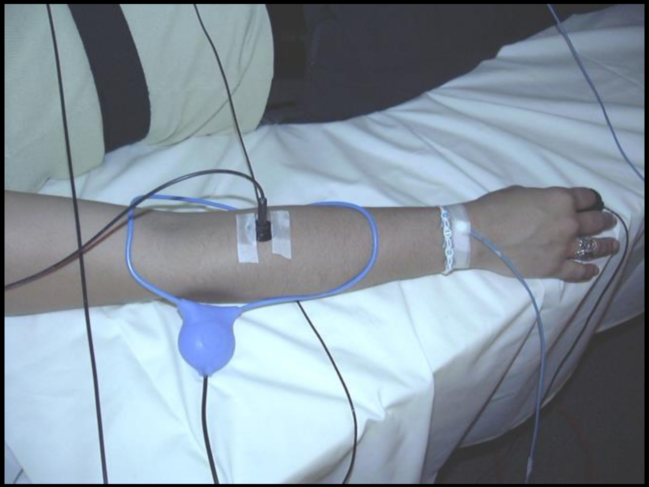
Biomedical Engineering Aspects of Dermal Blood Flow and Edema

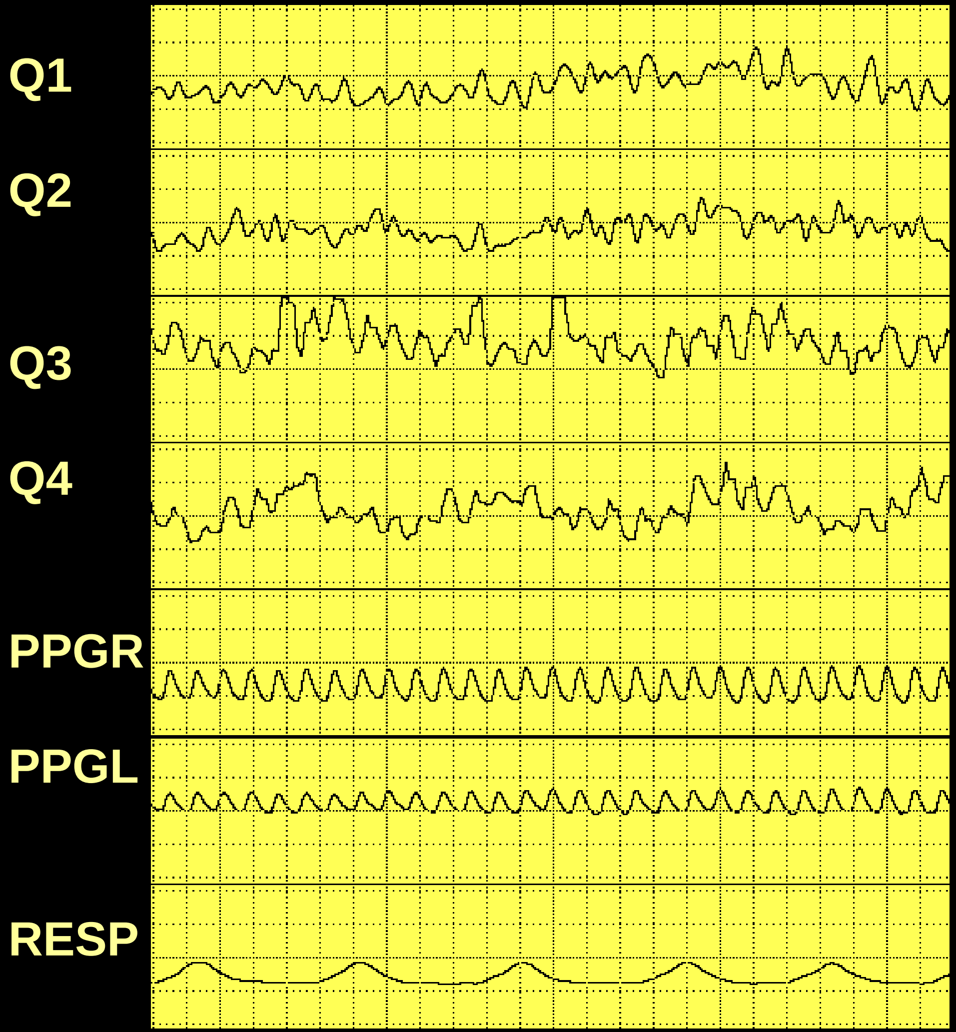
1. Skin Physiology and Blood Circulation
2. Blood Perfusion via Laser-Doppler Methods
3. Application of Spectral Analysis
4. Tissue Edema Mechanisms
5. Edema Assessment Methods
6. Demonstrations

Dr. H. N. Mayrovitz FIU Seminar
02/17/2006

Some Current Research

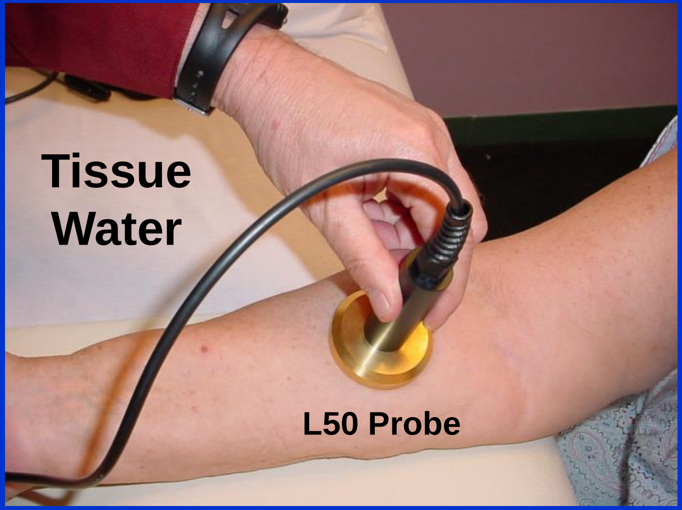
Impact of Electric & Magnetic Fields on Blood Flow





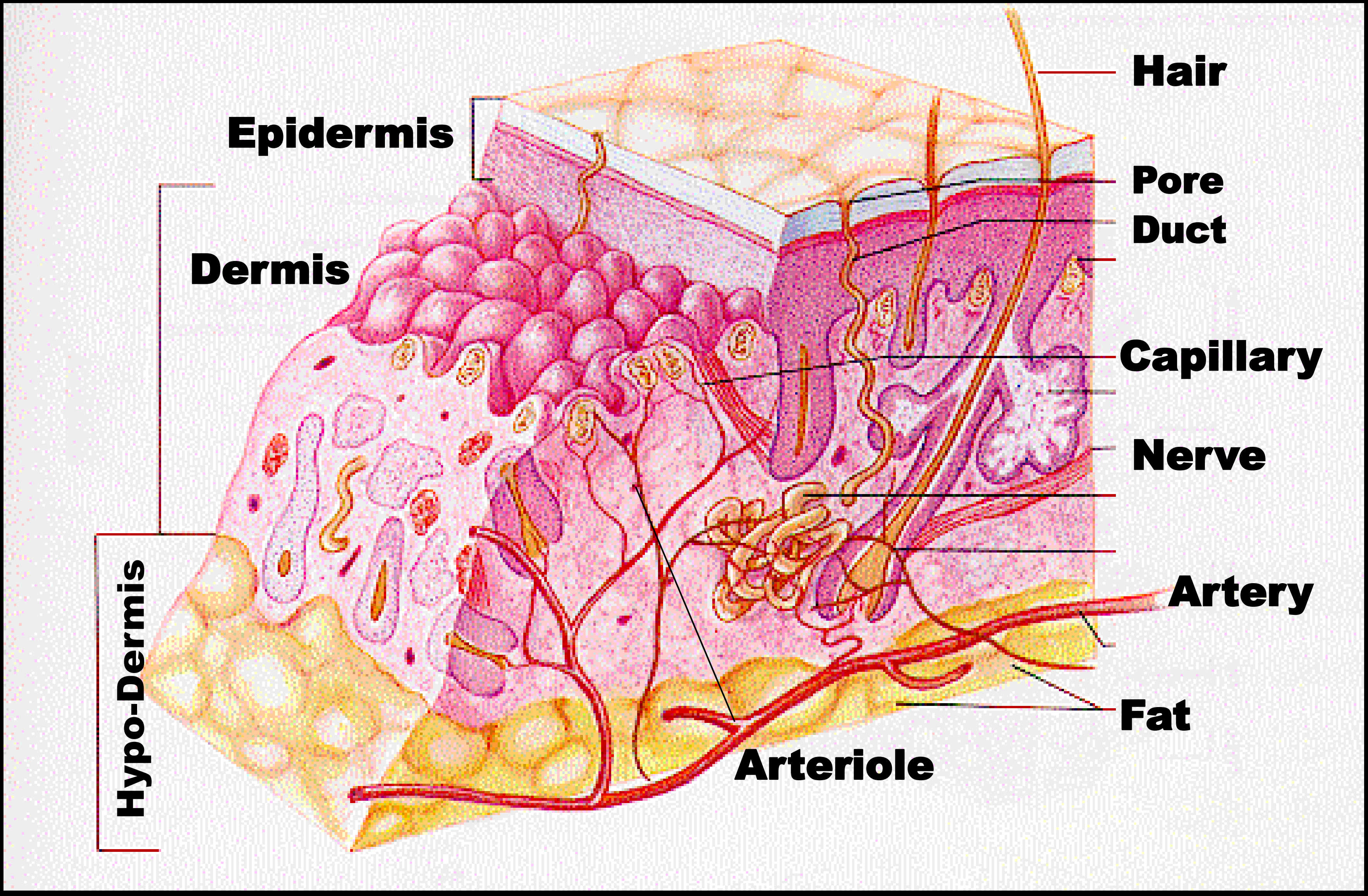
Some Current Research

Assessment Of Lymphedematous Limbs



Skin Physiology & Blood Circulation

Overview of Skin Features



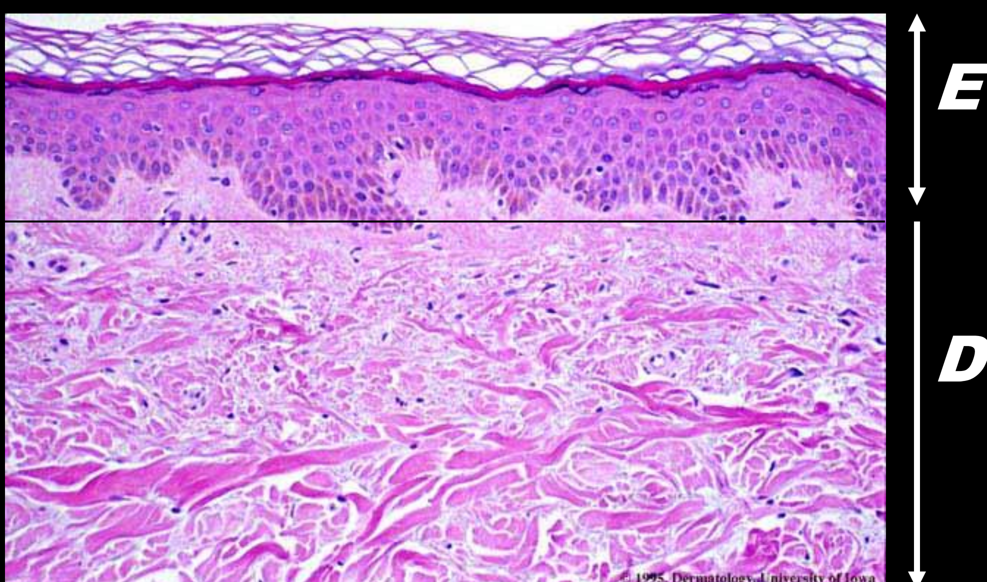
Skin Thickness

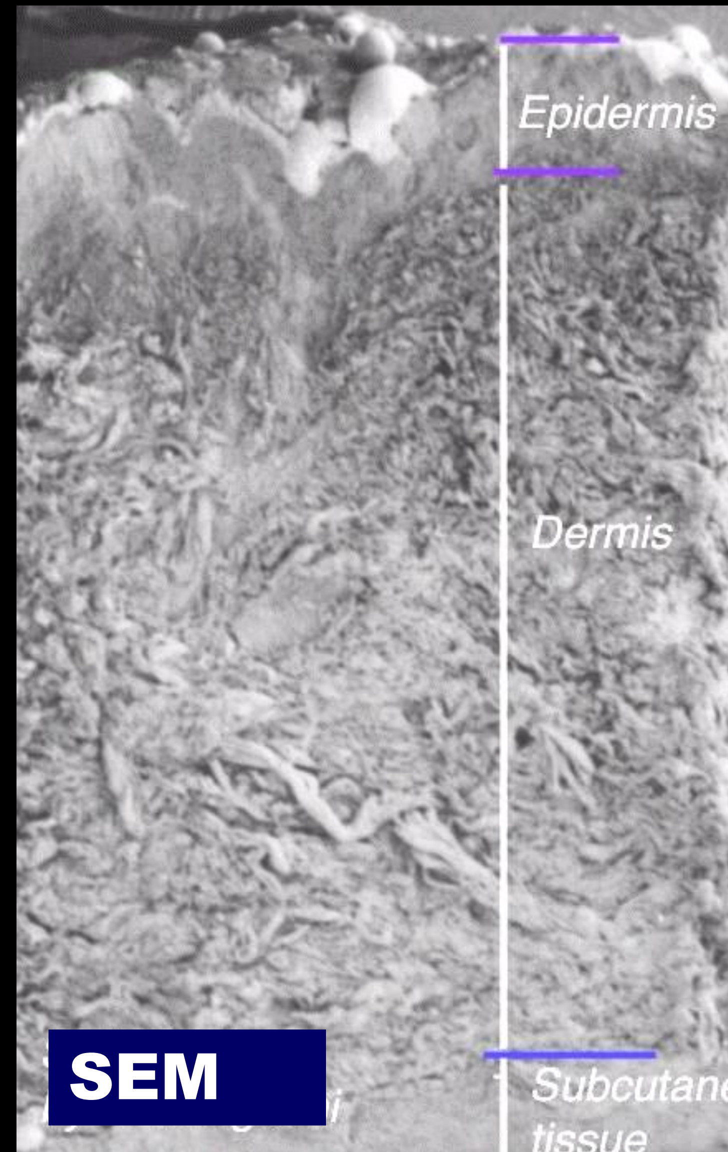
Acral (Most)

- **Thin Epidermis 50-200 μm**

Glabrous (hairless)

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





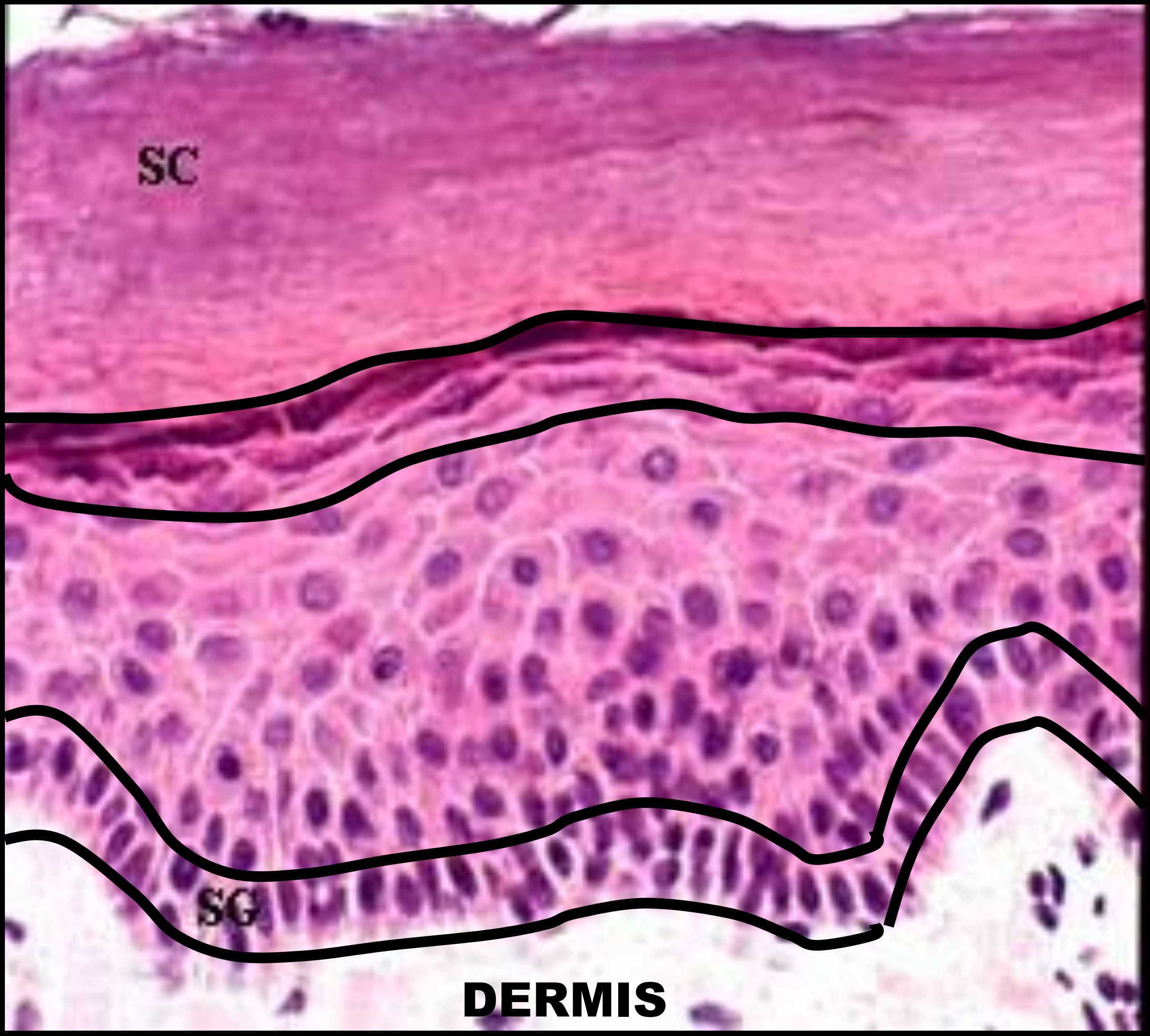
Epidermis (Histology)

Cornium

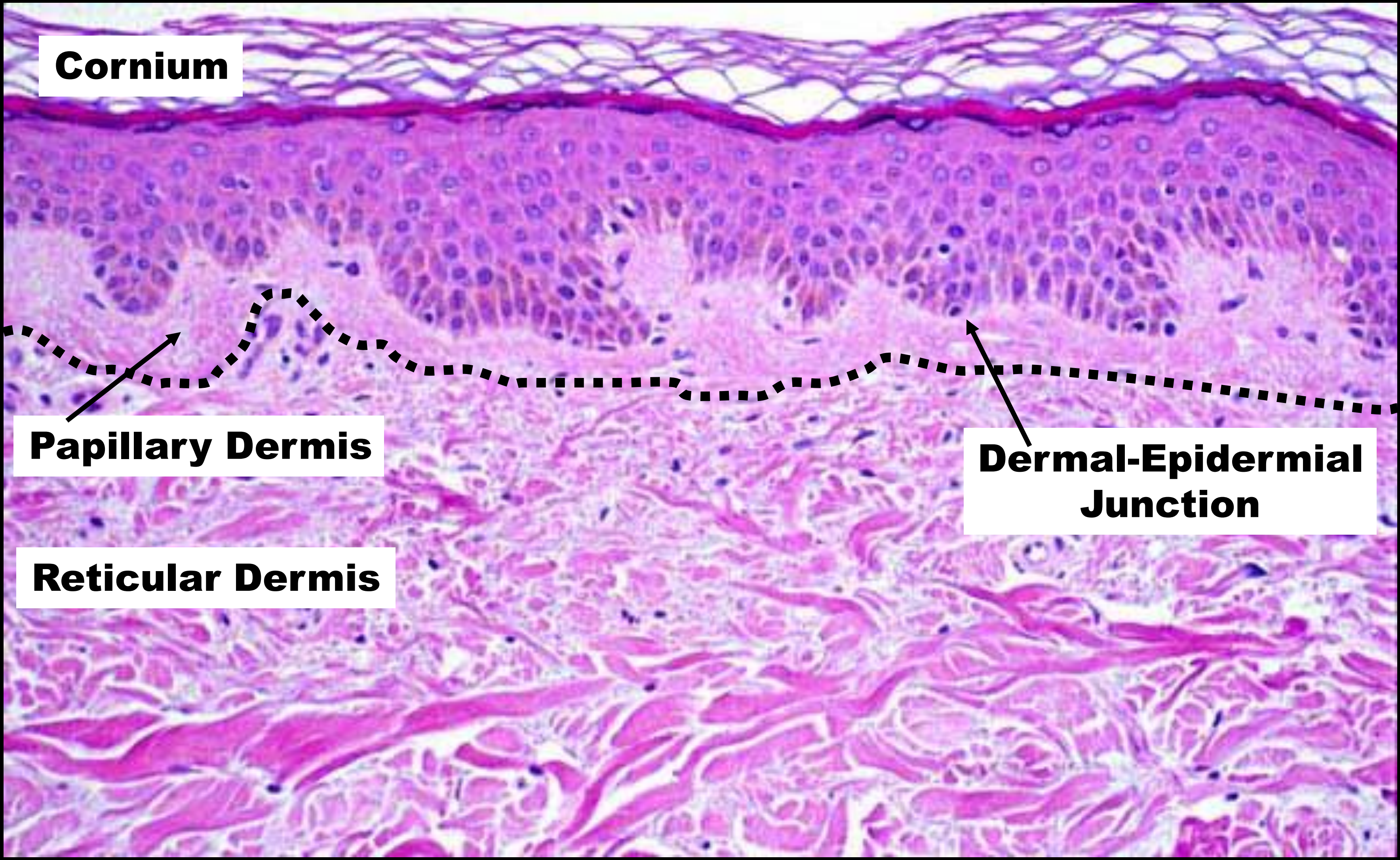
Granulosum

Spinosum

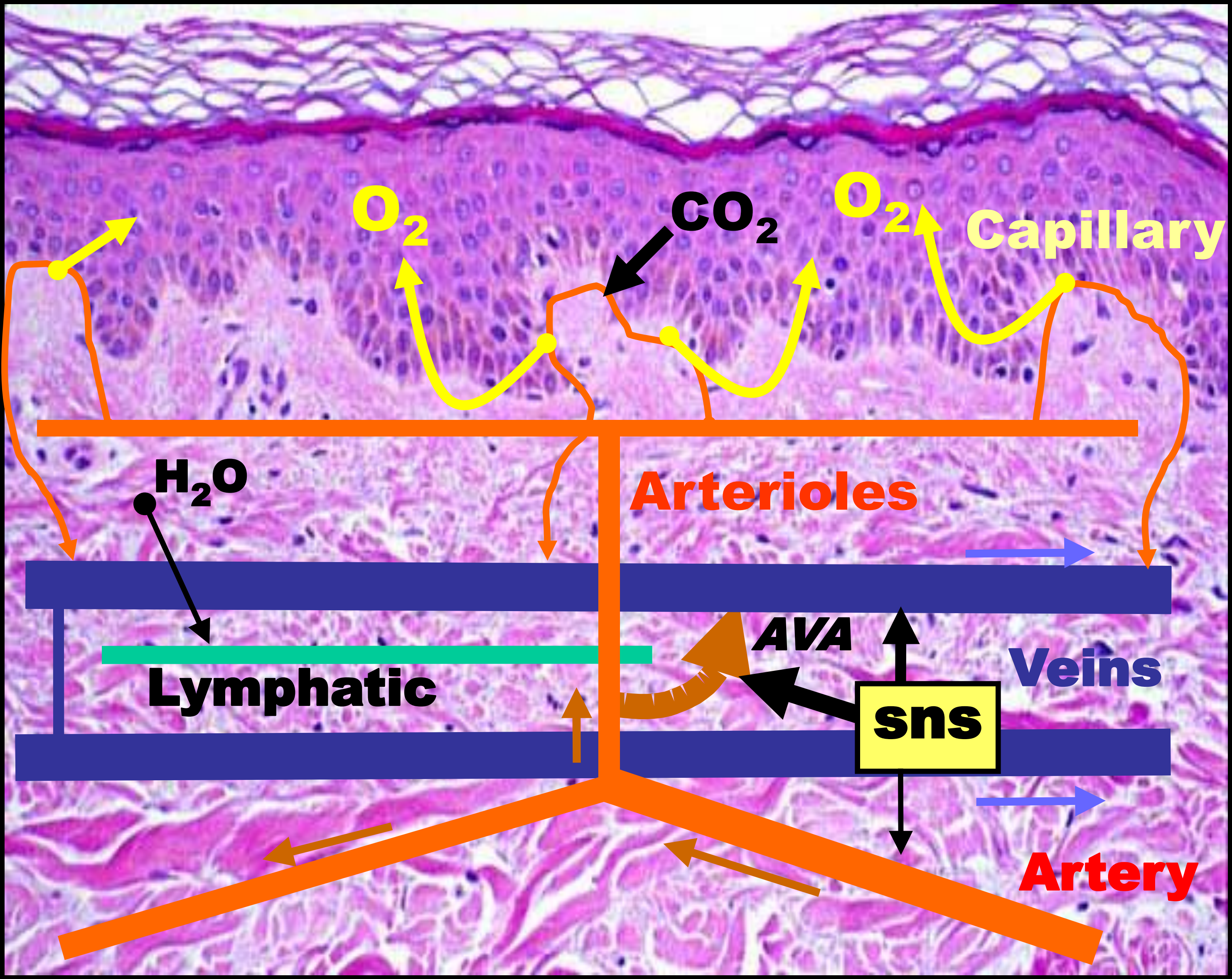
Germativum
(Basal)



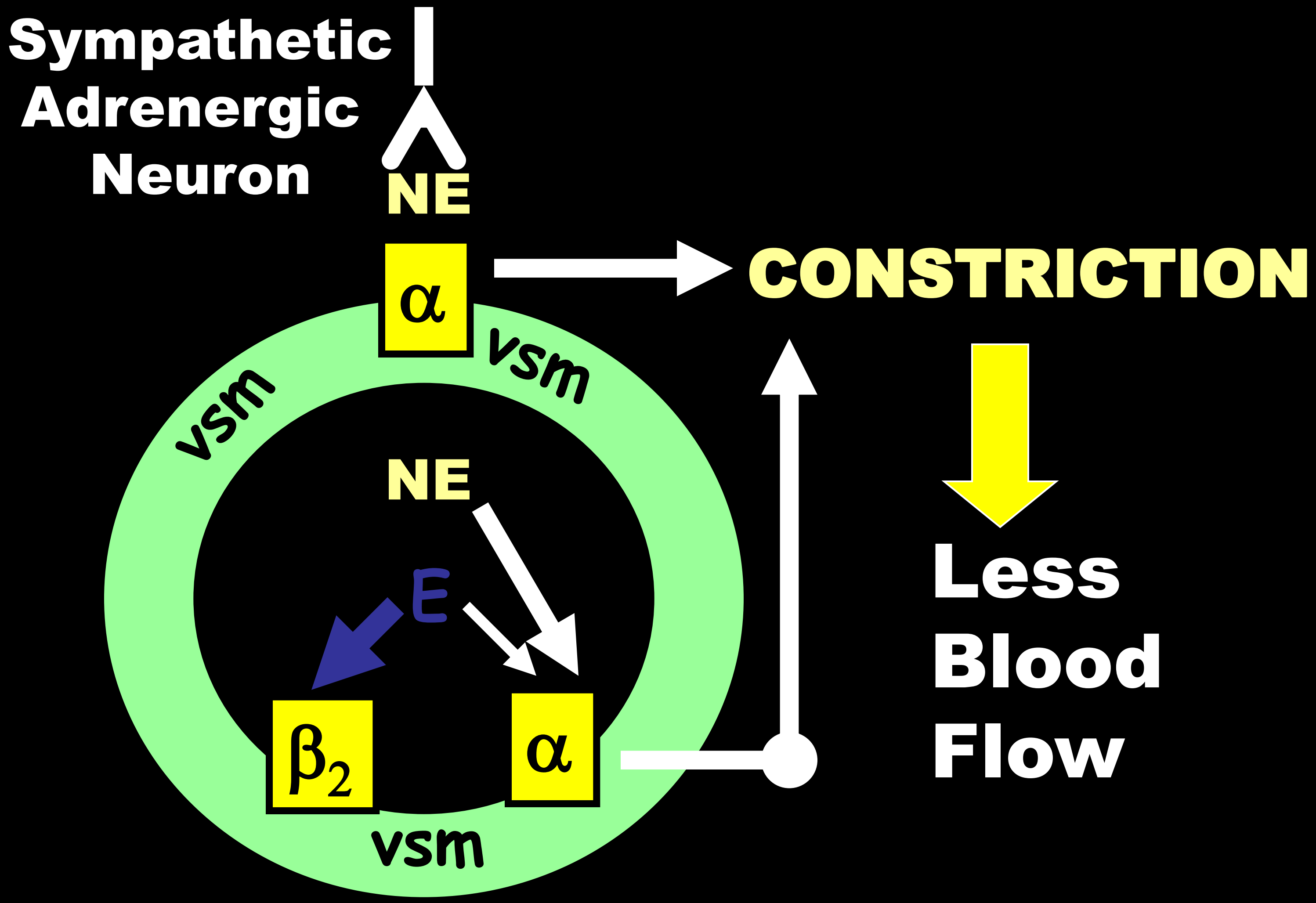
Dermis (Histology)



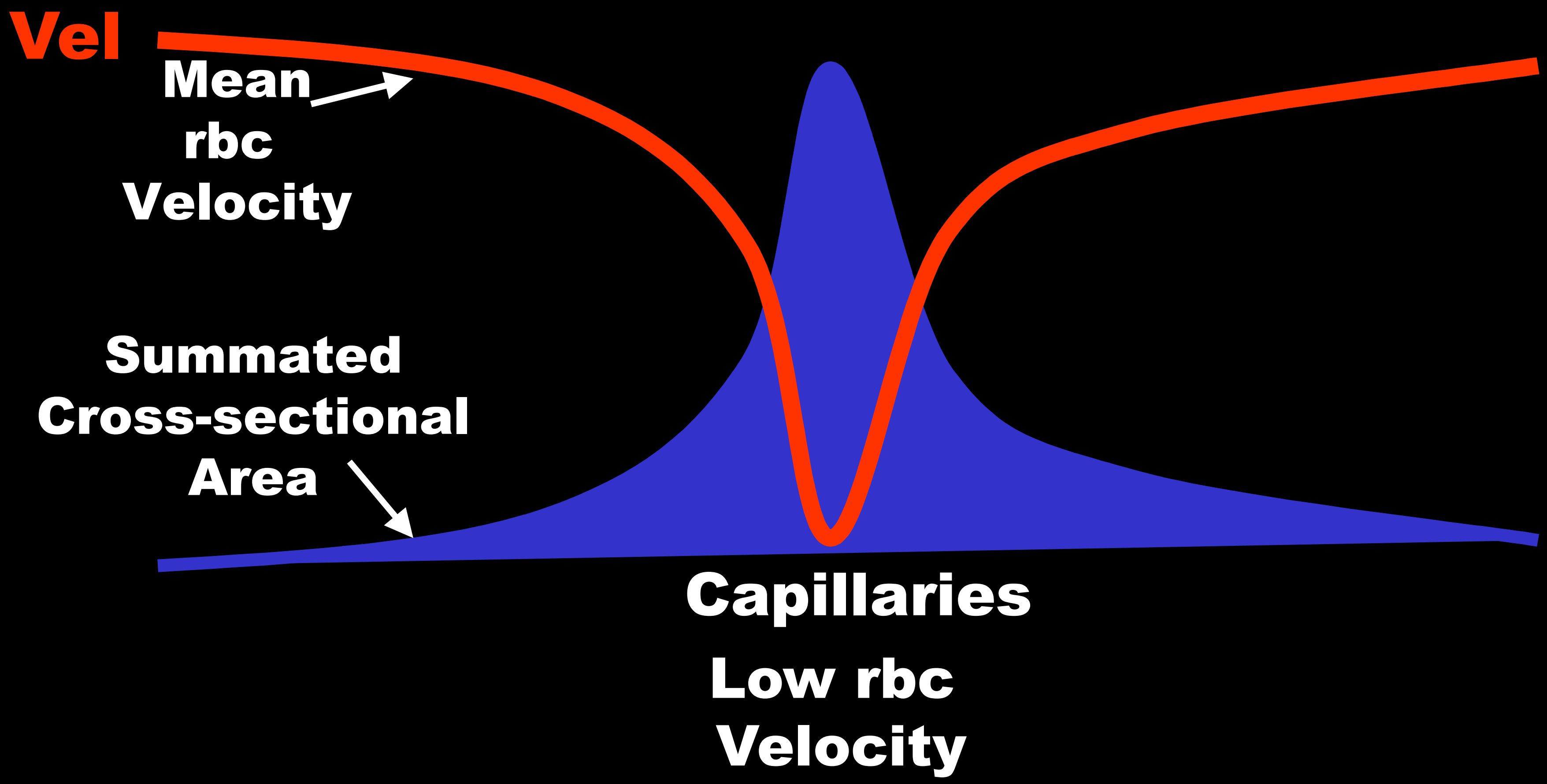
Blood Circulation Schema



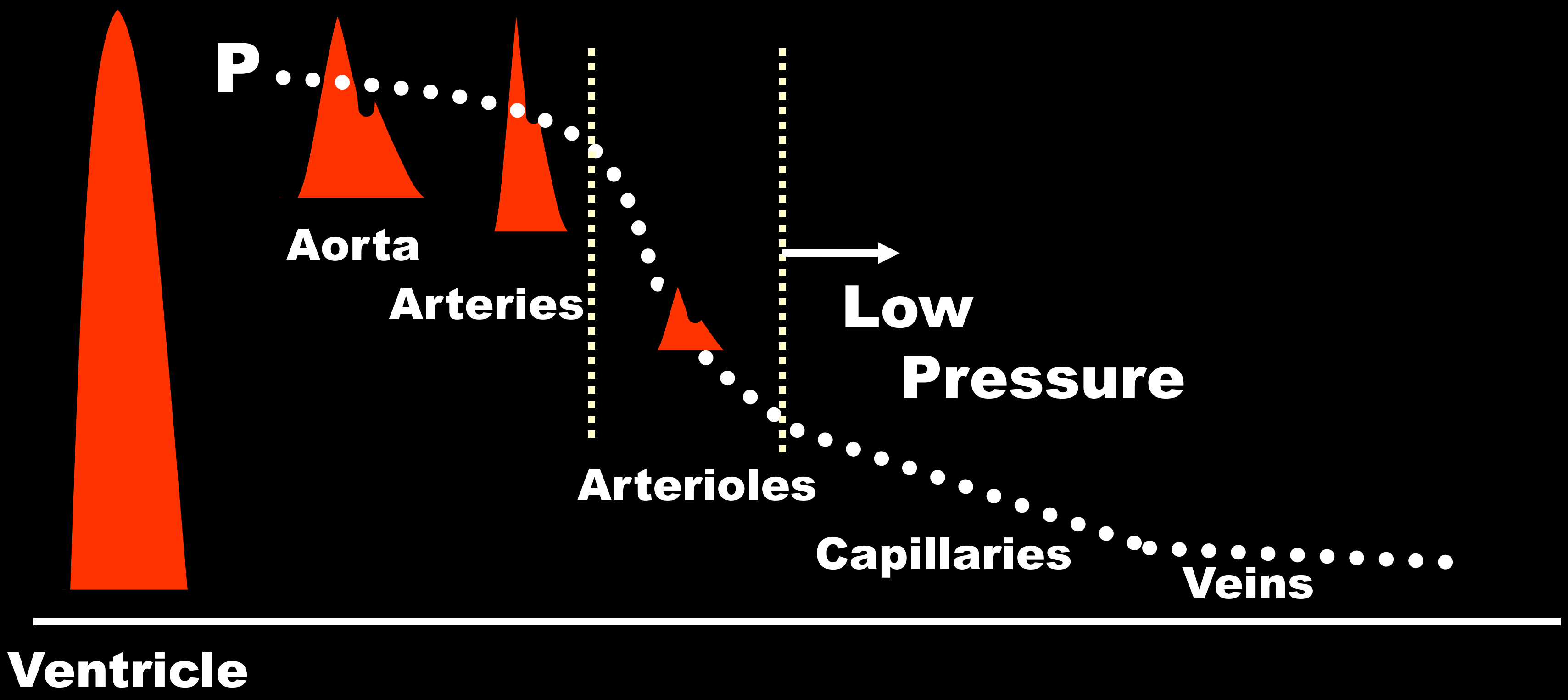
Arteriole and AVA's



Hemodynamic Factors
RBC Velocity



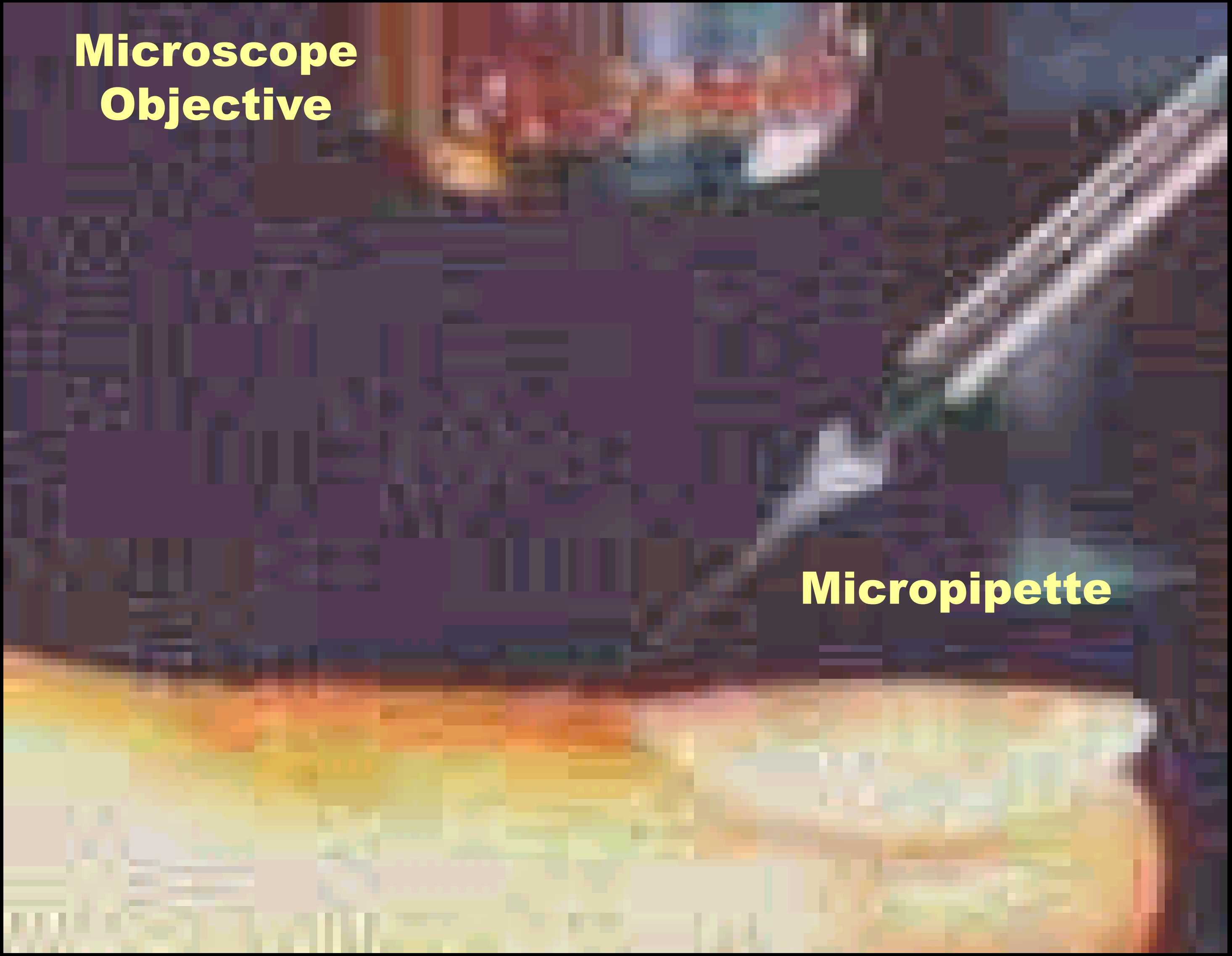
Hemodynamic Factors
Pressure



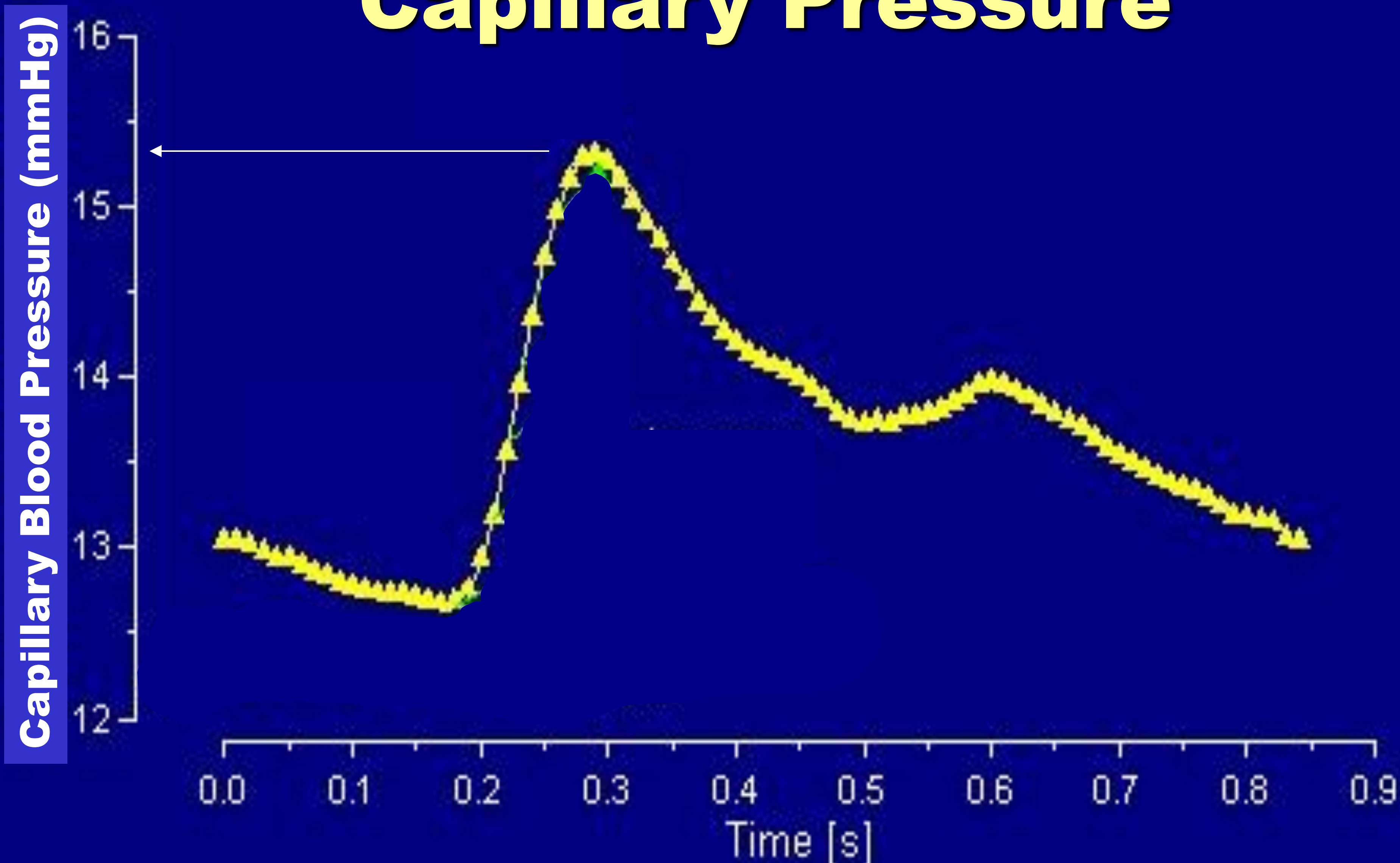
Capillary Pressure Measurement

Servo-null Method

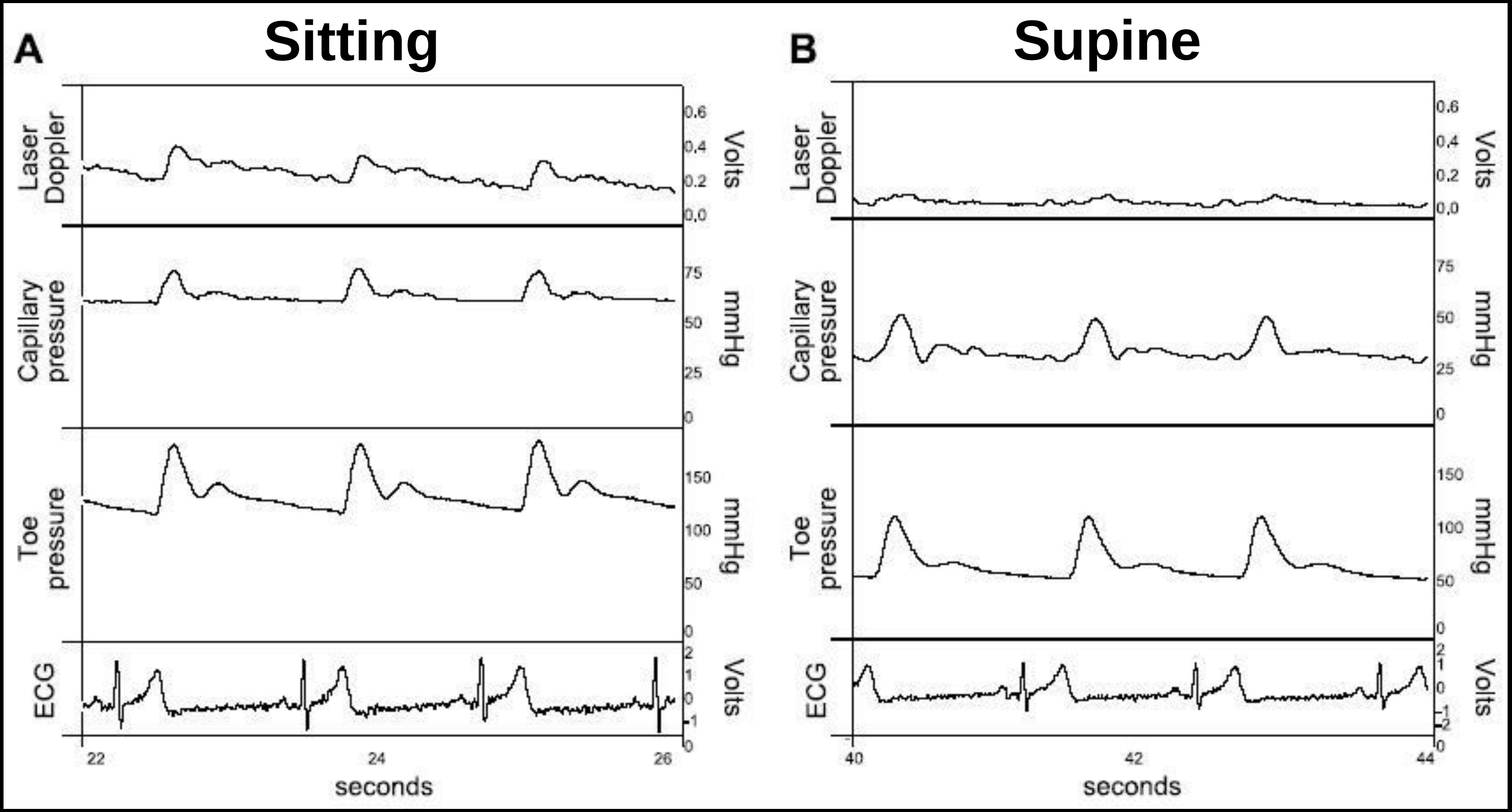
Skin Nailfold Capillaries



Capillary Pressure

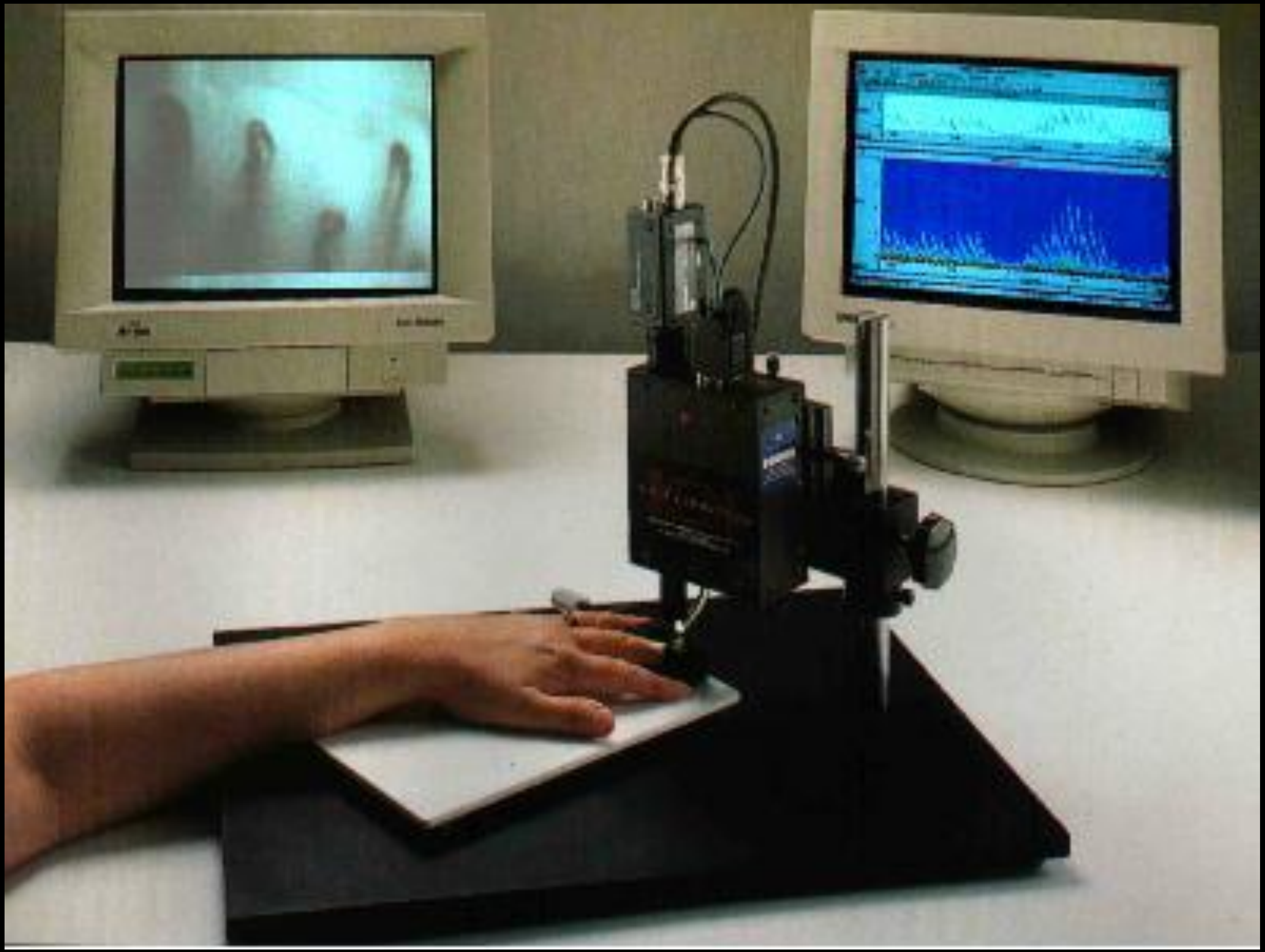


Illustrating Postural Effects

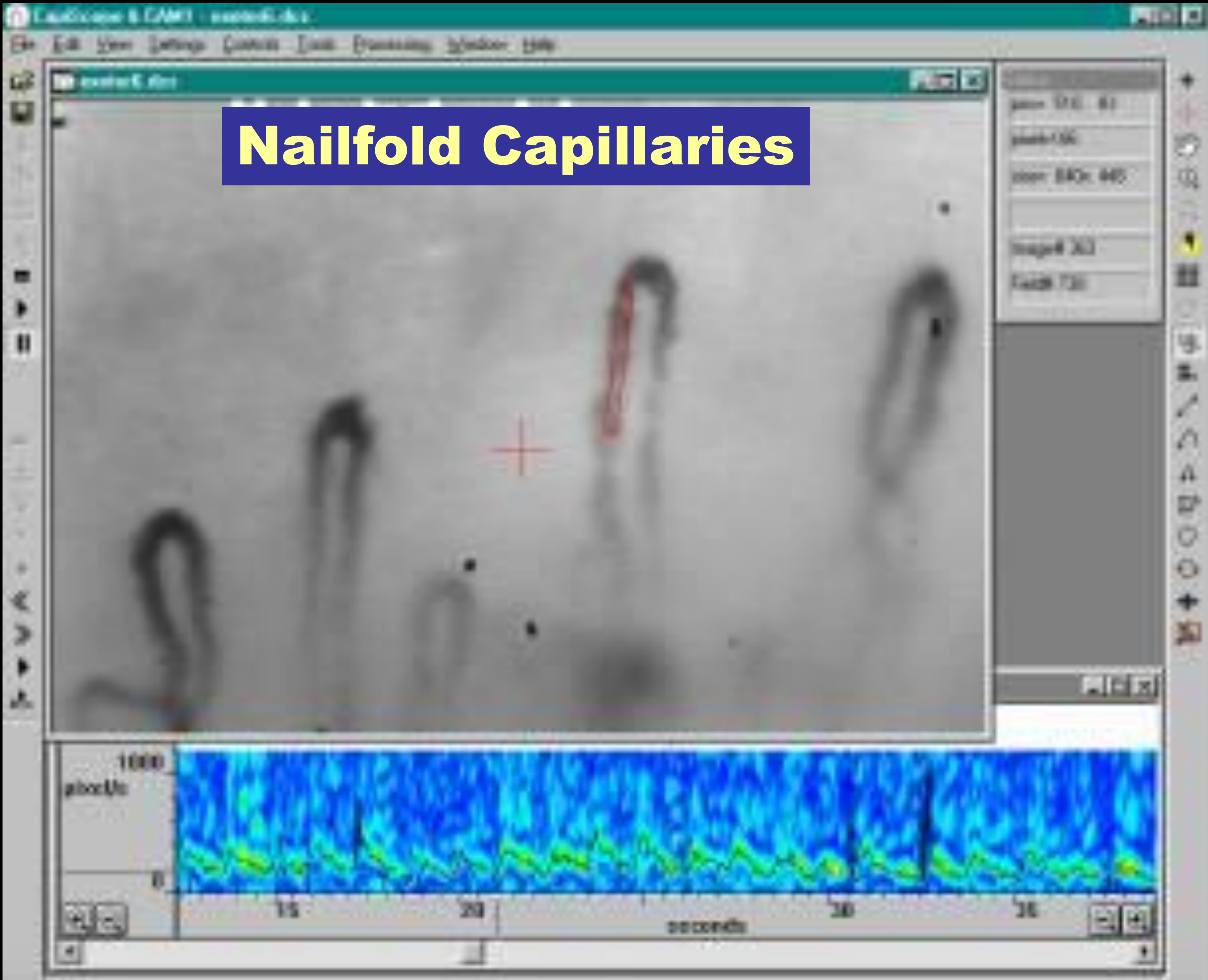


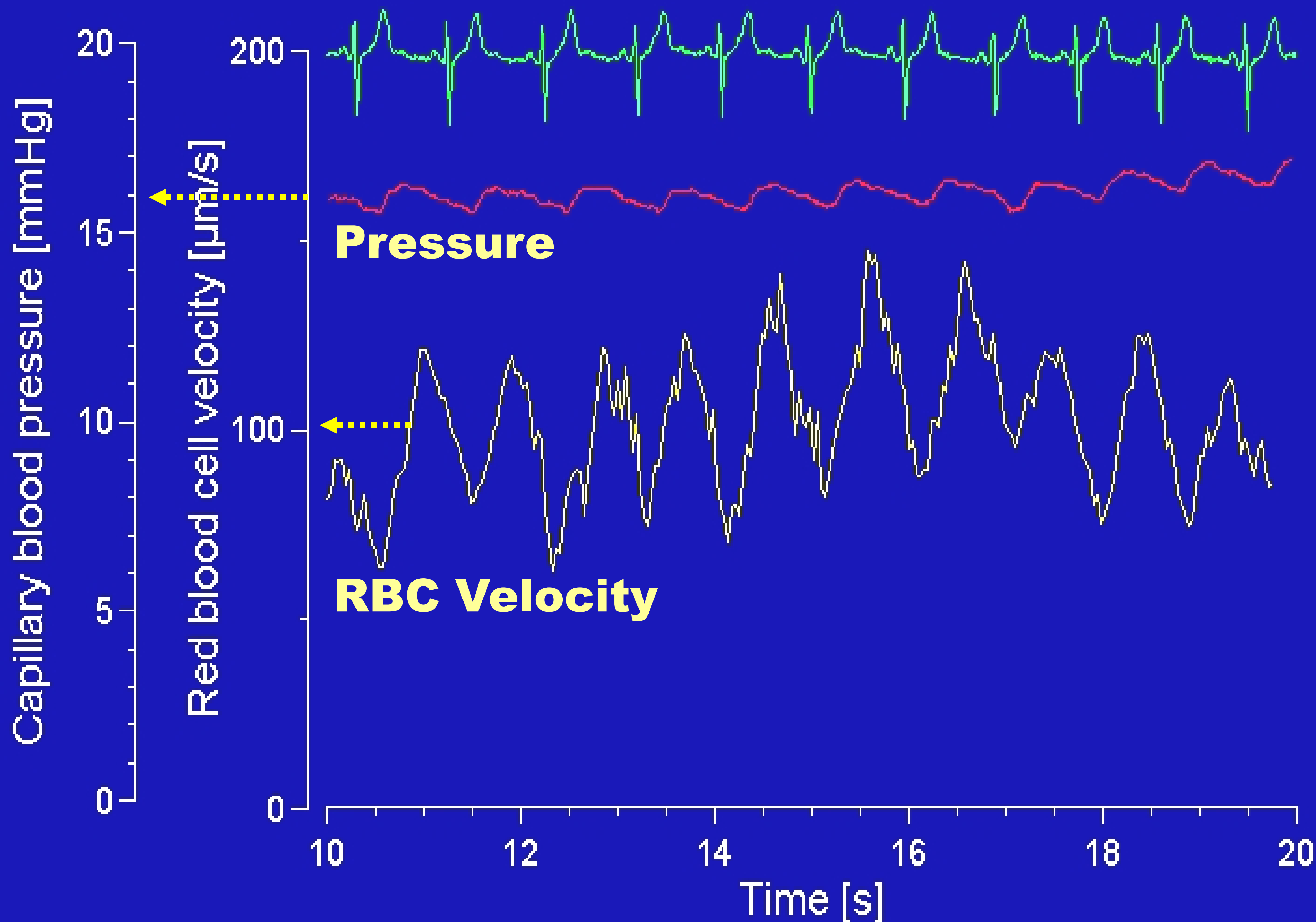
JC de Graaff et al. JAP 2003;95:2223-2228

Capillary RBC Velocity Measurement



Nailfold Capillaries





Capillary blood pressure [mmHg]
20
15
10
5
0
Red blood cell velocity [µm/s]
200
100
0
Pressure
RBC Velocity
10
12
14
16
18
20
Time [s]

Skin Blood Flow Methods and Tools

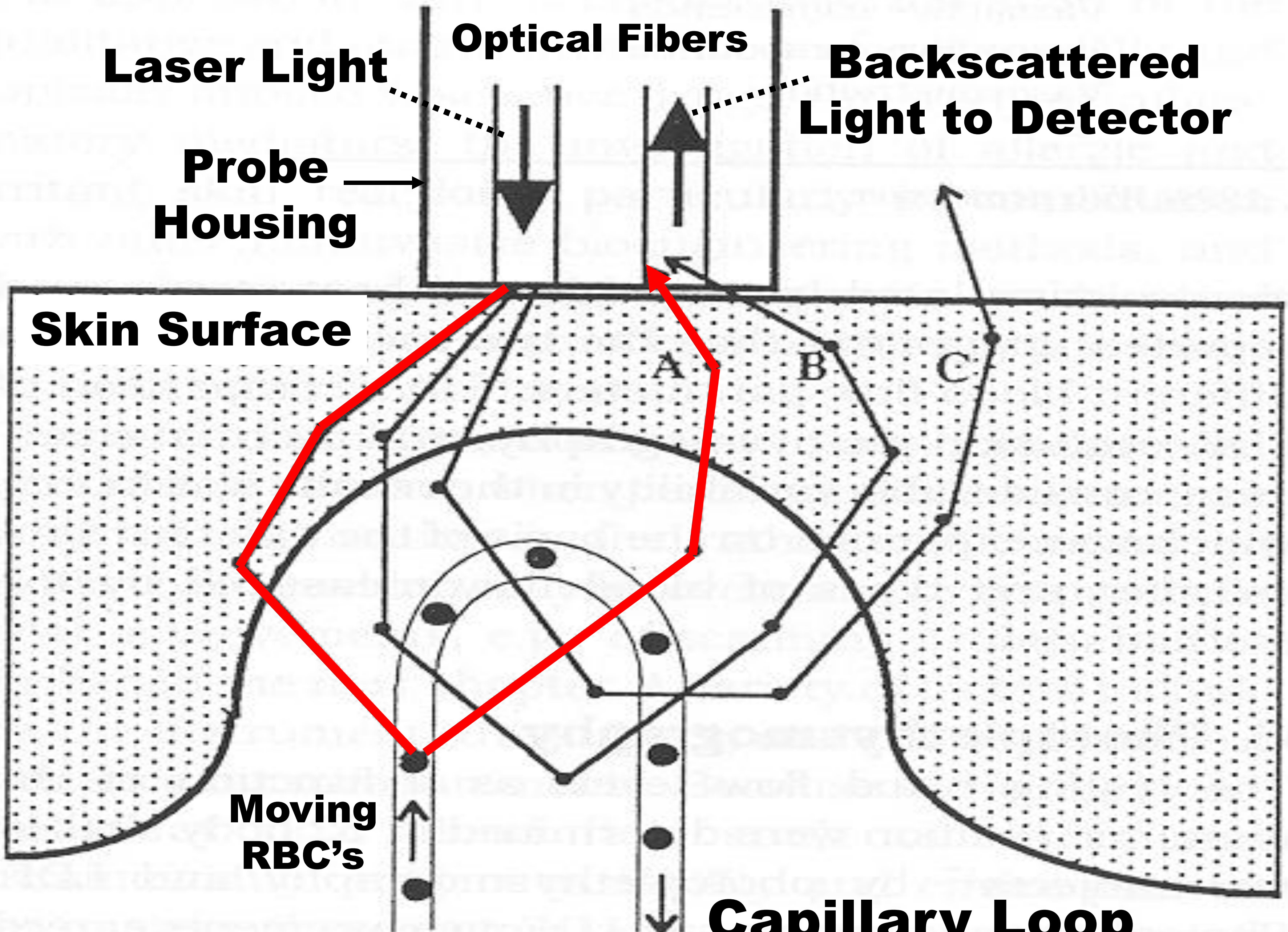
Laser-Doppler Flowmetry - LDF

- Temporal Information - Faster

Laser-Doppler Imaging - LDI

- Spatial Information - Slower

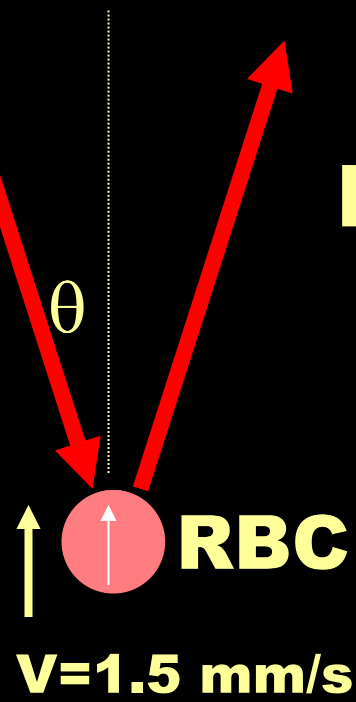
Laser-Doppler Principles


Optical Fibers
Laser Light
Backscattered
Light to Detector
Probe
Housing
Skin Surface
A
B
C
Moving
RBC's
Capillary Loop

Doppler-Shift ~ RBC Speed

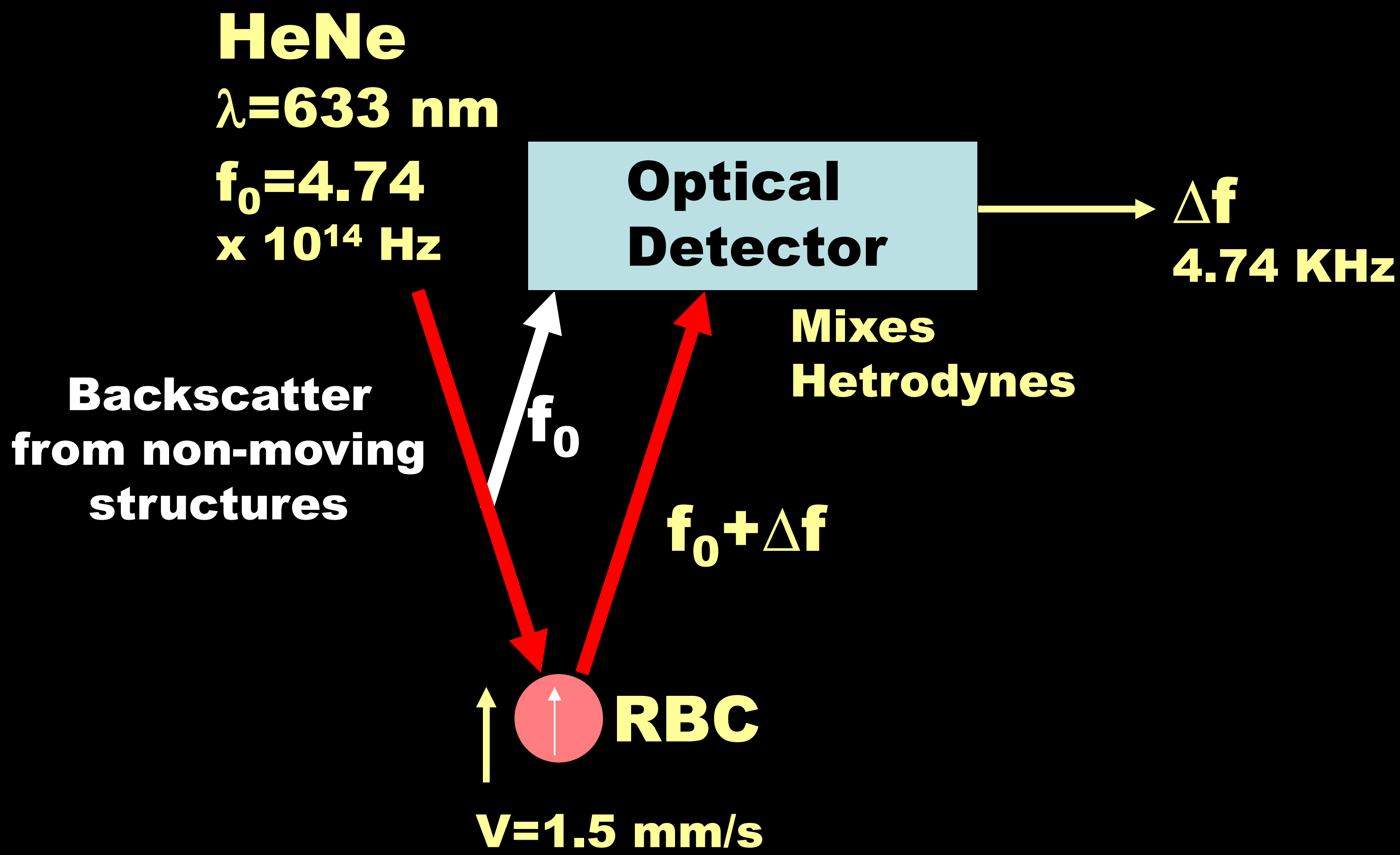
HeNe
λ=633 nm
f_0=4.74 x 10^{14} Hz

<u>Doppler-Shift</u>
$\Delta f/f_0 \sim 2V\cos\theta/C$
$\sim 10^{-11} \sim$4.74 kHz

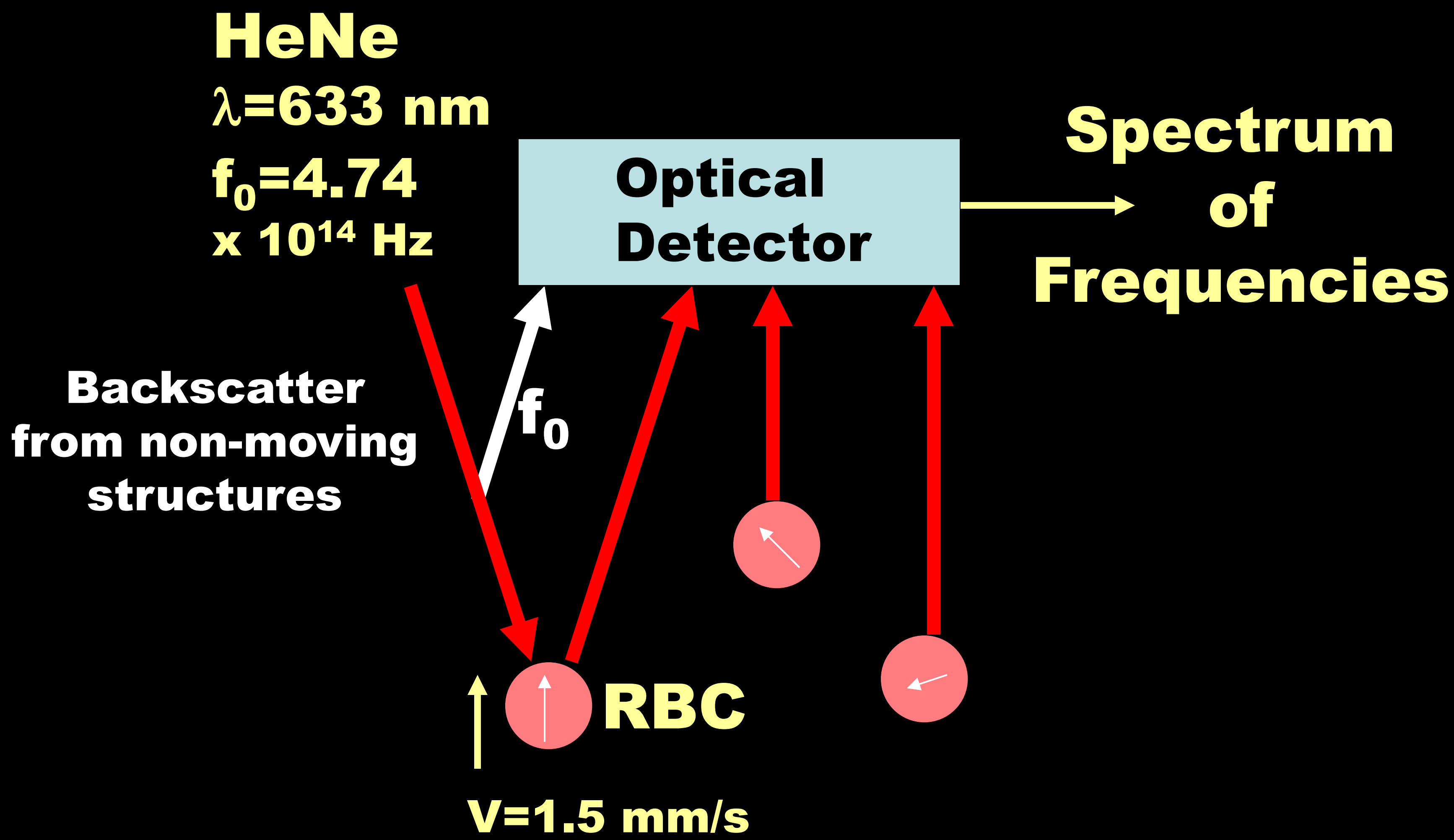


Doppler-Shift Directly ~ V

Detecting Frequency Shift

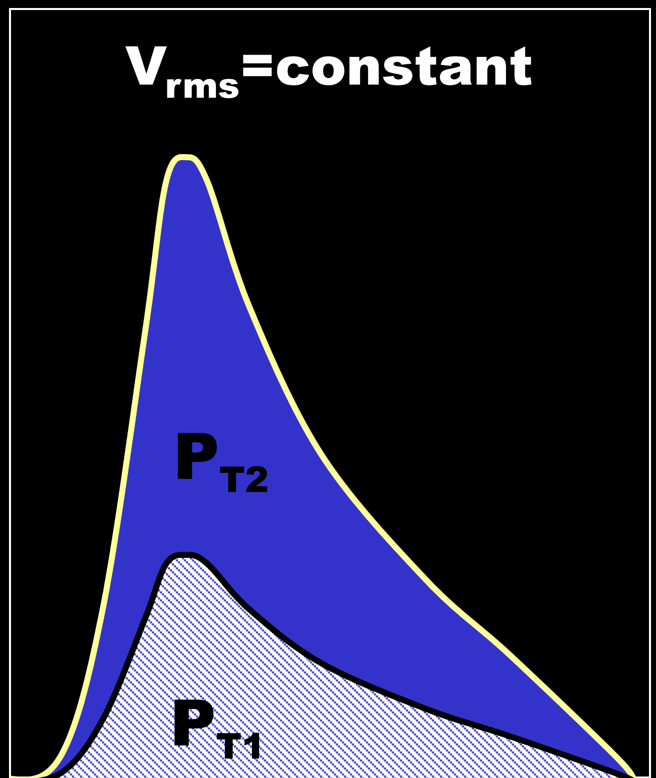


Multiple Moving Targets



Moving Volume Concentration

Doppler Power $P(\omega)$



Frequency (ω)

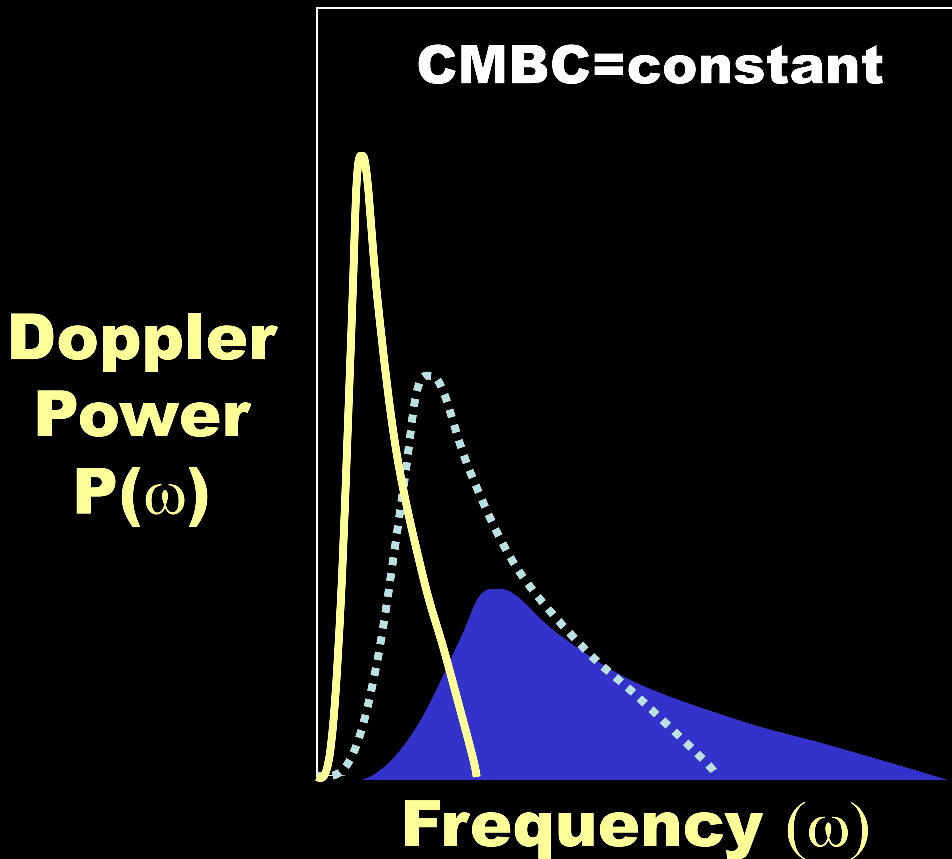
For a constant total light intensity coming back to the detector

$P_T \sim$ **CMBC**

Concentration
Moving
Blood
Cells

$P_T = \int P(\omega) d\omega$

Moving Cell Velocity



For a constant CMBC Total Doppler Power

$\int P(\omega)d\omega$ is constant

But, Doppler-Shift depends on <u>velocity</u>

$$\Delta f \sim V_{rms}$$

$$V_{rms} = \frac{\int \omega P(\omega)d\omega}{\int P(\omega)d\omega}$$

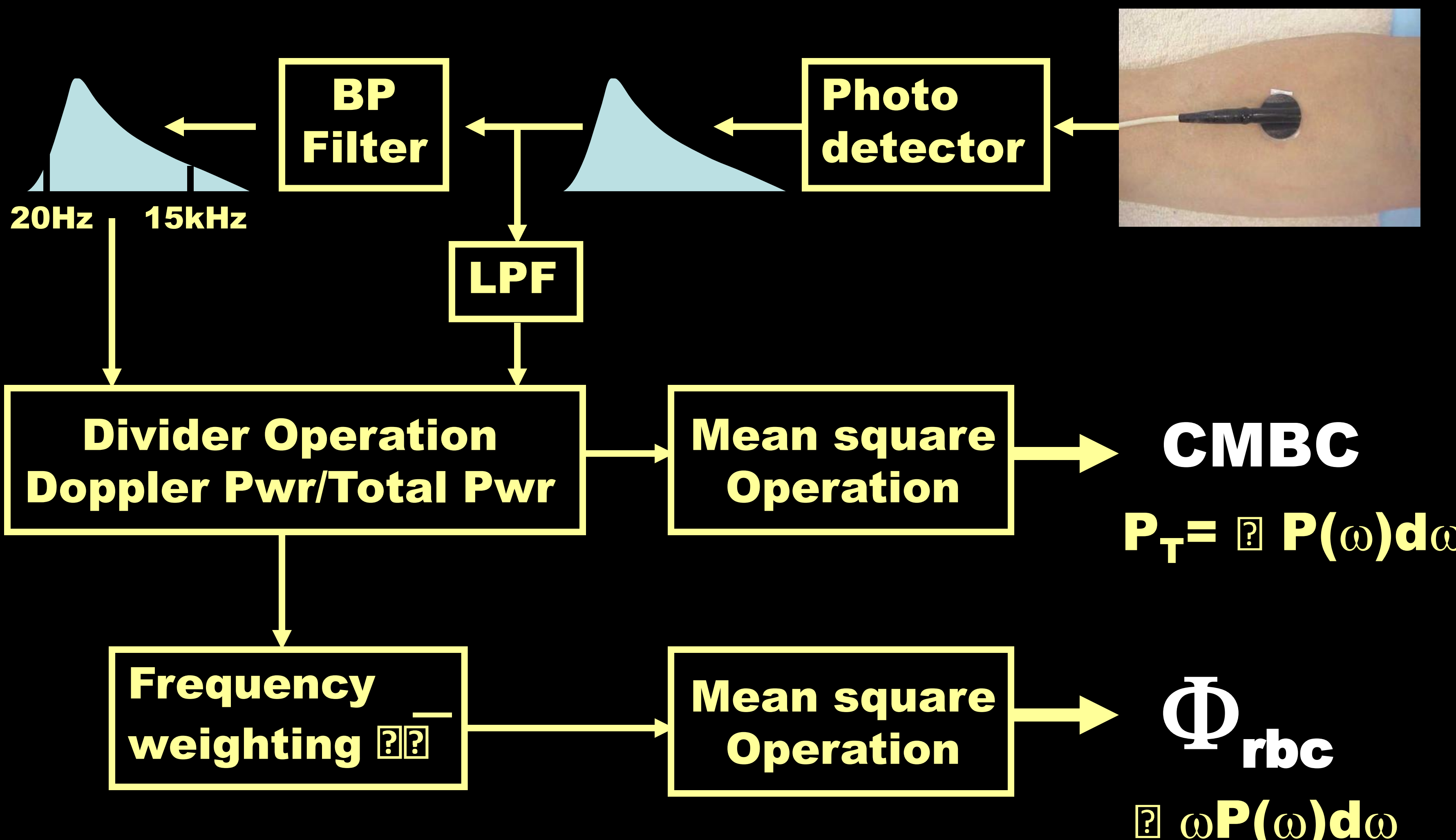
Blood Flux or Perfusion

$$\Phi_{rbc} = k \times V \times CMBC$$

Some call it Blood Flow [Q, volume/sec]
but is truly Blood Cell Flux [#/sec]

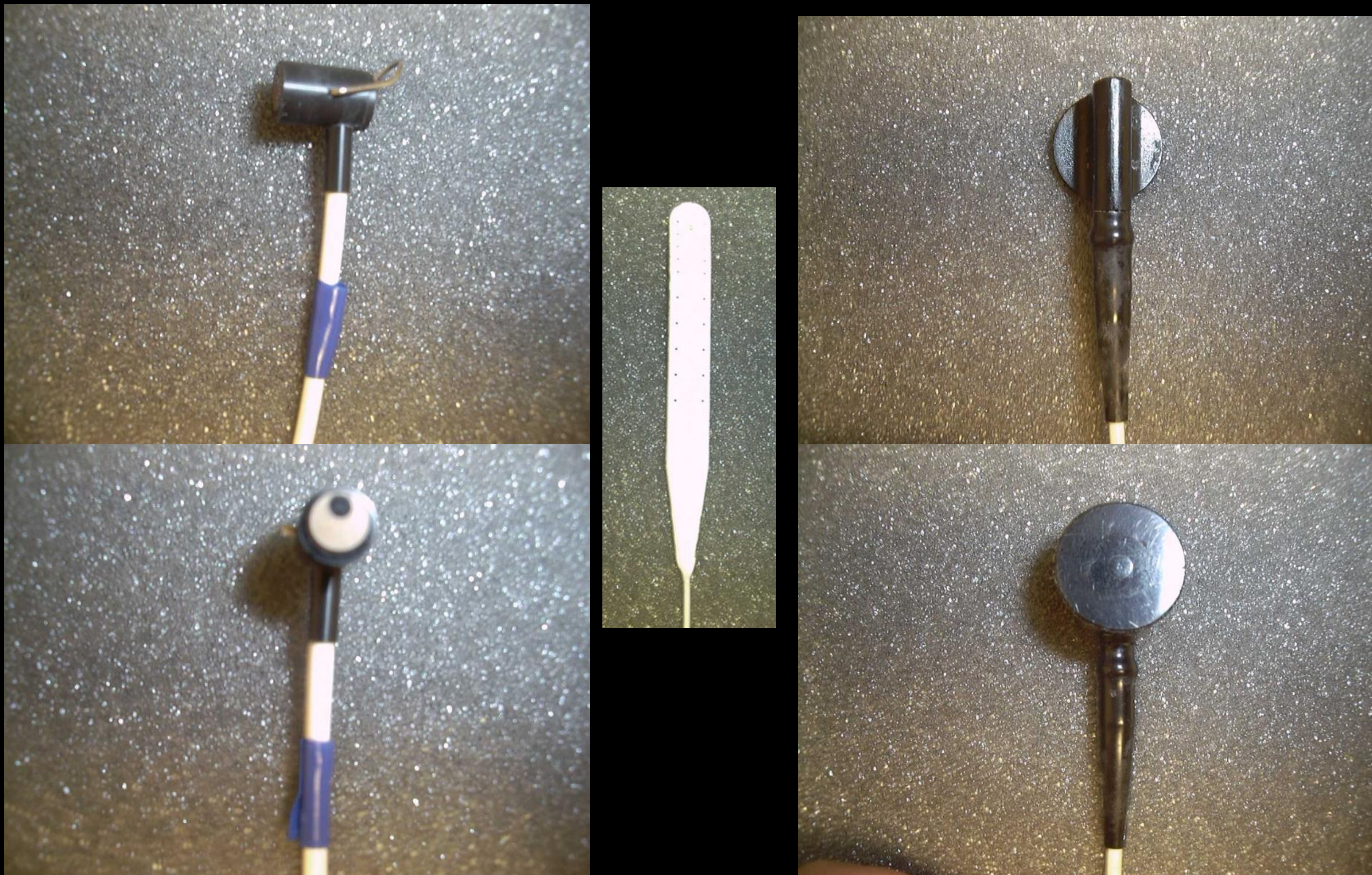
$$\Phi_{rbc} \sim Q \quad \text{(Perfusion)}$$

Basic Instrument Operation



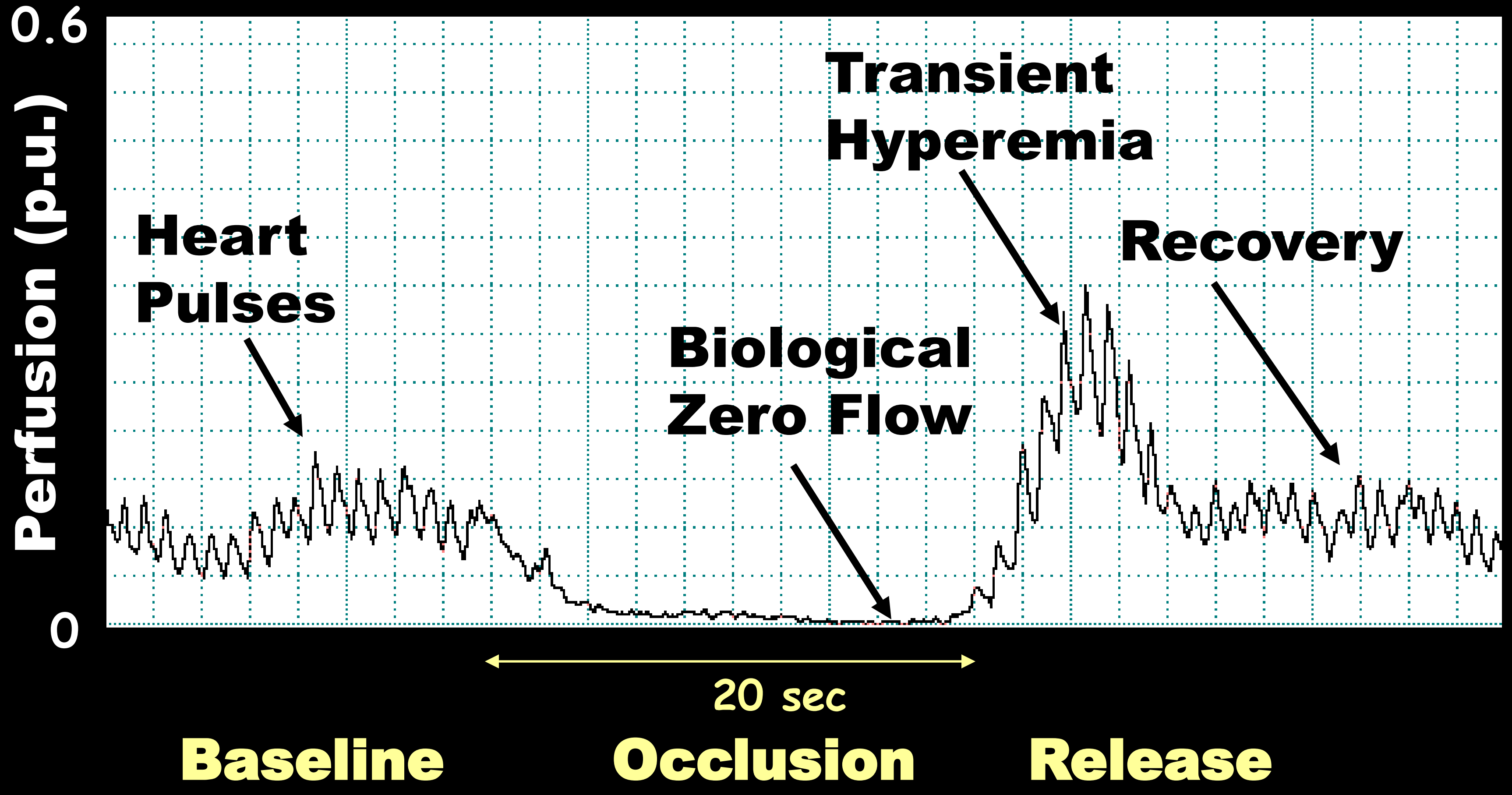
Instruments

LDF Probes

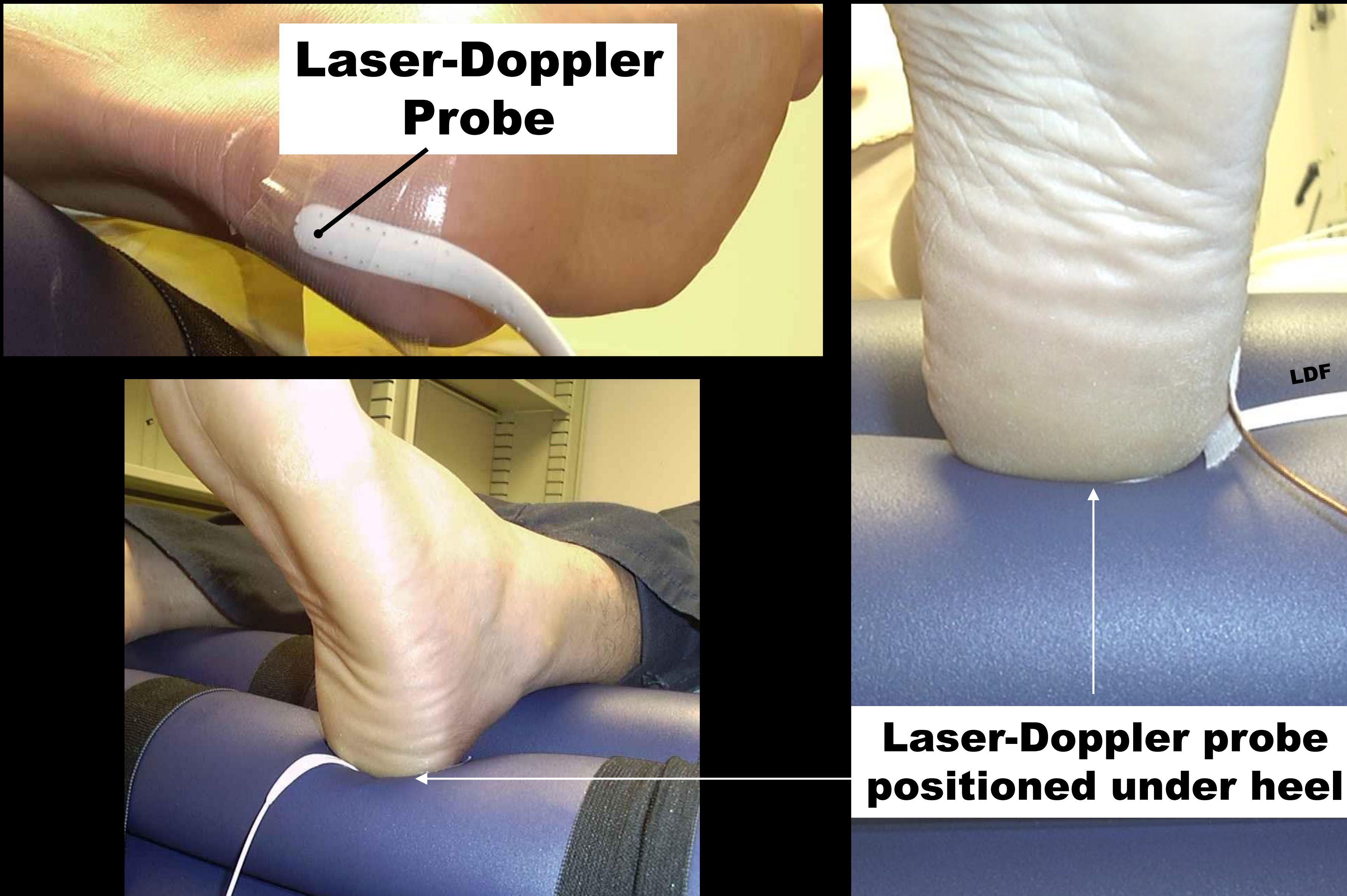


Examples of
LDF Recordings

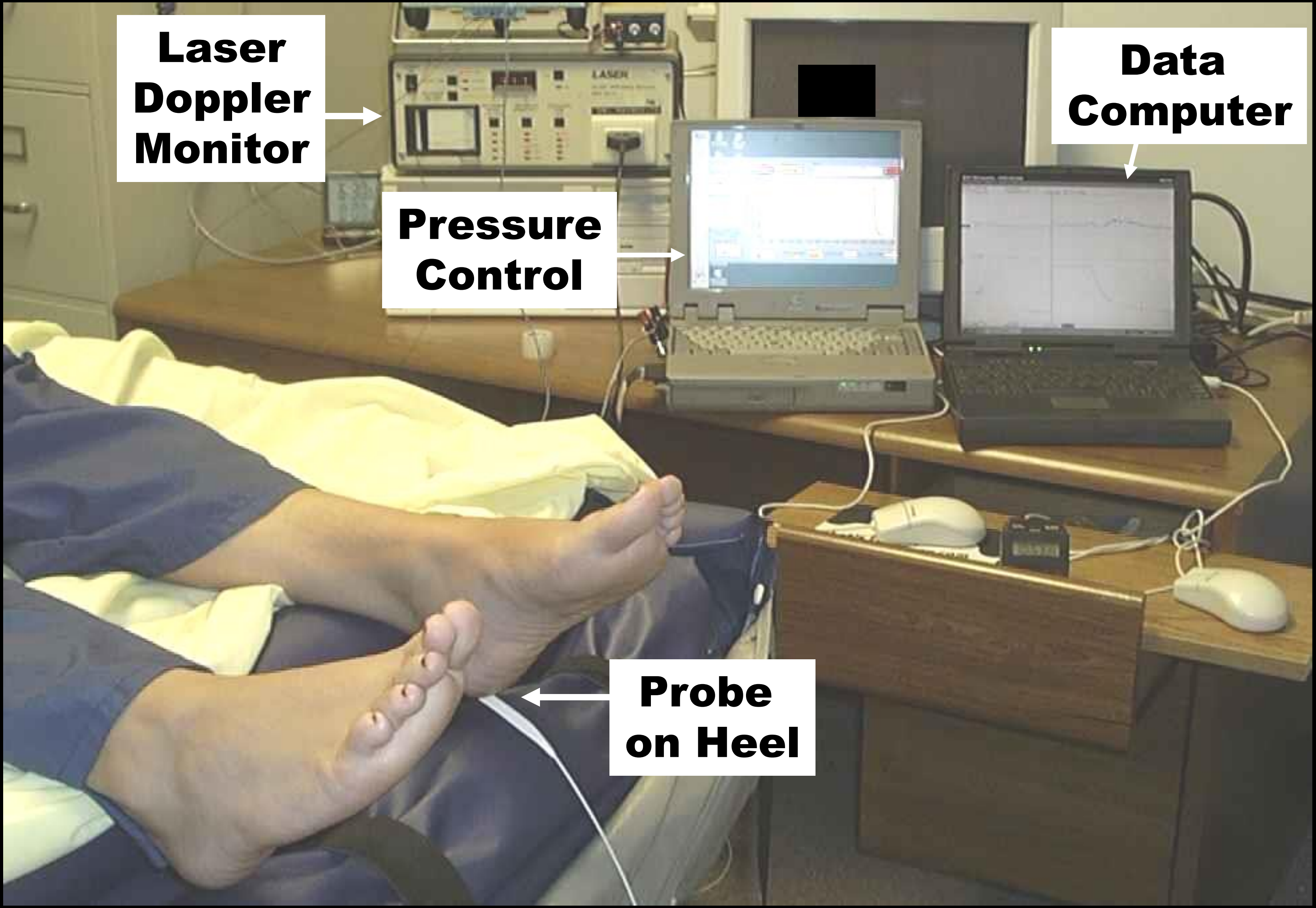
Blood Flow Arrest



Heel Compression Studies



Data Acquistion

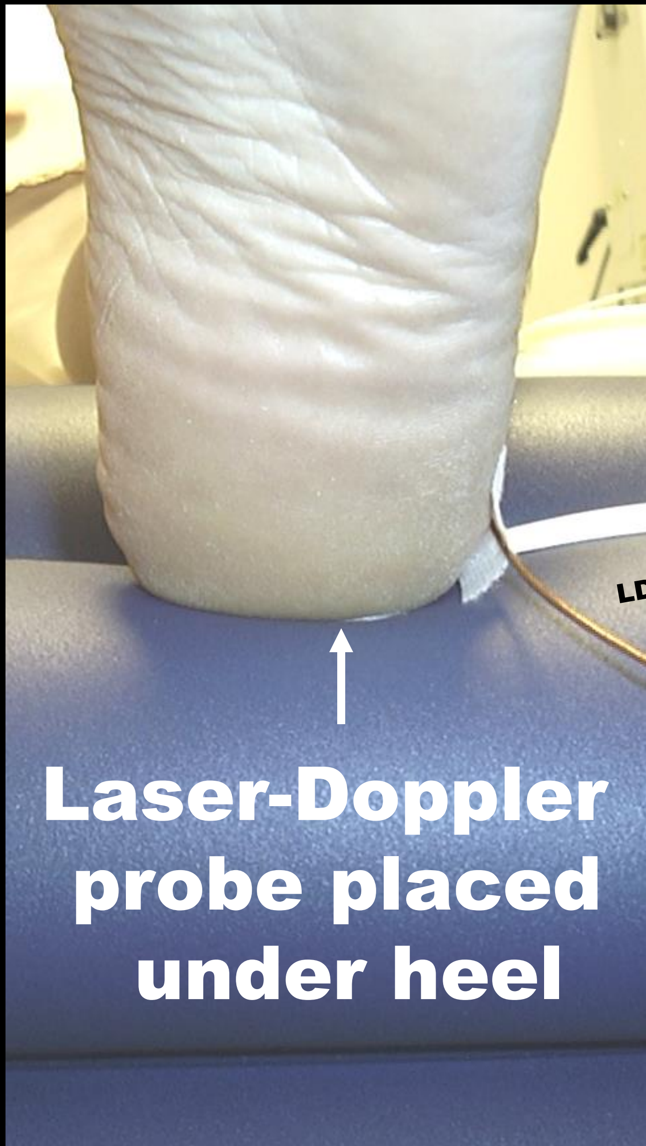


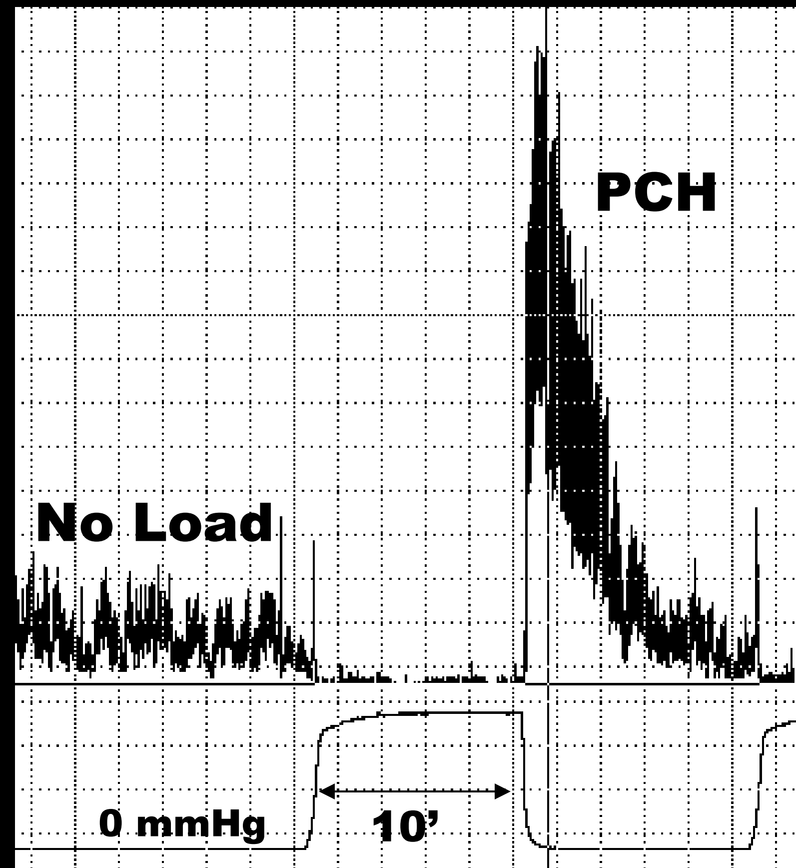
Heel Loading and Unloading

Heel Loaded

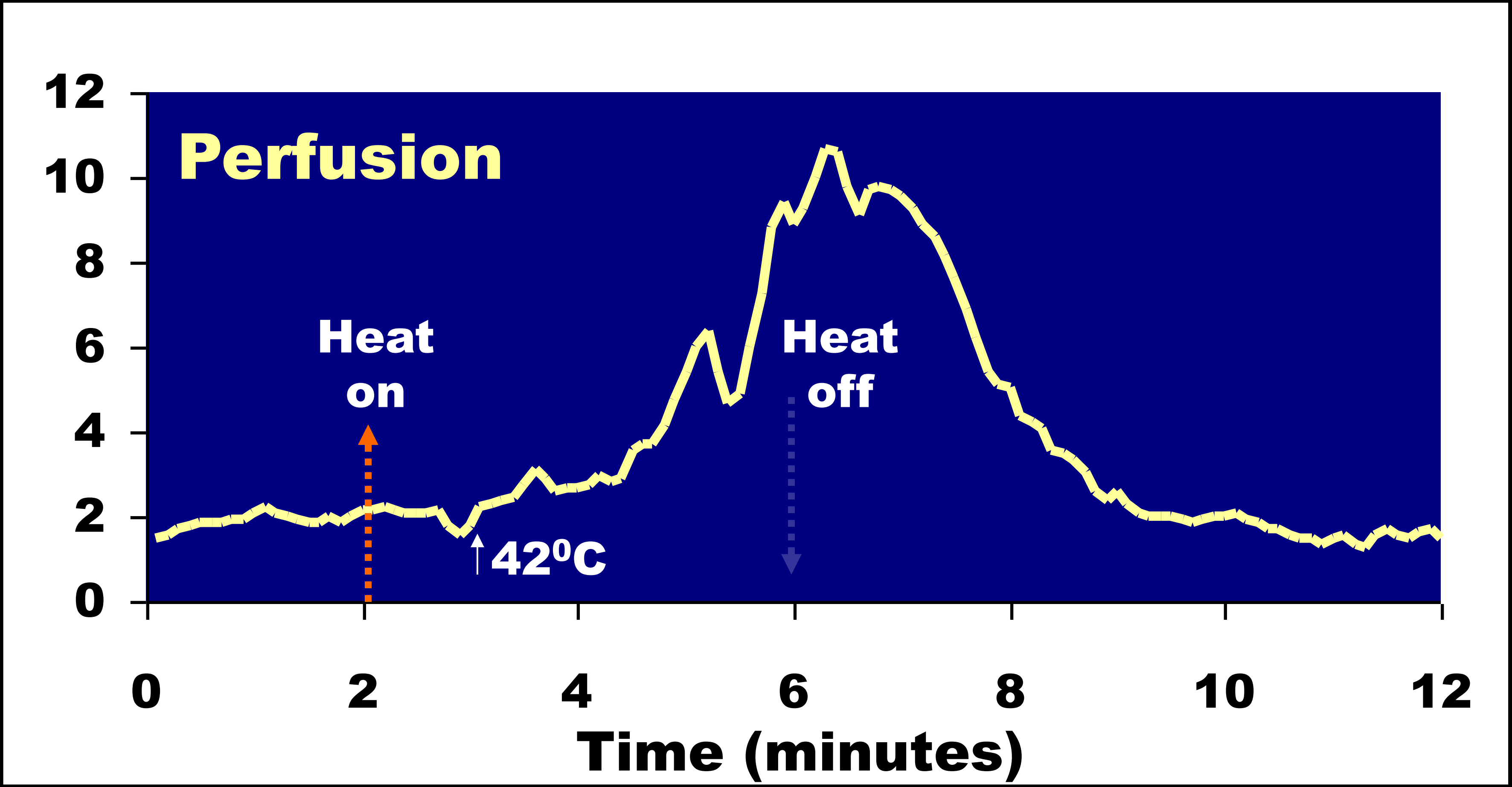
Heel Fully Unloaded

Typical LDF Response

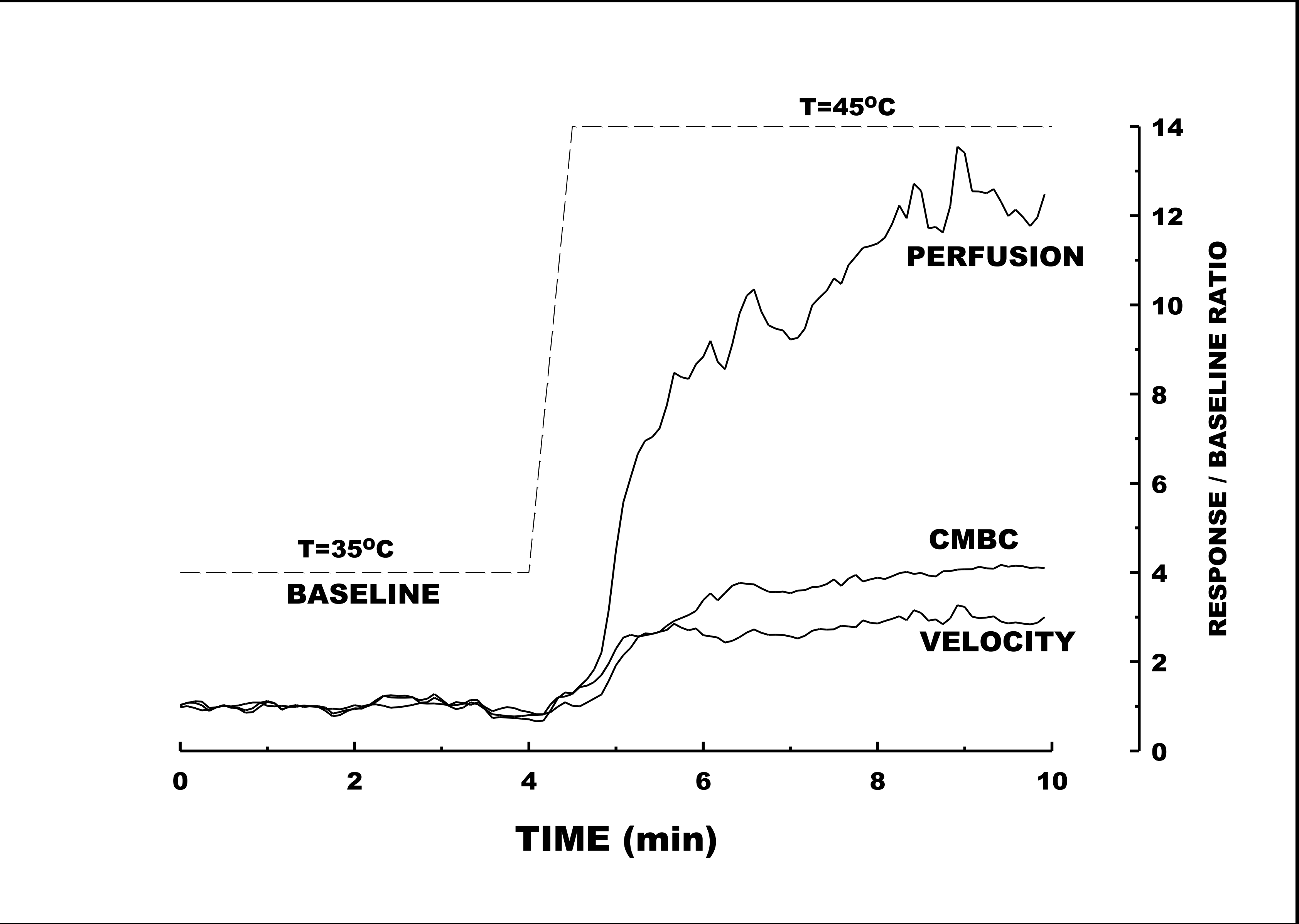




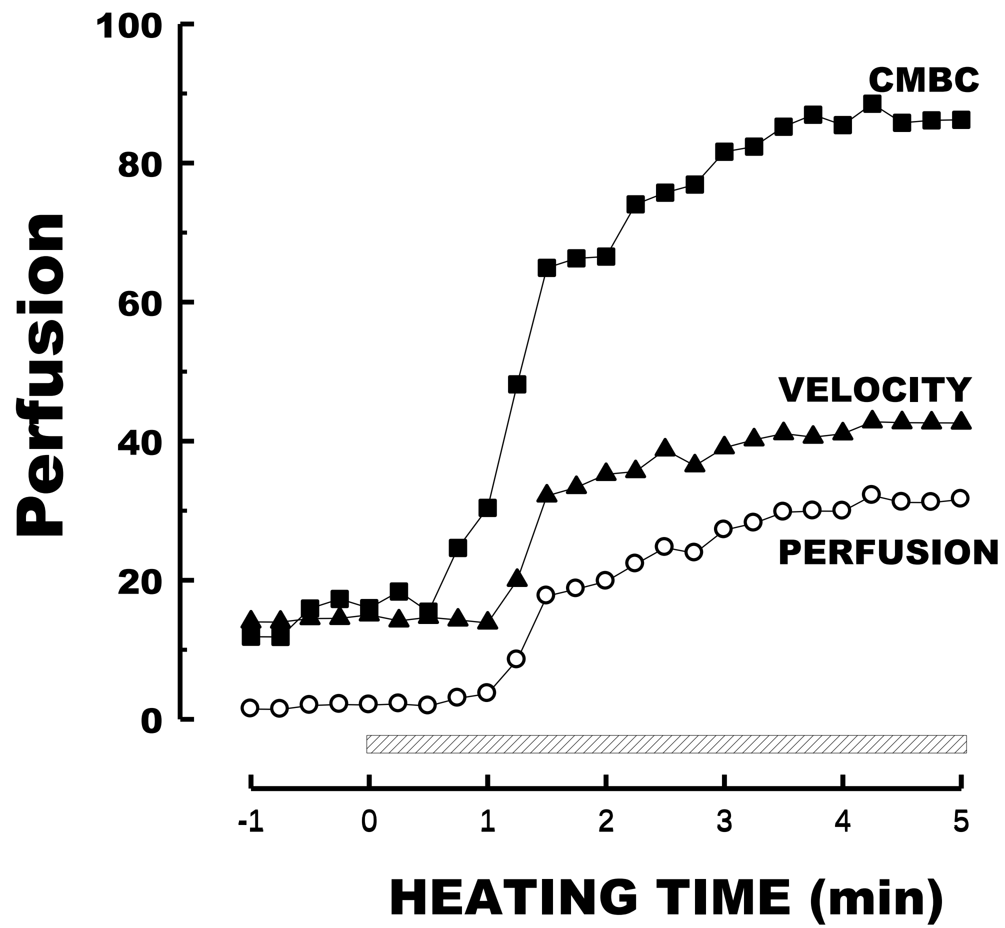
Local Skin Heating



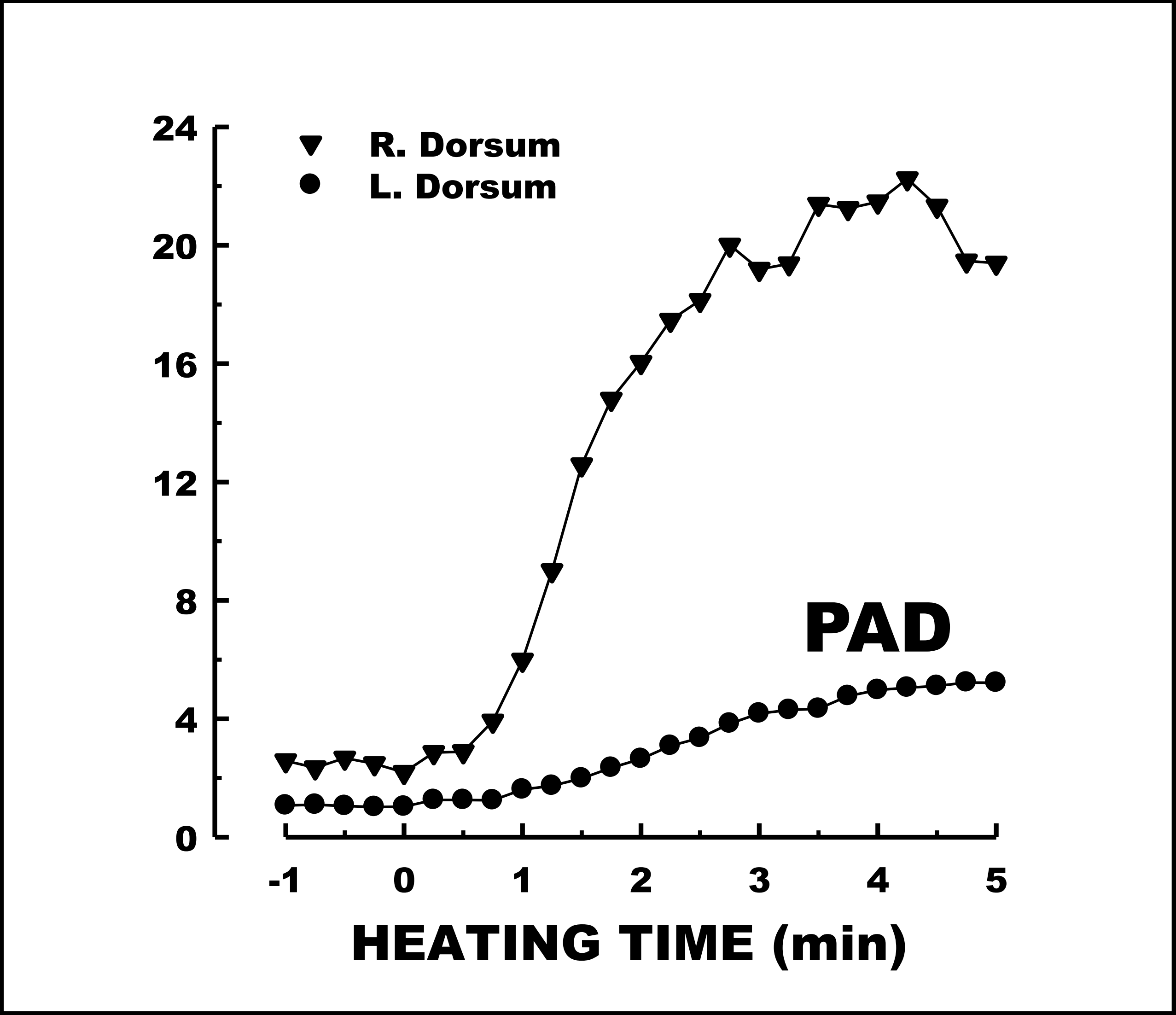
Component Responses



Normal Responses

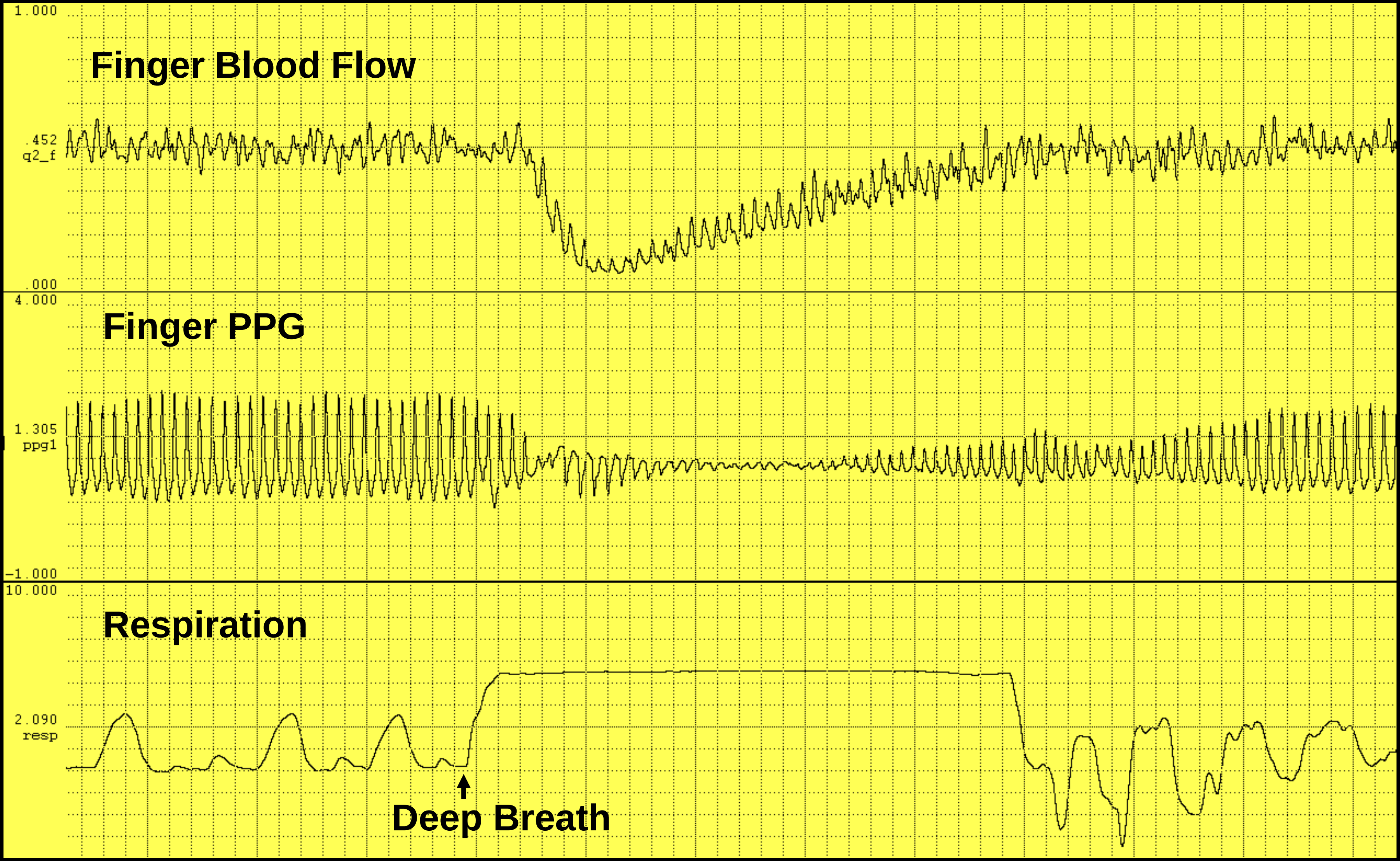


Diminished Response

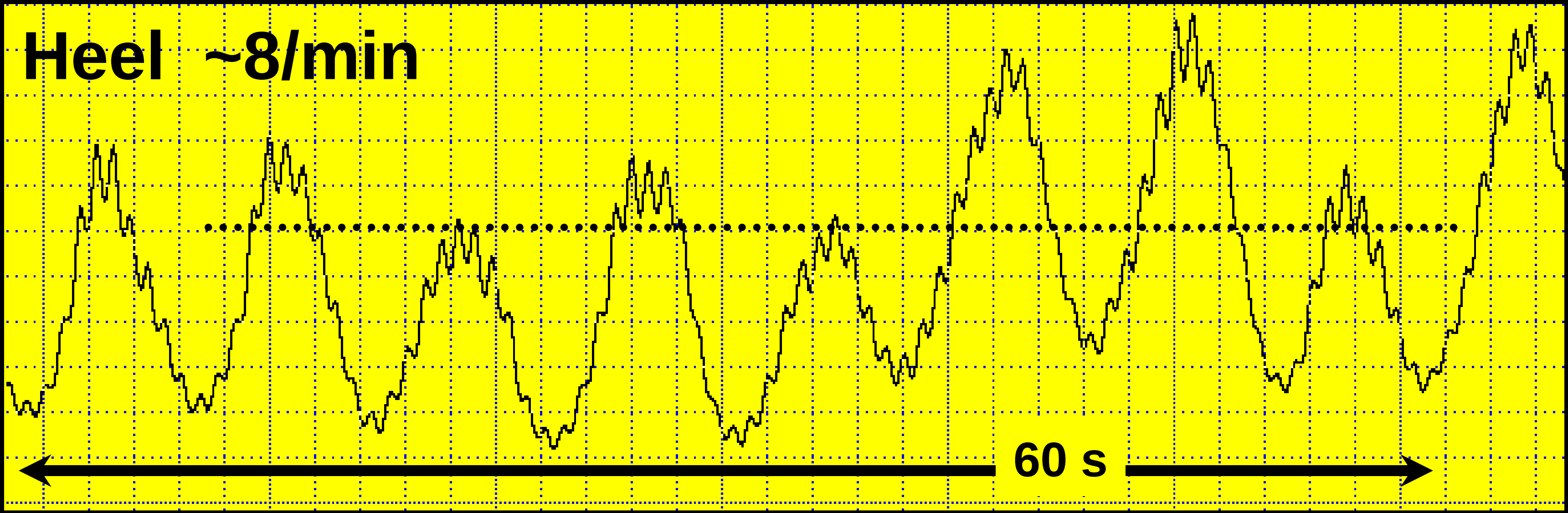


Inspiratory Gasp Response

Inspiratory Gasp



Flomotion



Spectral Analysis

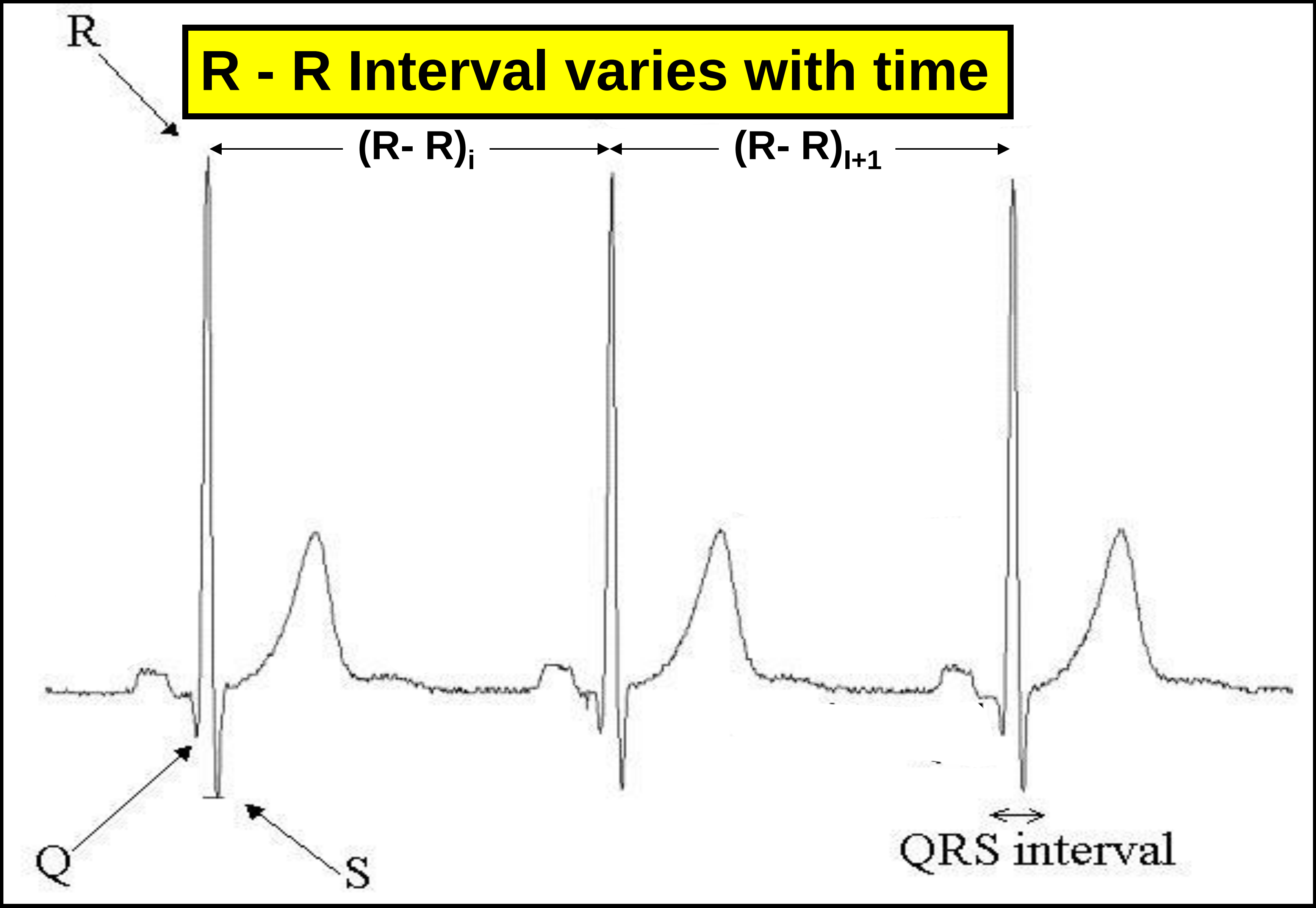
Why Spectral Analysis?

Detection and characterization of cyclical or periodic processes present in physiological signals

Rhythms are present in nearly all physiological signals - but not always evident to the ‘naked eye’!

Generating a time series signal from the Electrocardiogram

R- R Time Series



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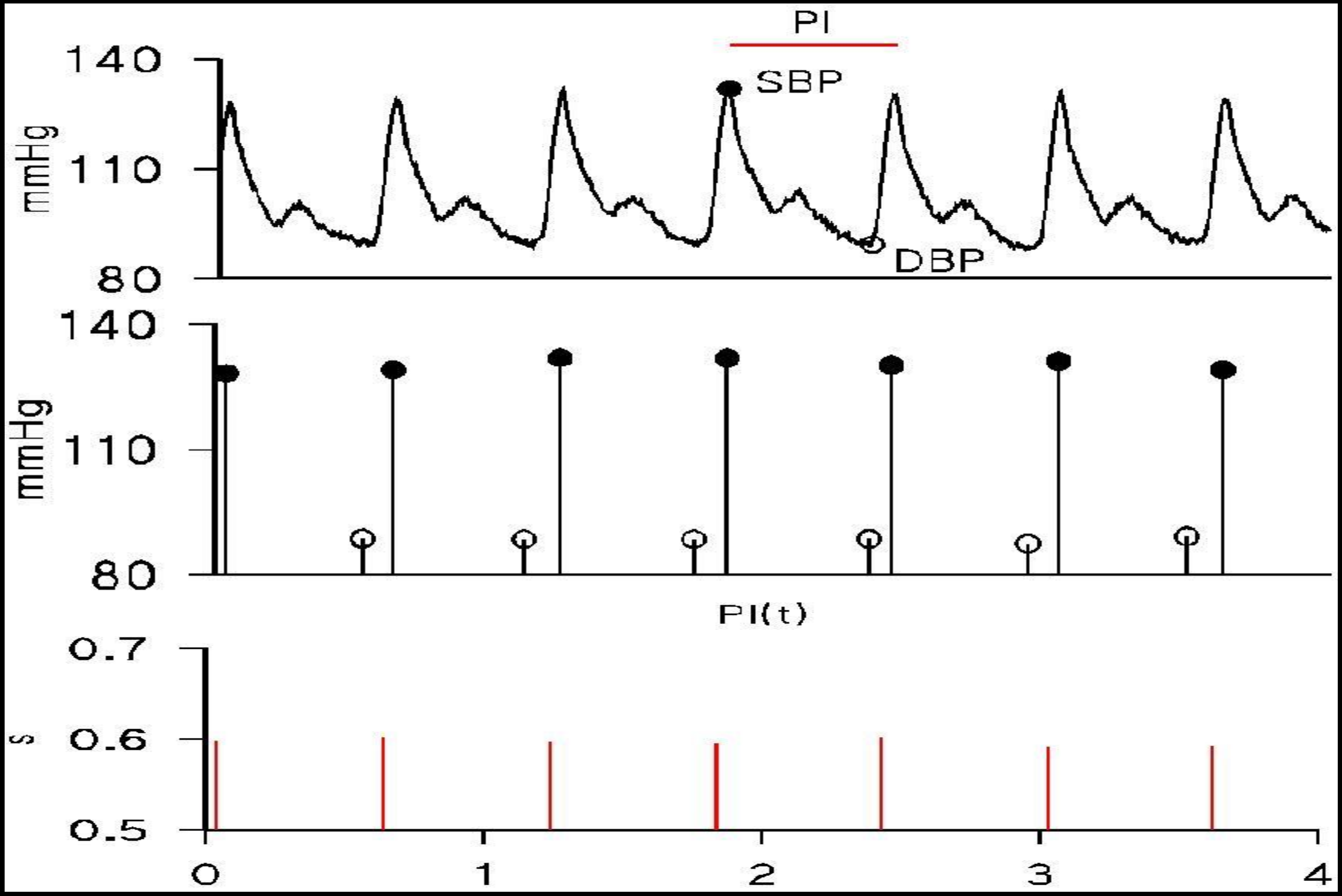
Time Series of Pulse Intervals



Time (sec)

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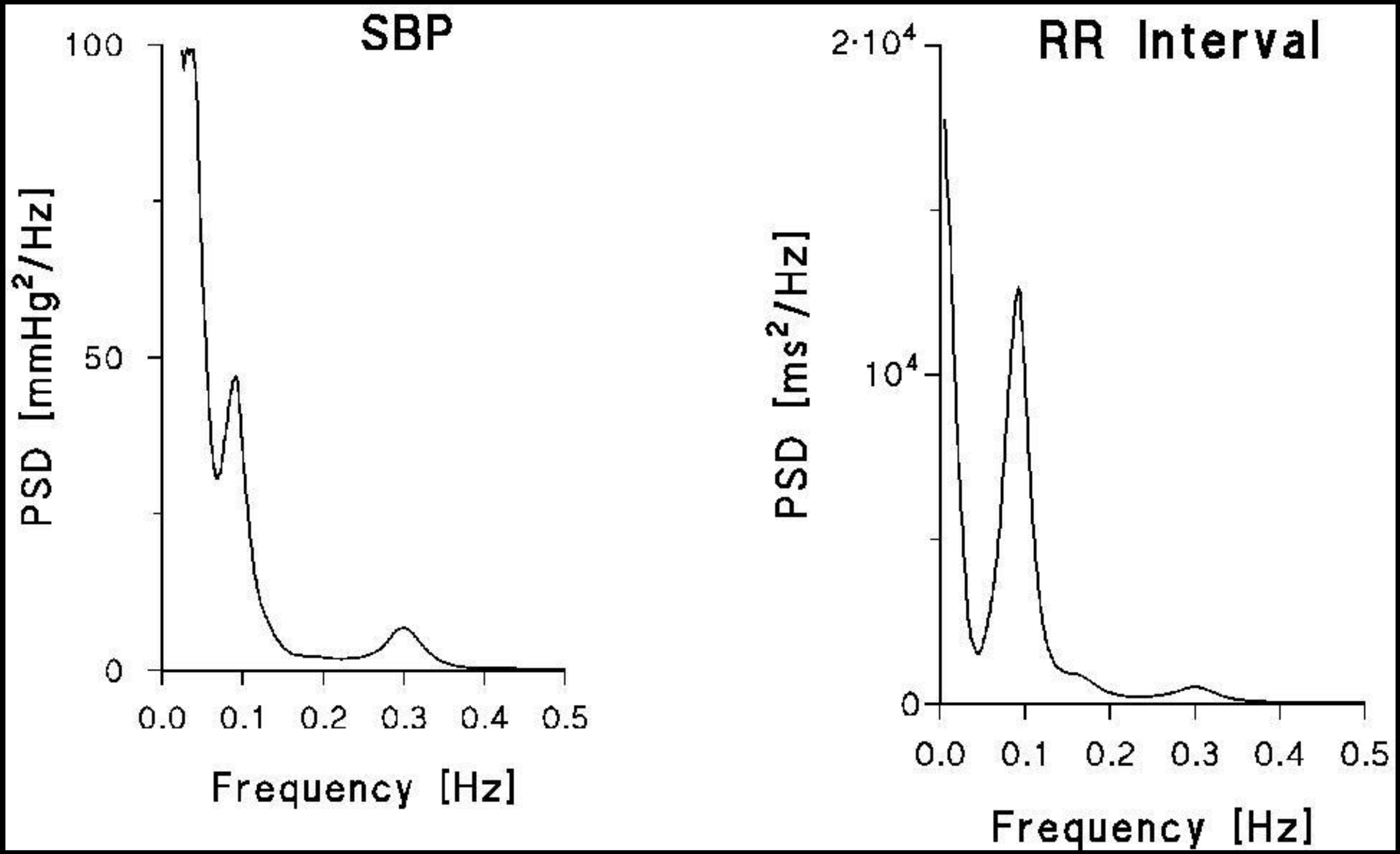
How do you extract spectral (frequency) components present in physiological signals?

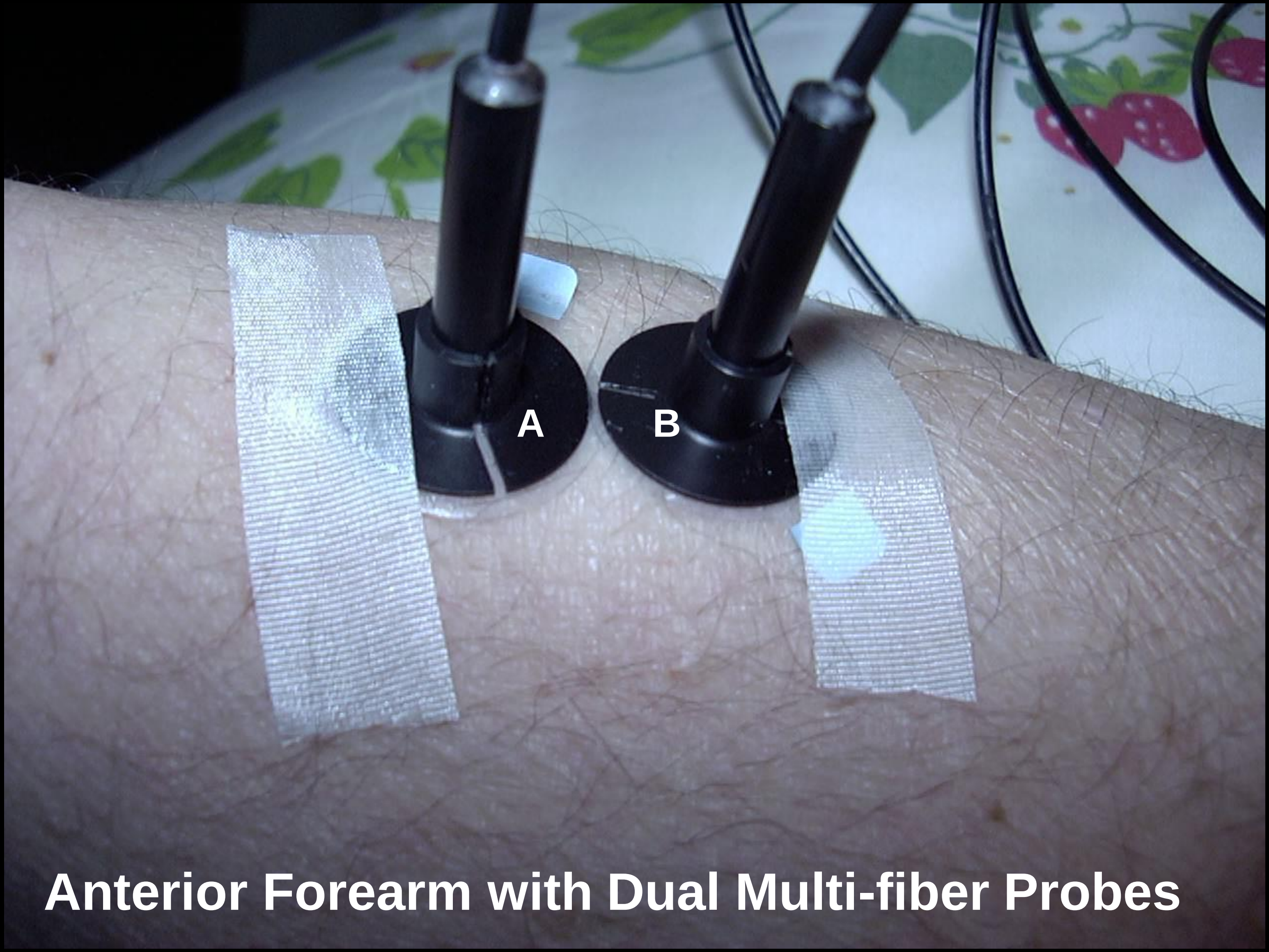
Power Spectral Density

Amount of power per unit (density) of frequency (spectral) as a function of freqeuncy

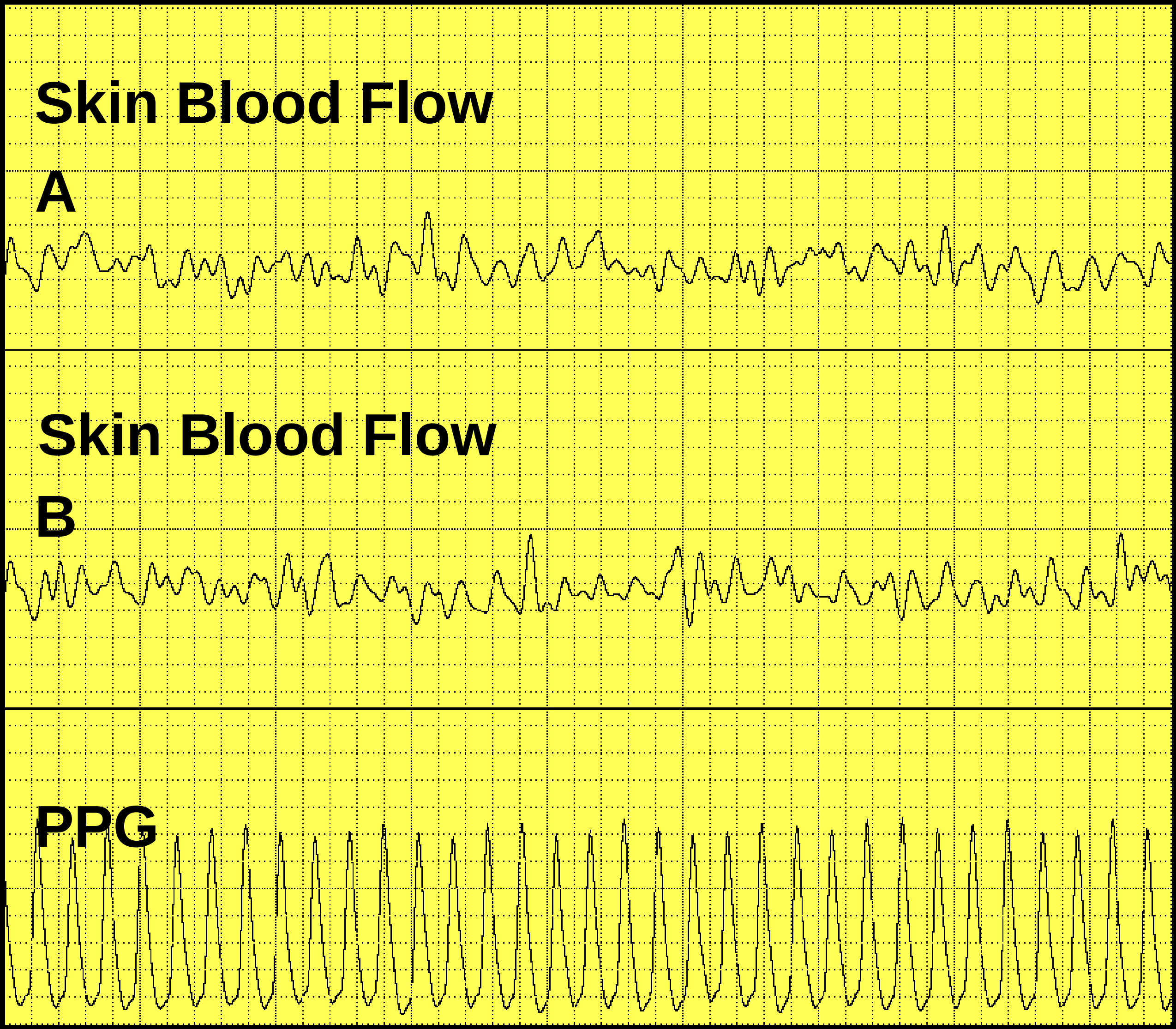
PSD describes how the power (or variance) of a time series is distributed with frequency!



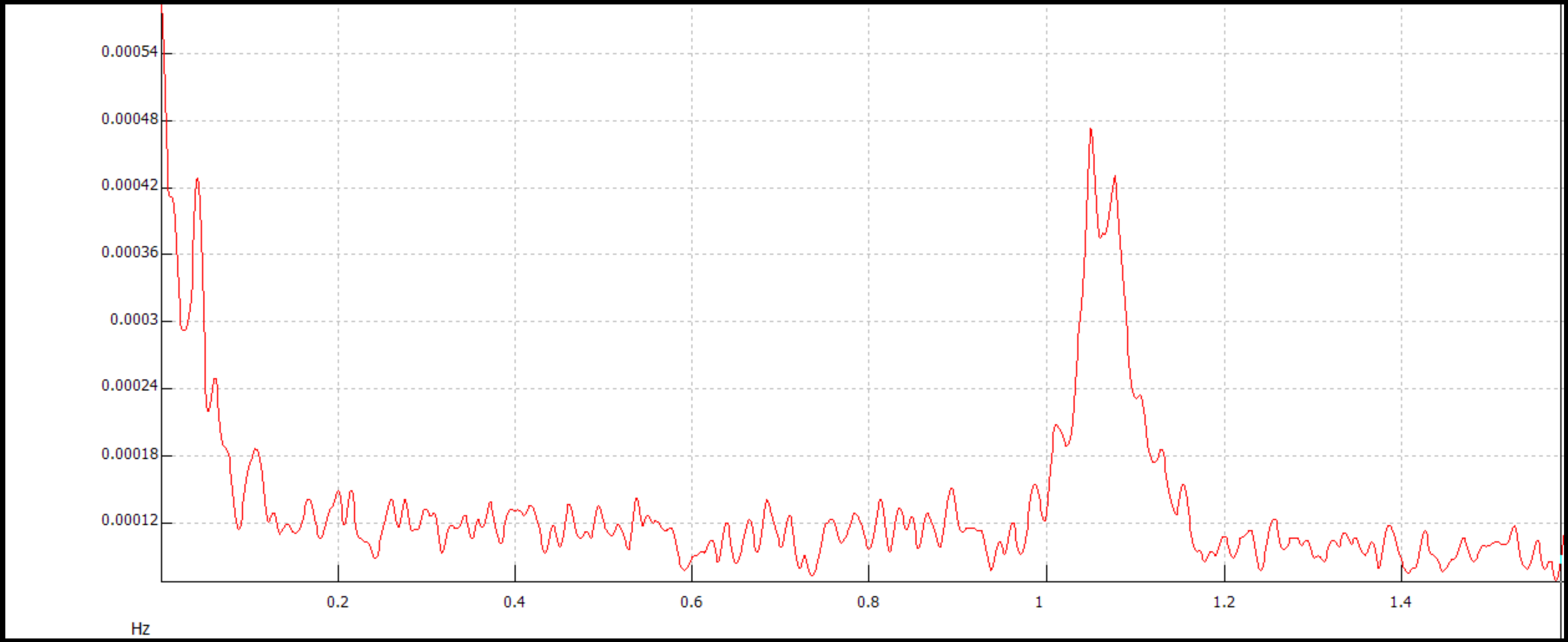
Blood Flow Signals


A
B
Anterior Forearm with Dual Multi-fiber Probes

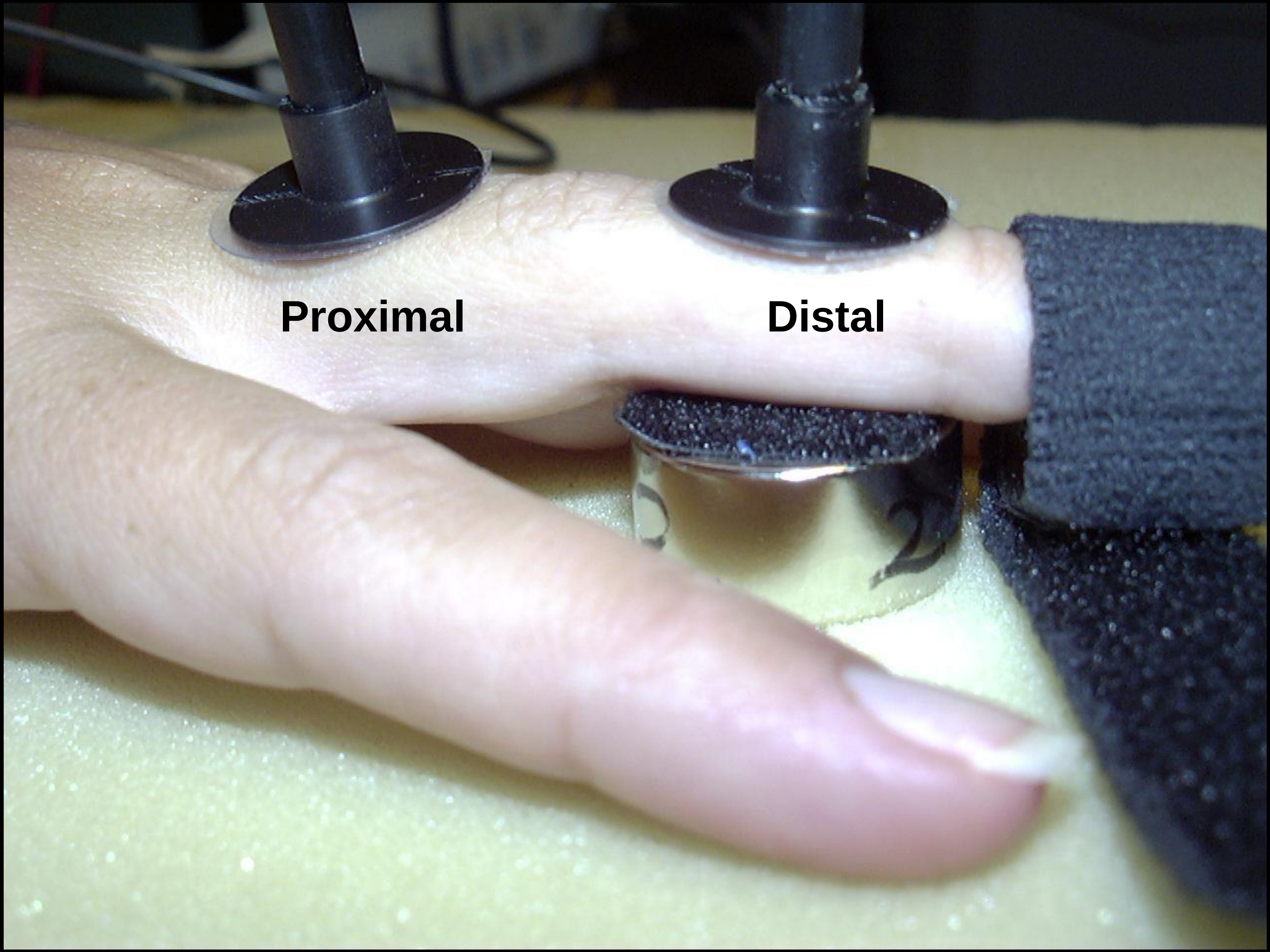
Blood Flow Time Series



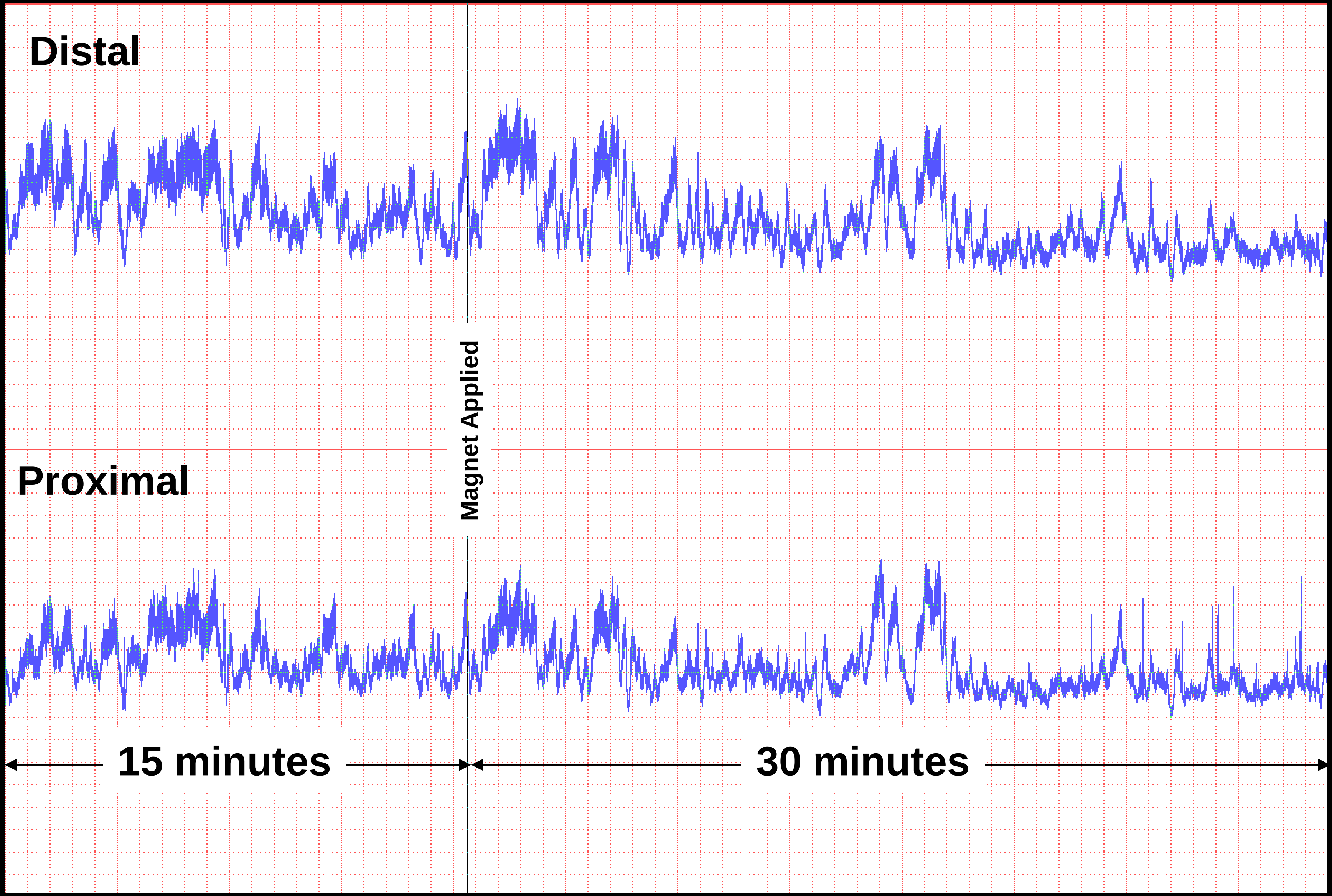
Power Spectral Density



Magnet Experiment



Blood Flow Signals



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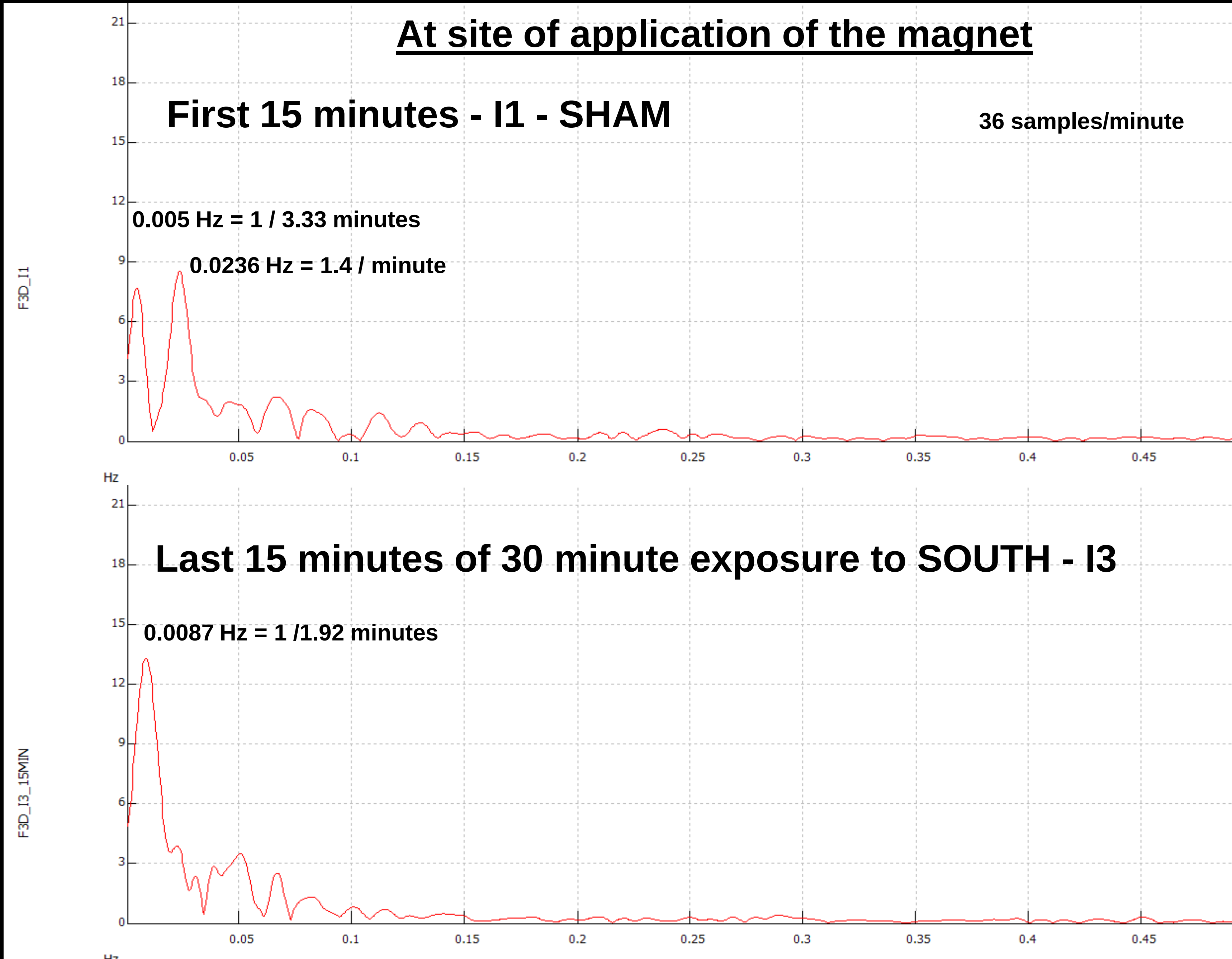
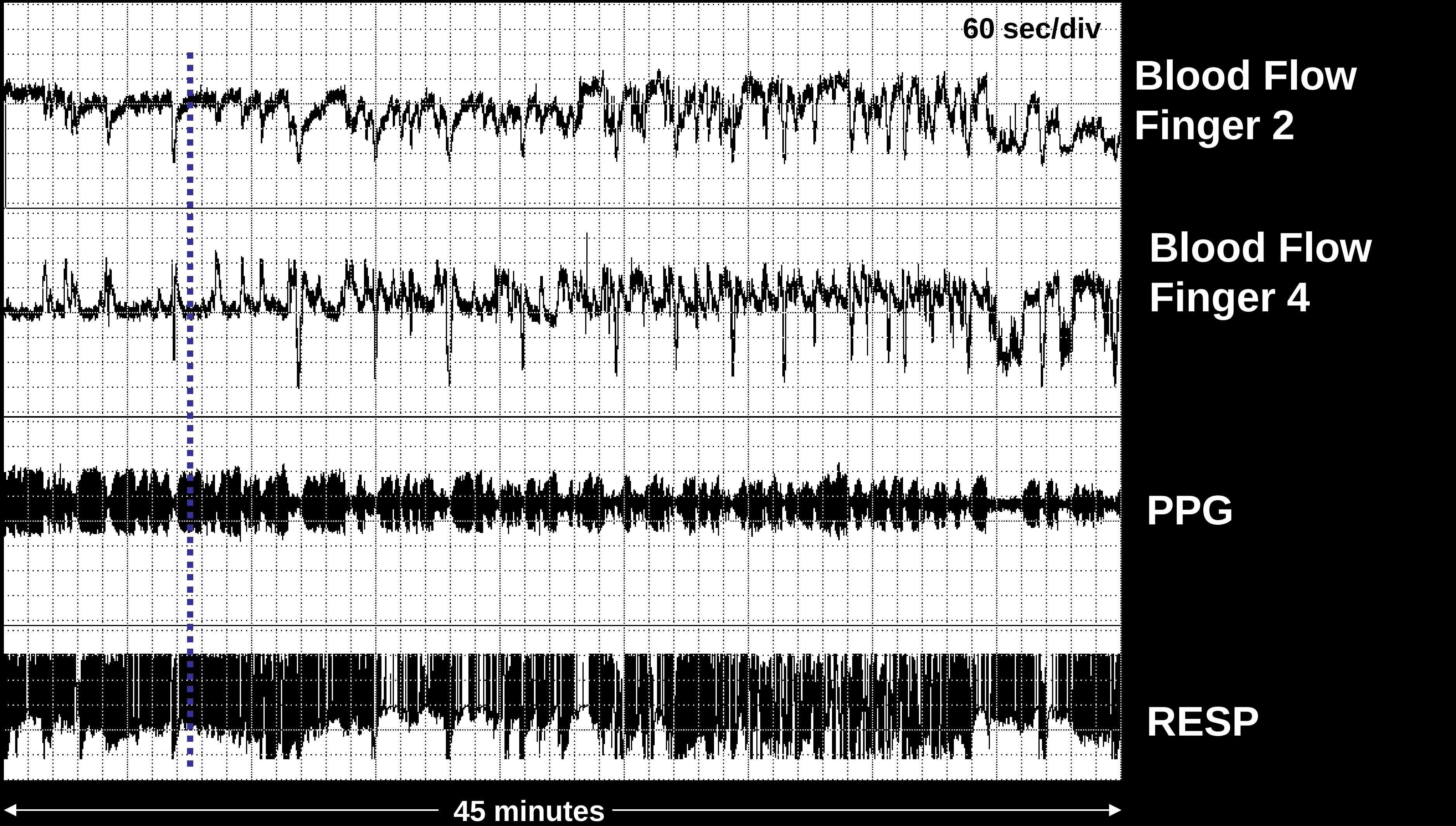
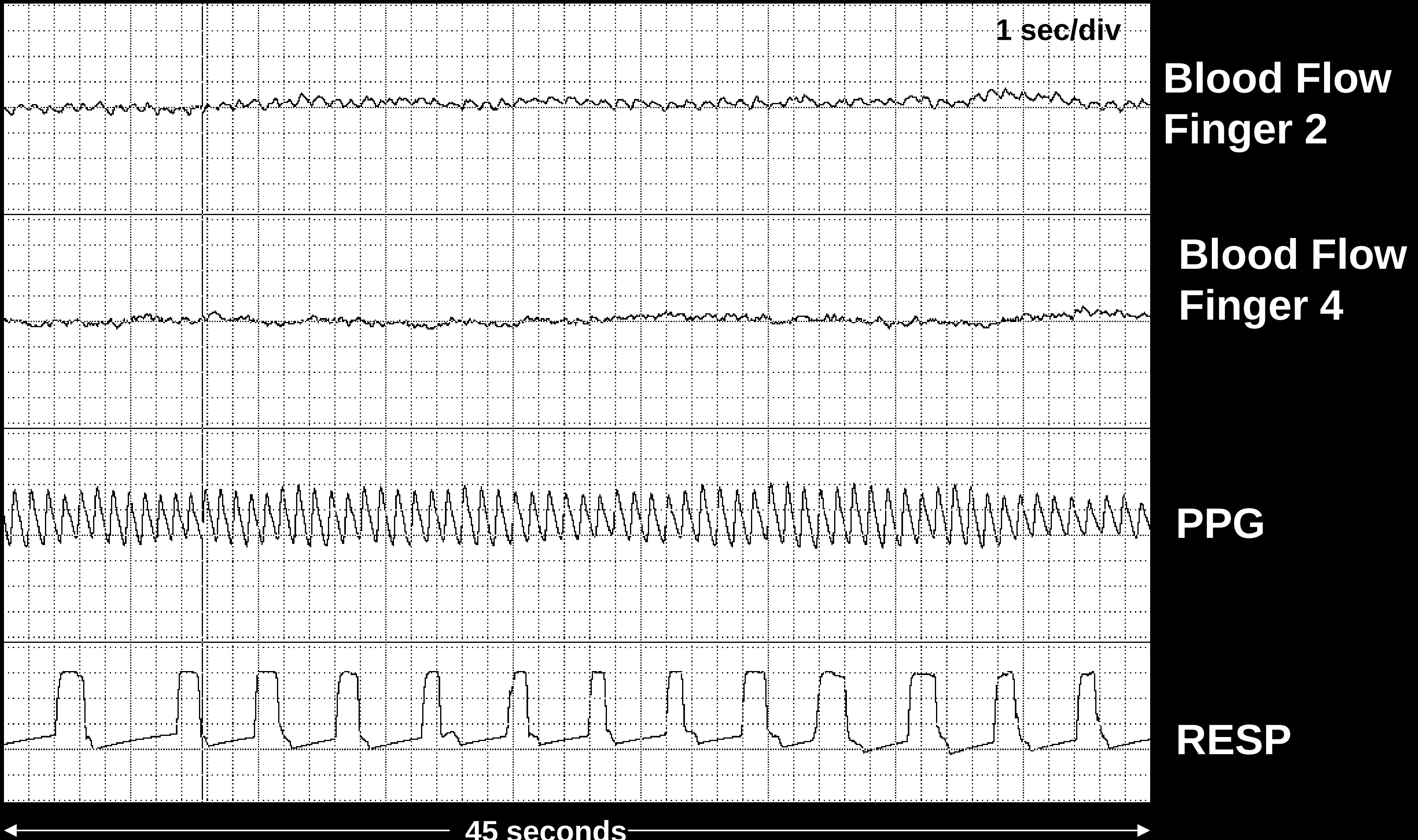

At site of application of the magnet
First 15 minutes - I1 - SHAM
36 samples/minute
0.005 Hz = 1 / 3.33 minutes
0.0236 Hz = 1.4 / minute
F3D_I1
Hz
Last 15 minutes of 30 minute exposure to SOUTH - I3
0.0087 Hz = 1 /1.92 minutes
F3D_I3_15MIN
Hz

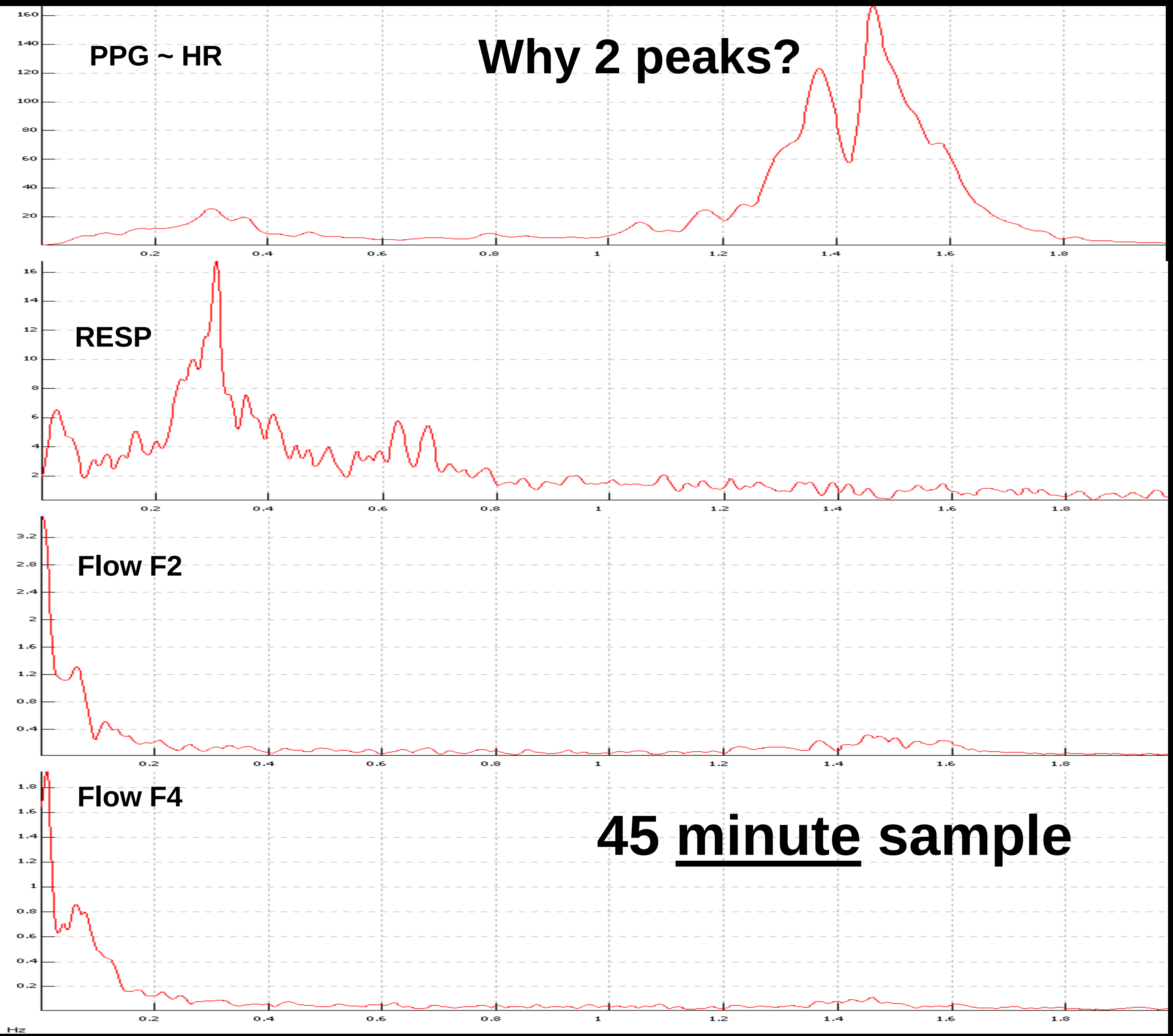
Another Magnet Experiment

Experiment Data Sequence



Experiment Data Sequence

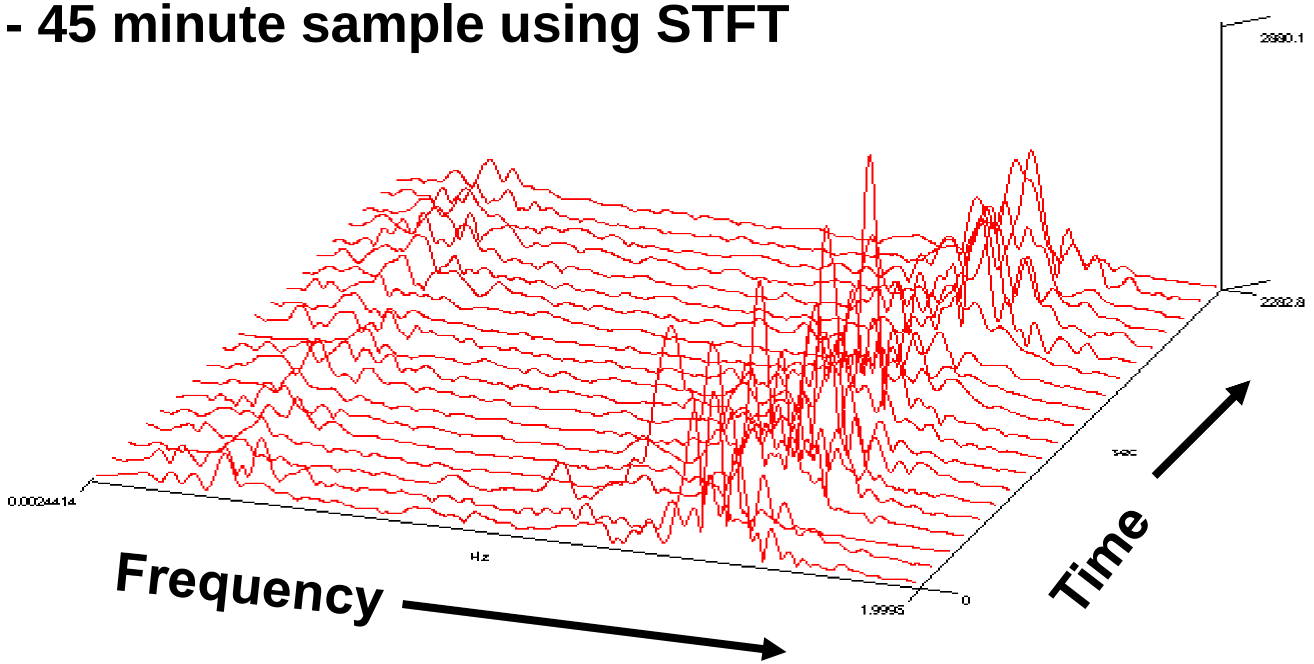


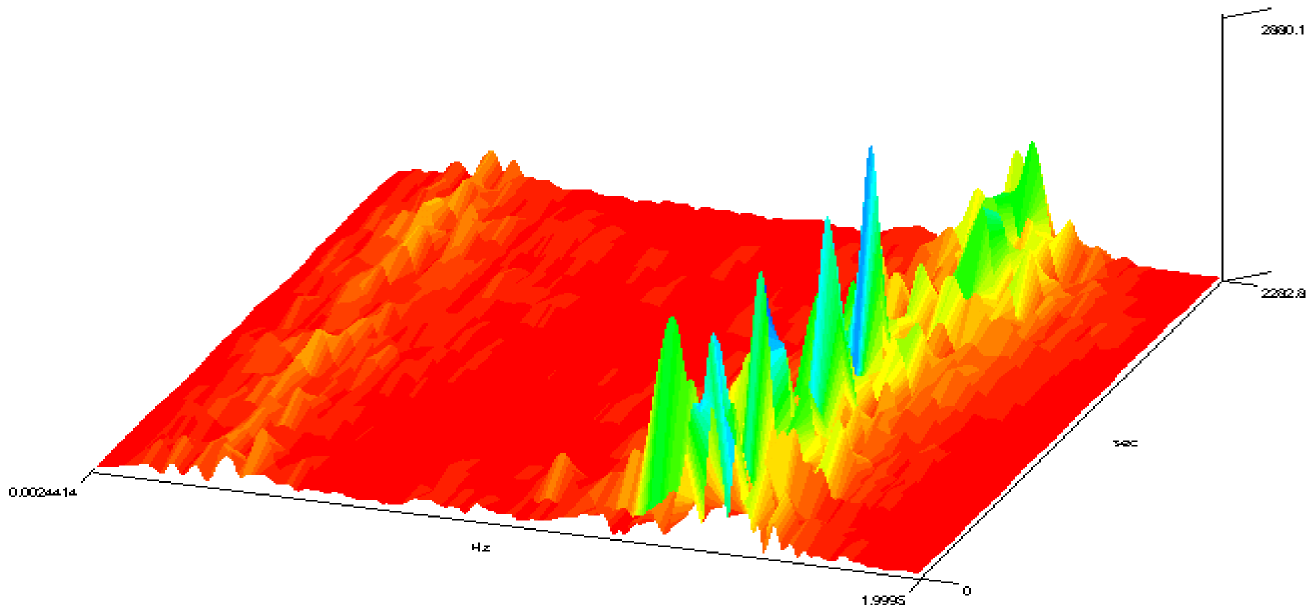

PPG ~ HR
Why 2 peaks?
RESP
Flow F2
Flow F4
45 minute sample
Hz

Physiological signals whose spectral content changes with time

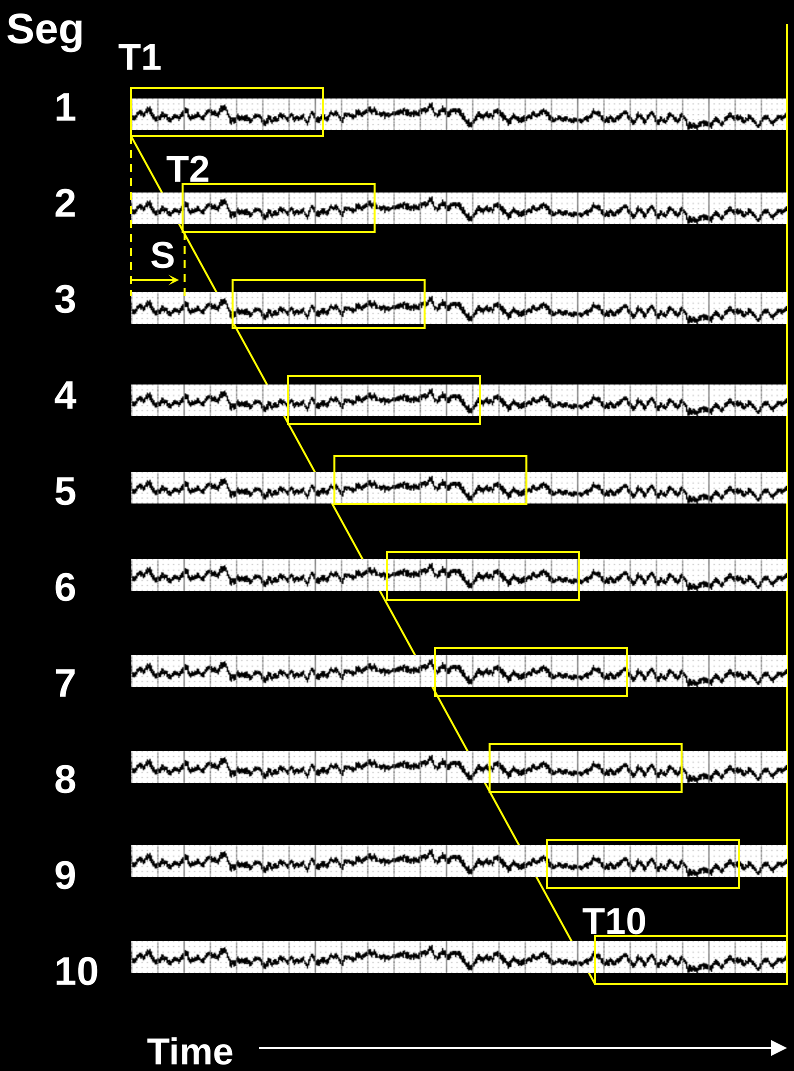
Principle of STFT
Short Time Fourier Transform

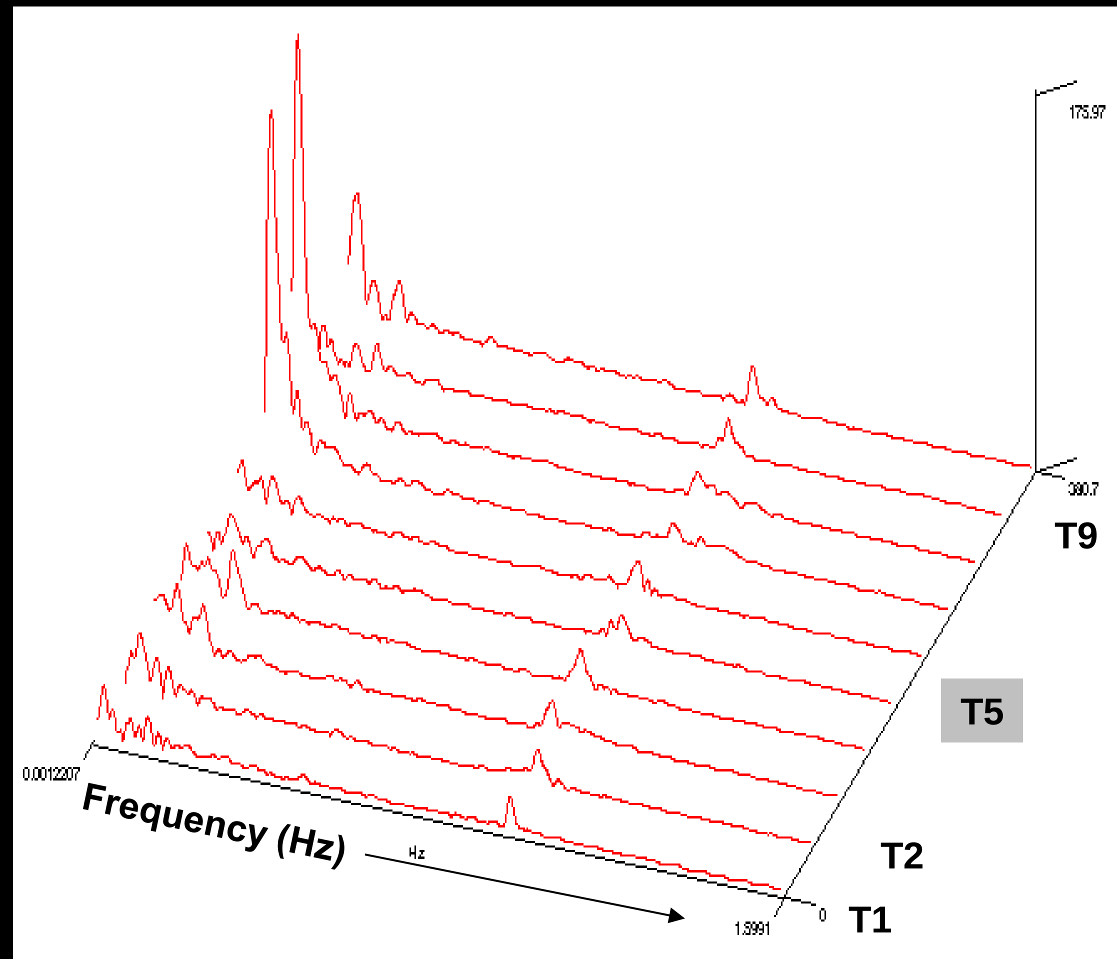
PPG - 45 minute sample using STFT





Principles of Short Time Fourier Transform Analysis





$T10 = T_{total} - N_{precision}/F_S$

$= 1200 - 819.2 = 380.7$ sec

$= (N_{segs}-1) \times S = 9 \times 846/20 = 9 \times 42.3$ sec $= 380.7$ sec

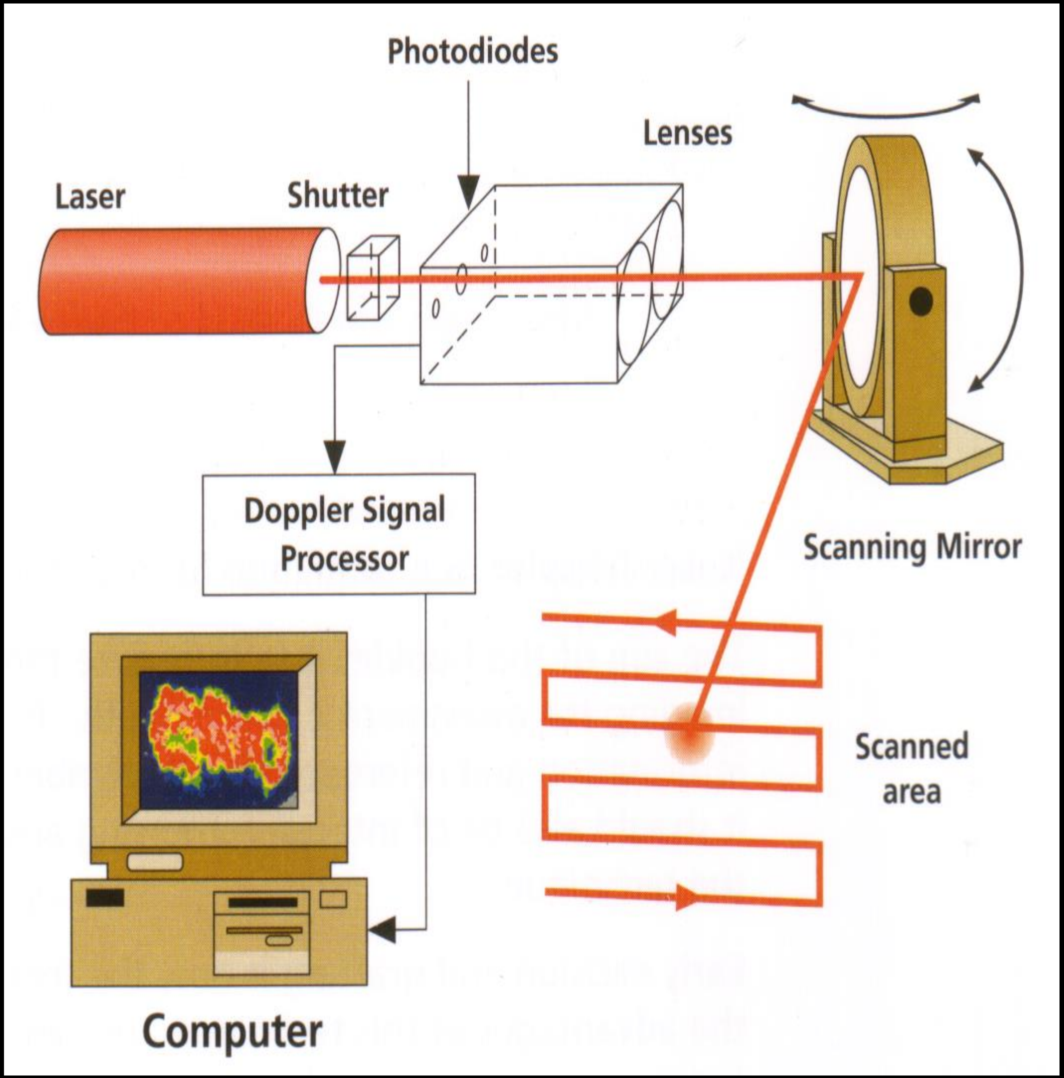
T_{total} = 20 minutes =1200 sec, F_S =20 s/sec

$N_{precision}$ = 16384 = 16384/20 = 819.2 sec

$F_{precision}$=(1/819.2) = 0.0012 Hz

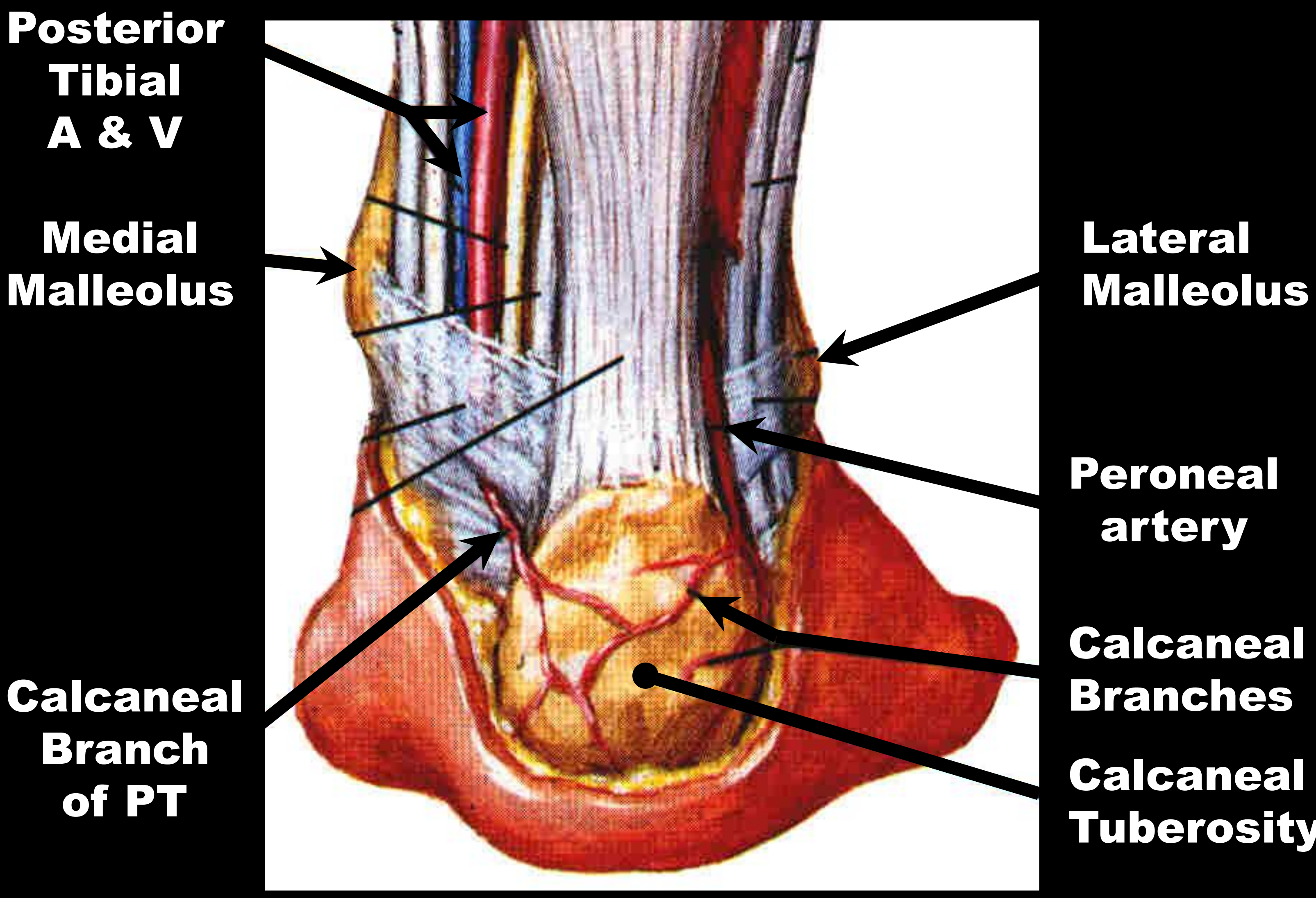
Laser-Doppler Imaging

Laser-Doppler Perfusion Imaging

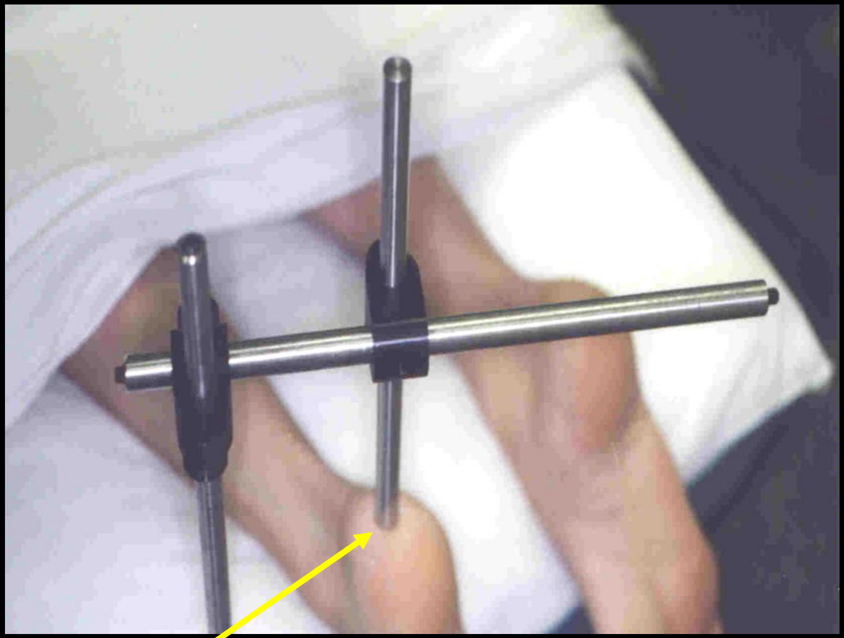


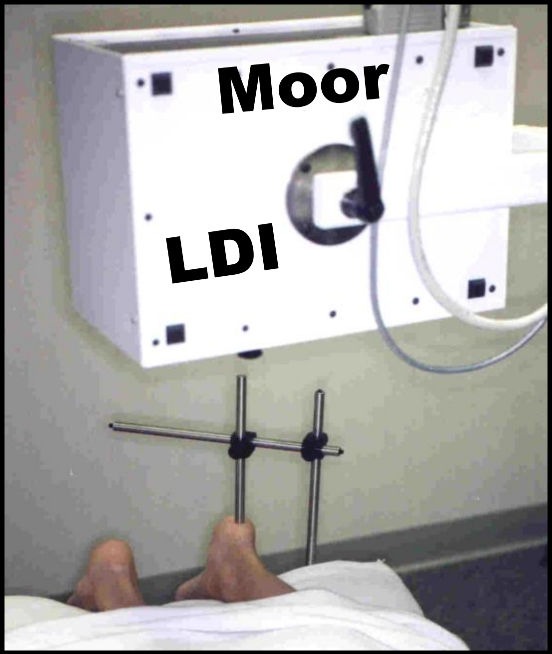
A laser beam is directed onto a mirror, the position of which can be changed by two motors. The computer moves the mirror to scan the spot in a raster pattern across the tissue being sampled. Moving blood in the tissue causes a **Doppler frequency shift**. This signal is collected by the mirror and focussed onto photodiodes.

Heel Target

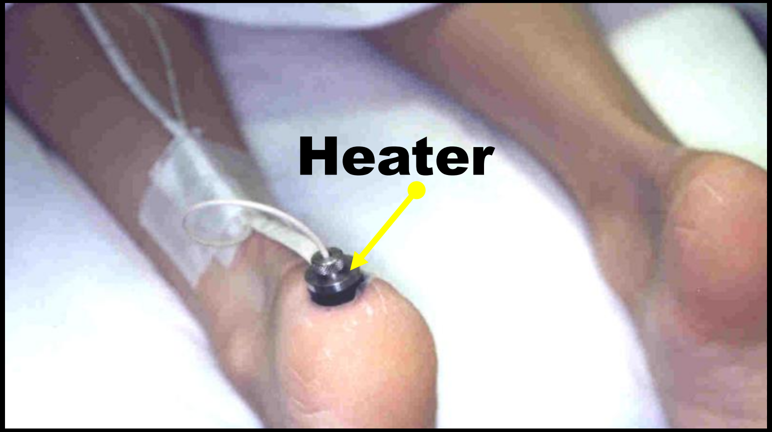

Posterior Tibial A & V
Medial Malleolus
Calcaneal Branch of PT
Lateral Malleolus
Peroneal artery
Calcaneal Branches
Calcaneal Tuberosity

Local Loading & PCH via LDI



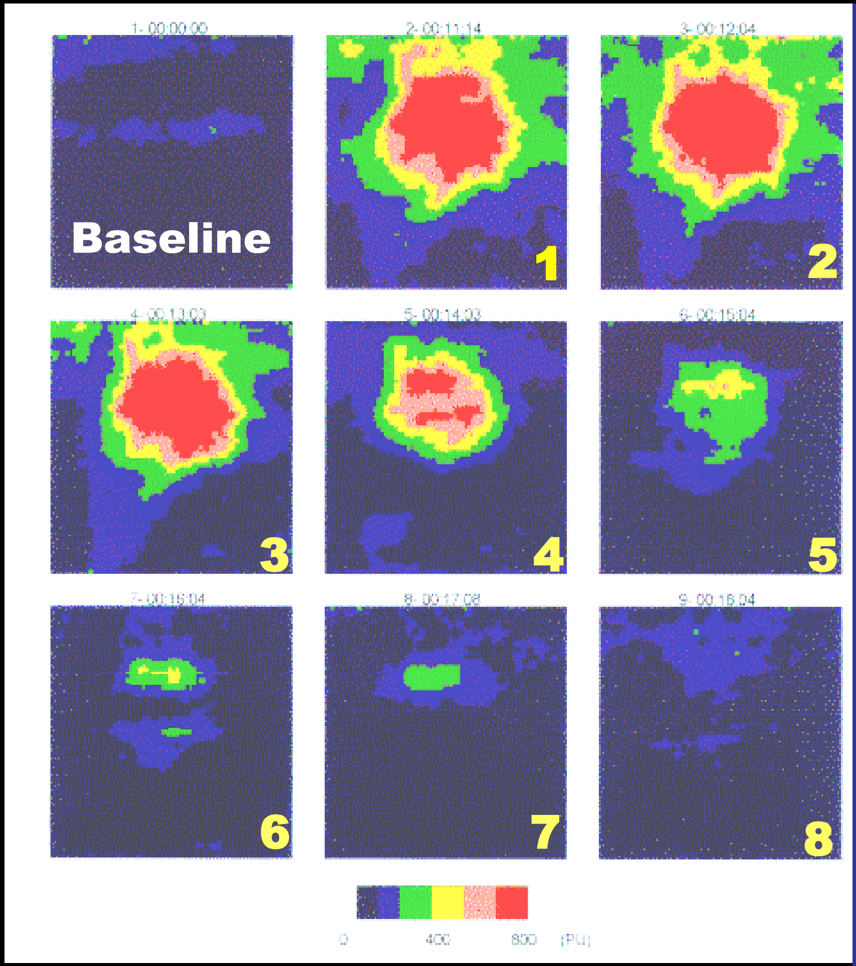


Load Placement on Heel

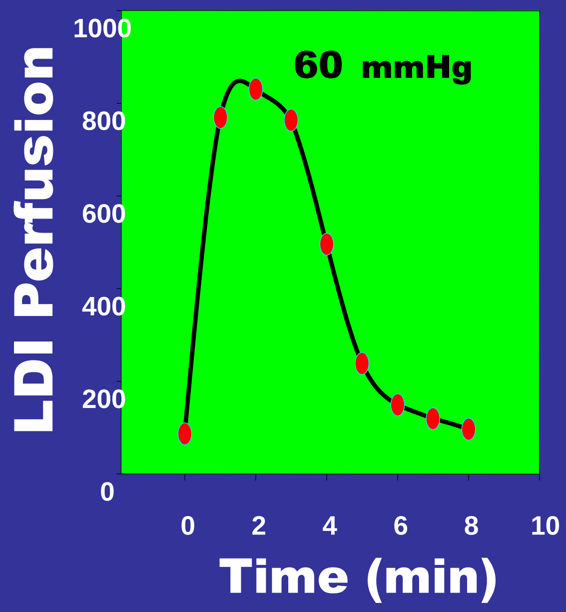


- Baseline - No Load
- Vary P and δ
- PCH
- Heat Response

Heel Hyperemia After 10’ Local Loading with 60 mmHg



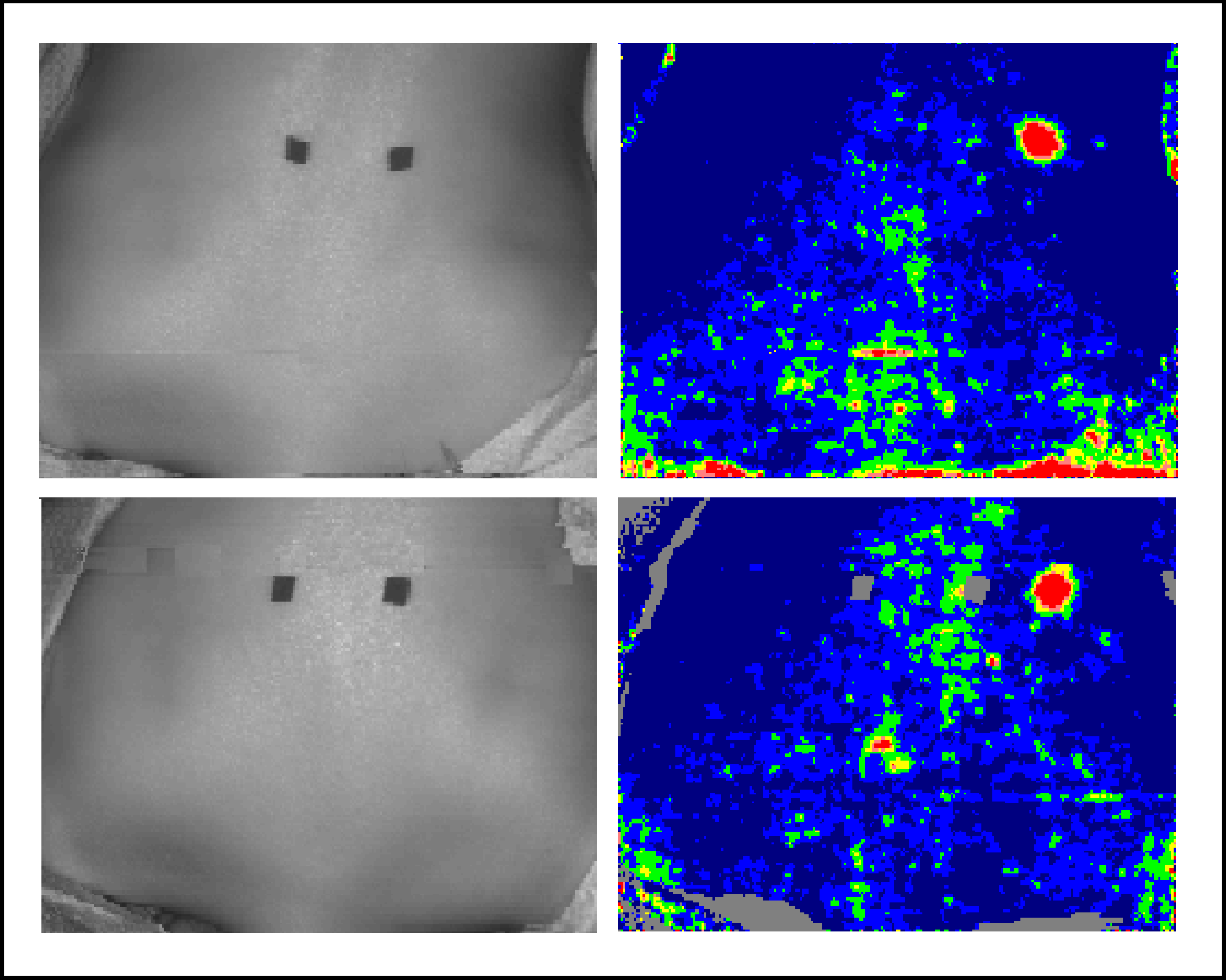
Temporal Response



PRE-LYING BLOOD PERFUSION

STATIC SURFACE

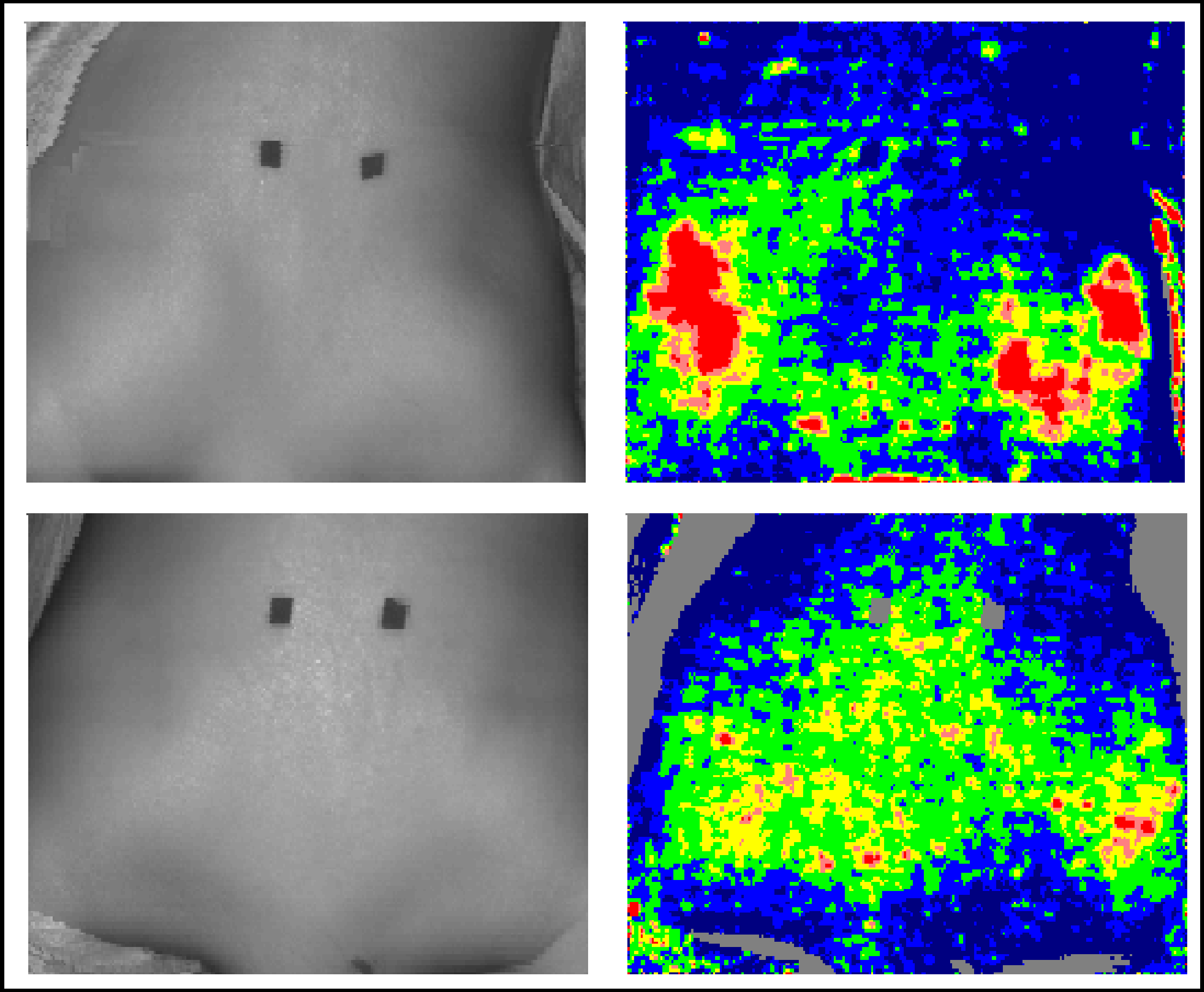
DYNAMIC 15 cycle/hr



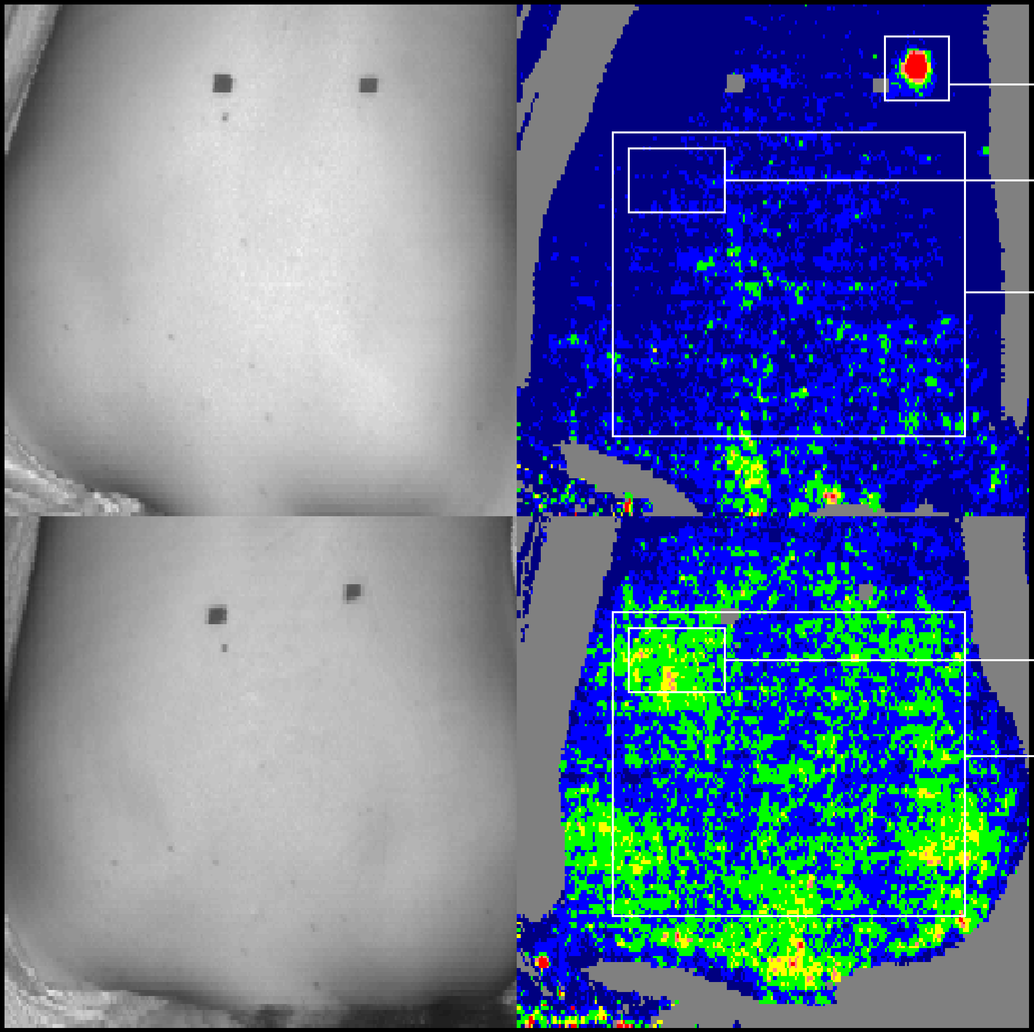
TWO-HOUR SUPINE LYING

STATIC SURFACE

DYNAMIC 15 cycle/hr

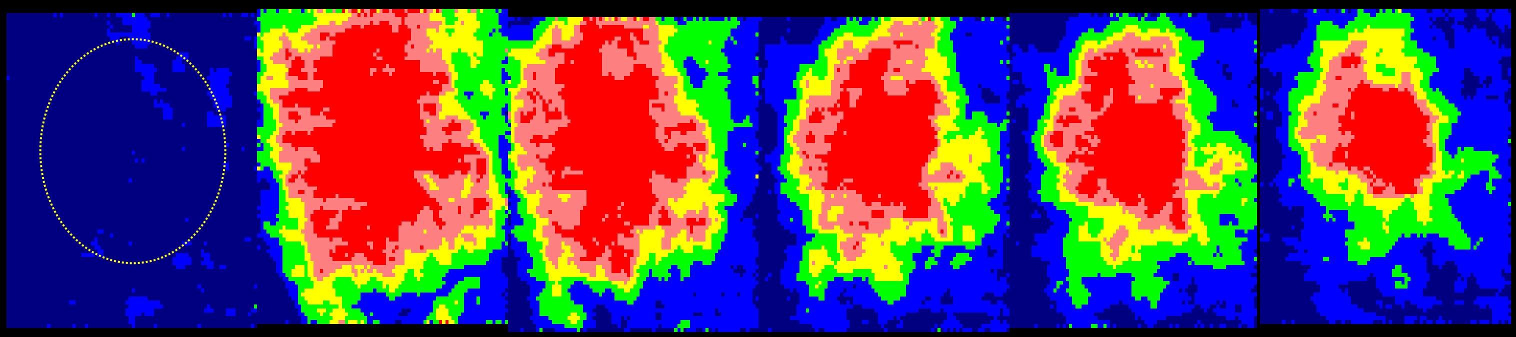


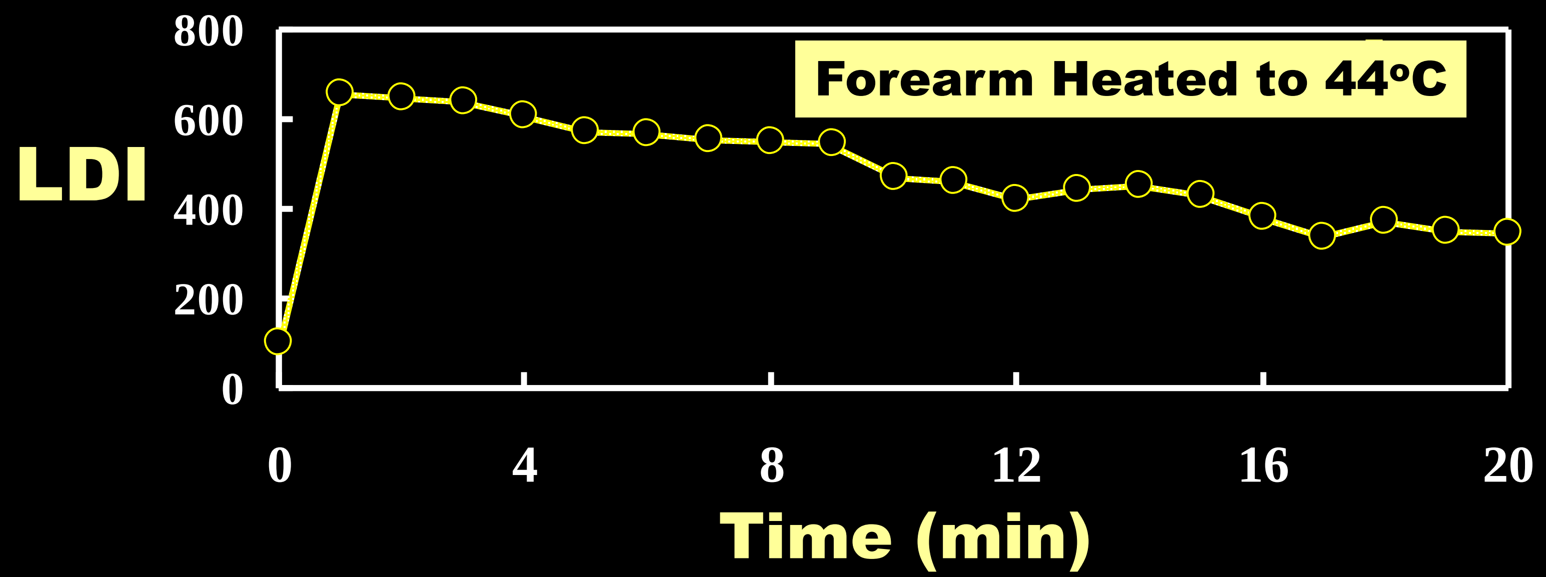
Quantifying LDI Data



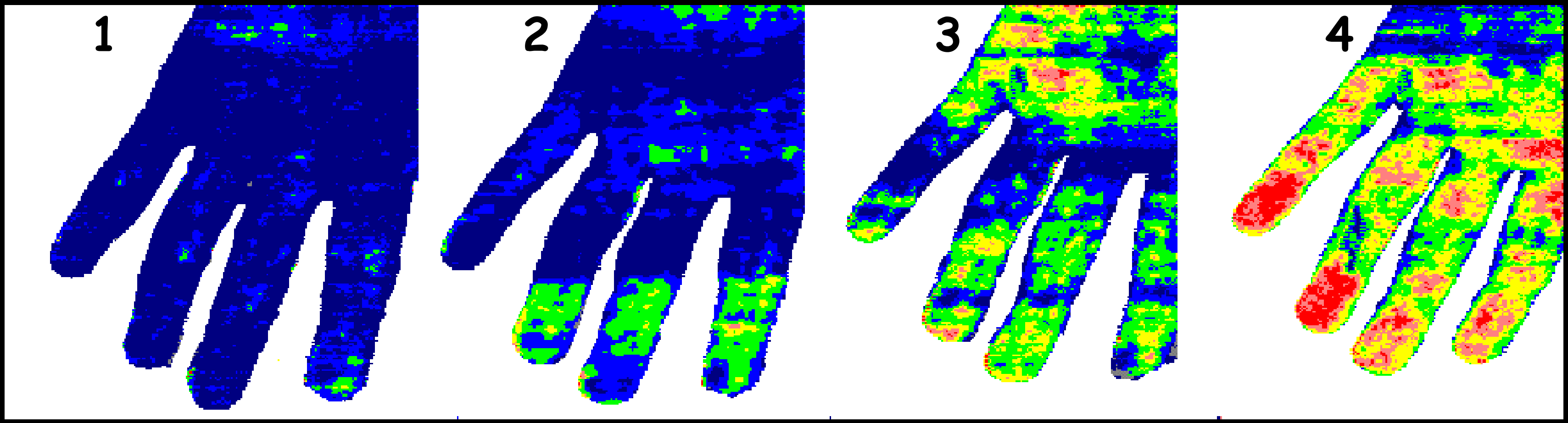
Scan area = 33 x 25 cm^2

LDI Perfusion Images
Local Heating



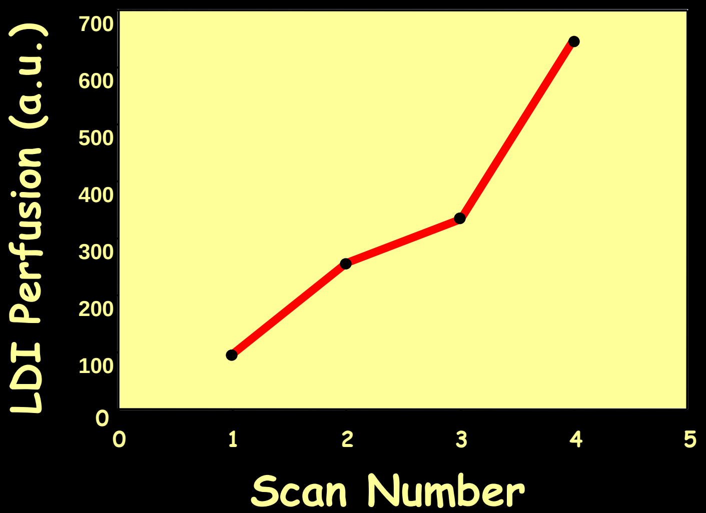


Whole Hand Heating

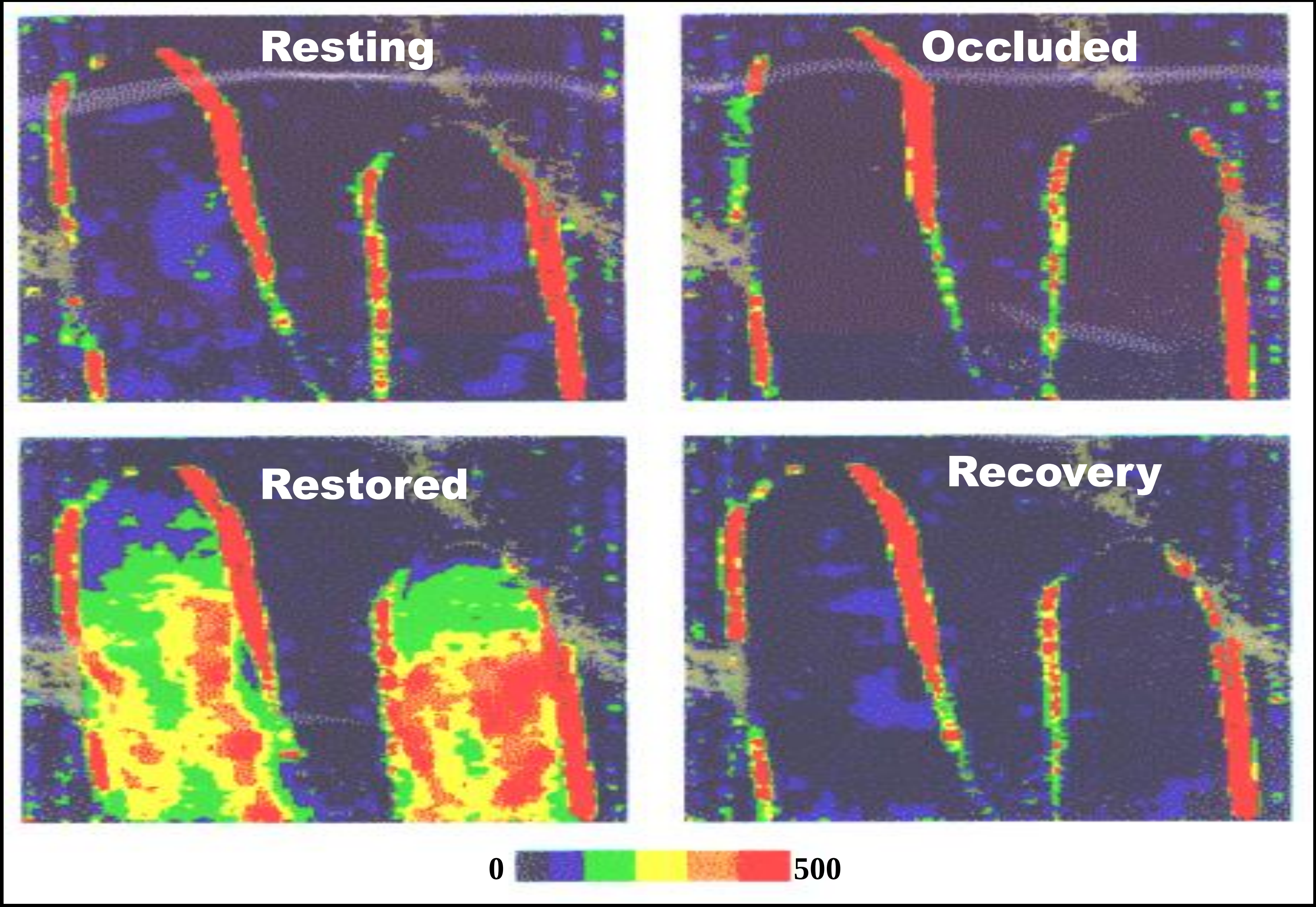


Hand being warmed →

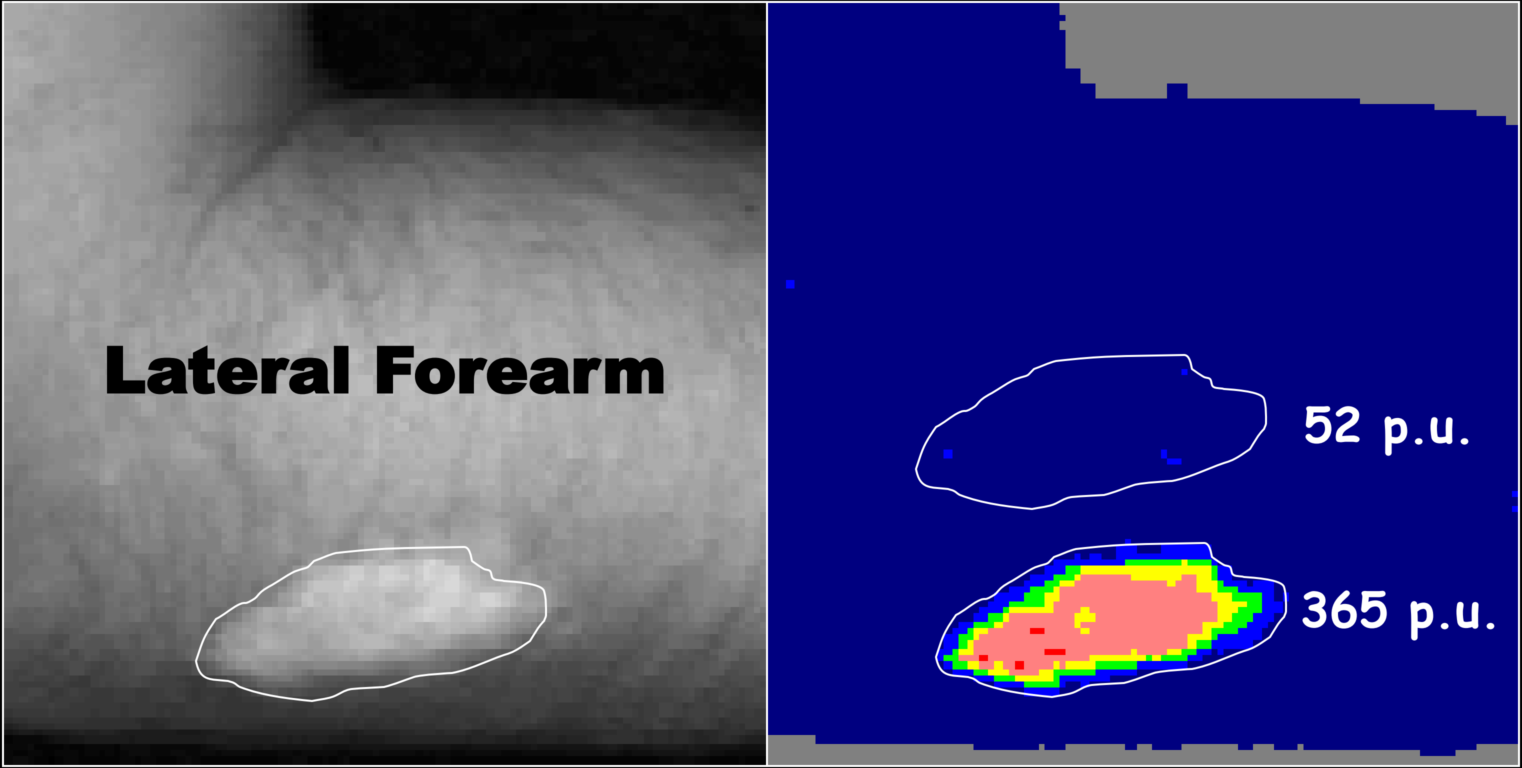
Index Finger Average
Blood Perfusion



LDI Perfusion Images
Flow Arrest



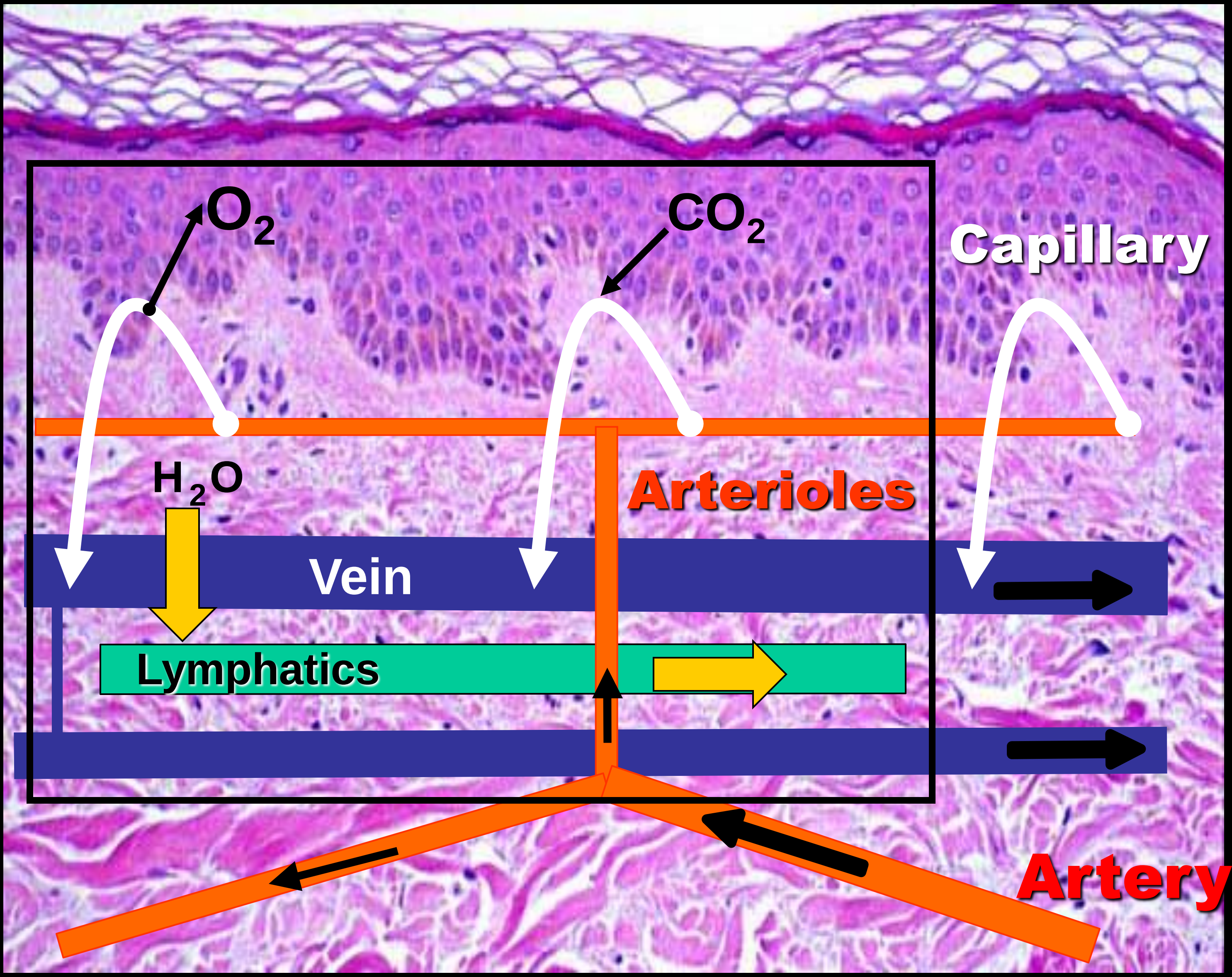
Epithelialized Acute Wound



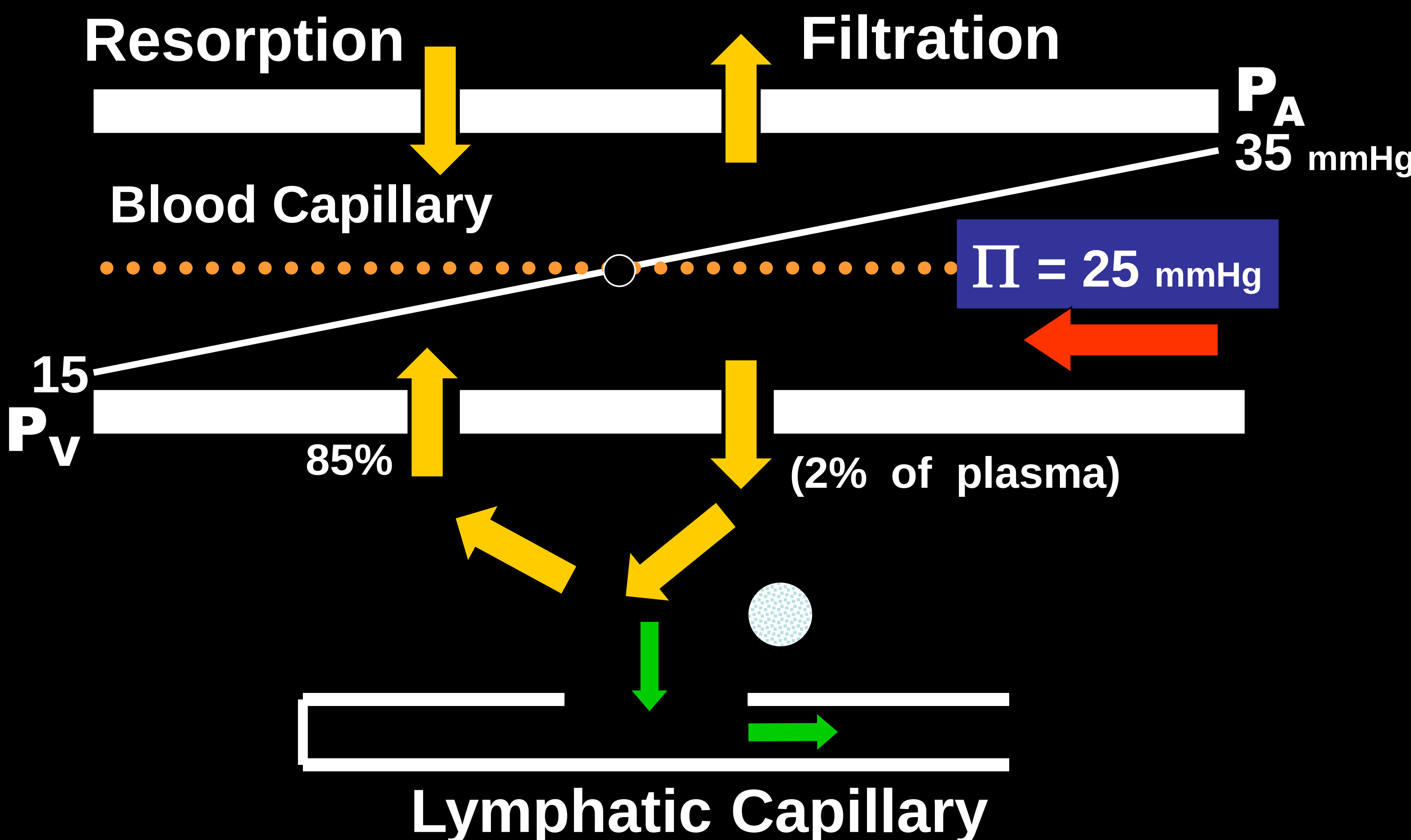
Ten days after wounding

Lymphatic Function

Circulation Schema



Fluid Balance



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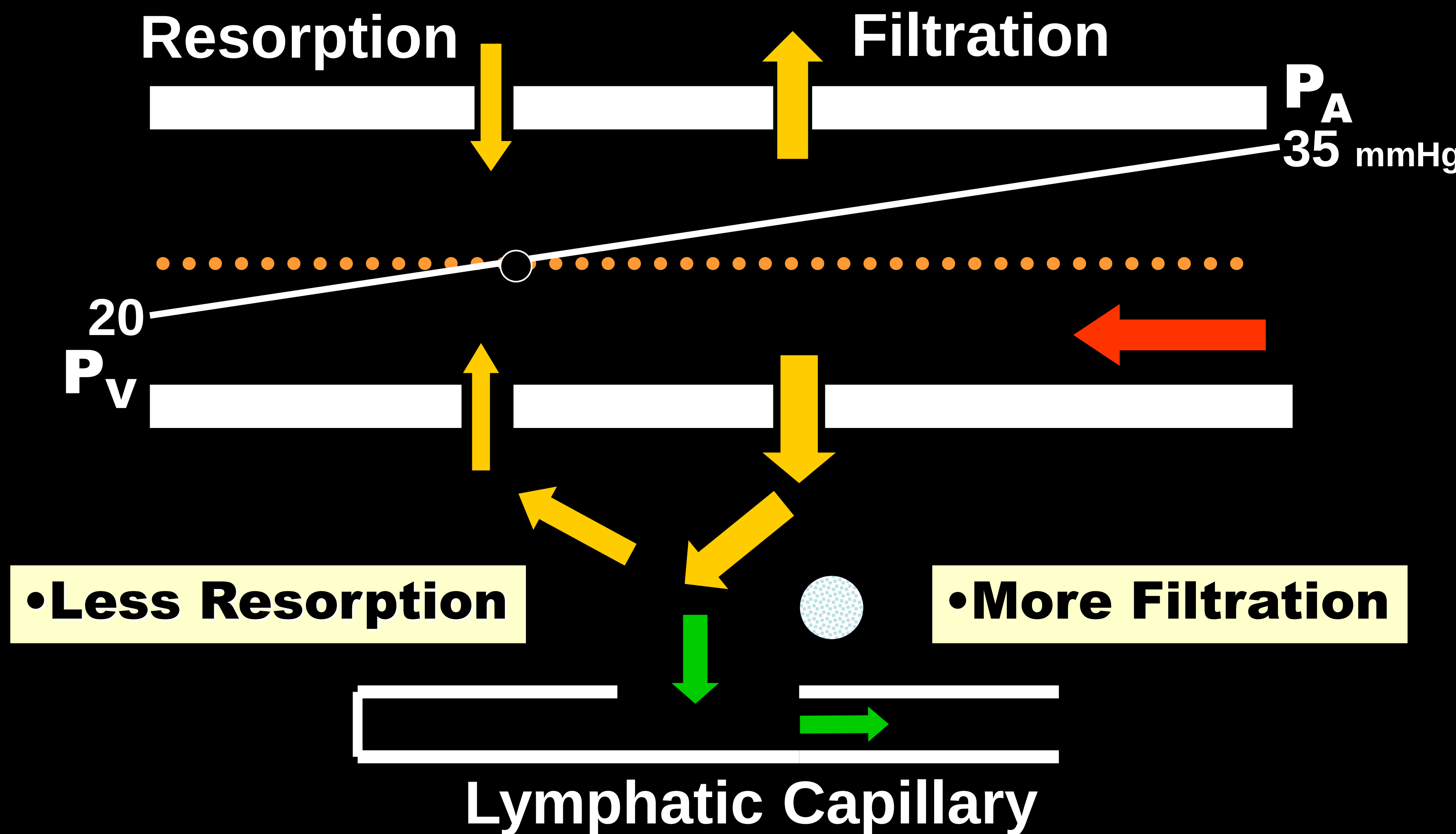
Increased Venous Pressure or Capillary Permeability



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If Net Filtration Exceeds Lymphatic Transport Capacity

Overload = Edema

+ [Protein]

= Lymphedema

Therapy Options
- **Reduce Filtration**
- **Increase Transport**

Tissue Properties


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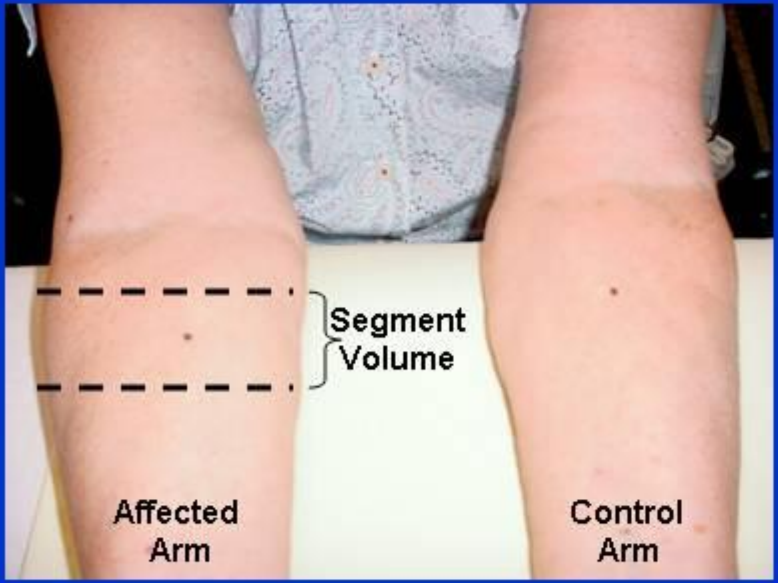
Tissue Water

Unilateral Postmastectomy Arm Lymphedema



%Edema = (Affected-Control)/Control
N= 10, Edema Range: 9 – 69%
Mean ± SD = 39.6 ± 18.5%
<u>Segmental Volumes</u>
Affected: 274.4 ± 52.5 ml
Control: 198.8 ± 42.0 ml
p-value: <0.0001

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That's All Folks!