Pulse Oximetry

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Beer’s Law
The combination of both Beer’s Law and Lambert’s Law

- Beer’s Law – the absorption of light is proportional to the concentration of a sample
- Lambert’s Law – absorption is proportional to the thickness of a sample
History

- Karl Matthes – 1935
  - First oximeter to measure O2 saturation

- Subsequent oximeters developed by Hewlett Packard were bulky and expensive ($10,000)

- 1972 – Takuo Aoyagi
  - Pulsatile changes in absorption of red and infra-red light to measure arterial oxygen saturation

- BiOx, Nellcor (started by anesthesiologist Bill New) and Novametrix began manufacturing in 1980’s

- 1987 – ASA recommends inclusion of pulse oximetry and capnography into operating room as standard of care
  - Prior to this, morbidity and mortality related to hypoxemia estimated at 1/2000 – 1/7000 cases
Principles

- Hemoglobin has a quaternary structure
  - Most commonly – Hgb A – 2 alpha and 2 beta subunits
  - Infants – Hgb F – 2 alpha and 2 gamma subunits

- Within each of these subunits is a Heme group with a bound Iron atom
  - Fe\(^{2+}\) can bind oxygen. Upon binding oxygen, Fe\(^{2+}\) is oxidized to Fe\(^{3+}\) (methemoglobin), which can not bind to oxygen

- Upon binding a molecule of oxygen, hemoglobin undergoes a conformational change
  - This change enables further oxygen molecules to be bound more easily
This conformational change makes oxygen binding a cooperative process, and is responsible for the shape of the oxygen-hemoglobin saturation curve.
Principles

- Pulse oximetry is based on the differential absorption of light by oxyhemoglobin and deoxyhemoglobin.

- The oxygenated hemoglobin allows red light to transmit through and absorbs more infrared light while the deoxygenated hemoglobin allows infrared to transmit through and absorbs more red light.

Figure 2-3. Hemoglobin light absorption graph
**Principles**

- A photodetector in the sensor measures unabsorbed light from the LEDs.
- The resulting signal is inverted and resembles the diagram below.

![Diagram of photodetector and light absorption](image.png)
Principles

- At each site, there are constant light absorbers present
  - Tissue, venous blood and non-pulsatile arterial blood

- Surge in arterial blood with each heartbeat results in more light absorbed.

- So the troughs of lower light absorption are subtracted from the peaks, leaving only arterial bloods light absorption being measured

- Hence “pulse oximetry”
Principles

- After the photodetector, the Red/Infrared ratio is calculated
  - This is compared to an algorithm that is specific to each company/device and is based on measurements obtained in healthy volunteers
  - This ratio corresponds to Sp0₂
    - 0.5 is approx 100%
    - 1 is approx 85%
    - 2 is approx 0%
Arterial oxygenation, and, because the variation in light absorption is proportional to the volume of arterial blood with each heart beat, it can be used to estimate volume status (with some computational help)
Sources of Error

Strength of Arterial Pulse

- Any factor that reduces arterial pulsations will reduce the ability of the instrument to obtain and analyze the signal
  - Hypothermia
  - Hypotension
  - Vasopressor use
Sources of Error

- Body Movement
  - Extraneous movements can cause intermittent changes in absorbance
  - Shivering
  - Parkinsonian tremors
Sources of Error

- Dyshemoglobinemias
  - Carboxyhemoglobin
    - CO binds to heme competitively with 250 times the affinity of oxygen
    - COHgb has same absorption pattern of 660nm light as O2Hgb
    - Readings are artificially high
Sources of Error

- Methemoglobin
  - Describes the oxidized form of hemoglobin (Fe^{3+})
  - Methemoglobin absorbs as much 660nm red light as it does the 940nm infrared
  - Sats approach 85%
    - Falsely low at high Sp02, falsely high at low SpO2
Sources of Error

- Methylene Blue, indigo carmine, indocyanin green
  - Cause drop in Sp02

- Color Interference
  - Pulse oximetry not affected by skin color
  - Is affected by artificial or opaque nail finishes that may interfere with transmission of light
Sources Of Error

 Physical Factors
 Electrocautery
    Interferes with signal
 BP Cuff
    Don’t place it on the same arm (and forget…)
 High intensity light
    Can interfere with signal
       (make sure the probe is covered)
Sources of Error

- Venous Pulsations
  - Secondary to AV fistulas

- Saturations below 80% are inferred, and not based on measurement
  - The R/IR ratio and its correlation to oxygen saturation is based on measurements made on healthy volunteers
  - Only a genocidal IRB would allow for measurements of both to be made at sats < 70%
Questions?