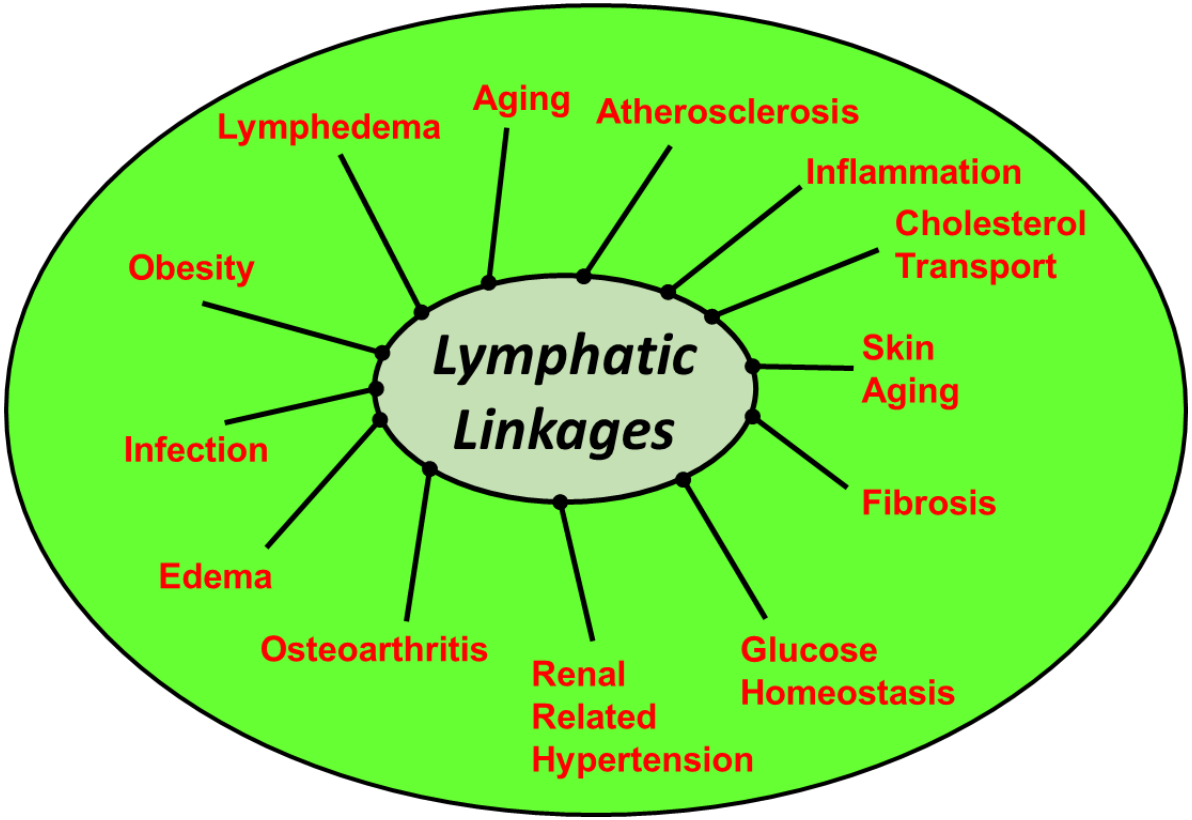
Lymphatic Function and Non-Invasive Assessment via Tissue Dielectric Constant



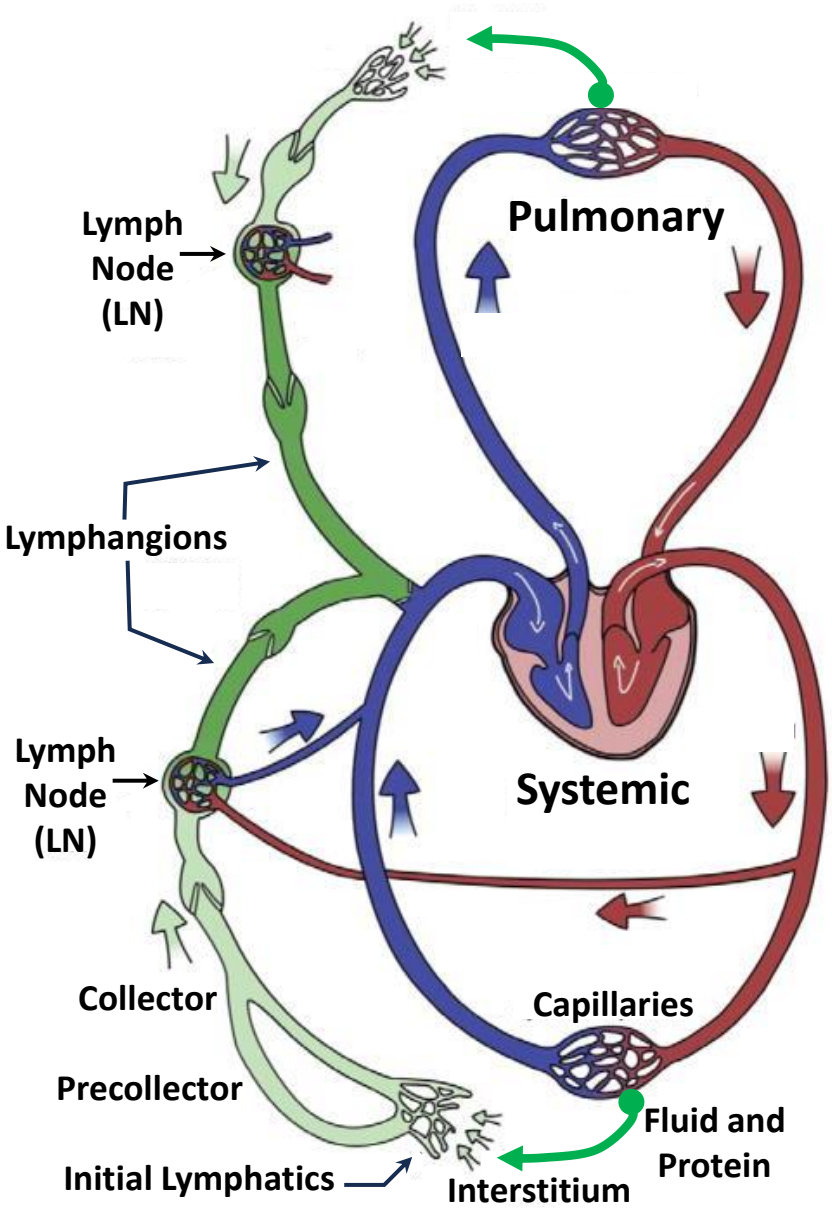
Understanding Lymphatic Flow and Providing Health Benefits

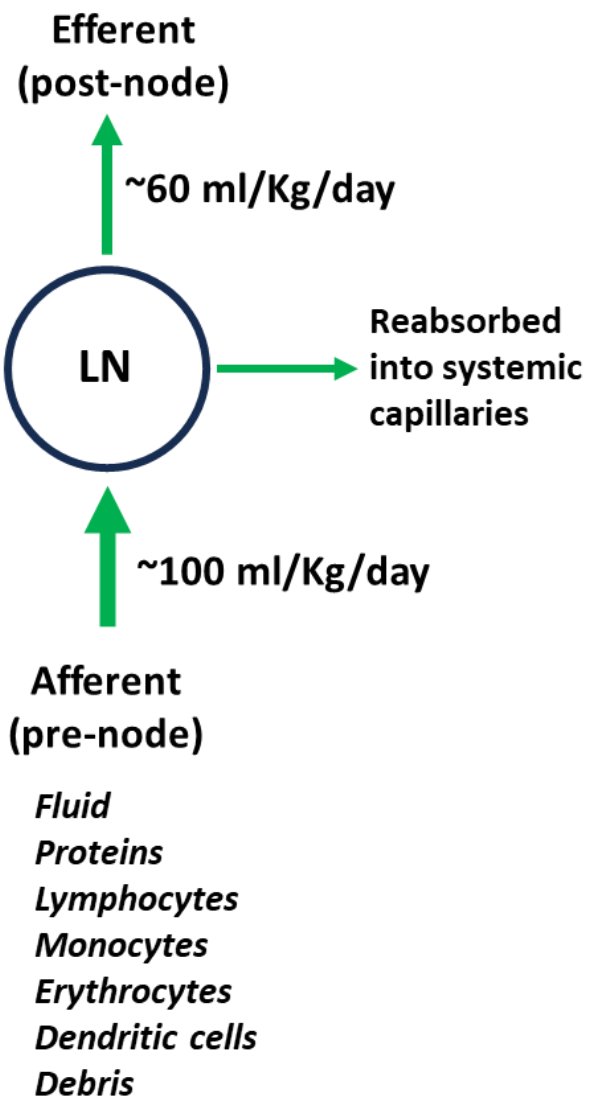
NU Skin Symposium, August 10, 2023

Harvey N. Mayrovitz

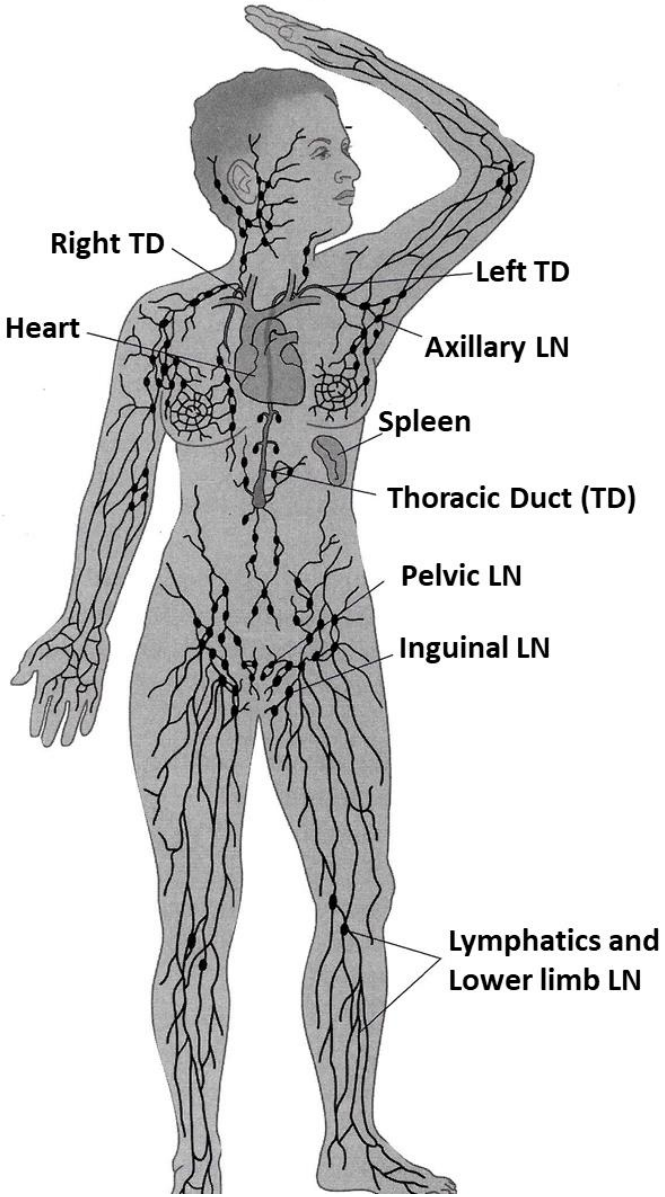
Part 1: Lymphatic Functional Aspects

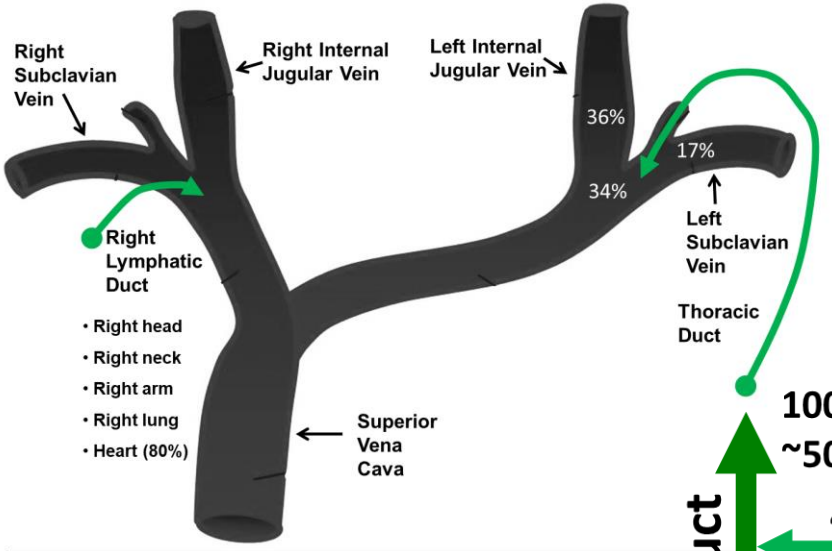
Lymphatics: The Third Circulation

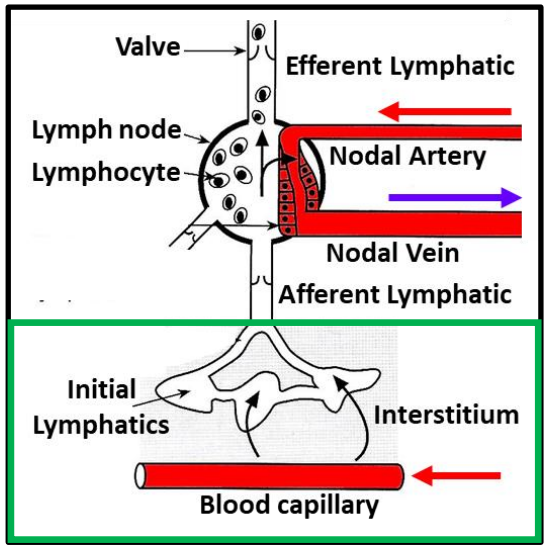


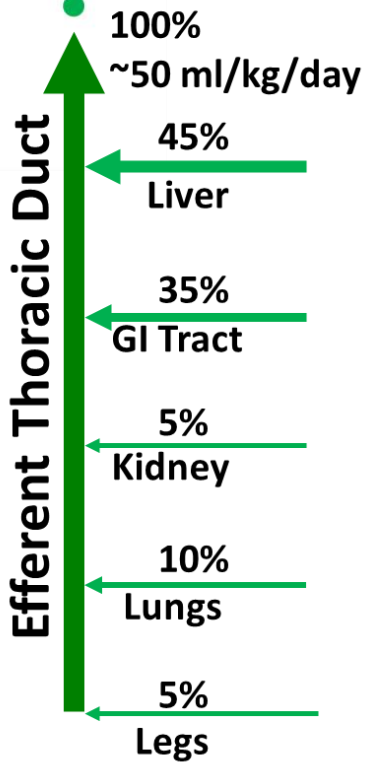


Lymphatics: Nodes & Drainage Pathways

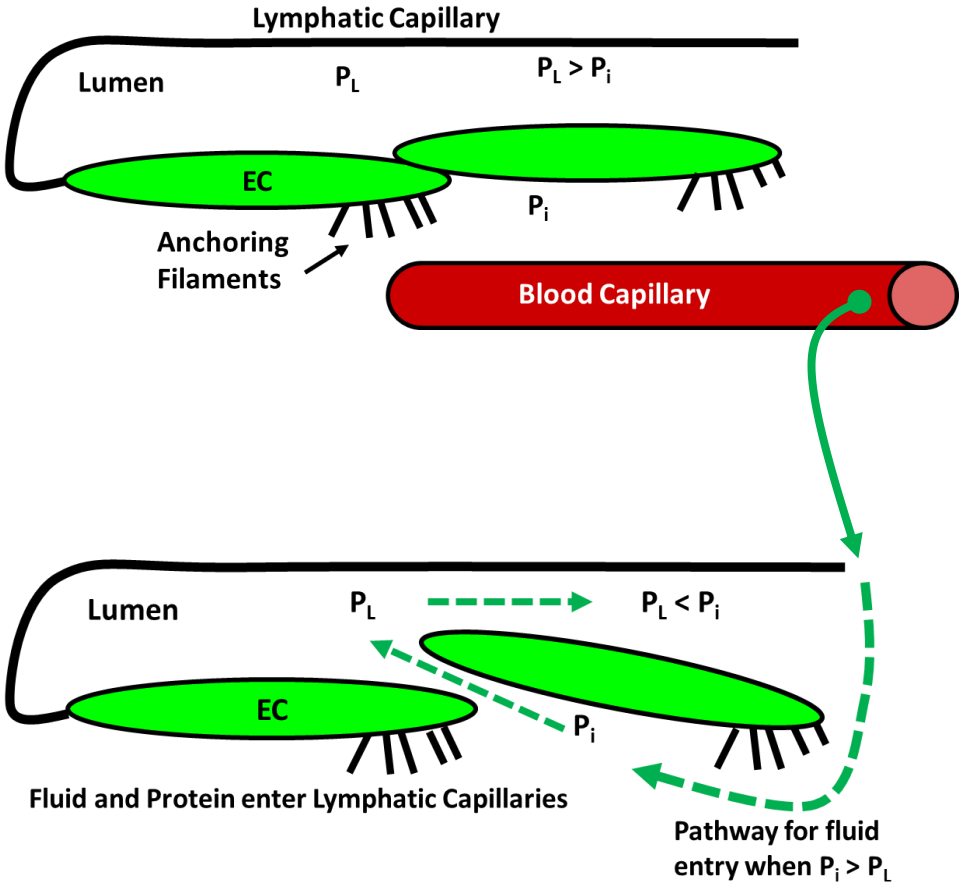


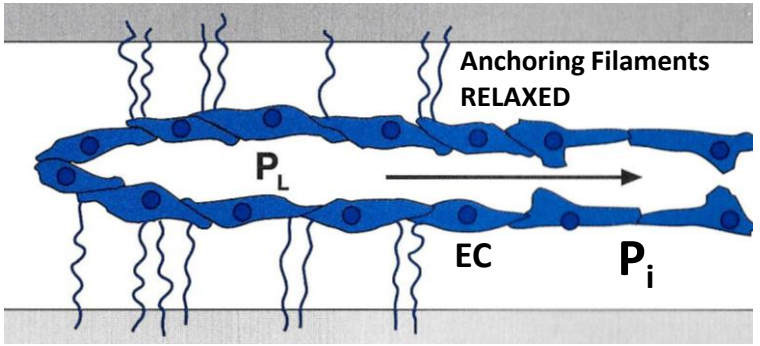


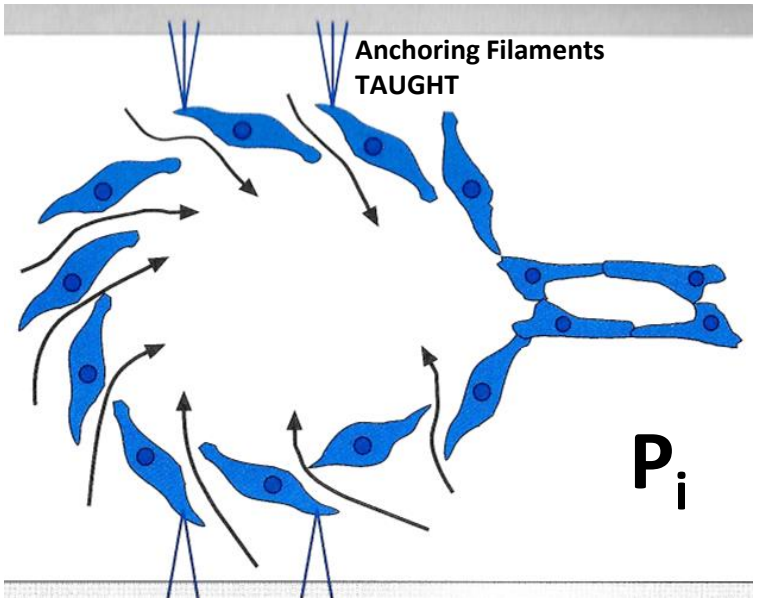




Lymph Entry into Terminal Lymphatics

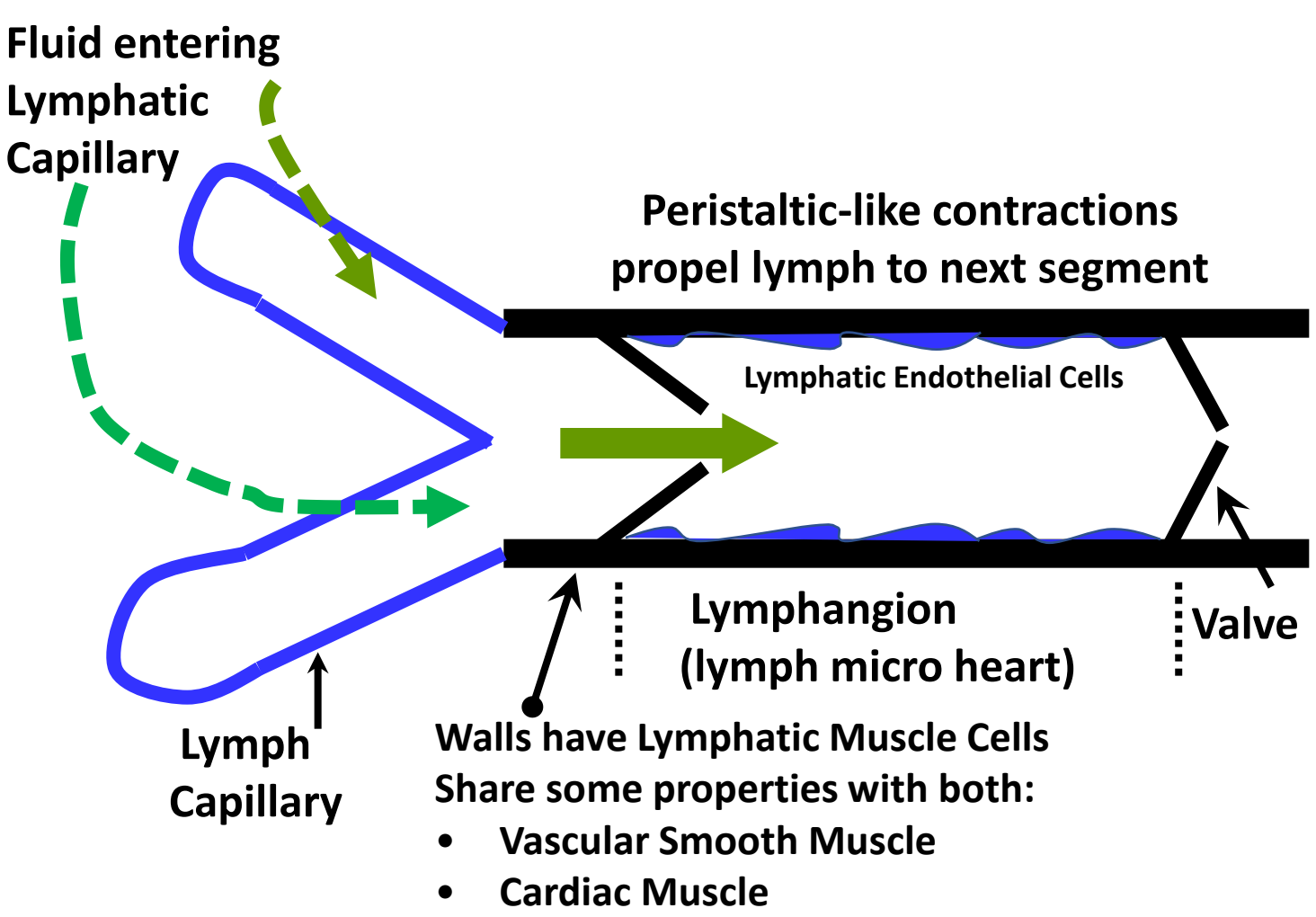


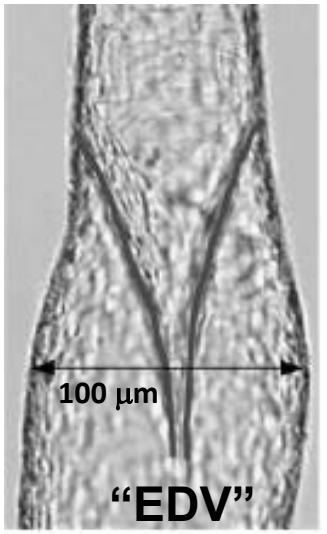


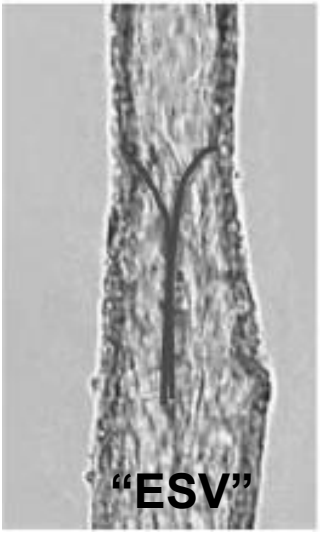


P_L = Intraluminal lymphatic pressure
P_i = Interstitial pressure
EC = Endothelial cell

Lymph Flow: Lymphangions



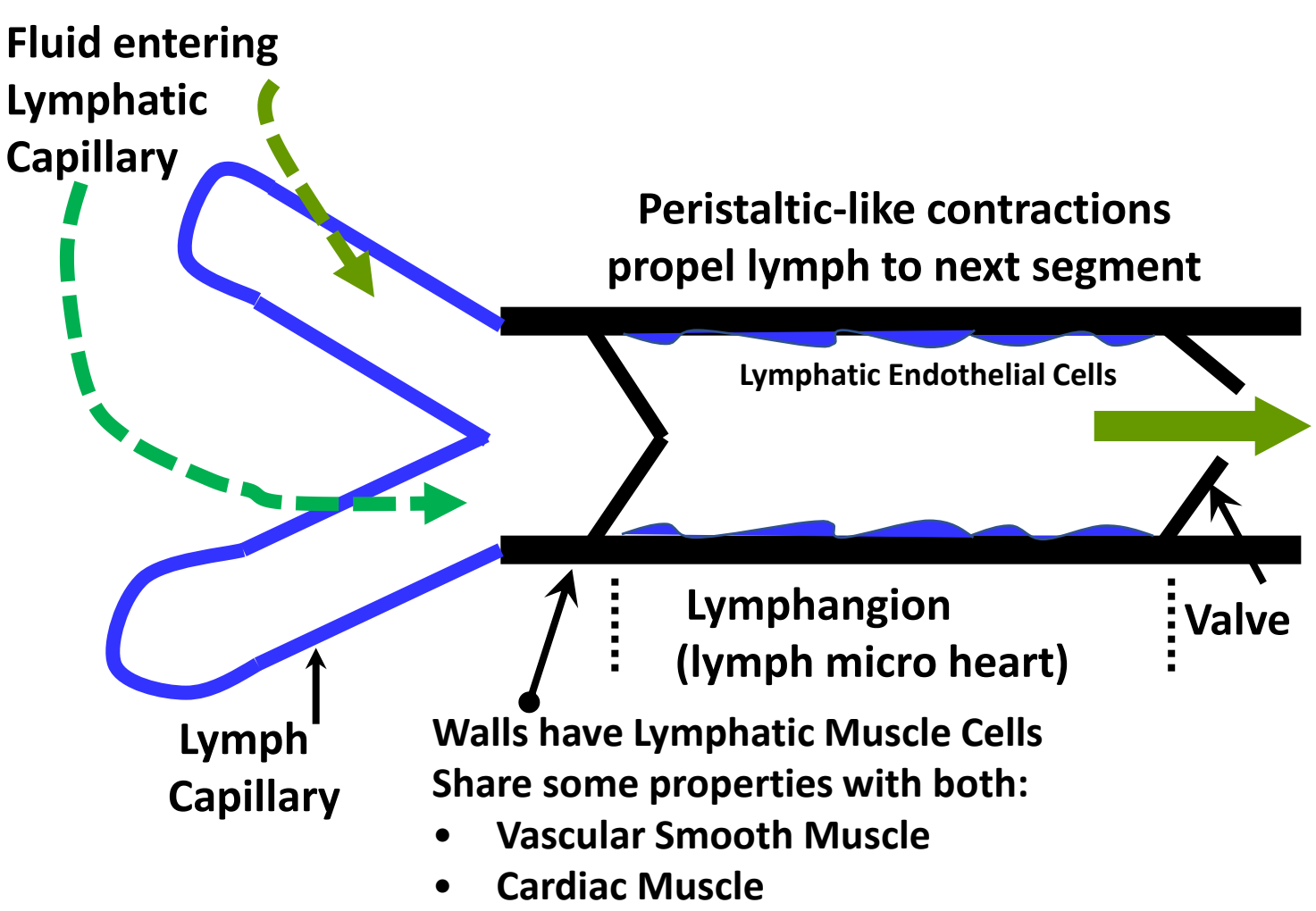


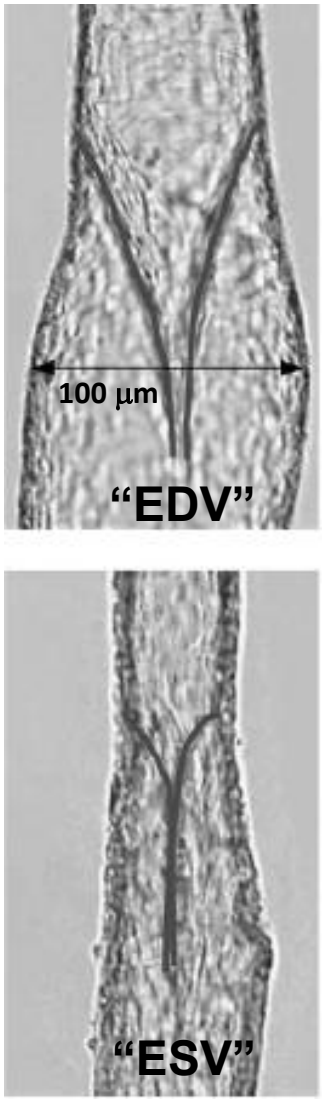


Zawieja LRB 2009;7:89

Contraction force (& frequency) is preload & afterload dependent - analogous to heart

Lymph Flow: Lymphangions





Zawieja LRB 2009;7:89

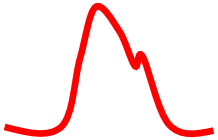
Contraction force (& frequency) is preload & afterload dependent - analogous to heart

Lymph Flow Modulation: Extrinsic

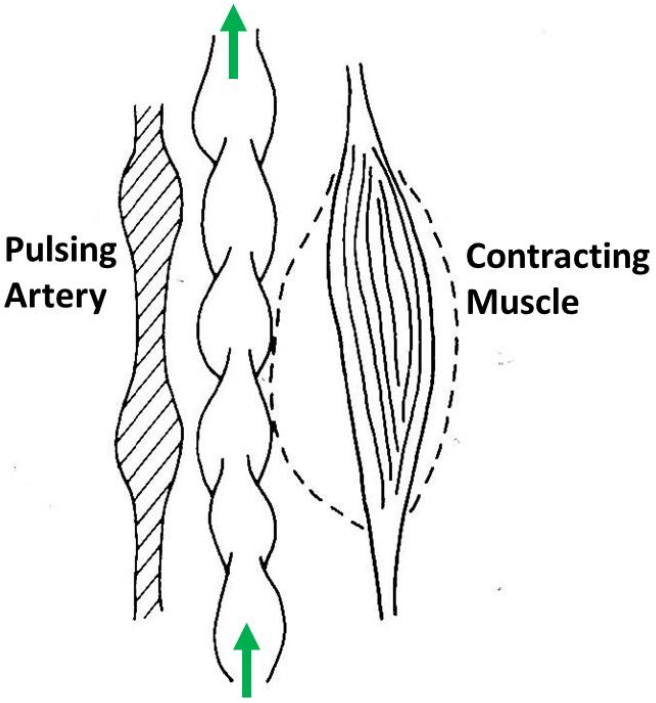
- **Muscular Movement**

- **Respiration**

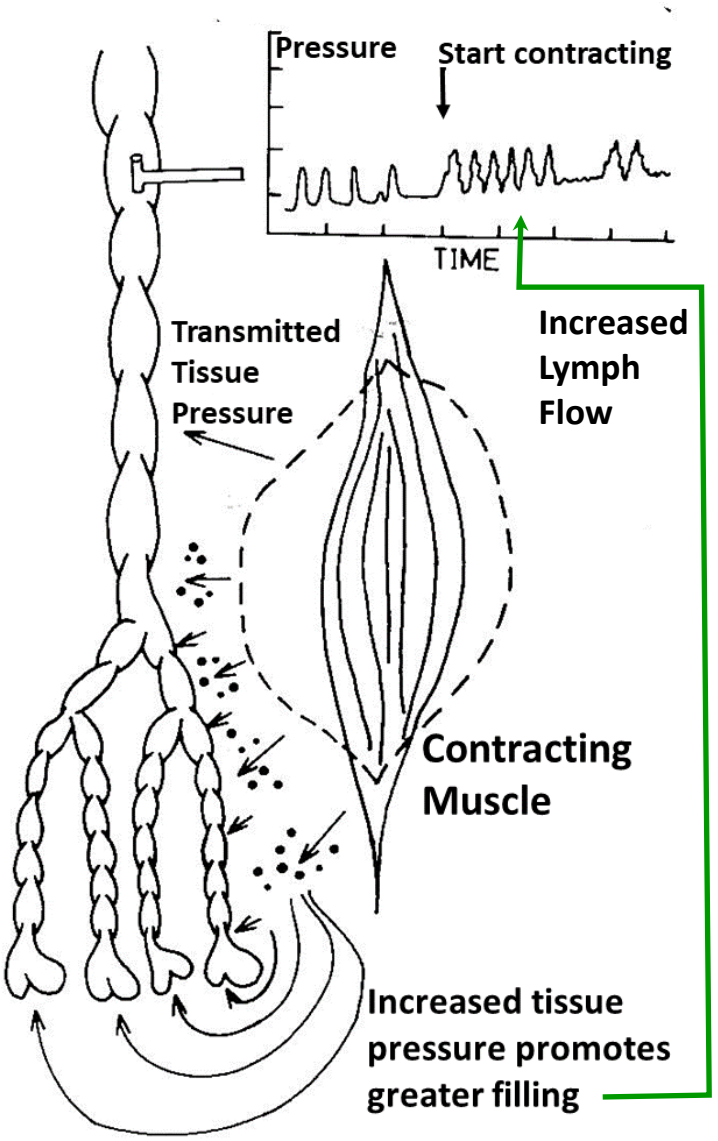
- **Arterial Pulses**



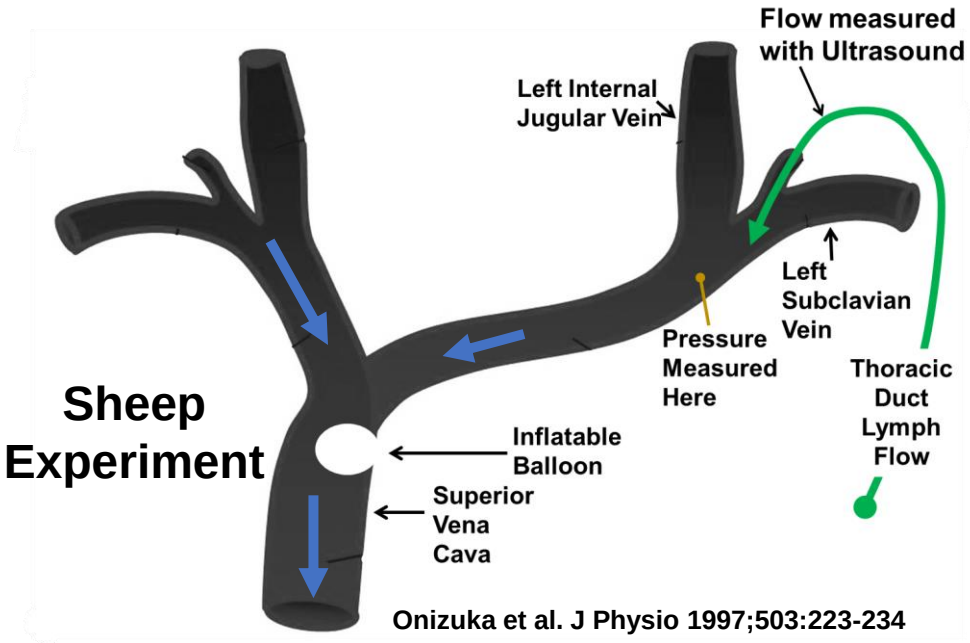
- **Massage**

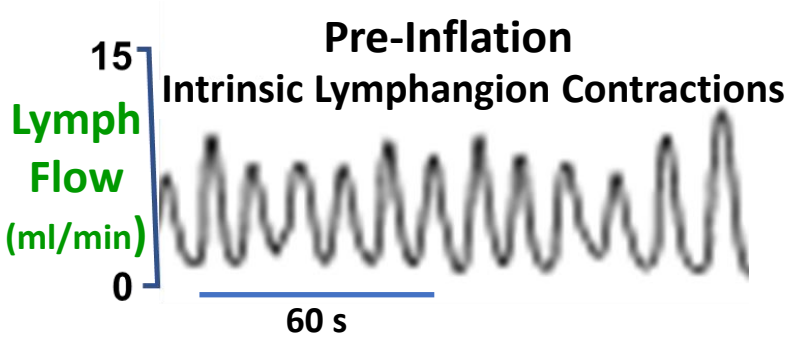


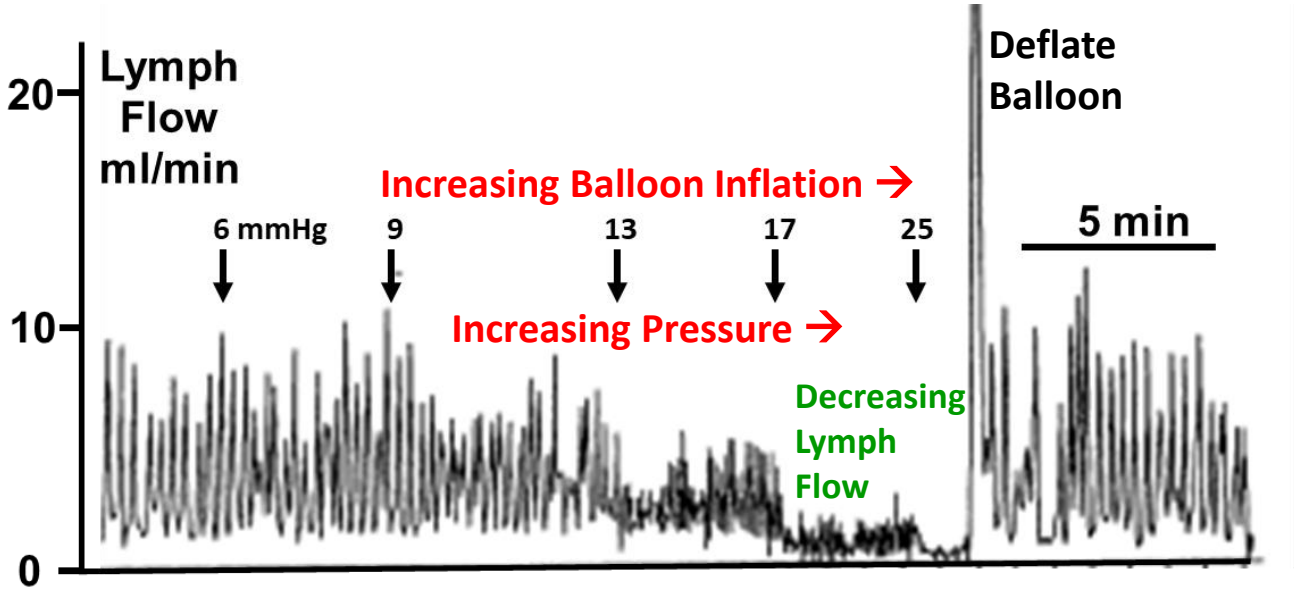
- **Direct pressure effect**
- **Enhance vasomotor action**



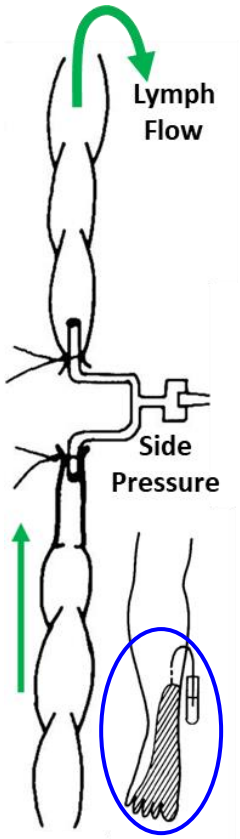
Lymph Flow Modulation: Intrinsic → Afterload



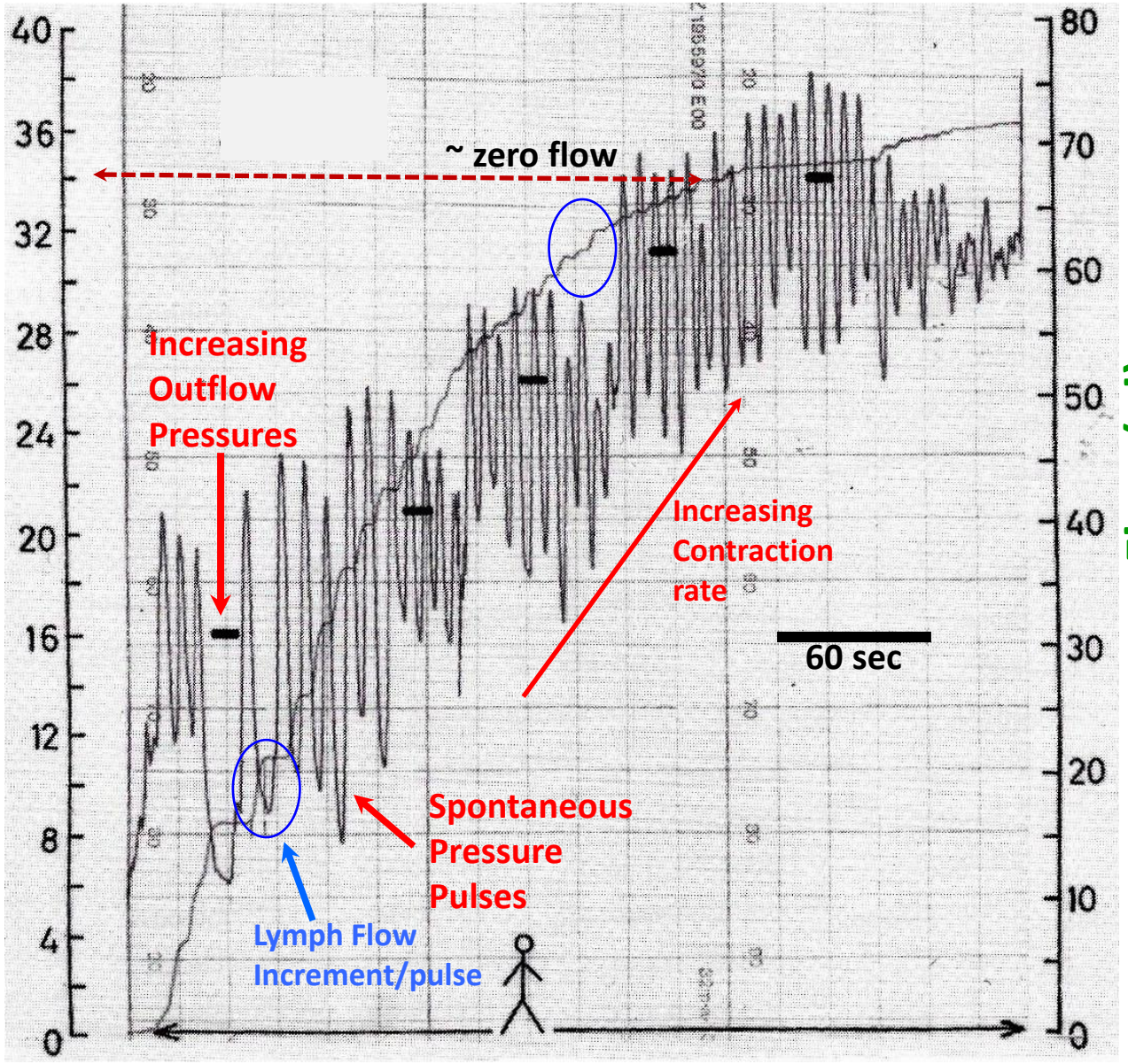




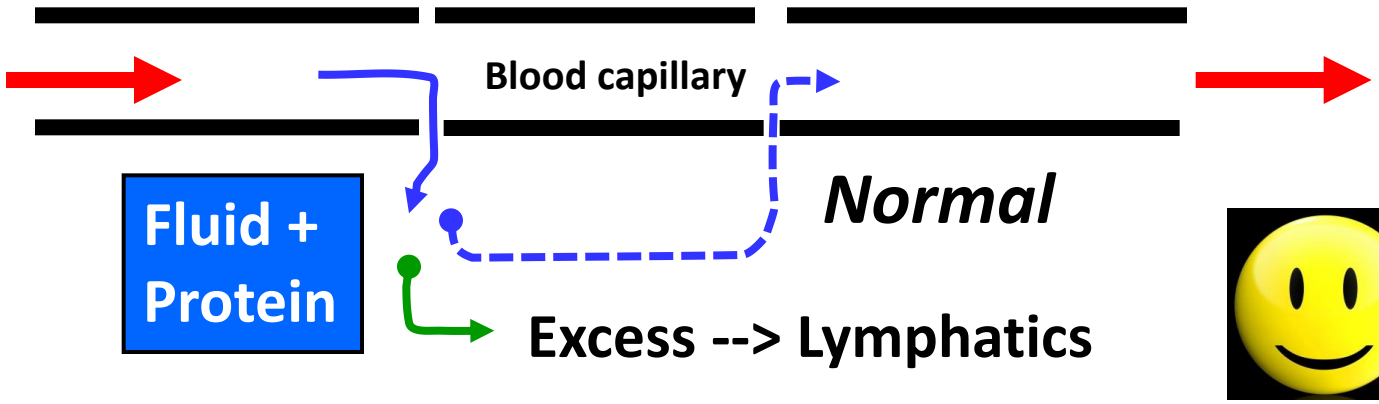
Lymph Pressure-Flow Measurements: Human



Olszewski WK and Engeset A: AJP 1980;239:H775



Edema - Lymphedema



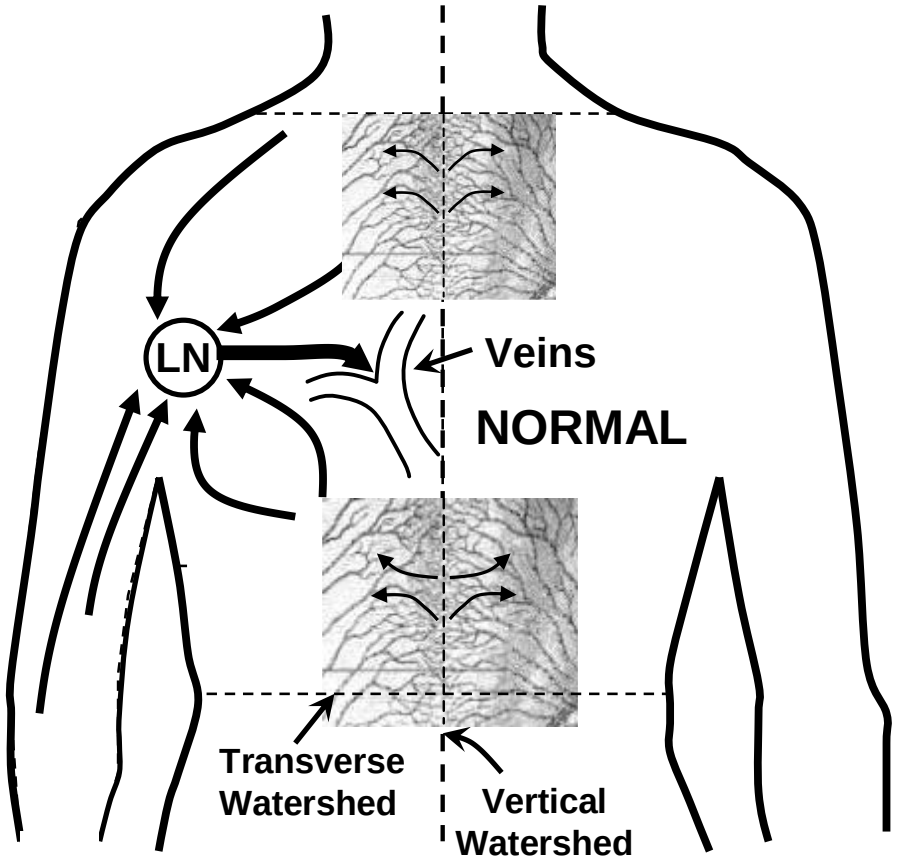
If Net Filtration Exceeds Lymphatic Transport Capacity

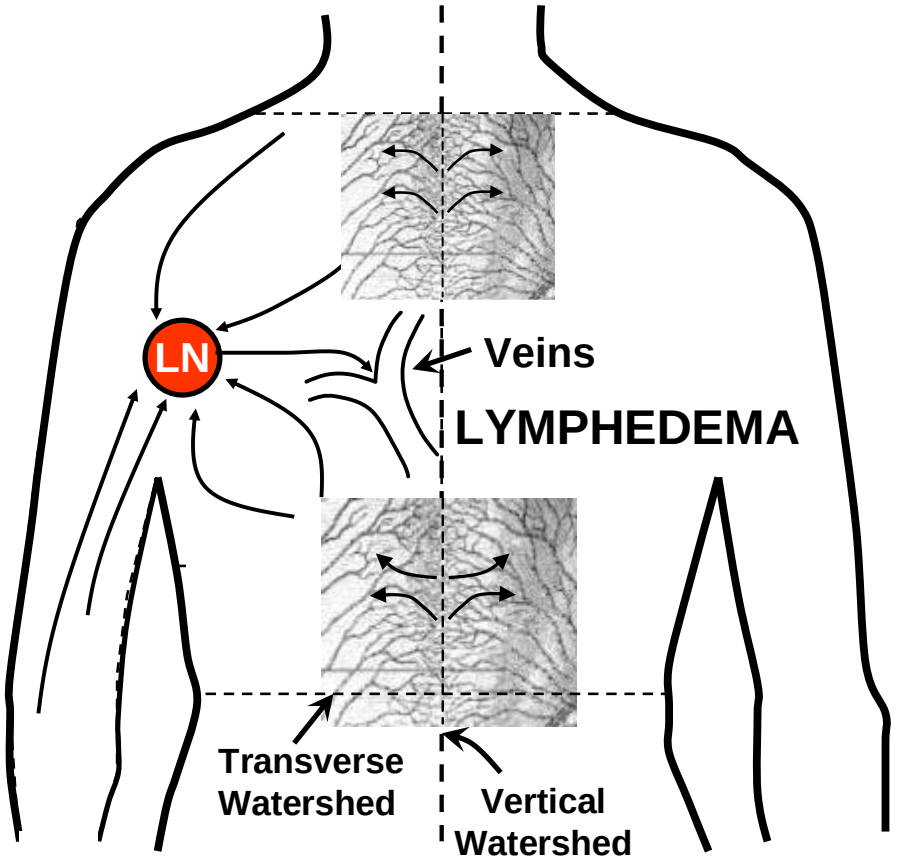
Overload = Edema

+ [Protein]

= Lymphedema

Diminished Lymphatic Drainage



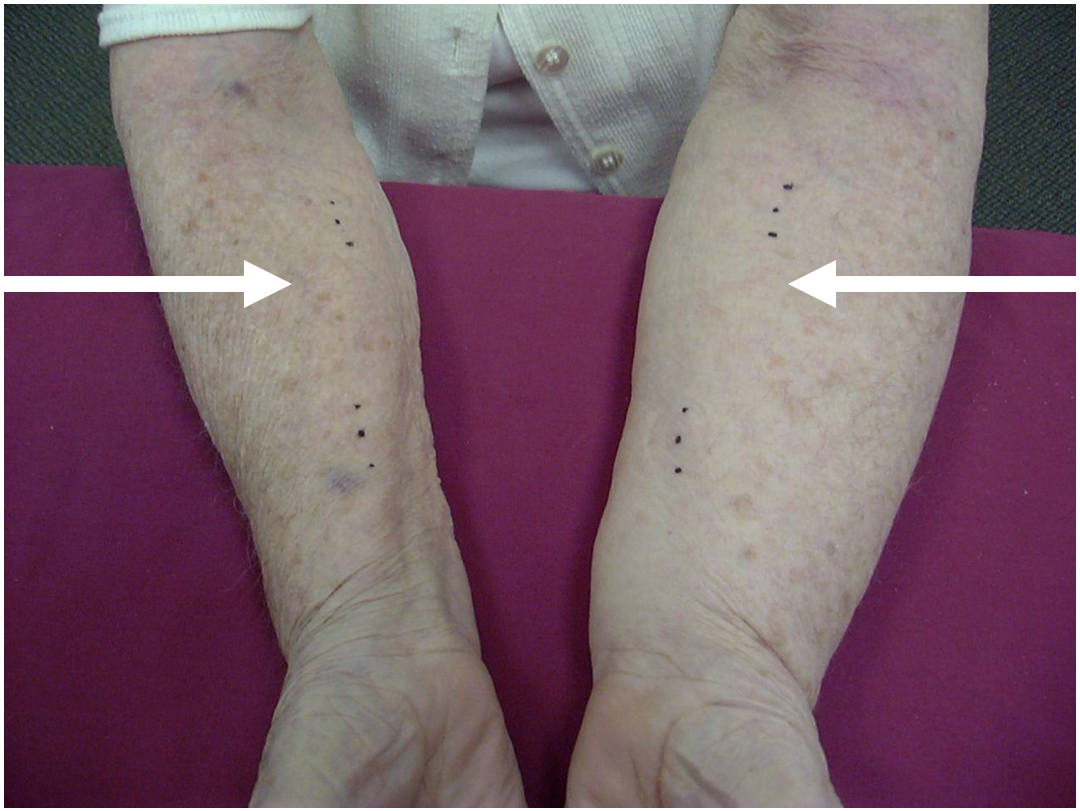


Lymph flow and drainage determined by normal physiological processes and lymphatic pathways

Lymph flow through normal pathways reduced or absent due to nodal or lymph vessel obstruction and dysfunction

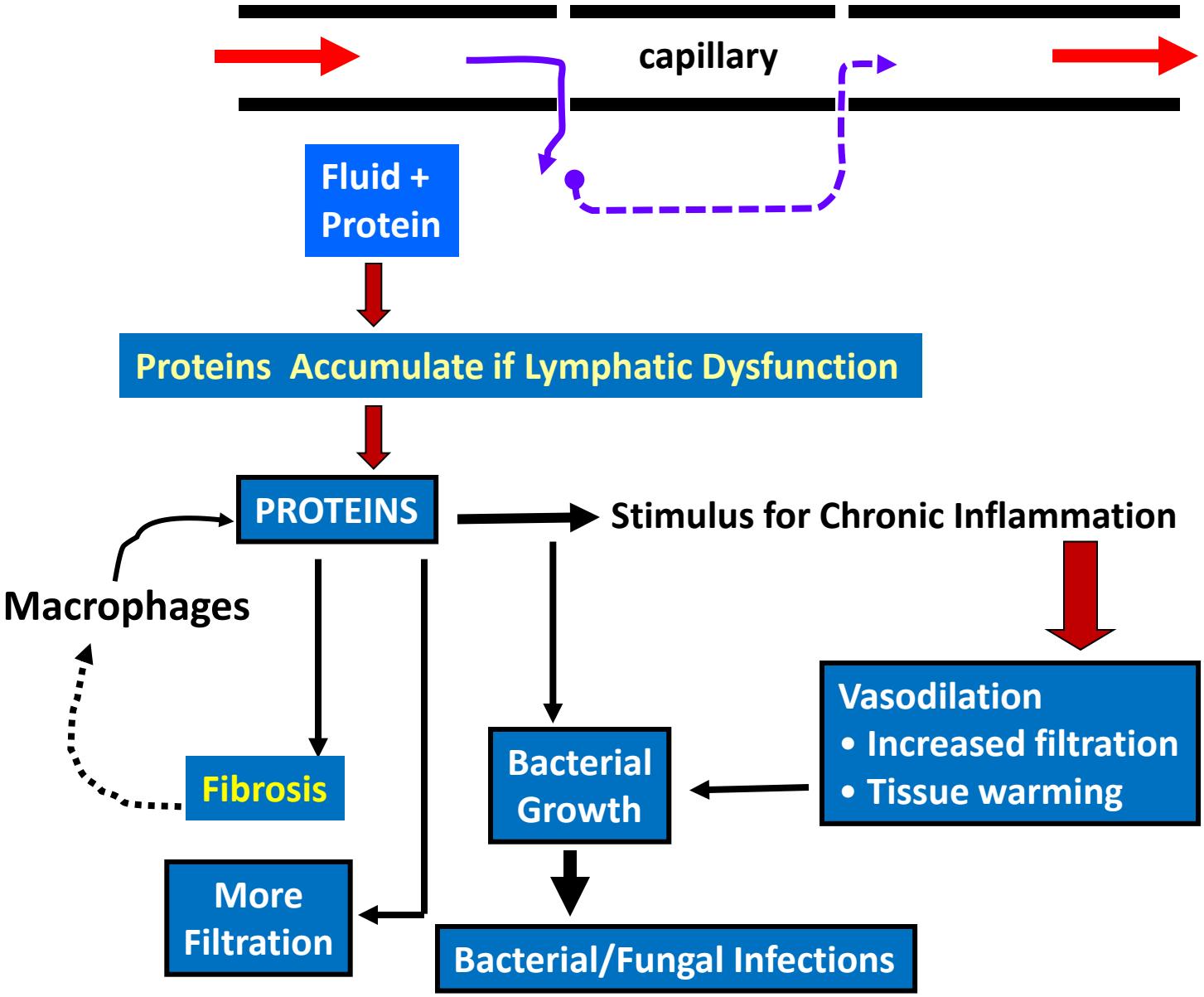
Potential Outcome

Lymphatic System Works OK Here

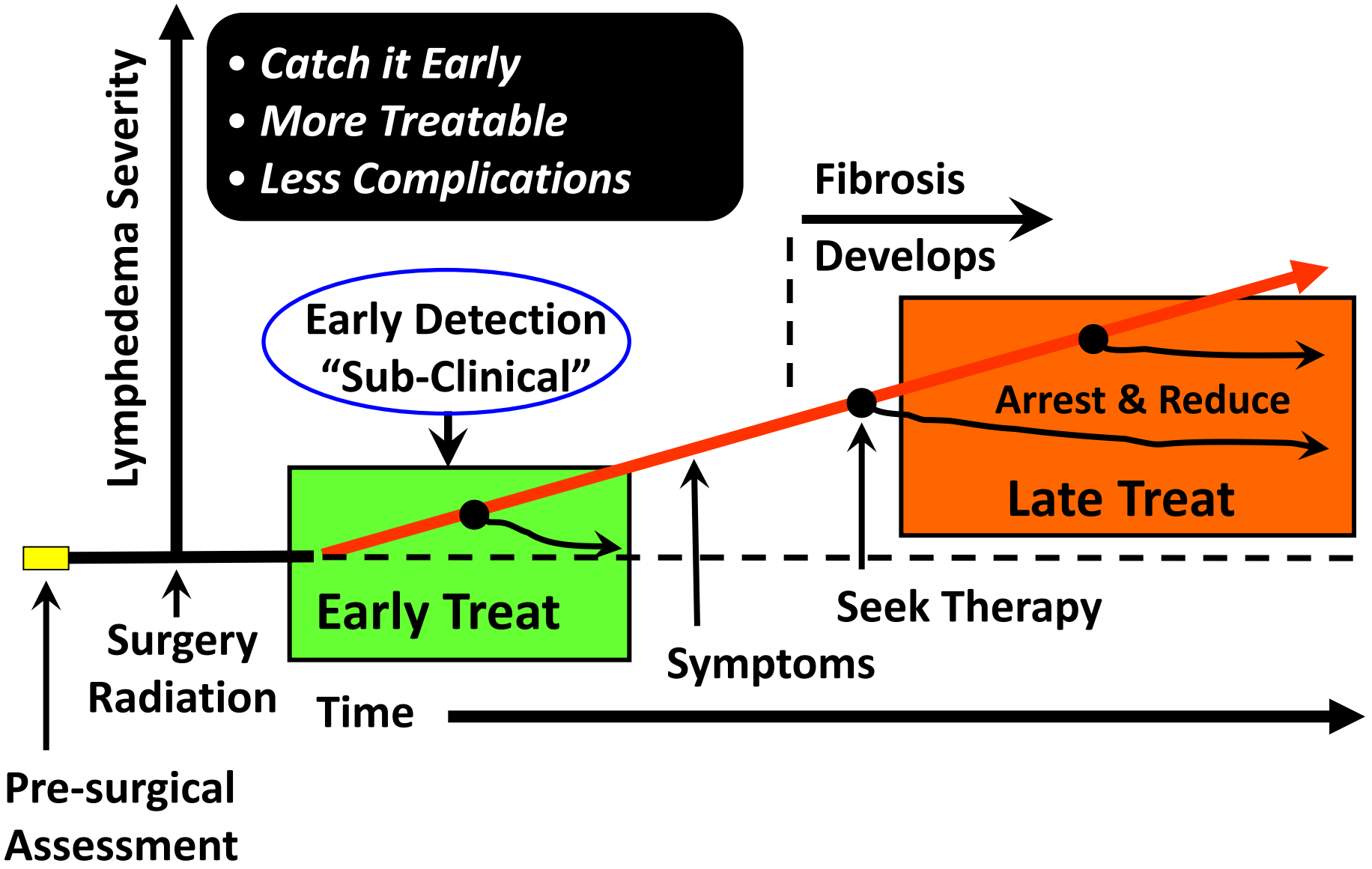


Lymphatic System Not OK Here

Potential Impacts

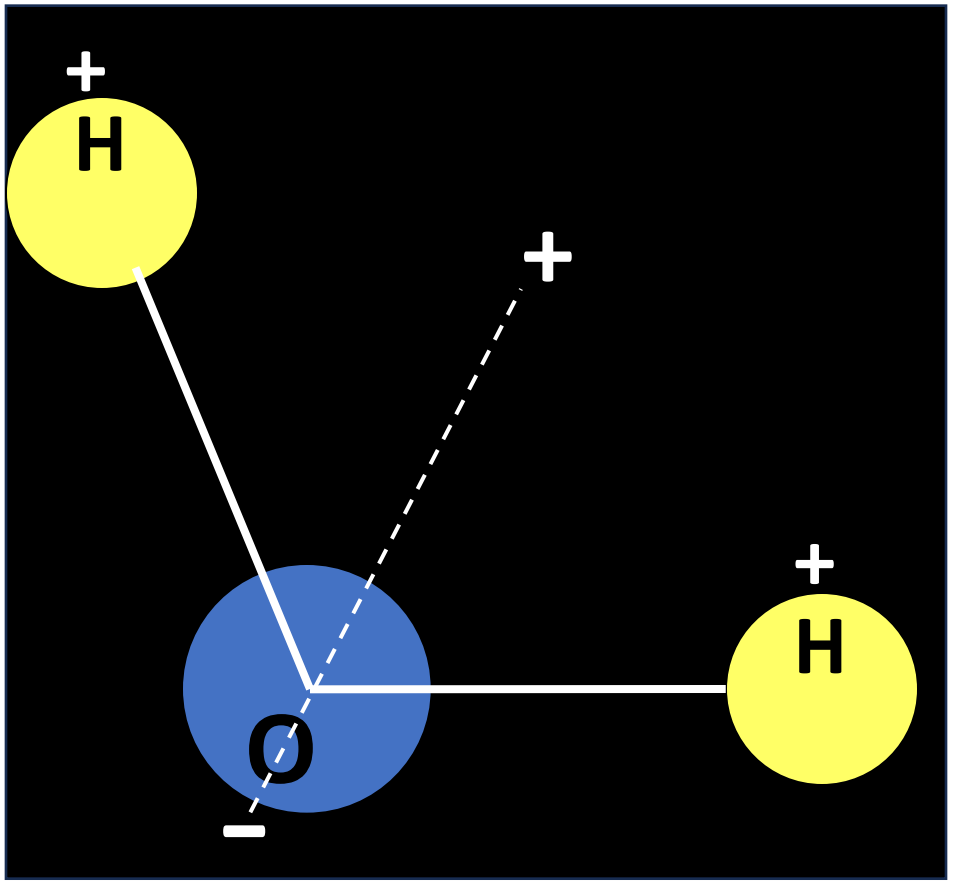


Worsens Without Proper Treatment

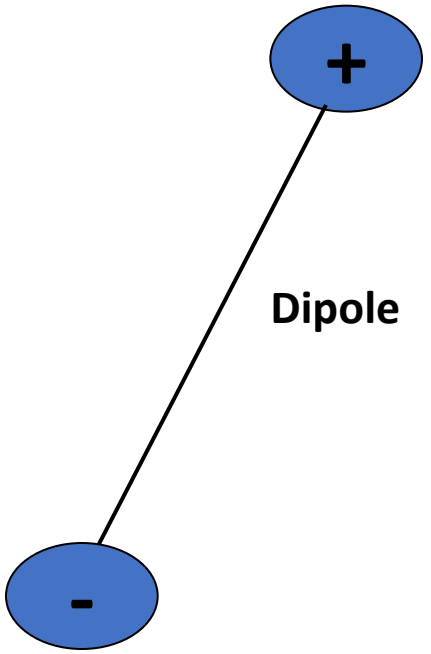


Part 2: Skin Tissue Dielectric Constant

What is Dielectric Constant?

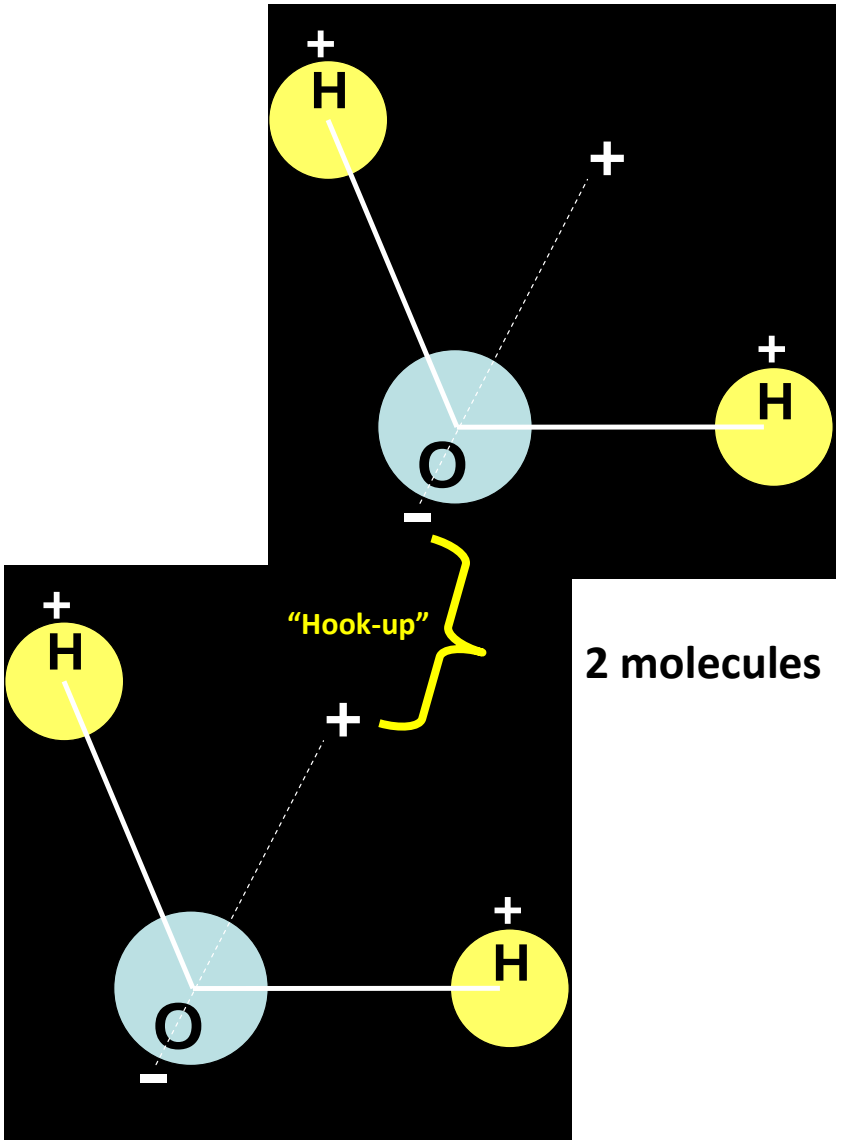


H_2O Molecule

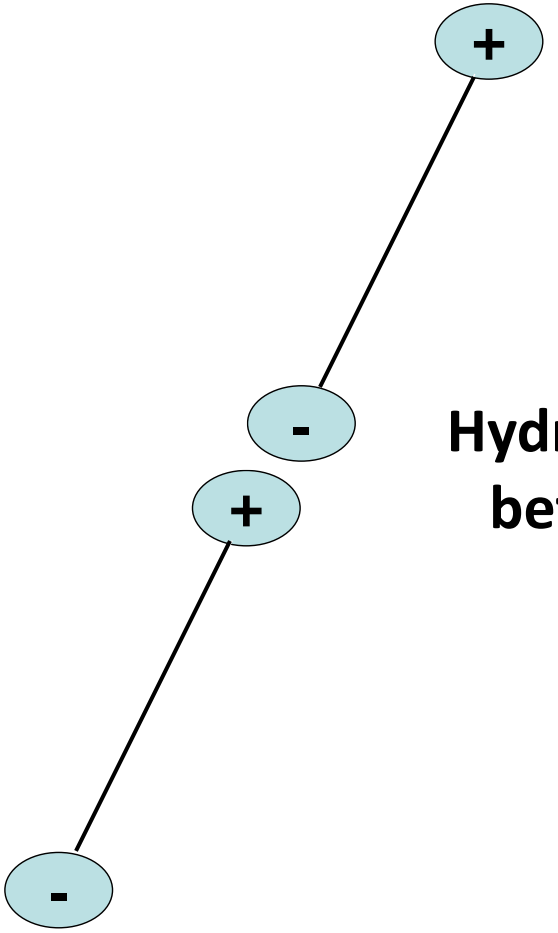


Charge Separation

What is Dielectric Constant?

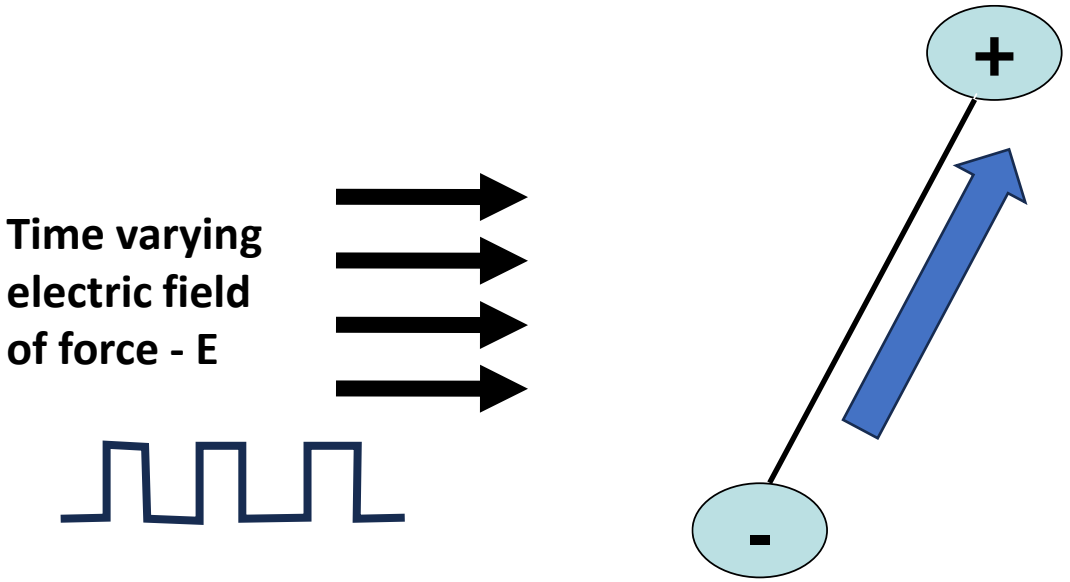


2 molecules

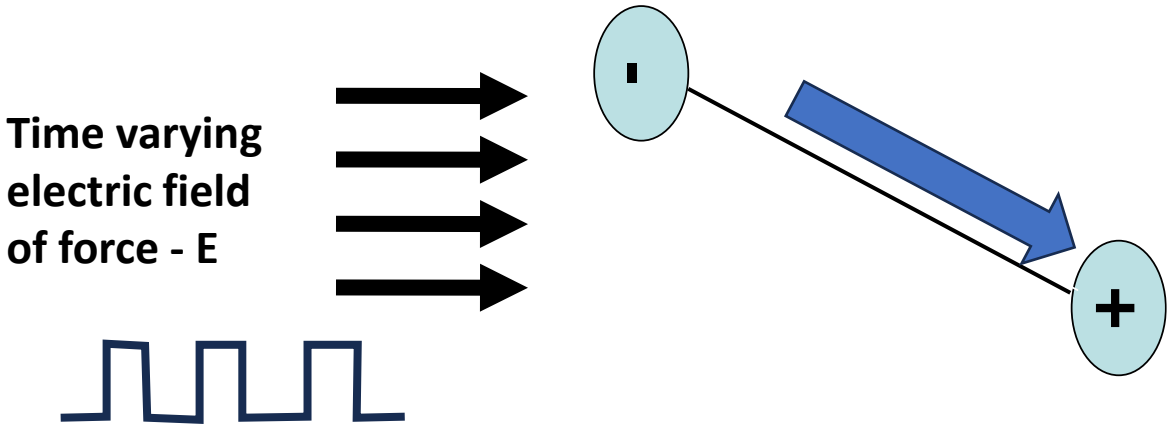


Hydrogen bonding between water molecules

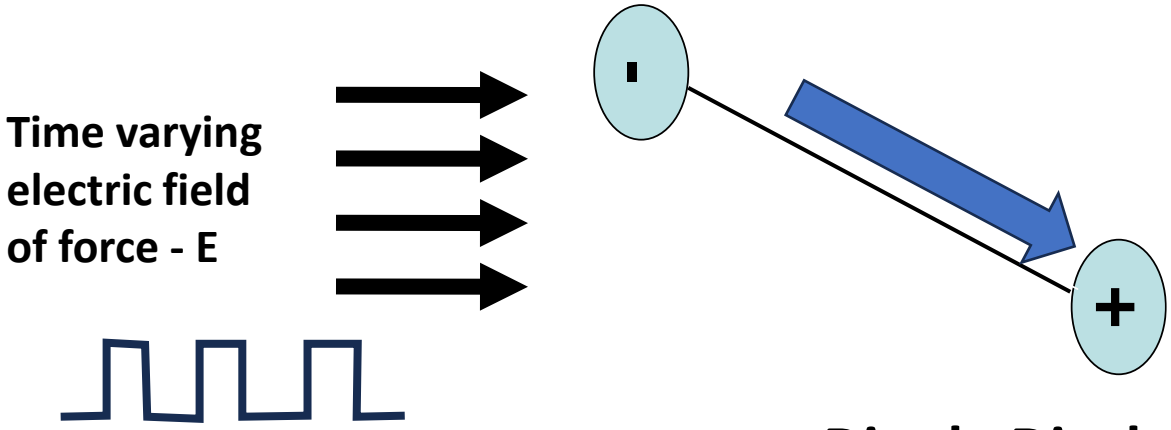
What is Dielectric Constant?



What is Dielectric Constant?



What is Dielectric Constant?



Dipole Displacement → D
"Displacement Current"

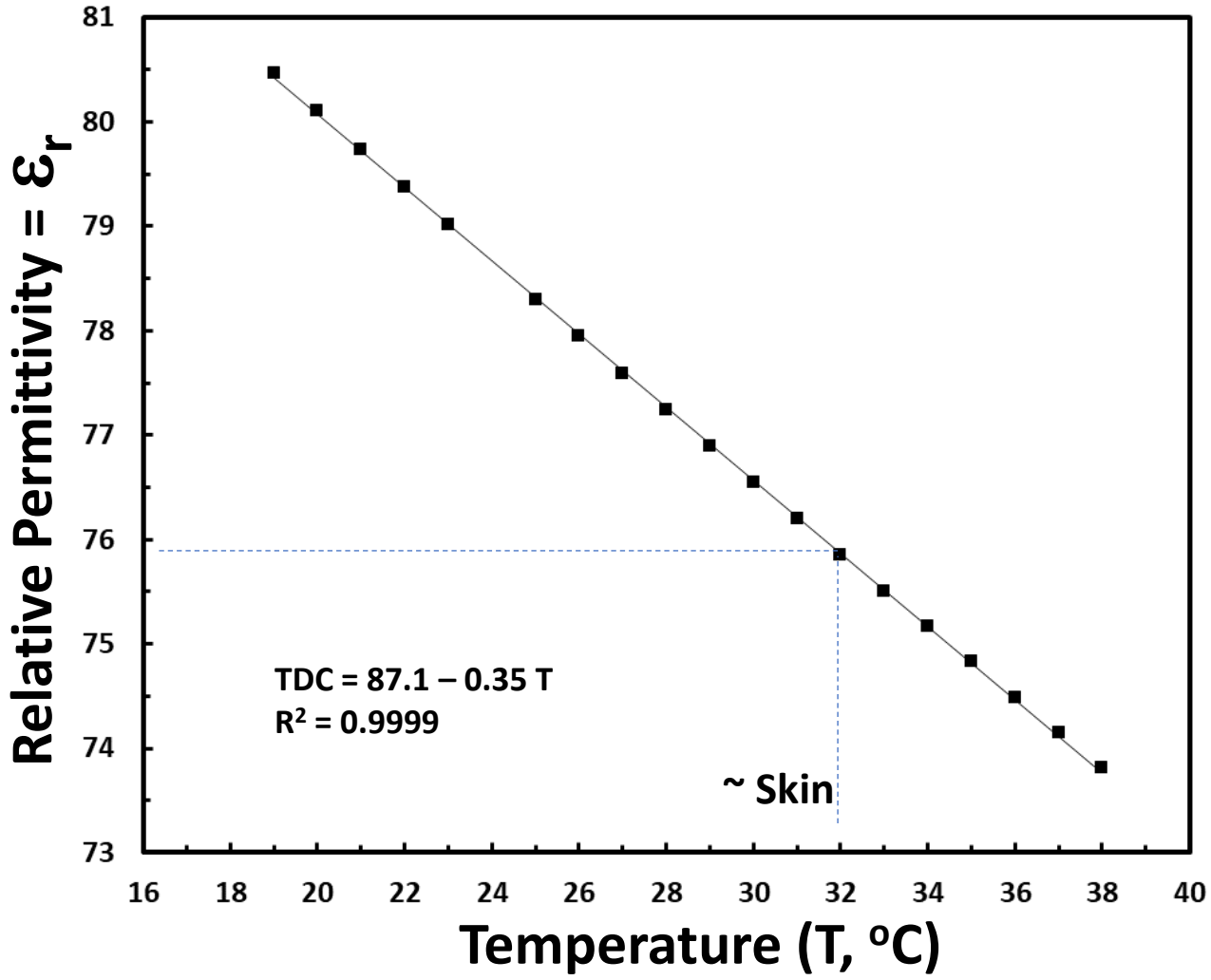
$$D = \varepsilon^* E$$

ε → "real part"

Complex Permittivity
Complex Dielectric Constant

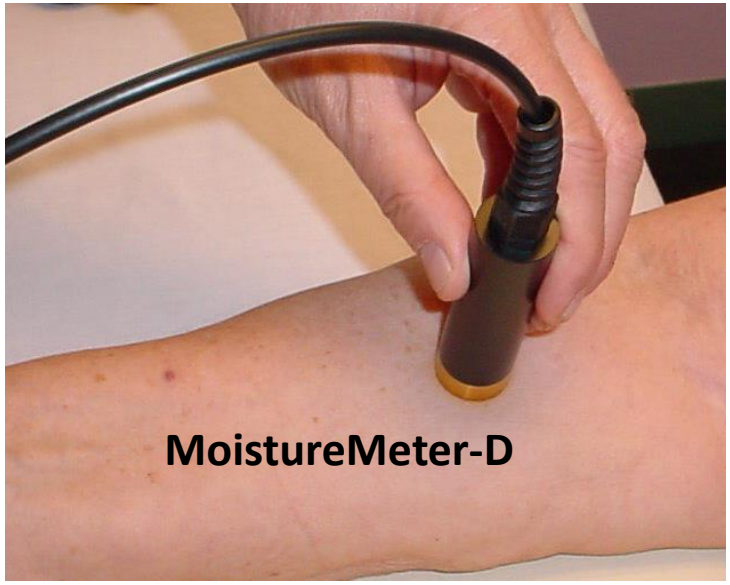
$$TDC = \varepsilon_r = \varepsilon/\varepsilon_0$$

Dielectric Constant of Water



Temp	ε
18.0	80.8
19.0	80.5
20.0	80.1
21.0	79.7
22.0	79.4
23.0	79.0
23.0	79.0
25.0	78.3
26.0	77.9
27.0	77.6
28.0	77.2
29.0	76.9
30.0	76.5
31.0	76.2
32.0	75.9
33.0	75.5
34.0	75.2
35.0	74.8
36.0	74.5
37.0	74.2
38.0	73.8

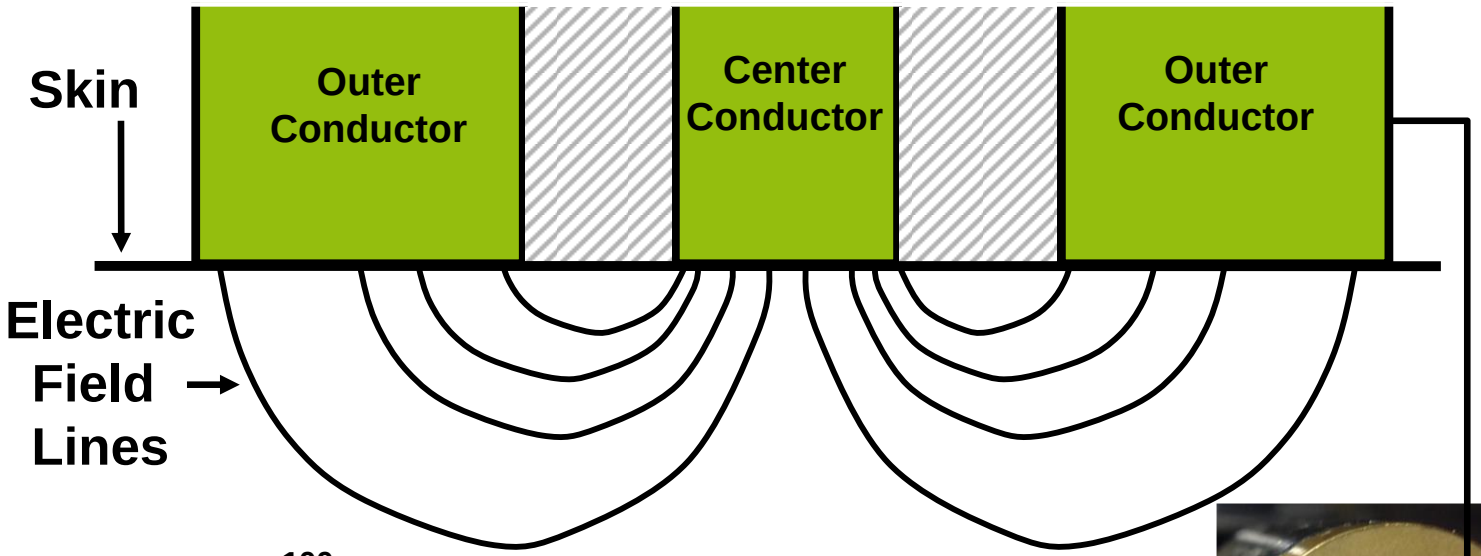
Assessing Skin Tissue Water Changes via Tissue Dielectric Constant (TDC) Measurements

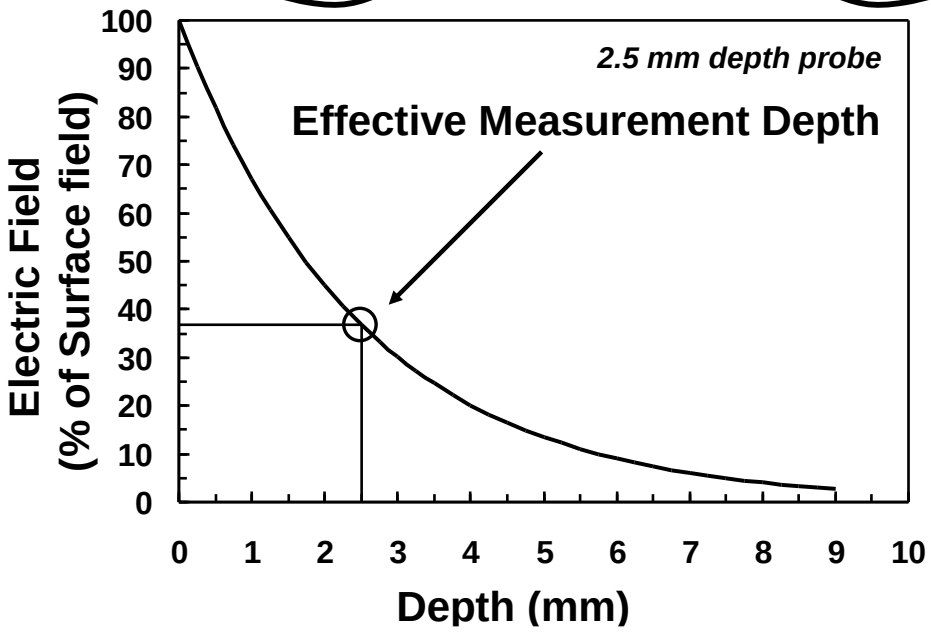


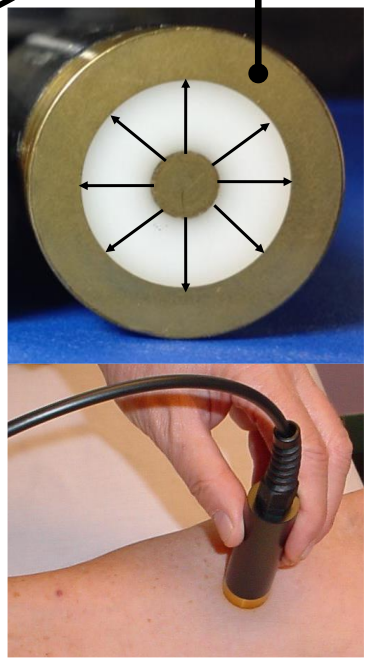
Original Research Multiprobe Version

- Low power 300 MHz incident wave
- Reflected wave depends on the tissue's composite dielectric constant
- Dielectric constant depends on total tissue water (free + bound)
- Can measure at almost any anatomical site

Effective Measurement Depth

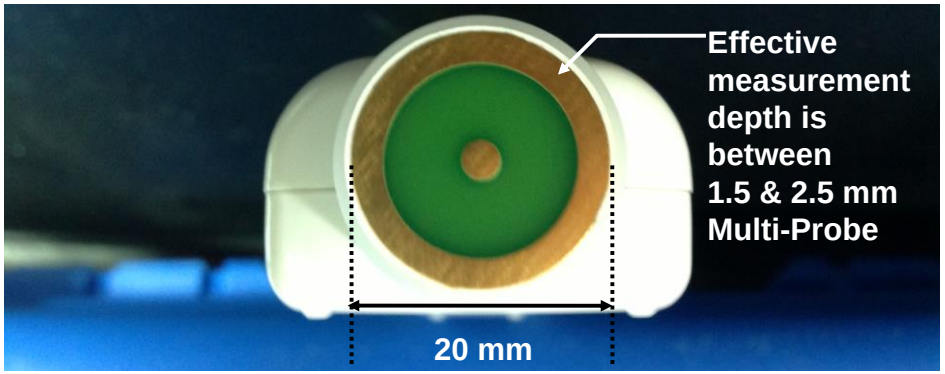


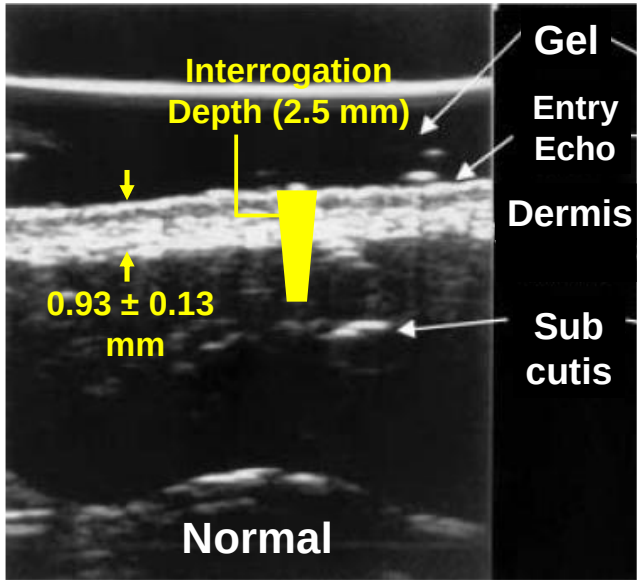




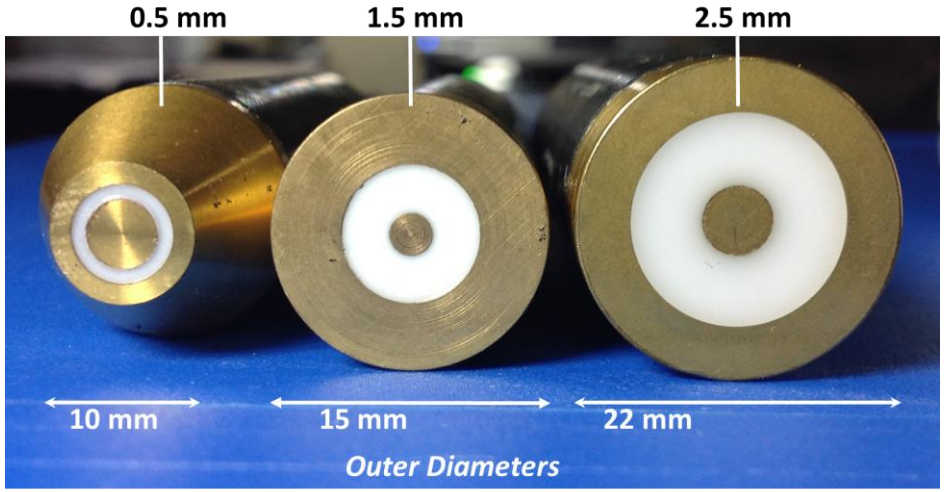
Device Versions

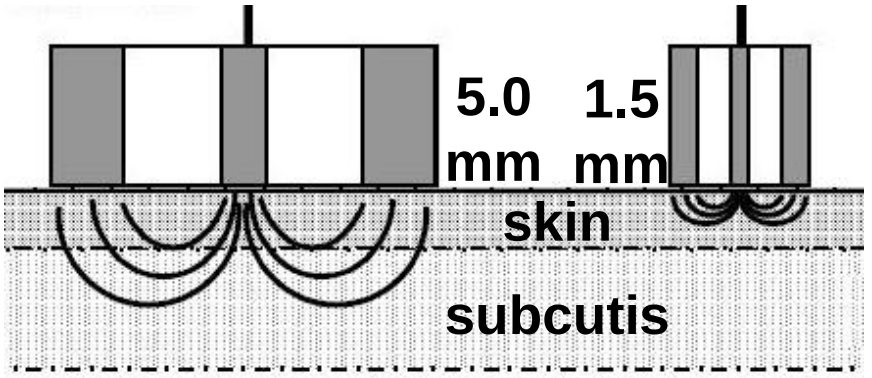
Self-contained Compact Version



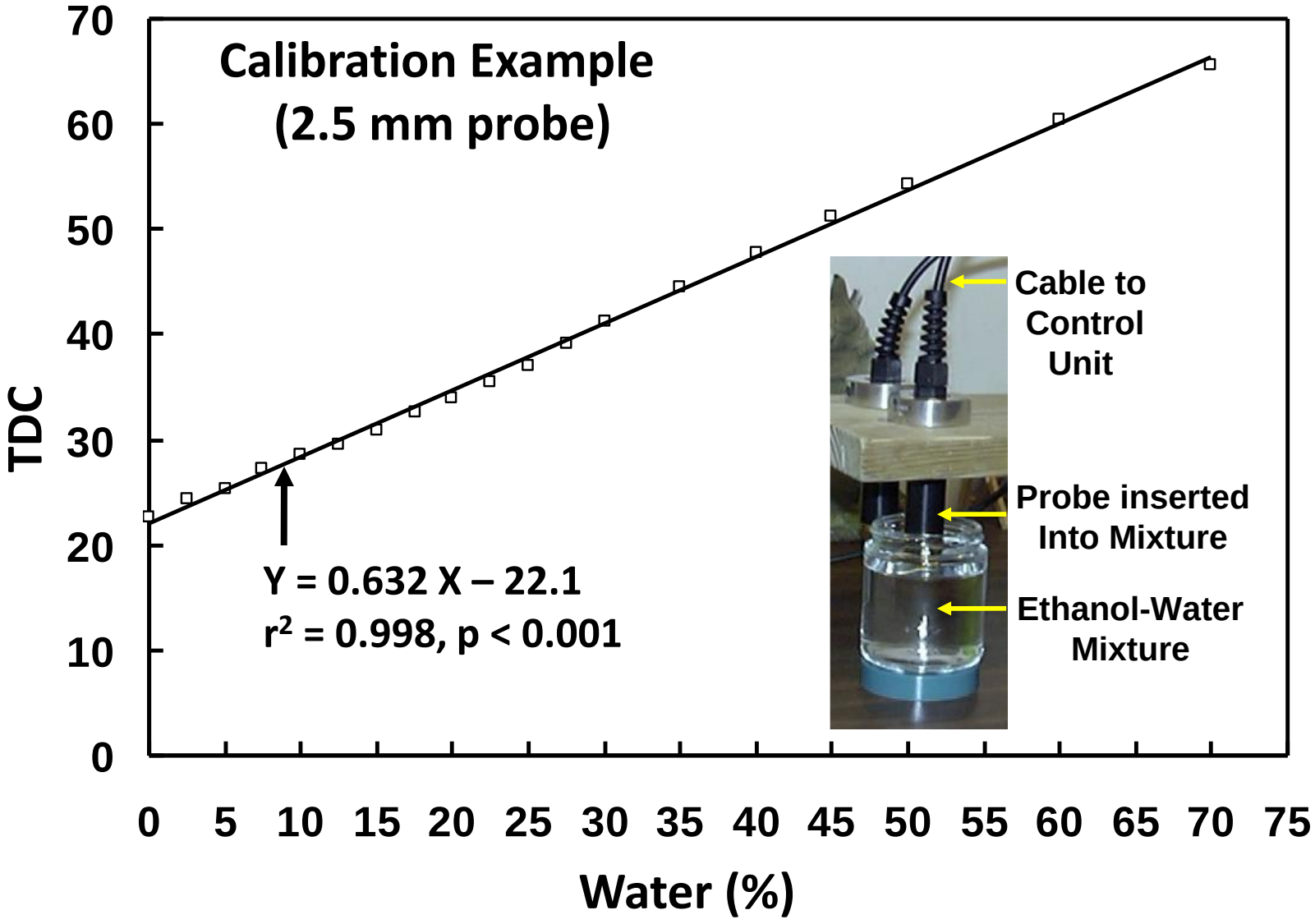


Multiprobe Version

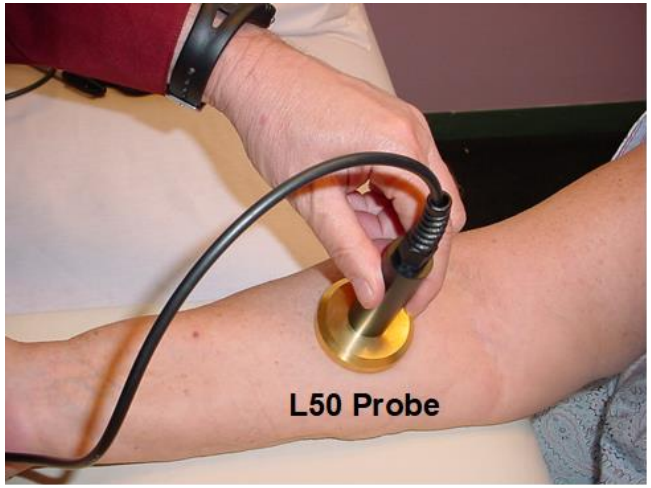


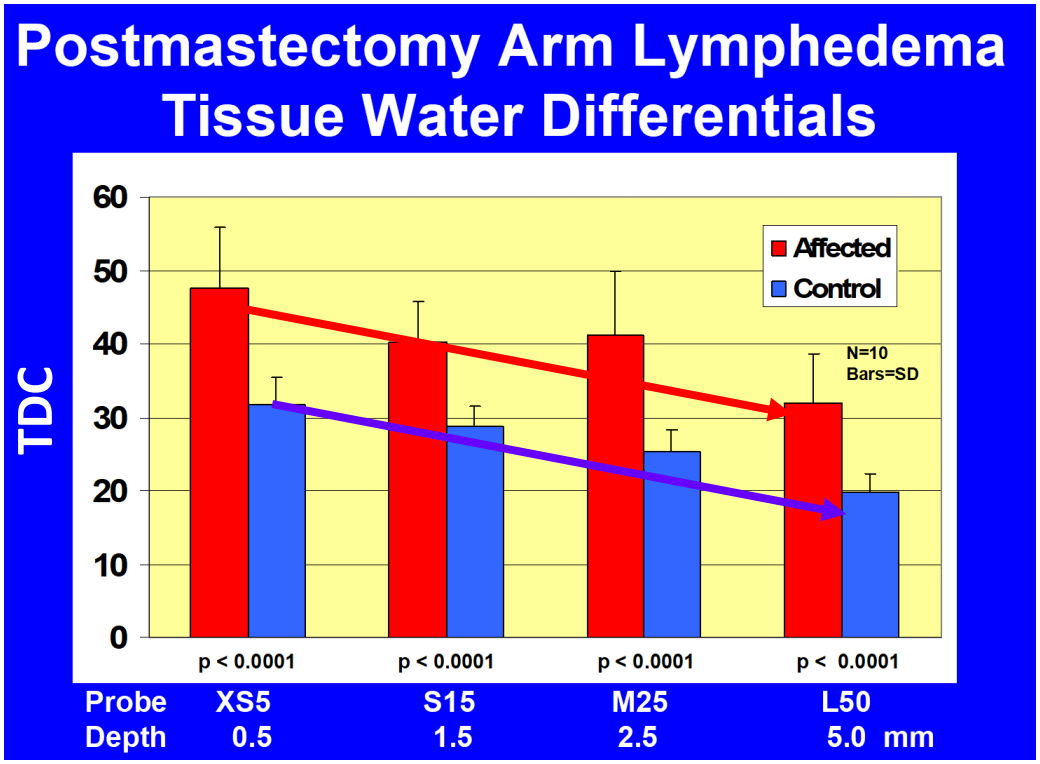


TDC Dependence on Water Concentration



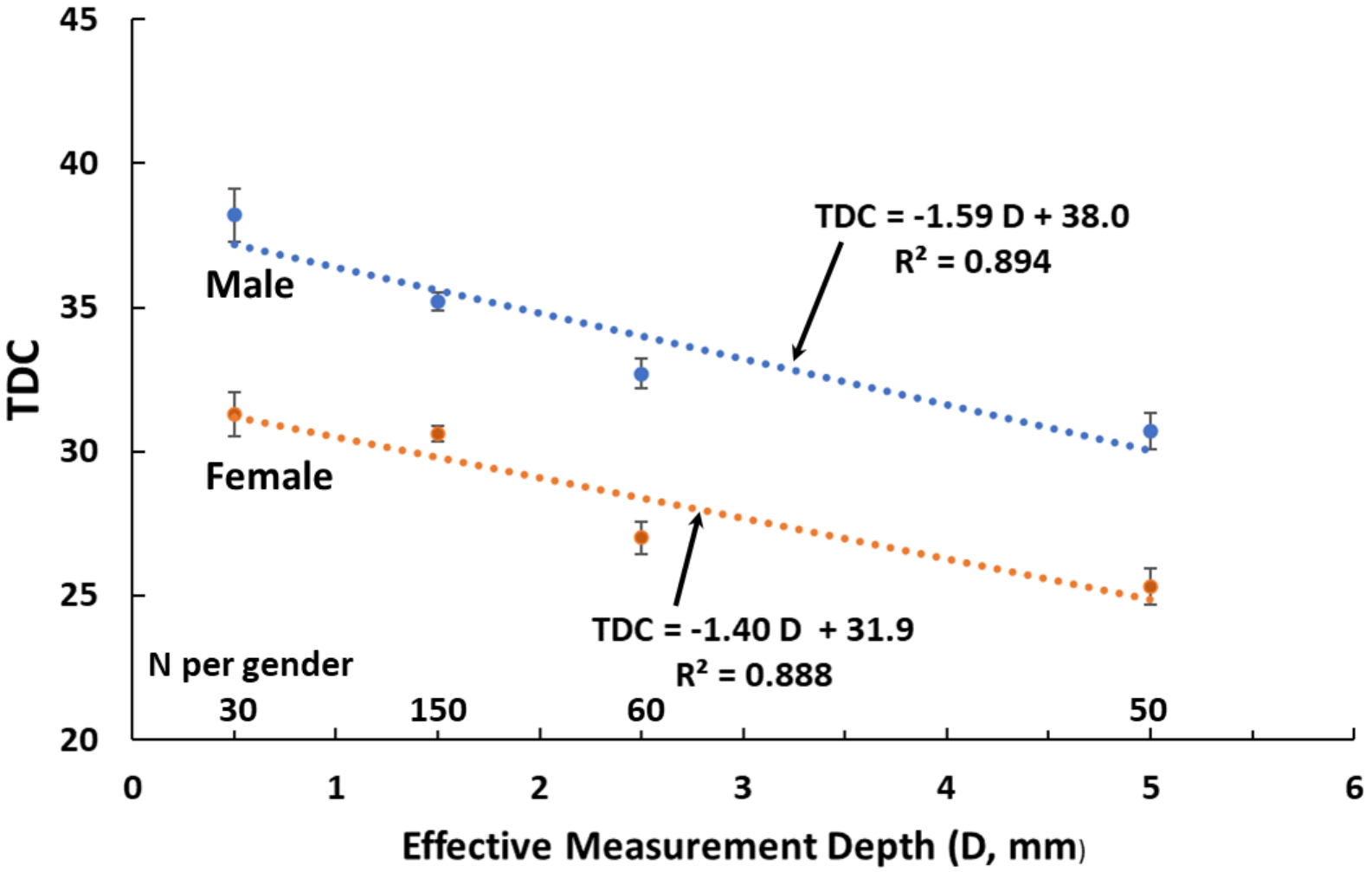
TDC Dependence on Depth: Lymphedema





- TDC decreases with depth in both arms
- TDC elevated in lymphedema at every depth

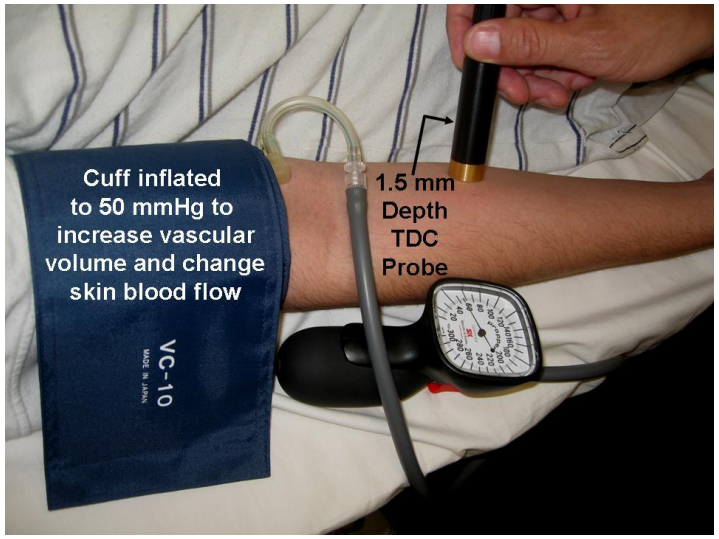
TDC Dependence on Depth: Healthy

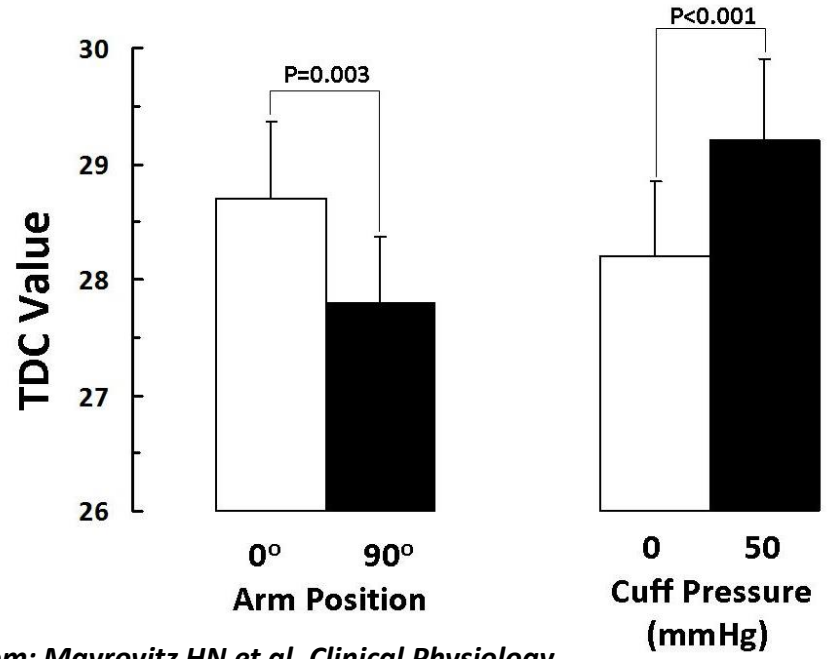


- TDC decreases with increasing depth (some tissues)
- Male values tend to be greater than female values

Data from: Mayrovitz et al.
Skin Research and Technology
2016;22:(1) 81-88

TDC Dependence on Vascular Components





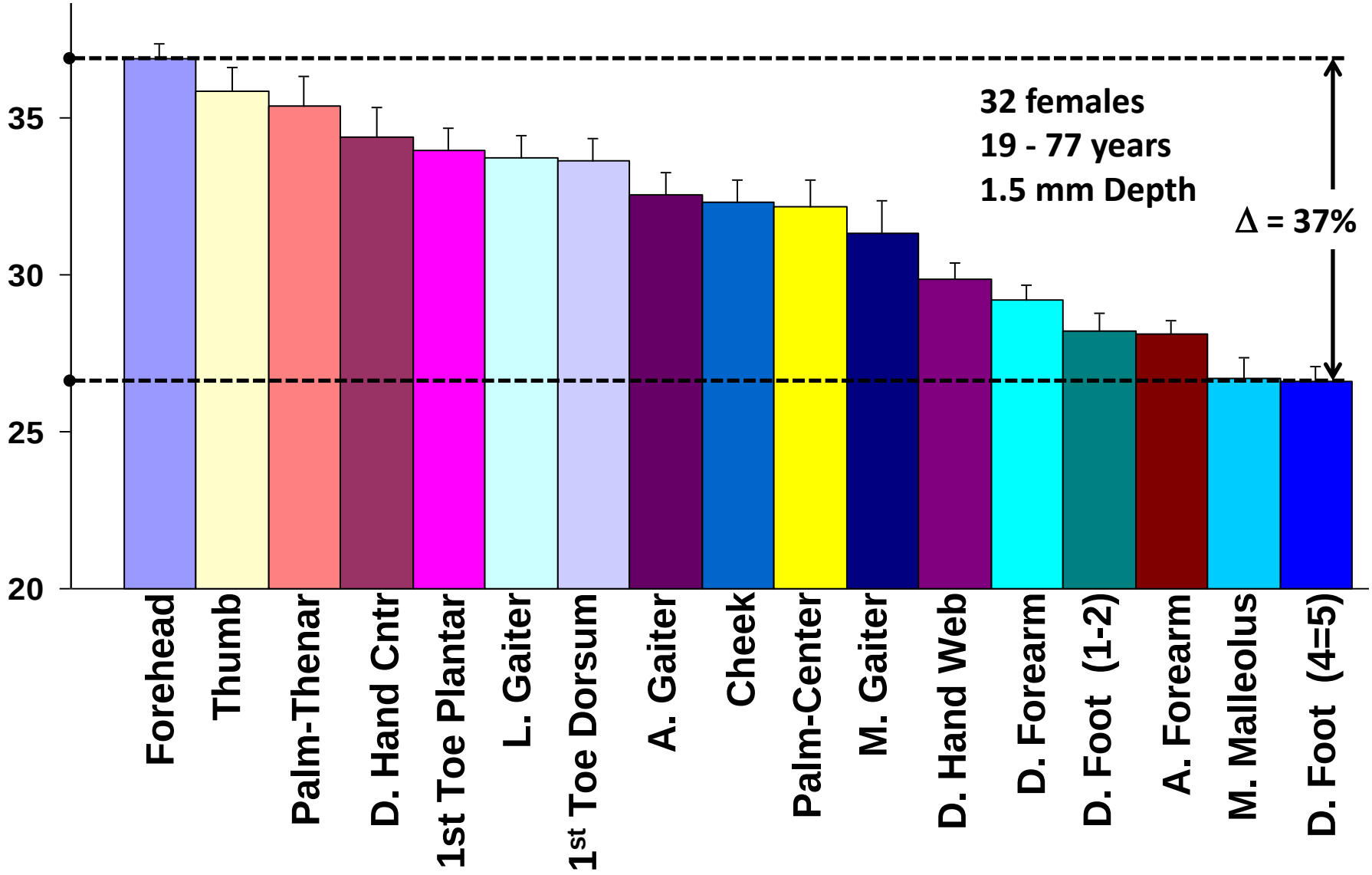
Very large vascular blood volume and blood flow changes

↓

Statistically significant but small changes in TDC values (~3.5%)

Data from: Mayrovitz HN et al. Clinical Physiology and Functional Imaging 2013;33:55-61

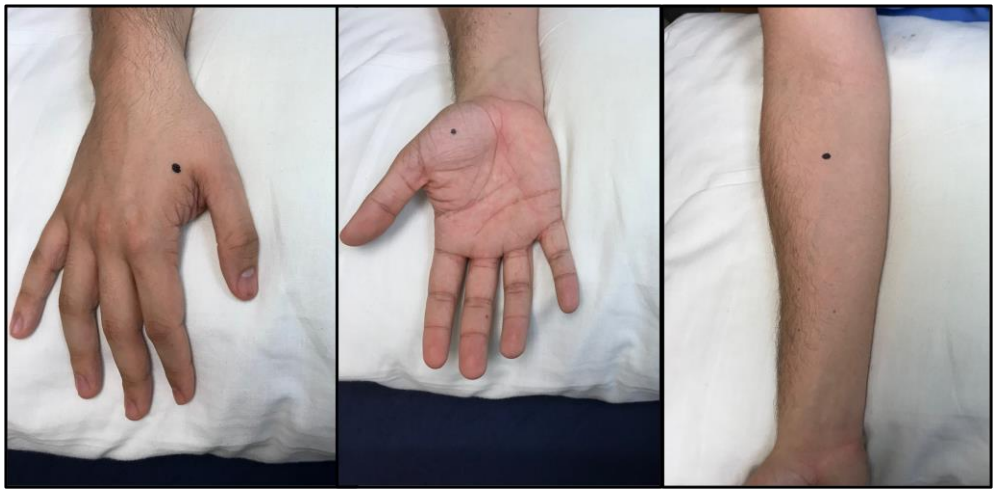
TDC Variability by Anatomical Site



Data From: Mayrovitz HN et al.
Skin Research and Technology 2013;19:47–54

Estimating Minimal Detectible TDC Change

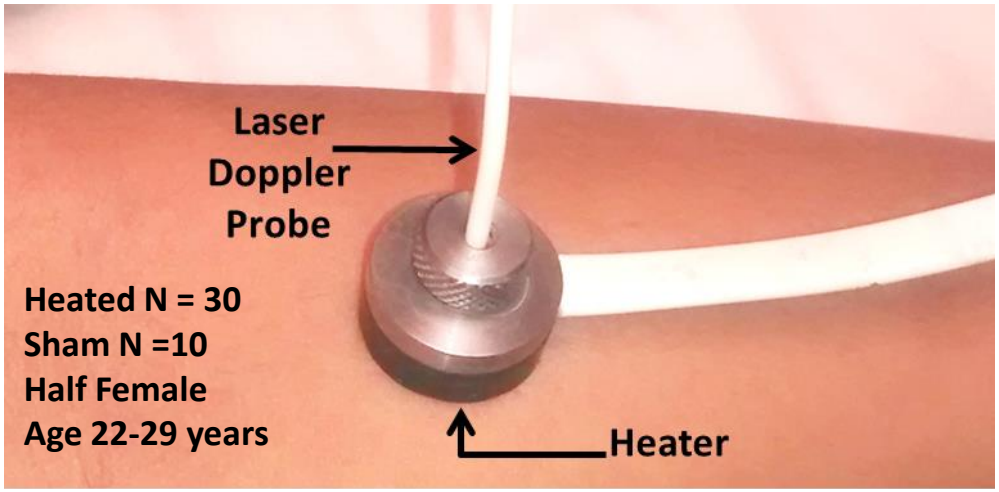
- 40 Healthy Subjects (half were female)
- 19 – 61 years of age
- Two measurers
- Test-Retest Design

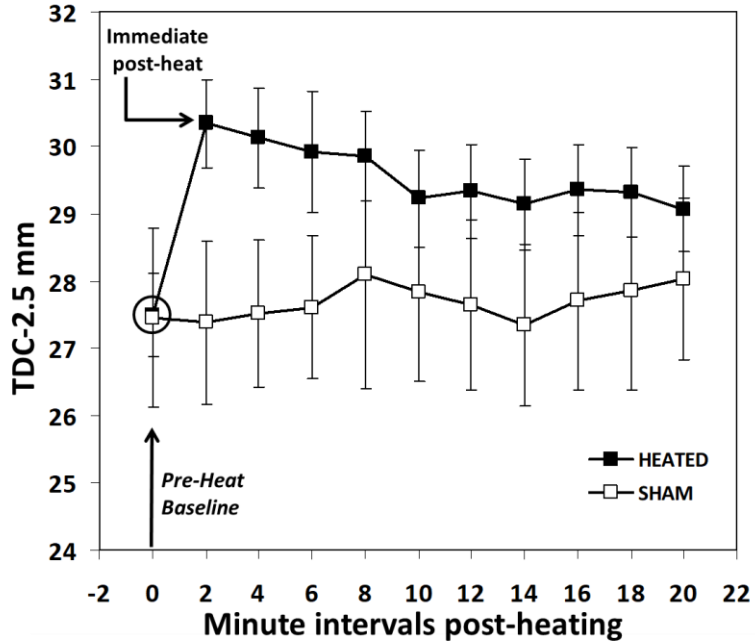


Site	*M1*	*M2*	*Average*
Forearm			
$ICC_{2,1}$	0.983	0.981	0.982
SEM	0.48	0.49	0.49
MDC	1.32	1.35	1.34 (2)
Hand dorsum			
$ICC_{2,1}$	0.948	0.942	0.945
SEM	1.16	1.24	1.20
MDC	3.21	3.43	3.32 (4)
Hand palm			
$ICC_{2,1}$	0.944	0.981	0.963
SEM	1.02	0.56	0.79
MDC	2.83	1.56	2.20 (3)

Data from Mayrovitz et al.
Lymphatic Research and Biology 2019;17:322-328

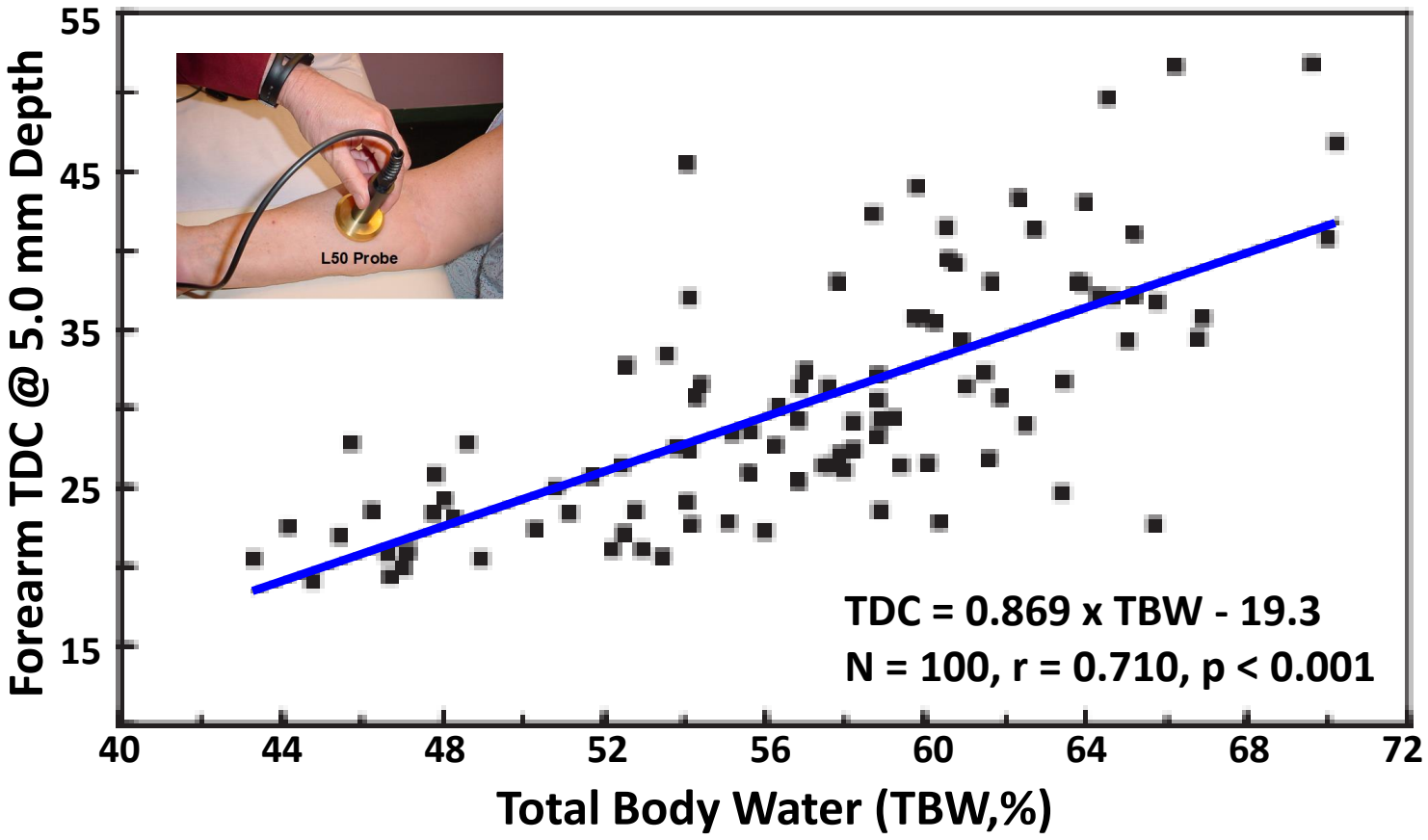
Measuring TDC Changes





Data from: Mayrovitz et.al Clinical Physiology and Functional Imaging 2020;40(2):76-82

TDC Dependence on Total Body Water Percentage



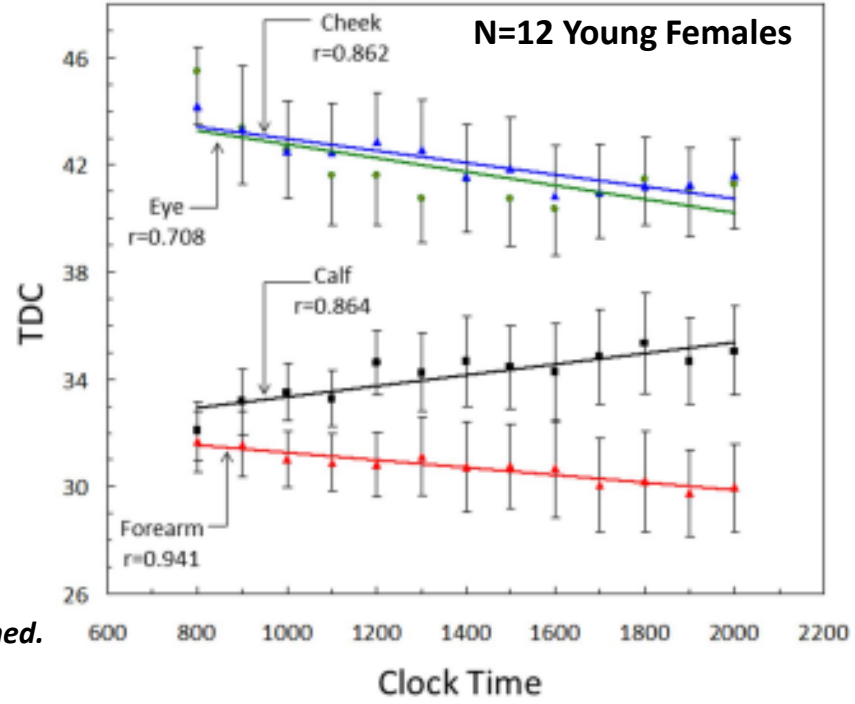
Inverse correlation with Total Body Fat %

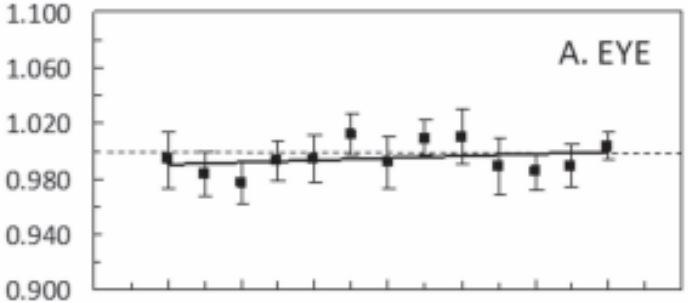
TDC = - 0.730 x TBF + 45.4, r = 0.773

Data from: Mayrovitz et al.
Skin Research and Technology
2017;23(4):471-478

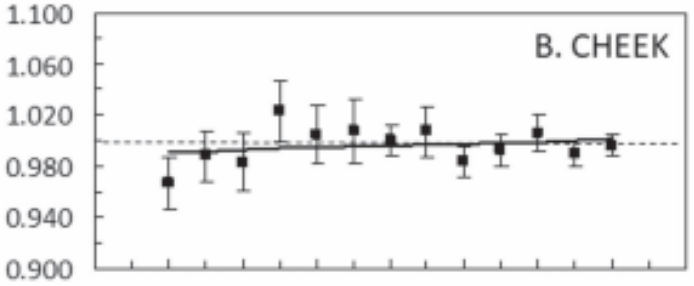
TDC Diurnal Variations

- Upper Body Decreases
- Lower Body Increases
- Inter-Side Ratios ~ 1.0





Inter-side Ratios ~ Constant



Data from:
Mayrovitz HN: Biomed. Phys. Eng. Express 2019;3 047001

Jowl TDC Aged Dependence

	YOUNG	MATURE	
N	30	30	P-value
Age	27.2 ± 7.8	56.4 ± 7.6	0.0001
TDC	36.3 ± 5.5	37.5 ± 4.8	0.440

Data from: Mayrovitz et al.: J Cosmetic Dermatol. 2018;17:1262–1270

Thanks for your Attention

Questions?