Guidelines for blood sampling and measurement of pH and blood gas values in obstetrics

Based upon a workshop held in Zurich, Switzerland, March 19, 1993 by an ad hoc committee* A. Huch*, R. Huch, G. Rooth

Department of Obstetrics, University of Zurich, Zurich, Switzerland
(Accepted 24 January 1994)

Abstract
Guidelines for the clinical indications for measuring pH and blood gas values in fetal blood, the procedures of blood sampling and measurement and some reference values for the evaluation of the data are given. They cover: prenatal sampling of blood from the umbilical vessels in conjunction with cordocentesis, intrapartum sampling of fetal capillary blood by skin puncture of the presenting part, post partum sampling of blood from a clamped section of the umbilical cord and general analytical techniques.

Key words: pH; Blood gases; Cordocentesis; Fetal blood; Cord blood

* Corresponding author.
# The list of participants is given in the Appendix

1. Introduction

1.1 Aim and scope of present guidelines

1.1.1. These guidelines provide information on the clinical indications for measuring pH and blood gas values in fetal blood, the procedures of blood sampling and measurement and some reference values for the evaluation of the data. The purpose is to assure the overall quality of this monitoring technique including the optimal utilisation and to allow data comparison from time to time and from place to place.

1.1.2. The guidelines cover (1) general interpretation, (2) prenatal sampling of blood from the umbilical vessels in conjunction with cordocentesis, (3) intrapartum sampling of fetal capillary blood by skin puncture of the presenting part, in this document called the Saling Procedure, (4) postpartum sampling of blood from a clamped section of the umbilical cord, and (5) general analytical techniques.
1.2. General interpretation of fetal pH and blood gas values

1.2.1. The fetal blood pH is an important diagnostic and prognostic parameter whether measured during pregnancy, during labour, or in cord blood after birth. Severe fetal acidemia is associated with increased perinatal mortality and increased risk for later impaired neurodevelopment. Acidemia is usually of mixed metabolic and respiratory origin and hence associated with an elevated carbon dioxide tension and a significant extracellular base deficit (BDecf). In the following, base deficit always means base deficit of the extracellular fluid. A significant base deficit indicates hypoxia in the fetal tissues resulting from anaerobic metabolism and lactic acid production. An elevated PC02 indicates reduced CO2 diffusion equilibrium in the placenta.

1.2.2. Blood from the umbilical vein reflects the placental function. The umbilical vein P02 is considerably lower than maternal arterial P02 and even slightly lower than the maternal placental venous P02, because complete oxygen diffusion equilibrium across the placenta is not achieved, whereas carbon dioxide equilibrium is virtually complete. Placental dysfunction causes a lower umbilical vein P02 and may also cause elevation of the umbilical vein PC02. Several factors may contribute to a low umbilical vein P02 such as a decreased diffusion capacity of the placenta and hypoperfusion on the maternal side of the placenta. It can also be due to a decreased oxygen availability in the maternal blood (maternal anaemia, hypoxaemia, or abnormally high haemoglobin-oxygen affinity).

1.2.3. The blood in the umbilical arteries represents blood coming from the fetus. A low umbilical artery P02 indicates a risk of fetal tissue hypoxia especially if the fetal haemoglobin concentration is also low. After delivery, blood pH is preferably measured in the umbilical artery, where the pH value is approximately 0.02 lower than in the umbilical vein. However, the pH difference is variable, depending upon the placental CO2 and H+ exchange, and may increase considerably following intermittent cord compression.

1.2.4. The oxygen parameters are relevant mainly in connection with cordocentesis. Fetal capillary blood obtained by skin puncture during labour often contains a mixture of small amounts of blood from the venules rendering the oxygen parameters of limited value. Blood from the umbilical arteries, sampled from a clamped section of the umbilical cord immediately after birth shows great variability in oxygen parameters.

2. Cordocentesis

2.1. Cordocentesis refers to ultrasound guided puncture of the fetal umbilical cord through the maternal abdomen during pregnancy. It is the procedure of choice for fetal blood sampling, supplanting fetoscopy. Other fetal blood sampling procedures, such as hepatic vein puncture and cardiocentesis, are rarely necessary for diagnostic procedures.

2.2. Indications and contraindications

2.2.1. This area of fetal medicine continues to evolve. Currently, fetal pH and blood gases are measured as an adjunct to other diagnostic or therapeutic endeavours which require cordocentesis such as:
   (1) Part of the evaluation of severe early onset growth deficiency where knowledge of the fetal pH and blood gases aids identification of the cause and thus guides any decision regarding the timing and route of delivery
   (2) Treatment of hydrops fetalis
   (3) Discordant twins associated with acute hydramnios
   (4) Fetal haemolytic anaemia

2.2.2. It would be unusual to undertake cordocentesis solely to determine the fetal acid-base status since
   (1) normal fetal heart rate and normal. Doppler velocimetry render unlikely the possibility of fetal acidemia and
   (2) retal acidemia, traditionally thought to necessitate delivery, is usually associated with either an abnormal fetal heart rate pattern or biophysical profile.

2.2.3. Possible indications for cordocentesis solely to measure pH and blood gases are at present limited to:
   (1) providing justification for not delivering a fetus at the border of viability with abnormal noninvasive tests (Doppler velocimetry, fetal heart rate pattern or biophysical profile);
   (2) monitoring of experimental treatment of severe, early onset growth deficiency associated with fetal hypoxaemia by maternal hyperoxygenation.
2.3. **Risks**

2.3.1. Maternal risk of infection is minimal and similar to the risk in a routine venipuncture.

2.3.2. For the fetus, like any invasive procedure, cordocentesis has risks. Serious complications occur in approximately 1% of procedures when puncturing the vein and in up to 10% when the sampling is made from an artery. The actual risk of the interventions reflects both the indications and the experience of the operator. Complications are:
   1. fetal bradycardia
   2. premature rupture of membranes
   3. amnionitis
   4. premature labour
   5. more rarely, haemorrhage or cord thrombosis

2.4. **Contraindications**

2.4.1. Cordocentesis is, at this time, contraindicated solely for the measurement of pH and blood gases in the following cases:
   1. Normally grown or growth deficient fetus with normal fetal heart rate and Doppler velocimetry.
   2. A preterm fetus with a reassuring heart rate pattern or biophysical profile.

2.4.2. Cordocentesis is contraindicated when the mother is infected by human immunodeficiency virus (HIV) unless prenatal diagnosis is the goal. It is also contraindicated should the mother have either hepatitis B virus (HBV), hepatitis C virus (HCV) or hepatitis D virus (HDV) unless the likely benefits outweigh the potential risk of infecting the fetus.

2.5. **Technique of cordocentesis**

2.5.1. Cordocentesis is performed by an experienced physician under real-time ultrasound guidance. A detailed description of the technique for cordocentesis may be found in many recent textbooks (e.g. Soothill PW, Fetal Blood Sampling, in High Risk Pregnancy, Management Options, James D, Steer P, Weindr C, Gonic B, Eds W.B. Saunders Co., Philadelphia, 1993).

2.5.2. (1) The umbilical vein is the preferred vessel since the risk of fetal bradycardia is significantly lower than when the artery is punctured.
   (2) It is essential the vessel punctured be unambiguously identified. If punctured at the cord origin, identification is made by injecting a small volume of either saline or pancuronium and observing the direction of its flow. If the cord is punctured at a midsegment, measurement of the actual pressure is preferred.
   (3) The cord may be punctured anywhere along its course but it is preferred by many to use the placental insertion where it is anchored; others prefer the free-loop technique.
   (4) If doubt arises as to whether the blood is fetal or maternal a Kleihauer test should be performed to verify the presence of fetal haemoglobin in the red cells.

2.5.3. The sample volume depends upon the anticipated tests and the gestational age.
   1. Experience demonstrates that at 20 weeks of gestation 2 ml and at 30 weeks 4-5 ml may be safely removed.
   2. It is not considered necessary to replace the volume removed or to administer antibiotics.

2.5.4-1 A 20- to 22-gauge (diameter, 0.9-0.7 mm) spinal needle (7-13 cm long) generally is used.

2.5.4-2 After identification of the vessel and under constant sonographic visualisation blood is drawn into a 1-ml syringe previously flushed with heparin (100 units/ml).

2.5.4-3 Once filled the syringe is sealed with an air tight cap and either tested immediately or placed on ice for short-term storage.
2.6. Reference values and interpretation of results

2.6.1. Fetal pH and blood gas parameters change with advancing gestational age. It is therefore essential to assess any measurement against gestational age related norms derived from normal fetuses.

2.6.2. To include a fetus with a problem in the normative data because the problem is not believed to alter the pH and blood gases, makes an a priori assumption which may not be correct. Because cordocentesis is rarely performed on fetuses who ultimately turn out to be completely normal, it has taken several years to construct norms based solely on normal fetuses.

2.6.3. Figs 1-4 give the 2.5, 50 and 97.5 percentiles for fetal umbilical vein pH, PC02 extracellular base deficit, and P02, respectively, derived from a population of normal fetuses.

2.7. Cut-off points

Abnormal values of pH, PC02, extracellular base deficit and P02 measurements are those falling outside the 2.5 centile for gestational age.

Fig. 1. pH in the umbilical vein blood obtained during cordocentesis. The lines represent the 2.5, 50 and 97.5 percentiles. Modified from Weiner CG, Sipes SL, Wenstrom K. The effect of fetal age upon fetal laboratory values and venous pressure. Obstet Gynecol 1992; 79: 713-718.

2.8. Relevance of blood gas parameters

2.8.1. Severely growth deficient fetuses found to have chronic antenatal hypoxaemia/acidaemia, i.e. outside the 2.5 percentile in Fig. 4 and outside the 97.5 percentile in Fig. 1, are at increased risk for impaired neurodevelopment as children.

2.8.2. It appears that acidaemia, rather than hypoxaemia alone, is associated with this impairment.

2.8.3. Any recommendation for delivery, based only upon the blood gas findings, and prior to, the appearance of an abnormal heart rate pattern or biophysical profile, must take into consideration the gestational age.

2.8.4. The greater the prematurity, the greater should be the physician's tolerance for abnormal blood gas values.
2.8.5. In case of hypoxaemia or acidaemia pregnancy should be terminated depending on gestational age.

**Fig. 2.** pCO₂ in the umbilical vein blood obtained during cordocentesis. The same material as in Fig. 1.

**Fig. 3.** Base deficit of the extracellular fluid in the umbilical vein blood obtained during cordocentesis. Calculated from the same data as in Fig. 1.
3. Intrapartum sampling of fetal capillary blood: The Saling procedure

3.1. The Saling procedure of fetal blood sampling designates the obtaining of fetal capillary blood by skin puncture during labour. This is usually scalp blood. The purpose is to obtain blood for a pH measurement, but is often supplemented with a complete acid base status. When the Saling procedure is used for appropriate indications and performed correctly its value is undisputed. There are, however, different opinions about the extent to which this procedure is needed in view of modern electronic surveillance techniques. Therefore, many clinicians do not carry out this important measurement. Fetal heart rate monitoring, at best, gives inadequate information and has a high false positive rate. Where practiced routinely fetal blood sampling seems to be made in about 5% of the deliveries. Thus it is difficult to train and to maintain the skill in units with limited numbers of complicated deliveries.

3.2. Indications

3.2.1. Fetal sampling is indicated when fetal heart rate patterns cause concern about fetal well-being. The technique is equally applicable to preterm fetuses. Guidelines for the interpretation of the fetal heart rate pattern and indications for fetal blood sampling have been published in the J Perinat Med 1981; 9: 165-177 (Saling) and in the Int J Gynaecol Obstet 1987; 25: 159-167 (Huch and Rooth).

![Umbilical vein pO2 graph]

Fig. 4. P02 in the umbilical vein blood obtained during cordocentesis. The same material as in Fig. 1.

3.2.2. Repeated sampling should be performed if the indications for fetal sampling remains.

3.3. Contraindications

3.3.1. Fetal blood sampling is not indicated in advanced second stage of labour. Suspicion of fetal acidaemia in this situation calls for immediate vaginal delivery by an appropriate technique in order to achieve delivery without wasting time on blood sampling.

3.3.2. The procedure is contraindicated when the mother is infected by HIV, HBV, HCV or HDV.
3.4. The procedure for fetal blood sampling

3.4.1. The Saling procedure should be performed by an appropriately trained obstetrician. Proper sampling technique requires practice and skill.

3.4.2. The procedure may be performed as soon as cervical dilatation allows and the presenting part of the fetus is accessible. The membranes must be ruptured before sampling.

3.4.3. Although most obstetricians perform the procedure with the mother lying on her back, there are several advantages for her lying on her side. This allows for the easiest access without causing a vena cava syndrome and may be more acceptable both for the parturient and for the midwives.

3.4.4. A conical endoscope is passed into the vagina and the introducer removed. The cervix is identified under direct vision. The end of the endoscope is manoeuvred through the cervix and the presenting part is first cleaned and dried. A thin layer of sterile paraffin should be applied. This helps to produce a thick drop of blood at the point of incision and also prevents carbon dioxide evaporation. Use of vasodilating solutions is not required.

3.4.5. The incision, not deeper than 2 mm, should be made with a jabbing motion of a sharp blade (similar to a fragment of a razor blade). Commercial lancets are available, mounted on a special holder and projecting 2 mm, thus preventing deeper cuts.

3.4.6. There is no consensus of opinion regarding the ideal timing of the sampling i.e. during the first half of a contraction or between the contractions.

3.4.7. The blood should be collected in glass capillary tubes coated with dry heparin. Commercial tubes of 8-10 cm length may be mounted on a special holder. Longer tubes of about 30 cm length especially designed for the Saling procedure do not require a holder. It is best that the blood should enter the tubes by capillary action. If mouth suction is preferred it is advised to use a valve or a trap to avoid sucking potentially contagious blood into the mouth.

3.4.8. The incision site should be observed until the next contraction to ensure the bleeding stops.

3.5. Risks

3.5.1. There is no significant maternal risk.

3.5.2. Fetal risks: excessive bleeding, infection and fetal trauma are very rare.

3.6. Reference values and interpretation of results

3.6.1. No significant influence of gestational age on the reference values has been established.

3.6.2. In routine practice only the pH value is used for the clinical evaluation. More information about the cause of the acidaemia is obtained by measuring PC02 and calculating extracellular base deficit as well. However, no clinical studies have indicated that the treatment or prognosis is different whether the acidaemia is predominantly due to an increase in PC02 or in base deficit.

3.6.3. There is no indication for immediate intervention if the pH value is above 7.24. A decision regarding the obstetric management is necessary if the pH value is below 7.20.

3.6.4. An additional value of a repeated Saling sampling is that an increase in pH indicates improvement of the fetal gas exchange and vice versa. The rate of fall of pH values will be faster if the fetus has reduced tolerance to hypoxia.
4. Cord blood sampling after delivery

4.1. Cord blood sampling after delivery involves sampling from the umbilical arteries and/or vein immediately after birth.

4.2. Indications and contraindications

4.2.1. Routine sampling of cord blood after all deliveries, whenever this is feasible, allows the population distribution to be determined. This may be of help in planning and auditing the clinical service. It also maintains the skills of staff involved with labour management and provides a focus for training of the interpretation of acid-base and blood gas information.

4.2.2. However, there is no evidence that routine measurement of pH and blood gases at birth is cost-effective and individual units should decide their sampling policy for themselves. Selective cord sampling, in such circumstances as a low Apgar score, meconium-stained liquor, operative delivery for fetal distress, abnormal fetal heart rate, and suspected fetal distress, requires routine clamping of the umbilical cord after delivery. Subsequent measurement would be performed as indicated.

4.2.3. Routine sampling of cord blood also allows for comparisons between different hospitals provided that a high percentage of the deliveries is monitored and that the same sampling technique is used. Unfortunately this is not the case at present.

4.2.4. There is no absolute contraindication to cord blood sampling. Precautions are necessary if contamination is a risk.

4.3. Sampling and storage

4.3.1. Sampling from the cord vessels may be performed with or without clamping. Direct aspiration from the artery or the vein should be performed immediately after the delivery of the baby if cord clamping is not employed.

4.3.2. Most commonly the cord is clamped. The technique is important as an adequate arterial sample is required. A minimum of three clamps is recommended.

4.3.2-1 After delivery of the baby, gently deliver as much cord as possible without traumatising the vessels. The blood will clot if endothelial integrity is disrupted.

4.3.2-2 The first clamp should be applied as far from the baby as possible - near the introitus (vaginal delivery) or uterine incision (caesarean section) - to prevent the arteries from emptying into the placenta.

4.3.2-3 Two clamps may then be applied near the baby and the cord divided between these clamps. The baby can then be moved away.

4.3.2-4 Do not use traction on the clamped section of cord to deliver the placenta.

4.3.2-5 The cord may be sampled at this stage if immediate analysis is available. If analysis is not immediately available then it is preferable to isolate a section of cord and defer sampling.

4.3.2-6 The first sample of heparinised blood should be taken from one or both of the (usually) firm arteries.

4.3.2-7 Sampling from the chorionic plate needs more attention. Branches of umbilical arteries are vessels which cross over others (the latter are veins).

4.3.3. The umbilical pH and blood gas values are less influenced by the onset of neonatal breathing than might be expected. Some centers routinely wait 1 min before clamping in order to allow most of the blood in the placenta to be transfused to the infant and to allow the infants to cry before the clamping.

4.3.4. Clamping before the baby is raised above the height of the placenta is also appropriate if loss of blood to the placenta is to be avoided.
4.3.5. There are two reasons why both the umbilical artery and vein should be sampled. First, it will ensure that the umbilical artery value can be recognised; the two samples must be appropriately different (the artery has lower oxygen tension and saturation, lower pH, greater base deficit and higher carbon dioxide tension). Second, umbilical artery blood represents the fetal circulation whereas umbilical vein blood shows the influence of the placenta. The balance between fetal acid production and placental oxygenation can only be assessed by comparing umbilical artery and vein samples.

**Table 1**
95% Confidence intervals for various parameters for a population of 4667 deliveries in one university hospital of the placenta. The balance between fetal acid production and placental oxygenation can only be assessed by comparing umbilical artery and vein samples.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Umbilical artery blood</th>
<th>Umbilical vein blood</th>
</tr>
</thead>
<tbody>
<tr>
<td>pH</td>
<td>7.06-7.23</td>
<td>7.14-7.45</td>
</tr>
<tr>
<td>PO2 (kPa)</td>
<td>1.3-5.5</td>
<td>1.7-6.0</td>
</tr>
<tr>
<td>PO2 (mmHg)</td>
<td>9.8-41.2</td>
<td>12.3-45.0</td>
</tr>
<tr>
<td>PCO2 (kPa)</td>
<td>9.1-3.7</td>
<td>7.5-3.2</td>
</tr>
<tr>
<td>PCO2 (mmHg)</td>
<td>68.3-27.8</td>
<td>56.3-24.0</td>
</tr>
<tr>
<td>BDecf (mmol/l)</td>
<td>15.3-0.5</td>
<td>12.6-0.7</td>
</tr>
</tbody>
</table>

4.4. **Risks**

Cord blood sampling presents no risks to mother or newborn provided early clamping is avoided when contraindicated, e.g. an overt anaemic newborn.
4.5. Reference values and interpretation of results

A number of reference values are available. Mean, median and ranges of values for pH, PC02, and base deficit vary between hospitals due to differences in population, sampling frequency and sampling technique. The higher the sampling rate the higher pH. Most published mean or median values range between 7.20 and 7.27.

![University Hospital Nijmegen 1975 - 1980](chart)

**Fig. 5.** Distribution of pH values in the umbilical arteries in a total population of 4667 deliveries in one hospital in the Netherlands.

4.5.1. The 95% confidence intervals for the total population of 4667 deliveries in one university hospital are given in Table 1. Fig. 5 shows the distribution of the pH values (from Eskes TKAB, Jongsma HW, Houx PCW, Percentiles for gas values in human umbilical cord blood. Eur J Obstet Gynecol Reprod Biol 1983; 14: 341-346). A somewhat different distribution is seen if only values from risk-free pregnancies or healthy infants at birth are taken.

Table 2 shows the values from 24298 deliveries between week 39 and 41 in the umbilical artery when there were no problems during pregnancy, labour and delivery (data from W Kunzel, Hessische Perinatalehebung 1986-1989, unpublished).

It is of course equally important to know the distribution of values in only healthy infants. Figs. 6-9 give the distribution of pH, PC02, base deficit and PO2, respectively in 663 term infants of normal weight and Apgar score 7 or more. (From JW Dudenhauen, C Luhr, Gas values in human umbilical artery blood of healthy newborn infants, unpublished).
4.5.2. Umbilical artery acidaemia is considered the most sensitive and objective indicator of fetal hypoxia during labour.

4.5.3. Measurement of pH provides biochemical information and evaluation of fetal adaptation to labour. Pre-existing placental function and additional influences during labour (contraction frequency, epidural, etc.) will affect fetal oxygen supply and carbon dioxide removal. The significance of such information depends upon appropriate interpretation in the context of clinical circumstances. Inferences about placental function and fetal adaptation may contribute to an understanding of neonatal condition. Gestational age and growth retardation are more important in predicting neurological morbidity than pH and blood gas values in the umbilical cord. In neonates born at term and with a normal birthweight, there is no significant correlation between blood gas values and neurological morbidity except when pH is very low.

4.5.4. The first indication of interference with gaseous exchange at the placenta is a respiratory acidaemia (raised PCO2 and normal base deficit). The presence of metabolic acidaemia in umbilical artery blood indicates, to some extent, the fetal response to hypoxaemia and hypoxia. The more marked the metabolic acidosis the longer the duration of the fetal acidaemia.

4.5.5. Many babies with acidaemia at birth have no clinical problems during the neonatal period. However, the risk of low Apgar scores and neonatal encephalopathy is increased with increasing severity of acidaemia, especially with a pH below 7.05.

4.5.6. More than 50% of clinically depressed newborns have normal umbilical arterial blood pH values, thereby excluding the possibility of significant oxygen deprivation.

Table 2
pH data from 24,298 deliveries between weeks 39 and 41 in the umbilical artery when there were no problems during pregnancy

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>n</td>
<td>1</td>
<td>6</td>
<td>117</td>
<td>1390</td>
<td>8528</td>
<td>11427</td>
<td>2708</td>
<td>121</td>
</tr>
<tr>
<td>%</td>
<td>0.5</td>
<td>6.0</td>
<td>35</td>
<td>47</td>
<td>11</td>
<td>0.5</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

5. General analytical techniques

5.1. Patient information

5.1.1. Ethical considerations require that the mother is fully informed about the procedure of blood sampling including the purpose and risks.

5.1.2. Several circumstances may affect the interpretation of the measured pH and blood gas data and should be recorded whenever present, e.g. abnormal body temperature, increased inspired oxygen, hyperventilation, sedative medication and type of analgesia in use.
5.2. Sample collection and specimen containers

5.2.1. Specimens from any patient could be infected with human immunodeficiency virus (HIV), hepatitis B virus (HBV), hepatitis C virus (HCV), hepatitis D virus (HDV) or as yet unknown infectious agents. Proper blood collection techniques minimise the risk to health care personnel. Gloves should be worn when appropriate.

5.2.2. The blood may be collected in glass syringes, plastic syringes, or glass or plastic capillary tubes. A total volume of blood of about 0.25 ml is sufficient for a single measurement with most blood gas analysers. However, many commercial syringes require filling with 1 or 2 ml of blood to obtain the correct heparin concentration and to avoid any significant dilution error.

![Graph showing distribution of pH values in the umbilical arteries in 663 healthy term infants with normal birthweight and Apgar score 7 or more. From Dudenhausen JW, Luhr C, unpublished data.](image)

5.2.3. Heparinisation of the blood is necessary. A maximum heparin concentration in the blood sample of 20-50 I.U. per ml is recommended. The low concentration (20 I.U./ml) requires immediate mixing of the sample. The higher concentration (50 I.U./ml) is required for effective anticoagulation during storage of the blood for more than 1 h. A higher heparin concentration may cause an error due to the acidic nature of heparin. Commercial syringes are available which contain a pellet of lyophilised heparin and capillary tubes are available with an inner heparin coating both ensuring an optimal heparin concentration. If the blood sample is used for measuring electrolytes as well (e.g. Ca$^{2+}$, K+, Na$^+$), it is necessary to use a pretitrated heparin preparation containing physiologic amounts of electrolytes. Such heparin preparations are available.

5.2.4. When using a heparin solution the concentration should be 1000 I.U./ml and the volume fraction of heparin solutions should be 2-5% in the final heparinised blood sample. A larger volume fraction causes a dilution error. Thus aspirating 1 ml requires 0.02-0.05 ml of the heparin solution in the syringe. Often the dead space volume of the needle and syringe tip amounts to 2-5% of the syringe volume. Sometimes, however, the dead space volume is larger and it is necessary to expel excess heparin solution to avoid dilution error.

5.2.5. After sampling, any air bubble should be immediately expelled. The needle should be removed with great care to avoid the hazard of self-inflicted wounds and the risk of infection. Mixing of blood and anticoagulant is accomplished by rolling the syringe gently between the hands for at least 5 s, then inverting the syringe repeatedly for another 5 s. Capillary tubes are closed with special plastic caps; mixing may be accomplished with a piece of wire (flea) and an external magnet.
Fig. 7. Distribution of pCO2 values in the umbilical arteries from the same series as in Fig. 6.

Fig. 8. Distribution of base deficit values in the umbilical arteries from the same series as in Fig. 6.

5.2.6. Before or immediately after sampling it is essential that the syringe or the capillary tubes are labelled in a manner that prevents any doubt about the identity of the donor of the sample. Such information includes the patient’s name, identification number, and date and time of sampling and the vessel sampled. Other information relevant to the interpretation of the data should be indicated on the requisition slip, e.g. sample type (arterial or venous).
5.3. Storage of the sample before measurement

5.3.1. Any delay between sampling and measurement should be as short as possible. If the syringe is kept at room temperature the delay should be maximally 30 min (shorter if leucocytosis or thrombocytosis is suspected).

![Graph of PO2 values in the umbilical arteries](image)

**Fig. 9.** Distribution of PO2 values in the umbilical arteries from the same series as in Fig. 6.

If a specimen cannot be analysed within 15 min after collection, it should be collected in a glass container and immediately placed in ice water at 0°C. Storage in ice water is recommendable and especially suited for glass syringes or glass capillaries and should be less than 2 h. Long slender syringes and capillary tubes should be stored in a horizontal position to facilitate subsequent resuspension of the blood cells. The times when the sample is drawn and when analysed should be recorded.

5.3.2. During storage of the blood, glycolysis with lactic acid formation tends to increase the base deficit, increase the PC02 and decrease the pH. The PO2 tends to fall due to oxidative metabolism in the blood cells. These processes are strongly dependent on the leucocyte concentration. If normal blood remained at 37°C (unlikely), in each 10 min period the PC02 would rise by 0.15 kPa (1.1 mmHg); pH would fall by 0.01 and the total oxygen concentration would fall by 0.05 mmol. With plastic syringes further but slight changes may occur due to gas exchange with the surroundings. Thus, with plastic syringes stored in iced water, the PO2 tends to rise due to O2 diffusion from the water.

5.4. Measuring pH and blood gas values

5.4.1. Several pH and blood gas analysers are commercially available. Generally they measure pH, PC02, and PO2 directly at 37°C using electrodes, and calculate the base deficit and the bicarbonate concentration.

5.4.2. The blood gas analyser should be located in the labour ward or in an adjacent laboratory, primarily in order to obtain the result immediately, but also to reduce the preanalytical variation by keeping the delay between sampling and measurement as short as possible.

5.4.3. Measurements may be performed by physicians, midwives, nurses, or laboratory technicians, provided they are adequately instructed by authorized laboratory personnel in the use of the blood gas analyser.
5.4.4. The analyser should be calibrated according to the manufacturer's recommendations. Because of the many designs, protocols and recommendations from manufacturer, it is not possible to give specific guidelines for blood gas analyser calibration methods. In case of any analytical problem such as electrode drift or deviating results from control solutions it is essential to perform a recalibration immediately before each sample measurement.

5.4.5. Immediately before introducing a blood sample into a blood gas or pH instrument the blood cells should be thoroughly resuspended. Syringes should be repeatedly inverted for at least 10 s and then rolled between the hands for another 10 s. Blood in capillary tubes is mixed by moving the metal 'flea' from end to end for at least 5 s.

5.4.6. Before injecting the sample into the analyser a few drops of blood should be expelled onto a cotton swab in order to ensure that a clot of blood does not form in the tip of the syringe. A capillary tube should be opened at one end by removing the plastic cap and the metal 'flea' should be slowly pulled out; this procedure also serves to reveal and remove minor clots of blood.

5.4.7. Measurements should be performed strictly according to the manufacturer's instructions. Too rapid or too vigorous injection of the blood into the instrument should be avoided.

5.4.8. Duplicate measurements should be performed (when sufficient specimen is available), especially whenever unusually high or low or unexpected results are obtained or whenever the instrument flags an unstable reading or electrode drift.

5.4.9. If the sample does not fulfil the criteria for a successful measurement the problem should be clearly specified and the data should not be included in any statistical evaluation.

5.4.10. Experienced laboratory personnel should supervise the daily quality control measurements which should be performed according to the manufacturers' instructions. Regular maintenance and service according to the manufacturers' instructions must be carefully observed and recorded in a maintenance and service log book. Reliable data for analytical precision and accuracy should be available at all times.

5.4.11. Participation in an external quality assessment program is recommended. If there are other pH/blood gas analysers in the same institution, or in nearby institutions it is recommended that the same blood sample be measured in duplicate on all available analysers at regular intervals in order to monitor the accuracy of measurements.

5.4.12. In principle the measured blood pH should be traceable to the reference method for blood pH measurement described by the International Federation for Clinical Chemistry. The measured gas tensions (PC02 and P02) should be traceable to certified gas mixtures with known partial pressures of C02 and O2.

5.5. Sources of error

5.5.1. Preanalytical errors: Failure to record conditions which may have implications for interpretation of the data such as medication (sedation) of the mother (and fetus); maternal oxygen supply, maternal hyperventilation, abnormal maternal temperature; uncertainty concerning the type of blood (fetal or maternal, arterial or venous). A large birth swelling (caput succedaneum) with stagnant blood may cause erroneous values with high PC02 and low pH values in cutaneous blood. Contamination of the fetal blood sample by admixture of maternal blood, amniotic fluid, or meconium may affect the measured values in an unpredictable way. Prolonged exposure of the blood sample to air or air bubbles in the syringe or capillary may cause erroneously high pH values, associated with low PC02 and high P02 values. Erroneous concentration or erroneous preparation of heparin may cause erroneously low pH values. Excessive volume of heparin solution may cause a dilution error (too low PC02 and haemoglobin concentration).

Storage errors: Too long storage at either room temperature (more than 15 min) or at O°C (more than 2 h). Blood clot or haemolysis. Inadequate resuspension of blood cells before measurement resulting in plasma rather than whole blood values.
5.5.2. Analytical errors: Electrode drift and shift; erroneous instrument temperature or barometer reading. Carry-over from previous sample generally tends to cause IOW P02 values to be too high, while high P02 values get too low - some instruments have built-in corrections for this type of error; bacterial or fungal contamination of the calibration solution or of the tubing and measurement cuvette; chemical contamination of the liquid junction; protein coating of pH electrodes affects the response time and the reading; electrostatic noise - halothane may cause a positive bias on the P02 although the effect is generally negligible with modern electrode design.

5.6. General risks

5.6.1. The greatest danger to mother and fetus is erroneous data due to erroneous sampling and/or measurement. Erroneous data may have important implications for the decisions concerning fetal care. False 'positive' and false 'negative' results inevitably occur with chosen statistical probability, e.g. false 'positive' with a probability of 2.5% when two-sided 95% tolerance limits have been chosen. This needs to be taken into account in the clinical interpretation of the data.

5.6.2. Operator risk involves the possibility of infection via exposure to contagious patient blood.

5.7. Notes on the base deficit of the extracellular fluid

5.7.1. The base deficit is defined as the titratable base when titrating back to a pH of 7.40 at PC02 of 5.3 kPa (40 mmHg). In practice the blood base deficit is calculated from the measured pH and PC02 using the blood haemoglobin concentration as a measure of the buffer value of the blood. The equation employed is called the Van Slyke equation.

5.7.2. The extracellular base deficit is calculated using a reduced haemoglobin concentration of one-third of the haemoglobin concentration of the blood since this corresponds to the average buffer value of the total extracellular fluid, as happens in vivo. If the blood haemoglobin concentration is not measured, a value of 9 mmol/l is assumed, i.e. the extracellular base deficit is calculated using a value of 3 mmol/l.

5.7.3. The extracellular base deficit reflects accumulation of non-carbonic acid, e.g. lactic acid, in the extracellular fluid and remains virtually constant during acid in vivo changes in PC02. Hence an increase in extracellular base deficit is the best indication of a metabolic acidosis. When PC02 is elevated base deficit of the blood is higher than base deficit of the extracellular fluid. In perinatal medicine, where PC02 is often elevated, this will be common. In such cases the uninformed will deduce that there is more metabolic acidosis than actually present. To prevent any such misunderstanding only base deficit of the extracellular fluid should be used.
6. References


Appendix: Participants in the Workshop

Dr Gérard Breart, Director INSERM U-149, 123, Bd. de Port-Royal, F-75014 Paris, France
Director Epidemiological Research Unit on Women and Children's Health.

Professor Jochen W. Dudenhauen, Leiter der Abt. für Geburtsmedizin, Universitätsklinikum Rudolf Virchow, Pulsstrasse 4-14, D-14059 Berlin, Germany.
President of the German Society of Perinatal Medicine, Secretary General of the World Association of Perinatal Medicine.

Dr Paul P. van den Berg, Department of Obstetrics and Gynaecology, Perinatal Research Group, P.O. Box 9101, NL-6500 HB, Nijmegen, The Netherlands. Member of the Dutch Society of Obstetrics and Gynaecology and representing Professor Tom Eskes who is on the board of the Dutch Society of Obstetrics and Gynaecology.

Dr A. Galindo INSALUD Dept. de Obst. y Ginec., Hospital Univ. ‘12 de Octubre’, Avenida Andalucia 40, Planta 5, E-28041 Madrid, Spain.
Representing Professor de la Fuente. Both are members of the Spanish Society of Gynaecology and Obstetrics.

Professor Wolfgang Holzgreve, Zentrum für Frauenheilkunde, West. Wilhelms-Universität Münster, Albert-Schweitzer-Strasse 33, D-48149 Munster, Germany.
Secretary of the German Society of Perinatal Medicine.

Professor Ingemar Ingemarsson, Department of Obstetrics and Gynecology, University Hospital, S-221 85 Lund, Sweden.
Chairman of the Perinatal Group, a subcommittee of the Swedish Society of Obstetrics and Gynaecology.

Professor Wolfgang Künzel, Direktor Universitäts-Frauenklinik, Klinikstrasse 28, D-35392 Giessen, Germany.
Chairman of the FIGO Committee on Perinatal Health. Vice-President of the German Society of Obstetrics and Gynecology.

Professor Otwin Linderkamp, Universitats-Kinderklinik, Im Neuenheimer Feld 150, D-69120 Heidelberg, Germany.
Representing the German-Austrian Society for Neonatology and Paediatric Intensive Care.

Professor Gian Carlo Di Renzo, Ist. di Ginecologia ed Ostetricia, Policlinico Monteluce, Via A. Brunamonti, 1-06122 Perugia, Italy.
Secretary and Treasurer of the European Association of Perinatal Medicine, International Delegate Italian Society of Perinatal Medicine, Secretary of FIGO Study Group of ‘Assessment of New Technologies’.

Professor Erich Saling, Institut für Perinatale Medizin, Mariendorfer Weg 28, D-12051 Berlin (Neukölln), Germany.
Founder President representing the German Society of Prenatal and Obstetrical Medicine.

Professor Ola D. Saugstad, Department of Pediatric Research, Medical Faculty University of Oslo, Rikshospitalet, Pilestredet 32, N-0027 Oslo, Norway.
Secretary, working group on Neonatology-European Society of Paediatric Research. Member of the Council of the Norwegian Perinatal Society.

Professor Dr Ole Siggaard-Andersen, Department of Clinical Chemistry, Herlev Hospital, Herlev Ringiev 75, DK-2730 Herlev, Denmark.
Danish Society for Clinical Chemistry. President, Danish Society for Biomedical Engineering. Unofficially representing the International Federation for Clinical Chemistry, Committee on pH, Bloodgases, and Electrolytes.