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Interpreting Umbilical Cord Blood Gases: Technical Issues: Part I

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In order to interpret the results of umbilical cord blood gases correctly, one must have an understanding of technical problems that can mislead on occasion. It is important to recognize:

1) When there is internal inconsistency within a blood gas sample,

2) When two blood gas samples likely derive from the same vessel,

3) When umbilical cord blood gas samples have been mislabeled, i.e., the samples are reversed,

4) When contamination of a blood gas sample with an air bubble(s) has occurred, and

5) The need for obtaining a complete blood gas analysis versus a pH alone.

"In order to interpret the results of umbilical cord blood gases correctly, one must have an understanding of technical problems that can mislead on occasion."

These issues are all addressed within this section or will be within Technical Issues: Part II. Although bicarbonate values are provided, they will not be discussed until the following section on uteroplacental insufficiency. Only the base deficit will be used to evaluate metabolic acidosis.

Case 1: Internal Inconsistency within a Blood Gas Sample (1st example)

The mother was a 22-year-old, gravida 1, para 0, aborta 0, with an intrauterine pregnancy at 39 0/7 weeks based on reliable dates, in active labor. (1) After six hours, her cervix was six cm dilated, completely effaced, and at minus one station. The baby had caput and molding. The mother's temperature was 37.7° C, and the fetal heart rate baseline was rising. Following full dilatation, the mother pushed for two hours without progress and ultimately underwent a primary cesarean delivery. Apgar scores were 9 and 9 at one and five minutes, respectively.

Cord blood gas results were as follows:

	Umbilical Vein	Umbilical Artery
pH	7.34	7.29
Pco_2 (mmHg)	38	46
(kPa)	*5.07*	*6.13*
Po_2 (mmHg)	16	14
(kPa)	*2.13*	*1.87*
HCO_3 (mmol/L)	20	22
BD (mmol/L)	5	15

Interpretation

The umbilical venous pH, PCO_2, and base deficit are normal. The PO_2 is marginally low. The umbilical arterial pH, PCO_2, and PO_2 are normal. The base deficit of 15 is moderately elevated. However, the base deficit is calculated from the pH and the PCO_2 (the hemoglobin concentration also plays a role as a buffer, but unless it is unusually high or unusually low, its effect is commonly ignored). If you are familiar with the usual relationship between the pH, PCO_2, and base deficit, you will recognize that a pH of 7.29 and a PCO_2 of 46 mmHg belie any significant metabolic acidosis (you would expect a normal base deficit). In my experience, the CSLI (Clinical and Laboratory Standards Institute) equations are the most commonly used by blood gas analyzers to calculate the base deficit. Indeed, calculating the base excess/deficit using CSLI with the equation for extracellular fluid base deficit (BDecf = -(PCO_2-24.8+16.2*(pH-7.4)) reveals that the correct base excess/deficit is approximately 5 mmol/L. (2) This is the value that was calculated and reported by the blood gas analyzer. However, the handwritten base deficit presented to the clinician was 15 mmol/L, constituting an internal inconsistency. In this instance, a transcription error occurred. Fortunately, the error was appreciated before the infant received any volume replacement. One must constantly be alert for such errors, and when they are suspected, you are encouraged to calculate the base deficit from the CSLI equation.

It is of interest to note that unless the fetus is dead, fetal core temperature is always higher than maternal core temperature. If the fetus were inert, its core temperature would be identical to the mother's core temperature. Biochemically, however, the fetus is a very active organism. Many biochemical reactions have heat production as a byproduct. The fetal temperature rises until fetal heat loss to the mother equals fetal heat production. This point of equilibration occurs at about 0.5° C (0.9° F) above the mother's core temperature. (3) In this case, the maternal temperature is reported as 37.7° C, and the fetal heart rate baseline as rising. When body temperature rises above normal, oxygen consumption increases, (4) (in the adult by approximately 10% per degree centigrade). (5) Therefore, a fetus with an elevated temperature and a borderline oxygen supply may be at increased risk of hypoxia (6) compared with a fetus with a normal temperature. A febrile mother will always have a febrile fetus. As the placenta is the main method of heat transfer between fetus and mother (high blood flow resulting in efficient convection), either uteroplacental insufficiency or cord compression initially results in elevation of fetal temperature by interfering with heat loss. (7) If uteroplacental insufficiency or cord compression becomes severe enough, fetal metabolism will fail, and fetal temperature will begin to decline.

Key Points

- Base deficit (and bicarbonate) is calculated from pH and PCO_2. If both pH and PCO_2 are normal, then base deficit (and bicarbonate) must also be normal.

- Fetal core temperature is about 0.5° C (0.9° F) higher than the maternal core temperature.
- When body temperature rises, oxygen consumption increases, a fetus with elevated temperature and borderline oxygen supply may be at increased risk of tissue hypoxia.

Case 2: Internal Inconsistency within a Blood Gas Sample (2nd example)

The mother was a 27-year-old, gravida 2, para 1, aborta 0, with an intrauterine pregnancy at 40 4/7 weeks verified by an early obstetric ultrasound examination. The mother had one previous low-transverse cesarean delivery and now desired a vaginal birth. Delivery was by emergent cesarean delivery under general anesthesia following fetal bradycardia that ranged between 60 and 90 bpm for 45 minutes. The infant was found floating freely in the abdomen due to uterine rupture. Apgar scores were 1, 3, 3, and 5 at one, five, 10, and 15 minutes, respectively.

Cord and followup blood gas results were as follows:

	Umbilical Vein	Umbilical Artery	1st UVC	2nd UVC
pH	6.77	6.72	6.67	6.82
Pco_2 (mmHg)	122	143	136	139
(kPa)	*16.37*	*19.07*	*18.13*	*18.53*
Po_2 (mmHg)	9	5	89	143
(kPa)	*1.20*	*0.67*	*11.87*	*19.07*
HCO_3 (mmol/L)	17	18	15	22
BD (mmol/L)	21	21	24	26

Initial attempts at intubation were unsuccessful. The infant was ventilated by bag and mask with 100% oxygen. Chest compressions were applied briefly. The infant was successfully intubated at 15 minutes of age. An umbilical venous catheter was passed. The initial two sets of blood gas values from the infant were drawn through the umbilical venous catheter (UVC) and were obtained at approximately 26 and 41 minutes of age. Ten mEq of sodium bicarbonate was administered following the first blood gas sample and before obtaining the second blood gas sample.

Interpretation

Both umbilical cord blood gas samples demonstrate very severe respiratory and metabolic acidosis, as one would expect the following 45 minutes of severe fetal bradycardia. The first infant blood sample, taken from an umbilical venous catheter, had a reported base deficit more severe than the umbilical artery cord gas. This is not surprising. At the time of birth, the infant's heart rate was low. As the fetal cardiac output is rate sensitive, (8) likely the infant's blood pressure was compromised, resulting in diminished circulation. Lactic acid produced at the tissue level no longer is efficiently cleared into the central circulation and subsequently into the umbilical arteries. Under these circumstances, the umbilical cord arterial blood gas does not fully reflect the metabolic acidosis ongoing at the tissue level.

The initial umbilical venous catheter blood gas reveals a PO_2 of 89 mmHg. Regardless of the concentration of inspired oxygen being delivered to the infant, a central venous PO_2 of 89 mmHg is not physiologically possible except under extraordinary conditions (congenital heart disease with an anomalous venous return below the diaphragm and near the position of the umbilical venous catheter). Contamination of the blood sample with an air bubble is similarly unlikely, as the PCO_2 would be lowered. The PCO_2 value of 136 mmHg is markedly elevated (suggesting the ETT may not have been in the trachea). Almost certainly, the umbilical venous catheter extended into the right atrium of the heart and through the foramen ovale into the left atrium. Blood returns from the lungs through the pulmonary veins into the left atrium. This easily explains the elevated PO_2, which is present in the second umbilical venous sample as well.

Both the first and second umbilical venous catheter samples report large base deficits of 24 and 26 mmol/L, respectively. Note that the second sample has a higher pH than the first (6.82 versus 6.67). Therefore, either the respiratory acidosis has improved (lower PCO_2), and/or the metabolic acidosis has improved (lower base deficit). In fact, the second sample from the UVC has both a higher PCO_2 (139 versus 136) and a worse metabolic acidosis (BD 26 versus 24) than the first UVC sample. When neither has occurred, the only conclusion possible is that an internal (computational) error has occurred. Elevating the PCO_2 by itself, i.e., increasing the respiratory acidosis, will result in a lowered pH. However, the pH has risen from 6.67 to 6.82. Therefore, we must conclude that the metabolic acidosis, as reflected by the base deficit, has become less severe. It is reported, however, that the base deficit has worsened from 24 to 26 mmol/L. This is not possible. Using the CSLI equationii to calculate base excess when the pH is 6.67, and the PCO_2 is 136 results in an extracellular fluid base deficit of 21 mmol/L. Similarly, when the pH is 6.82 and the PCO_2 is 139 results in a calculated BDecf of 12 mmol/L.

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The CSLI equation results confirm that the metabolic acidosis in the second sample is indeed less severe than in the first sample. The equation used to calculate base deficit is not identical from one manufacturer of blood gas analyzer to another. When either the pH or PCO_2 is severely abnormal, it is advisable to compare the calculated base deficit with the CSLI equation. If it is not reasonably close to the reported result, consider trusting the CSLI equation.

Key Points

- When blood from an umbilical venous catheter appears well saturated, suspect the catheter has passed from the right atrium through the foramen ovale into the left atrium.
- Be alert to the possible miscalculation of the base deficit, especially if either the pH or PCO_2 is severely abnormal. Consider using the CSLI equation for the extracellular fluid base deficit, to calculate a value and compare it to the value reported. If it is not reasonably, consider trusting the CSLI equation result.

Case 3: Contamination with an Air Bubble

The mother was a 38-year-old, gravida 5, para 3, aborta 1, with an intrauterine pregnancy at 40 3/7 weeks in active labor. The mother had morbid obesity (272 pounds) and class A diabetes mellitus that was said to be well controlled on diet alone. Uterine contractions occurred every two to three minutes; her cervix was seven cm dilated, completely effaced, and at zero station. Previous vaginal deliveries resulted in infants weighing 3850 g (8 lbs, 8 oz), 4080 g (9 lbs, 0 oz), and 4310 g (9 lbs, 8 oz). The estimated fetal weight was 4000 g (8 lbs, 13 oz). Three days before admission, a nonstress test was reactive. The membranes ruptured spontaneously, revealing trace meconium. One hour later, the cervix was nine cm dilated, completely effaced, and at plus one station. The mother was taken to the delivery room. Thirty minutes later, she delivered an infant with Apgar scores of 7 and 9 at one and five minutes, respectively. During delivery, there was brief difficulty delivering the anterior shoulder. Birth weight was 4675 g (10 lbs, 5 oz).

Cord blood gas results were as follows:

	Umbilical Vein	Umbilical Artery
pH	7.50	7.26
Pco_2 (mmHg) ***(kPa)***	20 *2.67*	50 *6.67*
Po_2 (mmHg) ***(kPa)***	92 *12.27*	11 *1.47*
HCO_3 (mmol/L)	15	22
BD (mmol/L)	4	5

Interpretation

The umbilical arterial sample is normal. In the umbilical venous sample, the pH is high, the PCO_2 low, and the PO_2 very high. Conceivably, severe maternal hyperventilation could cause fetal PCO_2 to be lowered to 20 mmHg and pH to be raised accordingly. A PO_2 of 92 mmHg, however, is not possible absent a hyperbaric chamber.

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In an expectant mother breathing room air, the PO_2 in the uterine vein is normally about 44 mmHg, and the PO_2 in the umbilical vein is normally about 28 mmHg. (10) If an expectant mother with normal heart and lung function were to breathe 100% oxygen, her arterial PO_2 would likely exceed 600 mmHg, and her mixed venous PO_2 would be approximately 50 mmHg. (11) The umbilical venous PO2 will always be lower than the PO_2 of the mother's uterine vein. The PO_2 in the intervillous space changes modestly in response to supplemental oxygen given to the mother. Only if the mother were in a hyperbaric chamber with high ambient oxygen, would it be possible for the umbilical venous PO2 to be raised into the range of 90 mmHg, as in the blood gas results provided above.

Normal barometric pressure averages 760 mmHg at sea level. The partial pressure of oxygen in dry air is approximately 160 mmHg (21% oxygen; 0.21 x 760). Therefore, contamination of either an umbilical venous or arterial blood sample with an air bubble will raise the PO_2. The partial pressure of carbon dioxide in air is only about 0.3 mmHg (0.041% carbon dioxide; 0.00041 x 760). (12) Therefore, contamination with an air bubble will lower the PCO_2 in the sample and consequently raise the pH. PO_2 is the most helpful indicator to alert the clinician to a sample that has been contaminated with an air bubble(s), as a substantially elevated PO_2 is almost always secondary to such contamination. Minor increases in PO_2 over the upper end of normal in umbilical cord venous samples may occur in association with slowed umbilical venous blood flow.

The effect of contamination with an air bubble may vary over a wide range. Many small air bubbles are far more effective than a single large air bubble in altering PCO_2, pH and PO_2. It is the surface area of the interface between air bubbles and the blood that is important. In the extreme, room air may be mixed with a blood sample sufficiently to drive the pH over 8.2 and the PCO_2 down to three mmHg. Many years ago, I did this using a tonometer, an instrument used historically for creating a blood gas sample with known PCO_2 and PO_2, to test the accuracy of a blood-gas analyzer. This device is extremely efficient at mixing thousands of tiny bubbles of a gas with a liquid substrate. Contamination with an air bubble does not affect the base deficit because pH rises an amount equal to the respiratory effect of the decrease in the PCO_2. Contamination with an air bubble is purely a respiratory event. Therefore, in the presence of contamination by an air bubble(s), one may rely on the accuracy of the base deficit, but not the pH, the PCO_2, or the PO_2.

The most reasonable interpretation of the umbilical blood gas values in the case presented above is the contamination of the venous sample with an air bubble. The base deficit may be relied upon as being unaffected and is normal. Fortunately, significant contamination of a blood sample with an air bubble resulting in confusing results appears to be less common than previously. Some current blood gas analyzers do not report results when air bubble contamination is detected.

Key Points

- Contamination of an umbilical cord blood gas sample with an air bubble lowers the PCO_2 (consequently raising the pH) and raises the PO_2.
- PO_2 is the most helpful indicator to alert the clinician to a sample that has been contaminated with an air bubble(s), as a substantially elevated PO_2 is almost always secondary to such contamination.
- Minor increases in PO_2 over the upper end of normal in umbilical cord venous samples may occur in association with slowed umbilical venous blood flow.
- The base deficit is not altered by contamination with an air bubble, as lowering PCO_2 is a respiratory event, not a metabolic one.
- In the presence of contamination with an air bubble(s), some blood gas analyzers report only "air bubble contamination," rather than blood gas results, making obfuscation of the true blood gas values less likely. Also, those using older model blood gas analyzers will also encounter this problem.

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