# Foetal & Neonatal Physiology

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**Amniotic Fluid**
- volume ranges 500-1500ml
- vol peaks @ 34-40 then slowly ↓s
- function:
  - protection against physical impacts ie a cushion
  - route for recycling foetal renal output
  - space for symmetric foetal growth
  - helps distribute pressure of uterine contractions evenly over foetus
- creation:
  - early preg: ultra-filtrate of foetal plasma : part of foetal ECF
  - late: mainly foetal urine ⇒ swallowed & reabsorbed in gut. turnover ~1-2days

**Foetal Circulation**
- 55% fetal CO ⇒ placenta
- blood in umbilical vein Spo2 80%
- placenta ⇒ liver
- ductus venosus allows blood to bypass liver ⇒ IVC
- Returning IVC blood ⇒ heart ⇒ through PFO ⇒ L atrium
  - allows blood with ↑ed Spo2 to go to brain
- SVC blood ⇒ R vent ⇒ pulmon artery ⇒ ductus arteriosus ⇒ aortic arch post to L subclavian
  - means blood with ↓ed Spo2 flow to trunks & LLs

**Saturations in Different Foetal Vessels**
- Ductus venosum = 80%
• IVC 67%
• Hepatic Portal blood = 26%
• SVC 30%
• systemic circulation = 60%

**Percentage of Blood Flow & Direction**

Changes At Birth

**Respiratory**

- changes:
  - loss of placental gas exchange
  - initiation of ventilation of newborns lung
  - start of pulmon gas exchange
  - establishment of FRC
- physiology of first few breaths:
  - pre delivery lung contains ~20ml/kg fluid
  - some expelled with thoracic compression during movement through vaginal birth canal
  - rest rapidly absorbed & replaced with air
1st breath: v large -ve ITP ie -60 to -70cmH20
next breaths: progressively less -ve ITP as establishment of air-liquid interface with surfactant
∴ FRC ↑s rapidly after 1st breath:
- 10mins FRC ~17ml/kg
- 30-60min ~30ml/kg (=adult value)

**CVS Changes**
- changes:
  - loss of umbilical circulation to placenta
  - closure of ductus venousus
  - functional closure of foramen ovale
  - closure of ductus arteriosus (reversible)
    (↑ NB is less responsive to O2 in prems)
  - large ↑pulmon circulation (reversible)

**Physiology of Changes**
- in fetus R & L heart pump in parallel rather than series
  ↩possible due to PFO & PDA
- umbilical vessels have thick muscular walls which v reactive to:
  - trauma
  - tension
  - catechoaines/bradykinin/angiotensin
  - changes in PO2
- @birth:
  - placental circulation cut off ie flow through umbilical vein ceases
  - ductus venosum closes - unknown mechanism :
    - peripheral resistance sudden ↑
    - aorta pressure rises until > than pulmon artery
  - infant ↑ing hypoxia ⇒ activation of resp centre of newborn
  - infant gasp initiates circulatory changes:
    - expansion of lung ⇒ ↓pulmon vascular resistance to ~10% of intrauterine value
      (↩ not O2 mediated as occurs with N2 inflation breaths)
    - ⇒ ↑LA pressure > RA & IVC due to:
      - ↓pulmon resistance ⇒ ↑LA filling
      - ↓RA filling due to occlusion of umbilical vein
      - ↑ed LV afterload due to closure of umbilical arteries
        ↩ functional closure of PFO (with fusion in days)
    - reversal of flow through ductus arteriosis - due to:
      - pulmonary artery pressure falls to 50% of intrauterine value (35mmHg
      - ↑aortic pressure
        ↩ within minutes ductus starts to close ⇒ turbulent flow = murmurs of newborn
    - placental transfusion – sucks blood from umbilical vein (upto 100mls blood)
- Ductus arteriosus:
  - Initial functional closure
  - 24-48hr anatomical closure by intimal thickening
  - Ductus Arteriosus closure not totally understood:
    - Incre in O2 arterial tension
    - ↓ing conc of prostaglandins, bradykinin, adenosine
      ↩ prostaglandin synthesis blocked by inhibition of cyclooxygenase at birth
DA post birth can be:
  - closed with drugs that inhibit COX
  - kept open with VDs eg NO/prostaglandins

- morphology changes of heart & vasculature - over weeks:
  - @ birth:
    - 2 ventricles = same weight - due to parallel foetal circuit
    - arterioles of pulmon circuit = thick & muscular
  - after birth:
    - RV fails to grow like LV
    - muscular layer of pulmon circulation is lost

### Physiology Changes Neonate ⇒ Infant
- neonate = 1st 28 days of life
- infant = 28d ⇒ 1 year

#### Cardiovascular Changes

<table>
<thead>
<tr>
<th></th>
<th>Term</th>
<th>6/12</th>
<th>1yr</th>
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<tr>
<td>blood volume</td>
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<td>80 ml/kg</td>
<td></td>
<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>P50</td>
<td>18</td>
<td>24</td>
<td>27</td>
<td>27</td>
<td></td>
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i.e:
- ↓ing:
  - HR
  - VO2
  - Hb
- ↑ing:
  - blood pressure
  - SV
  - p50

- blood pressure:
  - SBP in kids = ~80 + (age x2)
• heart rate:
  • basal Hr is higher compared with adults
  • rate is very sensitive and susceptible to bradycardia:
    - vagal stim
    - over anaesthetic (volatiles)
    - hypoxia
    \[\rightarrow\] will lead to dramatic ↓CO
• neonate/infant circ less adaptive with less developed autoregulation:
  • CO = HR dependant because of relatively fixed SV
    \[\leftrightarrow\] as LV is poorly developed and non-compliant
  • SNS + baroreflexes are not fully mature:
    - CVS blunted responses to exogenous catecholamines
    - low intracellular Ca stores
  • less able to vasoconstrict esp in light of hypovolaemia

**Resp Changes**
• lower gestational age ↓ed surfactant \[\rightarrow\] ↓lung compliance, ↑WOB, alevoli dry

<table>
<thead>
<tr>
<th></th>
<th>Cl (ml/kg)</th>
<th>Csp (ml/kg)</th>
<th>MV (ml/kg)</th>
<th>I:E</th>
<th>FRC</th>
<th>VO2 (ml/kg)</th>
<th>CV (ml/kg)</th>
<th>P50 (mmHg)</th>
<th>RR</th>
<th>DS (ml/kg)</th>
<th>TV (ml/kg)</th>
<th>Shunt</th>
<th>(A-a)O2 (mmHg)</th>
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<td>Neonate</td>
<td>5</td>
<td>.05</td>
<td>220</td>
<td>1:1</td>
<td>30</td>
<td>6</td>
<td>12</td>
<td>18</td>
<td>40</td>
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<td>10%</td>
<td>25</td>
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<tr>
<td>Adult</td>
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<td>.05</td>
<td>100</td>
<td>1:2</td>
<td>30</td>
<td>3.3</td>
<td>7</td>
<td>27</td>
<td>13</td>
<td>2.2</td>
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<td>2-5%</td>
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**ABG:**

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<th>Prem</th>
<th>term</th>
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<th>1yr</th>
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<td>7.37</td>
<td>7.4</td>
<td>7.41</td>
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<td>PO2</td>
<td>60</td>
<td>70</td>
<td>95</td>
<td>93</td>
</tr>
<tr>
<td>PCO2</td>
<td>37</td>
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<td>41</td>
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<tr>
<td>HCO3</td>
<td>20</td>
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• airway resistance x15 higher in neonate :adult (25 vs 1.6cmH20/L/s)
• sites of resistance:
  • neonate =
    - nose 28%
    - upper airway 46%
    - LRT 26%
  • adult =
    - nose 62%
    - upper airway 34%
    - LRT 4%
• lung development:
  • @ birth = bronchial tree fully developed
  • alveoli ↑size & number until @ 8yrs old - surface area: 8 \[\Rightarrow\] 70m²
  • floppy chest walls \[\Rightarrow\] closing volume >FRC until age 6 when equal
    \[\Leftarrow\] \[:. \Rightarrow\] atelectasis & V/Q mismatch
• GA: diaphragm splinting \[\Rightarrow\] further ↓FRC
• diaphragm:
most impt mm for resp in neonate/infant

- <1yr old =
  - diaphragm inserts horizontally ∴ mechanically inefficient
  - only 30% type I fibres (slow twitch, high oxidative fibres)
    ↦ ∴ easily fatigued esp by ↑airway resistance or impaired function
  ↦ ∴ <1yr old should have controlled vent for all procedures

- breath pattern = sinusoidal with no exp pause
- TV = limited by horizontal rib cage ⇒ only way to ↑alveolar vent is by ↑ing RR
- preterm's have ↓response reflexes to ↓O2 & ↑CO2
  ⇒ norm in term babies
- I:E ratio of 1:1 + exp grunting = ways to provide ‘auto peep’

**Airway Changes**

- <1yr:
  - large head + occiput ⇒ ↑flex neck & potential obstruction (pharyngeal buckling)
  - tongue relatively large for oropharynx
  - genioglossus muscle v sensitive to anaesthetic ⇒ difficult airway
  - epiglottis =
    - large
    - floppy
    - U shaped
    ↦ straight blade
  - larynx:
    - higher - C3/4 (vs C5/6)
    - ant tilted
    - funnel shaped
    - cricoid = narrowest part of URT
  - trachea:
    - diam = 6mm (vs 14mm)
    - length - proportional to weight = av 5cm

**Renal**

(changes esp seen ↑ed in prems)
- full complement of nephrons @ 36/40 but:
  - ↓creat clearance:
    - RBF ~5% CO ⇒ ↓GFR
    - @1month RBF ~20%
    - GFR reaches adult level ~2yrs
  - ↓Na retention = obligate salt losers
    ⇒ but also poor capability of handling high salt loads
  - ↓diluting AND concentrating ability
  - ↓glucose excretion:
    - offset by tendency towards hypoglycaemia in neonates/prems/DM mother
  - ↓HCO3 reabsorption

**GIT**

- ↓pH & ↑gastric volume
- fasting may ⇒ ↑↑gastric volume
  ⇒ ∴ clear fluids upto 2hrs pre-op may ⇒ ↓gastric volume and ↑pH
- immaturity of neonatal liver enzymes - phase 1 & phase 2
**Body Fluid Composition in Neonate**

- neonate has more water/less fat than adult:
  - newborn = 75% water \(\Rightarrow\) preterm even higher @23wks = 90% water (60%ECF, 30%ICF)
    - 40% ECF = water
    - 35% ICF = water
  - adult = 60% water
    - 20% ECF = water
    - 40% ICF = water
- term newborns usually lose 5-10% of weight in 1st weeks of life which almost all = water loss
- insensible water loss:
  - route of loss:
    - 2/3 via evaporation
    - 1/3 via resp tract
  - ↑↑ed preterm = ↑↑ed insensible water loss
- Na & K levels as adults
  - ↓↑Na - usually 2nd to over or under hydration in relation to insensible water loss
  - ↑↓K linked to acid base: alkalosis \(\Rightarrow\) K into cell \(\Rightarrow\) hypokalaemia and vice versa
- Ca levels:
  - initially high 2.75 \(\Rightarrow\) ↓ing to 2.12mmol/L over 2-3 days
  - ionised Ca is more impt as is active form
  - hypocalcaemia:
    - early onset: prem baby with DM, perinatal asphyxia
    - late onset: high phosphate level (hypoparathyroid), maternal anticonvulsant, vit D def

**Fluid Requirements**

- Day of life:
  - day 1: 2ml/kg/hr = 50ml/kg/day
  - day 2: 3ml/kg/hr
  - day 3: 4,2,1 rule
- electrolytes:
  - Na 3-5mmol/kg/d
  - K 2-3mmol/kg/d
  - Cl 1-3mmol/kg/d
- peri-op glucose:
  - 120mg/kg/hr = enough to prevent hypoglycaemia

**Glucose Homeostasis**

- glucose rapidly transported across placenta via facilitated diffusion
  \(\Rightarrow\) ie no foetal glycogentic or GNG capacity
- foetal BSL ~70% of mothers
- 3rd trim: foetus prepares for fasting immed post birth
  - accumulates stores of fat & glycogen:
    - glycogen 9g @33wks, 34g @40wks
  - upregulate enzymes required for mobilisation of stores
- post birth:
  - rapid upregulation in 1st hr of life of GNG enzymes eg pyruvate carboxylase, glucose-6-phosphatase
• plasma glucose nadir 1-2hrs post op
• hormone changes:
  - ↓ insulin
  - ↑ glucagon, ↑ adrenaline, ↑ GH ⇒ glycogenolysis, lipolysis, GNG
• ↑ fatty acid oxidation ⇒ ↓ glucose utilisation ⇒ ↑ plasma glucose
• glycogen stores limited (4g/kg) ⇒ need to become GNG dependant - usually within 4-8hrs
  ←: premature babies with ↓ glycogen supplies will frequently become hypoglycaemic
  ⇒ signs: apnoea, seizures, cerebral damage
• BSL -
  - normal term neonate = 2.7-3.3
  - preterm = 2.2
• as feed switch to adult CHO metabolism ⇒ laying down ↑ ing glycogen stores to survive fasting
  with ↓ ing need for GNG & avoiding hypoglycaemia

CNS
• ↓ central control of resp - prems esp prone to apnoea’s
• ↓ ventilatory response to CO2 in prems (norm in term)
• 1MAC:
  • Halothane : neonate = .87 1-6months = 1.08
  • Isoflurane : - neonate = 1.6% 1-6m = 1.87
  - prem <32w =1.28 32-37w = 1.4
  • Sevo : - neonate - 6 month = 3.2 –3.3 6m-12 yr = 2.5

Thermoregulation
• = poikilotherms ie
  • large BSA:weight
  • more susceptible to temp changes 2nd to radiation, convection, evaporation
• thermoneutral zone = range of ambient temps where VO2 = minimum
  • prem = 34-36C
  • term = 32
  • adult = 28
• neutral temp (NT) = ambient temp where Vo2 minimum
  • prem = 34
  • term = 32
  • adult = 28
• critical temp (CT) = ambient temp where naked, non anaesthetised cannot maintain core temp:
  • prem = 28C
  • term = 23C
  • adult = 1C
• interthreshold range = range core temp between which no autonomic response triggered
• problems specific to neonates/infants:
  • large BSA
  • little insulating fat
  • open/flaccid posture
  • large head with big proportion of blood flow
  • decr central control of T reg
  • less able to compensate with behavioural mechanisms
  • large MV
• response to cold:
• behavioural (crying) ⇒ skin vasoC ⇒ non-shivering thermogenesis (NST) ⇒ ↑ mm activity/movement
  ⇝ 1st few days newborns cannot shiver
• ongoing cold stress ⇒
  - bradycardia
  - apnoea
  - hypoglycaemia
  - met acidosis

• NST =
  - includes (non restricted to) metabolism of brown fat
  - brown fat = specialised fat:
    - multinucleated cells
    - many mitochondria
    - abundant blood supply
    - abundant autonomic nerve supply
    - catecholamines mediate metabolism
    - substrate used mostly = FA’s
  - cold stimuli ⇒ NA release ⇒ uncoupling of oxidative phosphorylation ⇒ ↑ heat production / gram of fat (rather than ATP production)
  - no mechanical work done
  - brown fat found in:
    - abdomen esp perinephritic
    - around large blood vessels
    - interscapular area
    - base of neck
  - brown fat = 2-6% neonate total body weight
  - ↑ brown fat metab redirects CO to brown fat (by ↑~25%) ⇒ direct heating of blood as well
  - NST needs O2 ∴ cold & hypoxia = v bad
  - can double heat production in neonate (in adult has v little effect)

• response to heat:
  - behaviour (crying/remove clothing) ⇒ skin vasoD ⇒ sweating
    - prems - cannot sweat
    - neonates = limited sweat but compensated by large evap heat loss 2nd to ↑ ed BSA

Metabolism
• due to large BSA metabolism and its assoc parameters correlate better with BSA than weight
  ⇝ VO2, VA, CO
Specific Problems of Prematurity

- **Respiratory:**
  - Respiratory distress syndrome (∫ surfactant)
  - Bronchopulmonary displasia ⇒ chronic lung disease
  - Apnoea / periodic breathing
  - Persistant pulmonary HTN

- **CVS:**
  - PDA: premature ductus = less responsive to oxygen (may remain patent)

- **CNS:**
  - Intraventricular haemorrhages
  - Reduced cerebral autoregulation

- **GIT:**
  - GORD
  - NEC (associated with hypoxia)

- **Metabolic:**
  - Prone to hypoglycaemia (low glycogen stores)
  - Hypocalcaemia (immature parathyroid fx + low vit D stores)
  - Jaundice (poor hepatic conjugation + ↑ bilirubin load)

- **Skin:**
  - Fluid losses (thin epidermis, large SA ⇒ ↑ insensible losses)
  - Infection: immature immune system

Vitals Signs

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<tr>
<td>&gt;12</td>
<td>15-20</td>
<td>100-120</td>
<td>60-100</td>
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Systolic bp = 80 + (age x2)

- weight = (age * 2) +9 or (age +4) *2
- calculations of drug doses:
  - <30kg = BWTx2 = % of adult dose
  - >30kg = BWT +30 = % of adult dose