Causes and consequences of fetal acidosis

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The fetus depends on the mother for placental exchange of oxygen and carbon dioxide. This in turn relies on adequate maternal blood gas concentrations, uterine blood supply, placental transfer and fetal gas transport. Disruption of any of these can cause fetal hypoxia, which, despite compensatory mechanisms, may lead to acidosis. When severe and acute (lasting hours), but especially if prolonged (days or weeks), hypoxia and therefore acidosis, are associated with significant morbidity and mortality with potential long term sequelae. Whether this damage is primarily due to reduced cell energy availability, as a result of hypoxia, or secondary to cell poisoning, as a result of acidosis, is unclear and indeed acidosis could simply be a marker of the cause and severity of the hypoxia.

The very different aetologies of acute vs chronic acidosis and the possible consequences will be reviewed, whether directly caused by the acidosis or indirectly by the hypoxia.

What is acidosis?
Acidosis means a high hydrogen ion concentration in the tissues. Acidemia refers to a high hydrogen ion concentration in the blood and is the most easily measured indication of tissue acidosis. The unit most commonly used is pH, which is log to base 10 of the reciprocal of the hydrogen ion concentration. Whereas blood pH can change quickly, tissue pH is more stable. The cut off taken to define acidemia in adults is a pH of less than 7.36, but after labour and normal delivery much lower values commonly occur in the fetus (pH 7.00), often with no subsequent ill effects. Studies looking at the pH of fetuses from cord blood samples taken antenatally and at delivery have established reference ranges. Other indices sometimes used to assess acidosis are the base excess or reference ranges. Other indices sometimes used to assess acidosis are the base excess or reference ranges. Other indices sometimes used to assess acidosis are the base excess or reference ranges. Other indices sometimes used to assess acidosis are the base excess or reference ranges.

The major sources of hydrogen ions in the fetus are carbonic and lactic acids from aerobic and anaerobic metabolism, respectively. The removal of CO₂ (and so carbonic acid) from the fetus depends almost entirely on the placenta. Unlike in sheep, lactate does not normally seem to be an important substrate for the human fetus and lactate acid is usually either further metabolised or excreted transplacentally. The latter has been shown by analyses of arterial and venous cord blood samples from human fetuses with low blood oxygen content due to anaemia secondary to severe Rhesus isoimmunisation. Lactate concentration was higher in the umbilical artery than the umbilical vein. The increased lactate is explained by increasing production from anaerobic metabolism and the difference in concentration between the umbilical artery and vein suggests that the placental circulation clears lactate from the fetal blood so helping to “repay” a fetal oxygen debt.

The causes of fetal hypoxia and therefore acidosis can be divided into maternal, placental, or fetal. The consequences of acidosis depend on its severity and duration and also the condition of the fetus before the insult, and we classify the causes of fetal acidosis into acute (hours) or chronic (days). In postnatal medicine acidosis is often described as respiratory (predominantly due to increased pCO₂) or metabolic (predominantly due to increased lactic acid). However, while acute fetal acidosis is almost always initially respiratory, this is quickly followed by mixed respiratory and metabolic acidosis if there is no improvement in oxygenation. Furthermore, the chronic acidosis of fetal life is also mixed, (fig 1) and we therefore prefer to use the terms acute and chronic.

Aetiology

Maternal
Anything that causes hypotension or hypovolaemia such as haemorrhage, a vasovagal attack, or epidural anaesthesia will reduce the maternal blood supply and so oxygen delivery to the uterus. Uterine contractions can also interrupt the uterine blood flow by a pressure rise and if prolonged, as in hypertonus, may cause hypoxia and so acidosis.

Placental
Abruptio can disrupt the utero-placental circulation by separating and so tearing the uterine spiral arteries from the placenta.

Fetal
Blood flow from the placenta to the fetus is often affected during labour and delivery by umbilical cord compression and this can sometimes happen before labour if there is reduced liquor or a true knot in the cord. Animal
Causes and consequences of fetal acidosis

F247

This indicates that the reduction needs to be reduced by at least 50% to produce hypoxia.4 In animal experiments, like acute cord compression, utero-placental blood flow also reduced perfusion of the intervillous spaces. In placental experiments have shown that there is significant reserve because the fetus can compensate by increased oxygen extraction,3 meaning blood flow to the fetus must be reduced by at least 50% to cause hypoxia.4

Figure 1 Relations between umbilical venous hypoxaemia (pO2) and umbilical hypercapnia (pCO2), hyperlacticaemia (blood lactate), or acidosis (pH); these are all expressed in multiples of SD from the appropriate mean for gestational age. Reproduced with permission from Nicolaides et al. Am J Obstet Gynecol;1989;161:996-100.

CHRONIC

Maternal

Maternal causes of chronic fetal acidosis include reduced oxygenation of maternal blood, such as in severe respiratory or cardiac disease, or reduced blood flow to the placenta as in connective tissue diseases—for example, systemic lupus erythematosus—and pre-eclampsia.

Placental

Antenatal fetal blood sampling by ultrasound guided needle aspiration from the umbilical cord (cordocentesis) in pregnancies with fetal growth restriction (FGR) has shown hypoxia as a result of impaired placental transfer of oxygen.5 This is thought to result from inadequate trophoblast invasion of the myometrium in early pregnancy, leading to reduced perfusion of the intervillous spaces. In animal experiments, like acute cord compression studies, utero-placental blood flow also needs to be reduced by at least 50% to produce fetal hypoxia.6 This indicates that the reduction in placental transfer seen in human FGR must be substantial to produce the hypoxia and acidosis found at cordocentesis in such cases.

Fetal

Even with normal placental function, conditions within the fetus can cause acidosis. Anaemia from rhesus disease, parvovirus infection, α-thalassaemia or feto-maternal haemorrhage, when severe enough to reduce fetal haemoglobin concentrations below 40 g/l (equivalent to an oxygen content below 2 mmol/l), can lead to a fall in pH.4,9 Arterio-venous shunting in fetal tumours, serious cardiac structural abnormalities, or arrhythmias are other conditions which can lead to chronic acidosis by decreased oxygenation as a result of reduced feto-placental blood flow.

Diagnosis of acidosis

ANTENATALLY

The use of ultrasound imaging to assess fetal size and wellbeing, Doppler studies of the fetal circulation, and cordocentesis have helped us to understand some of the mysteries of life before birth. During the 1980s cordocentesis was used to study the acid base status of the fetus and create reference ranges for umbilical arterial and venous blood gases in the second and third trimesters (fig 2).2 10 These studies provided the first direct evidence of chronic acidosis.5 However, cordocentesis carries a procedure related risk of 1% and cannot therefore be used routinely or repeatedly for monitoring. To overcome this, fetal medicine specialists have searched for non-invasive techniques to detect acidosis. In acute situations where severe hypoxia and acidosis are suspected, the non-invasive techniques used are fetal heart rate monitoring or biophysical profile score (fetal breathing/movements, gross body movement, tone and amniotic fluid volume). However, in pregnancies with placental dysfunction before labour, the onset of hypoxia and acidosis is more gradual and results of these tests are often normal until a preterminal stage12 where urgent delivery is required to prevent an intrapartum death.

An important breakthrough in antenatal surveillance was the demonstration that increased resistance in placental vasculature in pregnancies with hypoxia and acidosis due to

Key points

- The causes and consequences of acute (minutes or hours) and chronic (days or weeks) fetal acidosis are different.
- In the past much attention has been paid to acute acidosis during labour, but in previously normal fetuses this is rarely associated with subsequent damage.
- In contrast, chronic acidosis, which is often not detected antenatally, is associated with a significant increase in neuromotor and developmental delay.
- The identification of small for gestational age fetuses by ultrasound scans and the use of Doppler waveforms to detect which of these have placental dysfunction mean that these fetuses can be monitored antenatally.
- Delivery before hypoxia has produced chronic acidosis, may prevent subsequent damage and good timing of delivery remains the only management option at present.

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Acidosis occurs as a result of tissue hypoxia and it is unclear whether the consequences of this process are due primarily to the acidosis or the hypoxia. What has become clear over the past decade is that the consequences of hypoxia/acidosis are very different, depending on whether this is acute or chronic. The normal human fetus is adapted to survive labour and has compensatory mechanisms that allow it to withstand even severe hypoxia and acidosis for short periods of time. Several studies have looked at the neurological outcome of neonates who were severely asphyxiated at delivery. In 1994 Low et al. reported a study of neonates following respiratory or metabolic acidosis at delivery. Although the cutoff of pH used to define severe acidosis and the age at follow up varied, conclusions were similar from all the studies: although mortality may be slightly increased, the predictive value of acidosis at birth for neurological sequelae, especially in term neonates, is poor.

In contrast, the fetus exposed antenatally to chronic hypoxia and acidosis is much more at risk of associated long term morbidity. In 1994 Nelson et al. concluded that antenatal events were much more important than intra- or postpartum ones. This was supported by a study by Adams et al. in 1995 where all term, singleton neonates born over an 8 month period with a well defined diagnosis of encephalopathy within the first week of life were identified prospectively and matched with a well neonate.
Antenatal and intrapartum factors in both groups were compared and only 6% of cases had intrapartum risk factors alone. They concluded that in most of their cases intrapartum acidosis was not the cause and events occurring in the antenatal period were more often implicated. Further evidence for this association comes from a follow up study of infants with acid base status assessed as fetuses by cordocentesis. To remove the complications of extreme prematurity only cases delivered after 32 weeks were studied. Neurodevelopmental assessment showed a reduction in developmental quotient following chronic fetal acidosisa (fig 3).26

Conclusion
Prevention of severe acute acidosis depends on good labour ward monitoring and care. Prevention of chronic fetal acidosis, which is probably a much more common cause of damage, depends on detection of placental dysfunction antenatally by clinical fetal growth assessment, ultrasound scanning and Doppler ultrasonography. There is still no overall consensus on the best balance between keeping the fetus in an hypoxic/acidotic environment or very premature delivery.27 In fetuses with abnormal Doppler waveforms delivery should usually be by Caesarean section to avoid acute on chronic acidosis. Much current research is concentrating on improving placental transfer to develop a future in utero treatment for this group.

10 Soothill PW, Nicolaides KH, Rodeck CH, Campbell S. Effect of gestational age on fetal and interventricular blood gas and acid base values in Human pregnancy. Fetal Ther 1986;1:68-75.