pulse oximetry [created by Paul Young 02/10/07]

causes of error

Factor	Comment
COHb	Measured as HbO_2 – SpO_2 may be falsely high – see text
MetHb	Absorbs both wavelengths – see text
Low saturations	Progressive inaccuracy below 80%, usually falsely low SpO_2
Prominent venous signal	Dependent limb, tricuspid regurgitation (venous pulsations) – falsely low
Non-pulsatile flow	Cardiopulmonary bypass – poor signal
Vasoconstriction, limb ischaemia, shock states	Low pulsatile signal
Motion artefact	Tremor, voluntary movement – falsely low SpO_2
Ambient light	Strong sunlight, fluorescent light, flickering light – falsely low SpO_2
Anaemia	Effect unclear
Dyes	Methylene blue, indocyanine green – falsely low SpO_2
Black skin pigmentation	Variable precision and bias. May require separate calibration
Nail polish	Especially blue. Falsely low SpO_2
Optical shunting	Due to inadequate probe contact – falsely low SpO_2
Radio-frequency interference	Has been reported with MRI scanners – falsely high SpO_2

1. Dyshemoglobins and Vascular Dyes.
- Carboxyhemoglobin and oxyhemoglobin absorb equivalent amounts of red light, so that carbon monoxide poisoning results in a falsely elevated SpO2
- methemoglobin causes substantial absorption of both red and infrared light, so that the ratio approaches 1 (estimated SpO2 of 85%).
- Administration of methylene blue or indocyanine green dyes for diagnostic tests causes a false, transient (1- to 2-minute) drop in SpO2 to as low as 65%

2. Motion Artifact and Low Perfusion.
- Motion artifact and low perfusion are the most common sources of SpO2 inaccuracies
- Causes of motion artifact include shivering, twitching, agitation, intra-aortic balloon pump assistance, and patient transport. Signs of motion artifact include a false or erratic pulse rate reading or an abnormal plethysmographic waveform.
- Peripheral hypoperfusion from hypothermia, low cardiac output, or vasoconstrictive drugs may increase bias, reduce precision, and prolong the detection time for a hypoxic event.

3. Venous Pulsation and Cardiac Arrhythmia.
- Venous congestion and arteriovenous anastomoses cause the cutaneous veins to pulsate, resulting in a falsely low SpO2. Similar artifacts may occur during hypovolemia and high airway pressure ventilation. Cardiac arrhythmias apparently do not affect SpO2 accuracy.

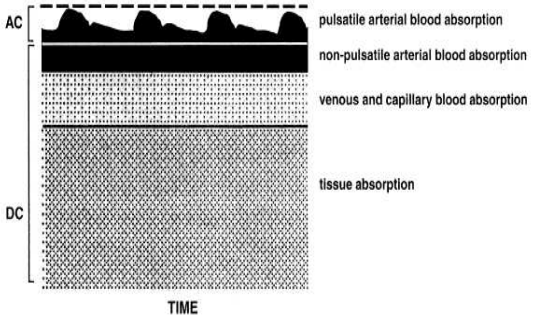
4. Nail Polish and Skin Pigmentation.
- Both dark skin pigmentation and dark nail polish interfere with the absorption of the wavelengths used by pulse oximetry. Pulse oximeters thus have greater bias and less precision in black patients. Whereas an SpO2 of 92% is sufficient to predict adequate oxygenation in white patients, a saturation of 95% is required in black patients.
- Dark nail polish falsely lowers SpO2, whereas red polish does not affect accuracy. When nail polish cannot be removed, mounting the oximeter probe sideways on the finger produces an accurate reading.

5. Ambient Light, Anemia, and Hyperbilirubinemia.
- Although pulse oximeters compensate for the presence of ambient light, the sensor should be shielded from intense light sources with an opaque material. Falsely low SpO2 readings occur when even minor gaps exist between the probe and skin, allowing reflected light off the skin surface to "shunt" directly to the photodiode.
- Under conditions of anemia (Hb 8 g/dL) and severe hypoxia (SaO2 54%), SpO2 bias is markedly increased (-14%).
- Hyperbilirubinemia does not affect SpO2 directly. However, carbon monoxide is a byproduct of heme metabolism, and icteric patients tend to have higher levels of carboxyhemoglobin, so that SpO2 may be falsely elevated.

reflectance pulse oximetry

- Reflectance pulse oximetry was designed to counter signal detection problems associated with finger probes during hypoperfusion.
- Whereas traditional probes work by transilluminating a tissue bed and measuring the forward-scattered light on the opposite side of the finger or earlobe, reflectance probes are constructed with the light-emitting diodes and the photodetector located on the same side. The photodetector measures the back-scattered light from the skin. Reflectance pulse oximetry probes are usually placed on the forehead, which is less susceptible to vasconstriction.
- Light "shunting" from poor skin contact and direct sensor placement over a superficial artery are associated with artifacts. Reflectance pulse oximetry is also limited by poor signal-to-noise ratio and variability among sites in the arrangement of blood vessels and tissue blood volume.

how pulse oximetry works



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Schematic depiction of the pulse oximeter light absorption signal, whereby the signal change caused by arterial blood flow (pulsatile, or alternating current, component) can be distinguished from that of the tissue and surrounding venous blood (baseline, or direct current, component). (Adapted with permission from Datex-Ohmeda Inc., Madison, Wis.)

- Pulse oximetry is a microprocessor-based instrument that incorporates both oximetry and plethysmography to provide continuous noninvasive monitoring of the oxygen saturation of arterial blood (SaO2).
- Oximetry uses spectrophotography to determine SaO2. Oxygenated hemoglobin (HbO2) and deoxygenated or "reduced" hemoglobin (HbR) species absorb light differently, so that the ratio of their absorbencies can be used to calculate saturation.
- In addition, there are two minor hemoglobin species: carboxyhemoglobin (COHb) and methemoglobin (MetHb) which are not measured by standard pulse oximeters

- The pulse oximeter probe is embedded into either a clip or an adhesive wrap and consists of two light-emitting diodes on one side, with a light-detecting photodiode on the opposite side.
- Either a finger or an earlobe serves as the sample "cuvette."
- The tissue bed is transilluminated, and the forward-scattered light is measured.
- Pulse oximetry targets the signal arising from the arterial bed as light absorbance fluctuates with changing blood volume. Arterial blood flow causes signal changes in light absorption (the pulsatile, or alternating current, component) that can be distinguished from venous and capillary blood in the surrounding tissues (the baseline, or direct current, component)
- The ratio of absorbencies is calibrated empirically against SaO2 measured by co-oximetry in normal volunteers subjected to various levels of oxygenation. Pulse oximeters are calibrated against measured SaO2 down to 70% (saturations below this level are determined by extrapolation).

- diodes on oximeter probe emit light at two wavelengths (660nm and 940nm) that pass through tissue. Light that is not attenuated is detected.
- oximeter calculates the ratio of pulsatile and mean light absorbances at each wavelength to create at pulse-added absorbance signal
- oxygenated blood absorbs at 660nm (red light), whereas deoxygenated absorbs preferentially at 940nm (infra-red)
- SpO2 is averaged over 3-6 seconds and updated every 0.5-1.0 seconds

accuracy

- Because pulse oximeters themselves cannot be calibrated, their accuracy is highly variable and dependent on both the calibration curve programmed into the monitor and the quality of signal processing.
- The accuracy of the calibration curve depends on laboratory testing conditions (co-oximeter used, range of oxygenation studied, and characteristics of sample subjects).
- Most manufacturers report an accuracy of ±2% at an SaO2 greater than 70% and ±3% when the SaO2 is 50% to 70%. In normal subjects tested at an SaO2 between 99% and 83%, pulse oximetry has a bias and precision that are within 3% of co-oximetry.
- Under hypoxic conditions (SaO2 78% to 55%), when the monitor must rely on extrapolated values, bias increases (8%) and precision deteriorates (5%).

dynamic response

- Because pulse oximeters detect very small optical signals (and must reject a variety of artifacts), data must be averaged over several seconds, thus affecting response time. Pulse oximeters may register a near-normal SpO2 when the actual SaO2 is less than 70%.
- A prolonged lag time is more common with finger probes than ear probes and is attributed to hypoxia-related peripheral vasoconstriction. Bradycardia also is associated with a prolonged response time.