MATERNAL CHANGES

- **Fluids**
  - blood volume increases by ~ 30%,
    a. increase in plasma ~ 50% \( \propto \) aldosterone & oestrogen
    b. increase in RBC mass ~ 30%
  - \( \rightarrow \) decreased [Hb] & haematocrit
  - plasma Na\(^+\), K\(^+\) and Cl\(^-\) fall slightly
  - albumin, globulins & total protein increase, but plasma [I\(n\)'s decrease
  - the albumin/globulin ratio of 1.6:1 \( \rightarrow \) 1:1 at term
  - a hypercoagulable state exists due to,
    a. an increase in clotting factors I, VII, VIII, IX, X, and fibrinogen
    b. a decrease in antithrombin III
  - plasma cholinesterase decreases ~ 30% and continues to fall for several weeks postpartum

- **Cardiovascular**
  - cardiac output increases up to 40%, reaching a plateau at ~ 30/52
  - this is due to;
    a. an increase in SV & HR
    b. decreased TPR - uterine AV shunt - decreased viscosity

  \textit{NB:} net change \( \rightarrow \) slight decrease in BP

  - CVP changes little, except during labor and due to the effects of aortocaval compression \( \rightarrow \) decreased renal & placental function
  - oxygen flux increases despite the slight decrease in [Hb] and O\(_2\) content, due to the marked increase in CO
  - 2,3-DPG increases at term which improves unloading of O\(_2\) to the foetus
  - cardiac work is increased, which may \( \rightarrow \) LVF when there is poor cardiac reserve
  - increased blood flow to the epidural venous plexuses decreases spinal CSF volume
  - this decreases the volume of LA required for epidural anaesthesia
  - the valsalva maneuver during delivery may increase CSF turbulence and cephalad spread of anaesthetic ??
Uterine Circulation

- in the nonpregnant state, blood flow parallels the metabolic activity of the myometrium and endometrium, undergoing cyclic variations with the menstrual cycle
- during pregnancy, blood flow increases rapidly with the increasing uterus and foetus, producing up to ~20 fold increase
- early in pregnancy the $O_2$ extraction of the uterus is low
- therefore, some factor increases blood flow in excess of needs (? oestrogen)
- as the size, and requirements of the foetus increase >> than blood flow during pregnancy, the $O_2$ extraction ratio increases progressively with pregnancy
- early studies showed that just prior to parturition uterine blood flow decreased markedly
- this has now been shown to be due to aortocaval compression, and if this is avoided there is actually no change
- average blood loss during delivery:
  a. vaginal delivery ~ 200 ml
  b. episiotomy ~ 150 ml
  c. LSCS + GA ~ 1000 ml
  d. LSCS + epidural ~ 600 ml

Respiratory

** overall ~ 50% loss of respiratory reserve
  i. increased BMR
  ii. increased $O_2$ consumption
  iii. decreased FRC
  iv. decreased CVS reserve
  v. airway changes

- thus, on induction mothers become hypoxic quickly
- capillary engorgement → hoarse voice + greater nasal and upper airways obstruction
- therefore nasal intubation is generally avoided
- due to increased abdominal contents, the diaphragm is elevated and its maximal excursion decreased
- lung volumes decrease from about 5/52 and changes are exacerbated by the supine position,
  i. FRC decreases up to 25%
  ii. RV decreases up to 25%
  iii. ERV decreases up to 25%
  iv. TV increases up to 25%
  v. VC unchanged
  vi. IRV decreases up to 25%
the overall V/Q ratio decreases → increased $P_{A\text{O}_2}$
however, there is little change in $P_{A\text{CO}_2}$ as the $P_{A\text{aCO}_2}$ gradient increases
increased levels of progesterone → bronchodilation and decreased airways resistance
lung compliance is unaltered, though, chest wall compliance is increased
minute volume is increased, increase in TV > RR

** NB:**

\[
\begin{align*}
P_{A\text{O}_2} &= 105 \text{ mmHg} \\
P_{A\text{CO}_2} &= 32 \text{ mmHg}
\end{align*}
\]

\[\]

ratio of $V_t/V_T$ is unaltered

** importance for anaesthesia;
  a. intubation - bleeding, hypoxia, difficult
  b. decreased respiratory reserve - low $P_{A\text{O}_2}$ & FRC, high BMR
  c. induction - rapid due to lowered MAC, low FRC, high MV

**Hepatic Function**

• LFT's show a general increase due to enzyme induction
• liver blood flow is not altered significantly

**GIT**

• tone of the lower oesophageal sphincter decreases
• in addition, tone decreases with,
  a. narcotics
  b. anti-ACh agents
  c. diazepam
• this, together with increases in,
  a. gastric emptying - decreased by pain, drugs
  b. intragastric pressure - uterus, lithotomy
  c. gastric acidity

**NB:** greatly increased risk of aspiration (Mendelson's Synd)
- **Endocrine**

  earliest changes are increased levels of,
  a. oestrogen
  b. progesterone
  c. βhCG

  there are increases in the size of,
  a. thyroid - remain euthyroid
  b. parathyroid - PTH rises → increased Vit.D₃, increased Ca⁺⁺ absorption, decreased Ca⁺⁺ excretion
    - plasma [Ca⁺⁺] remains normal, the increase supplying foetus
  c. anterior pituitary → ACTH & PRL
  d. adrenals → cortisol & aldosterone

- **Metabolism**

  increases in BMR & O₂ consumption by ~ 25% at term
  O₂ consumption increases by 100% at delivery

- **Acid-Base Balance**

  there are small decreases in plasma levels of Na⁺, Cl⁻, Mg²⁺, & Ca²⁺
  plasma HCO₃⁻ decreases to ~ 21 mmol/l to compensate for increased ventilation
  therefore, mother has less buffer reserve

- **Renal**

  there is a progressive increase in GFR starting early in the first trimester
  urine volume increases due to the need to excrete a greater mass of waste products, mother + foetus
  both BUN and [Cr]pl decrease due to an increased creatinine clearance
  during the 3rd trimester there may be alterations of renal function due to aortocaval compression
  generally tone decreases and volume increases in the collecting system

  **NB:** predisposing to UTI's
FOETAL PHYSIOLOGY

<table>
<thead>
<tr>
<th>Placental Circulation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Normal Values</td>
</tr>
<tr>
<td>Weight</td>
</tr>
<tr>
<td>Lobules</td>
</tr>
<tr>
<td>Diffusion Distance</td>
</tr>
<tr>
<td>Surface Area</td>
</tr>
<tr>
<td>( P_{ma} )</td>
</tr>
<tr>
<td>Blood Flow(_m)</td>
</tr>
<tr>
<td>Blood Volume(_m)</td>
</tr>
<tr>
<td>RBC Transit Time</td>
</tr>
<tr>
<td>( P_{mO_2} )</td>
</tr>
<tr>
<td>( P_f )</td>
</tr>
<tr>
<td>Blood Flow(_f)</td>
</tr>
<tr>
<td>( P_{fO_2} )</td>
</tr>
</tbody>
</table>

- the placenta is effectively the "foetal lung"
- the maternal portion is a large blood sinus, or lake, into which project the foetal placental villi
- these contain the small branches of the umbilical arteries and vein (see Ganong, fig. 32-17)
- \( O_2 \), \( CO_2 \) and nutrient exchange occur across the cellular layers covering the villi
- these are thicker and less permeable than those for the lung and exchange is considerably less efficient

- **Foetal Circulation** *(See Ganong, Fig. 32-19)*

  - ~ 55% of the foetal CO supplies the placenta via the umbilical arteries, where \( S_{uO_2} \sim 60\% \)
  - umbilical vein \( S_{vO_2} \sim 80\% \) c.f. 98% of maternal arterial blood
  - of this, the majority passes through the liver, a small fraction passing directly into the IVC via the ductus venosus
  - the portal and systemic venous blood of the foetus \( \rightarrow S_{vO_2} \sim 26\% \)
  - the mixed venous blood in the IVC \( \rightarrow S_{vO_2} \sim 67\% \)
  - most of the blood entering the RA from the IVC passes directly into the LA via the patent foramen ovale
  - most of the blood entering the RA from the SVC passes into the pulmonary artery, then via the ductus arteriosus into the descending aorta

  *\( NB: \)*  the net effect being the head receives the better oxygenated blood
**Foetal Respiration**

- The tissues of foetal and newborn mammals have high resistance to hypoxia.
- Three factors aid in foetal transfer of $O_2$,
  - a. $[\text{HbF}] \sim 50\%$ greater than $[\text{HbA}] \rightarrow$ greater $[O_2]$ ml
  - b. HbF binds 2,3-DPG less effectively $\rightarrow$ left shift
  - c. "double" Bohr effect, $\rightarrow$ HbF-CO$_2$ $\rightarrow$ HbA-CO$_2$

**NB:** HbF-$O_2$ dissociation curve lies above and to the left,

\[
\text{HbF-}P_{50} = 19 \text{ mmHg} \quad \text{vs.} \quad \text{HbA-}P_{50} = 26 \text{ mmHg}
\]

- The total diffusing capacity of,
  - a. the placenta at birth $\sim 1.2 \text{ ml/O}_2/\text{min/mmHg}$
  - b. normal lung $\sim 20 \text{ ml/O}_2/\text{min/mmHg}$

- The gamma chains of HbF have the neutral amino acid valine at 143 & 146 position.
- The replacement of histidine in beta chains is the basis for the decreased binding affinity for DPG.
- Maternal 2,3-DPG increases near term, improving unloading of $O_2$ to the foetus.
- HbA begins to appear around the 20th week of foetal life and at birth constitutes $\sim 20\%$ of the circulating Hb.
- No HbF is formed after birth and by 4 months $> 90\%$ is HbA.

- As $CO_2$ is 20x more diffusible and $[\text{Hb}]$ gradient is high, diffusion does not present a problem.
- Maternal $P_{CO_2}$ is reduced by hyperventilation of pregnancy.

<table>
<thead>
<tr>
<th>Normal Values</th>
<th>Maternal</th>
<th>Foetal</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hb concentration</td>
<td>12 g/100ml</td>
<td>18 g/100ml</td>
</tr>
<tr>
<td>Blood flow</td>
<td>600 ml/min</td>
<td>300 ml/min</td>
</tr>
<tr>
<td>Uterine/Umbilical aa.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$P_{aO_2}$</td>
<td>95 mmHg</td>
<td>15 mmHg</td>
</tr>
<tr>
<td>$SaO_2$</td>
<td>97%</td>
<td>58%</td>
</tr>
<tr>
<td>$P_{aCO_2}$</td>
<td>35 mmHg</td>
<td>48 mmHg</td>
</tr>
<tr>
<td>Uterine/Umbilical vv.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$P_{O_2}$</td>
<td>33 mmHg</td>
<td>30 mmHg</td>
</tr>
<tr>
<td>$SvO_2$</td>
<td>50%</td>
<td>80%</td>
</tr>
<tr>
<td></td>
<td></td>
<td>thus the maternal capillary blood $P_{50} = 33 \text{ mmHg}$</td>
</tr>
</tbody>
</table>
- **Double Bohr Effect**
  
a. HbF loses CO₂ shifting its dissociation curve to the left
  
b. HbA gains CO₂ shifting its dissociation curve to the right
  
→ increases the gradient for oxygen diffusion

- **Foetal Oxygen Extraction**

\[ Q_{fo2} \approx \frac{(80-60)}{100} \times (18\, \text{g} \times 1.37) \times (300/100 \, \text{ml/min}) \]
\[ \approx 15 \, \text{ml.O₂/min} \]

- **Placental Oxygen Extraction**

\[ Q_{po2} \approx \frac{(97-50)}{100} \times (12\, \text{g} \times 1.37) \times (600/100 \, \text{ml/min}) \]
\[ \approx 46 \, \text{ml.O₂/min} \]

**NB:** the foetus uses only ~ 1/3 of the placental MRO₂

- **Other Placental Functions**

  a. active nutrient absorption - where \([x]_F > [x]_M\)
     - amino acids, Cr, PO₄
  
b. metabolism - various drugs by MFO's and Plasma-ChE
  
c. metabolic functions - stores Pr., Fe, Ca⁺⁺
     - acts ~ liver early until foetal liver est.
  
d. hormone synthesis - ßhCG
     - oestrogen
     - progesterone
     - hPL
NEONATAL PHYSIOLOGY

- **Distribution of the Foetal Cardiac Output**

![Diagram of foetal cardiac output distribution](image)
Circulatory Changes at Birth

- umbilical vessels have thick, muscular walls that are extremely reactive to trauma, tension, catecholamines, bradykinin, angiotensin and changes in $P_{O_2}$
- closure of these vessels $\rightarrow$ increase in foetal TPR and BP
- when flow through the umbilical vein ceases, the ductus venosus closes by an unknown mechanism
- asphyxia from the cessation of placental circulation and cooling of the body
  $\rightarrow$ activation of the respiratory centre of the newborn

- with inflation of the lungs, pulmonary vascular resistance falls to about $1/10^{th}$ of its intrauterine value
- this is not caused by the presence of $O_2$, as inflation with $N_2$ produces the same decrease in resistance
- the LA pressure rises above that of the RA and IVC due to;
  a. decrease in pulmonary resistance $\rightarrow$ increased LA filling
  b. decreased RA filling due to occlusion of the umbilical vein
  c. increased LV afterload due to closure of the umbilical arteries
  $\rightarrow$ abrupt closure of the foramen ovale & fusion in several days

- pulmonary arterial pressure falls to $1/2$ of its intrauterine value $\rightarrow$ 35 mmHg
- this change, plus the increase in aortic pressure, reverses flow through the ductus arteriosus
- however, within minutes the ductus begins to close producing turbulent flow
  $\rightarrow$ "murmur of the newborn"

- closure of the ductus is usually complete 1-2 days after birth, and appears to be initiated by the raised $P_{A02}$
- possible mediators being prostaglandins, bradykinin, or adenosine
- at birth, the two ventricles are about the same weight, having been pumping in parallel in the foetal circuit
- the arterioles of the pulmonary circuit are thick and muscular, maintaining the high pulmonary vascular resistance during foetal life
- after birth, the RV fails to grow to the same extent as the LV, the later becoming predominant and the muscular layer of the pulmonary vessels is lost
- these changes take several weeks
### Respiratory Changes at Birth

<table>
<thead>
<tr>
<th>Normal Values</th>
<th>At Birth</th>
<th>Adult</th>
</tr>
</thead>
<tbody>
<tr>
<td>Respiratory Rate</td>
<td><strong>30-40 bpm</strong></td>
<td>15 bpm</td>
</tr>
<tr>
<td>Tidal Volume, TV</td>
<td>7.0 ml/kg (~20 ml)</td>
<td>same (~500 ml)</td>
</tr>
<tr>
<td>Minute Volume, $V_M$</td>
<td><strong>230 ml/kg/min</strong></td>
<td>70 ml/kg/min</td>
</tr>
<tr>
<td>Vital Capacity, VC</td>
<td>40 ml/kg</td>
<td>50-60 ml/kg</td>
</tr>
<tr>
<td>FRC</td>
<td>27-30 ml/kg</td>
<td>30 ml/kg</td>
</tr>
<tr>
<td>Physiological $V_t/V_T$</td>
<td>0.3-0.5</td>
<td>0.3</td>
</tr>
<tr>
<td>Physiological $Q_S/Q_T$</td>
<td><strong>0.1 (10%)</strong></td>
<td>0.01-0.03 (1-3%)</td>
</tr>
<tr>
<td>Lung Compliance, Specific</td>
<td>0.067 l/cmH$_2$O/l</td>
<td>same</td>
</tr>
<tr>
<td></td>
<td>67 ml/cmH$_2$O/l</td>
<td></td>
</tr>
<tr>
<td>Lung Compliance, Absolute</td>
<td><strong>0.005 l/cmH$_2$O/ml</strong></td>
<td>0.100 l/cmH$_2$O/ml</td>
</tr>
<tr>
<td></td>
<td>5 ml/cmH$_2$O/ml</td>
<td>100 ml/cmH$_2$O/ml</td>
</tr>
<tr>
<td>Compliance, chest wall</td>
<td><strong>0.26 l/cmH$_2$O/l</strong></td>
<td>0.06 l/cmH$_2$O/l</td>
</tr>
<tr>
<td></td>
<td>260 ml/cmH$_2$O/l</td>
<td>60 ml/cmH$_2$O/l</td>
</tr>
<tr>
<td>Total Pulmonary Resistance</td>
<td><strong>30-50 cmH$_2$O/l/s</strong></td>
<td>4-5 cmH$_2$O/l/s</td>
</tr>
<tr>
<td></td>
<td>~10x adult</td>
<td>~5x adult</td>
</tr>
<tr>
<td>Mean Time Constant (tau)</td>
<td>0.12 s</td>
<td>0.5 s</td>
</tr>
<tr>
<td>$PaO_2$ (NB: $Q_S/Q_T$)</td>
<td>65-80 mmHg</td>
<td>98 mmHg</td>
</tr>
<tr>
<td>$PaCO_2$</td>
<td>34 mmHg</td>
<td>40 mmHg</td>
</tr>
<tr>
<td>$O_2$ consumption</td>
<td><strong>7.0 ml/kg/min</strong></td>
<td>3.5 ml/kg/min</td>
</tr>
<tr>
<td></td>
<td>(thermonutral)</td>
<td></td>
</tr>
</tbody>
</table>

Airways Resistance:  
- high, proportional to $1/r^4$
- obligate nose breather

Compliance:  
- similar in infants/adults
  → *increased work of breathing*

\[ \text{the increased RR acts to decrease the work of breathing, increased due to}
\]
  
  a. lower compliance of chest wall
  b. the higher oxygen consumption
Respiratory Changes At Birth

<table>
<thead>
<tr>
<th>Element</th>
<th>Appearance</th>
<th>Maturation</th>
</tr>
</thead>
<tbody>
<tr>
<td>bronchi</td>
<td>16/52</td>
<td>~ 23/52</td>
</tr>
<tr>
<td>alveoli</td>
<td>17/52</td>
<td>post-partum</td>
</tr>
<tr>
<td>surfactant</td>
<td>24/52*</td>
<td>~ 36/52</td>
</tr>
</tbody>
</table>

* composition is different and production is unstable until 36/52

L/S ratio increases to 2:1 at term

production is decreased with stress, hypoxia, acidosis, etc.

- production is decreased with stress, hypoxia, acidosis, etc.
- stimulus to first breath includes circulatory changes, (raised TPR), and physical stimuli such as cold, pain, voices, etc.
- with the first gasps against the low compliance, lung PIP reaches -60 cmH₂O
- however this rapidly decreases as the lung expands and compliance increases

Intubation

- poor tone of the neck muscles and the large head → "floppy"
- high position of the larynx
- "V-shaped", highly mobile epiglottis
- the cricoid area is narrow, therefore use uncuffed tubes
- the trachea only 4 cm long, therefore tube easily dislodged, or positioned in right main bronchus
- relatively large nose → nasal and oropharyngeal airways ~ the same diameter
## Renal Changes

<table>
<thead>
<tr>
<th>Normal Values</th>
<th>Neonate</th>
<th>Adult</th>
</tr>
</thead>
<tbody>
<tr>
<td>GFR</td>
<td>10-20 ml/min/m^2</td>
<td>60-80 ml/min/m^2</td>
</tr>
<tr>
<td>· premature</td>
<td>0.7-0.8 ml/min/m^2 (70kg → 1.7m^2)</td>
<td></td>
</tr>
<tr>
<td>· at birth</td>
<td>1-2 ml/min/m^2</td>
<td></td>
</tr>
<tr>
<td>· at 1 month</td>
<td>50 ml/min/m^2</td>
<td></td>
</tr>
<tr>
<td>Maximum Urine Concentration</td>
<td>450-600 mosmol/l</td>
<td>1400 mosmol/l</td>
</tr>
<tr>
<td>Plasma Creatinine</td>
<td>· maternal at birth</td>
<td>· male ~ 55-120 µmol/l</td>
</tr>
<tr>
<td>· infant</td>
<td>~ 18-35 µmol/l</td>
<td>· female ~ 45-95 µmol/l</td>
</tr>
<tr>
<td>· child</td>
<td>~ 30-60 µmol/l</td>
<td>· pregnant ~ 30-80 µmol/l</td>
</tr>
<tr>
<td>· youth</td>
<td>~ 45-90 µmol/l</td>
<td></td>
</tr>
<tr>
<td>pH</td>
<td>7.35</td>
<td>7.4</td>
</tr>
<tr>
<td>[HCO_3^-]</td>
<td>20 mmol/l</td>
<td>25 mmol/l</td>
</tr>
</tbody>
</table>

1 decreases due to low muscle mass and high rate of anabolism

- the renal cortex is relatively underdeveloped at birth
- this reaches maturity by 12-18 months
- urea excretion is always low due to protein anabolism
- there is limited excretion/conservation capability of the kidney for salt, water and acid-base alterations
- renal drug excretion is decreased, e.g. tubular secretion of penicillin is low due to underdeveloped active tubular transport systems

## Fluid Requirements

<table>
<thead>
<tr>
<th>Body Compartment Volumes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Normal Values</td>
</tr>
<tr>
<td>Total Body Water</td>
</tr>
<tr>
<td>ECF</td>
</tr>
<tr>
<td>ICF</td>
</tr>
<tr>
<td>Blood Volume</td>
</tr>
<tr>
<td>H_2O/day</td>
</tr>
<tr>
<td></td>
</tr>
</tbody>
</table>

1 increases until 6/52, then decreases to adult values
### Daily Calculation Of Fluid Requirements

<table>
<thead>
<tr>
<th>Weight</th>
<th>Water Requirement</th>
<th>Cumulative Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 to 10 kg</td>
<td>100 ml/kg</td>
<td>1000 ml</td>
</tr>
<tr>
<td>10 to 20 kg</td>
<td>50 ml/kg</td>
<td>500 ml</td>
</tr>
<tr>
<td>20 &amp; over</td>
<td>20 ml/kg</td>
<td>?? ml</td>
</tr>
</tbody>
</table>

1. daily kcal can be substituted in the same formula

2. → 2500 ml for a 70 kg male

---

**Temperature Regulation**

- **Deficits In Regulation:**
  - a. minimal hypothalamic control of - cutaneous vasomotor tone
    - sweating
  - b. high SA/weight ratio ~ 2x adult
  - c. high evaporative losses - high RR & MV
  - d. inability to take evasive action

- **Gains In Regulation:**
  = posses "brown fat" → heat production by the uncoupling of oxidative phosphorylation in increased number of mitochondria
  - this is present in the neck, back, axillae, inguinal regions and around the kidneys
  - activity is mediated by the action of NA on β-receptors
  - this requires an increased O₂ consumption ~ 60%
  - neither neonates, nor adults, can temperature regulate via white fat

**NB:** → neonates must be kept in thermoneutral zone

~ 32-35 °C naked, or
~ 24 °C clothed