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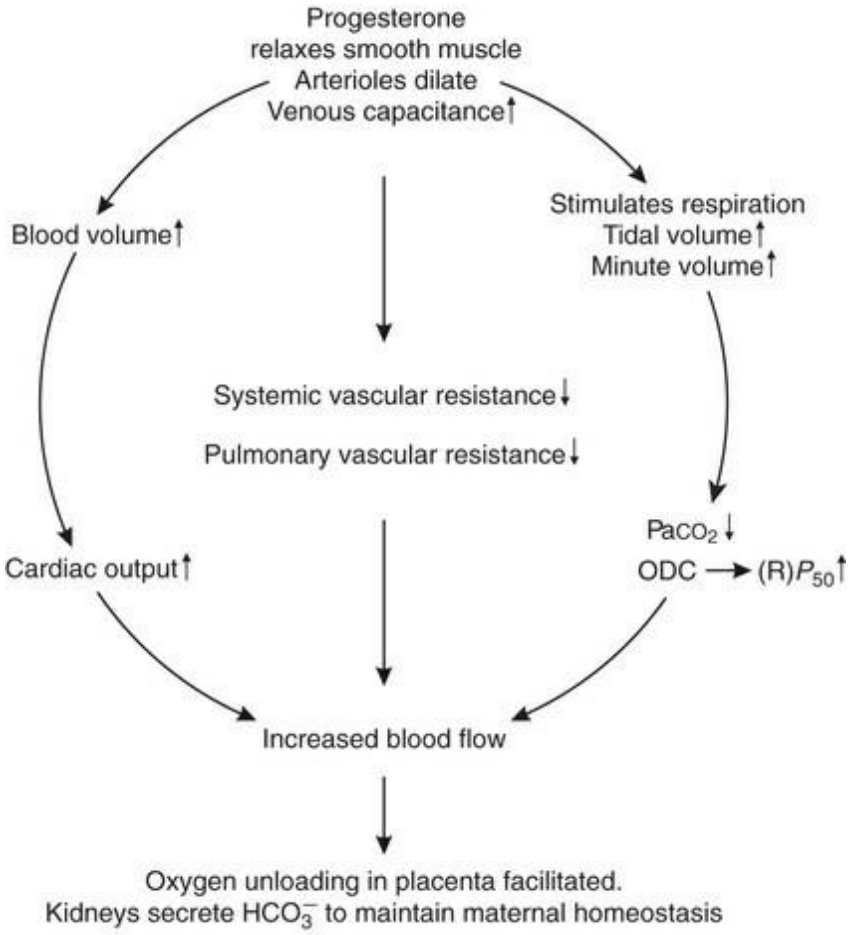
Title: Anatomy and Physiology of Pregnancy

Anatomy and Physiology of Pregnancy

The obstetric anaesthetist must understand maternal adaptation to pregnancy in order to manipulate physiological changes after general anaesthesia or regional analgesia and anaesthesia in such a way that the condition of the neonate at delivery is optimised. The physiological changes of pregnancy are exaggerated in multiple pregnancy.

Progesterone

Progesterone is the most important hormone in pregnancy. It is secreted in increasing amounts during the second half of the menstrual cycle to prepare the woman for pregnancy. After conception, the corpus luteum ensures adequate blood concentrations until placental secretion is adequate. The key physiological role of progesterone is its ability to relax smooth muscle. All other physiological changes stem from this pivotal function.



Haemodynamic changes

Variable	Change	Proportional change
Heart rate	Increased	20%–30%
Systolic blood pressure	Decreased	10%–15% 2.nd trimester
Diastolic blood pressure	Decreased	
Stroke volume	Increased	20%–50%
Cardiac output	Increased	40%–50% 3.rd trimester
Systemic vascular resistance	Decreased	20%
Pulmonary vascular resistance	Decreased	30%

Cardiovascular changes in pregnancy

• Blood volume increases from 65–70 to 80–85 ml kg^{-1} mainly by expansion of plasma volume (maximal at 30–32 weeks).
• Systemic and pulmonary vascular resistance are markedly decreased; this allows the increased blood volume to be accommodated at normal vascular pressures.

Aortocaval compression

When a pregnant woman lies supine, arterial pressure decreases because the gravid uterus compresses the inferior vena cava, reducing venous return and therefore cardiac output. At term, the vena cava is completely occluded in 90% of pregnant women, and stroke volume may only be 30% of that of a non-pregnant woman. The aorta is also often compressed, so femoral arterial pressure may be lower than brachial arterial pressure; this is the main cause of a reduction in uterine blood flow. The combination of both effects is known as aortocaval compression, which becomes clinically significant from around 20 weeks. Physiological compensation occurs via sympathetic stimulation and collateral venous return via the vertebral plexus and azygous veins. The effect of aortocaval compression varies from asymptomatic mild hypotension to cardiovascular collapse and is usually prevented or relieved by left tilt or wedging, although complete lateral position is required in some cases.

Regional blood flow

Blood flow to various organs increases, especially the uterus and placenta, where it rises from 85 to 500 ml min^{-1}. Blood flow to the nasal mucosa is increased. Nasal intubation may be associated with epistaxis. There is a considerable increase in blood flow to the skin, resulting in warm, clammy hands and feet. This vasodilatation, together with that in

the nasal mucosa, helps dissipate heat from the metabolically active fetoplacental unit.

Respiratory changes

Respiratory function undergoes several important modifications as a result of the actions of progesterone.

Variable	Non-pregnant	Term pregnancy
Tidal volume ↑	450 ml	650 ml
Respiratory rate	16 min^{-1}	16 min^{-1}
Vital capacity	3200 ml	3200 ml
Inspiratory reserve volume	2050 ml	2050 ml
Expiratory reserve volume ↓	700 ml	500 ml
Functional residual capacity ↓	1600 ml	1300 ml
Residual volume ↓	1000 ml	800 ml
PaO_2 slight ↑	11.3 kPa	12.3 kPa
$PaCO_2$ ↓	4.7–5.3 kPa	4 kPa
pH slightly ↑	7.40	7.44

espiratory changes in pregnancy

• The larger airways dilate, and airway resistance decreases.
• There are increases in tidal volume (from 10–12 weeks' gestation) and minute volume (by up to 50%).
• Progesterone exerts a stimulant action on the respiratory centre and carotid body receptors.
• Alveolar hyperventilation leads to a low arterial carbon dioxide tension ($PaCO_2$) during the second and third trimesters.
• The respiratory alkalosis is accompanied by a decrease in plasma bicarbonate concentration resulting from renal excretion. Arterial pH does not change significantly.
• The oxyhaemoglobin dissociation curve is shifted to the right because the increase in red cell 2,3-diphosphoglycerate (2,3-DPG) concentration outweighs the effects of a low PCO_2, which would normally shift the curve to the left.
• The double Bohr and double Haldane effects maintain efficiency of gas transfer.
• The functional residual capacity (FRC) and residual volume are reduced at term because of the enlarged uterus. Alveolar and arterial hypoxia develop more quickly than normal during apnoea or airway obstruction.
• Oxygen consumption ($V\dot{O}2$) increases gradually from 200 to 250 ml min^{-1} at term (up to 500 ml min^{-1} in labour). Carbon dioxide production parallels oxygen consumption.

Overall, several changes occur in pregnancy that contribute to airway difficulty and an increased rate of development of hypoxaemia during apnoea:

- Interstitial oedema of the upper airway, especially in pre-eclampsia.
- Enlarged tongue and epiglottis.
- Enlarged, heavy breasts that may impede laryngoscope introduction.
- Increased oxygen consumption.
- Restricted diaphragmatic movement, reducing functional residual capacity (FRC).

Renal changes

Measure	Non-pregnant	Pregnant
Urea (mmol L−1)	2.5–6.7	2.3–4.3
Creatinine (μmol L−1)	70–150	50–75
Urate (μmol L−1)	200–350	150–350
Bicarbonate (mmol L−1)	22–26	18–26
24-h creatinine clearance		Increased

Renal changes in pregnancy

Renal blood flow is increased . By 10–12 weeks, glomerular filtration rate (GFR) has increased by 50% and remains at that concentration until delivery. Glycosuria often occurs because of decreased tubular reabsorption and the increased load. The renal pelvis, calyces and ureters dilate as a result of the action of progesterone and intermittent obstruction from the uterus, especially on the right.

Gastrointestinal changes

Gastrointestinal changes also stem from the effects of progesterone on smooth muscle. A reduction in lower oesophageal sphincter pressure occurs before the enlarging uterus exerts its mechanical effects. These mechanical effects are greater when there is multiple pregnancy, hydramnios or morbid obesity. A history of heartburn denotes a lax gastro-oesophageal sphincter. Increased gastric acidity together with the sphincter pressure changes makes regurgitation and inhalation of acid gastric contents more likely to cause pneumonitis in pregnancy. Gastric emptying is delayed during labour but returns to normal by 18 hr. after delivery. Thus women are at risk of regurgitation of gastric contents during this time. Pain, anxiety and systemic opioids aggravate gastric stasis. Small and large intestinal transit times are increased in pregnancy and may result in constipation.

Changes in liver function and blood tests are summarised in the table below. Liver blood flow is notincreased.

Measure	Change in pregnancy
Albumin	Decreased
Alkaline phosphatase	Increased (from placenta)
ALT/AST	No change
Plasma cholinesterase	Decreased

Liver function and enzyme changes in pregnancy

Haematological changes

Variable	Non-pregnant	Pregnant
Haemoglobin (g dl^{-1})	140	120
Haematocrit	0.40–0.42	0.31–0.34
Red cell count (L^{-1})	4.2×10^{12}	3.8×10^{12}
White cell count (L^{-1})	6.0×10^{9}	9.0×10^{9}
Erythrocyte sedimentation rate	10	58–68
Platelets (L^{-1})	$150–400 \times 10^{9}$	$120–400 \times 10^{9}$

Haematological changes associated with pregnancy

• Red cell volume increases linearly but not as much as plasma volume, which results in decreased haematocrit (physiological anaemia of pregnancy).
• Decreased haematocrit promotes blood flow by reducing the blood viscosity.
• Cell-mediated immunity is depressed.
• There is an increase in platelet production, but the platelet count falls because of increased activity and consumption. Platelet function remains normal.
• Haematological changes return to normal by the sixth day after delivery.

Coagulation

Pregnancy induces a hypercoagulable state. Coagulation and fibrinolysis generally return to pre-pregnant levels 3–4 weeks postpartum. These changes are summarised as:
• There is an increase in the majority of clotting factors, a decrease in the quantity of natural anticoagulants and a reduction in fibrinolytic activity.
• Bleeding time, prothrombin time and partial thromboplastin time remain within normal limits.
• The increase in clotting activity is greatest at the time of delivery, with placental expulsion releasing thromboplastic substances. These substances stimulate clot formation to stop maternal blood loss.

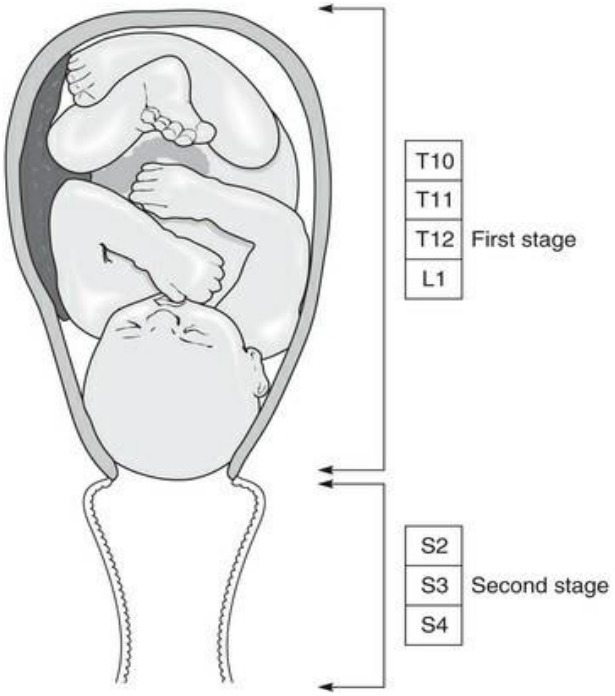
The epidural and subarachnoid spaces

In pregnancy the epidural veins are dilated by the action of progesterone. These valveless veins of Batson form collaterals and become engorged as a result of aortocaval compression during a uterine contraction. Spread of local anaesthetic in either the subarachnoid or epidural space is more extensive as a result of the reduced volume. Thus, the dose of local anaesthetic for epidural analgesia or epidural/subarachnoid anaesthesia is reduced by about one third. Progesterone-induced hyperventilation leads to a low $PaCO_2$ thus local anaesthetic drugs remain as free salts for longer periods.

During contractions, the pressure in the subarachnoid and epidural space becomes very high. Consequently, it is advised not to advance an epidural needle, insert epidural catheters or administer epidural top-ups at that time.

Pain pathways in labour and caesarean section

The pain of the first stage of labour is referred to the spinal cord segments associated with the uterus and the cervix, namely T10–12 and L1. Pain of distension of the birth canal and perineum is conveyed via S2–4 nerves. It is important to remember that the most sensitive layer is the peritoneum, and therefore the block should extend up to at least T4.



Nerve supply to the uterus and birth canal

The placenta

The placenta is both a barrier and link between the fetal and maternal circulations. Fetal well-being depends on placental blood flow. Placental blood flow depends on the perfusion pressure across the intervillous space and the resistance of the spiral arteries. The spiral and uterine arteries possess α-adrenergic receptors. Placental perfusion is reduced by a reduction in cardiac output (e.g. haemorrhage) or uterine hypertonicity (e.g. overstimulation with Syntocinon).

Functions of the placenta

1) Transport of respiratory gases.

2) Production of Hormones: Human chorionic gonadotrophin (hCG) production commences very early in pregnancy and peaks at 8–10 weeks. It stimulates the corpus luteum to secrete progesterone. Human placental lactogen (hPL) has similar effects to growth hormone and causes maternal insulin resistance. Oestrogens are secreted by the placenta and have a role in breast and uterus development. Progesterone is secreted by the placenta.

3) Immunological: The placenta modifies the fetal and maternal immune system so that the fetus is not rejected. Immunoglobulin G (I gG) is transferred across the placenta and confers some passive immunity but may also produce disease.

4) Placental transfer of drugs: Placental transfer of lipophilic drugs occurs by passive diffusion through cell membranes. However, hydrophilic molecules transfer at a rate that is around 100,000 times lower.

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GOOD LUCK

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