Interpreting Umbilical Cord Blood Gases: Blood Gas Components

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Definition of Terms

Blood gas samples are measured directly for pH, PCO_2 (partial pressure of carbon dioxide) and PO_2 (partial pressure of oxygen).(1) Bicarbonate (HCO_3-), base deficit (also reported as a negative base excess), and oxygen saturation values are all calculated from the measured parameters. Today, the base deficit is most commonly reported as extracellular fluid (BD_{ecf}), although it is usually labeled only as base deficit without a subscript identifier. The extracellular fluid base deficit is a corrected form of blood base deficit for which allowance has been made for the fact that blood makes up only about 37% of the extracellular fluid volume. BD_{ecf} is sampled from blood, not extracellular fluid. Please be aware that the base deficit may be reported as a blood base deficit (BD_b). This can be an issue for any centers that report BD_b, as decisions as to which newborns qualify for cooling as therapy for hypoxic-ischemic encephalopathy are partly reliant upon BD_{ecf}. (2) Additionally, there are some web sites on the internet that calculate a base deficit when a pH and a PCO_2 are entered. If the base deficit is not identified as either a BD_{ecf} or a BDb, be hesitant about relying on such calculations.

Although blood gas analyzers are preset to assume a specific hemoglobin value, (usually between 14.3 and 15.0 g/dL), and a patient temperature of 37.0° C, in a practical sense, values differing modestly from the preset value of hemoglobin or temperature make little clinical difference in interpretation of the data. Correcting for an elevated maternal temperature of 40.0° C, for example, decreases the analyzed pH by approximately 0.05 for pH between 7.10 and 7.45. (3) Increasing temperature increases the PCO_2 and PO_2 results, but bicarbonate and base deficit remain unaffected. Some authorities believe there is no scientific basis for temperature correction. (4) In modern blood gas analyzers, prior to processing the next blood sample, one may enter a hemoglobin value and/or a patient temperature, and the analyzer will recalculate the results.

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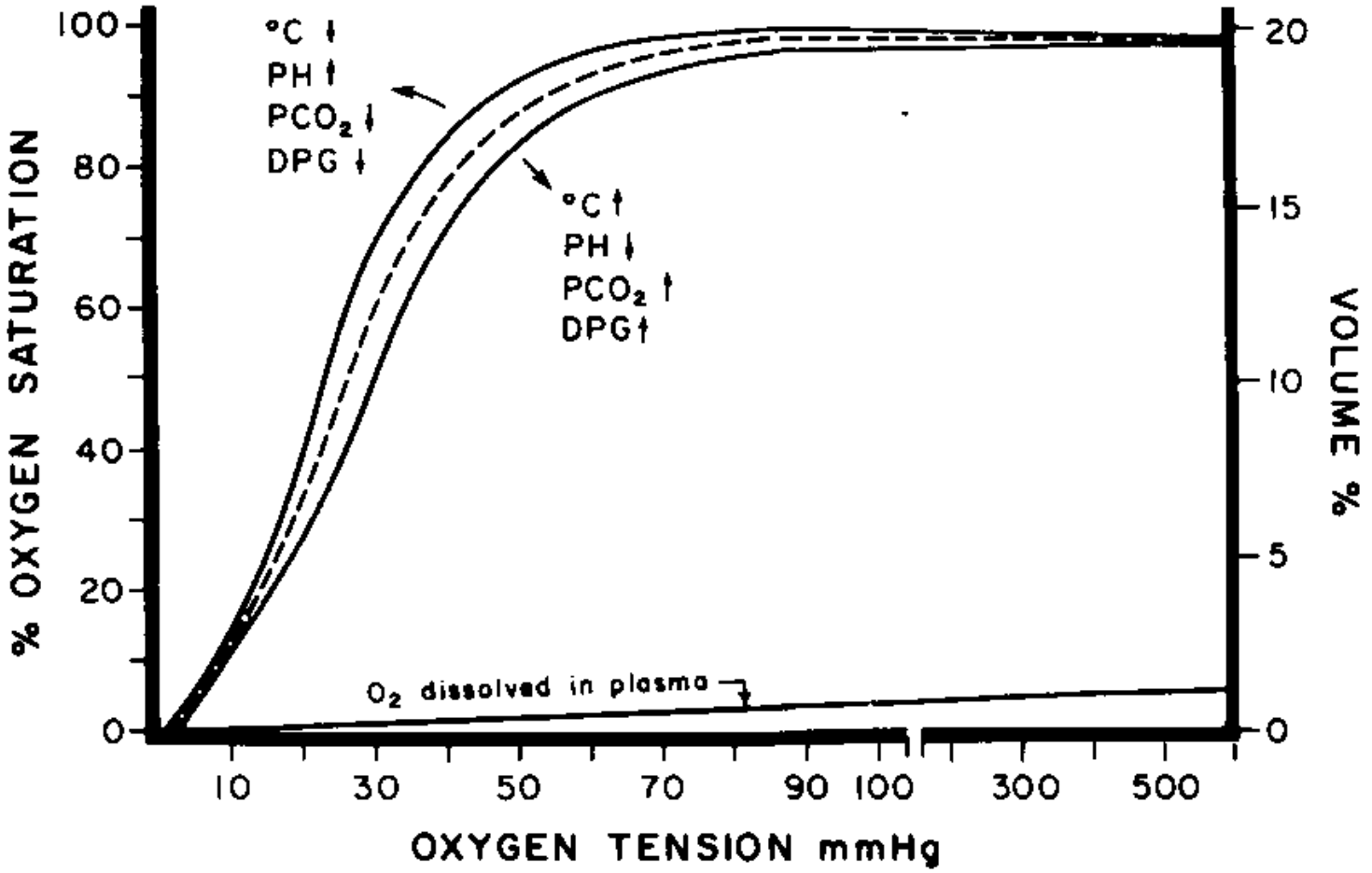

Figure 1. Factors shifting the oxygen dissociation curve of hemoglobin (Fetal hemoglobin is shifted to the left as compared with that of adult he¬moglobin.) Reprinted from Martin RJ, et al. Respiratory problems. In Klaus M, et al. [eds]: Care of the High-Risk Neonate. Philadelphia, WB Saunders Co; 1993, p 228, with permission from Elsevier.

The concentration of free hydrogen ion (H^+) or titratable acid in a solution is usually represented by the term pH. The pH of a solution is inversely proportional to the concentration of H^+ in that solution. In other words, the lower the pH, the higher the concentration of H^+ in solution. (5) It is important to remember that pH is a logarithmic scale, as is the Richter earthquake scale. An earthquake of magnitude 7 has an amplitude ten times greater than an earthquake of magnitude 6. A solution with a pH of 6.0 has ten times more titratable acid than a solution with a pH of 7.0. In a more physiologic range, a solution with a pH of 7.0 has approximately 2.5 times the titratable acid as a solution with a pH of 7.4.

In any mixture of gases, the pressure exerted by a single gas is determined by its concentration in the mixture as well as the atmospheric pressure (Dalton's Law of Partial Pressures). The pressure exerted by an individual gas is called the partial pressure of that gas. (6)

Although results of blood gas analysis report percent oxygen saturation in newborns, this value should be ignored (unless specifically stated that the value has been measured) as blood gas analyzers assume hemoglobin to be of the adult type, hemoglobin A (HbA). In the premature between 24 and 28 weeks' gestation, fetal hemoglobin (HbF) accounts for more than 90% of fetal blood, while at term, approximately 75% of hemoglobin is HbF. (7) Fetal hemoglobin shifts the oxygen dissociation curve to the left, as do several other factors (see Figure above). (8) This shift results primarily from the fact that 2,3-diphosphoglycerate (DPG) binds less well to HbF than to HbA. (9) Therefore, the reported oxygen saturation from a blood gas in newborns will be lower than the true oxygen saturation. As the middle portion of the oxygen dissociation curve is quite steep, this underestimation may be large.

Conversely, pulse oximeter readings in the newborn and young infant may be higher than the saturation calculated from the PO_2 in a blood gas. Over time, however, especially in tiny infants, calculated blood gas oxygen saturations approximate oxygen saturation as measured by a pulse oximeter. This happens because of the gradual conversion to the production of HbA over HbF and/or a more rapid replacement of HbF by HbA through repeated phlebotomy and subsequent transfusion of PRBCs containing HbA.

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In healthy adults breathing 100% oxygen, arterial PO_2 exceeds 600 mmHg (torr). The total volume of oxygen carried in arterial blood, however, increases only marginally as ambient oxygen is increased from room air to 100% (see Figure). This occurs because, at room air, hemoglobin is almost entirely saturated with oxygen. Under these circumstances, increasing the concentration of inspired oxygen adds only a small amount of oxygen dissolved in plasma. Experimentally in fetal lambs (10) and in the human fetus just prior to cesarean delivery, (11) umbilical venous PO_2 rises significantly when the mother's ambient oxygen is increased from room air to 100% but is never more than about 60 mmHg. Despite frequent administration of oxygen to the mother at the time of delivery, it is exceedingly rare to see an umbilical venous cord gas with a PO_2 as high as 50 mmHg. When the mother's ambient oxygen is raised to 60%, in the absence of uteroplacental-fetal pathology, the umbilical cord arterial PO_2 has been reported to rise as high as about 38 mmHg.

In the face of uteroplacental insufficiency,(10) maternal oxygen administration may be beneficial. (13,14) However, in cord occlusion, one would expect very limited benefit, if any at all, in the total amount of oxygen delivered to the fetus. It is axiomatic that maternally administered oxygen will benefit the fetus only if the fetal-placental circulation is intact. Accordingly, the main approach to improving fetal oxygenation must come through amelioration of the underlying condition, such as correcting maternal hypotension or relieving umbilical cord compression, for example. In the face of maternal oxygen desaturation (maternal hypoventilation, narcotics, high spinal, etc.), supplemental oxygen will likely be of major benefit to the fetus through improvement in the maternal arterial PO_2. Prophylactic maternal oxygen administration during the second stage of labor resulted in a significant increase in the percentage of arterial cord pH values less than 7.20. (15)

Relationship Between Umbilical Venous and Arterial Blood Gas Values

In vivo, blood from the umbilical vein has a predictable relationship with blood in the umbilical arteries. The "rules" governing the relationship between umbilical venous and umbilical arterial blood are as follows:

- Blood from the umbilical vein always has a higher pH than blood from the umbilical arteries.
- Blood from the umbilical vein always has a lower PCO_2 than blood from the umbilical arteries.
- Blood from the umbilical vein always has a higher PO_2 than blood from the umbilical arteries.
- Usually, base deficit and bicarbonate are approximately the same in umbilical venous and arterial samples.
    - o If the base deficit of one is significantly worse, it must be the arterial sample.
    - o The base deficit is more reliable than bicarbonate as a measure of metabolic acidosis or alkalosis.

If one to three of the four relationships are opposite to these rules, it is likely the samples came from the same vessel. If all four are opposite, consider the possibility of mislabeling of samples. The rules, as stated above, apply only to individual paired blood gas samples, not to population values, in which there is quite a bit of overlap in the normal range. The placenta acts as the lung for the human fetus. Consequently, if we consider that the lung (placenta) transfers carbon dioxide to the placenta and takes on oxygen, then it should come as no surprise that the vessel(s) bringing blood to the lung (placenta) will always contain more carbon dioxide and less oxygen than the vessel(s) bringing blood from the lungs (placenta) to the baby. The pH in the umbilical vein will always be higher than in the umbilical artery because PCO_2 is lowered as blood passes through the placenta. Consequently, pH must rise.

$CO_2 + H_2O \leftrightarrow H_2CO_3$ (carbonic acid) $\leftrightarrow H+ + HCO_3-$

As carbon dioxide falls, so must hydrogen ion (H+), the prototype

acid. The relationship between the values in umbilical venous and umbilical arterial blood is exactly opposite to that found in the systemic veins and arteries of children and adults but is the same as the relationship between pulmonary veins and the pulmonary artery. This is reasonable when we recall that the placenta acts as the fetal lung.

Key Points

- Blood gas samples are measured directly for pH, PCO_2, and PO2. Bicarbonate, base deficit, and oxygen saturation are all calculated from the measured parameters.
- Blood gas analyzers assume hemoglobin to be of the adult type. Therefore, in newborns, calculated blood gas oxygen saturation values are generally underestimated.
- Blood from the umbilical vein always has a higher pH, a lower PCO_2, and a higher PO_2 than blood from the paired umbilical arteries.
- The base deficit is more reliable than bicarbonate as a measure of metabolic acidosis or alkalosis.
- Usually, the base deficit is approximately the same in umbilical venous and arterial samples, but if one is significantly worse, it must be the arterial sample.
- If one to three of these four relationships are opposite to the rules, it is likely the samples came from the same vessel.
- Be sure your hospital is using extracellular fluid base deficit rather than blood base deficit, as decisions regarding cooling for hypoxic-ischemic encephalopathy are based in part on the former.

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