Blood Oxygen and Pulse Oximeters

Tutorial

Blood Pressure

Blood pressure readings provide valuable information about the condition of our bodies, indicating health or the lack of it. As the heart contracts (*systole*) and relaxes (*diastole*), the volume of freshly-oxygenated blood increases and decreases measurably within the artery walls. This action causes the artery walls to expand and contract in rhythm with the heart. The force of the blood exerted upon the artery walls is what is called *blood pressure*. Contraction produces the highest pressure, and relaxation the lowest.

A sphygmomanometer (shown in Figure 1) is one tool for measuring blood pressure. When our blood pressure is taken, it is measured at the brachial artery in the forearm in millimeters of mercury (mmHg). If our blood pressure reading is at or near 120 mmHg (*systolic*) over 80 mmHg (*diastolic*), we are considered to be in peak health, all else being normal.

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Figure 1. Sphygmomanometer

Gases in Blood

Blood pressure is not the whole story, however, since the exact concentration of gases such as carbon dioxide and especially oxygen in your blood cannot be determined by a simple blood pressure test.

To determine gas concentrations accurately, specifically saturated oxygen, a blood-gas sensing device must be used, and must be capable of detecting the wide range of nominal values for these gases. Gas concentrations in blood, specifically oxygen (O_2) and carbon dioxide (CO_2), can be expressed as milliliters of gas per liter of blood, and can be indicated by the partial pressure that the gases exert in your blood at a given temperature.

Pulse Oximeters

Because of their ease of use in many hospital- and critical-care situations, pulse oximeters have greatly increased in popularity since their introduction. Today, pulse oximeters are virtually required equipment in situations where the monitoring of arterial oxygen saturation (SaO_2) is essential, such as when anesthesia is in use, both during an operation and in post-operative recovery, intensive care, transport, and patient home care.

Pulse oximeters have proven to be capable and reliable, being highly accurate in measuring blood SaO_2 in the range of 80-100 %, while at the same time needing little, if any, calibration. No patient preparation is required before using the pulse oximeter; in addition, the devices are so simple to operate that specialized training is unnecessary.

How Pulse Oximeters Work

Pulse oximeters are defined as non-invasive, arterial, oxygen-saturation monitors which measure the ratio of two principal forms of hemoglobin in the blood: saturated arterial hemoglobin (also called *oxyhemoglobin*), HbO_2/SAT, to unsaturated (or *reduced*) hemoglobin, Hb.

The arterial oxygen saturation, SaO_2, is defined as the ratio of the concentration of oxyhemoglobin ($cHbO_2$) to the concentration of HbO_2 + Hb ($cHbO_2$ + cHb). Oxygen saturation is commonly expressed as a percentage and is calculated according to the formula in Figure 2.

$$SaO_2 = \frac{cHbO_2}{cHbO_2 + cHb} \times 100\%$$

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Figure 2. Formula for Determining Saturated Oxygen Level

Using this information, a correctly calibrated and operating pulse oximeter can accurately predict the level of oxygen in the blood, which in turn provides valuable data about the health of a patient, and in the case of anesthesia and post-operative recovery, the status of the patient.

Spectrophotometry

Pulse oximeters operate on the principle known as spectrophotometry, using wavelengths of light to determine the concentration of oxygen in the blood. Because we already know the wavelengths for the light absorption of blood hemoglobin, we can mathematically determine the arterial oxygen saturation in a patient's blood.

The light emitting diodes (LEDs) of a pulse oximeters shine two types of light—near infrared light (at 940 nanometers) and red light (at 660 nanometers)—wavelengths that pass through the skin and which are absorbed by both the oxyhemoglobin and the reduced hemoglobin. These light beams pass through the index finger of a patient to photo detectors on the opposite side of the pulse oximeter.

Figure 3 shows a typical pulse oximeter configuration, noting the location of the red and infrared LEDs.

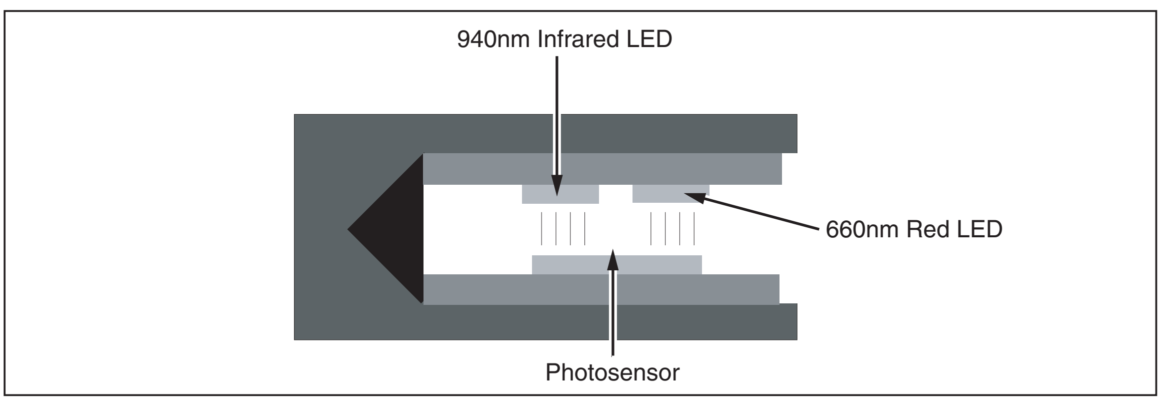

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Figure 3. Diagram of Sample Finger Probe for a Typical Pulse Oximeter

Using this dual light emitting and sensing technology, the pulse oximeter determines the amount of light absorbed by the blood and calculates the percent of oxygen saturation (SaO_2).

However, it is not quite that simple. Pulse oximeters must also calculate out the effect of absorption caused by the presence of venous and capillary blood and soft tissue in order to obtain the true SaO_2 value. To do so, pulse oximeters use a system that distinguishes between “ac” components (the pulsating arterial blood) and “dc” components (the *non*-pulsating components mentioned just above).

Figure 4 shows the different ac and dc components graphically.

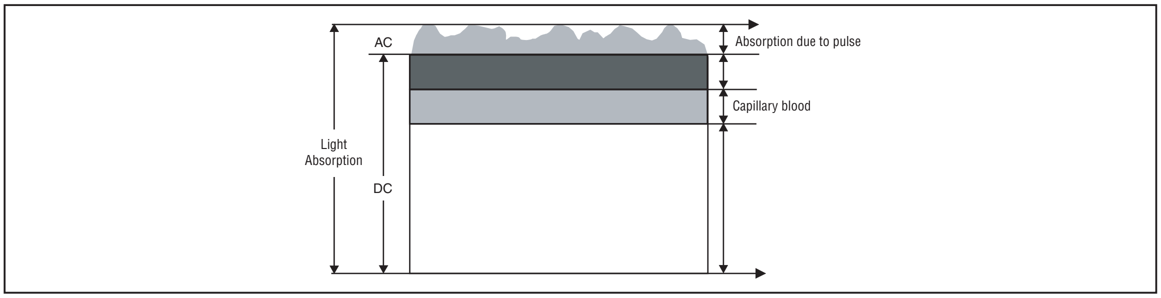

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Figure 4. Diagram of Light Absorbers in Tissue

The pulse oximeter determines the ac component of absorbency at each wavelength and divides this by the corresponding dc (amplitude) component. This results in a "pulse-added" absorbency that is independent of the light intensity. The ratio (R) of these pulse-added absorbances is calculated using the formula shown in Figure 5.

$$R = \frac{AC_{660}/DC_{660}}{AC_{940}/DC_{940}}$$

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Figure 5. AC/DC Infrared and Red Absorption Ratio

When the ratio of red-to-infrared absorbance equals 1.00, the saturation is approximately 81 %.

References

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