110	90–105/55–70
3–6 yrs	65–110	95–110/60–75
6–12 yrs	60–95	100–120/60–75
>12 yrs	55–85	110–135/65–85

Normal Blood Volumes

Age	Blood Volume
New-born	85 –90 ml/kg
6 weeks to 2 yrs	85 ml/kg
2 yrs to puberty	80 ml/kg

CARDIOVASCULAR SYSTEM

- The electrocardiogram shows an axis oriented to the right due to right dominance.

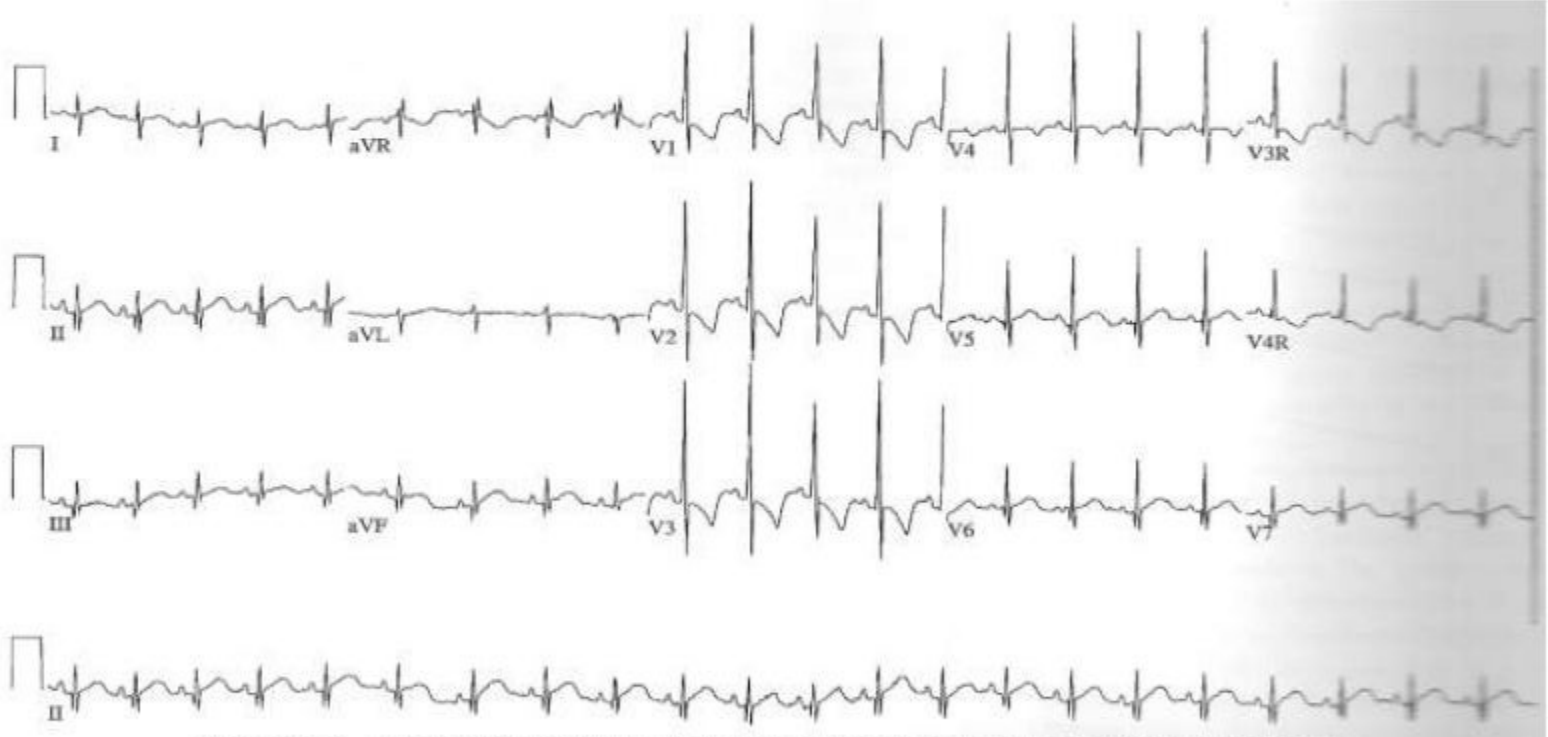


Figure 2-4 The normal newborn electrocardiograph demonstrates a preponderance of right-sided forces as evidenced by a QRS axis greater than 90 degrees, and decreasing R wave size from right to left in the precordial leads. T waves are normally inverted in lead AVR and the right-sided precordial leads.

Table - 1 : Physiological differences between neonatal and adult myocardium

	Neonate	Adult
Cardiac output	Heart rate dependant	Stroke volume and heart rate dependent
Contractility	Reduced	Normal
Starling response	Limited	Normal
Compliance	Reduced	Normal
After load compensation	Limited	Effective
Ventricular interdependence	High	Relatively low

Anesthetic considerations

Transitional circulation

- Neonates have a reactive pulmonary vasculature
- during first few weeks of life, reversion to fetal circulation.
- Factors: hypoxia, hypercapnia, acidosis, infection, hypothermia, prematurity
- Sudden increase in pulmonary artery pressure causes shunting of blood past the lungs through a patent foramen ovale or the ductus arteriosus, which may reopen.

- Fixed CO and HR dependent (CPR if HR <60)
- Low catecholamine store and blunted response
- Sensitive to Ca channel blocking property of volatile agents and opioids induced bradycardia

CENTRAL NERVOUS SYSTEM

- CMRO2- 5ml/100g/min
- CBF- 70-110ml/min/100g
- Intact cerebral autoregulation in full term and nonstressed infant.
- BBB is poorly formed
  - Drugs (barbiturates, opioids, antibiotics, bilirubin) cross BBB easily cause prolong & variable duration of action

Cerebral vessels in preterm infant are thin walled & fragile.

- Prone to Intra Ventricular Haemorrhage
- Risk increased with hypoxia, hypercarbia, hypernatraemia, low HCT,
- Awake airway manipulation, rapid bicarb administration, & fluctuation in BP & CBF

RENAL SYSTEM

Table: Distribution of water as a percentage of body weight

Compartment	Premature	Neonate	Infants	Adults
ECF	50	35	30	20
ICF	30	40	40	40
Plasma	5	5	5	5
Total	85	80	75	65

RENAL SYSTEM

- Immature infant kidney
- Diminished renal function due to small perfusion pressure and immature glomerular and tubular function.
- At 20 wks. after birth- nearly complete maturation of glomerular filtration and tubular function.
- At 2 year- complete maturation of renal function

- Full term infants have the same number of nephrons as adults
- Glomeruli are much smaller than in adults
- GFR in the newborn is 30% that of the adult (until 2yrs)
- Tubular immaturity leads to a relative inability to concentrate urine (mature at 8 mths)

Anesthetic considerations

- Meticulous fluid and electrolyte management
  - Dehydration is poorly tolerated
    - –increased insensible losses due to large surface area relative to weight
    - –larger proportion of ECF in children (40% BW as compared to 20% in adult)
- Increased half life of renally excreted drugs

HEMATOLOGIC SYSTEM

- Physiologic anemia at 3 months
- Fetal hemoglobin (HbF) predominates (70-90%) and low 2,3 DPG level
- Shifts to the adult type (HbA) by 3 to 4 months of age
- Vitamin K dependent clotting factors (II, VII, IX, X) and platelet function are deficient in the first few months

HEPATOBILIARY SYSTEM

- Hepatic metabolic capacity is immature at birth.
- Some enzyme system are developed but not induced(stimulated).
- Phase I reactions- Some CYP450 enzymes are fully developed, whereas others are approx. 50% of adult values.
- Phase II reactions- immature until the age of 1 year.

- Prolonged half life of benzodiazepines, morphine, and caffeine.
- Reduced plasma concentration of both albumin and alpha1-acid glycoprotein
- Low plasma level-decreased protein binding-higher free drug

GLUCOSE METABOLISM

- Reduced glycogen stores and impaired gluconeogenesis, increased metabolic rate.
- Hypoglycaemia is common in stressed neonate→ glucose level should be monitored regularly
- Neurological damage may result from hypoglycaemia
- Prevention: IVI D10%
- Hyperglycaemia is usually iatrogenic

TEMPERATURE REGULATION

- Greater surface area to body weight ratio with minimal subcutaneous fat
- Poorly developed shivering, sweating and vasoconstriction mechanisms
- Neonate produce heat by non shivering thermogenesis.
- Severely limited in premature infants and in sick neonates.

TEMPERATURE REGULATION

Neutral thermal environment

- 34ºC premature infant,
- 32ºC neonates and
- 28ºC in adolescents and adults

Effect of Low body temperature:

- Respiratory depression
- Acidosis
- Decreased cardiac output
- Increases the duration of action of drugs
- Decreases platelet function and
- Increases the risk of infection.

Summary

Differences(Physiological)

- HR dependent CO
- Faster HR
- Lower BP
- Faster RR
- Lower lung compliance
- Greater chest wall compliance
- Lower FRC
- Higher ratio of body surface area to body weight
- Higher total body water content

Summary

Differences(Anatomical)

- Non compliant left ventricle
- Residual fetal circulation
- Difficult venous & arterial cannulation
- Large head & tongue
- Narrow nasal passage
- Ant. & cephalad larynx
- Long curled epiglottis (omega shaped)
- Short trachea & neck
- Prominent adenoids & tonsil
- Weak intercostal & diaphragmatic muscle
- High resistance to airflow

Summary

Pharmacological

- Immature hepatic biotransformation
- Decreased protein binding
- Rapid rise in FA/FI
- Rapid induction and recovery
- Increased MAC
- Larger volume of distribution of water soluble drugs
- Immature neuromuscular junction

References

- Barash, Clinical Anesthesia 7th edition
- Morgan, Clinical Anesthesiology 6th edition
- Miller's Anesthesia 8th edition
- Aitkenhead, Textbook of Anaesthesia 7th edition

Thanks