Author(s): Louis D'Alecy, 2009

Citation Key

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Microcirculation

M1 – Cardiovascular/Respiratory Sequence

Louis D'Alecy, Ph.D.

Fall 2008

Monday 11/10/08, 10:00

Microcirculation, Exchange

25 slides, 50 minutes

1. Microcirculation
2. Diffusion
3. Exchange
    - Delivery
    - Removal
4. Ultrafiltration
5. Starling hypothesis

Essential Role of Cardiovascular System in Homeostasis
~ “constancy” of internal environment

(1) Adequate blood **flow** through capillaries

(2) Blood **composition** adequate for maintaining interstitial fluid composition

MICROCIRCULATION

Site of:

1. **regulation of tissue blood flow**
2. **nutrient & waste exchange between blood and cells**
3. **fluid exchange between plasma & interstitialfluid**
4. **Leukocyte migration between blood and interstitial fluid**

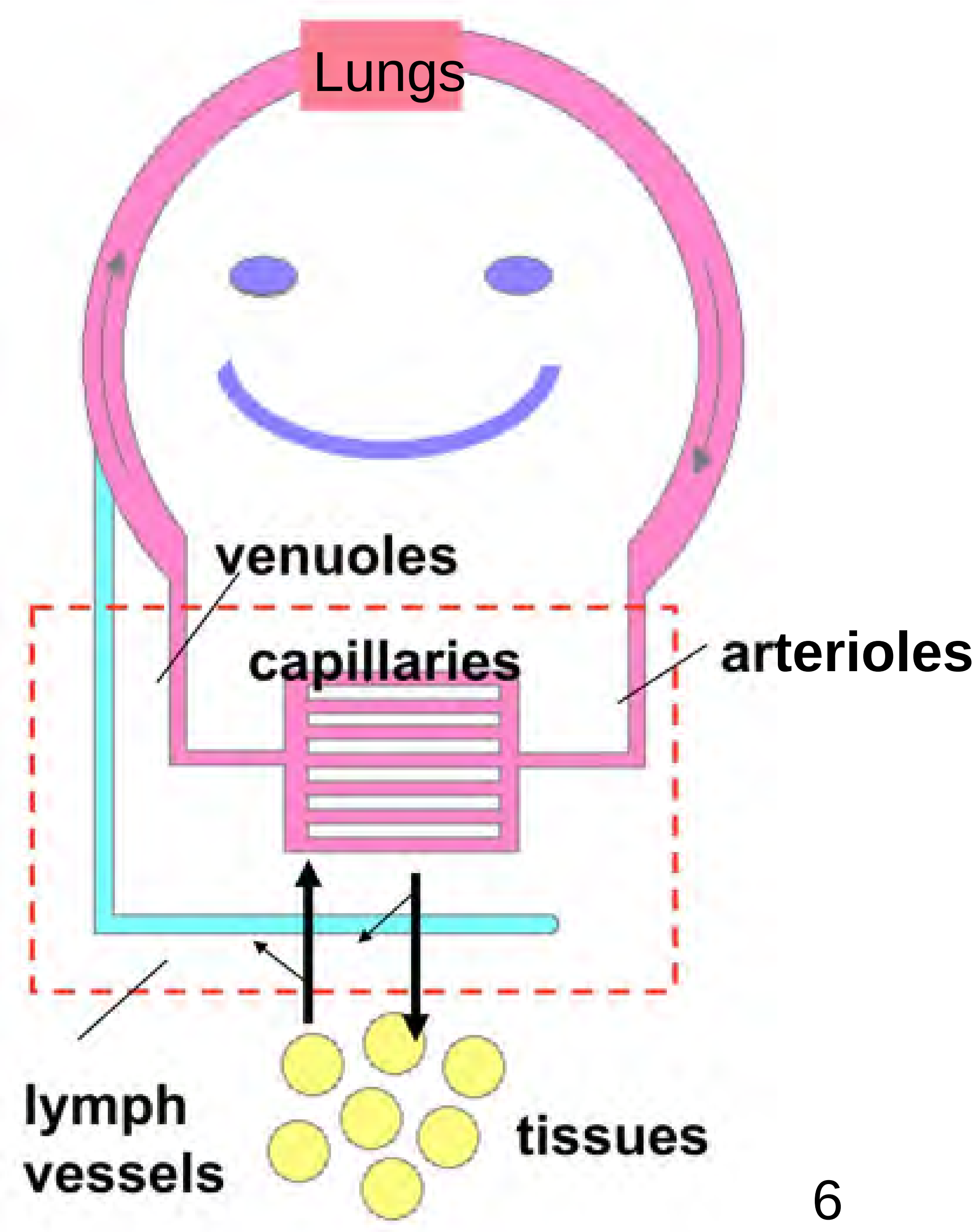


Image of
microcirculation
removed

Please see: http://www.bg.ic.ac.uk/Staff/khparker/homepage/BSc_lectures/2002/Capillary_sketch.jpg

CAPILLARY BLOOD FLOW

Velocity: 300 -1000 µm/sec

capillaries 0.5 - 1.0 mm long (500-1000 µm)

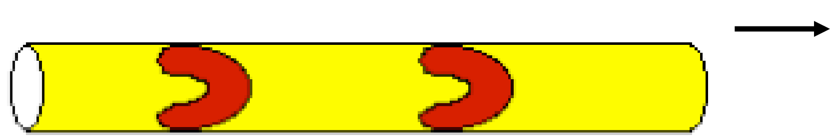
mean resting transit time 1 sec (0.5 - 2 sec)

exercise (increased CO) transit time 0.25 sec

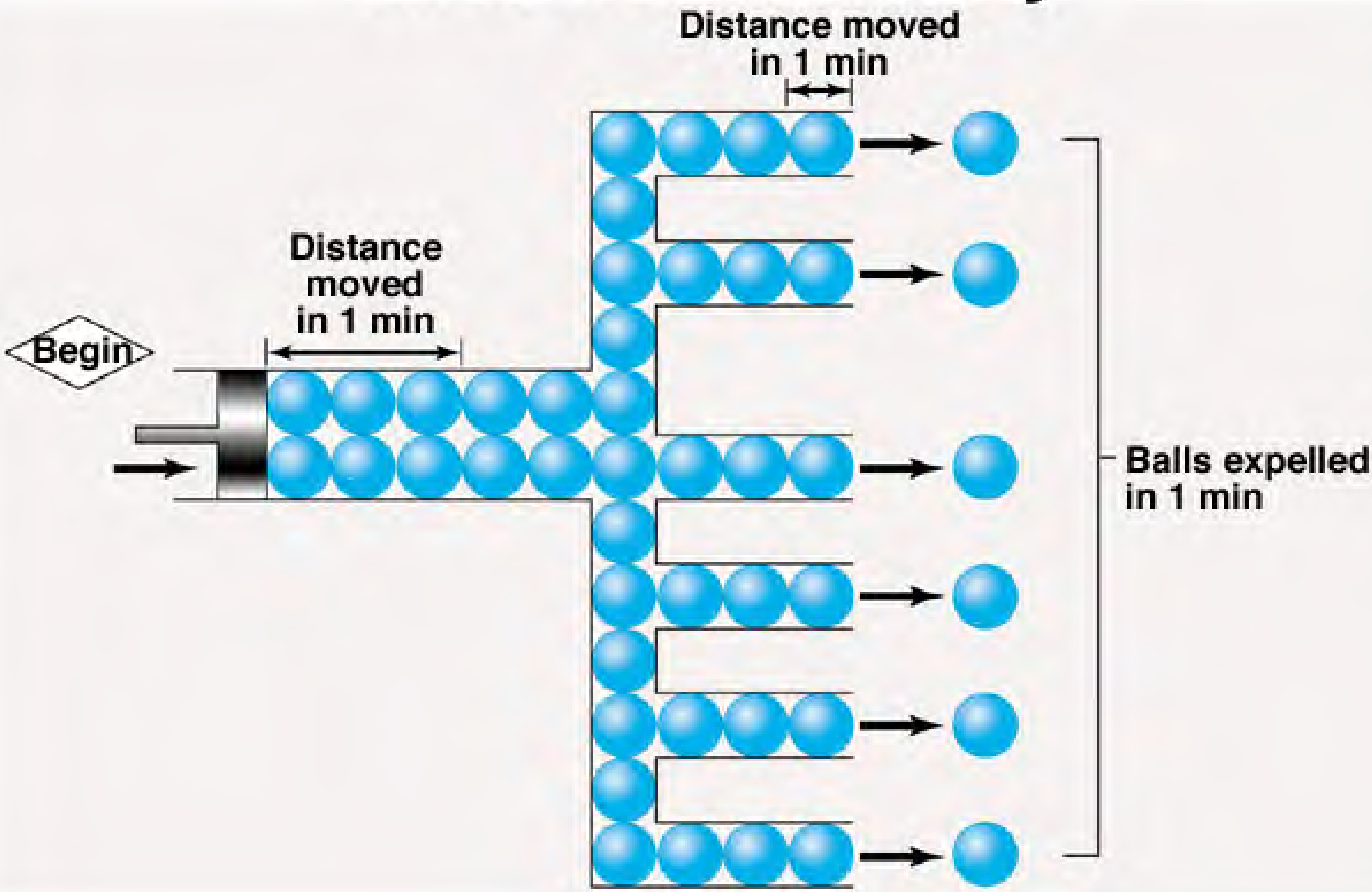
Vasomotion: flow waxes and wanes at approximately 15 second intervals due to local build up of metabolic vasodilators

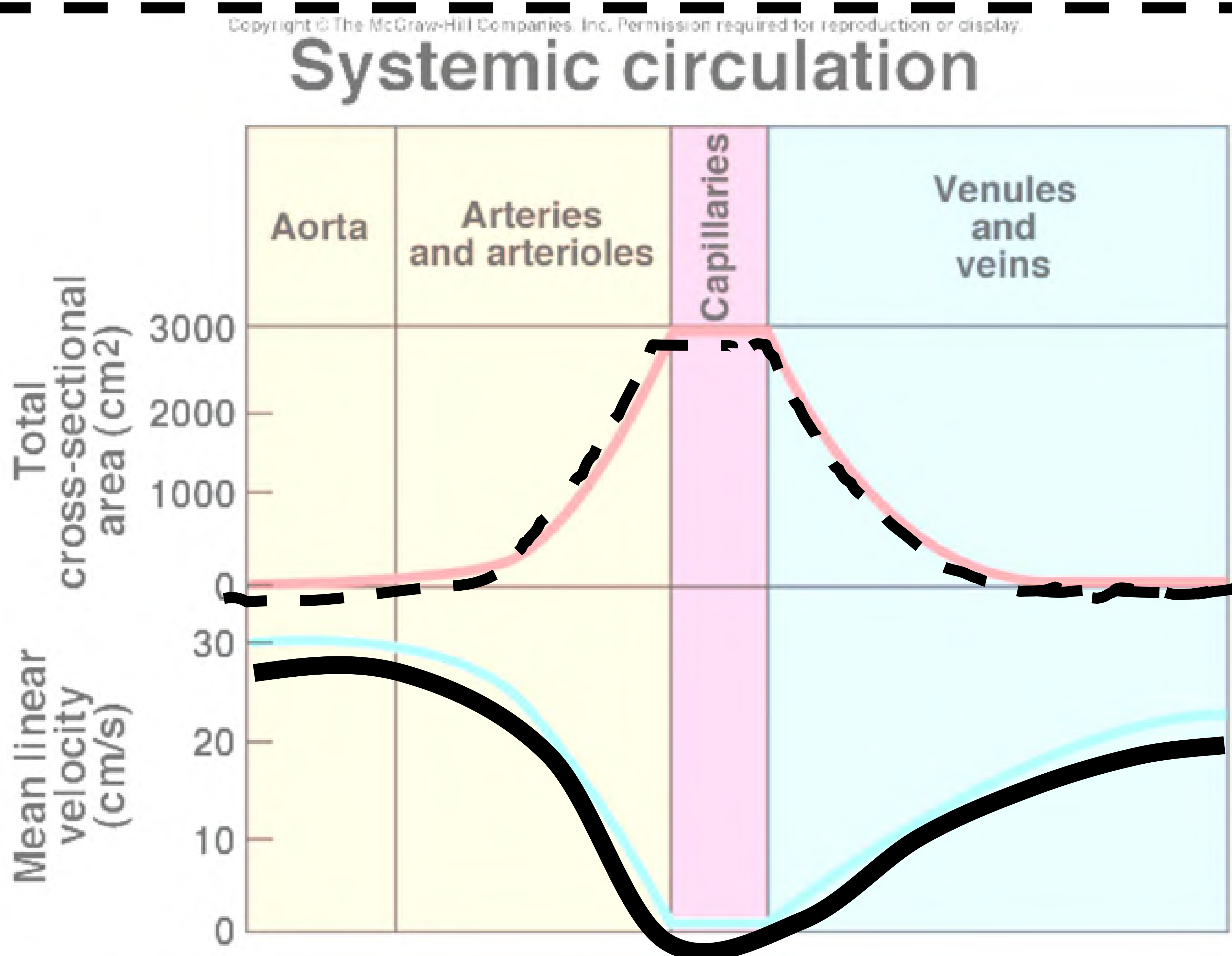
Plug flow: capillary diameter 5-8 µm,

RBC diameter 7 µm



Total cross-sectional area/flow velocity

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Systemic circulation
Aorta
Arteries and arterioles
Capillaries
Venules and veins
Total cross-sectional area (cm2)
3000
2000
1000
0
Mean linear velocity (cm/s)
30
20
10
0

McGraw-Hill

Effective Capillary Surface Area (not fixed)

Capillary Number per unit volume varies in different tissues
Thus so does total surface area cm^2 /g tissue

Skeletal muscle = 100 cm^2 /g vs. Heart & brain = 500 cm^2 /g

Under resting conditions not all of capillaries are open at same time nor do them have the same transit times.

Increased metabolic activity by way of local metabolites can recruit capillaries (↑#)
- increasing exchange area (↑A) and
- decreasing diffusion distance (↓ L) to cells

Four Factors Determine the Rate of Diffusion (X_d)

1) Diffusion Coefficient (D) **+**

2) Surface area available for diffusion (A) **+**

3) Concentration difference (Δ [x]) **+**

4) Distance to diffuse (L) **-**

Diffusion

$$X_d = DA \frac{\Delta [x]}{L}$$

X_d = rate of diffusion

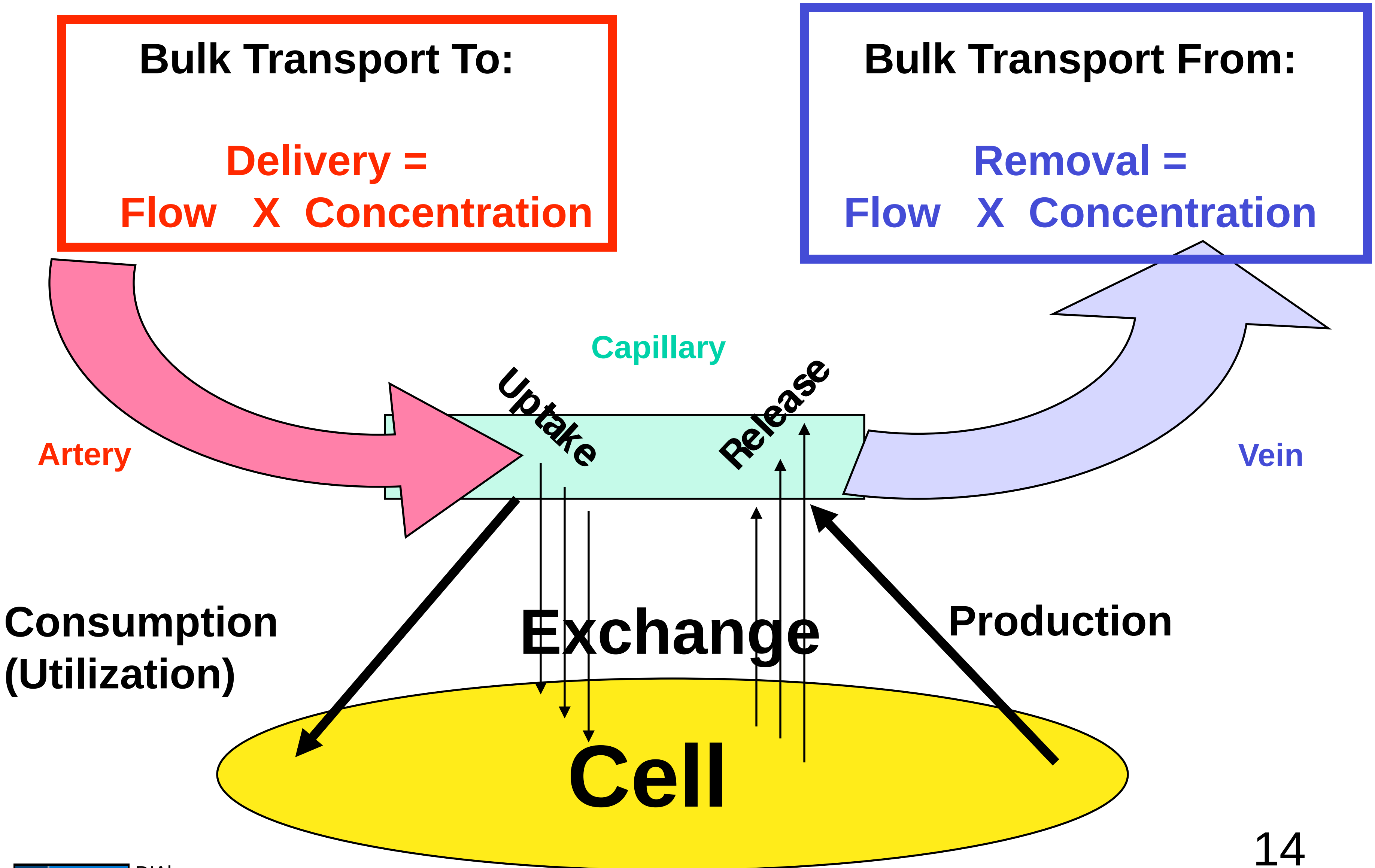
D = diffusion coefficient

A = surface are available for diffusion

$\Delta [x]$ = concentration difference

L = distance to diffuse

METABOLIC EXCHANGE



Tissue Delivery

Delivery = F x Concentration

(mg/min) = (L /min) x (mg/L)

<u>FLOW LIMITED EXCHANGE</u> occurs when diffusing substance has high capillary permeability and exchange is increase by:

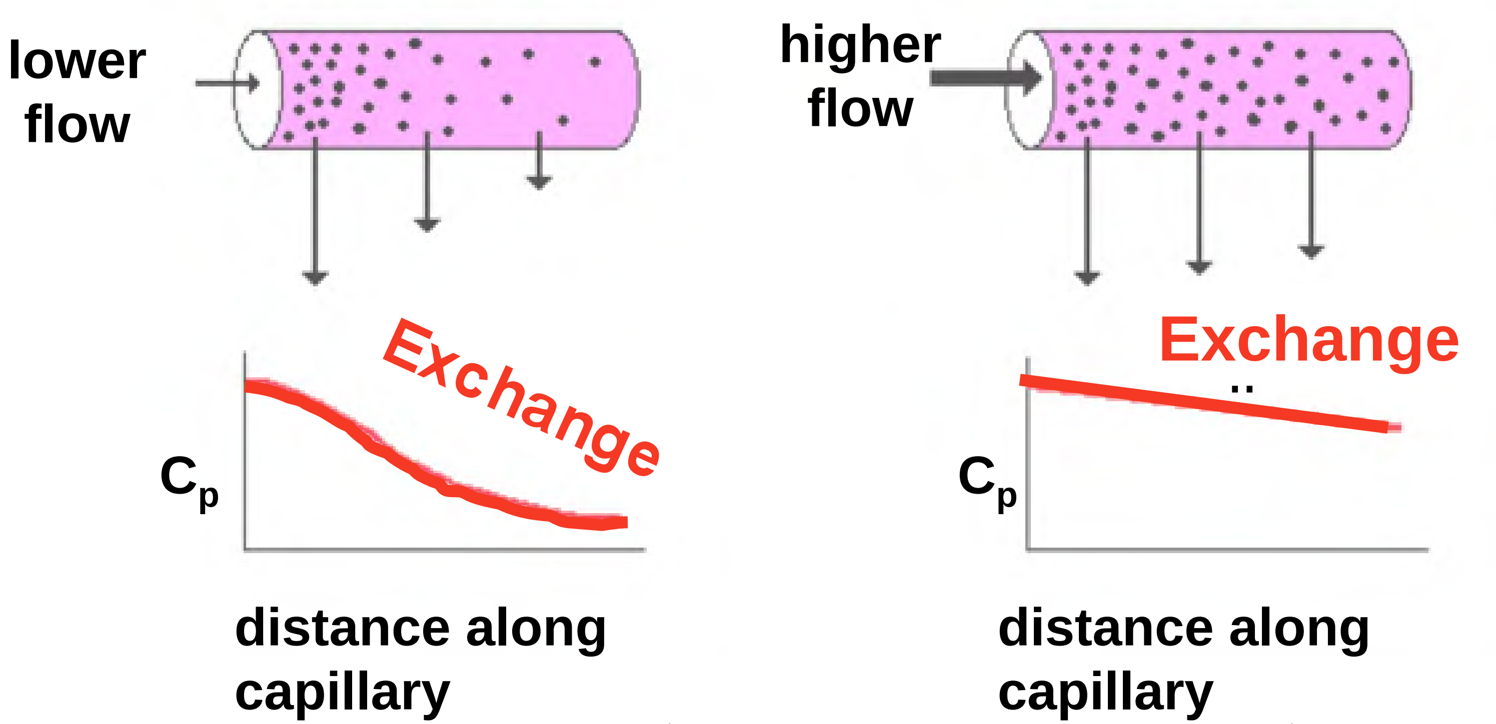
1) increasing Conc. Or 2) increasing flow

<u>DIFFUSION LIMITED EXCHANGE</u> occurs when diffusing substance has low capillary permeability and exchange is increase by:

1) increasing Conc. 2) increasing area by increasing number

Flow Limited Exchange (Diffusion)

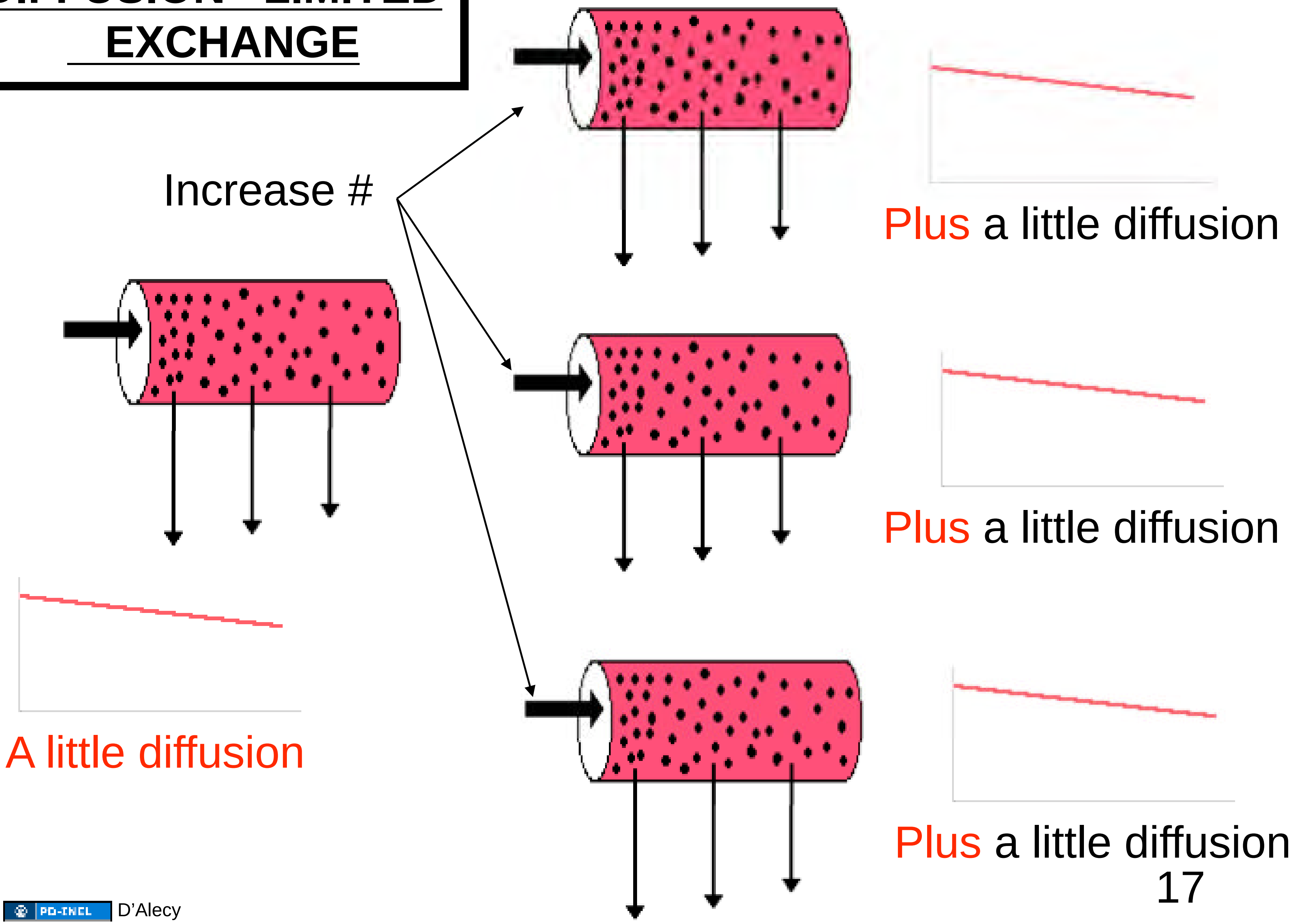
$$\text{Exchange} = X_d = DA \frac{\Delta [C_p - C_{isf}]}{L}$$

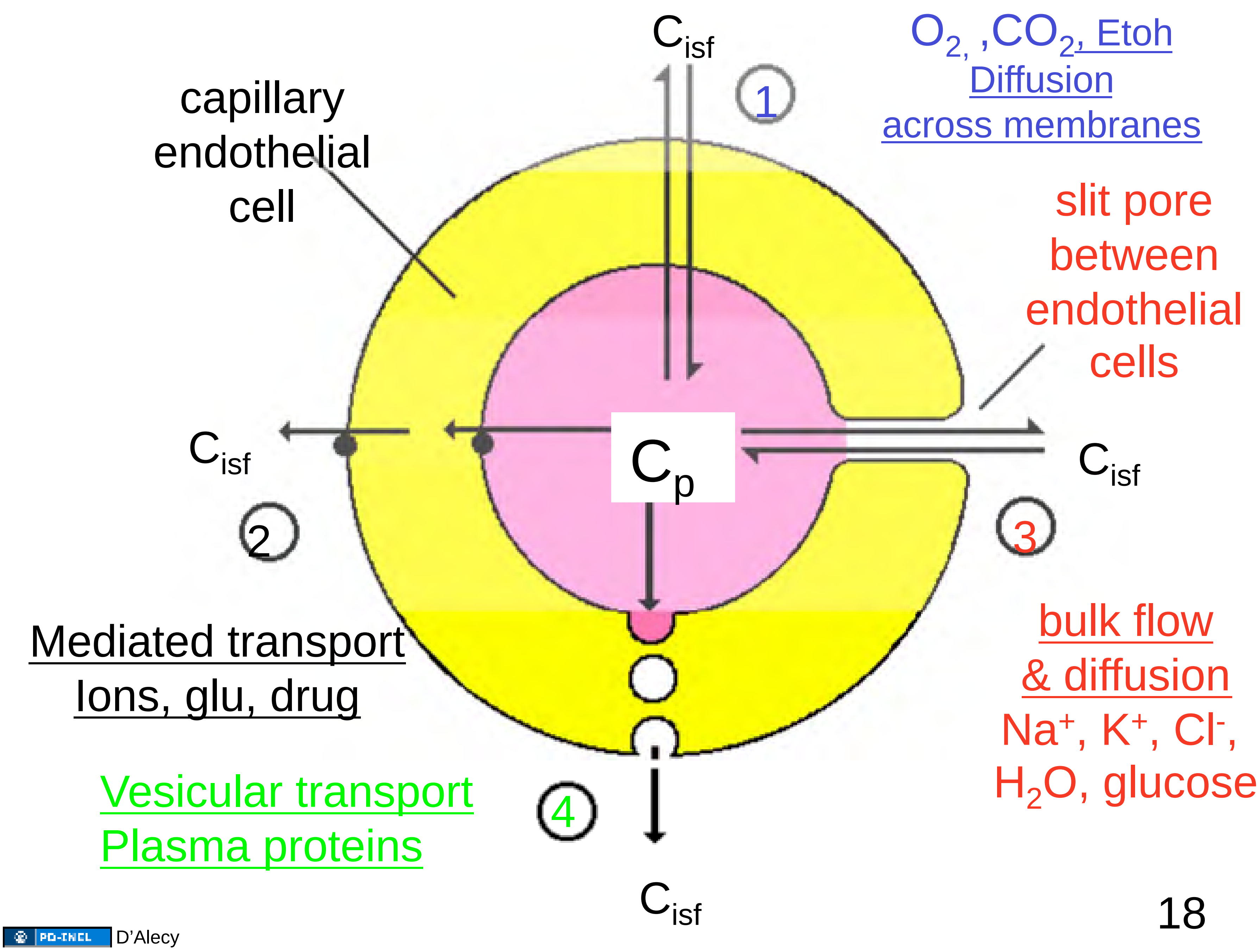


↑ arteriolar vasodilation → ↑ capillary flow → ↑ Exchange

DIFFUSION LIMITED EXCHANGE

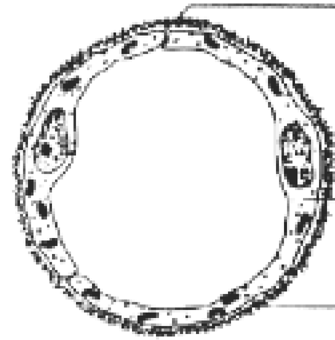
More # capillaries → more diffusion





C_{isf}
O_2, CO_2, Etoh
Diffusion
across membranes
1
capillary
endothelial
cell
slit pore
between
endothelial
cells
C_{isf}
C_p
C_{isf}
2
3
Mediated transport
Ions, glu, drug
bulk flow
& diffusion
Na^+, K^+, Cl^-,
H_2O, glucose
Vesicular transport
Plasma proteins
4
C_{isf}
PD-INEL D'Alecy

continuous capillary



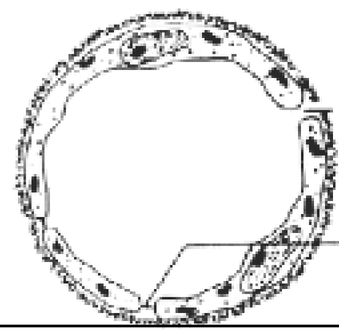
cell junction (slit pore)

endothelial cell

basement membrane

muscle, connective tissue, brain and exocrine glands

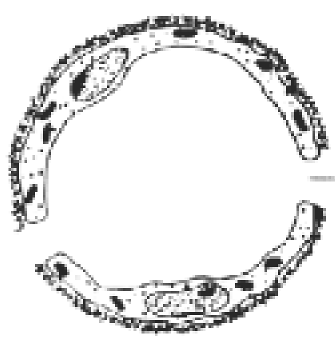
fenestrated capillary



diaphragm

kidney, intestines and endocrine glands

discontinuous capillary

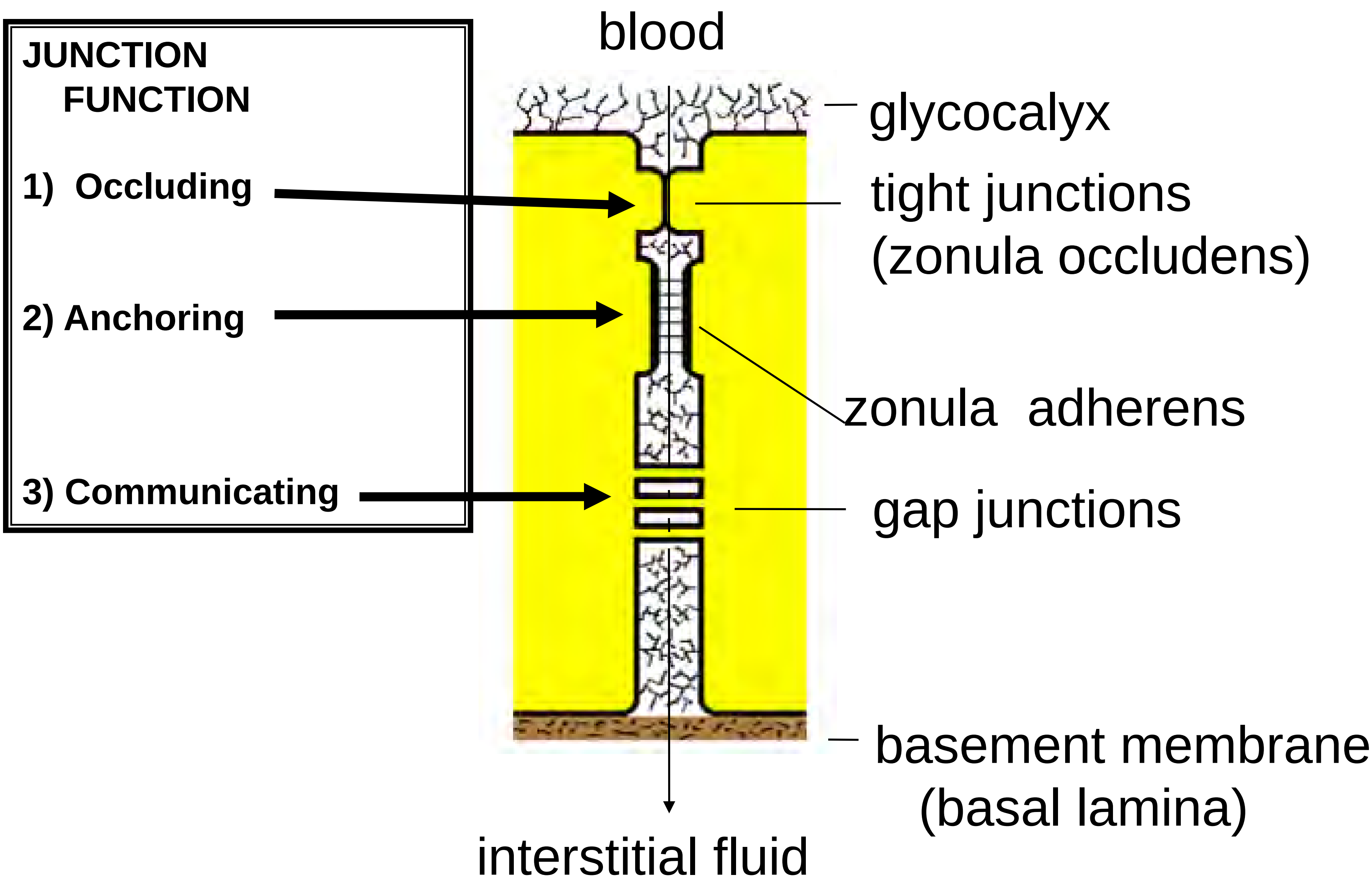


large gap

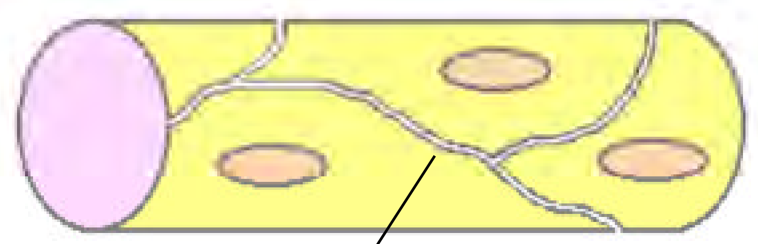
liver, bone marrow and spleen

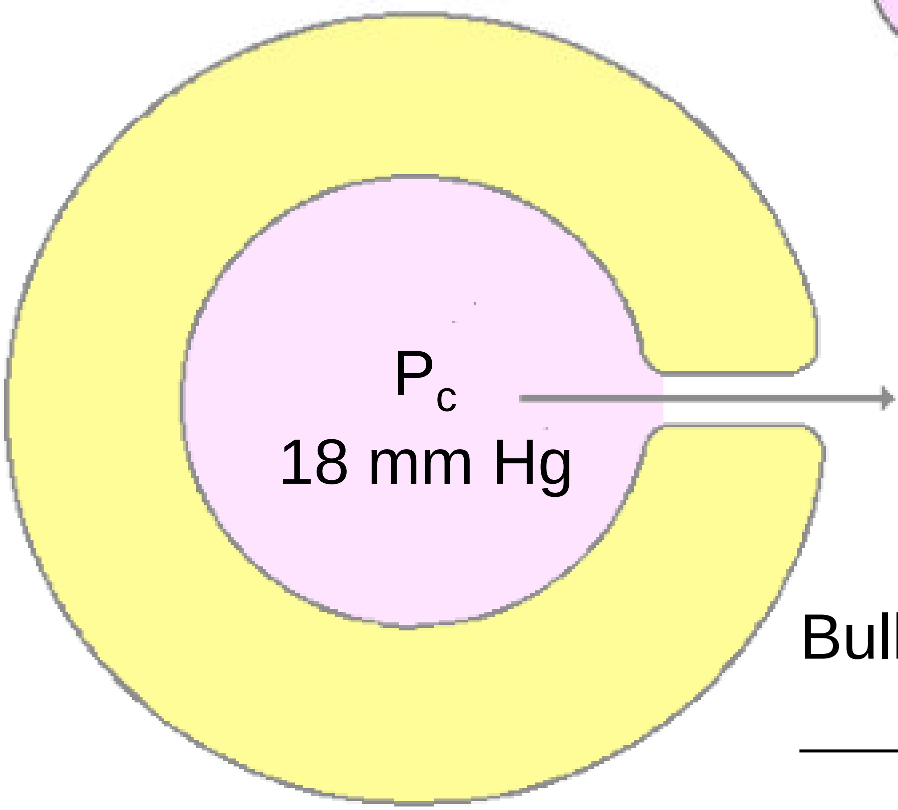
increasing capillary permeability

Endothelial Cell Junctions



ULTRAFILTRATION





capillary slit pores

P_{isf}

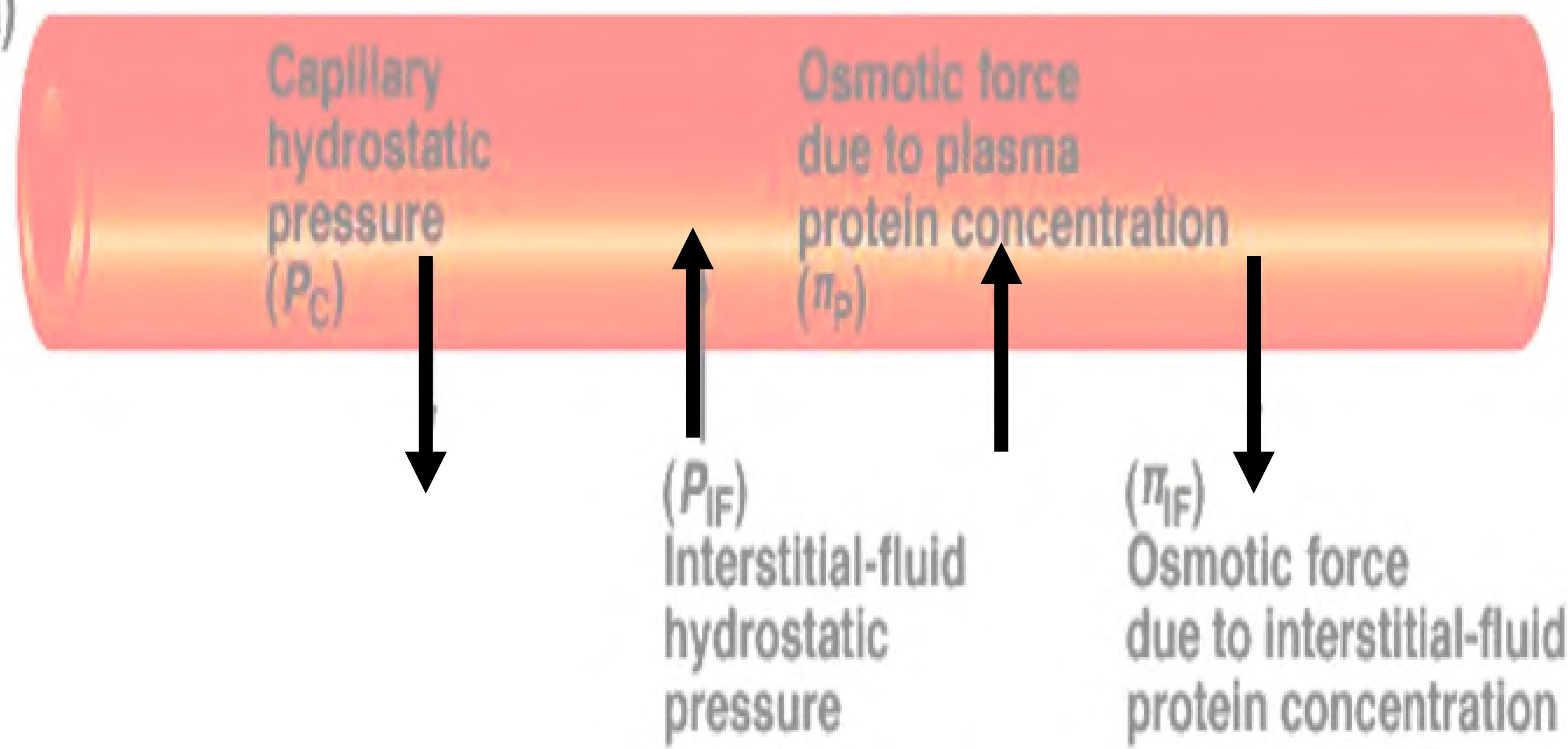
- 3 mm Hg

Bulk Flow Slit = $\frac{\Delta P = 21 \text{mm Hg}}{R}$

Bulk Flow Slit = $\frac{(P_c - P_{isf})}{R_{slit}}$

Fluid movement across capillaries

(a)

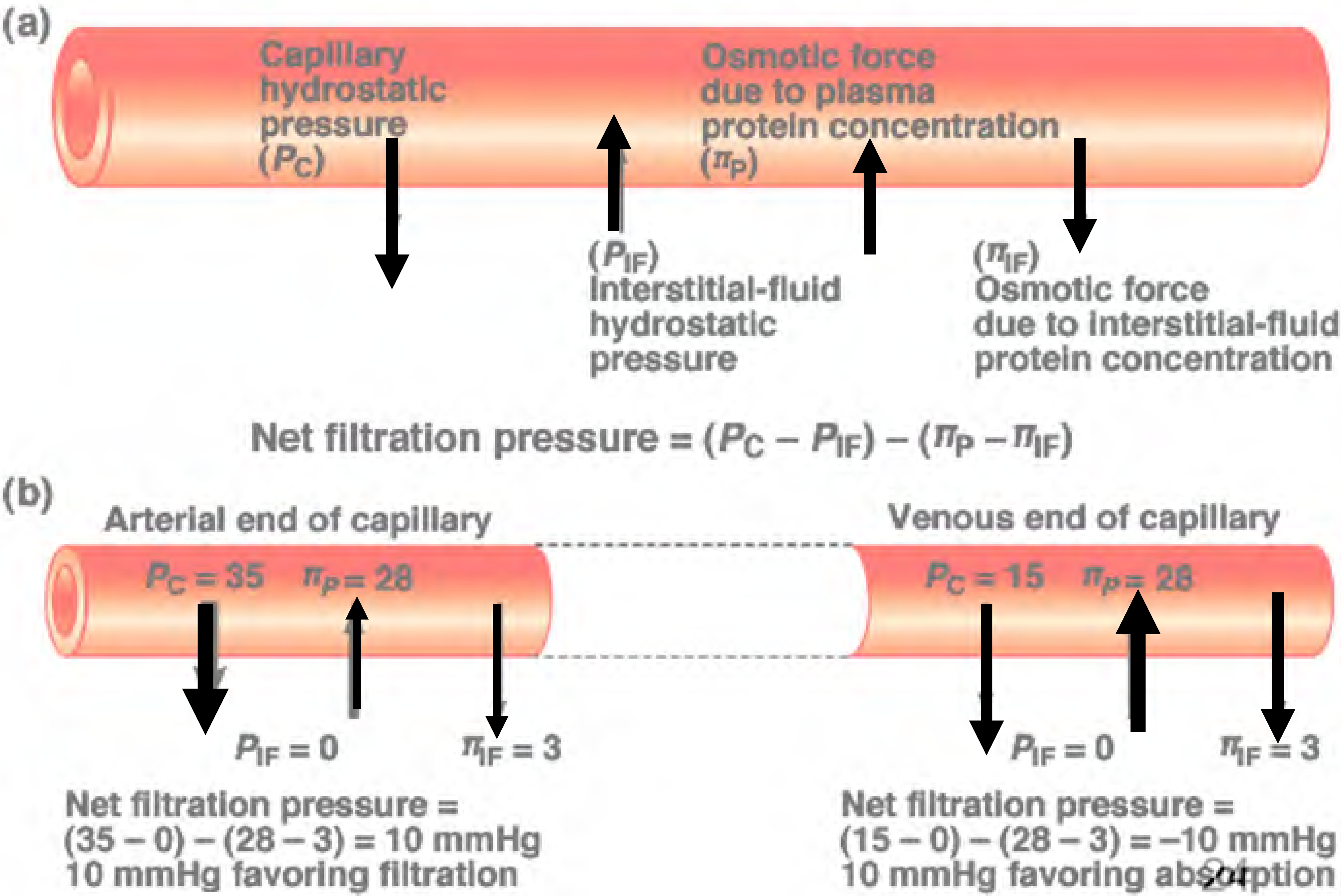


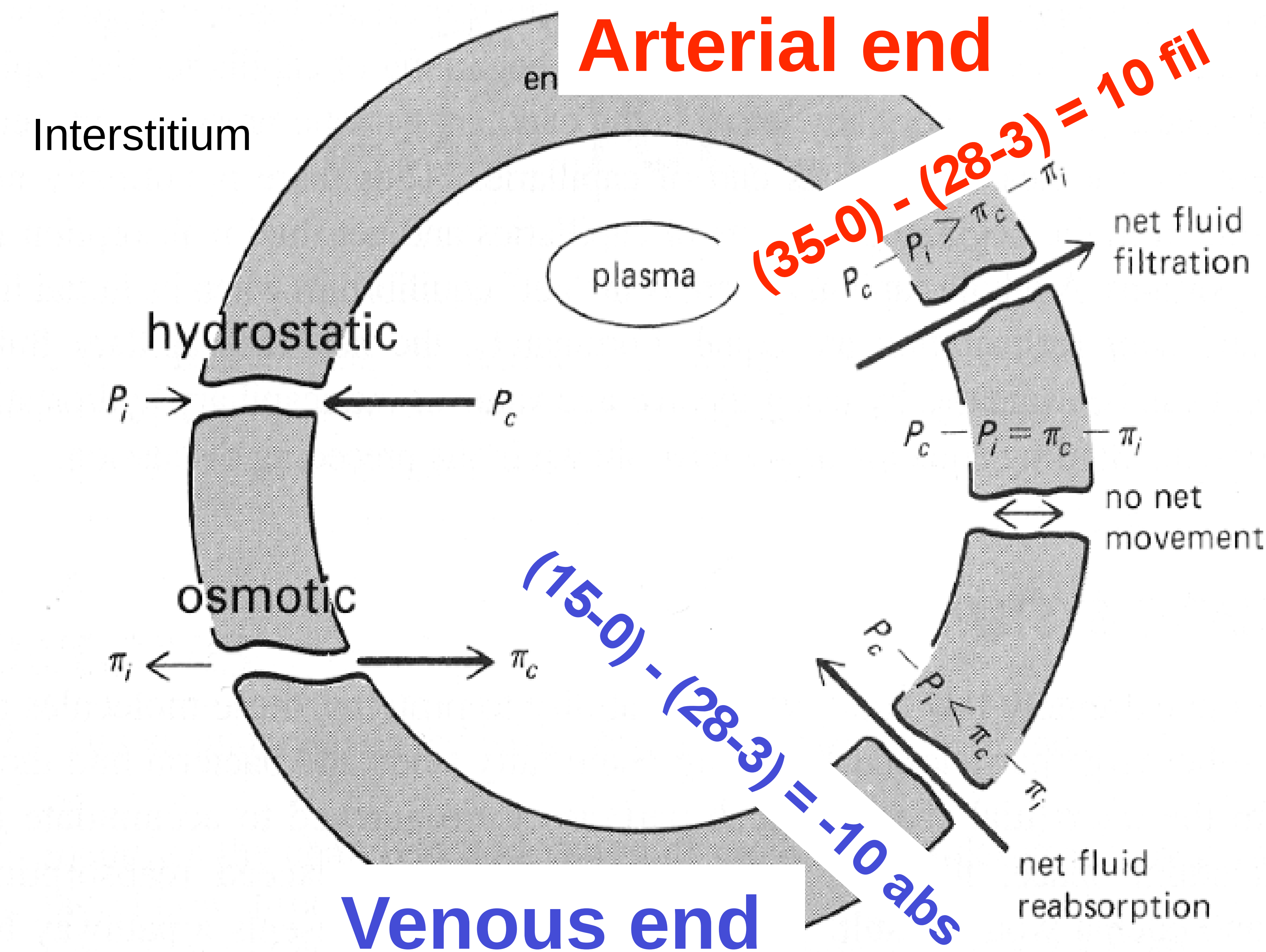
$$\text{Net filtration pressure} = (P_C - P_{IF}) - (\pi_P - \pi_{IF})$$

What determines capillary hydrostatic pressure P_c ?

- ↑Arterial pressure ↑P_c
- ↑Venous pressure ↑P_c
- Closure of arteriole ↓ P_c
- Closure of a venule ↑P_c
- Local arteriolar vasoconstriction ↓ P_c
- Local venoconstriction ↑P_c

Fluid movement across capillaries





Mohrman and Heller. Cardiovascular Physiology. McGraw-Hill, 2006. 6th ed.

What happens if you partially inflate a blood pressure cuff on your own arm?

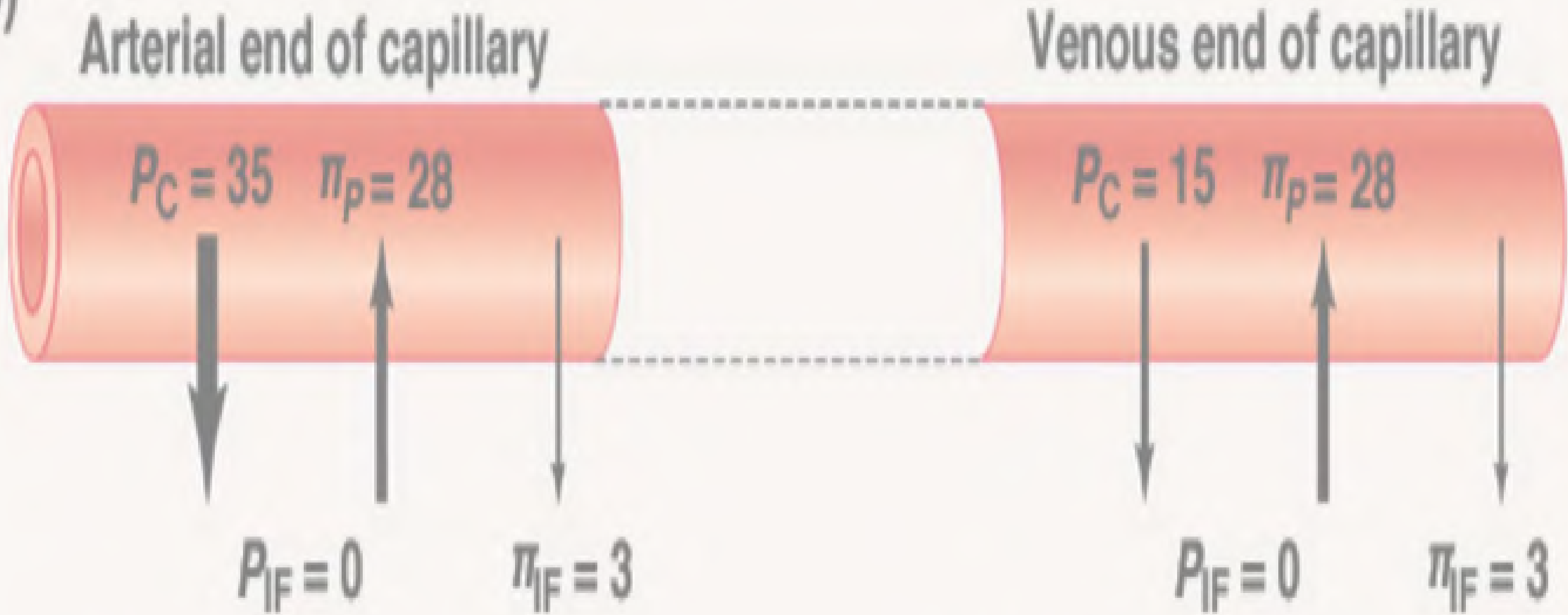
Did you ever leave one inflated too long?

Did your arm appear to swell?
How come? Why partially inflated?

Does the hydrostatic pressure at the venous end of the capillary can have a significant effect on net filtration!!?

$$\text{Net filtration pressure} = (P_C - P_{IF}) - (\pi_P - \pi_{IF})$$

(b)



Net filtration pressure =
$(35 - 0) - (28 - 3) = 10$ mmHg
10 mmHg favoring filtration

Net filtration pressure =
$(15 - 0) - (28 - 3) = -10$ mmHg
10 mmHg favoring absorption

Arterial end

Hydro - Osmo = ?
(35-0) - (28-3) =10 fil

Venous end

Hydro - Osmo = ?
(15-0) - (28-3) = -10 abs

Place cuff & inflate to 30 mmHg

Arterial end

Hydro - Osmo = ?
(35-0) - (28-3) =10 fil

Venous end

Hydro - Osmo = ?
(30-0) - (28-3) = 5 fil

Interstitial Swelling

Additional Source Information

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Slide 7: Please see: http://www.bg.ic.ac.uk/Staff/khparker/homepage/BSc_lectures/2002/Capillary_sketch.jpg
Slide 8: D’Alecy
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