

Umbilical cord blood gas analysis at the time of delivery

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Aims: it is now recommended that cord blood acid-base measurement is performed routinely at time of delivery in the UK as a measure of fetal response to labour. However, there remains some uncertainty about the value of this procedure. In this paper our experience of cord blood analysis is described and the literature is reviewed to: (1) provide an overview of the physiological basis of cord blood acid-base assessment; (2) describe the appropriate methodology and identify issues which have contributed to confusion and undermined the value of cord blood sampling; and (3) address the practical issues of cord blood sampling.

Conclusions: cord blood acid-base measurement has a sound physiological basis. It provides objective information which is a useful adjunct to subjective methods of newborn assessment, enables babies at risk of neonatal morbidity to be identified, can be helpful in litigation cases and is a prerequisite for clinical audit. However, to be of benefit the information must be correct and correctly interpreted.

INTRODUCTION

Evaluation of perinatal care requires *objective* neonatal outcome data. However, current methods of assessment of newborn babies (Apgar scores, the need for intubation and abnormal behaviour) are subjective, provide incomplete information and are not by themselves indicative of asphyxia. In the perinatal period asphyxia is defined as the combination of hypoxia and acidosis with impaired organ function (Greene & Rosen 1995). Thus, both clinical and biochemical information are required to differentiate between an asphyxiated baby and one which is depressed for other reasons (infection, congenital abnormalities or maternal analgesia). It is now recommended that cord blood acid-base assessment (artery and vein) is performed routinely at delivery in the UK as 'an objective measure of the fetal response to labour' (Royal College of Obstetricians & Gynaecologists 1993). Despite the accessibility of the umbilical cord after delivery, there remains uncertainty about the value of the procedure (Perkins et al 1993).

In this paper the aim is to describe our own experience of cord blood analysis and review the literature to:

1. provide an overview of the physiological basis of cord blood acid-base assessment;

2. describe the appropriate methods and identify issues which have contributed to confusion and undermined the value of cord blood sampling;
3. address the practical issues of cord blood sampling.

PHYSIOLOGICAL BASIS OF CORD BLOOD ANALYSIS

For the fetus, the placenta is the organ of gaseous exchange. The fetus obtains oxygen and nutrients from the mother via a single umbilical vein. Energy is produced in the fetal tissues by aerobic metabolism (the metabolism of glucose in the presence of oxygen). Carbon dioxide (CO₂), the waste product of this process, is carried by the blood back to the placenta via the two umbilical arteries. Consequently, arterial blood has lower oxygen and higher CO₂ than venous blood. The CO₂ is carried in the form of a weak acid and so the arterial pH is lower than the venous pH. At the placenta, CO₂ passes back to the mother and fresh supplies of oxygen pass to the fetus. Fetal metabolism under normal conditions is aerobic as summarised in Figure 1.

Gaseous exchange is impaired during uterine contractions which means that the intervals between contractions are very important for the fetus to

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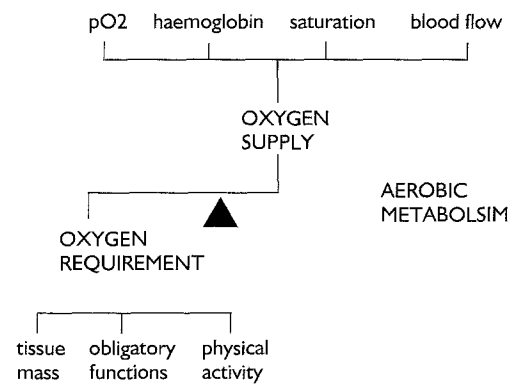


Fig. 1 The factors which determine oxygen supply and requirements. Aerobic metabolism occurs when these are in balance.

replenish its oxygen supply and to excrete accumulated CO_2 . Throughout labour the contraction rate increases. At the end of the first stage, contractions last 50–70 seconds and occur about three to four times in ten minutes. The fit healthy fetus is well able to cope with this stress and adapts appropriately to meet the challenge. However, if for some reason the gas exchange at the placenta becomes further impaired (contractions too frequent, maternal hypotension, cord occlusion, abruptio placenta, etc.) the fetus will retain CO_2 which lowers the pH of the blood. This fall in pH is termed a 'respiratory acidosis' which will be quickly resolved when the circulation is restored or the baby is delivered.

If, however, gaseous exchange continues to be impeded, then the fetus will have to rely more and more on the important defence mechanism of anaerobic metabolism (without oxygen) to supplement aerobic metabolism (requiring oxygen). During anaerobic metabolism, stores of glycogen in the heart, muscle and liver are broken down to provide energy. Lactic acid, a by-product of anaerobic metabolism, is initially buffered (neutralised) but will eventually cause the pH of the blood to fall further. This acidosis will now be comprised of both a respiratory component (retention of CO_2) and metabolic component (lactic acid from anaerobic metabolism). The extent to which anaerobic metabolism has occurred is derived from the base deficit of the extracellular fluid (BD_{ecf}) which can be calculated from the pH level of the blood and accumulated CO_2 . As the fetus continues to utilise glycogen stores to compensate for an insufficient oxygen supply, the acidosis becomes predominantly metabolic in origin and the pH decreases even further. Eventually a perilous situation will be reached where the fetus is in danger of exhausting its supply of energy.

METHODOLOGICAL ISSUES

The physiology clearly suggests that umbilical cord blood acid-base measurement at the time of delivery provides useful and objective information as to how the fetus has responded to labour. However, failure to address important methodological issues has con-

tributed to confusion and data have been subject to misinterpretation (Josten et al 1987). A major source of uncertainty has been whether to obtain blood from the umbilical vein or artery. Some investigators have reported only arterial values (Fee et al 1990), some have used only venous values (Huisjes & Aarnoudse 1979), and others have not specified which vessel was used (Halligan et al 1992). In fact *both* arterial and venous samples are required. Arterial cord blood reflects fetal acid-base status but can be difficult to obtain in some cases. Conversely, venous cord blood reflects a combination of maternal acid-base status and placental function and is easily obtained. Diffusion of hydrogen and lactate ions from the fetal blood into the placental extracellular compartment is a gradual process therefore analysis of arterial and venous blood can provide an indication of the possible time course of events. A larger arterial-venous difference can occur when normal placental function and gas exchange are interrupted by an acute reduction in blood flow (cord compression or profound bradycardia), while a metabolic acidosis in both the artery and vein indicates that the hypoxia has occurred over a longer time course. In addition, it is clearly important to validate that an arterial sample has indeed been obtained. The incorrect assumption that a venous value is an arterial value is unlikely to reflect the true condition of the baby.

Various pH values have been proposed as being 'abnormal' ranging from 7.20 (van den Berg et al 1987) to 7.00 (American Academy of Paediatrics 1986). In many cases the level of pH has been inappropriately based on mean and standard deviation values. The frequency distributions of pH and base deficit values for both the cord artery and vein are skewed. Therefore, any statistical description of these populations should be by centile values. Data from our group's analysis of 1448 validated paired (arterial and venous) umbilical cord blood samples found that the median arterial pH was 7.26 and 95% had an arterial pH between 7.05 and 7.38 (Westgate et al 1994). Other large studies have produced comparable data (Eskes et al 1983). It is now clear that many definitions of acidosis have been unrealistically high. There is now increasing evidence from large studies that it is only when the arterial pH is lower than about 7.05 and BD_{ecf} greater than 12 mmol/l that differences in outcome are seen (Low et al 1984, Goldaber et al 1991).

It is important to remember that pH is a logarithmic function of the hydrogen ion concentration. Consequently a fall in pH from 7.30 to 7.20 is not as significant as a fall from 7.10 to 7.00. In the latter case there are approximately twice as many free hydrogen ions generated. Additional difficulties have arisen because few workers have attempted to distinguish respiratory and metabolic acidosis which is essential given the different causes. Furthermore, it is important to calculate the base deficit value based on the correct compartment. The fetus and neonate have lower plasma protein concentrations and a relatively larger extravascular fluid compartment than adults.

Therefore, base deficit should be calculated from the whole BD_{ecf} rather than just the blood compartment otherwise overestimation of the metabolic component of the acidaemia will occur (Rosen & Murphy 1991).

Further confusion is due to the assumption that a linear relationship should exist between pH and Apgar scores (Josten et al 1987). There is not necessarily a contradiction between a high Apgar score and low pH. The fetus has a wide range of defence mechanisms and the catecholamine surge, in response to hypoxia, also produces a general neonatal arousal. This leads to a higher heart rate, stimulation of respiration, increased reflex irritability and improved tone. Some fetuses may suffer severe hypoxia and become profoundly acidotic, and yet compensate, preserving oxygen supply to vital organs (heart, brain and adrenals) so that no permanent harm is experienced. Other fetuses (such as the growth-retarded) are more vulnerable to the effects of hypoxia, and when subjected to the same stress suffer permanent organ damage.

RECOMMENDED SAMPLING METHOD

The umbilical cord normally contains two umbilical arteries and a larger umbilical vein. Immediately after delivery a segment of cord (minimum length 10 cm) should be isolated between two sets of clamps (Fig. 2). The segment of cord can then be excised for immediate sampling or this can be delayed until the placenta is delivered. Blood is taken first from the

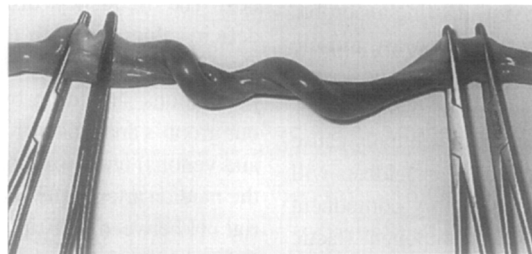


Fig. 2 A segment of umbilical cord isolated between two sets of clamps.

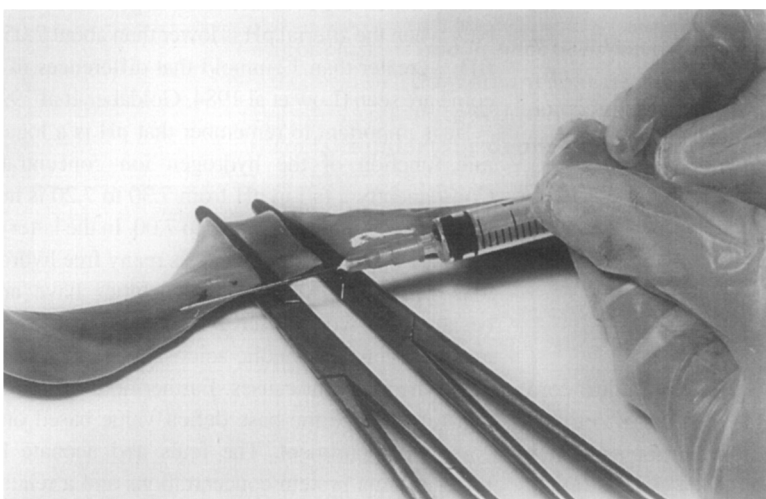


Fig. 3 The needle is inserted almost parallel to the vessel.

artery and then from the vein. The distended vein stabilises the artery and makes access easier. Blood is collected using 2 ml plastic syringes with a 21 gauge needle. The needle should be inserted almost parallel to the vessel (Fig. 3) to avoid the risk of the needle passing through the narrow artery and into the vein. As an aid to sample identification a larger quantity of blood should be taken from the vein.

Blood will not clot in the cord, but will in the syringe or analyser; therefore samples should be collected using heparinised syringes. These can be prepared on-site by adding one drop of liquid heparin (1000 units/ml) from a tuberculin syringe into a 2 ml plastic syringe, moving the plunger up and down and expel any residual heparin before capping with a 21 gauge needle. Heparin is an acid so it is important that the volume used to prepare syringes does not exceed 10% of sample volume as this can affect the results (Kirshon & Moise 1989).

Sources of error

Many studies have failed to describe error-checking and validation of cord blood results. The reported incidence of errors range from 10% (Riley & Johnson 1993) to 25% for trained clinical staff and 5% for experienced research workers (Westgate et al 1994). Sampling the same vessel twice, usually the vein, is a common error. An arterial sample will have a lower pH and higher CO_2 than the venous sample. Presumed paired results, actually taken from the same vessel, will obviously have similar pH and CO_2 readings. However, surprisingly little information is available on the minimum difference between the results before one could be confident that both vessels have been obtained. Huisjes & Aarnoudse (1979) allowed 0.03 pH units as the minimum acceptable venous-arterial difference, where as Eskes et al (1983) chose 0.02 pH units. Negative differences (the vein pH is lower than the arterial pH), which are physiologically improbable, have also been accepted by some workers (Egan et al 1992). A possible explanation for such results could be inadvertent transposing of the vessels either when taking the samples or on introduction into the analyser.

Ideally, sampling and analysis of cord blood should be undertaken as soon as possible after delivery. However, changes in pH and CO_2 occur slowly with time as a result of cellular metabolism (Siggard-Anderson 1961). Clamped cord segments or blood stored in syringes can be left at room temperature for up to 60 minutes without significant changes in pH or CO_2 (Sykes & Molloy 1984, Duerbeck et al 1992). Care must also be taken to avoid the introduction of air into the blood gas analyser as this may cause unreliable readings.

Selective sampling

There is also uncertainty as to whether cord blood analysis should be routine for all deliveries or selec-

tive. It would appear an attractive proposition to select so called 'high risk' cases for sampling; however, Murphy et al (1990) found that 40% of babies with a primary diagnosis of asphyxia were from labours classified as 'low-risk'. Low antenatal risk groups contribute to 58% of perinatal mortality and morbidity compared to 42% from high risk women (Wilson & Schiffrin 1980). Clearly risk assessment is a poor predictor of outcome. It has also been suggested that cord blood analysis can be limited to those babies with a low (not defined) five minute Apgar score (American College of Obstetricians & Gynecologists 1994) but this has a number of difficulties. The Apgar score is subjective and could lead to clinicians inflating scores to avoid analysis. In addition, this criterion will fail to detect vigorous babies who have responded appropriately to significant hypoxia by releasing high levels of catecholamines. We believe it is important to audit these cases.

It might be assumed that a selective policy will considerably reduce the cost of sampling. However, for blood gas analysis, costs decrease with increased volume. In a unit with 4200 deliveries a year routine sampling of all deliveries would cost approximately £0.41 a sample whereas a selective policy, obtaining samples from 50% of deliveries, would cost approximately £0.76 a sample. The economic argument for selective sampling is further weakened when the utility of routine sampling is considered. Routine sampling is a prerequisite for clinical audit. The percentage of babies born with a low pH or metabolic acidosis can be used as an audit of the quality of intrapartum care (Yudkin et al 1987). It provides objective information which is a useful adjunct to subjective methods of assessment of newborn babies and enables a group of neonates at risk of morbidity to be identified (Goldaber & Gilstrap 1993). In addition, normal acid-base results are reassuring and can help exclude a diagnosis of birth asphyxia. In some cases, this will assist in the deflection of litigation and prevent considerable financial loss to the hospital.

DISCUSSION

Cord blood acid-base measurement at time of delivery provides objective information but clearly this involves much more than just taking blood and measuring the pH. The information must be correct and correctly interpreted.

Little attention has been paid to the sources of error which can arise. Many units undertake this procedure on-site where the rigorous standards of laboratory conditions have not been applied. Quality control procedures are required with adequate strategies in place for error-checking and validation of results. From a practical perspective it would be unrealistic to expect all midwifery and medical staff to have the time or skill to validate results. In Plymouth we resolved this difficulty with the use of an intelligent knowledge-based computer system (Expert DataCare) developed by computer engineers, clinicians and physiologists in

our unit. The blood gas analyser is connected to a computer running the Expert DataCare system. The system screens the results and identifies errors which are highlighted to the operator. The details are stored in the computer database which facilitates audit and research. The results and interpretation are printed out on adhesive labels which are placed in the mother's and baby's records.

In experienced hands a low error rate can be achieved. However, the practical difficulties involved in training and education are difficult to address. The standard approach of 'cascade' training has a number of limitations. The quality of education becomes diluted over time, particularly in areas with rapid turnover of staff and it is difficult to assess consistency and quality of training. For cord blood analysis, it would be an onerous task indeed to transfer the required knowledge to a large number of staff. Furthermore, it would be difficult to identify individuals with the skills and time to act as trainers which combined with the costs, would probably make a conventional training programme prohibitive. In our unit we have overcome this practical problem with the use of an interactive computer-based teaching package which is currently undergoing a randomised trial with our midwives, doctors and auxiliary nurses. On-site computer systems have several advantages: the access and availability of learning materials are increased; learning time and time away from assigned duty are reduced; and there is also improved morale associated with maintaining a commitment to staff development (Hannah & Osis 1988).

For some units, routine cord blood analysis may be considered impractical owing to limitations of personnel. In Plymouth, the role of auxiliary nurses has been extended to include cord blood analysis. This reduces demands on midwifery and medical staff and has a positive effect on the ancillary staff because of increased job satisfaction. In addition, a recent prospective audit found auxiliary nurses obtained a higher level of valid paired samples than midwives. There are now many changes in the role of support workers within the health service (Redfern 1994). Our experience demonstrates the feasibility of trained ancillary staff undertaking cord blood sampling.

In clinical practice, it is likely that a selective sampling policy will not be applied in a consistent manner. Indeed, the more complex a policy is the more likely it is to fail in practice. Our own experience with selective sampling proved very unsatisfactory; clinical staff forgot to take bloods; asphyxia cases from normal deliveries were missed; and no data were available for apparently normal babies who developed early neonatal problems. We found the application of a simple and unambiguous sampling policy for all deliveries resulted in an easier and more efficient procedure. In an area with such a rapid turnover of staff it was also the most practical approach. As with some other procedures, for example management of the third stage of labour, a routine approach has been shown to be more effective than a piecemeal approach (Gyte 1994).

The imprecision of current clinical outcome measures is of great concern for researchers and clinicians. When Murphy et al (1990) undertook their review of cardiothecograms (CTG) they were given a list of 85 cases with a diagnosis of birth asphyxia; however, after detailed review, the paediatricians reversed their diagnosis in 25% of cases. In the UK, estimates of current liability for brain-damaged babies lie between £600 million and £1 billion (Symonds 1993). Clearly it can be difficult to establish on clinical evidence alone whether or not intrapartum asphyxia was responsible for damage. For adequate evaluation we need to build a picture of the condition of the baby at delivery. Apgar scores, abnormal newborn behaviour, the CTG and nature of the liquor are all important components but they do not indicate the timing of events (ante-partum, intrapartum or postpartum) and cannot exclude infection and developmental causes. Cord blood gas analysis is required to complete the picture and reflect the oxygenation of the fetus during labour.

New procedures are frequently introduced into health care settings, but in some cases their emergence into clinical practice occurs with little planning for widespread use. As our experience shows for cord blood analysis there are a number of resource, educational and technical requirements. In Plymouth we have resolved many of the methodological and practical difficulties. This has been achieved by focusing on the needs of midwives, doctors and auxiliary nurses, providing a structured education programme and developing novel technology to ease the introduction of cord blood acid-base measurement into routine clinical practice.

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REFERENCES

- American College of Obstetricians & Gynecologists 1994 Utility of umbilical cord blood acid-base assessment, Committee Opinion: Committee on Obstetric Practice Number 138. *International Journal of Gynecology and Obstetrics* 45: 303–304
- American Academy of Pediatrics 1986 Use and abuse of the Apgar score. *Pediatrics* 78: 1148–1149
- Duerbeck N B, Chaffin D G, Seeds J W 1992 A practical approach to umbilical artery pH and blood gas determinations. *Obstetrics and Gynecology* 79: 959–962
- Egan J F X, Vintzileous A M, Campbell W A et al 1992 Arteriovenous cord blood pH discordancy in a high risk population and its clinical significance. *Journal of Maternal–Fetal Medicine* 1: 39–44
- Eskes T K A B, Jongsma H W, Houx P C W 1983 Percentiles for gas values in human umbilical cord blood. *European Journal of Obstetrics and Gynaecology Reproductive Biology* 14: 341–346
- Fee S C, Malee K, Deddish R et al 1990 Severe acidosis and subsequent neurological status. *American Journal of Obstetrics and Gynecology* 162 (3): 802–806
- Goldaber K G, Gilstrap L C, Leveno K J et al 1991 Pathologic fetal acidemia. *Obstetrics and Gynecology* 78: 1103–1107
- Goldaber K G, Gilstrap L C 1993 Correlations between clinical events and umbilical cord bloods acid-base values. *Clinical Obstetrics and Gynecology* 36: 47–59
- Greene K R, Rosen K G 1995 Intrapartum asphyxia. In: Leveno M I, Lilford R J, eds. *Fetal and neonatal neurology and neurosurgery*, 2nd edn. Churchill Livingstone, Edinburgh
- Gyte G 1994 Evaluation of the meta-analysis on the effects, on both mother and baby, of the various components of 'active' management of the third stage of labour. *Midwifery* 10: 183–199
- Halligan A, Connolly M, Clarke T et al 1992 Intrapartum asphyxia in term and post term infants. *Irish Medical Journal* 85 (3) 97–100
- Hannah K J, Osis M 1988 Computers and staff development. In: Ball M J, Hannah K J, Jelger H G et al, eds. *Nursing informatics*. Springer–Verlag, New York
- Huisjes H J, Aarnoudse J G 1979 Arterial or venous pH as a measure of neonatal morbidity? *Early Human Development* 3: 115–161
- Josten B E, Johnson T R B, Nelson J P 1987 Umbilical cord blood pH and Apgar scores as an index of neonatal health. *American Journal of Obstetrics and Gynecology* 157 (1): 843–848
- Kirshon B, Moise K J 1989 Effect of heparin on umbilical arterial blood gases. *Journal of Reproductive Medicine* 34: 267
- Low J A, Galbraith R S, Muir D W et al 1984 Factors associated with motor and cognitive deficits in children after intrapartum hypoxia. *American Journal of Obstetrics and Gynecology* 148 (5): 533–539
- Murphy K W, Johnson P, Moorcraft J et al 1990 Birth asphyxia and the intrapartum cardiotocograph. *British Journal of Obstetrics and Gynaecology* 97: 470–479
- Perkins R P, Weaver P A, Sweeney W J 1993 Questioning the practice of routine umbilical cord blood pH sampling at delivery. *Journal of Maternal–Fetal Medicine* 2: 191–196
- Redfern L 1994 Health care assistants – the challenge for nursing staff. *Nursing Times* 90 (48): 31–33
- Riley R J, Johnson J W C 1993 Collecting and analysing cord blood gases. *Clinical Obstetrics and Gynecology* 36: 13–23
- Rosen K G, Murphy K W 1991 How to assess fetal metabolic acidosis from cord samples. *Journal of Perinatal Medicine* 19: 221–226
- Royal College of Obstetricians and Gynaecologists 1993 Recommendations arising from the 26th RCOG Study Group. In: Spencer J A D, Ward R H T, eds. *Intrapartum fetal surveillance*. RCOG Press, London
- Siggard-Anderson O 1961 Sampling and storage of blood for determination of acid-base status. *Scandinavian Journal of Clinical and Laboratory Investigation* 13: 196–204
- Sykes G S, Molloy P M 1984 Effects of delays in collection or analysis on the results of umbilical cord blood measurements. *British Journal of Obstetrics and Gynaecology* 91: 989–992
- Symonds E M 1993 Litigation and the cardiotocogram. *British Journal of Obstetrics and Gynaecology* 100 Suppl 9: 8–9
- van den Berg P, Schmidt S, Gesche J et al 1987 Fetal distress and the condition of the newborn using cardiography and fetal blood analysis during labour. *British Journal of Obstetrics and Gynaecology* 94: 72–75
- Westgate J, Garibaldi J M, Greene K R 1994 Umbilical cord blood gas analysis at delivery: a time for quality data. *British Journal of Obstetrics and Gynaecology* 101: 1054–1063
- Wilson J, Schifrin B S 1980 Is any pregnancy low risk? *Obstetrics and Gynaecology* 55: 653–657
- Yudkin P L, Johnson P, Redman C W G 1987 Obstetric factors associated with cord blood gas values at birth. *European Journal of Obstetrics and Gynecology Reproductive Biology* 24: 167–176