Physiology 1A

Haemodynamics

Tim Murphy
Wallace Wurth 316
tim.murphy@unsw.edu.au

1

From this lecture you should:

Know Poiseuille's Law and what it describes.

Understand the relationship between blood flow velocity and cross-sectional area in different sections of the vascular system.

Understand the concept of resistance to blood flow and the structure and arrangement of blood vessels to counter it.

Appreciate the concepts of laminar and turbulent blood flow.
Reference: Stanfield 6th Ed. Chapter 14 pp. 394 - 404.

2

Haemodynamics

Physical laws governing blood flow and blood pressure.

How is the circulatory system organised for effective delivery of blood flow to tissues and organs?

Inter-relationships between:
- velocity of blood flow
- blood pressure
- dimensions of the components (vessels) in the systemic circulation (resistance).

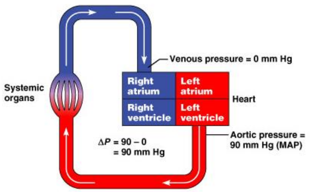
3

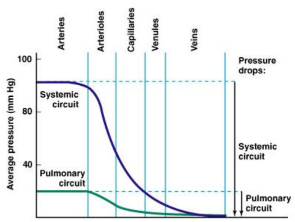
For blood to flow through the vessels, we need a driving force - pressure.

Flow is opposed by the resistance provided by the blood vessels.

$$\text{Flow} = \frac{\text{Pressure gradient}}{\text{Resistance}} \qquad Q = \frac{\Delta P}{R} \quad \text{(cf. Ohm's Law)}$$

4





Pressure and Flow

Poiseuille's Law describes laminar flow of newtonian (homogenous) fluids through cylindrical tubes in terms of:

-Flow

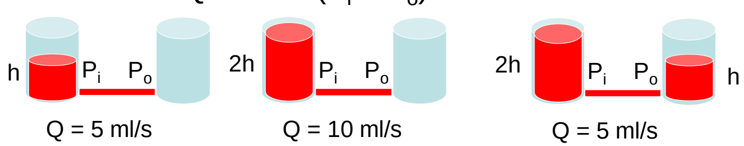
-Pressure

-Tube dimensions

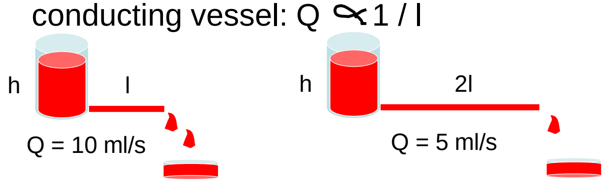
-Viscosity of fluid

Flow is directly proportional to the pressure gradient (inflow pressure – outflow pressure)

$$Q \propto \Delta P\ (P_i - P_o)$$

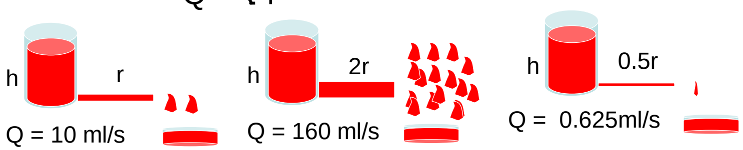


Flow is inversely proportional to the length of the conducting vessel: $Q \propto 1 / l$

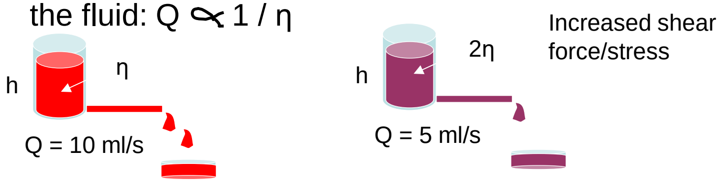


Flow varies directly as the fourth power of the radius of the conducting vessel

$$Q \propto r^4$$



Flow is inversely proportional to the viscosity of the fluid: $Q \propto 1 / \eta$



Put together, Poiseuille's Law:

$$Q = \frac{\pi (\Delta P) r^4}{8\eta l} \qquad \frac{\pi}{8} = \text{constant}$$

Radius of conducting vessel is most influential determinant.

9

Blood Flow Velocity

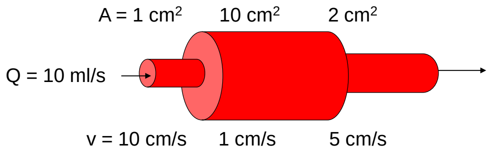
Velocity = distance/time (cm/s)

Flow = volume/time (cm^3/s)

Volume depends upon cross-sectional area of blood vessel. Therefore:

Velocity = Flow / Area $v = Q / A$

Flow is constant in a 'rigid' system

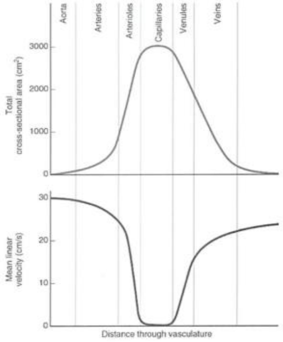


10

Blood flows faster in narrower vessels.
True?

<u>Total cross-sectional area (cm^2)</u>

Aorta	2.5
Arteries	20
Arterioles	40
Capillaries	2500
Venules	250
Veins	80
Venae cavae	8



Stanfield Fig. 14.15

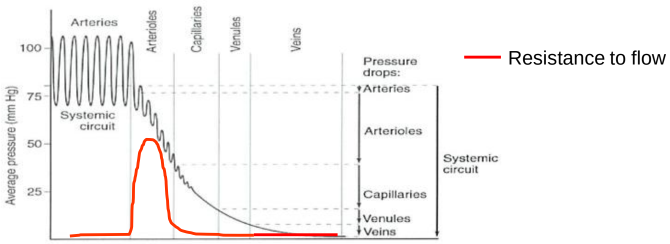
11

Resistance to Flow

Resistance (R) to blood flow is the ratio of the pressure gradient to flow (c.f. Ohm's Law, R = V / I).

$$R = \frac{\Delta P}{Q} = \frac{8\eta l}{\pi r^4}$$ (Stanfield; Poiseuille's Law)

Note effect of radius



Stanfield Fig. 14.9

12

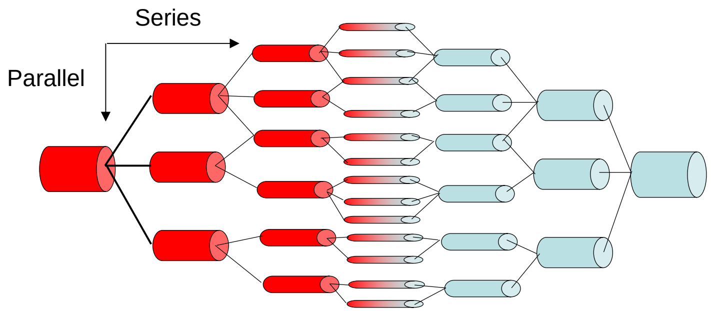
Resistance to flow is greatest in arterioles:

- low cross-sectional area relative to radius
- constriction of arterioles

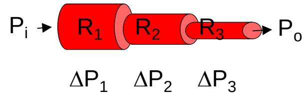
Resistance in series and parallel

Separate elements of circulation (artery, arteriole, capillary etc.) are arranged in <u>series</u>

Similar elements are arranged in <u>parallel</u>



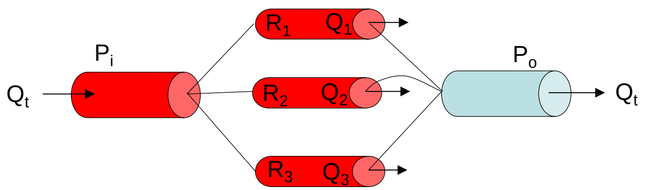
Resistance in <u>series</u> is sum of individual resistances:



$R = \Delta P / Q$

$$R_t = R_1 + R_2 + R_3$$

Reciprocal of resistance in <u>parallel</u> is sum of reciprocal of individual resistances:



$R = \Delta P / Q$: $\dfrac{1}{R_t} = \dfrac{1}{R_1} + \dfrac{1}{R_2} + \dfrac{1}{R_3}$ $\quad \dfrac{1}{R}$ is conductance

If R_1, R_2 and R_3 were equal then $1 / R_t = 3/R_1$: $Rt = R_1/3$

For parallel arrangement, total resistance < individual resistance of any one segment:

$R_t < R_1$, R_2 or R_3

Total Peripheral Resistance (TPR)

$$TPR = \frac{\text{arterio-venous pressure drop } (P_a - P_v)}{\text{flow}}$$

$$= \frac{\text{Blood Pressure}}{\text{Cardiac Output}} \quad (BP = CO \times TPR)$$

$$= \frac{100 \text{ mmHg} - 0 \text{ mmHg}}{5000 \text{ ml/min}}$$

$$= 0.02 \text{ mmHg/ml/min} = 0.02 \text{ PRU}$$

Individual tissues/organs may differ (e.g. kidney)

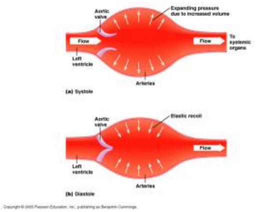
Effects of pressure and vascular resistance on tissue blood flow

Blood vessels are not rigid tubes

Aorta, large arteries:
elastic, fibrous conductance, compliance

Compliance is a measure of vessel 'elasticity'.

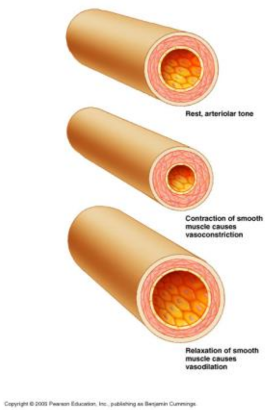
$$\text{Compliance} = \frac{\Delta V}{\Delta P}$$



17

Small arteries, arterioles:
Muscular, resistance, alter diameter, control flow

Capillaries: thin endothelial cells - exchange

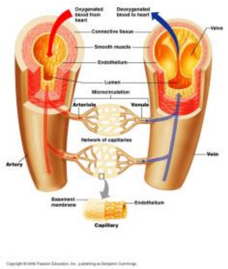


18

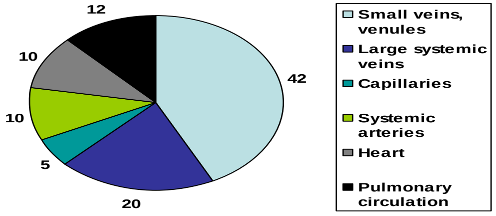
Venules:

Thin wall, little muscle. Low resistance
capacitance (reservoir)

Veins: Thin wall, v. low resistance
capacitance, conductance



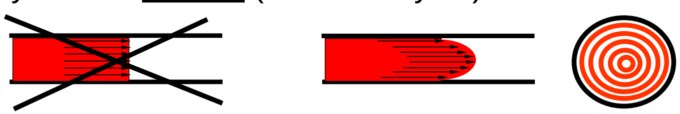
Distribution of blood by volume



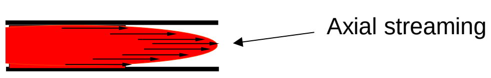
19

Laminar and Turbulent Flow

Due to friction with the vessel wall, flow of blood (and other fluid) at a constant velocity in a cylinder is laminar (series of layers).



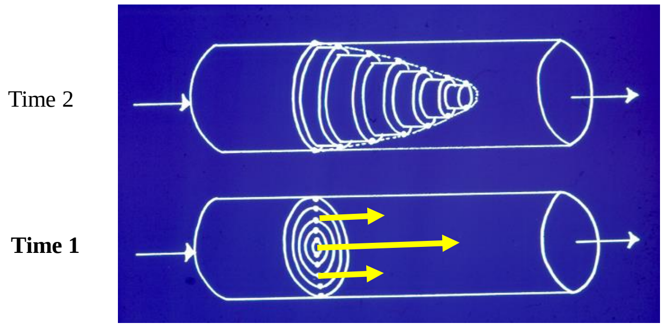
Increased velocity enhances the effect



Increased velocity increases shear stress or viscous drag on walls

20

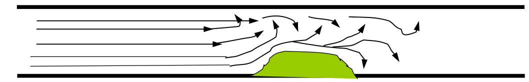
Laminar flow



Hodder Arnold / An Introduction to Cardiovascular Physiology © 2010 J. Rodney Levick

21

Irregular fluid motions within vessel causes <u>turbulent flow</u>



Greater pressure is required to force turbulent flow through a tube (Poiseuille)

Laminar $Q \propto \Delta P$
Turbulent $Q \propto \sqrt{\Delta P}$

22

Turbulent flow is <u>more</u> likely if:

- vessel is large diameter
- flow is faster
- blood viscosity is low (anemia)

Turbulent flow can be predicted by Reynold's number:

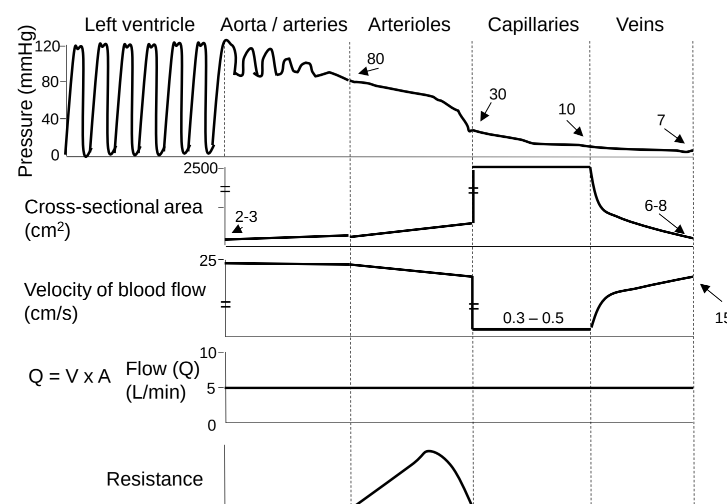
$$N_R = \frac{\text{density x diameter x velocity}}{\text{viscosity}} = \frac{\rho D v}{\eta} \quad \begin{array}{l} <2000\text{, laminar} \\ >3000\text{, turbulent} \end{array}$$

Turbulence may cause noise:

e.g. anemia (low viscosity, high velocity)

heart murmurs

23



24