**<CN>CHAPTER 1**

**<CT>What Is Meant by Interpreting Arterial Blood Gases?**

**<SCT>*One Blood Sample, Two Sets of Tests***

<H1>ONE BLOOD SAMPLE

This book is about how to interpret and use lab values obtained from a single arterial blood sample. Usually obtained from a radial, brachial, or femoral artery, the blood is brought to the lab in a heparinized, ice-encased syringe, where it is promptly tested. Turnaround time from arterial blood drawing to results reporting is typically 10–20 min.

Strictly speaking, *blood gas* refers to any element or compound that is a gas under ordinary conditions and that is also dissolved to some extent in our blood. With this definition in mind, choose which of the following values that represent *blood gases.* The terms are listed in alphabetical order.

<QICON>?</QICON>

<AL>

1. Base excess
2. Bicarbonate
3. Carbon dioxide
4. Carbon monoxide
5. Glucose
6. Helium
7. Hemoglobin
8. Krypton
9. Nitrogen
10. Oxygen
11. pH

Carbon dioxide, carbon monoxide, helium, krypton, nitrogen, and oxygen are gases under ordinary conditions and are also dissolved in our blood, hence they are all blood gases. Although pH is not a gas, it is routinely measured with arterial blood gases (ABG) and is now firmly fixed as part the *ABG test.* Similarly, bicarbonate, not a blood gas but the anion of carbonic acid, is routinely calculated as part of every blood gas test. Base excess is a calculation that reflects how much acid or base is needed to normalize the total buffer base in the blood (see Chapter 7).

Although glucose is also dissolved in blood, it is not a gas but a granular material at room temperature. Similarly, hemoglobin, the molecular carrier of oxygen within the red blood cell, is not a gas under any condition.

Nitrogen, krypton, and helium are inert gases dissolved in our blood (the last two in trace amounts). Because inert gases cause no clinical problems, they are not measured as part of the arterial blood gas test. (Nitrogen can cause the bends and other problems in compressed air diving, but this is a highly specialized area of medicine and the problems are not diagnosed with blood gas measurements.)

Carbon monoxide is a gas and is measured in its combined form with hemoglobin as percent carboxyhemoglobin (%COHb). Thus a value of 10% carboxyhemoglobin means that 10% of the potential oxygen-binding sites on hemoglobin are occupied by CO. Carbon monoxide *could* be measured in its dissolved state (as partial pressure of CO), but this component is minute, and its measurement is only an indirect guide to the %COHb. So %COHb is what the blood gas lab is set up to measure.

In summary, not all blood gases are routinely measured and not all blood gas measurements are of true blood gases. Carbon dioxide and oxygen are routinely measured as their partial pressures, PaCO2 and PaO2, respectively. Carbon monoxide, another blood gas, is measured as %COHb. Nitrogen, helium, and krypton (as well as other inert blood gases) are not measured at all.

<H1>TWO SETS OF TESTS

*All* blood gas labs have a machine to measure pH, PaCO2, and PaO2 and to calculate (or allow for calculation of) the bicarbonate value. When the second edition of this book was published in 1999, most blood gas labs had to have another machine, called a co-oximeter, to measure oxygen saturation, %COHb%, %MetHb, and hemoglobin content (Figure 1.1). All modern blood gas machines now incorporate the co-oximeter function as well as basic measurement of pH, PaCO2, and PaO2. (Fig. 1.2).

<FIG1.1> <FIG1.2>

Why do I emphasize *two sets of measurements?* The answer is that it is important to note not just the results for PaO2, PaCO2 and pH, but also the co-oximetry values. It is important to be aware that PaO2 can be normal in such life-threatening conditions as carbon monoxide poisoning and methemoglobinemia. Furthermore, the SaO2 value calculated from the PaO2 will be falsely high, thus setting the stage for possible serious misdiagnosis (see Chapter 6). So, when you see a value for SaO2 in the blood gas report, make sure it is measured, and not just calculated from SaO2.

In summary, keep in mind that a complete “blood gas analysis” involves two sets of measurements: blood gases, and measurements related to hemoglobin content and binding.

In the space that follows, write the values reported from a blood gas measurement in your lab, and state whether the SaO2 reported is calculated, measured, or both, i.e., two separate entries for SaO2.

<QICON>?</QICON>

This is one question I can’t answer for you. I recommend you find out the answers and not let it pass.

Now, for a question we can answer together: What is the maximum value attainable by adding the values obtained for SaO2, %COHb, and %MetHb from a single blood sample?

<QICON>?</QICON>

<AL>

1. 100%
2. 200%
3. Depends on the hemoglobin content

Just as %COHb is the percent of hemoglobin sites chemically combined with carbon monoxide, SaO2 is the percentage of hemoglobin sites chemically combined (*saturated*) with oxygen, i.e., the %O2Hb (SaO2 is the more popular term). A hemoglobin-binding site cannot contain more than one gas molecule at the same time, so the two percentages (%O2Hb and %COHb) are additive.

Methemoglobin is hemoglobin that has iron in its ferric or oxidized state (Fe+++) as opposed to the normal ferrous state (Fe++); hemoglobin with Fe+++ can bind *neither* oxygen *nor* carbon monoxide. Thus SaO2, %COHb, and %MetHb each represent separate portions of the total hemoglobin content and together cannot exceed 100%.

In summary, the blood gas machine is used to measure partial pressure of oxygen and carbon dioxide (PO2 and PCO2) and pH, and to perform some calculations based on these data. The co-oximeter (either a separate machine or incorporated into the blood gas machine) is used to measure the quantity and various states of hemoglobin, values that allow for calculation of oxygen content (see Chapter 2). All blood gas labs are set up to measure PO2, PCO2, and pH; many labs also run the arterial sample through a co-oximeter to measure additional values (Figs. 1.1 and 1.2). Normal values for blood gas measurements and calculations are shown in Table 1.1.

<TAB1.1>

<H1>ELECTROLYTE MEASUREMENTS

Many blood gas labs now also measure electrolytes in the arterial sample (sodium, potassium, chloride, bicarbonate, and occasionally calcium and magnesium). This has been made possible by incorporating special electrodes into the blood gas machine. The models shown in Figures 1.1 and 1.2 can measure electrolytes in the same arterial sample used for blood gas and co-oximetry measurements. Electrolytes as an aid to acid–base diagnosis are discussed in Chapter 7.

<H1>HOW MUCH PHYSIOLOGY DO YOU NEED TO KNOW FOR PROPER BLOOD GAS INTERPRETATION?

No doubt about it, a knowledge of some basic pulmonary physiology is crucial to understanding arterial blood gas data. The next chapter introduces the three physiologic processes and four equations important in blood gas interpretation.

Physiology textbooks teach the basics, but most of them don’t relate the material to specific blood gas data or the clinical setting. Without the basics, however, you cannot build any clinical understanding. If you have a standard physiology textbook, you might want to review the sections on oxygenation, ventilation, and acid–base balance as you work through this book. Texts particularly recommended for such review (if needed) are listed in Appendix E: Bibliography. *All You Really Need to Know to Interpret Arterial Blood Gases* is predicated on basic physiology as taught in medical school and in all respiratory therapy and 4-year nursing schools. You are the best judge of whether additional review is necessary.

<H1>WHAT OTHER INFORMATION IS NEEDED TO INTERPRET BLOOD GAS DATA?

In large part, this book is about how to integrate blood gas values *with additional information*, to intelligently assess alveolar ventilation, oxygenation, and acid–base balance. When you can do that you will have learned to properly interpret blood gas data. In addition to some knowledge of basic pulmonary physiology, three areas of information are necessary for proper blood gas interpretation.

<NL>

1. Information about the patient’s immediate environment:

<BL>

* Inspired oxygen (FIO2)
* Barometric pressure

<NL>

1. Additional lab data, for example:

<BL>

* Previous blood gas measurements
* Electrolytes, blood sugar, blood urea nitrogen (BUN)
* Hemoglobin content or hematocrit
* Chest x-ray
* Pulmonary function tests

<NL>

1. Clinical information, including the history and physical exam, with emphasis on the patient’s

<BL>

* Respiratory rate and other vital signs
* Degree of respiratory effort
* Mental status
* State of tissue perfusion

When confronted with isolated blood gas data, always ask yourself: **Do I have the necessary clinical and laboratory information to properly interpret these data?**

An isolated PaCO2 reveals little useful information without reference to the patient’s mental status and respiratory effort. A low PaO2 may mean one thing if the patient is inhaling supplemental oxygen and quite another if the patient is breathing room air. Similarly, knowledge of the chest x-ray may be crucial to interpreting a low PaO2. The pH and  sometimes make sense only in light of the serum electrolytes. To properly interpret blood gas data, you must know the full clinical and laboratory picture.

<H1>THE PATIENT’S ENVIRONMENT: FIO2 AND BAROMETRIC PRESSURE

The value for normal PaO2 depends on FIO2, barometric pressure, and the patient’s age. Air consists of a mixture of gases, containing approximately 21% oxygen, 78% nitrogen, and 1% other inert gases, a composition that is unchanged throughout the breathable atmosphere. At any altitude, the fraction of inspired oxygen (FIO2) is 0.21. (FIO2 is sometimes written as a percentage, e.g., 21%. Either format is acceptable.)

Barometric pressure is a function of the weight of the atmosphere above the point of measurement. At sea level, the barometric pressure averages 760 mm Hg, i.e., air pressure at sea level will sustain a closed column of mercury 760 mm high. The higher the altitude, the lower the weight of air at that point and the lower the barometric pressure. At the highest point on earth, the summit of Mount Everest, the barometric pressure is only 253 mm Hg (Fig. 1.3).

<FIG1.3>

Barometric pressure is the sum of the pressures of all the constituent gases. Each gas exerts its own *partial pressure,* which is the pressure it would exert if no other gases were present. Table 1.2 shows the partial pressures for gases in dry air at sea level.

<TAB1.2>

The partial pressure of any gas in dry air is the percentage of gas in the air times the barometric pressure:

PGAS in dry air = percentage of gas × PB

Why *dry* air? Air often contains water vapor, which exerts its own partial pressure. To obtain the partial pressure of any gas, such as oxygen or nitrogen, water vapor pressure must first be subtracted from the barometric pressure, since it dilutes out all the dry gases. Depending on the climate, the amount of water vapor in ambient air varies from 0 to fully saturated and the partial pressure of water vapor, from 0 to > 50 mm Hg. For example, if ambient air is partly saturated so that  is 27 mm Hg, then

PGAS = percentage of gas × (PB – 27)

Regardless of the  in ambient air, once air is inhaled it becomes fully saturated in the upper airway; hence all *inspired* air has a water vapor pressure of 47 mm Hg (at 98.6°F or 37°C; water vapor pressure varies slightly with body temperature). For this reason, knowledge of the ambient air  is not clinically important.

Table 1.2 lists the major gases in air and their partial pressures in dry air. Note that for clinical purposes, we round off the percentage of oxygen in the air to 0.21 (21%); this is the FIO2 (fraction of inspired oxygen) when breathing ambient, or room, air. (Although there is a tiny amount of CO2 in the atmosphere, for clinical purposes we assume an inspired PCO2 of 0.)

Since the percentage of oxygen is constant throughout the breathable atmosphere, but the barometric pressure decreases with altitude, the pressure of oxygen must fall with altitude (Fig. 1.2). To maintain acceptable oxygen levels at extreme altitude, there are two broad options: change the environment or adapt physiologically.

The first option involves increasing either the FIO2 or the barometric pressure. Airplane cabins are pressurized to 7000–8000 feet whenever planes fly much higher than those altitudes; this pressurization allows the FIO2 to be kept at 0.21 throughout the flight. Pressurization is, of course, not feasible out in the open. Mountain climbers carry portable oxygen to increase their FIO2 at extreme altitudes (e.g., above 20,000 feet).

Physiologic adaptation, although well characterized for various altitudes, should not be relied on at extremes of altitude. Nonetheless, as discussed in Chapter 4, physiologic adaptation has allowed people to reach the summit of Mount Everest *without supplemental oxygen.*

<BX\_CLI\_PRO\_1.1> **For all Clinical Problems in this book, consider your answers before checking answers supplied. In that way you can test your understanding, and are more apt to remember the information provided.**

|  |
| --- |
| **Clinical Problem 1.1.** Two men first climbed the summit of Mount Everest without supplemental oxygen in 1978, and others have done so since. What major physiologic adaptation do you suppose makes such a climb possible? |

</BX\_CLI\_PRO\_1.1>

One final point should be emphasized when discussing environmental pressures. The average *airway pressure* in the lungs will always equal the ambient or barometric pressure. (This is true during spontaneous breathing, i.e., without mechanical assistance. With mechanical ventilation, the average airway pressure will be slightly higher than ambient, the difference depending on the amount of positive pressure being delivered by the ventilator.)

When supplemental oxygen is breathed, the extra oxygen displaces nitrogen from the body’s tissues. The amount of nitrogen displaced depends on the FIO2 and how long the supplemental oxygen has been inhaled; but at any FIO2, the total gaseous pressure remains atmospheric (i.e., equal to barometric pressure). Oxygen pressure merely replaces the nitrogen pressure. Breathing 100% oxygen over a sufficient period of time will totally denitrogenate the tissues, a fact that becomes important when considering alveolar PO2 (Chapter 4).

<BX\_CLI\_PRO\_1.2>

|  |
| --- |
| **Clinical Problem 1.2.** What is the average airway pressure of a: |
| <AL>   * 1. Denver resident?   2. New Orleans resident?   3. Climber in the Andes?   4. Climber on the summit of Mount Everest?   5. Subject breathing air in a hyperbaric chamber pressurized to 2 atm? |

</BX\_CLI\_PRO\_1.2>

<BX\_CLI\_PRO\_1.3>

|  |
| --- |
| **Clinical Problem 1.3.** Denver’s elevation is 1 mile above sea level (5,280 feet). Assuming barometric pressure changes linearly with altitude, what is the dry air PO2 in Leadville, Colorado (altitude 10,200 feet), the highest incorporated city in the United States? |

</BX\_CLI\_PRO\_1.3>

<BX\_CLI\_PRO\_1.4>

|  |
| --- |
| **Clinical Problem 1.4.** What is the total pressure of all gases in the lungs, apart from water vapor, under the following conditions: |
| <AL>   1. PB = 760 mm Hg, normal body temperature (37°C)? 2. PB = 253 mm Hg, normal body temperature? 3. PB = 760 mm Hg, body temperature 39°C? (Is it more or less than your answer for 1.4a?) |

</BX\_CLI\_PRO\_1.4>

<BX\_CLI\_PRO\_1.5>

|  |
| --- |
| **Clinical Problem 1.5.** In general terms, what are the physiologic consequences during an airplane trip from the East Coast to California for someone who |
| <AL>   1. Is healthy, with PaO2 = 95 mm Hg? 2. Has mild chronic obstructive pulmonary disease (COPD) with PaO2 75 mm Hg? 3. Has severe COPD with PaO2 58 mm Hg? |

</BX\_CLI\_PRO\_1.5>

<BX\_CLI\_PRO\_1.6>

|  |
| --- |
| **Clinical Problem 1.6.** You take a hot-air balloon ride from sea level to an altitude of 4000 feet. At this altitude, will the following values be higher, lower, or the same as they are at sea level? |
| <AL>   * 1. FIO2   2. Barometric pressure   3. PaO2   4. Water vapor pressure in your lungs   5. Your average airway pressure   6. The sum of all the individual partial pressures (including water vapor pressure) in your alveoli |

</BX\_CLI\_PRO\_1.6>

<H1>ANSWERS TO CLINICAL PROBLEMS

<NL>

1. The alveolar gas equation, introduced in the next chapter, shows that alveolar PO2 is directly related to the inspired oxygen pressure and inversely related to the PaCO2. The inspired oxygen pressure is fixed by the FIO2 and barometric pressure. Mountain climbers adapt at altitude principally by lowering PaCO2, thereby raising their alveolar (and arterial) PO2.
2. The average airway pressure in any location equals the barometric pressure at that location (Fig. 1.2). Although the barometric pressure fluctuates slightly during the day, knowledge of the average barometric pressure at a particular altitude is sufficient for blood gas interpretation purposes. In Denver, average airway pressure is 640 mm Hg; in New Orleans (sea level), it is 760 mm Hg. For the Andes, the answer, of course, depends on the specific altitude, but 380 mm Hg is the barometric pressure (and hence the airway pressure) at some of the peaks. On the summit of Mount Everest, the barometric pressure has been measured at 253 mm Hg. Finally, in a hyperbaric chamber, the ambient pressure is determined by the chamber. At 2 atm, the ambient pressure is

2 × 760 mm Hg = 1520 mm Hg

which is also the average airway pressure of anyone in the chamber.

1. You are not expected to know the barometric pressure in Leadville, Colorado. However, from Figure 1.2 you can determine that PB falls about 120 mm Hg per mile of altitude. Since Leadville is almost 2 miles high, the PB is about 520 mm Hg. Since FIO2 is 0.21, the dry air PO2 in Leadville is approximately 109 mm Hg (compared to 160 mm Hg at sea level).

<AL>

* 1. Airway pressure = barometric pressure = 760 mm Hg. Water vapor pressure at 37°C = 47 mm Hg, which is subtracted to give the total gas pressure of 713 mm Hg (the sum of the partial pressures of oxygen, nitrogen, and carbon dioxide in the lungs at sea level).
  2. By the same reasoning as in 1.4a, the total dry gas pressure is (253 – 47) mm Hg, or 206 mm Hg.
  3. A febrile patient has a higher than normal water vapor pressure. At 39°C, water vapor pressure is about 52.4 mm Hg, 5.4 mm Hg higher than normal; subtracting this value from the barometric pressure of 760 mm Hg gives a dry gas pressure of about 707.6 mm Hg. (You are not expected to know the water vapor pressure at 39°C; a satisfactory answer to this question is “slightly lower than 713”). With most changes in body temperature, the change in dry gas pressure (sum of oxygen, nitrogen, and carbon dioxide pressures) is trivial; for this reason, water vapor pressure, for clinical purposes, is usually assumed to equal 47 mm Hg.

<NL>

1. In all three examples, the arterial PO2 can be expected to fall because of the drop in PB, although the fall will be lessened by mild hyperventilation. Regardless of how high the plane flies, the fall in PB is limited to a cabin pressure equal to about 7000 feet altitude, so the physiologic consequences for the healthy person are obviously insignificant. The drop in PaO2 will be more significant for the patient with mild COPD, but it should pose no clinical problem if resting PaO2 at sea level is 75 mm Hg. Patients with severe lung impairment, on the other hand, must be cautioned about airplane travel; a patient with PaO2 in the 50s should either not fly or receive supplemental oxygen en route, which can be provided by the airlines.

<AL>

* 1. Same.
  2. Lower.
  3. Lower; there will be some hyperventilation, but not enough to compensate for the fall in PaO2 from the lower barometric pressure.
  4. Same.
  5. Lower.
  6. Lower; this is essentially the same question as 1.6e.

**Figure 1.1.** Two blood gas machines: measurements and calculations (\*).

**Figure 1.2.** An analyzer console that incorporates both a blood gas machine and a cooximeter. From a single aliquot of blood, one can obtain all the information shown in Table 1.1.

**Figure 1.3.** Effects of altitude on barometric pressure (PB). The height of the column of mercury supported by air decreases with increasing altitude owing to the fall in PB. Here, PO2 is the partial pressure of oxygen in dry air. Since PO2 = 0.21 × PB, PO2 also decreases with altitude.

**TABLE 1.1. NORMAL ARTERIAL BLOOD GAS VALUES*a***

|  |  |
| --- | --- |
| MEASUREMENT | VALUE |
| pH | 7.35–7.45 |
| PaCO2 | 35–45 mm Hg |
| PaO2 | > 70 mm Hgb |
|  | 22–26 mEq/L |
| SaO2 | 93–98%b |
| %MetHb | < 2% |
| %COHb | < 3.0% |
| Base excess | –2.0 to 2.0 mEq/L |
| CaO2 | 16–22 mL O2/dL |

*a*At sea level, breathing ambient air.

*b*Age-dependent.

**TABLE 1.2. COMPOSITION OF DRY AIR AT SEA LEVEL**

|  |  |  |
| --- | --- | --- |
| GAS | PERCENT IN AIR | PARTIAL PRESSURE (mm Hg) |
| Nitrogen | 78.08 | 593.41 |
| Oxygen | 20.95 | 159.22 |
| Carbon dioxide | 00.03 | 0.23 |
| Other gases*a* | 00.94 | 7.14 |
| Total | 100.00 | 760.00 |

*a*Mainly argon.