Hemodynamic Monitoring:

Pulse Oximetry

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The Standards for Basic Anesthetic Monitoring were set and approved by the American Society of Anesthesiologists House of Delegates on October 21st, 1986. Pulse Oximetry is referenced in ASA Standard II, sub-section 2.2.2 and standard IV, sub-section 4.2.3 (ASA, 2015). The ASA guidelines state that during all anesthetics, the patient's oxygenation, ventilation, circulation, and temperature shall be continually evaluated, whilst ensuring the adequacy of a patient's circulatory system throughout all anesthetics (ASA, 2015). The ASA also denotes that: ("continual" is defined as "repeated regularly and frequently in steady rapid succession" whereas "continuous" means "prolonged without any interruption at any time.").

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History

Johann Heinrich Lambert's book *"Photometria sive de mensura et gradibus luminis, colorum et umbrae"*, published in 1760, formulated the law which states that absorbance of a material sample is directly proportional to its thickness (path length) (Columbia University Archive, 2016). Almost 100 years later, in 1852 a man by the name of August Beer; a German physicist, chemist, and Professor of Mathematics at University of Bonn, added that *"the absorbance is proportional to the concentrations of the attenuating species in the material sample"* (Blood in the case of pulse oximetry). Together, these two scientists developed the Lambert-Beer Law, which describes the disruption in amplitude of the wavelength of light, in relation to the thickness of the material in which it is traveling through (Van Meter et al, 2017). The Lambert-Beer Law is the foundational idea of oximetry.

In 1860, two professors at the University of Heidelberg in Germany, Gustav Kirchoff, and Robert Bunsen (inventor of the Bunsen burner) established the technique of analytical spectroscopy. The discovery of spectroscopy aided Felix Hoppe-Seyler; a German physiologist and chemist in the discovery of the oxygen carrying material in blood called *Hemoglobin* thereafter, in 1864. He defined hemoglobin as two parts, the *heme* dark-red, iron-containing, non-protein part, and the *globin*, the colorless protein part. He then applied absorption spectroscopy to hemoglobin, based on the principle that substances are colored because they absorb and reflect certain wavelengths of light. He demonstrated that if light passed through a solution of oxygenated hemoglobin; at that time, 540nm and 560nm wavelengths would be absorbed (twin-peak absorption pattern) (Hazelwood, 2001).

It was not until more than 100 years later, in Tokyo, Japan that the term "pulse" had been studied in coordination to the field of oximetry, by a young Japanese bio-engineer by the name of Takuo Aoyagi who worked at the Nihon Kohden Corporation, a Tokyo-based manufacturer that developed and distributed medical equipment. At the time, Aoyagi was researching the measurement of cardiac output through dye dilution. An ear oximeter, designed previously by Earl Wood in the United States in 1949, was used during the research. Aoyagi was troubled by interference from pulsatile variations in the light signal, encountering difficulty because of the constant artifact created by these pulsations. After this finding, he concluded that the change in arterial blood flow could be utilized to measure the oxygen saturation without the need for a zero calibration in a bloodless sample (Van Meter et. Al, 2017). Aoyagi chose different wavelengths of light than had been previously used, using 630 nm (red) and 900 nm (infrared) instead of using 805 nm, an isosbestic point; a wavelength at which the absorption of light by a mixed solution remains constant as the equilibrium between the components in the solution changes (UCDavis, 2019), for hemoglobin, which is a point of equal absorption by oxyhemoglobin and deoxyhemoglobin (Severinghaus, 2007). Nihon Kohden Corporation produced the first commercial pulse oximeter, the OLV-5100, and applied for a patent to the Japanese Patent Office on March 29, 1974, but not elsewhere in the world (Aoyagi, 2003).

These are key events throughout history that have pushed pulse oximetry to where it currently is and have helped serve as an establishment for the ASA Monitoring Standards.

Although the probe was very sensitive to motion, it showed that the principle of pulse oximetry was accurate. Based on Aoyagi's foundation, several groups within the United States began to develop their own versions of pulse oximeters (Van Meter et al, 2017). Improvements in diode technology led to several American companies to enter the field of pulse oximetry. In 1980, Biox Technology, an American medical technology company headquartered in Denver, Colorado marketed their first pulse oximeter in the United States (USPTO, 1983).

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Principles

The World Health Organization defines pulse oximeters as medical devices that monitor the level of oxygen in a patient's blood and alert the health-care worker if oxygen levels drop below safe levels, allowing rapid intervention (WHO, 2019). Practitioners can quickly recognize changes in blood oxygen saturation due to the changes in audible pitches and cadence.

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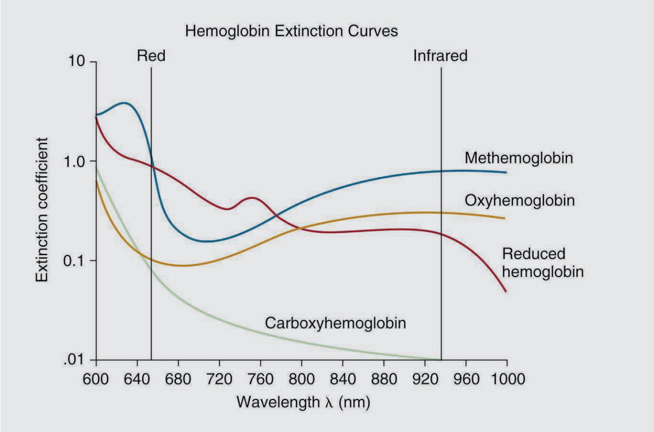
The pulse oximeter is often the very first monitor placed on the patient upon arrival to the operating room (Guimaraes et al, 2019). This noninvasive method is used to measure oxygenation, ventilation and circulation by determining the oxygen levels within the arterial blood. The oxygen levels are determined by measuring hemoglobin saturation (SpO2) via red and infrared light transmission through tissue. Hemoglobin is a protein that is found in red blood cells (RBCs) and can either contain oxygen (oxyhemoglobin) or not contain oxygen (deoxyhemoglobin). Oxyhemoglobin and deoxyhemoglobin absorb light differently: oxyhemoglobin absorbs more infrared light than red light and deoxyhemoglobin absorbs more red light than infrared. The oxyhemoglobin has significantly lower absorption of the 660 nm wavelength than deoxyhemoglobin, while at 940 nm the oxyhemoglobin absorption is slightly higher. This difference is used for the measurement of the amount of oxygen in a patient's blood by the pulse oximeter.

While SpO2 is used by the anesthetist to continuously monitor the oxygen delivered to metabolically active tissues, it is not a direct measurement of the oxygen content of blood. SpO2 serves as a surrogate measurement of oxygen saturation of hemoglobin in arterial blood (SaO2) (Guimaraes et al, 2019).

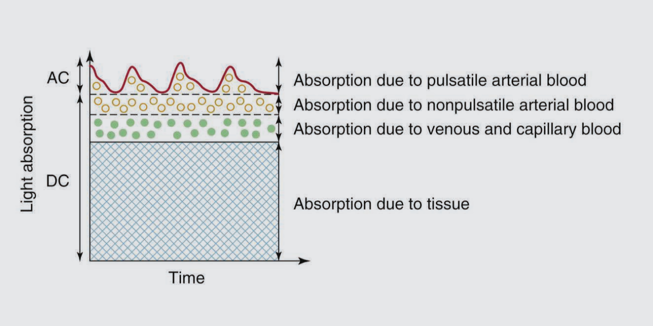
Equipment

There are three constituents that comprise a pulse oximeter: probe transducer, cable and monitor. Each of these works in conjunction with one another to provide an accurate reading of the patient's oxygen saturation levels.



The element that comes in direct contact with the patient is the probe transducer. The pulse oximeter contains a red (650nm) diode, an infrared (940-1000nm) diode, and a photoreceptor. The light-emitting diode (LED) is part of the probe that emits light at a specific wavelength and sends it through the tissue for the photo-detector to receive. After the signal is received, the photo-detector relays that signal to a computer that utilizes an algorithm, which are company specific and proprietary, to transmit the data to the monitor. The probes can either be disposable or reusable and are available in different sizes. In operating room type setting it is more common to utilize disposable probes in order to prevent any potential nosocomial infections. Proper size selection is important because it ensures that accurate values are recorded. For example, if the size if too large then light from the diode can be overcompensated and not reach the photocell without passing through the tissue, which can result in a false high SpO2 reading. It is important for the photocell to be aligned with the LED so readings can be recorded accurately.

The next component is the cable. The cable connects the probe to the oximeter console and it is important that there is a complete connection between the two components or else the monitor will not have an accurate reading or even a reading at all. The values are displayed on the console for the operator to read and monitor. Once the console receives the signal from the probe transducer via the cable then it is displayed in pulsatile waveform and oxygen saturation is displayed in a percentage with the strength of the probe signal.



Pulse Pitch

The pitch of the pulse oximeter sound correlates with the oxygen saturation. The lower the pitch, the lower the saturation will be. There are some pitfalls with this system and one of the main distractions tends to be the OR environment (Lichtor, 2014). The OR environment tends to be quite loud with respect to the staff and the music that the surgeon has requested. A loud environment is by no means conducive to utilizing a monitor that has a sound that is designed to help you readily identify SpO2 saturation when you are performing multiple tasks that directly affect the care of a patient undergoing a surgical intervention.

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The department of anesthesia at Vanderbilt University assessed whether training to make use of combined visual and auditory cues might improve resident physicians' ability to detect frequency changes due to oxygen saturation. The results were just as lackluster as one may imagine. It was concluded that both environmental noise and attentional load impaired response time to detect changes in tones representative of decreasing oxygen saturation. Environmental noise also impaired accuracy of tone determination. The utilization of perceptual training improved the residents' ability to detect changes in oxygen saturation determined by auditory pitch changes. Perceptual training also improved their response time in a noisy and attention-demanding environment like that of an operating room (Lichtor, 2014).

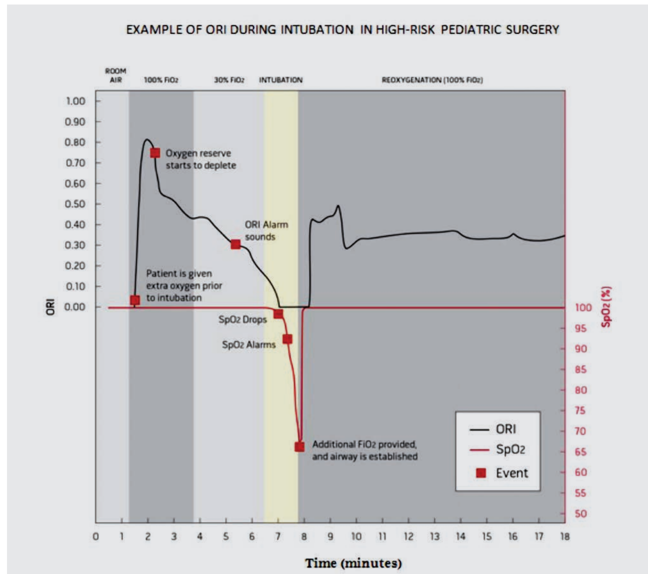
Measurement Method

There are two types of methods that are used to collect data from the pulse oximeter: transmission and reflection. The most common and readily used method for measuring saturation is transmission pulse oximetry. With this method, the light source is transmitted through tissue to the detector that lies directly on the opposite side. There are situations where it is beneficial and even crucial to utilize transmission and reflective probes in conjunction with one another. In cardiac and vascular surgery in particular, practitioners seem to be adopting the use of cerebral oximeters (reflective) in order to get a more accurate reading of SpO2. Wax et al referenced a study in their research that stated "*one study suggested that they may be more reliable than finger probes in patients with poor peripheral perfusion or low cardiac index*" (Wax et al, 2009).

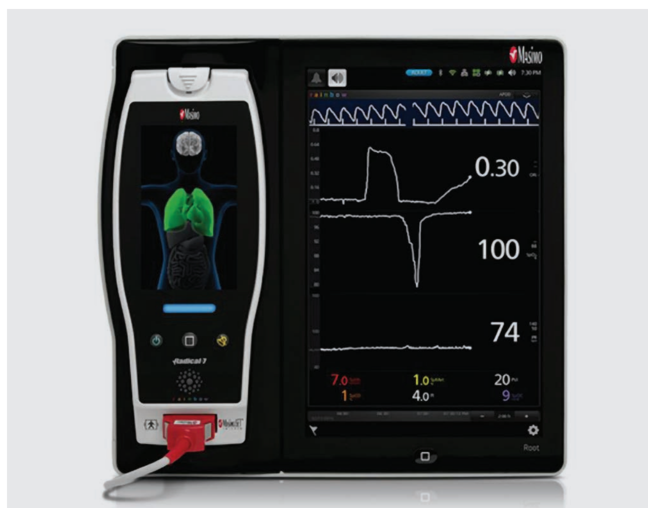
Common sites for transmission probes are the fingertip, toe, nose and earlobe because it provides a direct line with the light source and the photodetector, in contrast of the cheek or forehead sites. Unlike transmission, reflection pulse oximetry relies on backscattering; therefore, producing a weaker impulse. With reflection, the LED and photocell are on the same plane. There are ways that can maximize the signal such as heating the site being measured and applying pressure.

Advantages

Pulse oximetry possesses qualities that make it advantageous from other monitors. These qualities include being noninvasive, serving as a continuous monitor and being the most readily available. Being noninvasive, pulse oximetry is considered a routine monitor and can be placed before anesthesia is administered. This allows some ease for those patients who fear the idea of surgery and may have some concern with needles and pain. The measurement of oxygen saturation is important throughout surgery because providers must be alerted when there is a drop of saturation due to anesthetics or other factors. It is the most readily available because it is easy and fast to place on the patient and it also provides a variety of sizes and different probes for a variety of site applications.



ORI levels drop prior to SaO_2 lower FiO_2 administration and intubation, and rise during re-oxygenation.



Limitations

A limitation of the pulse oximeter that is often overlooked is the inability to detect hyperoxemia. There is growing evidence that the administration of oxygen in concentrations that produce hyperoxemia is associated with cellular injury (Vanderveen et al, 2006). More recent evidence also indicates that resuscitation of premature neonates with a high fraction of inspired oxygen (FiO2) is associated with

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greater mortality and worse outcomes (Rabi et al, 2007). The inability of the pulse oximeter to detect hyperoxemia is profound and worth noting.

Perfusion greatly affects the quality of information provided by the pulse oximeter. If a patient does not have adequate perfusion to their extremities it is impossible to get an accurate SpO2 reading. However, severity of poor perfusion should be noted. A recent study published in the 2018 edition of *Anesthesiology*, tested four different brands and discovered a confidence (p-value), in most cases of <0.0001. All devices had at least a 95% sensitivity and specificity in detecting hypoxemia (SaO2 ~ 88%) and severe hypoxemia (SaO2 ~ 78%) during motion. As to be expected, low perfusion was associated with less precision (Luoie et at, 2018).

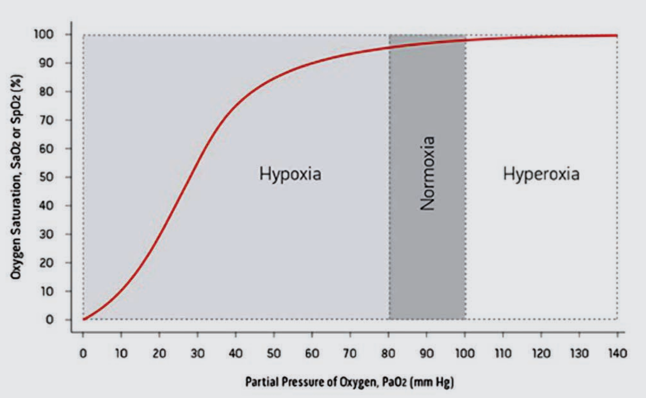

Figure 1. The oxyhaemoglobin dissociation curve illustrates the relationship between SaO2/SpO2 and PaO2.

In the case of poor perfusion, or amputation there are alternatives to placement. Ear probes are quite common practice when one cannot achieve reliable data from a digital probe. In the average patient, when placing a pulse oximeter on a digital site it is advised not to place the probe on the index finger as the patient can potentially cause corneal damage by rubbing their eyes during the emergence phase of anesthesia. When used properly the pulse oximeter is an ideal primary monitor to utilize during anesthesia as stated by the ASA monitoring standards.

Take the QUIZ On The Next Page

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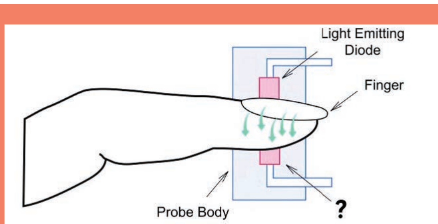
Continuing Education Quiz

To test your knowledge on this issue's article, provide correct answers to the following questions on the form below. Follow the instructions carefully.



1. The image below shows the placement of a pulse oximetry probe on a patient's finger. What part of the pulse oximetry probe is indicated by the "?"?
a) L.E.D.
b) Reflector
c) Photodetector
d) Pulsatile flow sensor

2. This principle describes the disruption in amplitude of the wavelength of light, in relation to the thickness of the material in which it is traveling through.
a) Boyle's Law
b) Lambert-Beer Law
c) The Venturi Effect
d) Poiseuille's Law

3. All of the choices below are components of a typical pulse oximeter; which component is not typical?
a) Transducer
b) Cable
c) Monitor
d) Piezoelectric Wafer

4. The article referenced a wavelength of light from the diode that measures deoxyhemoglobin; what was the wavelength and color of the spectrum? *(Select two)*
a) 560 nm
b) 740 nm
c) 940 nm
d) 660 nm
e) Indigo
f) Red
g) Infrared
h) Ethyl Violet

5. In pulse oximetry, the probe may be placed in different locations on the patient in order to obtain a reading. Which location is NOT utilized for pulse oximetry?
a) Earlobe
b) Forehead
c) Toes
d) Fingertips

6. Pulse oximetry has a fairly significant (often overlooked) disadvantage. What is this disadvantage?
a) The inability to spontaneously ventilate
b) The inability to detect hyperoxemia
c) The Lack of wattage in the diode
d) The inability to detect respirations

7. Pulse Oximetry is a non-invasive method of monitoring used to measure? *(Select all that apply)*
a) Hyperoxemia
b) Oxygenation
c) Circulation
d) Blood loss
e) Ventilation
f) Hemoglobin Levels

8. The article referenced a wavelength of light from the diode that measures oxyhemoglobin; what was the wavelength and color of the spectrum? *(Select two)*
a) 560 nm
b) 740 nm
c) 940 nm
d) 660 nm
e) Indigo
f) Red
g) Infrared
h) Ethyl Violet

9. The article references two principles that are used to collect data from the pulse oximeter, what are these two principles? *(Select two)*
a) Transmission
b) Absorption
c) Reflection
d) Oxidation

10. The pitch of the pulse oximeter sound correlates with the SpO2 of the patient. The_______ the pitch, the lower the oxygen _______ will be. *(Fill in the blanks by selecting two)*
a) Lower
b) Higher
c) Saturation
d) Detection

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8: A B C D E F G H
9: A B C D
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Quiz 1 of 2

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