

## Obstetric and foetal physiology – implications for clinical practice in obstetric analgesia and anaesthesia

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### Summary

Physiological changes in the parturient occur due to the needs of the developing foetus. Understanding these changes is important when administering anaesthesia to the obstetric patient. Additionally, understanding the physiological effects in the foetus allows for appropriate intrauterine monitoring and expedient delivery if there are signs of foetal hypoxia.

### INTRODUCTION

Physiological changes occur in the expectant mother very soon after conception. These changes ensure that her increased needs are met, as well as the needs of the zygote as it replicates into the complex foetus. All the physiological changes require additional energy, which for the developing foetus are completely met through placental transfer from the mother.

### PHYSIOLOGICAL CHANGES IN THE PARTURIENT TO MEET THE FOETAL NEEDS<sup>1,2</sup>

#### *Respiratory system*

The respiratory system ensures the increased oxygen demands from both the mother and foetus are met. Similarly, the increased amount of carbon dioxide from increased cell metabolism also needs to be excreted. The minute volume increases early on in pregnancy, achieved by a 60% increase in tidal volume and a 15% increase in respiratory rate. The increase in minute ventilation results in a decrease in arterial carbon dioxide tension to approximately 4kPa/30mmHg, causing a respiratory alkalosis with a compensatory increase in renal bicarbonate excretion. As the gravid uterus grows, there is significant reduction in functional residual capacity and compliance of the respiratory system resulting in an increased work of breathing. The functional residual capacity can be further reduced in the supine position hence, subjecting the mother to an increase risk of desaturation under anaesthesia as a result of decreased respiratory reserves.

Airway manipulation is fraught with risk in the pregnant patient. Oedema present throughout the body is also seen in the upper airways; resulting in a 10-fold likelihood of a difficult airway and hence

of a difficult intubation/failed airway during the induction of anaesthesia for caesarean section. The increase in oxygen demand and the reduction of functional residual capacity further shortens the time to desaturation during periods of apnoea. Hence adequate time for pre-oxygenation with a well-sealed face mask needs to be observed and most would recommend up to 3 minutes, if time allows. Nursing the patient in a reverse Trendelenberg (head-up) position of between 15-20 degrees, ramping and supplemental oxygen via a nasal prong cannulae (in addition to the face mask) during pre-oxygenation are methods that can be considered to counteract these potential difficulties. Once the airway is secured, higher airway pressures are usually needed as a result of the decreased chest wall compliance.

The potential for a difficult airway and rapid desaturation on induction of anaesthesia have contributed to the worldwide change towards the use of regional anaesthesia instead of general anaesthesia for caesarean section.

#### *Cardiovascular system*

Maternal blood vessels dilate as a result of the high progesterone levels in pregnancy, resulting in a drop in systemic vascular resistance. Cardiac output increases by up to 40-50% at term. The increased cardiac output is accomplished by an increase in heart rate and stroke volume. Flow is increased to most organs including the kidneys and the uterus. Blood flow to the kidneys increases by up to 80%. The blood flow to the uterus is approximately 750mls/min at term and this is responsible for the likelihood of massive hemorrhage occurring from placenta previa/accreta or atonic uterus in the period around delivery.

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Blood volume increases due to activation of the renin-angiotensin system. As the red cell mass increase is less than plasma volume expansion, dilutional physiological anaemia occurs.

### ***Gastrointestinal system***

The progression of pregnancy with increasing fundal height results in displacement of the stomach altering the gastric axis and increasing intra-gastric pressure. Furthermore, decreased lower oesophageal sphincter tone due to progesterone compounds the risk of aspiration. Thus, all mothers must be managed as if they have a full stomach despite having an adequate fasting time. As the acidity of the gastric fluid is the main culprit of lung injury, the use of non-particulate antacids (e.g. Sodium Citrate) and H<sub>2</sub> antagonists (such as Ranitidine) plus possibly a prokinetic (e.g. Metoclopramide) when general anaesthesia is being provided should be considered.

### ***Coagulation system***

In preparation for delivery, the coagulation system produces a hypercoagulable state in order to prevent haemorrhage. Unfortunately, this hypercoagulable state predisposes the mother to an increased risk of thromboembolic disease. The gravid uterus can also impede the venous system in the lower limbs, further increasing the risk of deep vein thrombosis (DVT). Deep vein thrombosis and pulmonary embolism (PE) remain important causes of morbidity and mortality for all pregnancies.

### ***The immune system***

An altered immune competence exists in pregnancy in order to allow “tolerance” of the presence of paternal antigen in foetoplacental tissue. This also results in higher predisposition to the development of sepsis and all care providers should be aware of this as a significant cause of morbidity or mortality in the parturient.

## **DIFFICULTIES WITH OXYGEN DELIVERY IN THE FOETUS**

Every year 2.7 million babies die in utero as stillbirths. In comparison, approximately 303,000 parturients die during pregnancy or in the peripartum period.<sup>3</sup> The disproportionately higher number of foetal deaths is due to the difficulty in oxygen transfer to the foetus from the mother. Oxygen inhaled by the mother crosses the placenta into the foetus and distributed via the foetal circulation.

### ***Meeting the needs of the foetus***

After conception, before the embryo is attached to the uterus, the oxygen and energy needs of the blastomere stage of the embryo are met just by diffusion alone.<sup>4,5</sup> After the embryo has attached to the uterus, the needs of the foetus are met by the growing placenta.<sup>6</sup> The placenta supplies oxygen and nutrients to the foetus and removes carbon dioxide and other waste products.

The physiological needs of the growing foetus are usually completely met by the mother. However, parturients with impaired function of the respiratory<sup>7</sup>, cardiovascular<sup>8</sup> or hematological<sup>9</sup> systems find it more difficult to accommodate the physiological needs of delivering oxygen and energy to the foetus, especially towards term. If the oxygen and energy needs of the growing foetus are not met, it fails

to grow to its potential and may be small for gestational age. This is commonly seen in parturients with chronic problems with oxygen and energy delivery, such as pre-eclampsia, smoking, anaemia, respiratory or cardiac disease. It can also be seen in babies born to mothers living at high altitude.<sup>10</sup> If the mothers and their ancestors live at high altitude over many generations, the ability to have normal sized babies improves – possibly as a result of adaptation over the generations to the chronic hypoxia.

### ***Signs of poor oxygen and energy deliveries***

More acute deficiencies in delivery of oxygen and nutrients to the foetus can result in adverse outcomes and may be felt as decreased foetal movement.<sup>11</sup>

This can be seen nearer term when the blood flow in the placenta is decreased or when the parturient has multiple pregnancies and demand outstrips supply.

Foetal bradycardia represents an absolute sign of inadequate supply of oxygen (and energy) to the foetal myocardium. In those foetuses who are already at the extreme stages of coping with hypoxia, contraction of the uterus may inflict a further compromise in oxygen delivery<sup>12,13</sup> as the uterine blood flow needs to traverse the uterine muscle before it arrives at the placenta. Foetal bradycardia especially when seen in early labour should alert the provider to be more vigilant in a suspected hypoxic baby and may warrant increased monitoring with a cardiotocograph. Foetal bradycardia which persists even without contraction of the uterus represents a reduced ability to cope with hypoxia than those who only develop bradycardia when there are uterine contractions.

## **MECHANISMS IN THE FOETUS TO COPE WITH HYPOXIA**

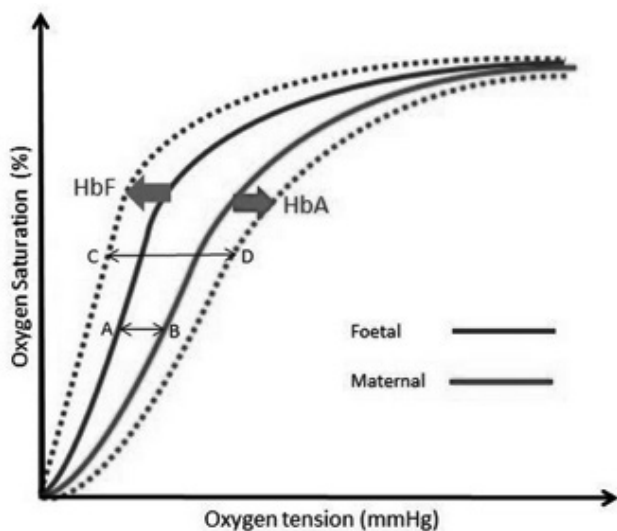
### ***Foetal hemoglobin***

Due to the relative hypoxia in which the foetus develops, there are several mechanisms that allow it to cope in such an environment.<sup>14,15</sup> The foetus has hemoglobin with higher affinity for oxygen - HbF. Unlike HbA in adults, which has 2- $\alpha$  and 2- $\beta$  globin chains, HbF has 2- $\alpha$  and 2- $\gamma$  chains. Its higher affinity for oxygen allows oxygen to transfer from maternal haemoglobin to foetal haemoglobin even at very low differences in oxygen tensions. In addition, the newborn baby's hemoglobin averages about 16-18g.dL<sup>-1</sup> compared to the average adult's haemoglobin concentration of 12-15g.dL<sup>-1</sup>. The higher hemoglobin level enables the foetus to have increased oxygen carrying capacity.

### ***Double Bohr Effect***

Oxygen diffuses across the uterine vessels of the parturient to the umbilical vessels of the foetus in the placenta. Unlike in adult lungs, the diffusion of oxygen across the placenta is less efficient as the surface area is smaller and the diffusion thickness is higher.<sup>16</sup> The diffusion gradient for oxygen across the placenta is also relatively small, unlike the oxygen gradient found in the adult lung.

The “double Bohr” effect facilitates the transfer of oxygen across the placenta (see Figure 1). Carbon dioxide produced by the foetus diffuses across the placenta to the mother. The increased partial pressure of carbon dioxide on the maternal side shifts the maternal



**Figure 1:** The Bohr effects are represented by the shift from the complete lines to the dotted lines. At the placenta level, the gradient for diffusion of oxygen (without the Bohr effects) is represented by the oxygen tension difference BA. With the Double Bohr effects, the gradient is increased to the oxygen tension difference DC.

oxyhaemoglobin dissociation curve to the right whilst the lower carbon dioxide levels on the foetal side shifts the HbF curve to the left. Thus, the transfer of oxygen across the placenta is increased from the mother to the foetus.

### Redistribution of blood

Hypoxia in the foetus like hypoxia in the adult will see redistribution of blood flow in the foetus in such a way that blood flow to the brain and the heart are prioritized whilst those of other less important organs, such as the gut and kidneys, get reduced blood flow.<sup>17</sup>

## AVOIDING ACUTE AND CHRONIC HYPOXIA IN THE FOETUS

### Avoiding supine hypotension syndrome in the parturient

Knowledge of foetal and maternal physiology allows us to maximize oxygen delivery to the foetus through the mother. By 20 weeks gestation, the uterus is large enough to compress the inferior vena cava if the parturient is placed in the supine position, which reduces venous return and cardiac output.<sup>18,19</sup> The compression may not be limited to the vein as it may also compress the aorta. Compression of the aorta will further decrease flow to the placenta and aggravate the situation of poor oxygenation in the foetus. Supine hypotension most commonly occurs immediately pre-delivery following the administration of an epidural or a spinal injection (where the hypotension is more pronounced due to the vasodilation in the lower

limbs after the regional blockade. However, it can be a significant problem for most parturients in the later weeks of pregnancy. Therefore, all parturients should be encouraged to lie on the left or right side or with a left lateral tilt when lying down.

### Avoiding severe anaemia in the parturient

Anaemia is a burden in parturients from low resource countries, where iron deficiency may commonly occur.<sup>9</sup> With reduced hemoglobin, the impact on the growth of the foetus is even more severe if they have the additional burden of preeclampsia – both of which can impair oxygen and energy delivery to the foetus.

### Avoiding the use of excessive doses of uterotonics

Whilst uterotonics administered after the delivery of the shoulder is to be encouraged to prevent post delivery atonia of the uterus, excessive doses of uterotonics during the labor itself may predispose to hypertonia that can compromise the oxygen delivery of the foetus.<sup>20</sup> When a parturient is administered uterotonics to accelerate and facilitate delivery, the foetal heart should be monitored. The foetal heart rate is a sensitive monitor to alert the care provider about the existence of foetal hypoxia.

## HYPOXIA AND THE URGENCY TO EXTRICATE THE FOETUS

As the foetus is constantly in a state of relative hypoxia, a slight imbalance compromising its oxygen supply warrants a hastened delivery through the performance of an instrumental delivery or emergency lower segment caesarean section. Life threatening hypoxia causes profound fetal bradycardia and may be due to situations where the oxygen delivery is acutely interrupted e.g. placental abruption or prolapsed cord.

### In utero resuscitation

While waiting for urgent delivery, in utero resuscitation of the foetus should be performed. Such measures include nursing the mother in the left lateral position, which ensures a non-compromised blood supply to the foetus by preventing aortocaval compression.<sup>22</sup> Supplemental oxygen provided to mother, indirectly increases the supply to the foetus. Tetanic or hyperstimulation of the uterus caused by uterotonics, which impedes blood flow to the placenta, should be stopped. Adequate hydration of the mother may also be beneficial.<sup>20</sup>

### Foetal blood sampling

The sampling of foetal scalp blood during labor or cord blood during delivery gives an indication of the level of foetal compromise prior to delivery and at the time of delivery respectively.<sup>23</sup> The uteroplacental status is primarily dependent on the maternal condition and is reflected by the umbilical vein sampling. Examples are the presence of maternal anaemia, hypoxia, hypertension, hypotension, ruptured

**Table 1:** The accepted normal range of parameters of umbilical arterial blood sample.

	pH	PCO2 (mmHg)	HCO3 (mmol/L)	PO2(mmHg)	Base Excess(mmol/L)
<b>Newborn</b>	7.18 – 7.38	32 – 66	17 – 27	6 – 31	- 8 – 0
<b>Premature</b>	7.14 – 7.4	32 – 69	16 – 27		- 7.3 – 1.3

\*In the Premature infant the PO2 is based on gestation age

uterus, placental abruption or inadequate placental delivery of oxygen. On the other hand, umbilical artery sampling reflects foetal tissue oxygenation and the uteroplacental status. Examples of foetal conditions are heart failure and anaemia.

In 2012, Yeh et al<sup>24</sup> concluded that “ideal” cord pH is between 7.26-7.30 (Table 1). Furthermore, the threshold pH for adverse neurological outcomes is 7.10. However, there is a weak association with adverse outcome above 7.00. Furthermore, a normal cord pH value also does not preclude the absence of neurological morbidity. Thus, other variables which can lead to an adverse outcome, should be taken into consideration.

Delivering the foetus rapidly when it is showing signs of compromise allows the pediatric provider to administer oxygen directly to the newborn. The blood gas sampling of the uterine artery at the time of delivery would serve as a very useful guide to the degree of compromise in the newborn so it is important that the blood gas is read immediately.

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