Oxygen Saturation Monitors & Pulse Oximetry
Key Points

Oxygen Saturation Monitors & Pulse Oximetry:

- Role of hemoglobin in respiration
- Basic principle of how SpO₂ is determined by absorption of red and infra-red
- Know the wavelengths of red and infra-red used in a SpO₂ sensor
- Oxygen saturation SpO₂ vs oxygen content in the blood
  i.e. the ‘oxygen dissociation curve’
- Tone modulation in pulse oximeters - why?
- Know the forms Hemoglobin can take
- What does Perfusion Index (PI) measure
- Sources of inaccuracy in SpO₂ measurement
- Detection of cerebral O₂ saturation
- Know the names Nellcor & Masimo

www.youtube.com/watch?v=WXOBJEXxNEo
or http://safeYouTube.net/w/owkc
‘Ventilation’ refers to the physics of gas movement into the lungs. (mechanical)

‘Respiration’ refers to the exchange of oxygen and carbon dioxide in cells by means of hemoglobin in the blood. (chemical)
Hemoglobin -

Each hemoglobin unit has 4 heme groups, each of which can carry one oxygen molecule.
Heme -
Oxygen transport in the blood -

Red blood cell

Oxygen from lungs

Oxygen released to tissue cells

Hemoglobin molecules

Oxygen bonded with hemoglobin molecules
Saturation defined:

Assume 100 hemoglobin molecules together carry a maximum of 400 (100 x 4) oxygen molecules.

If these 100 hemoglobin molecules were carrying 380 oxygen molecules they would be carrying (380 / 400) x 100 = 95% of the maximum number of oxygen molecules that could carry.

They would be “95% saturated”.

Oxygen saturation is referred to as “SpO₂”.

(Peripheral capillary Oxygen Saturation)
PaO₂ and PvO₂ are the **partial pressures** of O₂ in the arterial or venous blood. Same applies to CO₂.

SaO₂ and SpO₂ (saturation) **both** describe the percentage of hemoglobin that is carrying oxygen, but:

SaO₂ is determined by **laboratory analysis (a co-oximeter)**.  
SpO₂ is determined by a **pulse-oximeter**.

Pulse oximeters are widely used, but SaO₂ is still considered the ‘gold standard’ for assessing oxygenation.

### Table 31-1.  
**Typical Values of Blood Oxygen Level**

<table>
<thead>
<tr>
<th></th>
<th>%SaO₂</th>
<th>PaO₂</th>
<th>PaCO₂</th>
<th>%SvO₂</th>
<th>PvO₂</th>
<th>PvCO₂</th>
</tr>
</thead>
<tbody>
<tr>
<td>Adult</td>
<td>96–98%</td>
<td>85–100 mmHg</td>
<td>38–42 mmHg</td>
<td>70–75%</td>
<td>35–40 mmHg</td>
<td>41–51 mmHg</td>
</tr>
<tr>
<td>Neonates</td>
<td>%SaO₂</td>
<td>63–87 mmHg</td>
<td>PaCO₂</td>
<td>~94%</td>
<td>31–35 mmHg</td>
<td></td>
</tr>
</tbody>
</table>
The Oxygen Dissociation Curve:

Percent saturation (sO$_2$, %)

Oxygen partial pressure (pO$_2$, mmHg)
Effects of blood CO$_2$, temperature, or pH on the curve:
Basis for SpO$_2$ monitoring:

De-oxygenated hemoglobin (Hb) partially absorbs light at 660nm. Oxygenated hemoglobin partially absorbs light at 940nm. (visible light is 400-720 nm)

If we measure the absorption of both wavelengths at any given instant and determine their ratio, we have the percentage of total hemoglobin that is carrying oxygen. *i.e.* the “Oxygen saturation”.

In practice, two LED’s each send a 660nm or 940nm signal through any perfused tissue to a sensor, which receives the partially absorbed signals.

Those signals are sent to the monitor where they are processed and display the % saturation, pulse rate, and (optionally) a plethysmographic (volume) waveform.
higher absorption; low signal level

lower absorption; high signal level

(absorption)

OxyHemoglobin

de-oxygenated Hemoglobin

Wavelength (nm)
(absorption)

Extinction ($10^x$)

(Orange) 660 nm

(Red) 660 nm

(Infrared) 940 nm
a way to remember this...

**SeXy DARLiNg!**

at **SiX** hundred .... wavelength

**DeoxyHb Absorbs Red Light**

- **Deoxy Hb**
- **Oxy Hb**

![Graph showing absorbance of light wavelengths with Deoxy Hb and Oxy Hb at different wavelengths](image-url)
What the monitor sees:

Variable absorption due to pulse-added volume of arterial blood

Absorption due to arterial blood

Absorption due to venous blood

Absorption due to tissue

Time
Figure 31–3. Absorption Signal from Pulse Oximeter Finger Probe.

Waveform due to arterial pulsatile signal ($\lambda_1 = 660$ nm)

Waveform due to arterial pulsatile signal ($\lambda_2 = 940$ nm)

660 nM red
940 nM IR
R-curve for an SpO₂ monitor:

Each manufacturer has a specific R-curve for their monitors, determined by the components and algorithm they use.

(When testing monitors, we must know the manufacturer’s R-curve.)

(note the non-linear line)
Tone Modulation in Pulse Oximeters:

Almost all pulse oximeters emit a brief audio tone with each pulse, whose pitch is harmonized with the saturation value.

The higher the saturation, the higher the pitch.
Forms of Hemoglobin:

Hemoglobin $Hb$: Hemoglobin without attached $O_2$)

Oxyhemoglobin $HbO_2$: Hemoglobin with attached $O_2$)

Carboxyhemoglobin $COHb$: Hemoglobin with attached $CO$, Carbon Monoxide) gives inaccurate SpO$_2$

Methemoglobin $MetHb$: (pronounced MET-hemoglobin) cannot bind to $O_2$ and gives inaccurate SpO$_2$

Sources of Inaccuracy in Pulse Oximetry:

Motion of the perfused tissue (Motion Artifact)

Poor tissue perfusion due to cold temp or vascular disease

Carboxyhemoglobin: typically high in smokers. (May be mis-read as HbO$_2$.)

Methemoglobin: from toxins. (May be mis-read as either HbO$_2$ or Hb.)

Diagnostic dyes in bloodstream: methylene blue, cardio green, & others

Nail polish

Skin pigmentation

Ambient light that is rich in infrared (e.g. surgical lights)
Inaccuracy due to Carboxy-Hb and Met-Hb:

**Graph:**
- **Extinction coefficient** vs. **Wavelength (nm)**
- **Methemoglobin**
- **Oxyhemoglobin**
- **Reduced hemoglobin**
- **Carboxyhemoglobin**

**Wavelength (nm):**
- 660 nM (red)
- 940 nM (infrared)
Perfusion Index (PI):

- A measurement of signal strength, which indicates the amount of pulsatile blood flow at the specific site on the patient’s body where a sensor is placed.
- References the pulse signal to the offset.
- Especially useful in newborns.
Pleth Variability Index (PVI):

\[
PVI = \frac{P_{\text{Max}} - P_{\text{Min}}}{P_{\text{Max}}} \times 100\%
\]

Measures the changes in PI (Perfusion Index) during each respiratory cycle.

Useful to check balance between the intrathoracic (chest) pressure and intravascular fluid volume.

e.g. during asthma attack, or to adjust the patient’s blood volume.
Advanced hematological monitoring:

Oxygen Saturation (SpO₂)

Pulse Rate (PR)

Perfusion Index (PI)

Hemoglobin (SpHb ®)

Oxygen Content (SpOC ®)

Carboxyhemoglobin (SpCO ®)

Methemoglobin (SpMet®)

Pleth variability index (PVI®)

Note: all ® Masimo
Masimo rainbow® Pulse CO-Oximetry™

Masimo rainbow® is a noninvasive monitoring platform enabling the assessment of multiple blood constituents and physiologic parameters that previously required invasive or complicated procedures, in addition to providing Masimo SET® Measure through Motion and Low Perfusion™ pulse oximetry.

**SpHb**  **RRa**  **SpCO**  **SpMet**

**Masimo rainbow® Measurements:**

- Total Hemoglobin (SpHb®)
- Oxygen Content (SpOC™)
- Carboxyhemoglobin (SpCO®)
- Methemoglobin (SpMet®)
- Plus: Masimo SET measurements of Oxygen Saturation (SpO₂), Pulse Rate (PR), Perfusion Index (PI), and Pleth Variability Index (PVI®)
Proprietary algorithm for Masimo’s Signal Extraction Technology (“SET”)

Diagram showing the flow of data from digitized, filtered, and normalized signals through different algorithms and measurement processes to a post-processor.
“SatSecond” as an alarm parameter:

The change in saturation and the time span factored together as a determinate for alarms.

Two examples where no alarm is activated:

A

- 2-point drop in SpO₂
  - x 3 seconds
  - 6 SatSeconds
  - No alarm.

B

- 5-point drop in SpO₂
  - x 1 second
  - 5 SatSeconds
  - No alarm.
“SatSecond” as an alarm parameter:

The change in saturation and the time span factored together as a determinate for alarms.

Two examples where an alarm is activated:

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Change in Saturation</th>
<th>Time Span</th>
<th>SatSeconds</th>
<th>Alarm Duration</th>
</tr>
</thead>
<tbody>
<tr>
<td>C</td>
<td>5-point drop in SpO₂</td>
<td>× 6 seconds</td>
<td>30</td>
<td>2 seconds</td>
</tr>
<tr>
<td>D</td>
<td>2-point drop in SpO₂</td>
<td>× 10 seconds</td>
<td>20</td>
<td>5 seconds</td>
</tr>
</tbody>
</table>
Nellcor’s OxiMax™ technology -

A small, digital memory chip resides within every Nellcor OxiMax sensor, transmitting sensor-specific data to the monitor to enhance pulse oximetry performance and provide responsive, clinician-friendly features.
Earlier calibration of sensor (1980’s & 1990’s)

Nellcor’s ‘OxiMax’ calibration
Nellcor’s “Max-Fast” sensor:

Reflects signal from bone at the forehead.

Greater sensitivity,

Eliminates motion artifact
1. **Masimo**
   Radical

2. **Rozinn**
   Electronics
   Ho₂lter+

3. **SIMS BCI**
   Capnocheck
Disposable sensors -
- rainbow ReSposable™
  >30kg
  Adult

R2-25a

R2-25r
Reusable sensors -
Nonin’s “Onyx” miniature pulse oximetry monitor:

First self-contained miniature SpO₂ monitor
Onyx knock-offs -
GUARD YOUR HEALTH!

Monitors:
• Pulse Rate
• Asthma
• Heart Rate
• Respiratory Health
• COPD

LIKE HAVING A PHYSICIAN AT YOUR FINGERTIP!
It’s the most painless, non-invasive way yet to monitor your current pulse rate and oxygen saturation levels. Perfect for those with heart or respiratory problems, asthma or COPD. Packs powerful & important moment-to-moment health information in just 2 ½". Ergonomic design with easy-see LED readout for day or night use. FDA approved unit includes zippered pouch with belt loop & 16” L strap to hang around neck. Requires 2 AAA batteries available everywhere.

Clinically Tested
FDA Approved!

#90145, Fingertip Pulse Oximeter...$49.99
Regional $O_2$ Saturation ($rSO_2$): Detection of $O_2$ saturation in the brain

Detects red and infrared signals by reflection in brain tissue
rSO₂: Bilateral cerebral oxygenation during surgery:

- Induction Intubation
- HOB up to “beach chair” position
- NIBP 176/96
- NIBP 180/98
- NIBP 91/53
- NIBP 134/60
- NIBP 175/83
- Critical Cerebral Desaturation Threshold
- Incision
- Vent changes to increase CO₂
- Vent changes to increase CO₂
- Nitro-Paste On and Off
- 1u PRBCs infusing slowly
- dressing wound
- etCO₂ 32
- etCO₂ 33
- etCO₂ 38
- etCO₂ 43
- etCO₂ 41
- Right Cerebral rSO₂
- Left Cerebral rSO₂
Cerebral Oxygen Monitoring: Regional Oxygen saturation (rSO₂)
Somanetics ‘INVOS’ rSO$_2$ monitor:

http://www.somanetics.com/our-technology
Most major manufacturers include either Nellcor or Masimo SpO₂ technology in their monitors as ‘OEM boards’:

**MS-2040 Masimo SET OEM Board**
*First Sub-45 mW Signal Extraction Pulse Oximetry Platform*

Dimensions and specifications on the MS-2040 board are as follows:

**Single-stack version (MS-2040)**

- Size = 2 inches by 1.38 inches
- Board thickness = 0.36 inches
- Mounting hole diameter = 0.125 inches

**Double-stack version (MS-2040ds)**

- Size = 1.8 inches by 1.15 inches
- Board thickness = 0.46 inches
- Mounting hole diameter = 0.110 inches
Major Players in Pulse Oximetry:

Manufacturers of stand-alone monitors:
- Nellcor
  - Masimo
    - Nonin
    - Invivo Research

Manufacturers of multi-parameter monitors who license SpO₂ subassemblies from Nellcor or Masimo:
- Philips
  - Spacelabs
    - Datex-Ohmeda
    - G.E. Medical
Pulse Ox testers for biomed shops -

There is no such thing as an SpO₂ ‘simulator’!

A simulator mimics a parameter with a directly equivalent voltage, impedance, pressure, etc.

There are no true SpO₂ simulators because O₂ saturation cannot be directly duplicated in a test device. SpO₂ test devices only mimic the SpO₂ by means of an optical or opto-mechanical component.

ref: www.hospimedica.com/whitepapers/52c1c251319ad_SP02.pdf
Pulse Ox testers for biomed shops -

Netech’s “FingerSim” -

Pronk’s “OxSim OX-1” -

Fluke Spot Light -
Pulse Ox testers for biomed shops -

Fluke Index 2 -

Fluke ProSim 8 with SpO2 tester

Clinical Dynamics “SmartSat”
SpO₂ monitors should be tested at a variety of saturation values, normal and abnormal, including variations in the pulse rate, and pulse volume (or amplitude), if possible.

Example of tester options: