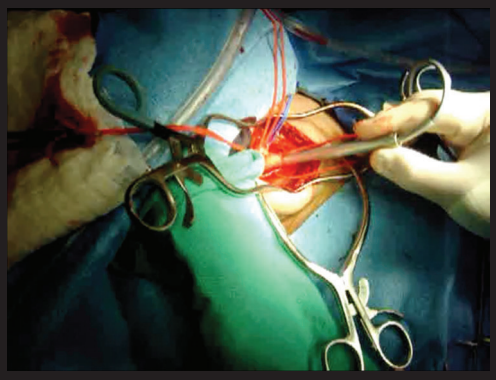
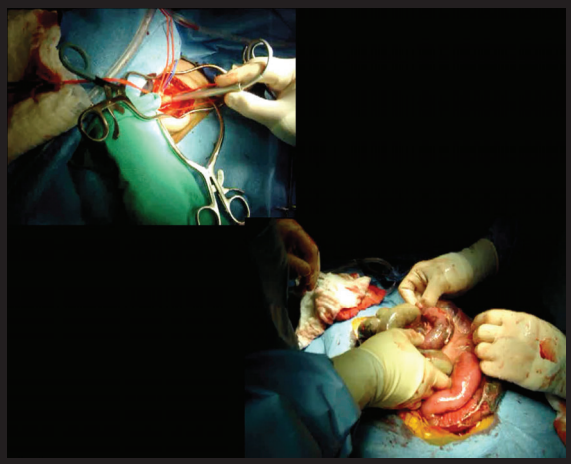
Glycocalyx: What is it and what is it important?

Ulises Baltazar, MD, FACS, CLT
Vascular Surgery
Assistant Professor of Vascular Surgery Weill-Cornell University
Director of the Veno-Lymphatic Service

Houston Methodist Hospital Sugar Land
Sugar Land, Texas

"When you are a hammer….
everything looks like a nail"



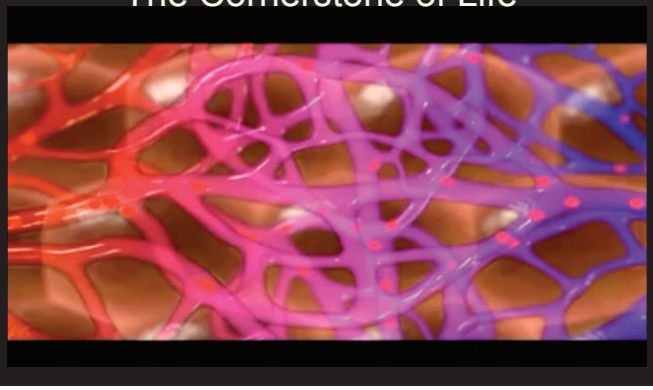


What is

The Cornerstone of Life?

Microcirculation

The Cornerstone of Life



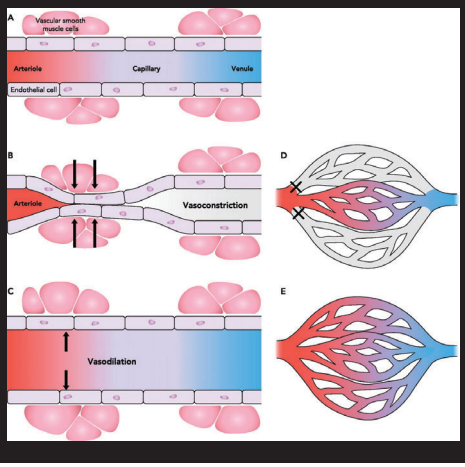
Microcirculation

- Dynamic "organized chaos"
- Empty-filled capillaries
- Fluxmotion

Metabolic
Physical
Humoral
Nervous

"Microcirculation in insulin resistance and diabetes: more than and compilation"
Wienersperger NF, Bouskela, E
Diabetes Metab 2003:29, 6S77-6S87

Microcirculation



Microcirculation

Microcirculation

- Capillary flow regulation (Getting the blood there)
- Hydrostatic - Oncotic equilibrium (Osmosis Starling principle)
- Filtration (Lymph formation revised Starling principle)

Microcirculation

- Capillary flow regulation

Microcirculation

- Capillary flow regulation
  - Arteriolar myogenic response
  - Venoarteriolar reflex
  - Pre capillary arteriolar vasomotion

"Microcirculation in insulin resistance and diabetes: more than and compilation"
Wienersperger NF, Bouskela, E
Diabetes Metab 2003:29, 6S77-6S87

Microcirculation

- Arteriolar vasomotion
  - Nitric Oxide (NO)
  - Endothelium-Derived Hyperpolarizing Factor (EDHF)

"A unique role of NO in the control of blood flow" Pohl U, De Wit C, News Physiol Sci, 19, 74-80, 1999

Microcirculation

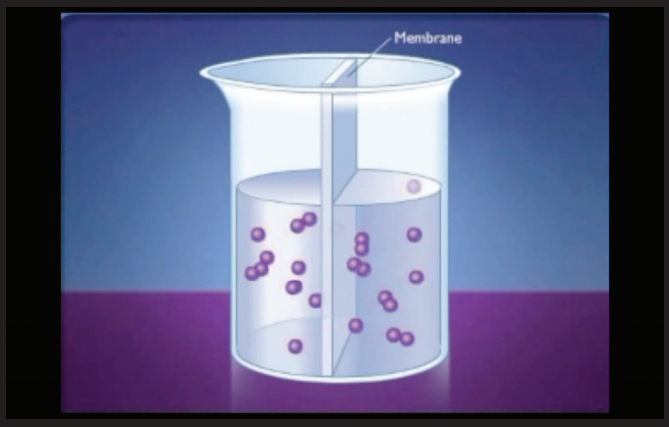
- Arteriolar vasomotion
  - Slow-wave
    - Arteriolar contraction → oscillations of membrane potential
  - High amplitude
  - 1-10 Hz

"Vasomotion and flow motion: physiological mechanisms and clinical evidence" Intlagietta M, Vasc Med Rev, 1, 101-112, 1990
"Electrophysiolocial basis of arteriolar vasomotion in vivo" Bartlet II, Crane GJ, Neidl T, et al, J Vasc Res, 37, 568-575, 2000

Microcirculation

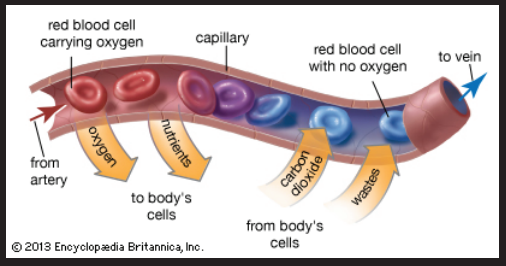
- Hydrostatic - Oncotic equilibrium

Microcirculation



Microcirculation

Hydrostatic-Oncotic pressure
Arterioles-Venues



Microcirculation

- Filtration

Microcirculation

Carl Friedrich Weilheim Ludwig
1816-1895

- Suggested that lymph was formed by plasma filtration through capillary walls

Microcirculation

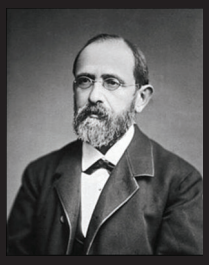
Julius Friedrich Cohnheim
1839-1884

- Expanded Ludwig's concept to vascular pressure and different capillary permeability throughout the body

Microcirculation

Rudolph Peter Heinrich Heidenhain
1834-1897

- 1854 published his secretion theory and his work on lymphagogues substances (crayfish extract)



Microcirculation

Ernest Henry Starling
1866-1927

- 1893 Intravenous injection of peptones

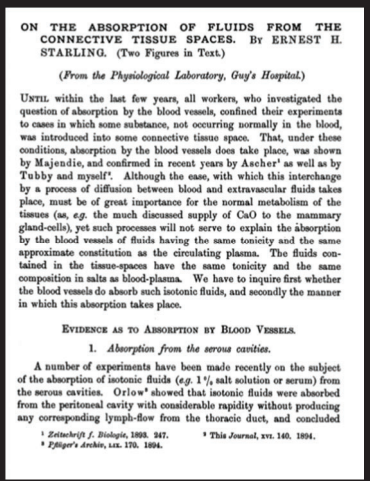
Microcirculation

Starling Principle

Ernest Henry Starling
1866-1927

- 1896 Basic concept of tissue fluid absorption
- Incomplete

Microcirculation



ON THE ABSORPTION OF FLUIDS FROM THE CONNECTIVE TISSUE SPACES. By ERNEST H. STARLING. (Two Figures in Text.)

(*From the Physiological Laboratory, Guy's Hospital.*)

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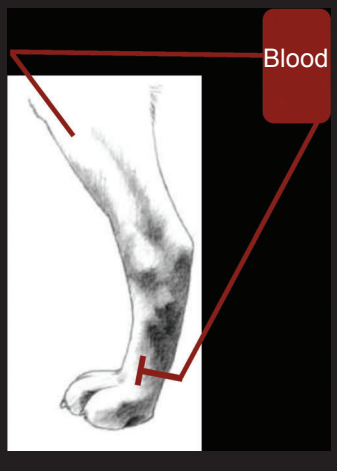
Evidence as to Absorption by Blood Vessels.

1. *Absorption from the serous cavities.*

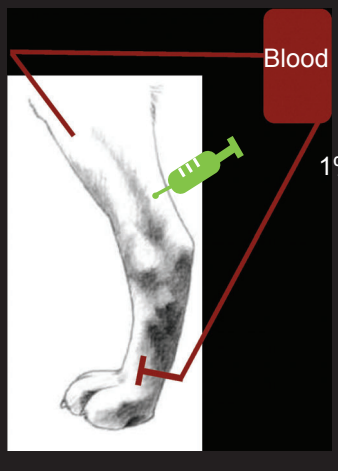
A number of experiments have been made recently on the subject of the absorption of isotonic fluids (*e.g.* 1 % salt solution or serum) from the serous cavities. Orlow[3] showed that isotonic fluids were absorbed from the peritoneal cavity with considerable rapidity without producing any corresponding lymph-flow from the thoracic duct, and concluded

[1] *Zeitschrift f. Biologie*, 1893. 247.
[2] This *Journal*, xvi. 140. 1894.
[3] *Pflüger's Archiv*, lix. 170. 1894.

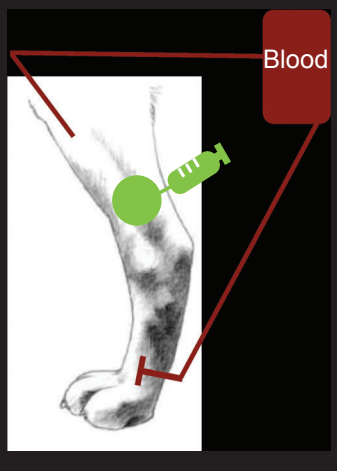
Microcirculation



Microcirculation



Microcirculation



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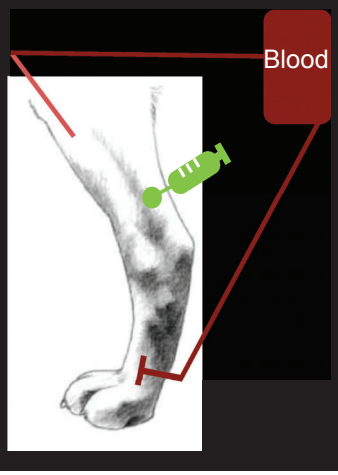
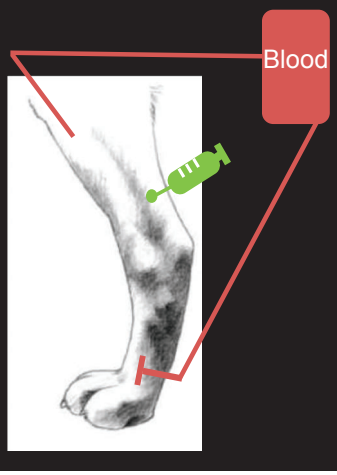
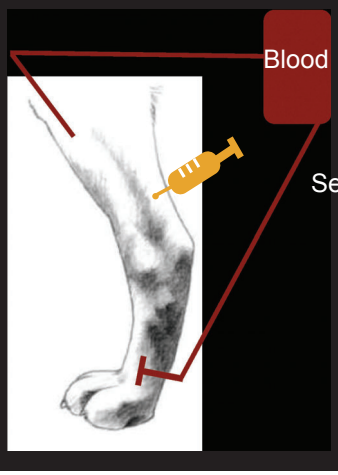


Microcirculation



Microcirculation



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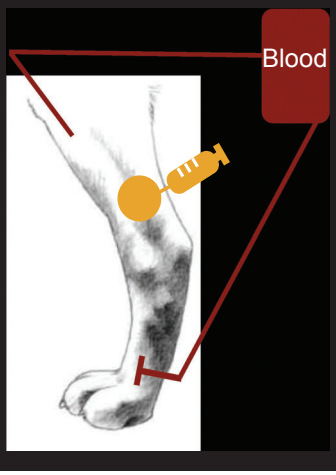
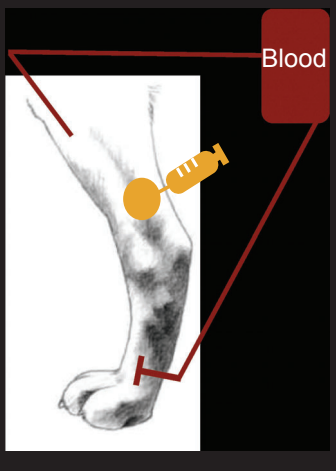


Microcirculation



Microcirculation

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Microcirculation

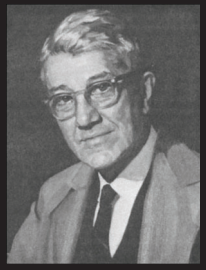
William D Haliburton
1860-1931

- 1904 disputed Starling's discoveries and he believed that filtration dominated over secretion

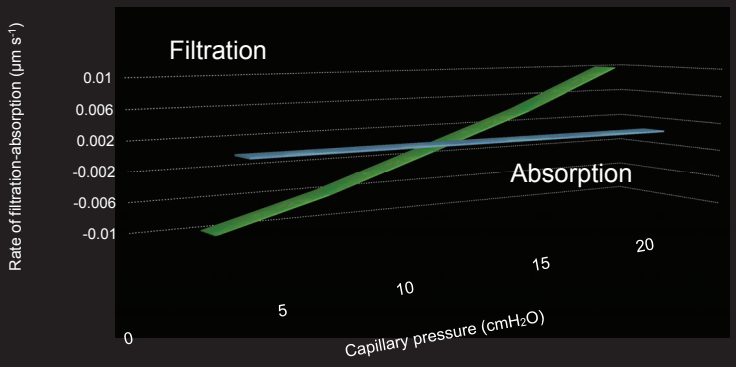
Microcirculation

Eugene Markley Landis
1901-1987

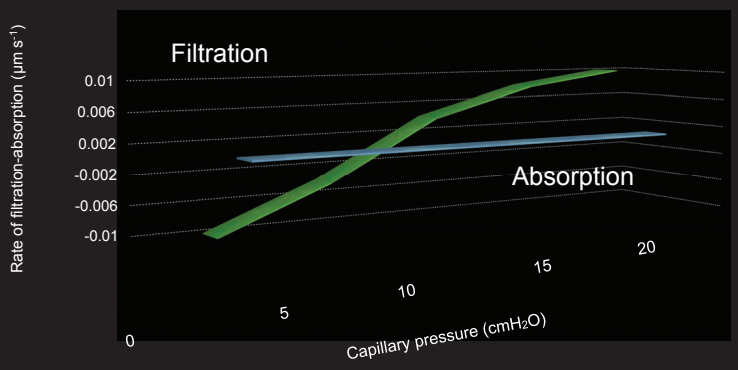
- 1927 first direct experimental evidence of Starling's principle



Microcirculation

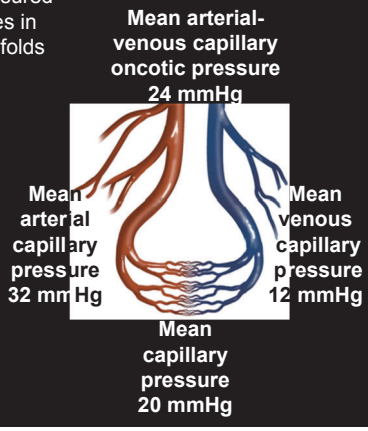


Microcirculation

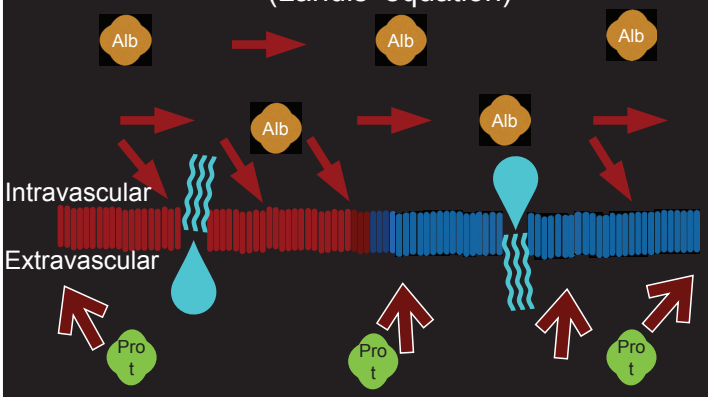


Microcirculation

- 1930 Landis measured capillary pressures in human fingernail folds at heart level



Starling's Principle (Landis' equation)



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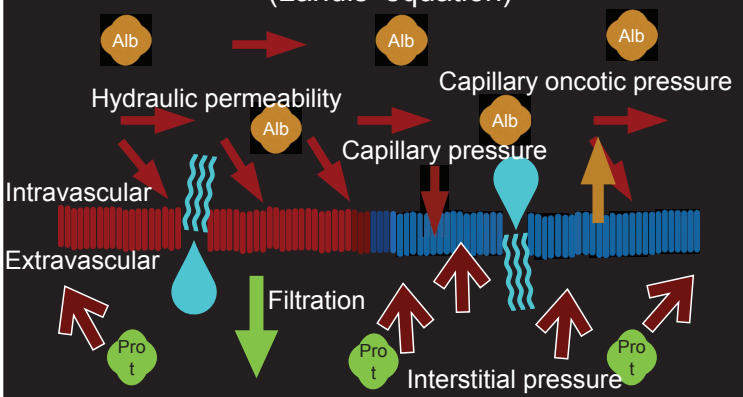
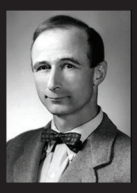


$$Jv/A = L_p((P_c - P_i) - (\Pi_c - \Pi_i))$$

Microcirculation

Armando Soto-Rivera
1920-2004



John Richard Pappenheimer
1915-2007

- 1948 they proposed the term isogravimetric state

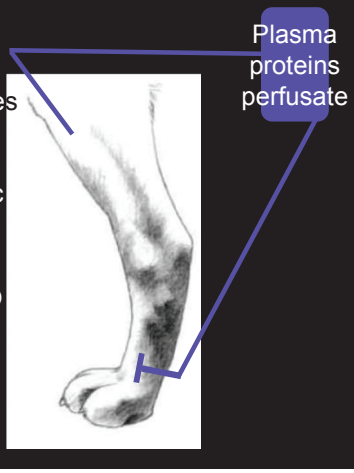
Microcirculation

Constant limb weight=0 net fluid movement=isogravimetric state

Microcirculation

Capillary pressure varies according the plasma oncotic pressure to achieve isogravimetric state

Rate of filtration-reabsorption=P_c-$P_{c(iso)}$

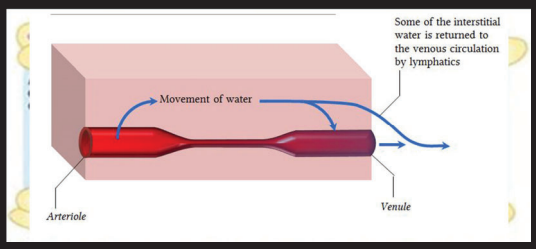


Plasma proteins perfusate

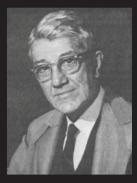
Microcirculation

Classic Starling Principle

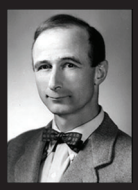
- Landis, Pappenheimer and Soto-Rivera
- Krogh, Landis and Turner 1931
  - Hydrostatic and oncotic pressures



Microcirculation



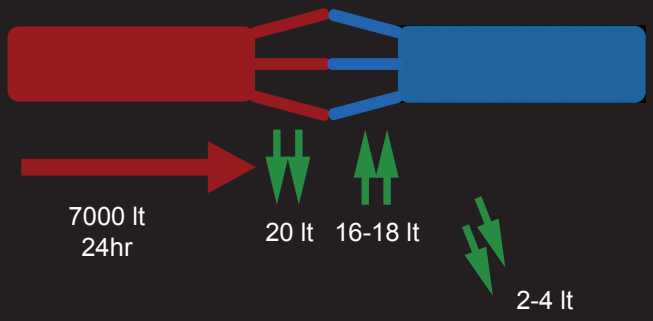
Eugene Markley Landis
1901-1987



John Richard Pappenheimer
1915-2007

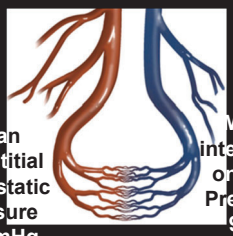
- 1963 quatinfied the values of filtration-absorption

Microcirculation



Microcirculation

- 1963 Guyton measured the interstitial hydrostatic and oncotic pressures



Mean Interstitial hydrostatic pressure -2 mmHg

Mean interstitial oncotic Pressure 9-12 mmHg

Microcirculation

P_c=32 mmHg π_c=24 mmHg	P_c=20 mmHg π_c=24 mmHg	P_c=12 mmHg π_c=24 mmHg
P_i=-2 mmHg π_i=9-12 mmHg	P_i=0 mmHg π_i=9-12 mmHg	P_i=0 mmHg π_i=9-12 mmHg

Microcirculation

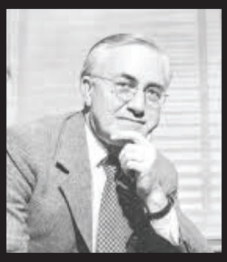
Ernest Ruska
1906-1988

Max Knoll
1897-1969

- 1931 developed the electron microscope. 10 nm resolution
- 1944 2 nm resolution

Microcirculation

James Frederic Danielli
1911-1984



- 1940 First postulated the presence of the Glycocalyx

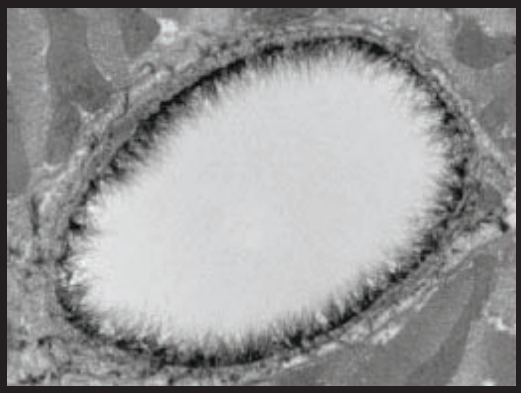
Microcirculation

Glycocalyx

- Hydrogel-like layer
- Hemodynamic function 1970
- Main structure
  - Glycoproteins y proteoglycans

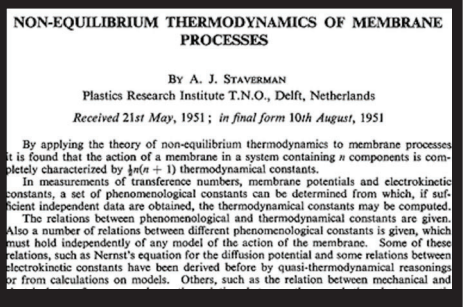
Microcirculation

Glycocalyx



Microcirculation

1951 Staverman's Reflection Coefficient



NON-EQUILIBRIUM THERMODYNAMICS OF MEMBRANE PROCESSES

By A. J. Staverman
Plastics Research Institute T.N.O., Delft, Netherlands

Received 21st May, 1951; *in final form 10th August*, 1951

By applying the theory of non-equilibrium thermodynamics to membrane processes it is found that the action of a membrane in a system containing n components is completely characterized by $\frac{1}{2}n(n+1)$ thermodynamical constants.

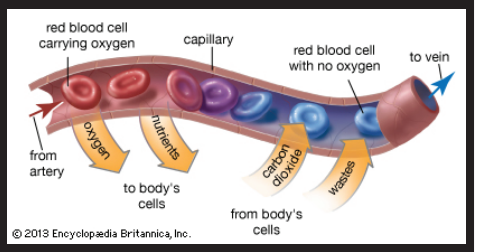
In measurements of transference numbers, membrane potentials and electrokinetic constants, a set of phenomenological constants can be determined from which, if sufficient independent data are obtained, the thermodynamical constants may be computed.

The relations between phenomenological and thermodynamical constants are given. Also a number of relations between different phenomenological constants is given, which must hold independently of any model of the action of the membrane. Some of these relations, such as Nernst's equation for the diffusion potential and some relations between electrokinetic constants have been derived before by quasi-thermodynamical reasonings or from calculations on models. Others, such as the relation between mechanical and

Microcirculation

1951 Staverman's Reflection Coefficient

Vessel Permeability
Tight or moderate
<3nm
Fenestration
>3nm

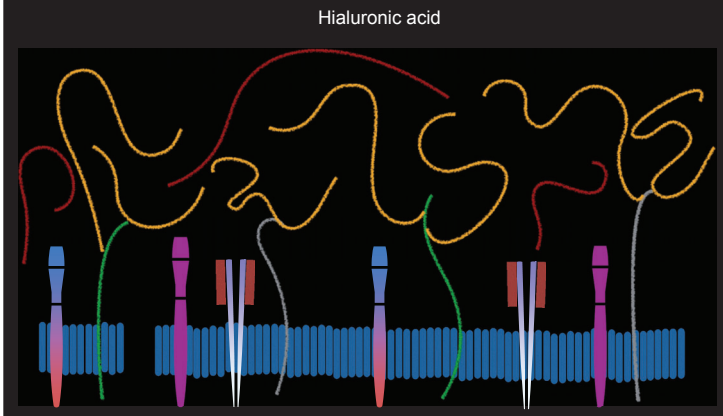


Lymphedema

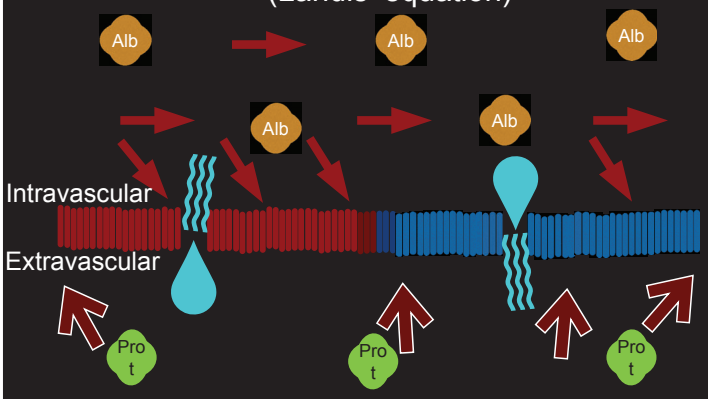
Glycocalyx

- 500-2000 nm
- Total surface 4000 - 7000 m^2 (0.98 - 1.7 acres)
- Negative net charge
- Rheologic function and microenviroment control

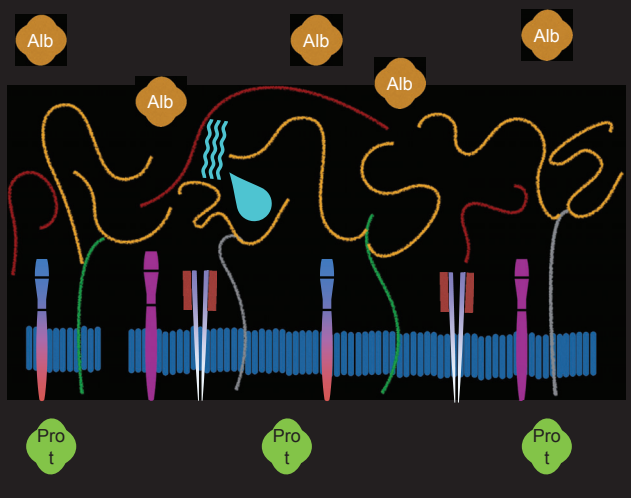
Glycocalyx model



Starling's Principle (Landis' equation)



Glycocalyx model



Microcirculation

Charles C Michel

Roger H Adamson

J Rodney Levick

Sheldon Weinbaum

Microcirculation

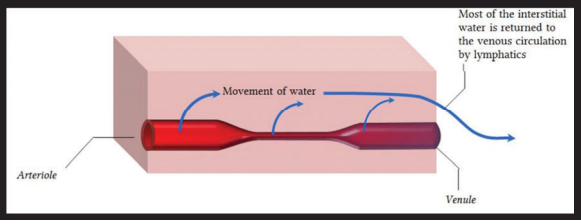
Charles C Michel

- 70's-60's replicated Starling's findings
- 1987 Transient-state and Steady-state of absorption

Lymphedema

Revised Starling Principle

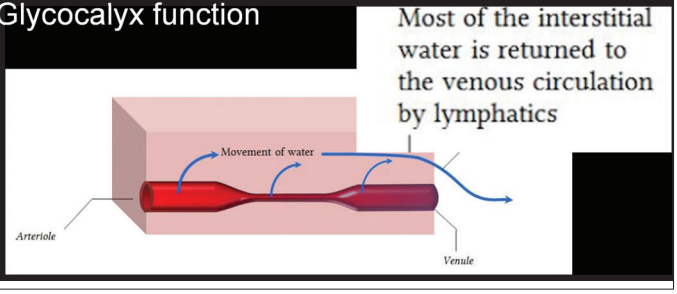
- Adamson 2004- Levick and Michel 2010
  - Glycocalyx function



Lymphedema

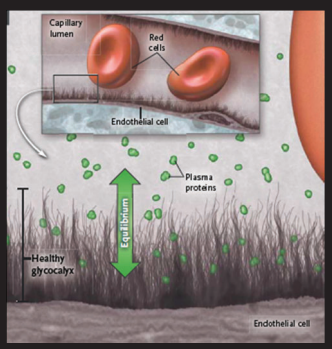
Revised Starling Principle

- Adamson 2004- Levin and Michel 2010
  - Glycocalyx function

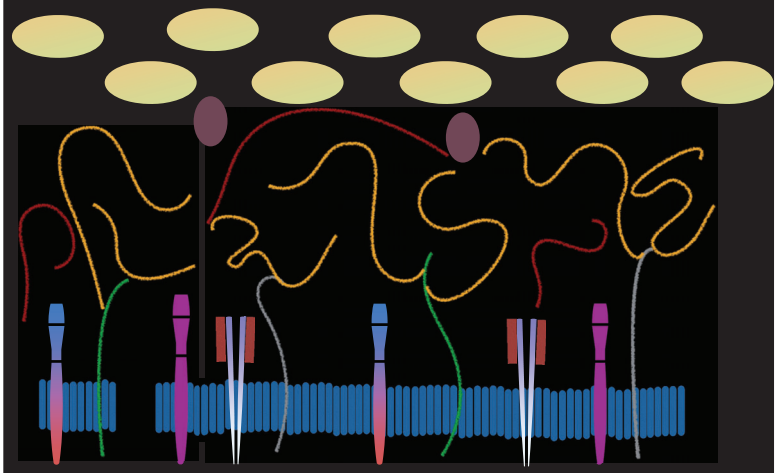


Lymphedema

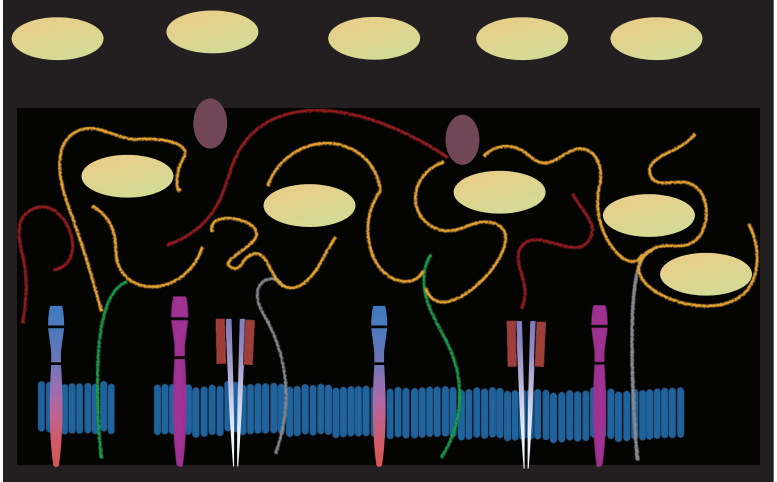
Glycocalyx model



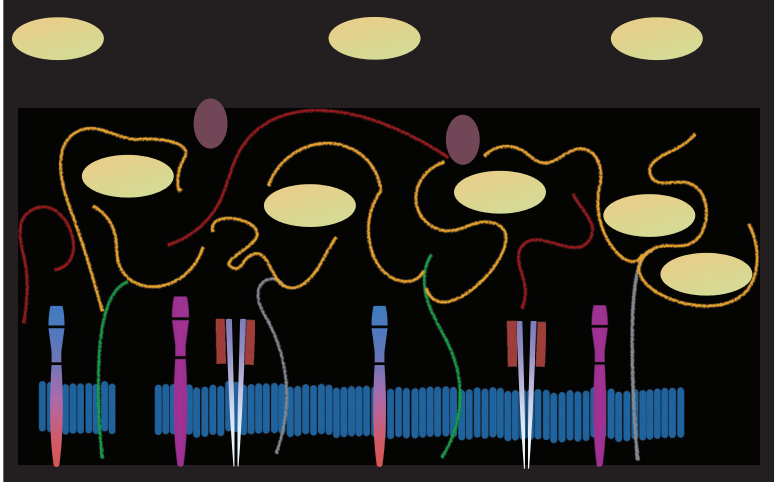
Glycocalyx model



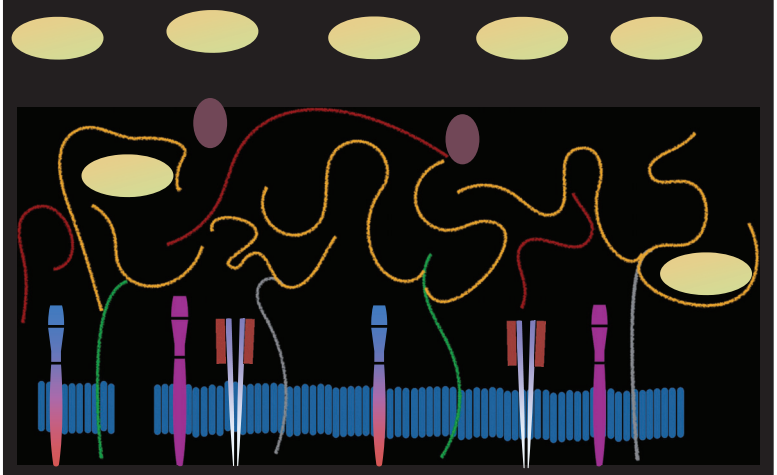
Glycocalyx model



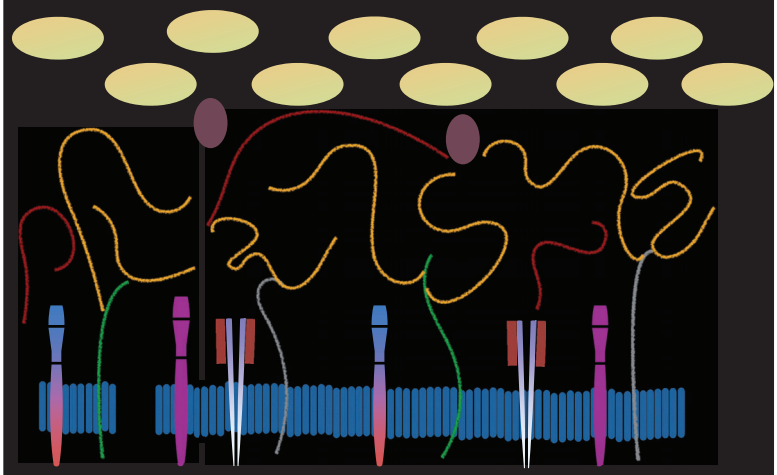
Glycocalyx model



Glycocalyx model

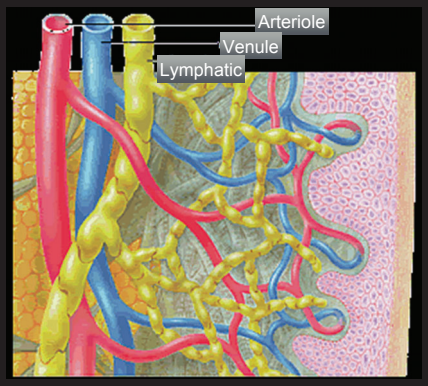


Glycocalyx model



1-1.5 liters of fluid

Microcirculation



Lymphedema

- Tobias Bertsch, MD
- Guenter Klose, CLT

TEAM EFFORT!!!!

Sadly some patients can't be helped