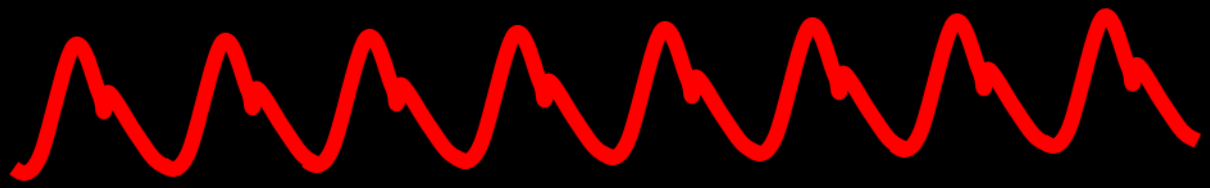
Noninvasive Detection of Arterial Pulses and Their Utilization



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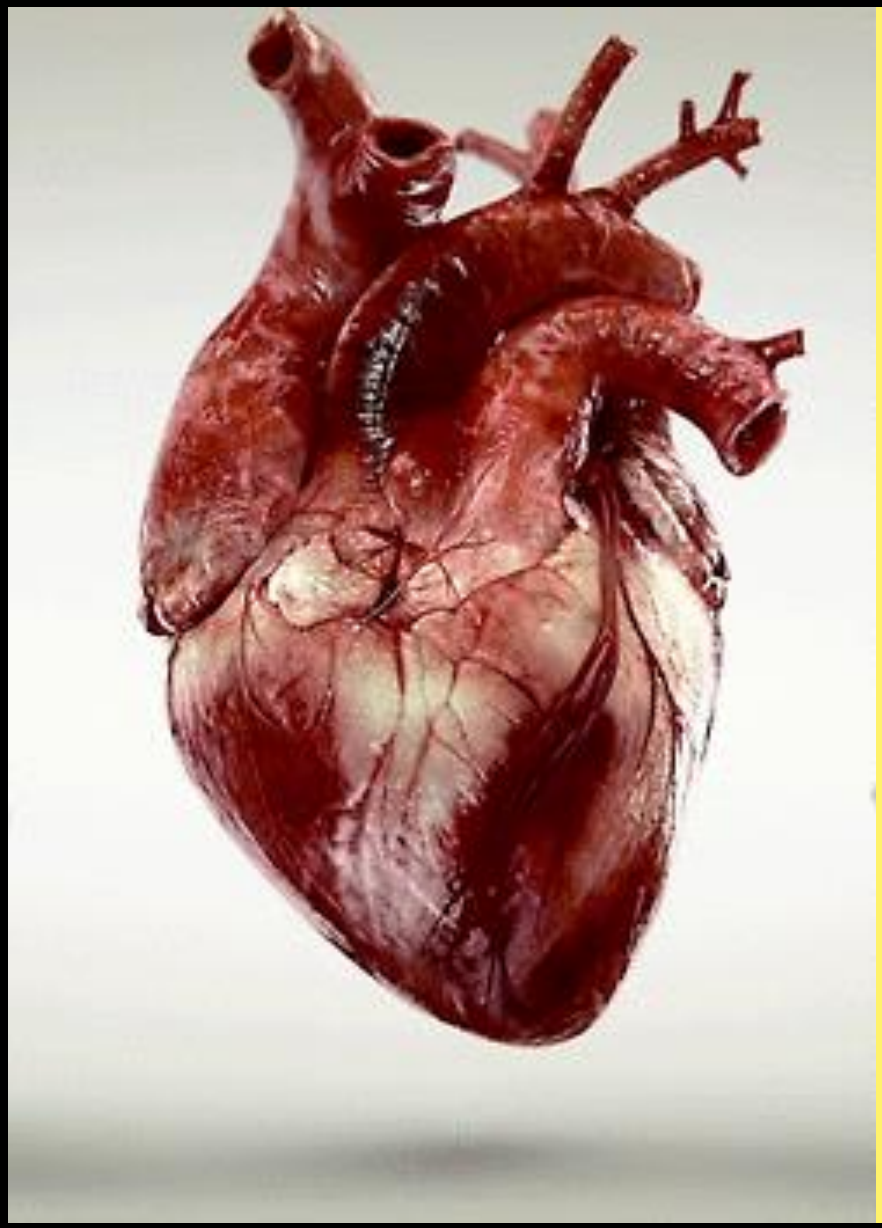
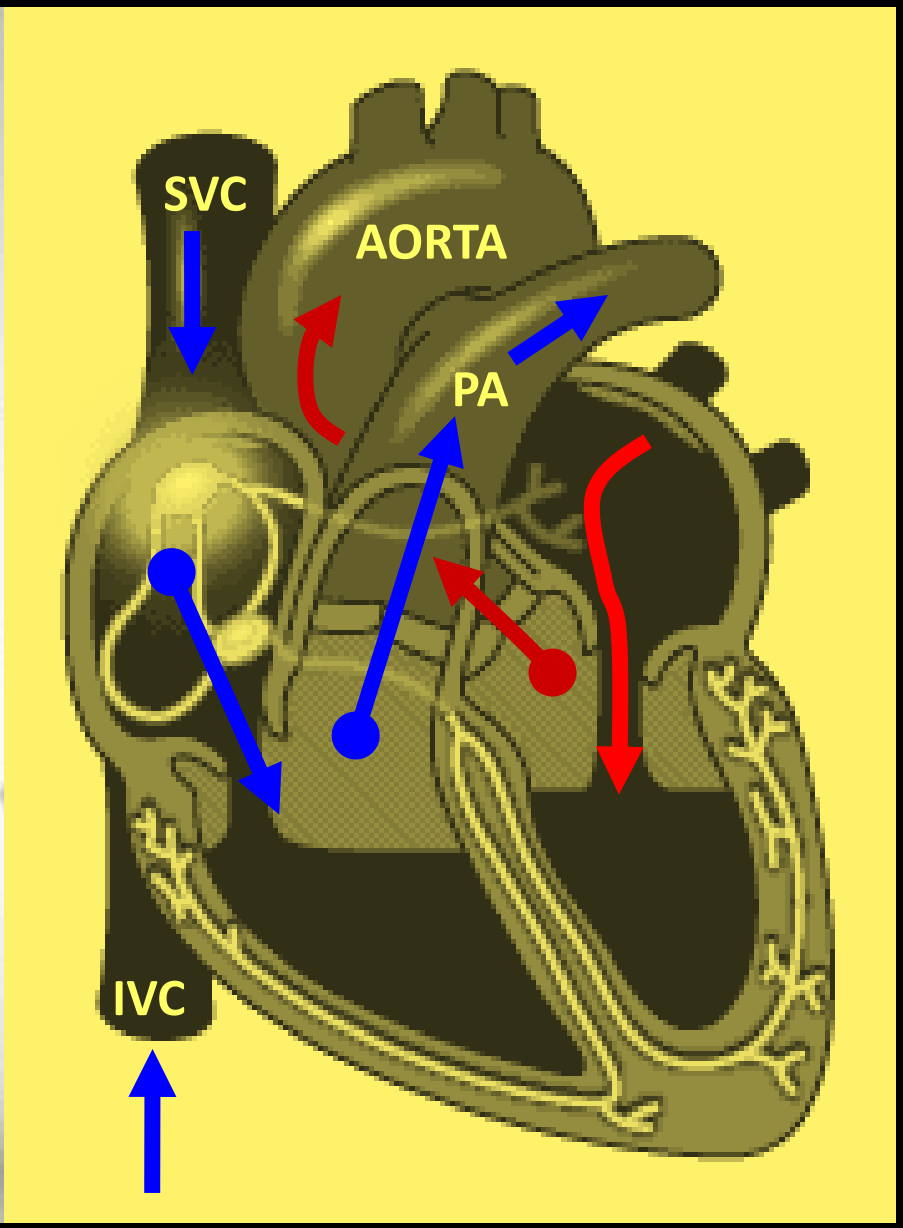
Dr. Kiran Patel College of Allopathic Medicine
Nova Southeastern University
mayrovit@nova.edu
September 19, 2022

The beating heart generates the arterial pulses

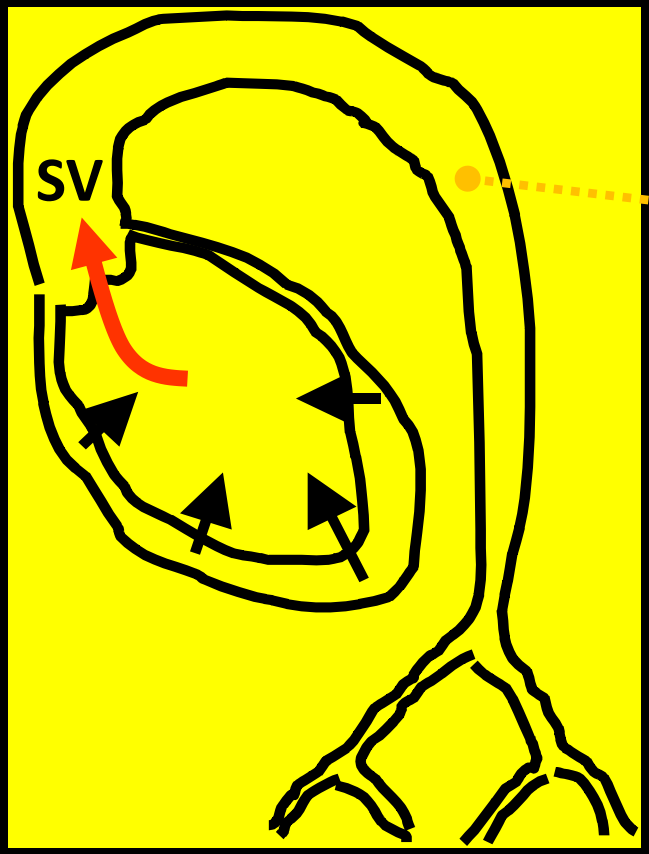
The Beating Heart Generates Pressure Pulses

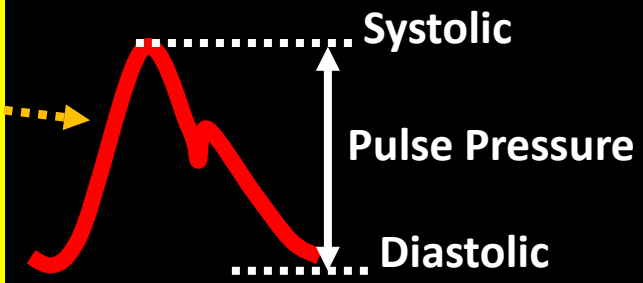


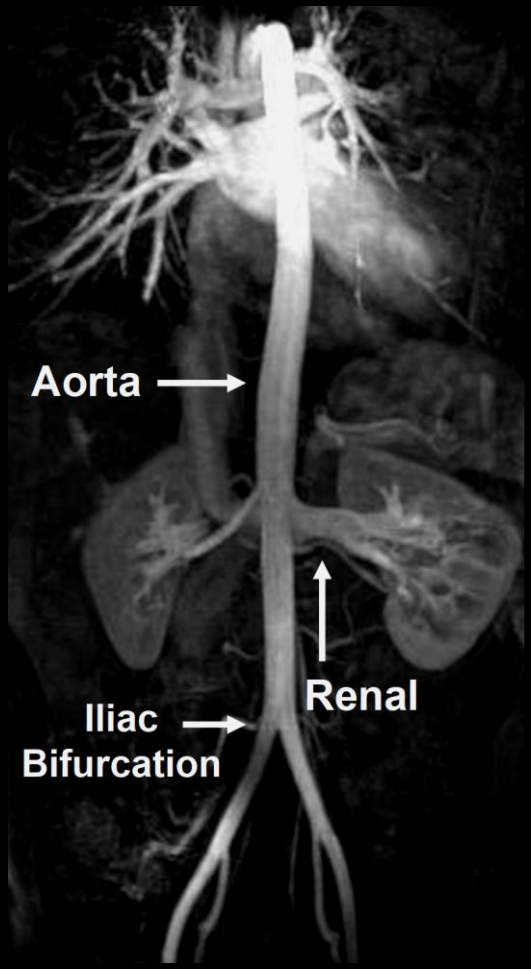


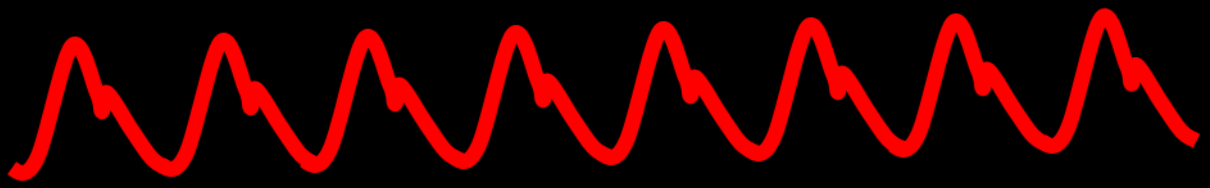
The pulses are transmitted to all arteries

The Arterial Blood Pressure Pulses

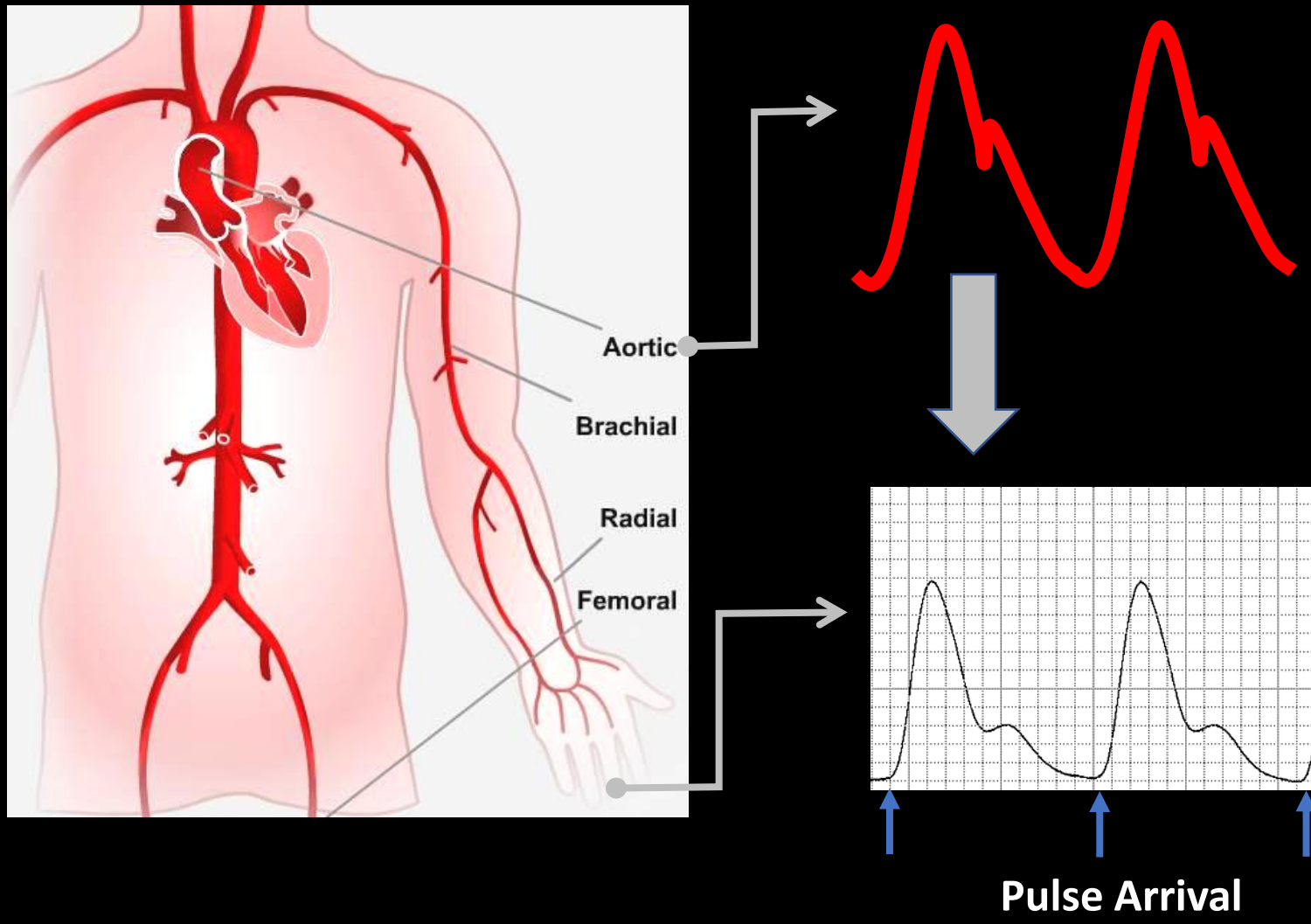








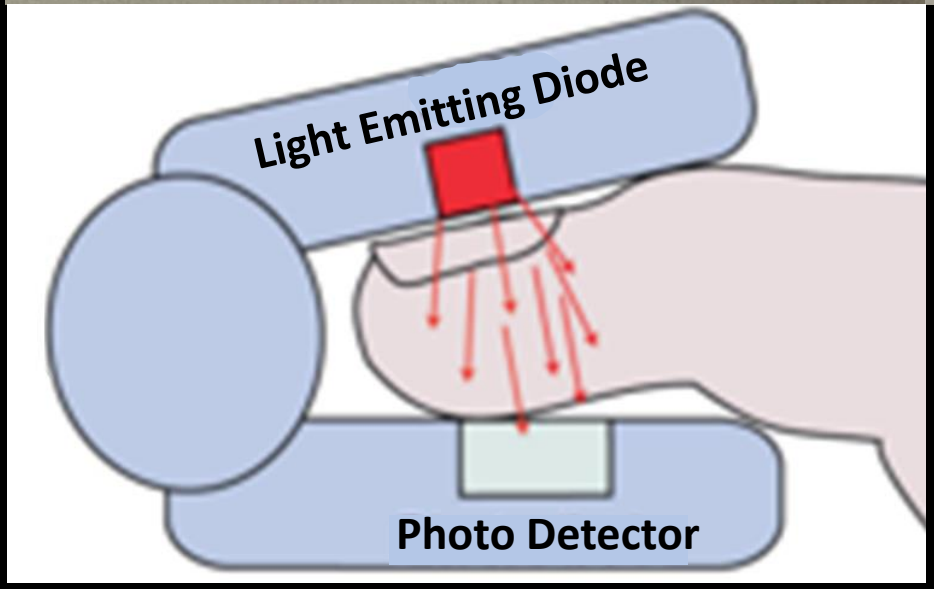
Heart Pulses Transmitted to Fingers



Measuring the pulse features at the finger

Light Transmission Through Finger Tissues

Pulse Detection: Photoplethysmography (PPG)

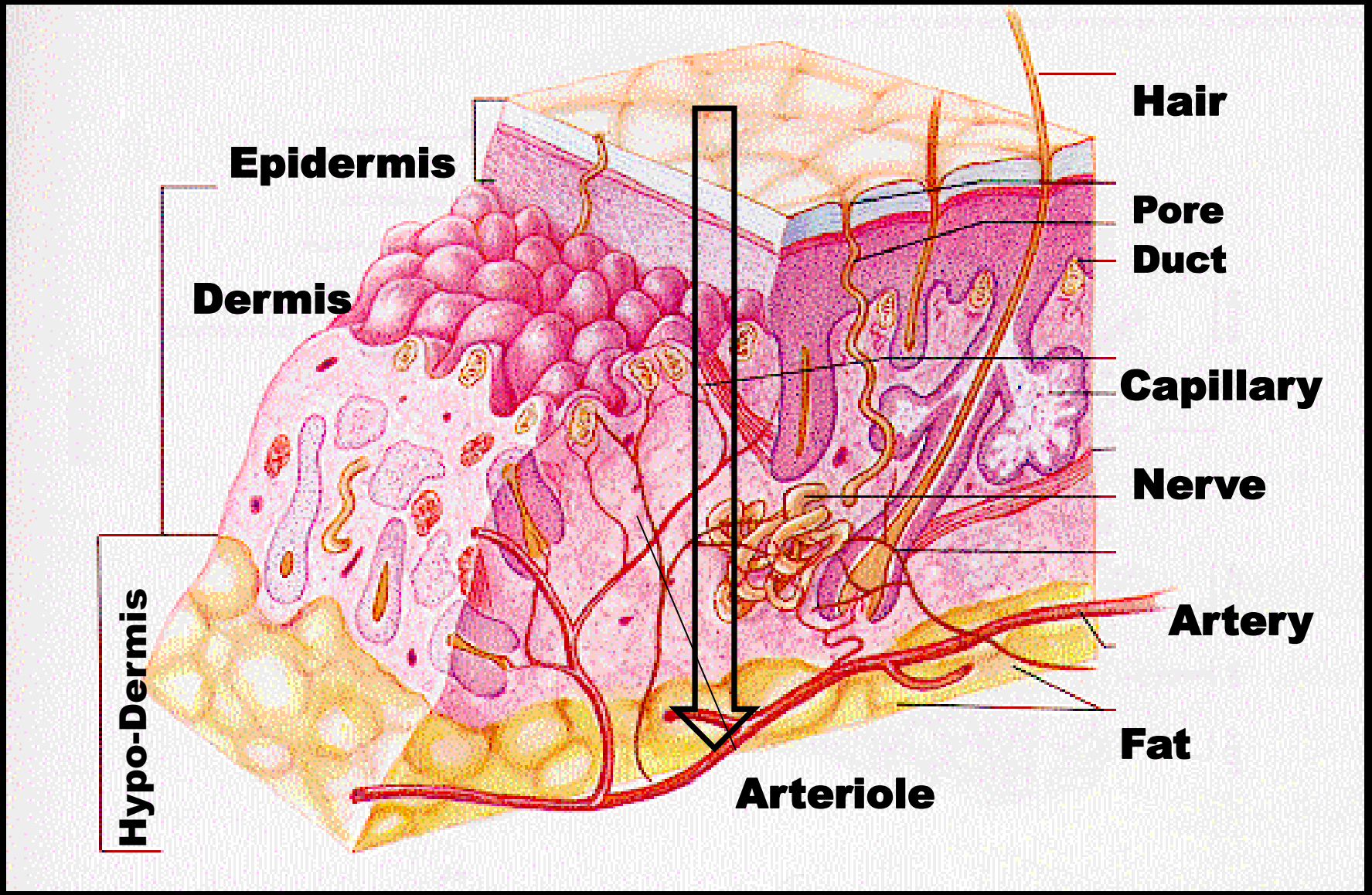


SpO2 = Oxygen % Saturation

How does it work?

Skin features affecting pulse measurement

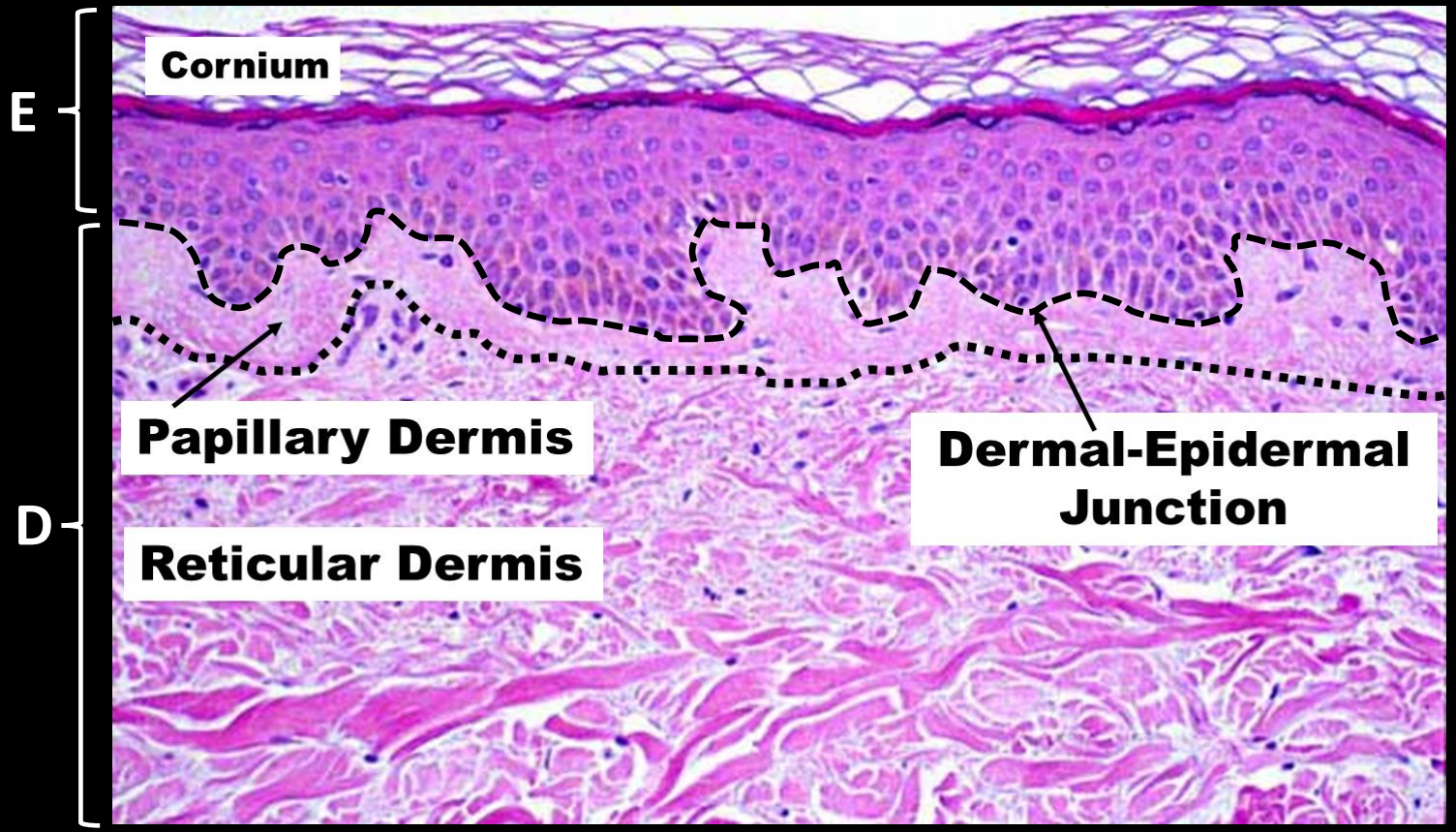
Overview of Skin Features



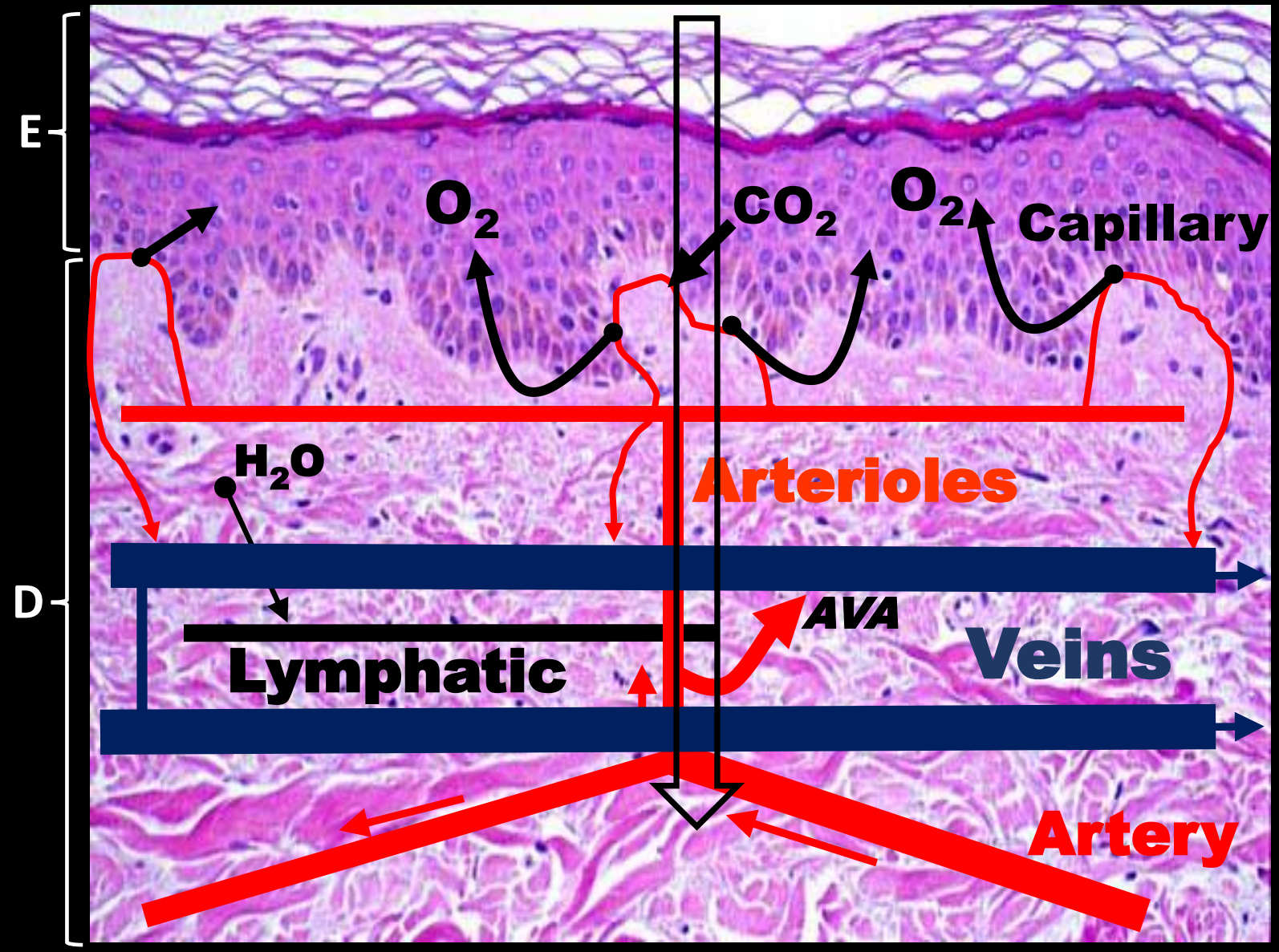
Skin Thickness

Acral Skin (Most)
- Thin Epidermis (E)
- 50-200 μm

Glabrous Skin (hairless)
- Palms of hands (Palmer)
  Soles of feet (Plantar)
- Thick Epidermis ~ 0.5- 5 mm

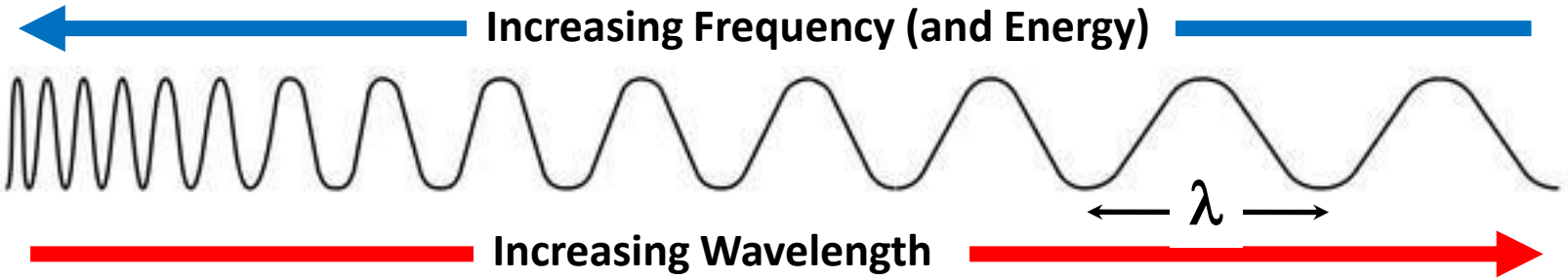


Blood Circulation Scheme

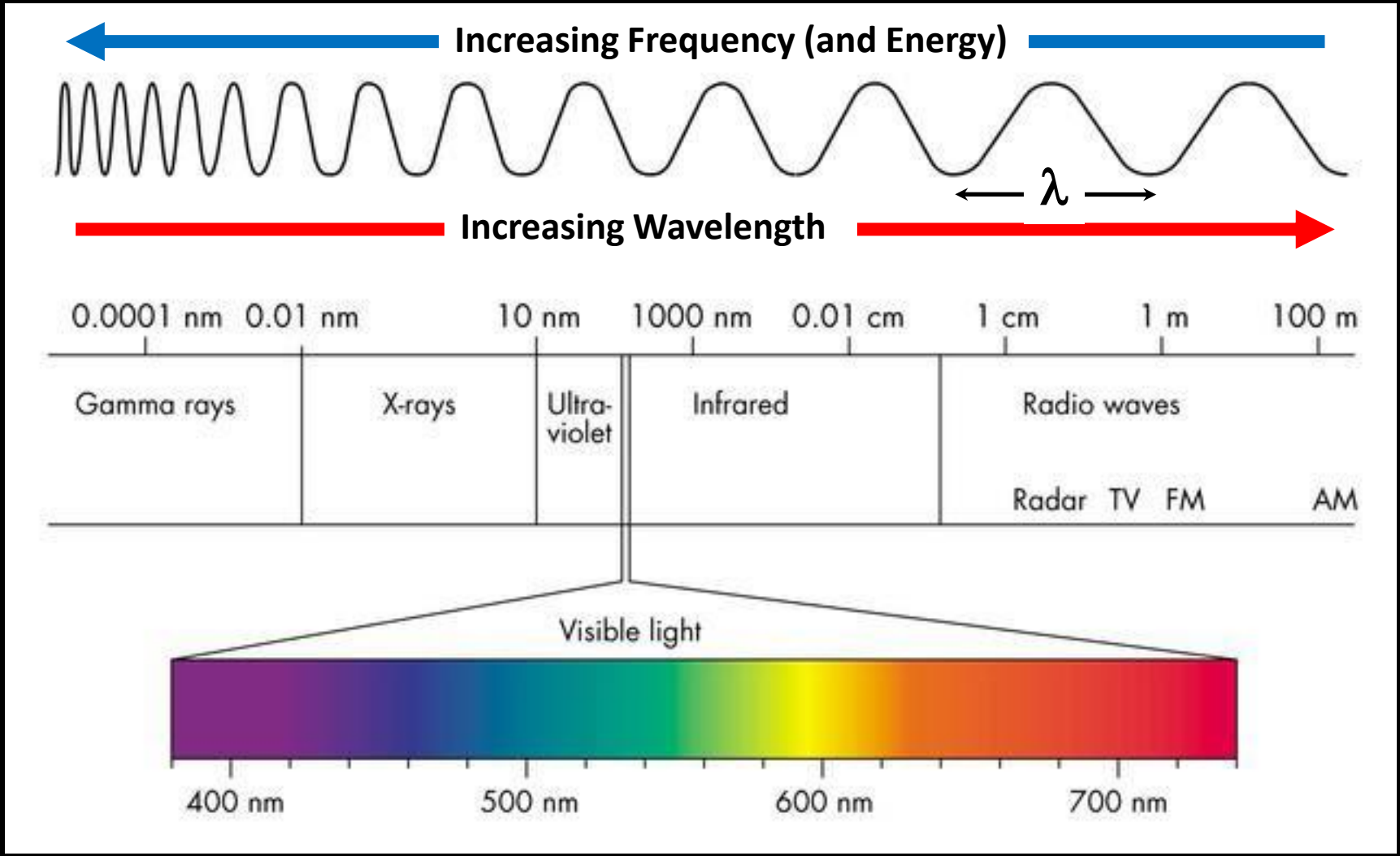


Light absorbed by skin: Wavelength dependent

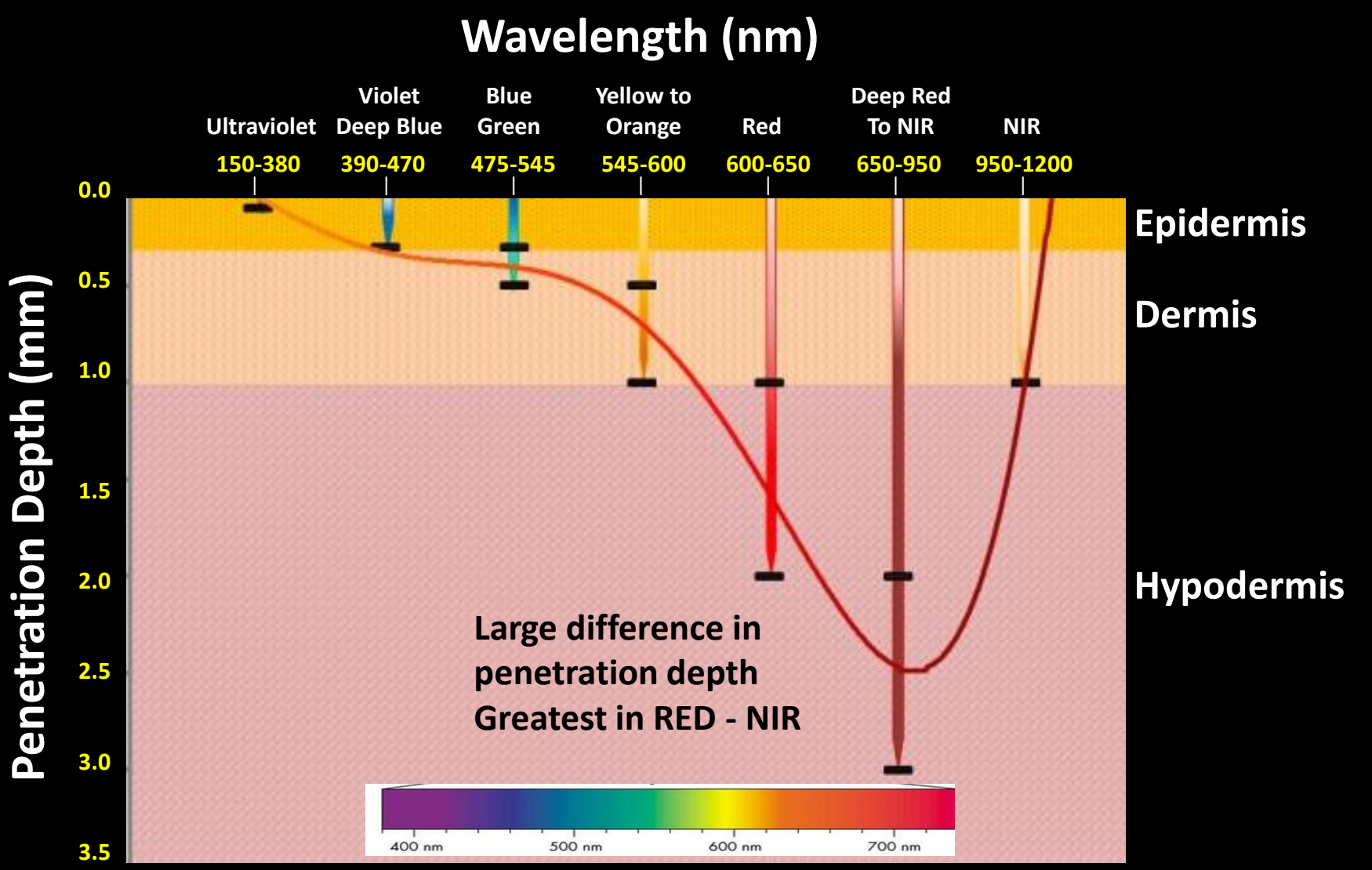
Wavelength of the Electromagnetic Spectrum



Wavelength of the Electromagnetic Spectrum



Light Absorbed by Skin Depends on Wavelength



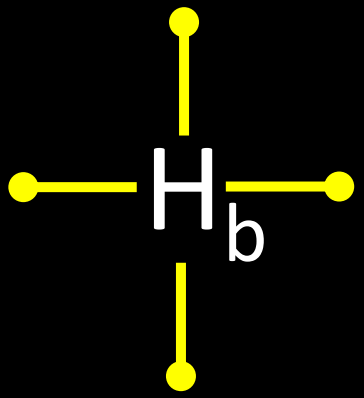
After Chang et al, 2015

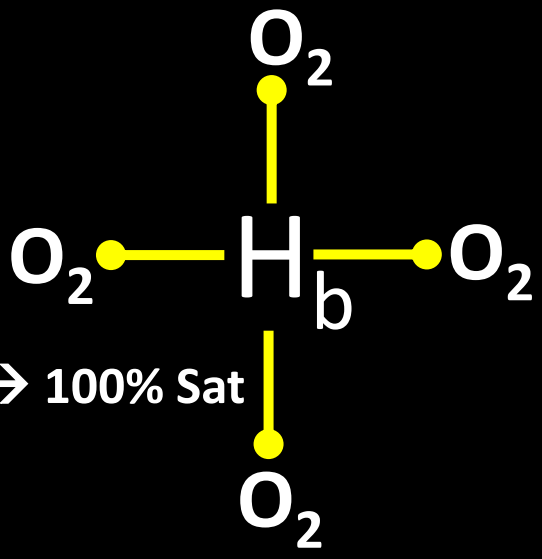
Hemoglobin and its Oxygen Saturation

Blood Hemoglobin (H_b) Property and Saturation (Sat)

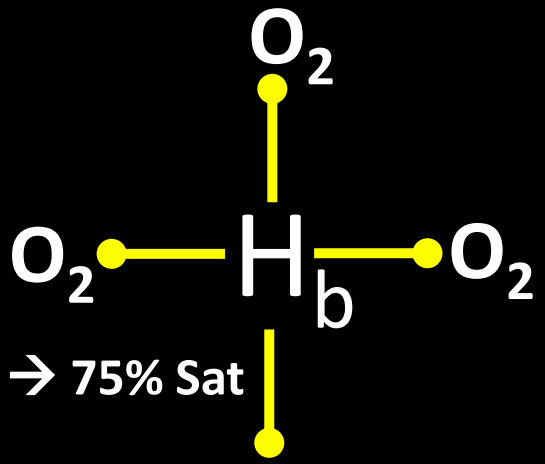
Hemoglobin (H_b) carries oxygen (O_2) within red blood cells (RBC)

4 binding sites for O_2

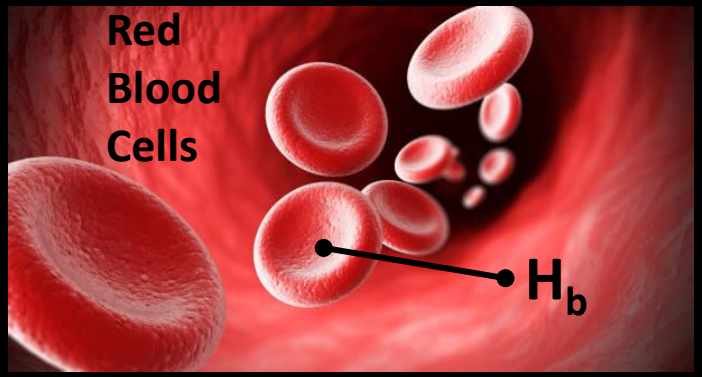




4/4 → 100% Sat



3/4 → 75% Sat



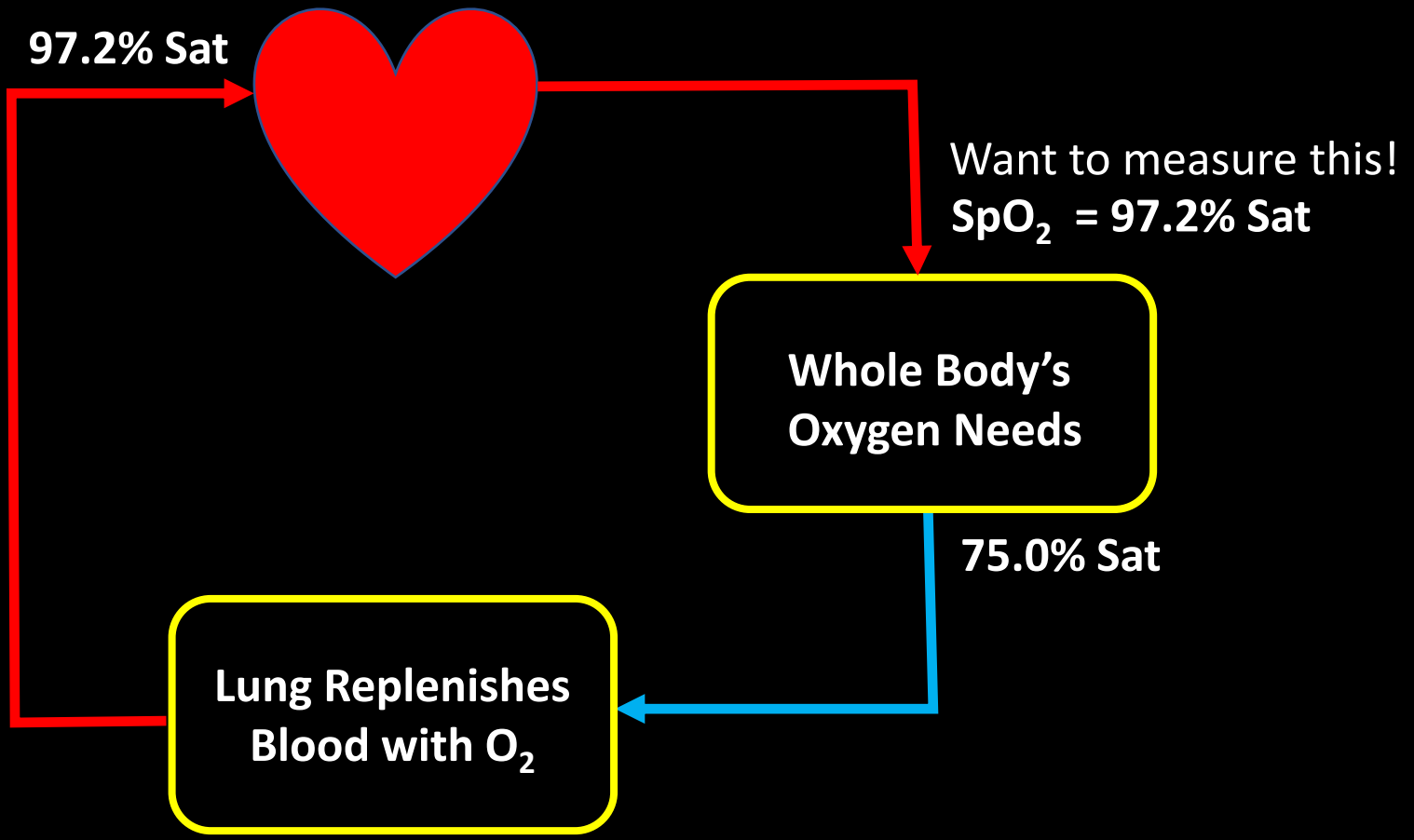
270×10^6 H_b molecules per RBC

If 240 x 10^6 are 100% Sat and 30 x 10^6 are 75% Sat
What is the overall Saturation?

$$\%Sat = \frac{1.00 \times 240 + 0.75 \times 30}{270} = 97.2\%$$

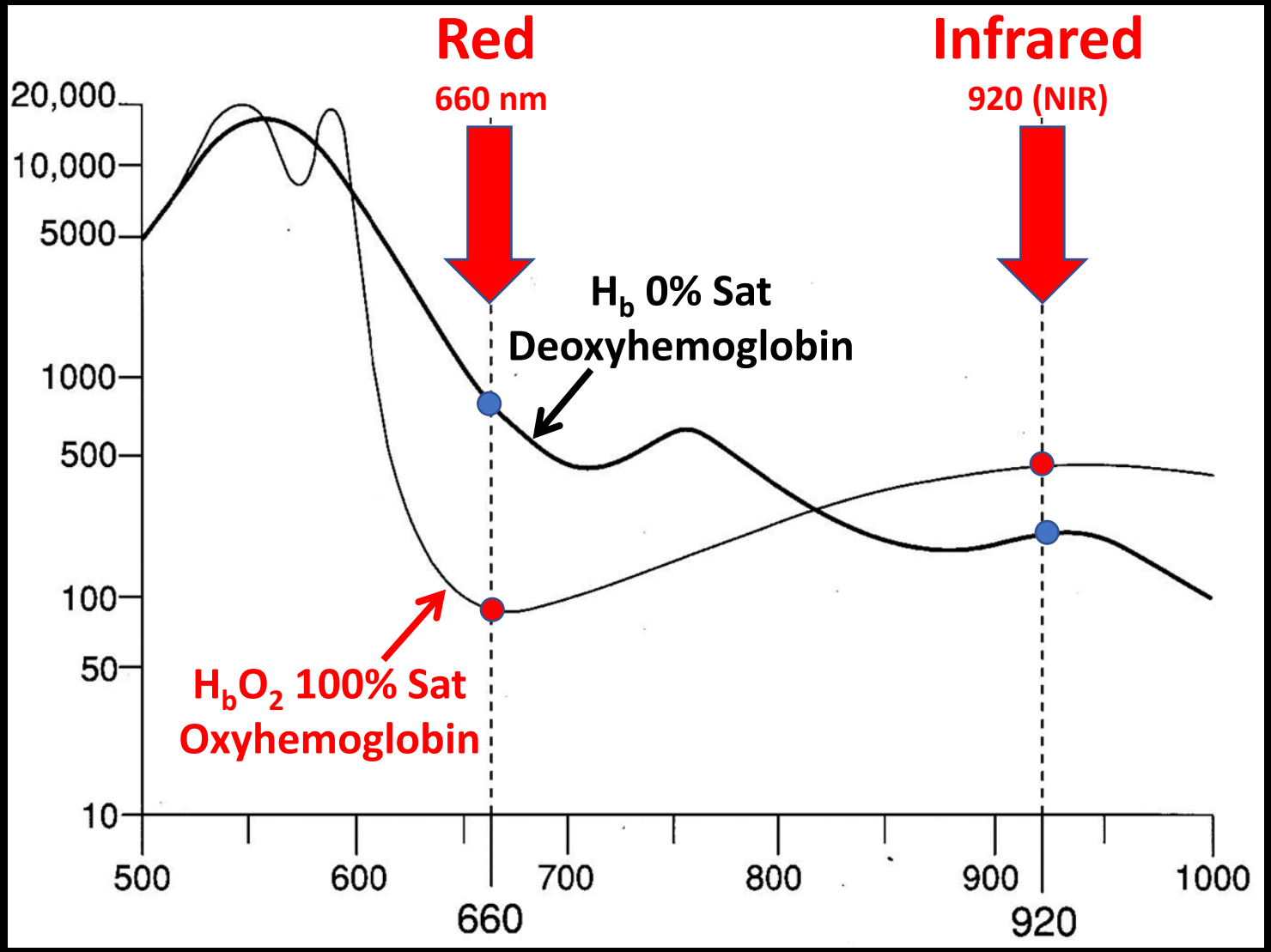
Normal

Oxygen Circuit



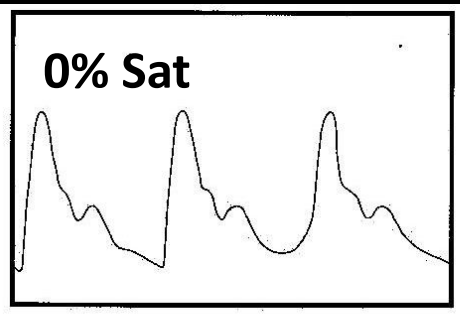
Light absorbed by H_b is wavelength dependent

Light Absorbed by Blood H_b Depends on Wavelength

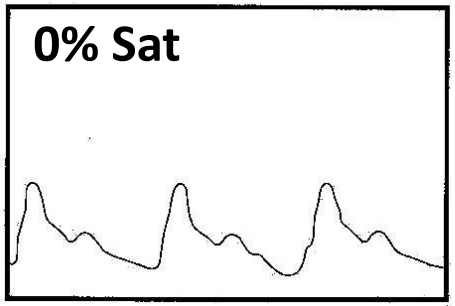


Light Absorbed by Blood H_b Depends on Wavelength

Red Light Absorption Pulse Signal (660 nm)

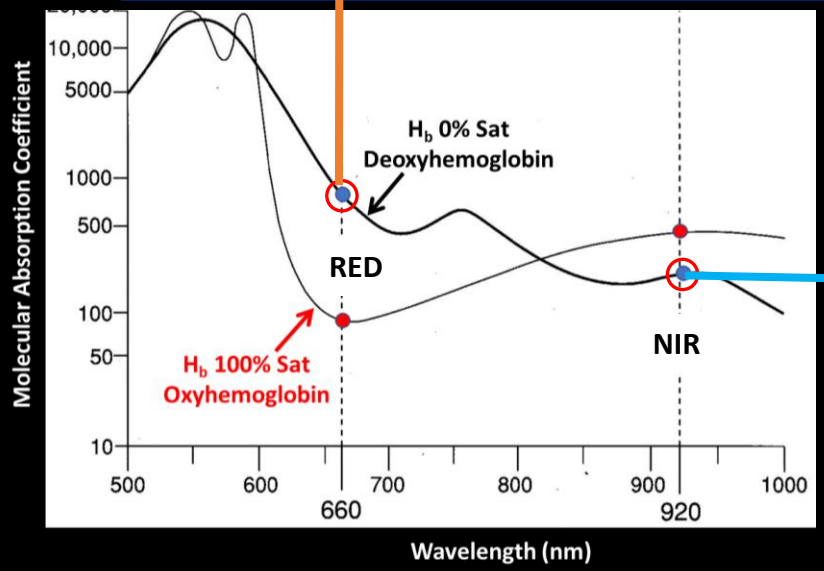


NIR Light Absorption Pulse Signal (920 nm)



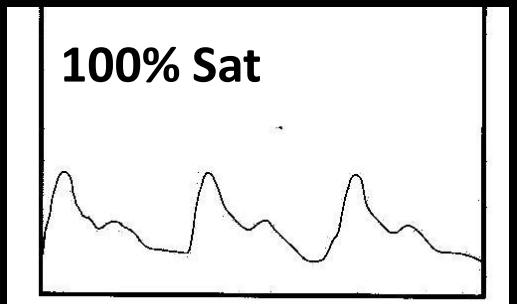
Large Absorption

Less Absorption

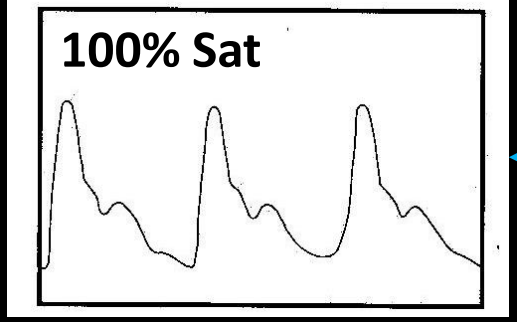


Light Absorbed by Blood H_b Depends on Wavelength

Red Light Absorption Pulse Signal (660 nm)

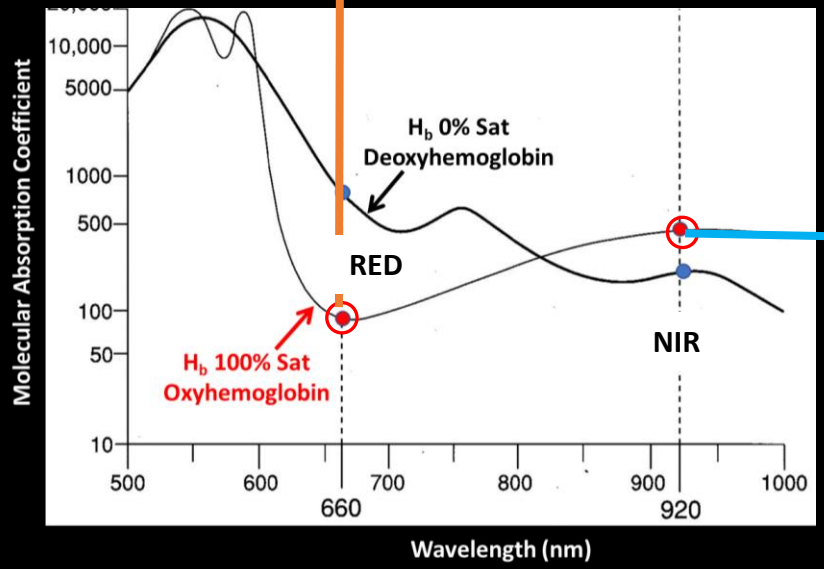


NIR Light Absorption Pulse Signal (920 nm)



Less Absorption

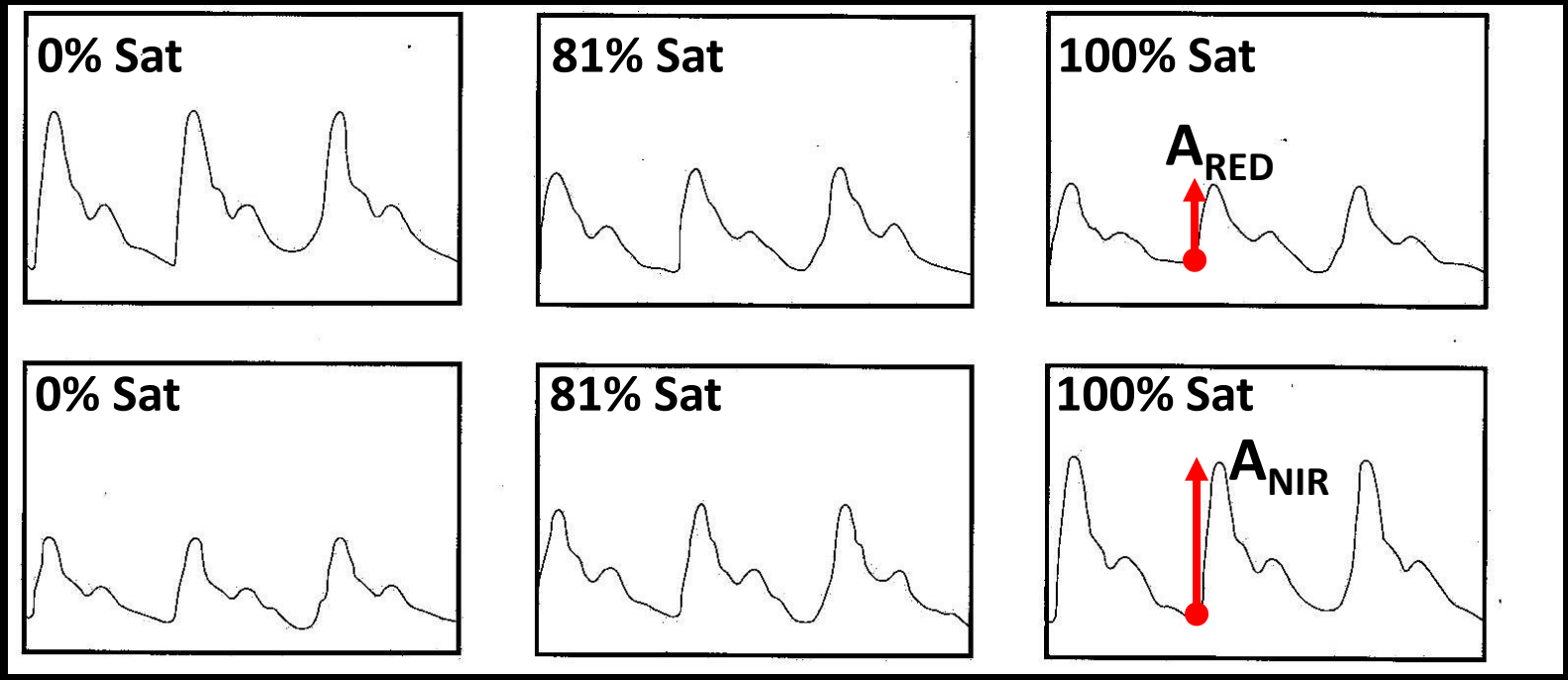
Large Absorption



SpO_2 Depends on Relative Pulse Amplitudes

Red Light Absorption Pulse Signal (660 nm)

NIR Light Absorption Pulse Signal (920 nm)

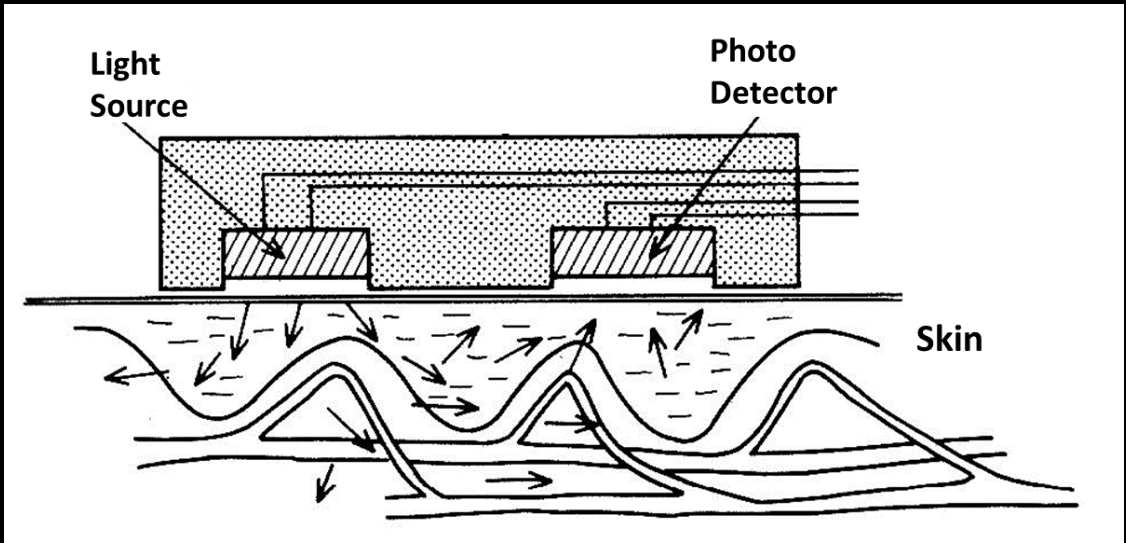


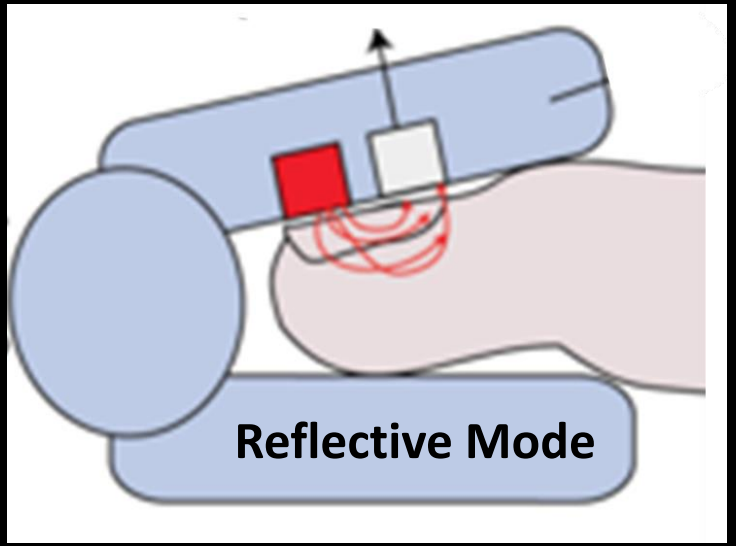
$$SpO_2 = \%Sat = \frac{H_bO_2}{H_b + H_bO_2} \rightarrow \frac{A_{NIR}}{A_{RED}}$$

Reflective Photoplethysmography (PPG)

PPG / SpO_2 Not Restricted to Finger Measurements

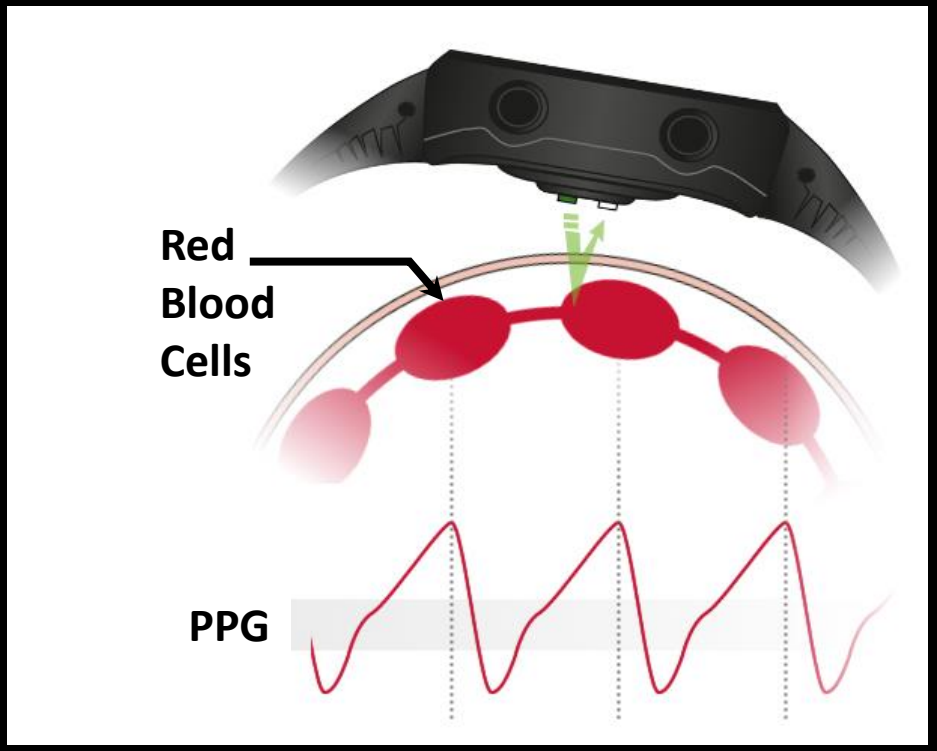
Almost Any Skin Area via Reflective Mode





- Earlobe
- Nose
- Forehead
- Forearm
- Etc.

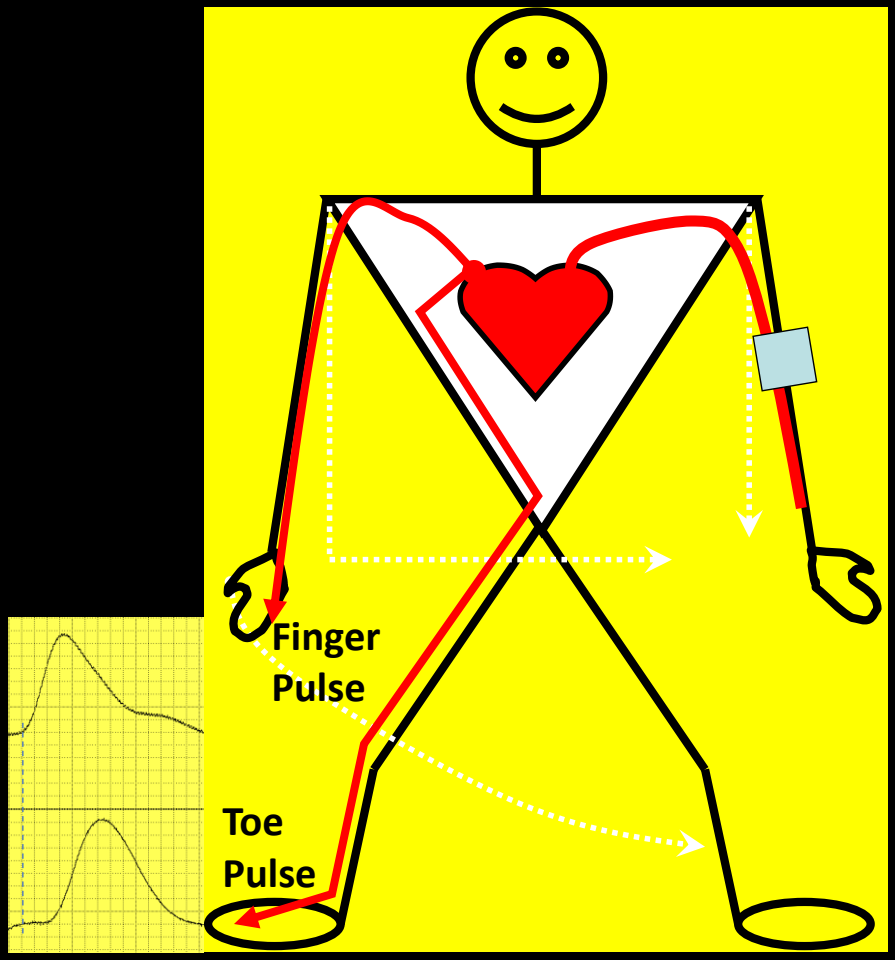
Forearm Reflective PPG to Measure Heart Rate



Noninvasive Measure of Arterial Stiffness

PPG Useful For Multiple Physiologic Measures

- SpO_2 ✓
- Heart Rate ✓
- **Blood Vessel Stiffness**
- Heart Rate Variability
- Blood Pressure
- Respiration Rate
- Arrythmias

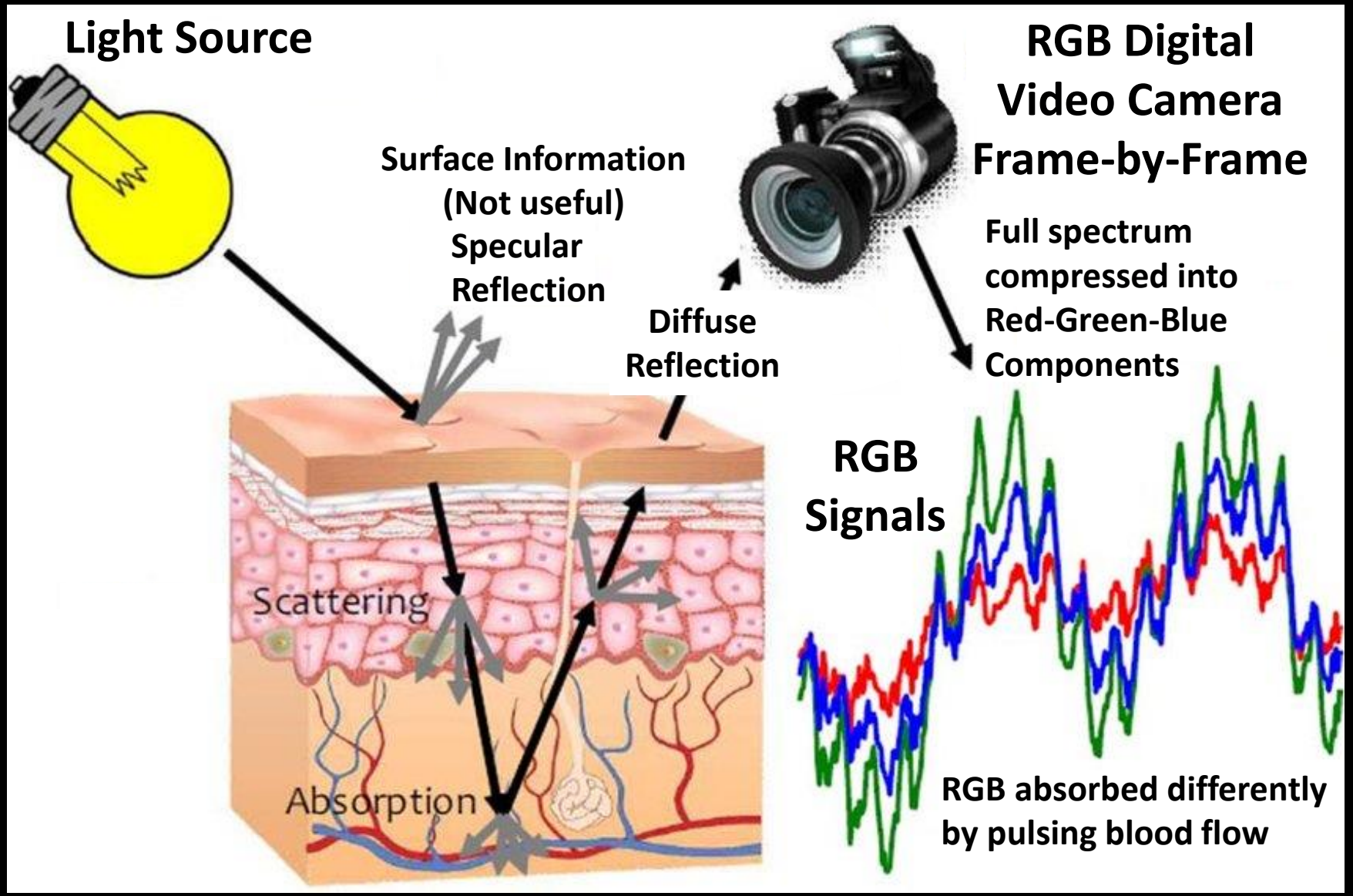


Less Delay → Stiffer Arteries

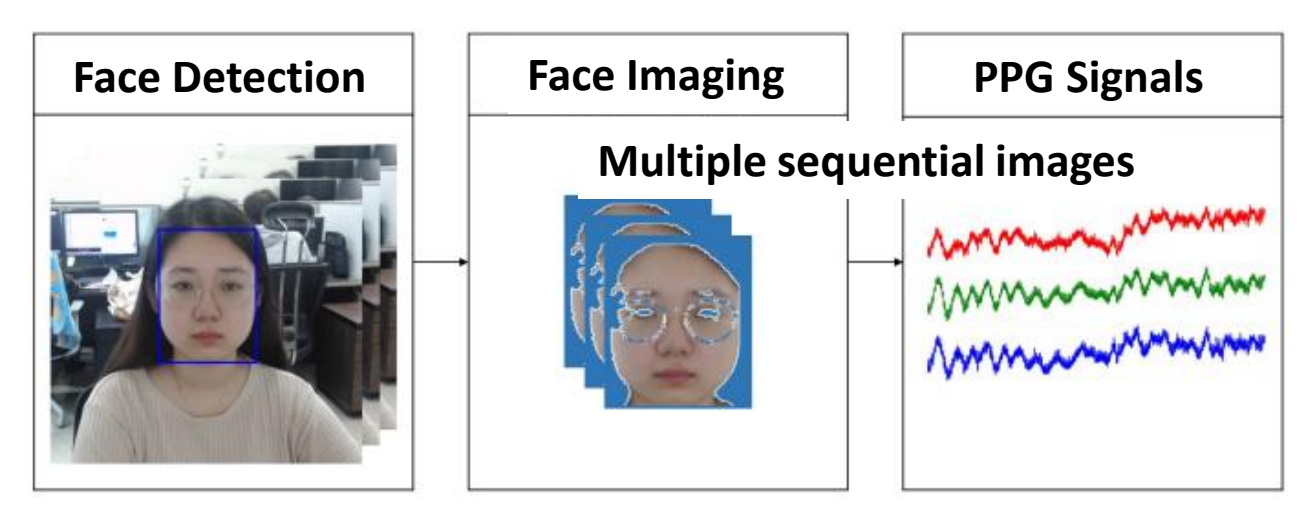
PPG Used to Assess Blood Vessel Stiffness

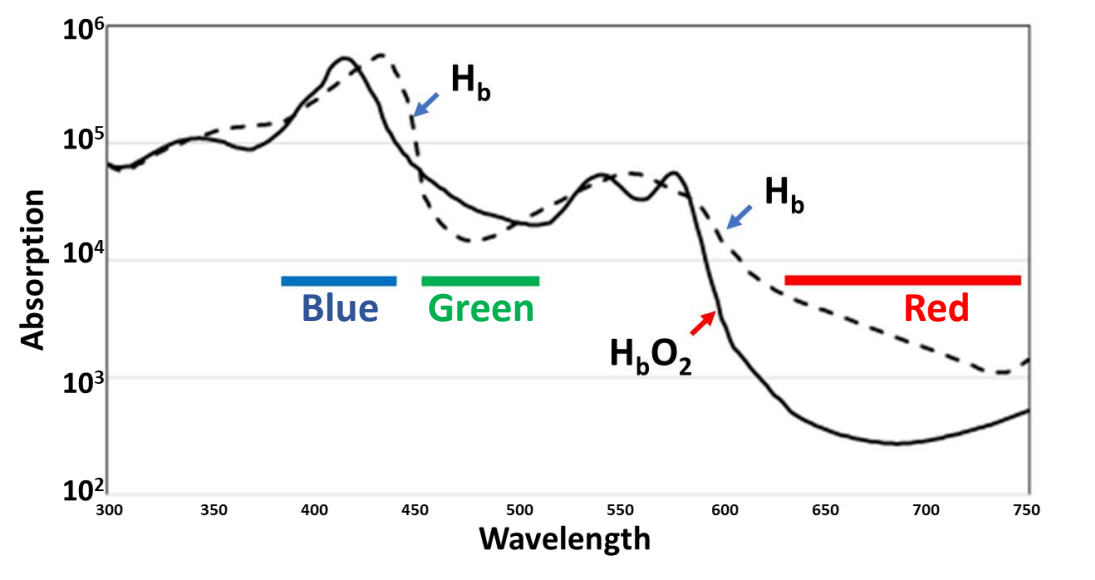
Remote – Non-Contact Imaging Approaches

Newer Remote Imaging Methods (rPPG)



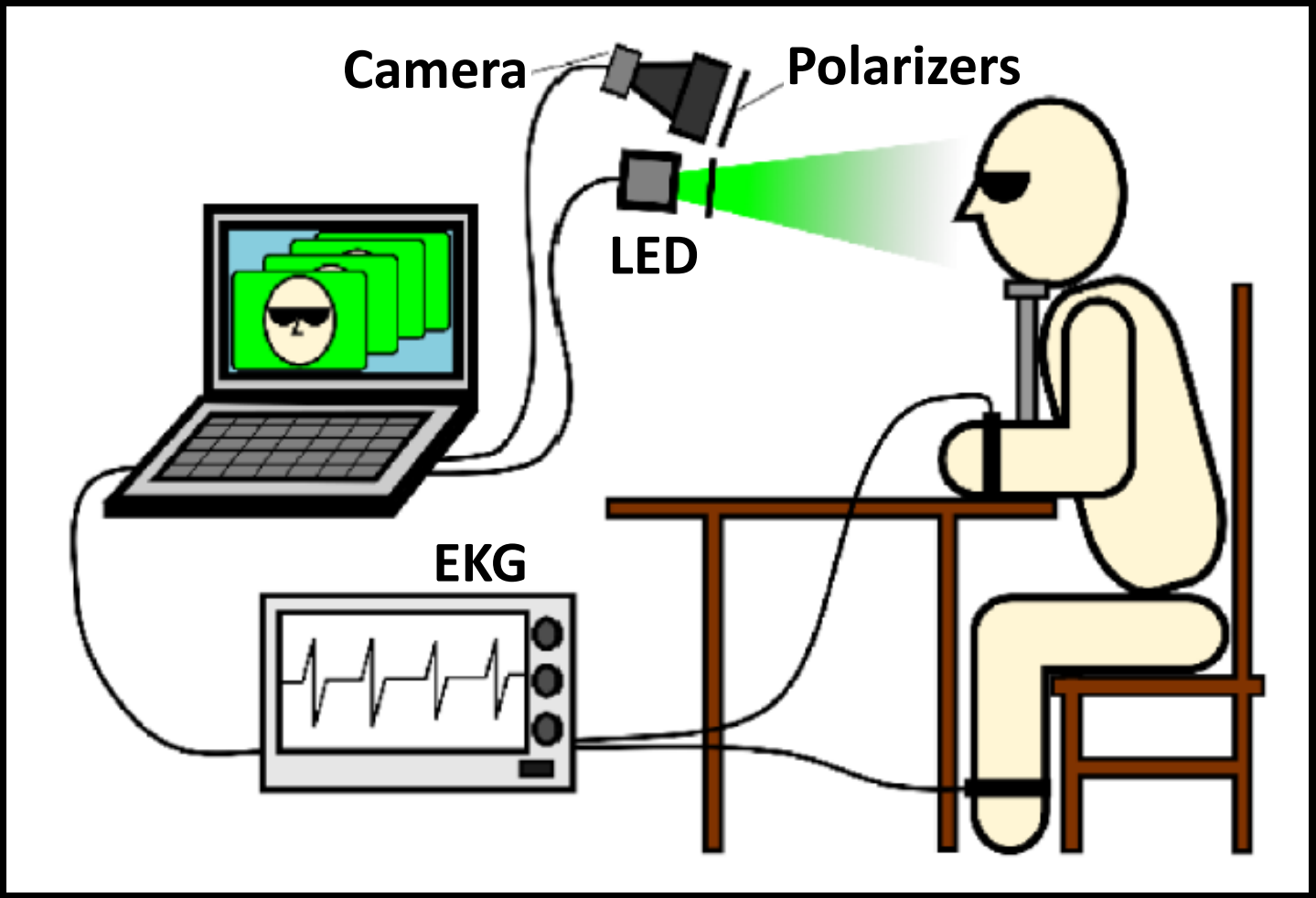
Newer Remote Imaging Methods (rPPG)





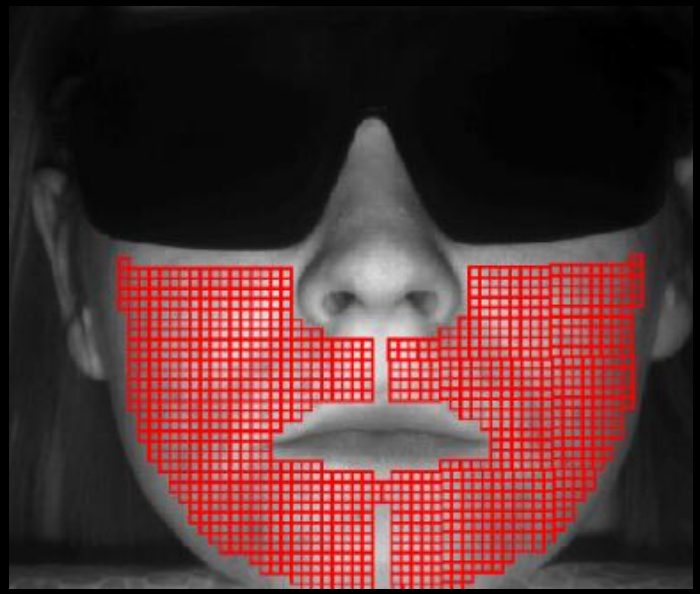
Kim, N.H.; Yu, S.-G.; Kim, S.-E.; Lee, E.C. Non-Contact Oxygen Saturation Measurement Using YCgCr Color Space with an RGB Camera. Sensors 2021, 21, 6120. https://doi.org/10.3390/s2118612

Pulse Wave Delay Using Remote Imaging PPG



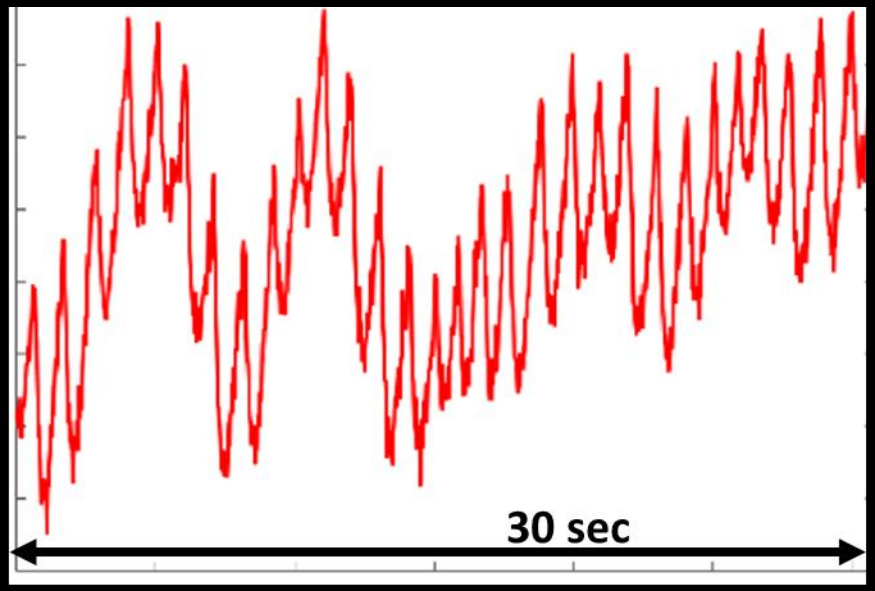
Accurate measurement of the pulse wave delay with Imaging photoplethysmography. Biomedical Optics Express Kamshilin et al. 2016;7:12, 5138

Facial PPG Signal from Large Region of Interest (ROI)



ROI

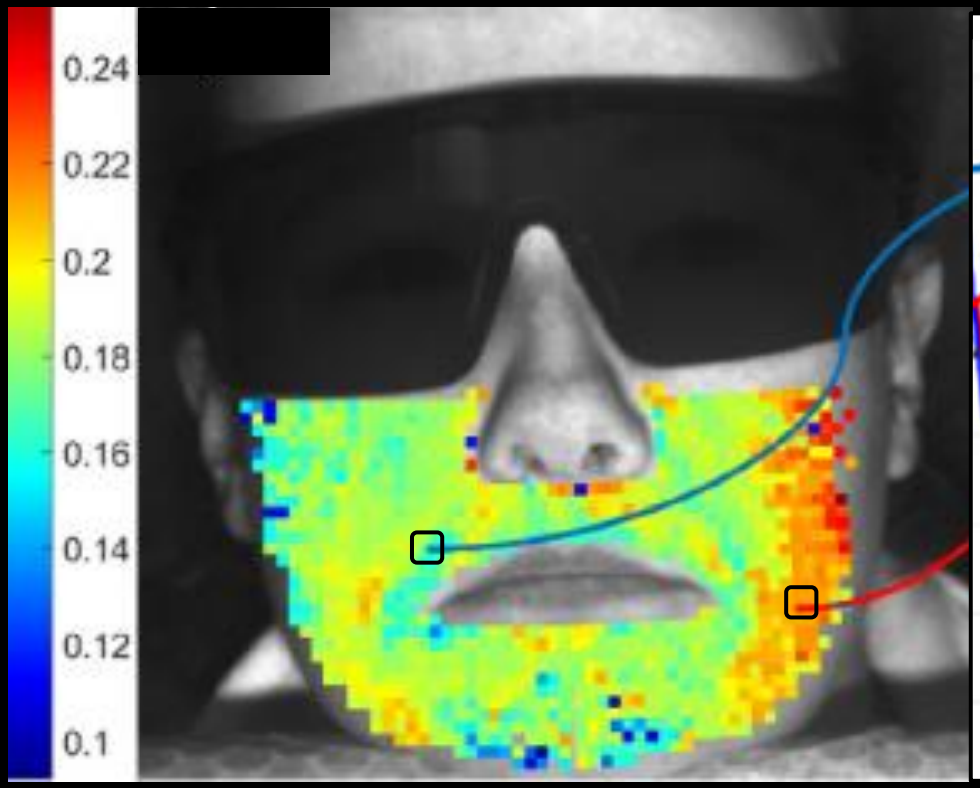
PPG Signal

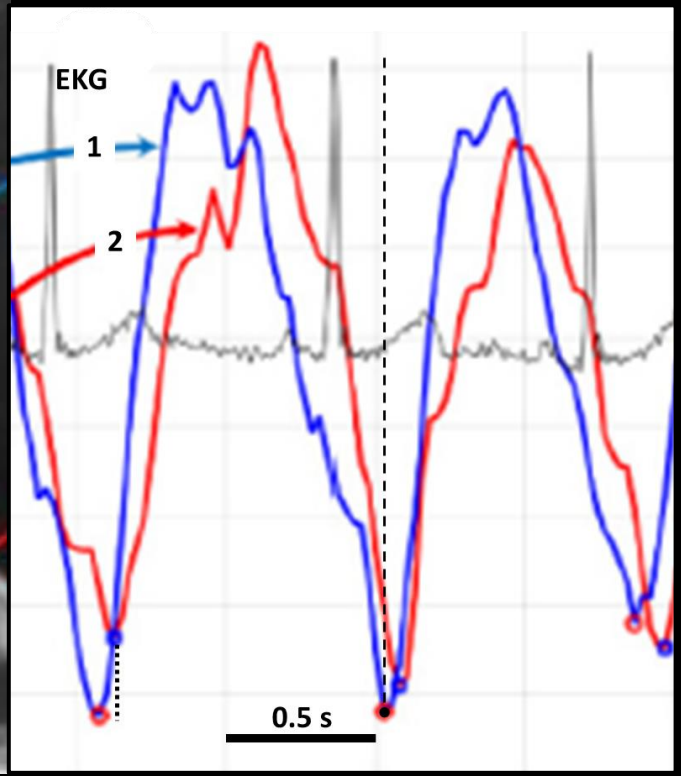


- Heart Rate
- Heart Rate Variability
- Arrythmias
- Other Possibilities

Facial PPG Signals from Multiple Facial ROI

Measures Pulse Delay to and in Face





- Large Vessel Changes
- Small Vessel Changes
- Other?

Epidermis Layers (Stratums) and Cells

Keratinocytes

Langerhans Cells
- Immune Response

Merkel cell
- Touch

Melanocyte
- Pigment

Stratums

Corneum (horny)
- Dead flat cells

Lucidum (clear)

Granulosum (grainy)
- Makes keratin
- Thin cells

Spinosum (spiny)
- Extension of basal

Basal (Germinativum)
- Mitosis and upward migration replaces shed keratinocytes


"That's
all
folks!"