Paediatric physiology (and anaesthesiology)

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What can we cover in 40 minutes?
- Definitions
- Anatomy (mostly airway)
- Physiology
- A bit of pharmacology
- Critical incidents
- Take home messages

What we will NOT cover
- Foetal circulation
- Transition from foetal to post-natal circulation
- Physiology of the first breath

Definitions
- Prematurity = Less than 37 weeks PCA
- Extreme Prematurity = Less than 28 weeks
- Neonate = up to 44 weeks from date of conception
- Infants = 1 month to 1 year
- Child = 1-12 years
- Young (Small) child 1-6 years
- Adolescent = 13-16 years

Airway Anatomy

Neonates / Infants
- Large Head with prominent occiput pillows are unhelpful as they may position the head and neck in a way to obstruct the airway
- Relatively larger tongue easier to obstruct the airway
- Short Neck and Small Mandible
- Obligate nose breathers when <5 months – narrow nasal passages

Paediatric airway management

Not DIFFICULT but DIFFERENT!
Larynx
- Floppy U-shaped epiglottis lifted out of the way on laryngoscopy
- More anterior and cephalad larynx (C4) hence moving head more anterior ('sniffing the morning air' will not help during laryngoscopy)
- Cricoid ring = narrowest part of the upper airway easy to damage mucosa if ETT is too tight

Trachea and Lungs
- Short trachea (from cricoid to carina) easy endobronchial intubation
- Soft tracheal cartilage – can collapse with negative inspiratory pressure
- Bronchi at same angles bronchial intubation as likely on both sides
- Higher airway resistance (nasal passages are responsible for 50%)

Body surface area to mass ratio
- The smaller the child the larger the ratio
- Increased heat loss
- Need to maintain temperature
- Higher metabolic rate
Higher metabolic rate

- Higher oxygen demand
- Desaturation occurs quicker
- Higher resting heart rate and respiratory rate

Cardiovascular system

- Stroke volume is relatively fixed
  - Myocardium less compliant
  - Frank-Starling curve is flatter
- Cardiac output increases predominantly by increasing heart rate
- Limbs are smaller in relation to the body
- Less blood pooling, less volume to mobilise

Cardiovascular system

- Relatively vasodilated
- Blood pressure maintained until decompensate
- Response to neuro-axial blockade
- Approximate Systolic BP = 80 + (age x 2)
  - Neonates Systolic BP = 50-60 mmHg

Respiratory system

- Tidal volume relatively fixed
- Minute ventilation increases by increasing predominantly respiratory rate
- Ribs more horizontal - less ‘bucket-handle’ movement
- Respiration mostly diaphragmatic
- Relative deficiency in Type 1 muscles (age of 2)

Respiratory system

- 20-50 million alveoli at birth, underdeveloped
  - 300 million at 3 months
- Bronchial tree is fully developed
- Chest wall is very compliant
  - Unable to oppose the diaphragm to maintain FRC
- Tidal volume 7ml/kg (irrespective of age)
Respiratory system

- Elastic tissue poorly developed
  - Lung compliance is reduced
- Ventilatory units have short time constant (time to fill or empty a lung unit (Cstat x Raw)
- Alveolar ventilation maintained by high respiratory rate, high work of breathing, high oxygen consumption (15% vs 5% in adults)

- Closing capacity exceeds FRC up to the age of 6
  - Implications for pre-oxygenation and “oxygen reserve”
- Infants generate physiological CPAP by abducting the cords during expiration (4 cm H2O)

Effect of airway oedema

Poiseuille’s Law

The resistance to flow is a function of the viscosity of the gas, the length of the pipe and the radius of the pipe to the fourth power

Oxygen delivery and consumption

- Oxygen consumption 7 ml/kg/min (adults 3.5)
- Cardiac output 200 ml/kg/min (100)
- Blood volume 80 ml/kg at term, 75 at age of 2
- Haemoglobin 160-180 g/l (80% HbF) at term, 100g/l at 3 months, 120-140 at 1 year

Nervous system

- Relative autonomic disbalance
- Parasympathetic system is fully developed at birth (phylogenetically older)
- Whereas sympathetic continues to mature
- More susceptible to vagal stimulation, eg bradycardia, laryngospasm
- Less pre-existing vasoconstriction
- Tolerate neuro-axial blockade better

- Blood-brain barrier is immature
- Increased sensitivity to opiates and other neuro-depressants
- Probably normal by 6 months
Temperature control
- Increased heat loss
- Rapid onset of hypothermia
- No shivering until 3 months
- Use brown fat (up to 6% of total fat)

Renal
- Reduced GFR 65 ml/min
- Reduced tubular function
- Reduced concentrating ability
- Excretory load is decreased as 50% of nitrogen is incorporated into growing tissue
- Maturation by the age of 2

Gastro-intestinal system
- Gastro-oesophageal reflux is common in neonates
- Questionable clinical significance
- Coordination of respiration and swallowing matures by 5 months

Pharmacokinetic differences
- Total body water is proportionately higher
- Higher volume of distribution of water soluble drugs
- Fat content is lower
- Lipid soluble drugs dependent on distribution have prolonged effect
- Lower protein binding
- Phase II conjugation reactions are immature

Peri-operative critical events in children
The Big Three!
- Hypoxia
- Laryngospasm
- Bradycardia

Hypoxia
Why?
- Increased work of breathing
- Small FRC (low intrapulmonary O₂ reserve)
- Higher basal metabolic rate
- Diaphragm dependence
Direct causes of hypoxia

- Laryngospasm
- Bag and mask ventilation difficulties
- Multiple intubation attempts
- Endobronchial intubation
- Reduced diaphragmatic compliance from stomach inflation, etc

Laryngospasm

Why

- High parasympathetic tone
- Inadequate anaesthesia (induction, emergence)
- Vagally stimulating procedures e.g. laryngoscopy or extubation

Laryngospasm in paediatric practice

- Incidence 0.5 - 2.0%
- The younger the child the higher the incidence
- ½ on emergence, ¼ on maintenance and induction

Laryngospasm

Reflex arc

Afferent: internal branch of superior laryngeal nerve, pharyngeal branch (both vagus), but also tracheobronchial tree and abdominal viscera (vagus)

Efferent: recurrent laryngeal nerve - cords adduction

Self-limited mostly: prolonged hypoxia and hypercapnia abolish the reflex???

Laryngospasm in paediatric practice

- Does NOT happen when fully awake or deeply anaesthetised
- Tonsillectomy - high risk
- Awake versus deep extubation versus flexible LMA
- Complete vs incomplete

Treatment

- CPAP with 100% oxygen
- Deepen anaesthesia
- Succinylcholine remember the higher dose! (higher Vd water soluble drugs)
  - May and almost certainly will worsen bradycardia (due to hypoxia and increased vagal output)
  - Have atropine ready
Bradycardia
- High parasympathetic tone, most likely during vagally stimulating procedures e.g. laryngoscopy, extubation and squint surgery
- Most dangerous (and common?) cause is HYPOXIA
- Repeated succinylcholine doses (but also a single dose)
  - SA node muscarinic receptors stimulation

The Other Big Three...
- Succinylcholine 2 mg/kg
- Atropine 20 mcg/kg
- Propofol 2-4 mg/kg (induction)

To conclude
- Paediatric airway anatomy
- Physiology
- Its application in anaesthesia
- Critical incidents
- Better understanding and safer practice

Resources
http://www.aagbi.org/education/educational-resources/tutorial-week/my-events/tutorial/Paediatric%20Anaesthesia