Monitoring Blood Gases & pH During Open-Heart Operations

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Tensions of oxygen and carbon dioxide, and pH, in blood may be considered indicators of adequacy of lung (and oxygenator) function and tissue perfusion. The cardiologist draws such inferences during preoperative study, and anesthesiologist, surgeon, and extra-corporeal apparatus technician make similar assessments before, during, and after cardiopulmonary bypass.

Malfunction of myocardium or hypovolemia are implied when there are wide arteriovenous differences of oxygen, CO2, or pH. During bypass the implication is inadequate rate of flow. Postoperatively one infers improper blood volume, excess vasoconstriction for which "dilators" or blocking agents are indicated, or poor myocardial contractility requiring stimulation or control of rhythm.

Normally there are 20 cc. of oxygen in 100 cc. of arterial blood (20 volumes percent) and 15 cc. in 100 cc. of venous blood (15 volumes percent). Percent oxygen saturation is approximately 100 percent in arterial blood, 75 percent in venous blood of patients with normal circulation. Thus, 5 cc. oxy gen difference (5 volumes percent difference) is equivalent to 25 percent oxygen saturation difference between arterial and venous blood. For practical considerations, 5 percent saturation is approximately 1 volume percent.

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Oxygen tension in arterial blood refers to the gas which has diffused through walls of alveoli and capillaries of lung. A human being with normal function of lungs and heart, breathing room air at sea level, has tension (capital P is the symbol for tension; partial pressure is a synonym for tension) of oxygen of approximately 100 mm. Hg in arterial blood, and 35 in venous blood. Fortunately, for ease of remembrance and usefulness of application, there are numerical relationship between percent oxygen saturation and PO2. These may be seen in the oxyhemoglobin dissociation curve.

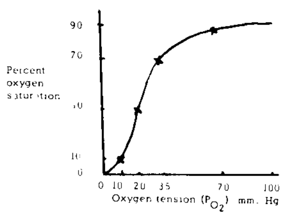

Figure 1. Oxyhemoglobin dissociation curve

% Oxygen Saturation	Oxygen Tension	Ratio
1 - 10%	1 - 10 mm.Hg	1:1
40 - 70%	20 - 35 mm.Hg	2:1
90 - 100%	70 - 100 mm.Hg	Sliding, toward 1:1

Figure 2. Normogram of relationships between oxygen saturation and tension.

The oxyhemoglobin dissociation curve shows the relation between percent oxygen saturation and PO2 (partial presssure; oxygen tension). It may be noted there is a ratio of 1:1 u p to 10 (10 percent saturation, 10 mm. Hg); 2:1 between PO2 of 20 mm. Hg, equivalent to 40 percent to 70 percent saturation: tapering toward 1:1 again at 90. Thus, PO2 20 mm. Hg is equivalent to 40 percent saturation; 25 mm. Hg is 50 percent saturation; 30 mm. Hg is 60 percent saturation: and 35 mm. Hg is 70 percent saturation: These approximate conversions are helpful to all personnel concerned with perfusion and oxygenation of blood of patients.

What is the importance of knowing percent oxygen saturation of venous blood? Spencer, et. al noted that prediction of survival correlated closely with percent oxygen saturation of venous blood, since the latter corresponds with adequacy of tissue perfusion.

When venous saturation is 70 percent, the team may be confident of supplying tissues with their oxygen requirements. Venous saturations below 60 percent demand correction of causes, for brain function may be depressed if blood flow to the brain is so low that percent oxygen saturation of blood draining from the brain is below 60 percent. Death may be imminent if saturation is below 40 percent. Metabolic acidosis will occur rapidly and progressively at this low saturation.

Arterial blood PO2 normally is 100 mm. Hg. It seems unreasonable to allow patients with heart disease undergoing heart surgery and cardiopulmonary bypass to have lower PO2. There is an exception which is tolerated during cardiopulmonary bypass, where 70 mm. Hg is the lowest value permissible in blood leaving the oxygenator. This corresponds to saturation of 90 percent, the level frequently observed in pediatric and adult patients with heart or lung diseases, and in most normal patients following anesthesia. It is rare that PO2 falls to this level and the drop unusally is transient, using a disc oxygenator. Attempts to raise PO2 from levels below 100 mm. Hg involves increased flow rate of gases or increased disc speeds, both of which lower PCO2. In the interest of physiologic perfusion, it is preferred to maintain near-normal PCO2. In the interest of simplicity, it is preferred to omit the addition of gasses containing carbon dioxide.

Partial pressure of carbon dioxide (PCO2) normally is 38 mm. Hg in arterial blood, 44 mm. Hg in venous blood. The commonest deviation is low PCO2 readily induced with a few deep breaths. Hyperventilation may be due to

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the use of diluents to replace blood primes in large volume pump oxygenating systems. The various diluents presently available are not in themselves inherently without dangers. Perfusion and postperfusion management must take cognizance of the specific deficits of each of the diluents of appropriate protective measures to be taken. These include overinfusion and buffering. Moreover, the mere presence of a large volume of urine during and immediately after perfusion does not signify excellent renal function. In fact renal function during perfusion, even with optimal hemodilution, is invariably depressed. However, primary renal failure following hemodilution perfusion is rare. Most difficulties with renal function are the result of inadequate cardiac output immediately after cardiopulmonary bypass.

nervousness before anesthesia, induced during excessive ventilation by an anesthesiologist prior to intubation, and maintained (usually inadvertently) during operation. Carbon dioxide production is diminished, as is oxygen consumption, during anesthesia with muscle relaxation and respiratory assistance. Among the many physiologic aberrations described as a consequence of low PCO2 are cardiac arrhythmias and diminished blood blow to the brain. "Pump technicians" are well-advised, therefore, to maintain physiologic perfusions with PCO2 in normal ranges. Excessively high PCO2 is rarely encountered during cardiopulmonary bypass. If carbon dioxide is used in the operative field, the suction apparatus aspirates CO2 into the collection reservoir, mixing blood and CO2 en route, raising the level of CO2 tension of blood enterin gthe oxygenator. The surgical team can eliminate this problem by requesting minimal suction, as the "pump technician" supplies just enough to keep suction lines filled with blood, not air and CO2. Most oxygenators are efficient in eliminating CO2, achieved by increased flow rates of gas and disc speed. Venous PCO2 can be high, with wide ateriovenous differences, when circuation is improving and metabolic products are returning from tissues. If hypotension and poor perfusion occured before bypass was started, venous PCO2 may be high. If "dilators" or hemodilution are responsible for increased perfusion, venous PCO2 may be high transiently. Increased CO2 production (and possibly increased regional blood flow) during re-warming and accompanying electric shock of defibrillation or cardioversion can raise venous PCO2.

The pH is an expression of acidity. The pH in blood is lowered by acidifying substances in preservatives in which blood is collected, metabolism of blood cells, high PCO2, and low rates of perfusion.

The longer the interval between collection and use of blood used to prime the oxygenator, the lower the pH will be.

The pH of arterial blood has a normal range of 7:35 to 7:45. Below 7:34, acidosis exists; above 7.45 the condition is called alkalosis. If pH is 7.35 to 7.45, with PCO2 45 to 35 mm. Hg, respectively, ("eucapnic", or normal PCO2), neither acidosis nor alkalosis exists. (Please note the relation indicated in the sequence of writing; PCO2 45 mm. Hg corresponding to pH as low as 7.35, and the relatively lower extreme of normal PCO2 of 35 mm. Hg corresponding to pH 7.45.) **If** pH is 7:35 and PCO2 is 35 mm. Hg, the PCO2 is 9 mm. Hg below normal for arterial blood. This requires the classification of acidosis, but because the devaition is small, buffers rarely are added, for the body's capabilities in buffering should quickly correct this minor abnormality. Surgeon, anethesiologist, and pump technician ought to be aware that this is a trend into acidosis, and correct contributory factors. The team must not overlook this "masked" metabolic acidosis.

In addition to low pH implying inadequate perfusion of organs as the **cause**, low pH can **effect** depressed organ function. It has been proved that low pH can depress renal function.

	pH units	P_{CO_2} mm.Hg
Arterial blood	7.44	38
Venous blood	7.38	44
Arteriovenous Difference	.06	6

Figure 3. Relation between pH units and P_{CO_2}.

There is an approximate relationship between pH and PCO2, permitting one to estimate the pH value if PCO2 were presumed to be normal.

It is evident that 0.01 pH units is equivalent to 1 mm. Hg change, but in opposite directions. This is useful information for the "open-heart team".

It is recommended that the pump technician determine pH and gas tensions of blood prior to perfusion. Frequently the PCO2 of priming blood is 60 mm. Hg, which is 20 mm. Hg above normal. In figure 3 it is evident that 1 mm. Hg change in PCO2 effects a change of 0.01 pH units. When PCO2 is 60 mm. Hg (20mm. Hg too high; too acid), pH may be expected to be 0.20 units too acid (too low), i.e. pH 7.18.

Correction of PCO2 of—40 mm. Hg is achieved by putting gas (air; oxygen) through the oxygenator, and rotating the discs of a disc oxygenator. Simultaneously pH will change as PCO2 does. The practice of adding NaHCO3 or THAM (tris-amine) buffers to correct pH, without regard to PCO2 changes the pH, but may be criticized for its lack of understanding. The pH may be adjusted with buffers when PCO2 is normal.

PCO2 of priming volume blood may be low if blood has been circulated and oxygenated prior to bypass. If PCO2 is 20 mm. Hg, what pH would be expected? Answer: 0.20 units above nomal, i.e. pH 7.60. What is the explanation and action when PCO2 is 20 mm. Hg, and pH is 7.40? This is compensated acidosis, and addition of buffers may be considered indicated.

The satisfaction of the technician working with extracorporeal apparatus, with its humanitarian importance, is enhanced by the fascination of the physiology he observes, influences, and treats. Matters not mentioned which influence variations in pH, PO2, and PCO2 stimulate study and though. Improved perfusions and results parallel this understanding.